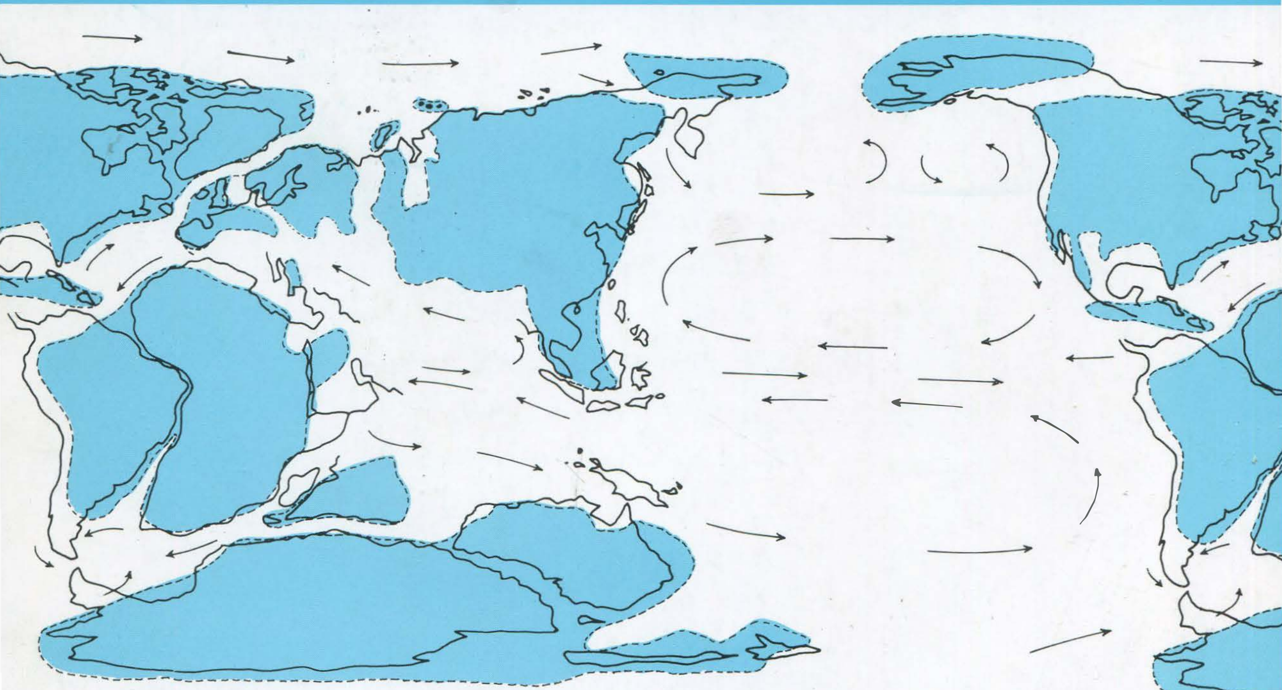
THE CRETACEOUS SYSTEM IN EAST AND SOUTH ASIA

RESEARCH SUMMARY 1994

NEWSLETTER SPECIAL ISSUE

IGCP 350



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■IGCP 350 National Working Group of Japan
c/o H. Okada
Department of Earth and Planetary Sciences
Kyushu University, Fukuoka 812, Japan
Tel. 81-92-641-1101 : FAX 81-92-632-2736

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Contents

Preface

IGCP-350, "Cretaceous Environmental Change in East and South Asia", began in 1993 with the active participation of members from 12 countries. The first international organisational meting was held in Fukuoka, Japan, in November 1993, in order to establish a working framework for effective international cooperation, and to discuss the status of research in participating regions, and future project goals.

This meeting was attended by regional coordinators from eight countries, including some Japanese Cretaceous researchers. Presentations made by the regional coordinators were of sufficient interest and quality that it was decided to make them more widely available through this special issue of the project newsletter. Papers in this issue cover aspects of the Cretaceous geology in Australia, India, the Philippines, China, Korea, Japan, and the Russian Far East.

The intention of this issue is to assess the status of research pertaining to the project in respective regions. We requested from the authors current information about Cretaceous sedimentary and biological environments, the timing and manifestation of principal tectonic and volcanic features, the stratigraphy and location of potential sections showing the correlation between marine-nonmarine strata, economic resources, and project currently underway in their regions. With a better understanding of the above features, research on the environmental change that occurred during the Cretaceous can be more easily assessed.

We are confident that these contributions will provide a helpful base from which we can proceed with the goals of the project. The quick response from the authors in preparing these papers is appreciated. We wish to acknowledge with thanks the support of UNESCO, the IGCP National Committee of Japan, and Kyushu University in holding the first international project meeting. The following individuals provided invaluable assistance during the meeting and field excursions: Dr. Wonn Soh, Mr. Takashi Sakai, Dr. Futoshi Nanayama, Ms. Eiko Goya, and Ms. Seiko Hayakawa.

One of us (H. Okada) would like to express his sincere thanks to the Ministry of Education, Science and Culture (Monbusho), Japan, for the Grant-in-Aid for Co-operative Research (Grant No. 06304001) and to the Japan Petroleum Exploration (Japex) Co., Ltd. for supporting the publication of this special issue.

Hakuyu Okada (Project Leader)
Kyushu University, Japan

Niall J. Mateer
University of California, U.S.A.

Scope and overview of IGCP 350

Hakuyu Okada

Department of Earth and Planetary Sciences, Kyushu University, Fukuoka 812, Japan

Introduction

A new International Geological Correlation Programme (IGCP) project entitled "Cretaceous Environmental Change in East and South Asia" (1993-1997) has been initiated. This project is an outgrowth of IGCP 245 "Nonmarine Cretaceous Correlation" (1986-1991), which presented a better understanding of stratigraphical and paleontological correlation within and between nonmarine basins in the world.

At the last international meeting of IGCP 245, held in Fukuoka in 1991 jointly with "International Symposium on Origin, Sedimentation and Tectonics of the Late Mesozoic to Early Cenozoic Sedimentary Basins at the Eastern Margin of the Asian Continent", a successor project was proposed by the project leader Dr. N. J. Mateer and project representatives from Asian countries. The title of "Environmental and Biological Change in East and South Asia during the Cretaceous" was chosen.

The legacy of IGCP 245 facilitated establishing the project in April, 1993 and organization of research groups in participating countries has begun. Thanks to the kind cooperation of many colleagues, 12 countries (Russia, Korea, China, Philippines, Vietnam, India, Australia, U.S.A., Canada, France, Spain, and Japan) and more than 190 scientists currently participate in this project.

Background of IGCP 350

The Cretaceous world was very unique during the Phanerozoic climatically (Barron and Washington, 1982), in faunal diversity (Fischer and Arthur, 1977), the presence of anoxic conditions in the ocean (Schlanger and Jenkyns, 1976;

Jenkyns, 1980; Sliter, 1989), high sea-level (Vail et al., 1977), and oceanic circulation (Arthur, 1979; Roth, 1987). In terms of global tectonics, the prototypic framework of the continent and ocean realms in the eastern Asian region seems to have been largely established by the advent of the Cretaceous (Zonenshain et al., 1987). Then, were the eastern and southeastern parts of the Asian continent under specific environmental conditions?

The plume tectonic theory appears to have impacted the environment in this region, thus its development in the Cretaceous should be taken into account. It has already been suggested that the greenhouse effect and high sea-level during the Cretaceous were attributed to a huge undersea volcanism (Schlanger et al., 1981; Larson, 1991a, b; Tarduno et al., 1991), and has been strongly supported by the theory of the plume tectonics (Maruyama et al., 1993)

According to this theory, there was a hot superplume rising from the core-mantle boundary beneath the Central Pacific in the Cretaceous and a voluminous stack of subducted slabs of oceanic plates, corresponding to a huge cold plume, is traced to the depth 670 km beneath Central Asia. This superplume seems to control all the thermal activity in the upper crust of the Central Pacific, which corresponds exactly to the Darwin Rise proposed by Menard (1964).

Most oceanic plateaus are now believed to have been formed by oceanic flood basalts, which include the Ontong Java Plateau (Tarduno et al., 1991), Manihiki Plateau (Schlanger, 1976), Kerguelen Plateau (Storey et al., 1989), and Shatsky Rise (Shipboard Scientific Party, 1975). Although the basalt basement of the Shatsky Rise has not been confirmed by drilling, all the others consist of voluminous oceanic basalts of Aptian (Tarduno et al., 1991).

It is indeed remarkable that such an enormous volume of basalt was supplied in quite a short period, less than 3 million years (Tarduno et al., 1991). This volcanism significantly may account for not only the oceanic anoxic events but also sea-level pulses in the Cretaceous.

On the other hand, on the continent at that time the thinning of the crust is believed to have taken place due to the stacking of subducted plate slabs, resulting in the formation of large-scale intra-continental sedimentary basins that characterize the Cretaceous Asian continent.

Event analysis

The notion that plume tectonic regimes played an important role during the Cretaceous, leads us to consider the impact of superplume volcanic events in the proto-Pacific as a key for understanding the Cretaceous environments in East Asia. It is desirable, therefore, that "events" or "events analysis" have a major role in this project, and I propose that "Towards Events Analysis in the Cretaceous" be added as the sub-title of IGCP 350.

In this context, the stratigraphic correlation in all possible ways be applied to identifying the synchroneity of various geological and biological events. For this purpose, inter- and multi-disciplinary approaches such as bio-, litho-, chemo- and magnetostratigraphic correlations be strengthened for intra- and inter-regional studies.

As the final goal of this project, interactions between the continent and the ocean, as well as the geological linkage between the proto-Pacific realm and the Tethyan and Boreal regions will be clarified in terms of environmental change events through the multi-disciplinary approaches such as tectonics, sedimentation, stratigraphy, biotic analysis, igneous activity and resources.

Concluding remarks

The region from the Indian subcontinent to the Russian Far East covered by this project is an ideal area for the study of environmental changes during the Cretaceous as it is the cross-roads of the proto-Pacific, Tethys, Boreal and the Asian continent (Fig. 1). The continental margins were mostly bordered by subduction zones, giving unique tectonic features between the continent and the ocean.

Integrated information from this area will contribute to the better understanding of the Cretaceous world, not only in East and South Asia but also in other areas of the world. For further development of IGCP 350 activity, close linkage with other working groups, such as "Apticore-Albicore" (Larson et al., 1993) and IGCP 362 (Tethyan and Boreal Cretaceous), will also be important.

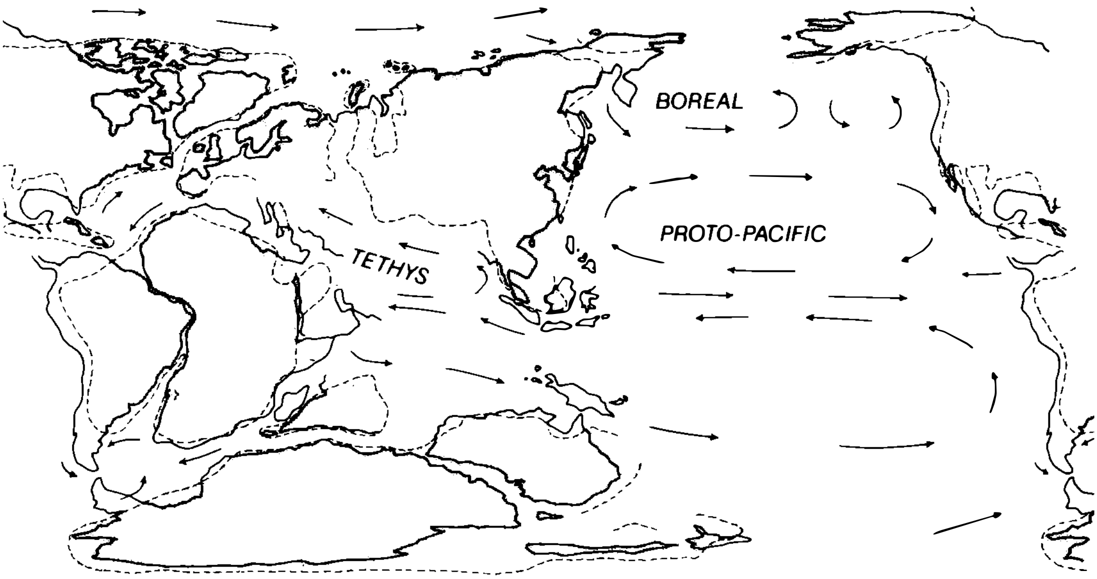

Fig. 1. Paleogeography and ocean circulation in the Early Cretaceous (from various sources).

It is hoped that all the phases of researches during the IGCP 350 activity will stimulate and enhance the study of the Cretaceous in other regions of the world.

References

Arthur, M.A. 1979. North Atlantic Cretaceous black shales: the record at Site 398 and a brief comparison with other occurrences. *Initial Reports of the Deep Sea Drilling Project* 47, 719-751.

Barron, E.J. and Washington,W.M. 1982. Cretaceous climate: a comparison of atmos-pheric simulations with the geologic record. *Palaeogeography, Palaeoclimatology, Palaeoecology* 40, 103-133.

Fischer, A. and Arthur, M.A. 1977. Secular variation in the pelagic realm. In *Deep- water carbonate environments* (eds. Cook, H.E. and Enos, P.), *Society of Economic Paleontologists and Mineralogists Special Publication* 25, 19-50.

Jenkyns, H.C. 1980. Cretaceous anoxic events: from continents to oceans. *Journal of the Geological Society* 137, 171-188.

Larson, R.L. 1991a. Latest pulse of earth: evidence for a mid-Cretaceous super-plume. *Geology* 19, 547-550.

Larson, R.L. 1991b. Geological consequences of superplumes. *Geology* 19, 963-966.

Larson, R.L., Erba, E., Fischer, A.G. and Premoli Silva, I. 1993. *Apticore-Albicore.* iii + 56pp. (Joint Oceanogr.Inst., Washington, D.C.).

Maruyama, S., Fukao, Y. and Obayashi, M. 1993. Plume tectonics -A new paradigm after plate tectonics.*Kagaku (Science)* 63, 373-386. (in Japanese)

Menard, H.W. 1964. *Marine geology of the Pacific.* 271pp. (McGraw-Hill, New York).

Roth, P.H. 1987. Mesozoic calcareous nannofossil evolution: relation to paleoceanographic events. *Paleoceanography* 2, 601-611.

Schlanger, S.O. and Jenkyns, H.C. 1976. Cretaceous oceanic anoxic events: causes and consequences. *Geologie en Mijnbouw* 55, 179-184.

Schlanger, S.O., Jenkyns, H.C. and Premoli Silva, I. 1981. Volcanism and vertical tectonics in the Pacific basin related to global Cretaceous transgression. *Earth and Planetary Science Letters* 92, 234-246.

Shipboard Scientific Party 1975. Site 305: Shatsky Rise. *Initial Reports of the Deep Sea Drilling Project* 32, 75-158.

Sliter, W.V. 1989. Aptian anoxia in the Pacific Basin. *Geology* 17, 909-912.

Storey, M., Saunders, A.D., Tarney, J., Gibson, I.L., Norry, M.J., Thirlwall, M.F., Leat, P., Thompson, R.N. and Menzies, M.A. 1989. Contamination of Indian Ocean asthenosphere by the Kerguelen-Heard mantle plume. *Nature,* 338, 574-576.

Tarduno, J.A., Sliter, W.V., Kroenke, L., Leckie, M., Mayer, H., Mahoney, J.J., Musgrave, R., Storey, M. and Winterer, E.L. 1991. Rapid formation of Ontong Java Plateau by Aptian mantle plume volcanism. *Science* 254, 399-403.

Vail, P.R., Mitchum, R.J. and Thompson, S. 1977. Seismic stratigraphy and global changes of sea level. Part 4: Global cycles of relative change of sea level. *AAPG Memoir* 26, 83-97.

Zonenshain, L.P., Kononov, M.V. and Savostin, L.A. 1987. Pacific and Kula/Eurasia motions during the last 130 Ma and their bearing on orogenesis in Northeast Asia. In *Circum-Pacific orogenic belts and evolution of the Pacific Ocean Basin* (eds. Monger, J.W.H. and Franchesteau, J.), *AGU Geodynamic Series* 18, 29-47.

The Cretaceous in the Russian Far East

Galina L. Kirillova

Institute of Tectonics and Geophysics, Far East Branch of Russian Academy of Sciences, Khabarovsk 680063, Russia

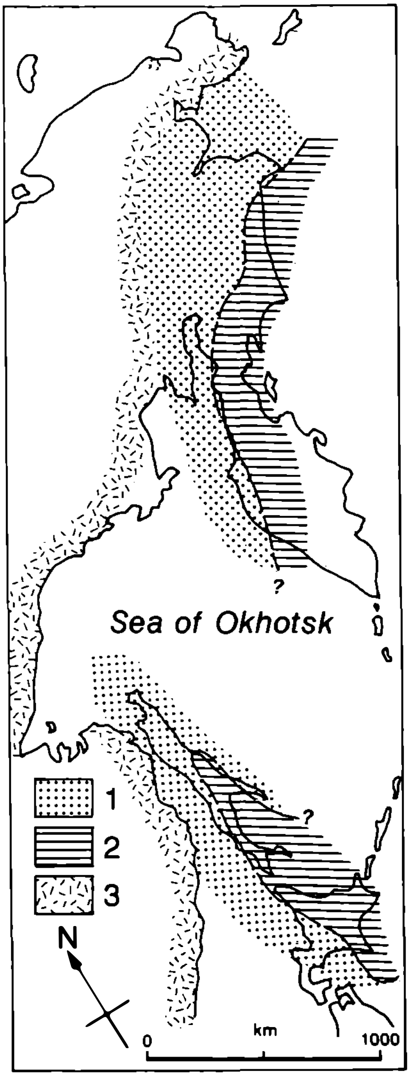

Fig. 1. Schematic paleogeographic map of Russia's Far East for the Late Cretaceous (from Krassilov, 1990).
1 - continental coal-bearing deposits, 2 - marine deposits, 3 - volcanic belts.

Sediments of the Cretaceous are widespread in Russia's southeast, comprising about one-third of the territory. They are represented by both marine and continental terrigenous coal-bearing and volcanogenic facies (Fig. 1), the relations of which changed in space and time, having a general trend of marine facies shifting to the east.

In the past years a number of significant results have been published. In 1990 a new stratigraphic correlation scheme of the Far East was compiled (Stratigraphic Correlation Schemes of the Far East, 1994), and a number of regional and special maps were published (Geologic Map of the USSR Far East and Adjacent Areas, 1991; Geological Map of the Khabarovsk Territory and Amursk Region, 1991; Volcanic Belts and Volcano-Tectonic Structures of East Asia, 1992; Atlas of the Mesozoic and Cenozoic Maps of Eurasian Shelfs, 1992; Geological Map of Sakhalin, in press).

A new framework for the tectonics and geodynamics of Russia's Far East was published as part of the circum-Pacific map series (Nokleberg, 1994). In the course of research associated with IGCP-245, further details about the nature of nonmarine Cretaceous rocks have been elucidated (Krassilov, 1989, 1990).

Within the Cretaceous marine sediments of Russia's southeast, 14 horizons have been distinguished based on biostratigraphic features: three approximate a stage level, seven are more limited than a stage, and four extend beyond the stage level. In the nonmarine Cretaceous section, ten floral horizons have been established, one of them corresponds to a stage, three horizons comprise two stages each, and six are smaller than a stage. The Albian is divided further by a flora.

In some sections, the combined evidence of fauna, flora, and palynomorphs enables a detailed stratigraphic standard to be created. In the northern and southern parts of the region, the Jurassic-Cretaceous boundary is observed.

Russia's southeastern margin is shown to belong to the Pacific palaeobiogeographic realm. The Boreal realm is characterised by the dominant *Buchia*, whereas the ammonite faunas indicate a Mediterranean influence during the Berriasian and Valanginian. Five-km-thick turbidites are characteristic sediments in the Khingan-Okhotsk continental margin at that time. Spilites, diabase, and siliceous clay shale are rarely developed, but occur mostly in the extreme east, on Sakhalin.

In the western part of this region, clastic coal-bearing sediments, with an abundant flora, measures up to 1000 m, having been deposited in intraplate rift basins. Volcanic formations are from two sources: intraplate rifts and from island arc systems. The thickness of the volcanics also reaches 1000 m. During the middle Valanginian and, in some regions the early Hauterivian tectonic activity began, as reflected by hiatus, thrusting, and olistostrome accumulation; the latter containing clasts of Carboniferous-Jurassic cherts, spilites, and limestones. Sedimentation continued only in the central part of Sikhote-Alin.

During the late Hauterivian to Barremian, Boreal inoceramids and ammonites became very common. The geographic distribution of facies remained much the same, with coal-bearing beds in the west and volcanics in the east. In the western part of Sakhalin and on Moneron, island arc volcanics occur from the Valanginian to the Barremian. Further to the east, a forearc basin developed, and in upper Aptian to lower Albian deposits, andesites, tuffs, volcanoclastics, and turbidites predominate, reaching a thickness of 5000 m. At this time there occurred a mixing of Boreal and Tethyan ammonites *(Aucellina)* and inoceramids. Tethyan *Trigonia* and *Acteonella* appeared from the middle Albian. Middle Albian alternating marine-nonmarine beds are seen in the Suchansk basin. The Hauterivian to middle Albian is the period of principal deposition in the western and southern parts of the region (Suchansk and Bureya basins).

The middle-upper Albian boundary is characterised by a marine to nonmarine environmental change throughout Sikhote-Alin, except the extreme North-east and Sakhalin. Substantial folding and left-lateral displacements mark the beginning of the east Sikhote-Alin marginal-continental volcanic belt with alternating intermediate-acid volcanics from the Albian to Maastrichtian. The average thickness is approximately 15 km. Volcanoclastics containing inoceramids continued to accumulate in the northeastern part of Sikhote-Alin from the late Albian to middle Turonian, and volcanics of the east Sikhote-Alin belt were deposited from the middle Turonian to middle Coniacian. The western boundary is not yet clear. The Okhotsk-Chukoka belt (lower Albian-Maastrichtian) is considered to be the northeastern continuation of this belt. In western Sakhalin, sedimentation changed from deep marine to coastal marine during the upper Albian.

In the western part of the region the formation of volcanic areas occurred until the Coniacian, when lacustrine and alluvial deposits dominated. These sediments contain a continuous record of plant megafossils palynomorphs until the end of the Cretaceous. Maastrichtian beds contain dinosaur fossils, and the existence of Cretaceous-Tertiary "impactites" have been reported in the Amur-Zeya basin.

In southern Primoreya upper Albian to Cenomanian volcanics are displaced by variegated, red beds that may indicate a climate change.

The location of the continent-ocean boundary during the Late Cretaceous lay across what is now Sakhalin, where alternating marine-nonmarine (Coniacian-Campanian) occur, the latter containing substantial coal accumulations. By the Paleocene, coal beds predominate.

Both marine and continental sediments, including coal-bearing beds, are well-developed in northern Sakhalin. Japanese and Russian investigators associate this zonation with the existence of two interperpendicular subduction zones in the Late Cretaceous, each with their own island arc, back arc, and forearc systems (Rozhdestvensky, 1992).

In western Sakhalin, three sedimentary cycles are clearly distinguished in Upper Cretaceous strata, having marine transgressionary maxima identified in the lower Turonian, Santonian, and upper Campanian. Endemic Pacific ammonites and inoceramids are common in the marine beds, and in the Turonian and Campanian are often of giant size. Radiolaria and foraminifers are widespread and common.

In the eastern part of Sakhalin, deep-water sedimentation (mudstone, chert, tuff) continued until the Maastrichtian, together with syndepositional thrusting and olistostrome formation. At the end of the Maastrichtian, deposition in eastern Sakhalin was under shallow water with occasional coal accumulations. A rich marine fauna and flora occur in Maastrichtian-Danian sediments in the Lesser Kuril ridge (Krassilov, 1989).

During the Paleocene tectonic activity embraced most of the eastern Asian margin, but in the Nemuro-Lesser Kuril forearc basin, marine sedimentation persisted until the early Eocene.

Cretaceous sediments of Russia's southeast contain important mineral deposits, gold, tin, silver, copper, zeolites, and other volcanogenic metals. Coal-bearing beds yield economically significant amounts of coal. Gas accumulations have been found, but are not significant.

References

Atlas of Mesozoic and Cenozoic Maps of Eurasian Shelves 1992.

Geological Map of the Khabarovsk Territory and Amursk Region 1991. 1:2 500 000 (Ministry of Geology of the USSR, Leningrad).

Geologic Map of Sakhalin, 1: 500 000. In press.

Krasnyi, L.I. and Putintsev, V.K. (eds.) 1984. *Geological structure and economic minerals of the USSR*, volume 8: eastern part of the USSR, 560 pp. (Nedra, Leningrad).

Krasnyi, L.I., Putintsev, N. and Vasiliev, B.I. (eds.) 1991. *Geologic Map of the USSR Far East and Adjacent Areas,* 1:1 500 000 (Ministry of Geology of the USSR, Leningrad).

Krassilov, V.A. (ed.) 1989. *Cretaceous of the Far East*, 148 pp. (Far Eastern Branch of the USSR Academy of Sciences, Vladivostok).

Krassilov, V.A. (ed.) 1990. *Continental Cretaceous of the USSR,* 24 pp. (Far East Branch of the USSR Academy of Sciences, Vladivostok).

Nokleberg, W.J. (ed.) 1994. *Circum north Pacific tectono-stratigraphic terrane map*. In press.

Rozhdestvensky, V.S. 1993. Geodynamic evolution of the Hokkaido-Sakhalin folded system. *Tikhookeanskaya geologia* 2, 76-87.

Stratigraphic Correlation Schemes of the Far East 1994 (Khabarovsk). In press.

Volcanic Belts and Volcano-Tectonic Structures of East Asia 1992. 1 : 3 000 000 (Khabarovsk).

Cretaceous biostratigraphy of Russian Far East

Valentina S. Markevitch

Institute of Biology and Pedology, Far East Branch of Russian Academy of Sciences, Vladivostok 690022, Russia

Many sections of the continental and marine Cretaceous have been studied in the Russian Far East. Some new data on the occurrence of nonmarine bivalves, gastropods, ostracods, conchostracans, fish and insects have been obtained, and the succession of the faunal assemblages analysed. The biodiversity and changes in the taxonomic composition on the evolution boundaries have been investigated.

The stratigraphy and palaeoflora of the Cretaceous deposits of the terrestrial volcanic belt stretching along the eastern margin of Asia and the bordering island arcs, are presented.

Correlation of volcanic events along the Sikhote-Alin and Okhotsko-Chukotsk branches of the belt based on the refined phytostratigraphical age assignments and marine intercalations suggests a series of evolutionary stages traceable throughout the belt which developed as a unit. It is established that the evolutionary stages of these branches are similar. Some zonal scales for ammonites and bivalves of Early Cretaceous age occur in NE Russia and Sikhote-Alin (Pokhialaynen, 1989; Konovalov and Vereshchagin, 1969; Konovalov, 1976) and the Lower-Upper Cretaceous of Sakhalin.

The evolutionary pathways of the plant development since the time of appearance, then further prosperity and up to extinction were observed. The floragenesis problems were given special attention: the formation of Cainophyticum elements in the entrails of the Mesophyticum, the global centres of angiosperm origin, the extinction of the ancient floras at the Mesozoic-Cenozoic boundary. According to Krassilov (1986), current evolutionary theory is still incapable of resolving many fundamental problems of species and speciation, macroevolution, directed development, and evolutionary progress. These problems are considered from the ecosystem perspective in which the evolutionary impulse spreads downwards from the upper system levels, from the biosphere to communities, organisms and genomes.

For the first time palynological data were used to determine rates of macro- and microevolution and to elucidate coherent and noncoherent stages of development of the Cretaceous palynoflora in the east of Russia (from south Primorye to Chukotka). The extinction and appearance of species as well as the change of dominant forms are generally considered as elementary evolutionary. Species extinction is regarded by adherents of the classical evolutionary concept as a consequence of competitive relationships.

In accordance with the other hypotheses an extinction is due to the catastrophic impacts of cosmic and geological character, or as a result of change in the structure of ecological systems or a correlation of various species involved. Rates of speciation were low in the Berriasian-Barremian interval. They increased abruptly in the Aptian-early Albian and then decreased in the middle Albian. In the Late Cretaceous the process of speciation quickened steadily until the middle Campanian. Rates of evolution were slowest in the middle Campanian to early Maastrichtian. The rate of change in generic composition was low from the Berriasian to Valanginian, increasing by the mid-Cretaceous, due mainly to the appearance of angiosperms. In the Late Cretaceous the rate of evolution at the generic level decreased up to the Campanian, increasing toward the Maastrichtian-Danian boundary. An inverse dependence between the rates of speciation and appearance of genera testifies to diverse quality of micro- and macroevolutionary processes. Noncoherent stages correspond to the ecological crises and fall within intervals of the upper Albian- middle Turonian, with a peak boundary of Albian and Cenomanian, and from the upper Maastrichtian to the late Danian (with a peak at the Maastrichtian-Danian boundary).

Krassilov (1986) has introduced ecomorphological data on the problem of angiosperm origins and their early evolution. Palynological data permits us to construct a phylogeny of early angiosperm pollen morphotypes, with monosulcate appearing first, in turn followed by zonosulcate, equatoria, colpate, and trichomonosulcate types.

Fourteen palynological zones are recognized in the Cretaceous and

Paleocene strata exposed along the Pacific coast of Russia, from Primorye in the south to Chukotka in the extreme north-east. Each palynozone corresponds to a distinct stage of floristic evolution. The palynological correlation scheme incorporates all data from marine faunas, macroflora, and continental faunas. A comparison with palynological zonations with other parts of Asia, North America and Australia reveals a potential for intercontinental correlation of Cretaceous and Paleocene rocks (Markevitch, 1987, 1989a, 1989b, 1990).

Palaeontological research has been focused at the base of the Cretaceous regional stratigraphic sections in the Sikhote-Alin and Mongolian-Okhotsk tectonic zones. Dinosaur occurrences in the Koriak uplands and Priamurye have been studied in detail by Bolotsky (1990) and Nessov and Goloneva (1990).

The macroflora, palynomorphs, and foraminifers have been carefully documented across the Cretaceous-Paleogene boundary in rocks deposited following the emergence of an island arc system. This palaeontological data has proved useful in determining the chronology and environmental development of this system, and the climatological regimes in the region.

Chinese and Russian collaboration in 1993 revealed much new information about terrestrial vertebrate taphonomy, palaeogeography and habitats as reflected in the Tsagayan Formation in Primurye. This fauna consists of ankylosaurs and hadrosaurs, turtles, crocodiles, and includes ostracods, conchostracans, insects, and fish; a terrestrial flora is also present. A trophic analysis of this biotic is being constructed, but preliminary results indicate that the Primursky basin was warm and humid during early Tsagayan time, but the climate cooled and became progressively drier during the remainder of this stage.

Periodic Cretaceous climate changes have been recorded in NE Asia, which are reflected mainly as humid to arid to humid cycles in the red-beds and coal beds throughout the region. Palaeontological changes coincide with the environmental changes.

References

Bolotsky, Y.L. 1990. The Blagoveshchenskian locality of Cretaceous dinosaurs.

In *Continental Cretaceous of the USSR* (ed. Krassilov, V.A.), pp. 109-113 (Far East Branch, USSR Academy of Sciences, Vladivostok).

Konovalov, V.P. 1976. Acteonellian strata of Sikhote-Alin. In *Essays of geology and palaeontology of the Far East* (ed. Ablaev, A.G.), pp. 39-45 (Far East Science Center, USSR Academy of Sciences, Vladivostok).

Konovalov, V.P. and Vereshchagin, V.N. 1969. Stratigraphy of the Cretaceous deposits of Primorye. In *Geology of the USSR: 32 Primorye* (ed. Nalivkin, D.), pp. 255-317 (Nedra, Moscow).

Krassilov, V.A. 1986. *Unsolved problems of evolutionary theory,* ix+136 pp. (Far East Science Center, USSR Academy of Sciences, Vladivostok).

Markevitch, V.S. 1987. New data of the Maastrichtian palynoflora of the Primorye. In *Palynology of the East of the USSR* (eds. Krassilov, V.A., Markevitch, V.S. and Verkhovskaya, N.B.), pp. 17-32 (Far East Science Center, USSR Academy of Sciences, Vladivostok).

Markevitch, V.S. 1989a. On the age of Arkagala Suite. In *Volcanogenic Cretaceous of the USSR* (ed. Krassilov, V.A.), pp. 93-98 (Far East Branch, USSR Academy of Sciences, Vladivostok).

Markevitch, V.S. 1989b. Palynological characteristics of the Cretaceous deposits in the Anadyr river basin. In *Volcanogenic Cretaceous of the Far East* (ed. Krassilov, V.A.), pp. 88-92 (Far East Branch, USSR Academy of Sciences, Vladivostok).

Markevitch, V.S. 1990. Palynostratigraphy of the Cretaceous deposits in the North-East of the USSR. In *Continental Cretaceous of the USSR* (ed. Krassilov, V.A.), pp. 132-143 (Far East Branch, USSR Academy of Sciences, Vladivostok).

Nessov, L.A. and Golovneva, L.A. 1990. History of the flora, vertebrates and climate in the late Senonian of the north-eastern Koriak uplands. In *Continental Cretaceous of the USSR* (ed. Krassilov, V.A.), pp. 191-212 (Far East Branch, USSR Academy of Sciences, Vladivostok).

Pokhialaynen, V.P. 1989. Correlation of the marine and continental Cretaceous formations in the north-east of Asia. In *Volcanogenic Cretaceous of the Far East* (ed. Krassilov, V.A.), pp. 56-63 (Far East Branch, USSR Academy of Sciences, Vladivostok).

Ponomarenko, A.G. 1990. Insects and the Lower Cretaceous stratigraphy of Mongolia. In *Continental Cretaceous of the USSR* (ed. Krassilov, V.A.), pp. 103-108 (Far East Branch, USSR Academy of Sciences, Vladivostok).

Rasnitsyn, A.P. 1987. The rates of evolution and evolutionary theory (hypothesis of the adaptive compromise). In *Evolution and biocenotic crises* (eds. Tatarinov, L.P. and Rasnitsyn, A.P.), pp. 46-63 (Nauka, Moscow).

Zherikhin, V.V. 1978. *The development and replacement of Cretaceous and Cenozoic faunistic assemblages,* ix+197 pp. (Nauka, Moscow).

An outline of nonmarine Cretaceous stratigraphy of China

Chen Pei-ji

Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China

Nonmarine Cretaceous rocks are extremely well-developed in China, and include variegated beds, red beds, coal-bearing horizons, evaporites and volcanics (Figs. 1 and 2). These deposits contain a diverse and abundant continental fauna (conchostracans, ostracods, bivalves, gastropods, insects, fish, and dinosaurs) and flora. Petroleum, coal, and evaporite resources within these deposits have regional importance.

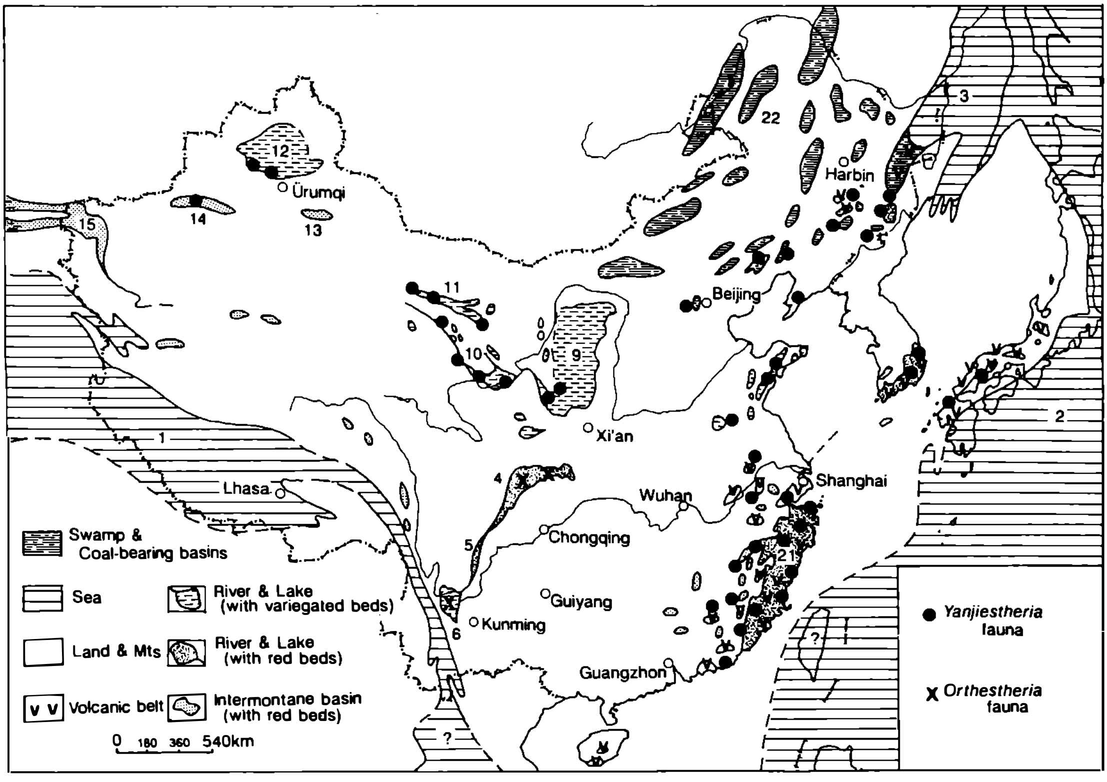

Fig. 1. Sketch map showing the Early Cretaceous palaeogeography and conchostracan provinces in China. 1 - Tethys, 2 - Pacific, 3 - Wusuli fault, 4 - Shu lake, 5 - Xichang lake, 6 - Yunnan lake, 7 - Puer lake, 8 - Ba lake, 9 - Qingyang lake, 10 - Datong river, 11 - Chao lake, 12 - Junggar basin, 13 - Turpan basin, 14 - Kuqa basin, 15 - unnamed river, 16 - Kashi gulf, 17 - Songhua lake, 18 - Yunmen lake, 19 - Gan river, 20 - Fuchun river, 21 - active volcanic zones in the eastern coastal lowland, 22 - swamp and coal-forming basins in NE China.

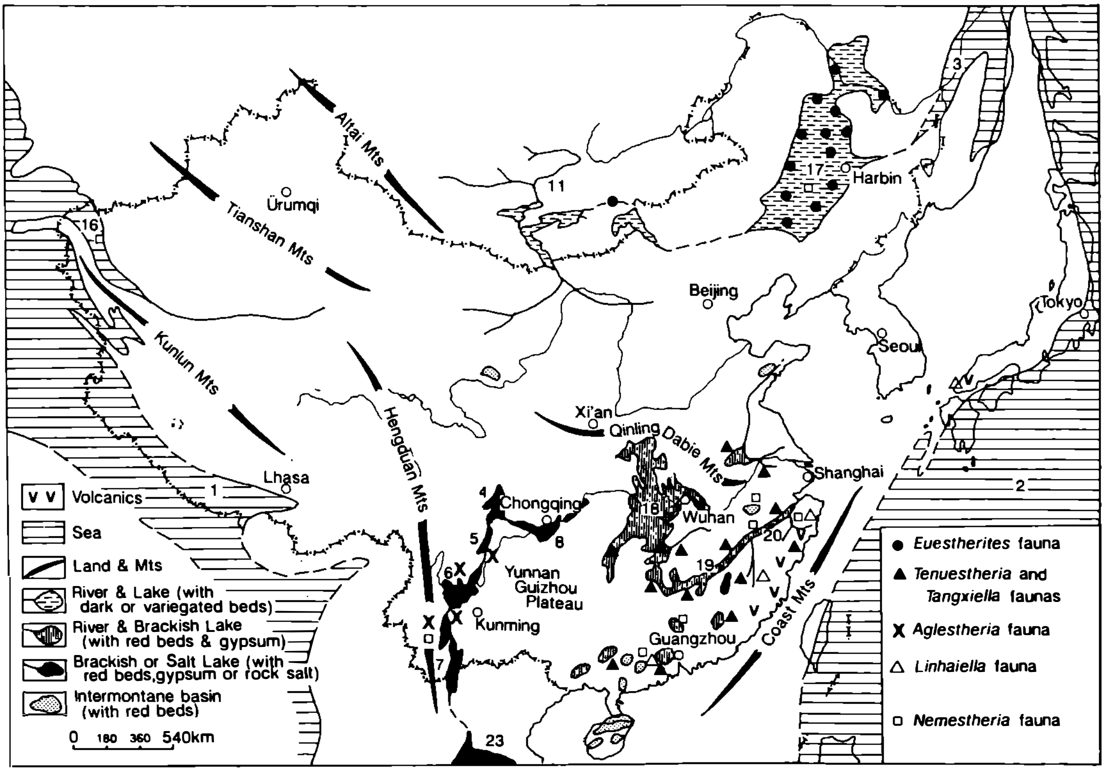

Fig. 2. Sketch map showing the Late Cretaceous palaeogeography and biogeographic provinces. (See Fig. 1 for additional explanation.)

During the past decade a number of studies have been published on nonmarine Cretaceous strata in China (e.g., Zhou et al., 1980; Chen and Shen, 1982; Chen et al., 1982; Chen, 1983; 1987, 1988, 1989, 1992; Hao et al., 1986; Ye and Zhong, 1990; Zhou and Chen, 1990). Recent magnetostratigraphic and radiometric dating works (Li et al., 1989; Fang et al., 1990) have complemented biostratigraphic studies. A reassessment of China Cretaceous biostratigraphy has been undertaken during the past five years, which has resulted in an improved assemblage sequence and zonation for a number of fossil groups in eastern China.

Researchers on different fossil groups have held divergent opinions concerning the placement of the Jurassic-Cretaceous boundary in northeastern China. Now it is possible to link the Lower Cretaceous succession in western Liaoning province with the Upper Cretaceous column in the Songliao basin, Heilongjiang, via strata in eastern Jilin. In northeastern China, therefore, a relatively complete nonmarine Cretaceous sequence comprising 13 formations is

identified (Fig. 3). The basal part of this sequence is dominated by coal-bearing bodies (Shahai and Fuxin formations), the middle part by volcanics (Dalenghe Formation), and the upper part that is characterized by oil-bearing strata (Qingshankou and Nenjiang formations) with coaly intercalations at the top (Furao Formation). The remaining formations (Sunjiawan, Longjing, Quantou, Yaojia, Sifongtai and Mingshui) are red beds.

Nonmarine rocks in the coastal areas of southeastern China are quite different from those in northern China, and consist mainly of volcanics, red beds, and variegated deposits intercalated with substantial thicknesses of evaporites at the top. Coal is absent. Gu (1983) and Ding et al.(1989) maintain that the basal part of this succession (Laocun, Huangjian and Shouchang formations) is Upper Jurassic; there is, however, increasing unanimity from recent magnetostratigraphic, biostratigraphic and radiometric work (see Chen, 1989; Li et al., 1989), which reveals the absence of Upper Jurassic and even lowermost Cretaceous rocks in southeastern China.

Stage \ Area	Songliao basin	E. Jilin	W. Liaoning
Maastrichtian	Furao Fm. Mingshui Fm.		
Campanian	Sifangtai Fm.		
Santonian	Nenjiang Fm.		
Coniacian			
Turonian	Yaojia Fm.		
Cenomanian	Qingshankou Fm. Quantou Fm.	Upper Red Beds	
Albian	Denglouku Fm.	Dalazi Fm.	
Aptian		Longjing Fm.	
Barremian		Tongfosi Fm.	Dalenghe Fm. ● ●
Hauterivian			Sunjiawan Fm.
Valanginian			Fuxin Fm.
Berriasian			Shahai Fm.

Stage \ Area	Zhejiang West	Zhejiang East	Age Ma BP
Maastrichtian	Tongxiang Fm.		
Campanian	Quxian Fm.	Laijia Fm.(b)	
Santonian	Lanxi Fm.	Laijia Fm.(a)	
Coniacian		●	
Turonian	Fangyan Fm.	Tangshang Fm. ● ●	
Cenomanian	Chaochuan Fm.		
Albian			
Aptian	Guantou Fm. ●		110
Barremian			
Hauterivian	Hengshan Fm.	Moshishan Fm. ● ●	117
Valanginian	Shouchang Fm. ●		122
	Huangjian Fm. ● ●		128
Berriasian	Laocun Fm. ●		130

Fig. 3. Subdivision of nonmarine Cretaceous strata in NE China and SE China (Zhejiang). ● ● - main volcanic sequence, ● - volcanic intercalations or tuff.

The Lower-Upper Cretaceous boundary in southern China also has been subject to varying interpretations, but recently discovered fossils from the Chaochuan Formation, Zhejiang province, are known to be Cenomanian in the Hekou Formation of neighbouring Fujian province. The boundary in Zhejiang can be placed between the Chaochuan and Guantou formations.

In western China nonmarine Cretaceous strata are composed of variegated and red beds without volcanics. The Lower Cretaceous variegated rocks are called the Zhidan Group (including the Yijun, Luohe, Huanhe-Huachi, Luohandong› and Jingchuan formations) in the Shaan-Gan-Ning basin, the Tugulu Group (Qingshuihe, Hutubihe, Shenjiakou, and Lianmuqin formations) in the Junggar and Turpan basins, the Kapushaliang Group of the Kuqa basin. The Hekou Group and Datonghe formations in the Hekou basin belong to the Cretaceous Datong river valley. The Yanjiestheria fauna was distributed in the above-mentioned areas of NW China during the Early Cretaceous. A hiatus exists from the upper Lower Cretaceous until the Campanian. Uppermost Cretaceous red beds, containing dinosaurs, ostracods and charophytes, lie disconformably above Lower Cretaceous variegated beds, but their distribution is areally limited.

Cretaceous rocks in SW China consist mainly of red beds with occasional grey-green calcareous mudstones and marlstones in the middle part of each formation. During the Late Cretaceous there existed five major salt or brackish lakes in this region (Fig. 2).

References

Chen, P.J. 1983. A survey of the nonmarine Cretaceous in China. *Cretaceous Research* 4, 124-143.

Chen, P.J. 1987. Cretaceous palaeogeography in China. *Palaeogeography, Palaeoclimatology, Palaeoecology* 59, 49-56.

Chen, P.J. 1988. Distribution and migration of Jehol fauna with reference to nonmarine Jurassic-Cretaceous boundary in China. *Acta Palaeontologia Sinica* 27, 659-683.

Chen, P.J. 1989. Classification and correlation of Cretaceous in south China. In

Selected papers for symposium on Cretaceous of south China (eds. Chen, P.J., Xu, K.D. and Chen, J.H.), pp. 25-40 (Nanjing University Press, Nanjing).

Chen, P.J. 1992. Lower Cretaceous volcano-sedimentary rocks of east China with reference to the age of the horizontal displacement of the Tancheng-Lujiang fault. In *Aspects of nonmarine Cretaceous geology* (eds. Mateer, N.J. and Chen, P.J.), pp. 1-14 (China Ocean Press, Beijing).

Chen, P.J., Li, W.B., Chen, J.H., Ye, C.H., Wang, Z., Shen, Y.B. and Sun, D.L. 1982. Sequence of fossil biotic groups and stratigraphical classification of Jurassic and Cretaceous in China. *Scientia Sinica series B* 11, 1227-1248.

Chen, P.J. and Shen, Y.B. 1982. Late Mesozoic conchostracans from Zhejiang, Jiangsu and Anhui. *Palaeontologia Sinica n.s. B* 17, 1-117.

Ding, B.L., Lan, S.X. and Wang, Y.P. 1989. *Nonmarine Jura-Cretaceous volcano-sedimentary strata and biota of Zhejiang, Fujian and Jiangxi,* 139 pp. (Jiangsu Science and Technology Publishing House, Nanjing).

Fang, D.J., Wang, Z.L., Jin, G.H., Gao, R.Q., Ye, D.Q. and Xie, J.L. 1990. Cretaceous magnetostratigraphy in the Songliao basin, China. *Scientia Sinica B* 33, 246-256.

Gu, Z.W. 1983. On the boundary of nonmarine Jurassic and Cretaceous in China. In *Studies on stratigraphic boundaries in China* (ed. Nanjing Institute of Geology and Palaeontology), pp. 65-82 (Science Press, Beijing).

Hao, Y.C., Su, D.Y., Yu, J.X., Li, P.X., Li, Y.G., Wang, N.W., Qi, H., Guan, S.Z., Hu, H.G., Liu, X., Yang, W.D., Ye, L.S., Shou, Z.X. and Zhang, C.B. 1986. *Cretaceous of China* (Geological Publishing, Beijing).

Li, K.Y., Shen, J.L. and Wang, X.P. 1989. Isotope geochronology of Mesozoic terrestrial volcanic rocks in the Zhejiang-Fujian-Jiangsi area. *Journal of Stratigraphy* 13, 1-13.

Ye, D.Q. and Zhong, X.C. (eds.) 1990. Cretaceous in oil- and gas-bearing areas of northern China, 354 pp. (The Petroleum Industry Press, Beijing).

Zhou, Z.Y., Chen, P.J., Li, B.X., Wen, S.X., Li, W.B., Zhang, L.J., Ye, M.N., Liu, Z.S. and Li, Z.P. 1980. Nonmarine late Mesozoic strata in Yanbian district, E. Jilin. *Bulletin of the Nanjing Institute of Geology and Palaeontology* 1, 1-21.

Zhou, Z.Y. and Chen, P.J. (eds.) 1990. *Biostratigraphy and geological evolution of Tarim,* 366 pp. (Science Press, Beijing).

Cretaceous System of Kyongsang basin, SE Korea

Chang Ki-Hong

Department of Geology, Kyungpook National University, Taegu 702-701, Korea

Introduction

Recent advances in the geology of Japan have disclosed that extensive accretions in the subduction zone occurred in Japan during the Jurassic Period (Ichikawa et al., 1985; Mizutani and Kojima, 1992). The general coincidence of Japanese accretion and the Korean Daebo orogeny and granite genesis suggests that they are genetically related within one tectonic framework. At the start of the Cretaceous Period, an entirely different tectonic framework evolved in Korea and its vicinity.

Extensional setting

Since the end of the erliest Cretaceous time, extensional tectonics have persisted in Korea and its vicinity until the present. During the Cretaceous, Korea was a part of the East Asian continent where extensive crustal upheaval and voluminous nonmarine sedimentation occurred. Facies distribution and palaeocurrent analysis suggest that Cretaceous sedimentary basins in Korea were intermontane grabens and semigrabens, with the sediment provenance being in the intergraben regions (Chang, 1987).

The largest known accumulation of Cretaceous strata in Korea (Fig. 1) lies in the Kyongsang basin, where fluvio-lacustrine conditions prevailed throughout its evolution. The sediment derived from the Jurassic Okchon orogenic belt to the northwest and from uplifted accretionary complexes in Japan, which at that time lay adjacent on the eastern margin (Chang, 1988). The Cretaceous extensional tectonics are relatively well known from the sedimentary, tectonic and magmatic records within the Kyongsang basin.

The process of basin evolution was controlled by an extensional crustal

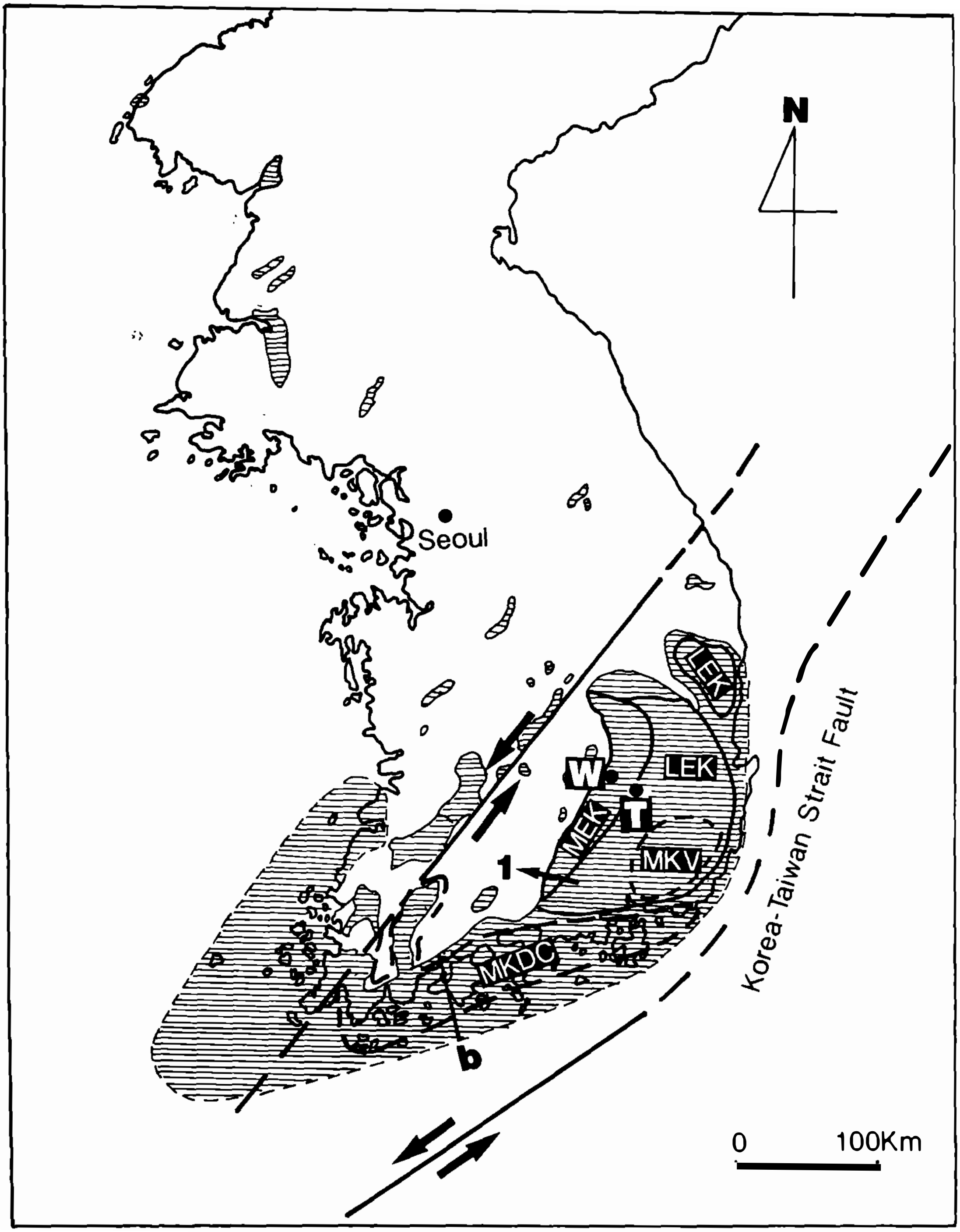

Fig. 1. Cretaceous sedimentary basins in Korea. The Kyongsang basin (1) lies in the SE part of Korea and the SW boundary (b) is somewhat arbitrary. MEK - depocenter of the Sindong Group (middle Lower Cretaceous), LEK - depocenter of the Hayang Group (upper Lower Cretaceous). MKV - extrusive center of the Yuchon Group (mid-Cretaceous), MKDC- depocenter of the Yuchon Group (mid-Cretaceous), T- Taegu City,W-Waegwan.

regime and related volcanic episodes. Volcanism culminated in the formation of the Yuchon Group. Concomitantly with this volcanism, the Bulguksa granite body was emplaced in the Kyongsang basin.

Basin history

The earliest sedimentation in the Kyongsang basin resulted in the Myogok Formation, which crops out in a restricted area in the northwest part of the basin. The age of this formation is believed to be Late Jurassic based on freshwater bivalves (Yang, 1976), or earliest Cretaceous based on palynomorphs (Chun, 1991). This formation is about 70 m thick and consists of sandstone and black shale, folded by the "Nakdong disturbance".

During the Early Cretaceous, a NNE-trending trough formed in the western part of the basin that was infilled with sandstone, shale, marl and conglomerate derived from the WNW according to palaeocurrent data. Sedimentary megacycles revealed in the outcrops indicate that the source area was subject to intermittent tectonic uplift.

An eastward expansion of the subsiding area resulted in deposition of the upper Lower Cretaceous Hayang Group (1,000-5,000 m) composed of shale, sandstone and minor amounts of marl and conglomerate, derived from surrounding source areas, and from volcanic rocks extruded into the basin. The dominant source lay in what is now the East Sea as determined from palaeocurrent patterns and facies' distribution. During the deposition of the Hayang Group, a new tectonic feature became active as manifest by WNW-trending growth faults that divided the basement of the basin into smaller crustal blocks. Syndepositional block movements resulted in abrupt lateral lithological and stratal thickness variations, which have hampered intrabasinal correlations.

The Yuchon Group unconformably overlies the Hayang Group and earlier rocks. This group occurs extensively in the southern part of the Kyongsang basin and extends laterally toward the west beyond the structural confines of the basin. The Sindong, Hayang and Yuchon groups constitute the Kyongsang Supergroup, which also is called the Kyongsang synthem (Chang, 1985), as it is a major unconformity-bounded stratigraphic unit.

Sedimentary environment

All fossils and sedimentary features of the Kyongsang Supergroup indicate a nonmarine origin; no marine fossils have been recorded. Plant megafossils, charophytes, freshwater mollusks, conchostracans, insects, chelonians, dinosaurs (body and trace fossils), and avian footprints have been reported.

The frequent occurrence of channel beds and related lithologies, such as coarse-grained clastics, intraclasts and clay galls, shows the predominence of fluvial environments. Caliche beds, calcareous nodules and nodular marl are evidence for seasonal aridity on the floodplain. Lacustrine limestones, usually less than 1 m, are generally argillaceous.

Age

The age determination of the Kyongsang Supergroup is based on fossils and the correlation with well-dated strata in Japan. The stratigraphically important charophyte, *Clypeator jiuquanensis,* ranges from Hauterivian to early Barremian (Wang and Lu, 1982). This taxon is found in the lower horizon in the upper half of the Nakdong Formation in the Waegwan-Taegu area (Seo, 1985). Accordingly, the base of the Kyongsang Supergroup is assumed to be Hauterivian.

The age of the uppermost part of the Hayang Group is based on palynomorphs from the lower Konchonri Formation, described as "not younger than early Albian and not older than Hauterivian, presumably of Aptian to early Albian" age (Choi, 1985). The age of the Konchonri Formation is supported by the implied age range of the overlying Yuchon Group, which is divided into the Lower Jurassic Intermediate Volcanic Subgroup and the upper Unmunsa Acidic Subgroup. These two subgroups correspond with the Shunan and Abu groups, respectively, in the Inner Zone of SW Japan. They were isotopically dated as latest Albian (Shunan) and Cenomanian (Abu) by Shibata et al. (1978).

During the Cretaceous, the Inner Zone of SW Japan lay close to Korea on the Asian continental margin. The formation of nonmarine sedimentary basins and associated igneous activity have a strong genetic relationship in both regions.

In 1936 Kobayashi and Suzuki described *Plicatounio naktongensis* and *Trigonioides kodairai* from their "Nakdong-Wakino Series". The occurrence of these species in Korea is confined to the middle part of the Hasandong Formation (Sindong Group).

The maximal intrusive age range of the Bulguksa granite is from 85 Ma to 70 Ma; isotopic ages for the granite vary from Aptian-Albian to Cenozoic, which, in the Kyongsang basin, young to the east. This trend forms the basis for the following hypothesis of the basin development.

Basin genesis

Cretaceous sedimentary basins are numerous on the Korean peninsula, with a concentration in the southern part of South Korea. This concentration concerns both volume and areal extent, especially along the Korea Strait, which suggests that this area was an axis of sedimentation and igneous activity formed by a major wrench fault underlying the Korea Strait.

According to Xu et al. (1987), a major Mesozoic sinistral fault (the Korea-Taiwan Strait fault) occurred between Korea and Japan. The migration of the Kyongsang basin depocenter and magmatism to the east is consistent with the sinistral movement of the Korea-Taiwan fault during the Cretaceous. I believe that a new sediment provenance appeared adjacent to the MKDC (see Fig. 1) carried by the sinistral motion of the fault.

References

Chang, K.H. 1985. *Treatise on the geology of Korea,* 270 pp. (Minum-sa)

Chang, K.H. 1987. Cretaceous stratigraphy. In *Geology of Korea* (ed. Lee, D.S.), pp. 175-194 (Kyohak-sa).

Choi, D.K. 1985. Spores and pollen from the Kyongsang Supergroup, southeastern Korea and their chronologic and paleontologic implications.

Journal of the Palaeontological Society of Korea 1, 33-50.

Chun, H.Y. et al. 1991. Stratigraphic and paleontologic study of Myogog Formation. *KIGAM, KR-91(B)-2,* 75 pp.

Ichikawa, K., Hada, S. and Yao, A. 1985. Recent problems of Paleozoic microbiostratigraphy and Mesozoic geohistory of southwest Japan. *Memoir of the Geological Society of Japan* 25, 1-18.

Mizutani, S. and Kojima, S. 1992. Mesozoic radiolarian biostratigraphy of Japan and collage tectonics along the eastern continental margin of Korea. *Palaeogeography, Palaeoclimatology, Palaeoecology* 96, 3-22.

Seo, S.J. 1985. *Lower Cretaceous geology and paleontology (Charophyta) of central Kyongsang basin, Korea.* Ph.D. thesis, Kyungpook National University, 177 pp.

Shibata, T. et al. 1978. Isotope ages and stratigraphic control of Mesozoic igneous rocks in Japan. Contribution to the geologic time scale: *American Association of Petroleum Geologists, Studies in Geology* 6, 143-164.

Wang, Z. and Lu, H.N. 1982. Classification and environment of Clavatoraceae with notes on its distribution in China. *Bulletin of the Nanjing Institute of Geology and Palaeontology,* 77-104.

Xu, J. et al. 1987. Formation and evolution of the Tancheng-Lujiang wrench fault system: a major shear system to the northwest of the Pacific Ocean. *Tectonophysics* 134, 273-310.

Yang, S.Y. 1976. On the nonmarine molluscan fauna from the Upper Mesozoic Myogog Formation, Korea. *Transactions and Proceedings of the Palaeontological Society of Japan N. S.* 102, 317-333.

The Lower Cretaceous biostratigraphy in Japan

Masaki Matsukawa

Laboratory of Palaeontology, The Nishi Tokyo University, Uenohara, Yamanashi 409-01, Japan

During the Early Cretaceous, the Japanese islands were located on the eastern margin of the Asian continent as evidenced by the interfingering relationship between nonmarine and marine sediments. There are, therefore, a variety of nonmarine and marine fossils and sedimentary facies, the distribution of which has revealed the paleobiogeography in eastern Asian, the paleocurrent patterns in the northwestern Pacific, and the Early Cretaceous palaeoecosystem.

Matsukawa and Obata (1992) correlated nonmarine and marine formations, including ammonite indices, which permitted correlation of marine stage nomenclature from Japan to the nonmarine Gyongsang Group in South Korea. Because of Asian mainland excluding NE Heilongjiang (China) and Sikhote-Alin (Russia), consists of terrestrial facies, the Japanese Lower Cretaceous sequences enables a correlation between nonmarine sequence of Asia with the marine sequence in Europe. Matsukawa et al. (1993) attempted a correlate between nonmarine and marine formations with Barremian ammonites in Heilongjiang and Sikhote-Alin areas. They identified the Early Cretaceous second transgression that is well known in Japan (Matsukawa and Obata, 1992).

Since discovery of a single humerus of an indeterminate sauropod from the Aptian Miyako Group in Japan, many dinosaur remains, including fragments of bone, teeth and footprints have been recovered from fluvio-lacustrine sediments (Matsukawa and Obata, 1994). Some of these specimens indicate that they occupied a different habitat (coastal margins) from those of from further inland. Footprints of iguanodontid and slender-toe gracile theropods from both eastern Manchuria (NE China) and Tetori (Japan) appear to lie within a common paleobiogeographical province, which probably includes the psittacosaurid faunal complex. This supports the idea that Japan was connected to the Asian continent during the Early Cretaceous (Matsukawa et al., 1994).

Sedimentological and stratigraphical evidences indicate common dinosaur tracks along a fluvial system flowing from NE China to central Japan, strongly suggesting that dinosaur had the ability to move between NE China and central Japan in the Early Cretaceous (Matsukawa et al., 1993).

Extraction and observation of terrestrial megaplant fossil cuticle from the outer side of Japan (e.g., Kimura and Okubo, 1985) supports the notion that paleoclimate conditions during the Early Cretaceous were subtropical or subtropical and arid climate in the region (e.g., Kimura, 1984).

Five nonmarine bivalve assemblages from the Tetori Group (Middle Jurassic to mid-Cretaceous) reflect a gradation of environments from brackish to freshwater, with species composition varying according to salinity (Matsukawa and Ido, 1993). They are corroborated by sedimentological features characteristics of lake floor to distal mouth bar through lake slope facies (Masuda et al., 1991). According , these assemblages are useful as paleoenvironmental indicators, although not necessarily as indices of biochronological zones (Matsukawa and Ido, 1993). For examples, the freshwater bivalves *Trigonioides (Wakinoa) tetoriensis* Maeda was reported from the Upper Hauterivian? to Barremian Tatsukawa Formation of the outer side of Japan, as determined by ammonite indices (Tashiro and Okuhira, 1993), but which also occurs in the uppermost part of the Tetori Group, assignable to the mid-Cretaceous.

The Tethyan, NW European, Boreal and northern Pacific ammonites occur in Barremian strata in Japan (Matsukawa and Obata, 1993). The occurrence of three species of crioceratid from Japan is viewed as Tethyan immigrant species, or their descendants, based on crioceratid lineage and their distribution. The Boreal *Simbirskites (Milanowskia)* species was a migrant from the NW European province via the Arctic region (Matsukawa, 1988). The distribution of these Tethyan, NW European, Boreal and northern Pacific ammonites provides important additional evidence for the existence of both cold and warm water currents originating in high and low latitudes. This model is based on oceanic circulation patterns and concordant global distribution of ammonites during Barremian (Matsukawa and Obata, 1993).

Because of the interfingering relationship between nonmarine and marine sediments, the coast of the eastern margin of the Asian continent in Early

Cretaceous time is identified with Japan, NE China and Sikhote-Alin (Russia). These areas were strongly influenced by sea-level changes, of which three transgressionary phases have been recongnized around Japan (Matsukawa and Obata, 1992).

From facies relationships, paleocurrent directions, the occurrence of common fossil species, and the tectonic framework, we can attempt a reconstruction of the paleogeography (Futakami and Matsukawa, 1994). As one of example, the Tetori Group and the Severosuchanskaia Formation in southern Sikhote-Alin are interpreted to have been deposited under a same Barremian gulf which had a north facing mouth. The occurrence of ammonites and inoceramids, known from the Tethys, NW Europe, northern Pacific and Boreal provinces, in SW Japan, NE China and Sikhote-Alin, provides important evidence for both cold and warm currents originating in the Arctic and near the Equator, respectively. Both current distributions in SW Japan, NE China and Sikhote-Alin during the Barremian are inferred from the coriolis force. The gulf is identified from the Tetori Group and the Severosuchanskaia Formation and is considered, therefore, to be influenced by the Arctis current (Matsukawa et al., 1993).

Radiolarian biostratigraphical research has established a biochronological scale which has provided an age constraint for barren the zone in ammonite biochronology (e.g., Taketani, 1987; Ishida et al., 1992). They also provide for an understanding of an accretionary tectonic setting during the Early Cretaceous (e.g., Yao, 1984). Attempts to reconstruct paleocurrent patterns during the Early Cretaceous using radiolarians, are currently being undertaken.

References

Futakami, M. and Matsukawa, M. 1994. Cretaceous ammonite paleobiogeography in east Asia. *Chikyu Monthly* 16, 255- 262. (in Japanese)

Ishida, K., Hashimoto, H. and Kozai, T. 1992. Litho- and biostratigraphy of the Lower Cretaceous Hanoura Formation in eastern Shikoku – Part 1. Hiura and Tsukigatani routes in Katsuuragawa area –. *Journal of Science, University of Tokushima* 26, 1-57.

Kimura, T. 1984. Mesozoic floras of east and southeast Asia, with a short note on the Cenozoic floras of asia. *Geology and Palaeontology of Southeast Asia* 25, 325-350.

Kimura, T. and Okubo, A. 1985. *Nilssonia dictyophylla* sp. nov. from the Lower Cretaceous Choshi Group, in the outer zone of Japan. *Proceedings of the Japan Academy* 61, 430-432.

Masuda, F., Ito, M., Matsukawa, M., Yokokawa, M. and Makino, Y. 1991. Depositional environments. 1991 Fukuoka International Symposium, IGCP-245 Field Trip Guide Book: *Lower Cretaceous nonmarine and marine deposits in Tetori and Sanchu, Honshu* (ed. Matsukawa, M.), pp.11-17.

Matsukawa, M. 1988. Barremian ammonites from the Ishido Formation, Japan – Supplements and faunal analysis –. *Transaction and Proceedings of the Palaeontological Society of Japan, N.S.* 149, 396-416.

Matsukawa, M. Futakami, M., Chen, P.J. and Lockley, M.G. 1993. Early Cretaceous paleogeography: a possible dinosaur freeway in East Asia. *Program and Abstracts IGCP-350: Cretaceous Environmental Change in E and S Asia, First Meeting for the Regional Coordinators,* p.13.

Matsukawa, M. and Ido, K. 1993. Nonmarine molluscan community and paleoecology of the Jurassic - Cretaceous Tetori Group, Japan. *Cretaceous Research* 14, 365-381.

Matsukawa, M., Kalinin, J.A., Futakami, M. and Chen, P.J. 1993. Paleogeography and paleocurrents of the Barremian strata in Japan, NE China and Sikhote-Alin (Russia). *Palaeogeography, Palaeoclimatology, Palaeoecology* 105, 71-81.

Matsukawa, M. and Obata, I. 1992. Correlation of nonmarine and marine formations in the Lower Cretaceous of Japan: A contribution to nonmarine formations in Asia. In *Aspects of nonmarine Cretaceous geology* (eds. Mateer, N.J. and Chen, P.J.), pp.133-147 (Chinese Ocean Press, Beijing)

Matsukawa, M. and Obata, I. 1993. The ammonites *Crioceratites (Paracrioceras)* and *Shasticrioceras* from the Barremian of southwest Japan. *Palaeontology* 36, 249-266.

Matsukawa, M. and Obata, I. 1994. Dinosaurs and sedimentary environments in the Japanese Cretaceous: a contribution to dinosaur facies in Asia based on molluscan palaeontology and stratigraphy. *Cretaceous Research* 15, 101-125.

Matsukawa, M. Futakami, M., Lockley, M., Chen P.J., Chen, J.H., Cao, Z.Y. and Bolotsky, U.L. 1994. Dinosaur footprints from the Lower Cretaceous of eastern Manchuria, northeastern China: implications for the recognition of an ornithopod ichnofacies in East Asia. *Palaios* 9, In press.

Taketani, Y. 1987. Lower Cretaceous radiolaria from Oshima island, Miyagi Prefecture, northeast Japan. *Bulletin of the Fukushima Museum* 1, 23-39. (in Japanese with English abstract)

Tashiro, M. and Okuhira, K. 1993. Occurrence of *Trigonioides* from the Lower Cretaceous of Shikoku, and its significance. *Geological Report of the Shimane University* 12, 109. (in Japanese with English abstract)

Yao, A. 1984. Subduction of the Mesozoic complex in Kii-Yura area, southwest Japan and its bearing on the Mesozoic basin development in the southern Chichibu Terrane. *Journal of Geosciences, Osaka City University* 27, 41-103.

Cretaceous Oceanic Anoxic Events : current studies in Japan

Hiromichi Hirano

Institute of Earth Science, Waseda University School of Education, Nishiwaseda 1-6-1, Shinjuku, Tokyo 169-50, Japan

The Cretaceous Oceanic Anoxic Events in Japan were mentioned by Hirano et al. (1990), who suggested existence of oceanic anoxic event in the Northwestern Pacific in relation with the phyletic evolution of desmoceratine ammonoids at the boundary between Cenomanian and Turonian. Later, Hirano et al. (1991) studied the chemical stratigraphy in three sections of the Middle Yezo Group in Oyubari area, Hokkaido, with special reference to the excursion of sulfide sulfur contents. They successfully detected the reduction condition at the level between the Cenomanian and the Turonian as determined by ammonoid and inoceramid biostratigraphy (Fig. 1).

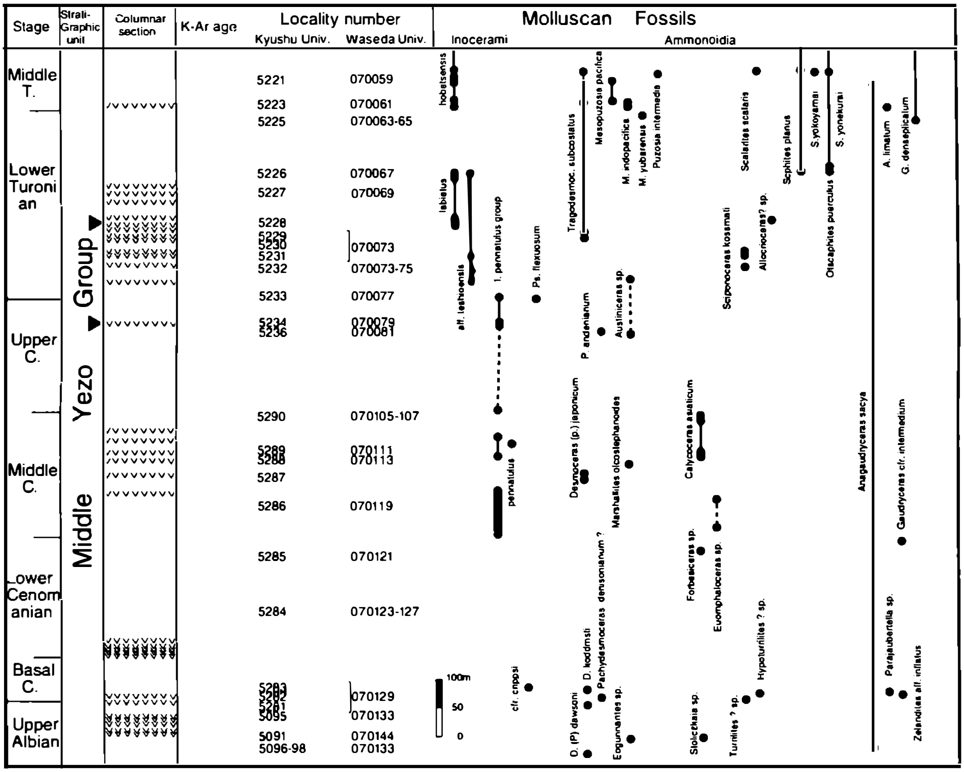

Fig. 1. Biostratigraphic section of the Hakkinzawa River, Oyubari area, Hokkaido. The column of K-Ar age is now in progress. Revised after Hirano et al. (1977).

The carbon isotope ratio excursion is internationally used for the detection of the C/T-OAE level, but such data has not yet been obtained. Sampling and chemical analyses of material from Tunisia and southern France confirmed the propriety of sulfur contents as the index of redox conditions. The results indicate that sulfur contents are adequate as the redox index in relation with the C/T-OAE. On the basis of these results, I discussed the phyletic evolutionary mode of desmoceratine ammonoids at the time of C/T-OAE (Hirano, 1933).

On the occasion of IGC-29 field trip some specialists observed the same sections discussed above and agreed that the black shale bed represents the latest Cenomanian sea level high stand. Weak bioturbation is in agreement with our sulfur analysis result, indicating reduction to weak reduction condition (Hirano et al., 1992). Recently Hasegawa and Saito(1993) showed a carbon isotope ratio excursion along the same section with the spike of isotope ratio at the same stratigraphic level as our sulfur content spike.

Biostratigraphy of sections across the C/T boundary has been studied under the supervision of Prof. Matsumoto for many years. In these years he refined the biostratigraphic resolution with his coworkers and the stratigraphic distance between the uppermost Cenomanian and the basal Turonian is about 10m (Nishida et al., 1993; personal communication with Matsumoto) in comparison with 20m to 30m of our result in 1991.

Maeda (1992) mentioned that the Aptian-Albian oceanic anoxia is traceable for 2000 km from Sakhalin to western Japan. Oxygen depleted condition is also mentioned for the Coniacian deposits of the Upper Yezo Group of Hokkaido (Hayakawa, 1992).

References

Hasegawa, T. and Saito, T. 1993. Global synchroneity of a positive carbon isotope excursion at the Cenomanian/Turonian boundary:Validation by calcareous microfossil biostratigraphy of the Yezo Group, Hokkaido, Japan. *The Island Arc* 2, 181-191.

Hayakawa, H. 1992. Coniacian low-oxygen benthic assemblage. *Fossils* 53, 48-

49. (in Japanese)

Hirano, H., Okamoto, T. and Hattori, K. 1990. Evolution of some Late Cretaceous desmoceratine ammonoids. *Transactions and Proceedings of the Palaeontological Society of Japan, N.S.* 157, 383-412.

Hirano, H. 1993. Phyletic evolution of desmoceratine ammonoid through OAE at Cenomanian-Turonian oceanic anoxic event. *Systematics Association Special Volume* 47, 267-284.

Hirano, H., Matsumoto, T. and Tanabe, K. 1977. Mid-Cretaceous stratigraphy of the Oyubari area, central Hokkaido. *Palaeontological Society of Japan Special Papers* 21, 1-10.

Hirano, H., Nakayama, E. and Hanano, S. 1991. Oceanic anoxic event at the boundary of Cenomanian/Turonian Ages –First report on the Cretaceous Yezo Supergroup, Hokkaido, Japan from the view of biostratigraphy of megafossils, sedimentary- and ichno-facies and geochemistry–. *Bulletin of Science and Engineering Research Laboratory, Waseda University* 131, 52-59.

Hirano, H., Tanabe, K., Ando, H. and Futakami, M. 1992. Cretaceous forearc basin of central Hokkaido:Lithofacies and biofacies characteristics. *29th IGC field trip guide book*, 1, *Nagoya University*, 45-80.

Maeda, H. 1992. Records of "oceanic anoxia" in the Middle Cretaceous System in Japan. *Fossils* 53, 47-48. (in Japanese)

Nishida, T., Matsumoto. T., Maiya, S., Hanagata, S., Yao, A. and Kyuma, Y. 1993. Integrated mega- and micro-biostratigraphy of the Cenomanian stage in the Oyubari area, Hokkaido –with special reference to its upper and lower limits–. Part 1. *Journal of the Faculty of Education, Saga University,* 41 (II), 11-57.

Philippine Cretaceous System

Priscilla J. Militante-Matias, Marietta M. de Leon and Juanita A.V. Denoga

National Institute of Geological Sciences, University of the Philippines, Diliman, Quezon City 1101, Philippines

Introduction

The occurrence of Cretaceous fossils in the Philippines was reported as early as the 1950s, but it was not until the 1960s that paleontologists showed interest in Cretaceous fossils and began studies on them. Foraminifera were the first studied (Reyes and Ordoñez, 1970), both large (*Orbitolina*) and small. Despite that Cretaceous rocks are widely distributed in the country, so far eleven localities have reported foraminifers. Other fossils recorded are ammonites, radiolarians and calcareous nannofossils, although these are reported from only few localities. This may be attributable to the few workers on this subject.

Cretaceous studies continue, but mostly in connection with mineral exploration and general mapping.

Regional geology and tectonics

Island arc elements and accreted terranes comprise the Philippine archipelago. The Philippines is composed of the Calamian microplate with its Paleozoic basement, and the remainder of the archipelago with its Cretaceous and younger island arc or magmatic arc elements, ophiolites and possibly continental fragments. Both terranes were probably rifted off the Andean-type China margin.

The Cretaceous and younger portion of the Philippines may, at least in part, have been rifted off the China margin in the Late Cretaceous or Early Paleocene and pushed southeastward as the proto-South China Sea opened.

Karig (1982) has suggested that the northern Philippines is a collage of accreted terranes, some of which may have moved to their present position by strike-slip faulting and oblique convergence from hundreds or thousand kilometers to the south. The tectonic development of the southeastern part of the Philippines has yet to be deciphered, although two fossil island arcs in eastern Mindanao and surrounding areas that contain Cretaceous to Miocene volcanic rocks have been identified. These rocks probably did not originate on the China margin. The northern and central Philippines have acted as a single block since the Late Miocene as suggested by the consistent Late Miocene magnetic directions in Luzon, Marinduque and Negros. Late Miocene to Pliocene paleomagnetic data indicate that the collision-related rotations in the Philippines were completed by the beginning of Late Miocene time.

The other tectonic province of the Philippines, the Calamian microplate, was rifted off the China margin beginning in the Middle Eocene, and this terrane consists of more inland continental material than the magmatic arc-subduction complex province rifted in the previous phase of attenuation and spreading. Sea floor spreading in the present-day South China Sea commenced in the Middle Oligocene and pushed the Calamian microplate southeastward, ahead of it. Spreading ceased in the Early Miocene and, in the late Middle Miocene, attempted subduction of the leading edge of the Calamian microplate continental crust locked the Borneo-Palawan subduction zone causing the system to become inactive.

Historical background

The foraminiferal study of Reyes and Ordoñez (1970) was significant because it established the presence of Cretaceous rocks in seven provinces in the country, namely: Rizal, Catanduanes, Camarines Norte, Camarines Sur, Cebu, Samar and Davao. The work of Ordoñez (1970) on the Cretaceous radiolarian occurrences in Rizal confirmed foraminiferal data. After Reyes and Ordoñez (1970), most of the limited works on Cretaceous sections were either carried out in connection with company or survey research projects, thus the reports were not published or readily available for public consumption.

Espiritu et al. (1968) identified well preserved Late Cretaceous foraminiferal assemblages from a sheared clastic sample collected within the contact of two Miocene formations, the Middle Miocene Vigo Formation and the Upper Miocene Canguinsa Formation. The occurrence of Cretaceous rocks here serves as conclusive evidence that an earlier sedimentation previous to the deposition of the Vigo Formation took place in Bondoc Peninsula. Moreover, it is the first time that sediments of Cretaceous are encountered in the area. Hashimoto et al. (1984) cited Douglas (1960), who mentioned unidentified, specimens of *Orbitolina* from the Philippines and, the recovery of the same genus by Kitamura from the calcareous sandstone below the Bonagbonag Limestone in Catanduanes.

Miranda (1976) mentioned the occurrence of *Orbitolina* from the Caramoan Peninsula but did not indicate its locality. Hashimoto et al. (1977-1984) studied in detail the different Philippine Cretaceous areas in Rizal, Samar, Cebu, Catanduanes and Palawan. Tan (1986) updated the work of Hashimoto et al. by including newly identified Cretaceous areas such as Leyte, Marinduque, Catanduanes and Davao Oriental, and elaborated on the foraminifer distribution in each area.

Significant developments in Cretaceous studies occurred in the late 1970s and early 1980s with the establishment of calcareous nannofossils as a Cretaceous biostratigraphic tool. Results of the calcareous nannofossil investigations of Cretaceous strata of Rizal, Palawan and Cebu are contained in unpublished reports of Müller and de Leon (1979-1985) deposited at the Bureau of Energy Development and Cepek (1984). The discovery of a Cretaceous ammonite in a float in Catanduanes by Sendon in 1982 prompted Fe P. Tumanda to conduct paleontological investigations in the Comagaycay River area, which resulted in the collection and identification of an in situ Early Cretaceous assemblage (Tumanda, 1985).

Reports by Gramann (1983a and 1983b) in Porth et al. (1989) and Amiscaray and Nilayan (1986) on Cebu have also contributed significantly to the study of Philippine Cretaceous.

Recent studies on the Cretaceous Bonagbonag Limestone in Catanduanes province by Denoga et al. (1991) deal with microfacies and micropaleontology.

An ongoing review of this rock unit by de Leon and Militante deals with its calcareous nannofossil content.

Distribution of Cretaceous rock units

Cretaceous rocks are generally described by Gervacio (1971) as "extensive transgressive graywacke-shale sequence intercalated with spillites associated with limestone lenses and tuffaceous clastics".

The different Cretaceous rock units in the Philippines are best treated by basin, of which eleven are defined (Bureau of Energy Development et al., 1986) (Fig. 1).

Cagayan

The record of Cretaceous in the Cagayan basin which is considered to be one of the largest in the Philippines, is its basement complex consisting of melange of basalt and andesite flows associated with pyroclastics and metamorphosed sediments and limestones. The basement, however, is undifferentiated in age from Cretaceous to Early Oligocene.

Central and West Luzon

In general, in the central Luzon basin sedimentary rocks of older than Oligocene have been metamorphosed or indurated and incorporated into the basement complex consisting of basic and ultrabasic rocks, diorites, volcanics, and volcaniclastics. However, isolated occurrences of unmetamorphosed Cretaceous (as in the limestone of Tanay, Rizal) to Oligocene sediments are found in the eastern flank of the basin.

Ilocos

The Bureau of Energy Development et al. (1986) report that "in the northwestern part of the trough (Ilocos) thin red radiolarites of the Baruyen Chert formation were deposited in pelagic environment during the Middle Cretaceous (Robertson, 1984). This unit could belong to the upper part of the ophiolite suite ("Ilocos Ophiolite"), as suggested by its intimate association with quartzites, serpentinites and serpetinized peridotites in Pasuquin Plateau".

Late Cretaceous sedimentation is evident in the southeastern portion of the trough through relict structures found in the low to medium-grade

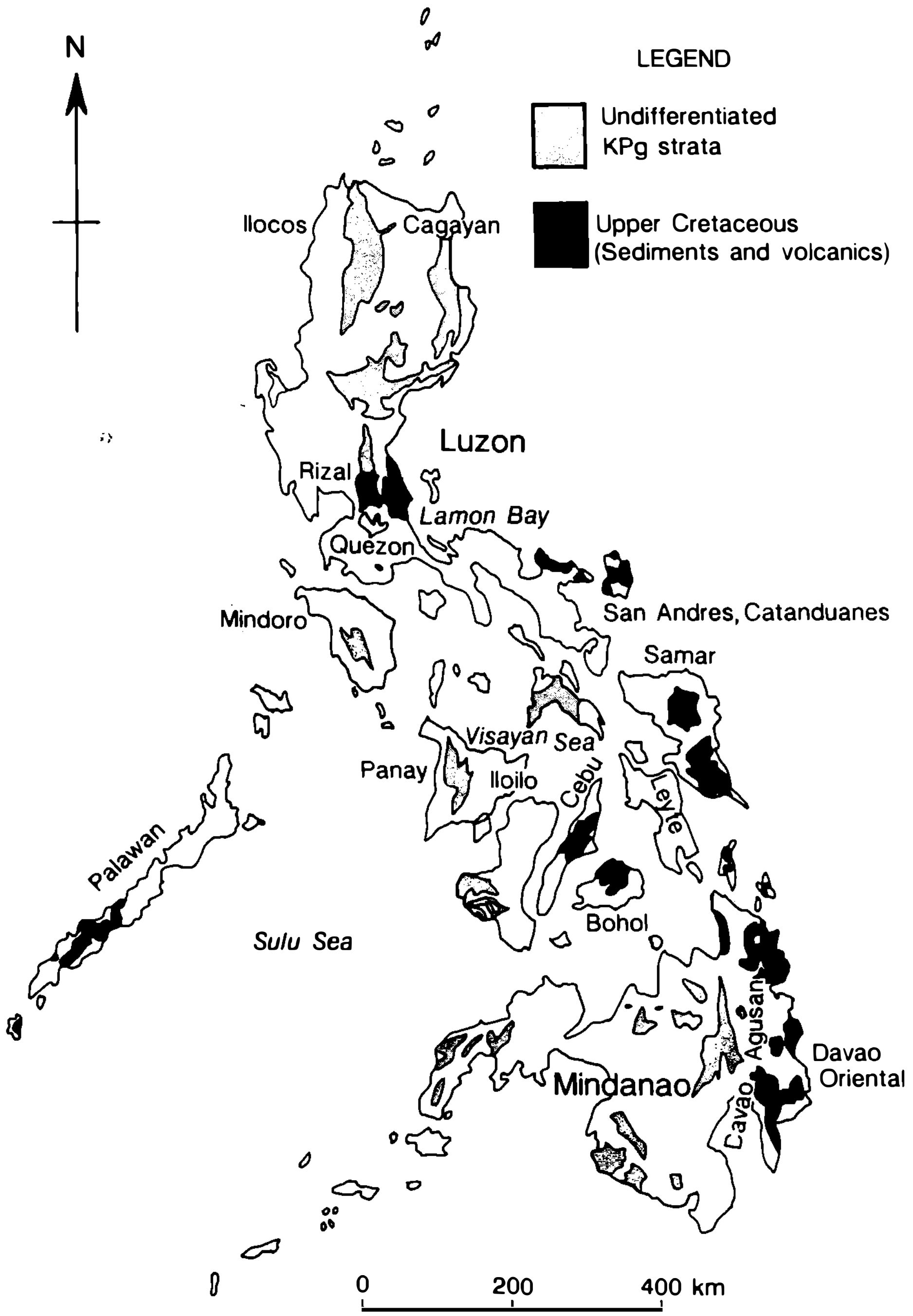

Fig. 1. Distribution of Cretaceous rocks in the Philippines.

metamorphics of the Dalupirip schists exposed in the southwest of Central Cordillera. The metamorphism that took place within the area may have been related to the orogenic phase that affected the southern proto-Central Cordillera during the Late Cretaceous.

Bicol Shelf-Lamon Bay

In the Bicol Shelf-Lamon Bay basin, the Cretaceous magmatic activity generated ophiolites, spilitic basalts and volcaniclastics. Orogenic movements, which are believed to have occurred after the Cretaceous, caused the emplacement of the ultramafic complex and metamorphism of existing rocks bringing in new rocks that make up the basement complex.

Southeast Luzon

Cretaceous and older basement rocks on land are found in Camarines Norte and Caramoan Peninsula. They are chiefly ultramafics (peridotites, pyroxenites, gabbros and dunites) and metamorphics (chlorite schists, sericite schists and quartzites). Other rocks in the assemblage are spilitic basalts and andesitic flows and volcaniclastics associated with cherts and limestones.

The true basement on Pollillo Island consists of schists and diorites believed to be of pre-Cretaceous age. On top of this basement are altered volcanic flows and tuffaceous sediments of Cretaceous to Paleocene age and are considered to be the economic basement.

The Yop Formation, Lower Cretaceous according to Rangin et al. (1984, in Bureau of Energy Development et al., 1986), occurs on Catanduanes Island. The formation consists of intercalated volcanic and sedimentary rocks comprising submarine basaltic lava flows with volcanic breccia, diabase porphyry and interbedded chert, and volcanic sedimentary rocks. It lies conformably below the Bonagbonag Limestone.

The Bonagbonag Limestone is Late Cretaceous in age, and in its type locality shows basal ferruginous schistose shale with minor siltstone beds (Bureau of Energy Development et al., 1986). While Cruz (1968), Tan (1986) and Bureau of Energy Development et al. (1986) believe the Bonagbonag Limestone to be predominantly coralline, Hashimoto (1982) and Denoga et al. (1991) think otherwise, based on their investigation of the rock unit from its type section, which reveals a pelagic limestone: micritic character and the presence of various planktonic foraminifers (e.g., *Globotruncana* spp.)

Iloilo-Panay

The Cretaceous System is represented in the Iloilo-Panay basin by ophiolitic pillow lavas, ultramafics, radiolarites and mafic dikes that form part of the basement in the western part of the basin. Cretaceous to Paleocene (?) quartzites, slates and graywackes occur in the basement in the southeasternmost part of the basin (Guimaras) and the western portion of Masbate shelf. The presence of these quartzites and meta-quartzose sandstones suggests that eastern Panay, as in some parts of the Visayan basin, is underlain by continental crust and may have been contiguous with the Eurasian Plate margin. The continental fragment bearing Guimaras may have rifted off from the Eurasian continental plate margin towards the south during the opening of the proto-South China Sea in Mid- to Late Cretaceous (Bureau of Energy Development et al., 1986).

The western Iloilo-Panay basin consists of the "Antique Ophiolite" which comprises the ultrabasic and basic plutonics, gabbro and diorite dikes, basaltic lavas and siliceous sediments in the NE-SW trending Batuan and Maglaya ranges northeast of San Jose, Antique. The associated radiolarian chert is dated Early Cretaceous and Late Jurassic-Early cretaceous by Matsumaru and McCabe (in McCabe et al., 1982; Bureau of Energy Development et al., 1986].

On the west Masbate shelf of the Iloilo-Panay basin, the Bureau of Mines and Geosciences (1982) grouped the red and purple slates and graywackes (Kaal Formation) overlying the oldest rocks of Jurassic and older, with metavolcanics and called them the Cretaceous Formation.

Visayan Sea and Samar

Cretaceous metamorphic rocks, ultramafics, volcanic flows and intrusives constitute a part of the so-called basement of Visayan Sea and Samar basin. Deposition of sediments in a shallow to transitional environment during the Early Cretaceous is manifest in the area of Tuburan, Cebu where pelletoidal, micritic limestones consisting of mollusks, algae and foraminifers, and volcanics with limestone lenses are exposed.

Deeper deposition occurred in the Late Cretaceous as reflected by the limestones within the vicinity of Pandan, Cebu. The limestone is micritic, siliceous and laminated and is found interbedded with clastics such as shale and sandstone. It contains considerable amounts of planktonic foraminifers.

Deep water limestone deposition occurred at the same time in Samar, resulting in the San Jose Limestone.

Agusan-Davao

Very few data are available on the Agusan-Davao basin. However, reports available indicate the occurrence of a Cretaceous pelagic fauna in fine-grained sediments associated with continental crust material (Agusan-Davao Consortium, 1977 in Bureau of Energy Development et al., 1986; Tan, 1986).

Reyes and Ordoñez (1970) reported a Cretaceous limestone float in Davao, which resembles that of the Cretaceous limestone in Samar.

South Palawan-Sulu Sea

Presumed Cretaceous to Paleocene rocks in southern Palawan are the economic basement made up of spilitic lava flows of basaltic to andesite composition, chert with abundant radiolarian, reddish brown micrites, mudstones in association with metamorphics and igneous intrusives. In the Reed bank area, sediments of Early Cretaceous age are encountered. These sediments vary from quartz-rich sandstones to limestones.

North Palawan-Mindoro

Rocks believed to be Cretaceous to early Tertiary in age form a part of the ophiolite assemblage making up the basement of northern Palawan. Upper Jurassic and Lower Cretaceous shales, siltstones and shallow-water limestones are present. Meanwhile, Upper Cretaceous rocks in the northeastern part where the Cuyo platform is made up of mostly sandstone and conglomerates deposited in very shallow to nonmarine environment.

Cretaceous fossils and their distribution

Ammonites

The ammonite assemblage in the Comagaycay River, Alibuag, San Andres, Catanduanes is associated with few foraminifera and trace fossils. Among the genera identified are the *Neophylloceras, Neograhamites, Gunnarites* and *Dufrenova* and they indicate Early Cretaceous age. The presence of foraminiferal species such as *Gavelinella* cf. *G. drycreekensis* (?), *Dorothia praeoxycona* (?), *Haplopragmoides* (?) sp., *Nodosaria* sp. and *Ammodiscus* sp. lends support to age based on ammonites. According to Tumanda (1985), the foraminifers are very poorly preserved rendering identification difficult though few forms are still recognizable.

Calcareous nannofossils

Calcareous nannofossil species recorded from Tanay samples include *Watznaueria* spp., *Micula decussata, Cribrosphaerella ehrenbergi, Quadrum gartneri. Rotelapillus* sp., *Tranolithus phacelosus, Retecapsa crenulata, Eiffelithus turriseiffelii, Cyclagelosphaera margarelli* and *Rhagodiscus* sp., among others. Recent analysis of samples from the Bonagbonag Limestone section in San Andres, Catanduanes also reveals the presence of Late Campanian-Early Maastrichtian calcareous nannofossils.

Foraminifera

Being the most studied Cretaceous fossil, the foraminifera has been found to exist in more localities in the country than any other groups of microfossils. As of to-date, there are at least eleven localities of foraminifera.

Tanay, Rizal

The planktonic foraminiferal species recovered from this area are: *Globotruncana arca, G. fornicata, G. lapparenti, G. stuarti, G. stuartiformis, G.* cf. *concavata, G. ganseri, Hedbergella trocoides, Praeglobotruncana stephani, Planomalina buxtorfi, Rotalipora appennica* and *Heterohelix globulosa,* among others. Larger foraminiferal species identified include *Lepidorbitoides minor, Omphalocyclus macroporus, Sulcorbitoides* sp. The age of the Kinabuan Formation based on the above assemblages is therefore assigned as Upper Cretaceous (Campanian-Maastrichtian). The Kinabuan Formation as a rock unit composing of "flysch-like deposits of thinly interbedded silty shale and medium to coarse-grained, slightly calcareous sandstone with tuffaceous and siliceous layers.

Gumaca, Quezon

Well preserved Late Cretaceous assemblages of *Globotruncana fornicata, G. concavata, G. lapparenti bulloides, Biglobigerinella multispina, Planomalina casevei, Planulina taylorensis, Marsonella oxycona, Planoglobulina glabrata* and *Heterohelix globulata* were recovered and identified by Espiritu (1968) from a sample collected within the contact of the Middle Miocene Vigo Formation and Late Miocene Canguinsa Formation.

The presence of the foraminifera may not reconcile with the Miocene formations but it is significant because it suggests "evidence of sedimentation in Bondoc Peninsula prior to the Vigo Formation". The exposure of the fossil assemblage may have been due to some tectonic movements.

San Andres, Catanduanes

Cretaceous rocks are represented in the Yop Formation and the Bonagbonag Limestone. While the Yop Fromation is believed to be Lower Cretaceous, the Bonagbonag Limestone is Upper Cretaceous on the basis of specimens of *Globotruncana* and *Heterohelix* recovered.

Calape, San Jose and Maylupe, Samar

Reyes and Ordoñez (1970) identified foraminiferal assemblages of Late Cretaceous age from a sample from these areas. However, their formational locality is unknown. Hashimoto et al. (1978) recovered *Globotruncana* in samples from central Samar.

Padre Burgos, Southern Leyte

A limestone sample from the Villajacinta River in this province revealed *Globotruncana* in a pelagic environment (Tan, 1986).

Tuburan, Cebu

Lower Cretaceous rock in Cebu is represented by a pelletoidal, massive and micritic limestone whose type section is located in Barrio Marmol in Tuburan, Cebu. It occurs as large boulders within the so-called Cansi Volcanics which workers also believe to be Cretaceous. It is regarded by Gramann (1983, in Porth et al., 1989) as Aptian to Albian on the *Orbitolina* group recovered.

In Pandan, Cebu are exposed greenish-gray, calcareous, partly siliceous siltstones and light gray silty *Globotruncana*-bearing limestone of middle to late Late Cretaceous according to Gramann (1985, in Porth et al., 1989).

Magsaysay, Davao Oriental

Samples collected by Tan (1986) from Lapu-Lapu Creek in Cuabo, Magsaysay indicate the presence of Cretaceous in the province. Foraminiferal assemblage recorded includes *Rotalipora appenninica, Hedbergella* sp. and *Planomalina* sp. Cretaceous sections in Davao generally comprise pillow basalts with intercalated pelagic sediments consisting of limestone with small lenses of red chert and ferruginous shale. In 1970, Reyes and Ordoñez reported a Cretaceous limestone float found to be similar to those Cretaceous limestones in Samar province.

Palawan Province

Cretaceous rocks are present in both onshore and offshore Palawan Province. Current studies are being undertaken to identify the localities of these Cretaceous sections which are chiefly of chert-spillite sequence associated with ultramafics.

Radiolaria

The first attempt on radiolarian study was made by Ordoñez (1970) on samples from Tanay, Rizal. The specimens were recovered from the lower sandstone-shale sequence of the Kinabuan Formation exposure along the Sampaloc-Daraitan Road in Sitio Sumangay, Barrio Macaira. According to the author, the samples are generally poorly preserved with the better preserved forms already replaced preventing precise identification. In the absence of materials to which the identification of the fifteen collected forms can be based upon, the author compared her specimens to those of Campbell and Clark and of Pessagno (1963) (in Ordoñez, 1970). The assemblage indicates Late Cretaceous age and is similar to those described from Middle California and Puerto Rico by Campbell and Clark and by Pessagno, respectively.

There is, however, an ongoing study by Fe P. Tumanda on the radiolarians of Palawan, Ilocos Norte and Pangasinan provinces. The radiolaria in Pangasinan are contained in chert clasts of conglomerate found in the vicinity of the Zambales ophiolite.

Radiolarians have proved useful in dating previously called "basement complex" and in interpreting the Paleozoic and Mesozoic tectonics of the country. They have been found associated chiefly with ophiolites and melanges as in the Ilocos Norte's Beruyen Chert.

Ordoñez (1970) recorded the following species of radiolarians in the Tanay area: *Stylospongia verteroensis, S. planoconvexa, Stylospongia* sp., *Pseudoaulopahcus lorensis, P. gallowayi, P. lenticulatus* and *P. pargueraensis.*

Palynomorphs

Records of palynological studies on selected Philippine Cretaceous samples are mostly contained in unpublished reports stored at the Department of Energy's Data Bank and Library. Palynological studies conducted are mostly on samples from the offshore Palawan-Mindoro areas in connection with oil exploration.

The following palynological assemblages from offshore northwest Palawan wells suggest Late Jurassic to Late Cretaceous age: abundant *Classopollis*, *Zonalapollenites* sp. cf. *Z. danipieri and Distalstriatrisporites* / *Cicatricosisporites*.

From offshore northeast Palawan, the top of *Laevigatosporites* sp., *Psilatricolpites minimus, Psilatricolpites* sp.. *Leiotrilete* sp. (in the absence of Tertiary restricted-ferns) and bottom of *Tetraporites* sp. in Dumaran-1 well indicates Late Cretaceous while in Roxas-1, similar age is indicated by the top of *Ephedripites* spp., *E.* sp. *E. jansonii* and the bottom of *E.* sp. *E. multicostatus, E.* sp. *E. regularis, Classopollis* sp., *Triorites minutipori, Psilatricolpites* spp.

Summary

1. Cretaceous rock units in the Philippines are generally extensive transgressive graywacke-shale sequence intercalated with spillites associated with tuffaceous clastics and/or limestone lenses (Gervacio, 1971; Bureau of Mines and Geosciences, 1982).
2. To-date, five groups of Cretaceous fossils have so far been identified: ammonites, calcareous nannofossils, Foraminifera, Radiolaria and palynomorphs.
3. There are at least 11 confirmed Cretaceous localities in the Philippines: Rizal, Quezon, Camarines Norte, Camarines Sur, Marinduque, Catanduanes, Samar, Leyte, Cebu, Palawan and Davao Oriental.
4. Studies are presently being undertaken to identify the other Cretaceous localities in conjunction with various projects such as reconnaisance survey, mineral exploration, biostratigraphic studies, etc.

References

Amiscaray, E.A. and Nilayan, M.S. 1986. Orbitolina from Tuburan, Cebu. *Bureau of Mines and Geosciences Report of Investigation* 67, 1-7.

Bureau of Energy Development, Robertson Research (Australia) Pty. and Flower Doery Buchan Pty. 1986. *Sedimentary basins of the Philippines, their geology and hydrocarbon potentials,* 8 volumes.

Bureau of Mines and Geosciences 1982. *Geology and mineral resources of the Philippines,* 1, 1-406 (Bureau of Mines and Geosciences, Manila).

Cruz, A.J. 1968. *Geologic investigation of marble claims in Virac and Calolbon, Catanduanes.* Bureau of Mines. (Unpublished report).

Denoga, J.A.V., de Silva., L.P., Jr. and Militante-Matias, P.J. 1991. A preliminary report on the Bonagbonag Limestone of Catanduanes. *Proceedings Fourth Annual Geological Convention, Quezon City,* 107-117.

Espiritu, E., Ordoñez, E.P. and Flores, M.G. 1968. Biostratigraphy of Bondoc Peninsula. *The Philippine Geologist* 22, 64-90.

Gervacio, F.C. 1971. Geotectonic development of the Philippines. *Journal of the Geological Society of the Philippines* 25, 18-38.

Hashimoto, W. 1969. Paleontology of the Philippines. *Geology and Paleontology of Southeast Asia* 6, 293-329.

Hashimoto, W. 1981. Geologic development of the Philippines. *Geology and Paleontology of Southeast Asia* 22, 83-94.

Hashimoto, W. 1982. Paleontology of the Philippines. Supplement 1 (1969-1981). *Geology and Paleontology of Southeast Asia* 24, 129-138.

Hashimoto, W. et al. 1977. Cretaceous System of Southeast Asia. *Geological Society of the Philippines* 31, 18-37.

Hashimoto, W, Matsumaru, K. and Kurihara, K. 1978. Larger Foraminifera from the Philippines VI. Larger foraminifera found from the Pinugay Hill Limestone, Tanay, Rizal, Central Luzon. Contributions to the geology and paleontology of Southeast Asia, CXCIII. *Geology and Paleontology of Southeast Asia* 19, 65-71.

Hashimoto, W., Matsumaru, K. and Kurihara, K. 1978. Larger Foraminifera from the Philippines VII. Larger foraminifera found from the Lutak Hill

Limestone, Pandan Valley, Central Cebu. Contributions to the geology and paleontology of Southeast Asia, CXIV. *Geology and Paleontology of Southeast Asia* 19, 73-88.

Hashimoto, W. and Sato, T. 1973. Geological structure of North Palawan and its bearing on the geological history of the Philippines. *Geology and Paleontology of Southeast Asia* 13, 145-161.

Hashimoto, W., Sato, T. and Kanno, S. 1984. Geological summary of APRSA activities in the Philppines. *Geology and Paleontology of Southeast Asia* 25, 61-82.

Karig, D.E. 1982. Accreted terranes in the northern part of the Philippine Archipelago. In *Geology and Tectonics of the Luzon Marianas Region, Philippines*. SEATAR Comm. Special Publication, (eds. Balce, G.R. and Zanoria, A.S.), 1, 67-82.

Miranda, F.E., 1977. Geological-geochemical survey of Caramoan Peninsula, Camarines Sur. *Bureau of Mines Report of Investigation* 86, 9-10.

Ordoñez, E.P. 1970. Notes on the Upper Cretaceous radiolaria of Tanay, Rizal. *Geological Society of the Philippines* 24, 120-123.

Porth, H., Müller, C. and von Daniels, C.H. 1989. The sedimentary formations of the Visayan basin, Philippines. *Geologisches Jahrbuch* 70, 29-87.

Reyes, M.V. and Ordoñez, E.P. 1970. Philippine Cretaceous smaller foraminifera. *Geological Society of the Philippines* 24, 1-44.

Takayanagi, Y., Takayama, T. and Oda, M. 1974. Notes on the Cenozoic planktonic foraminifera and calcareous nannofossils from Panay, Philippines. Contributions to the geology and paleontology of Southeast Asia, CLXXXI. *Geology and Paleontology of Southeast Asia* 18, 77-86.

Tan, M. 1986. *Distribution of Cretaceous foraminifera in the Philippines.* Philippine Bureau of Mines, 15 pp. (Unpublished report).

Tumanda, F.P. 1985. *Preliminary report on the fossil findings in Comagaycay River, Alibuag, San Andres (Calolbon), Catanduanes.* Bureau of Mines and Geosciences, 8 pp. (Unpublished report).

Tumanda, F.P., Maac, Y., Agadier, M. and Nilayan, M. 1986. Notes on the paleontology of northern Marinduque. *Bureau of Mines and Geosciences Report of Investigation* 68, 2-3.

The Cretaceous of India: a brief overview

Ashok Sahni and Ashu Khosla

Centre of Advanced Studies in Geology, Panjab University, Chandigarh 160014, India

Introduction

The Cretaceous is well represented in India by several different features: magmatic, volcanic and sedimentary rocks are widely distributed in the peninsular shield as well as confined to narrow linear belts in the Himalayas (Fig. 1). Continental flood basalts represented by the Rajmahal Traps on the eastern margin of the Indian plate and the Deccan Traps outcropping along the western and central part of the Indian shield provide a spectacular geological landmark in its geodynamic history. The Cretaceous Period also saw many dramatic changes in basinal configurations as a result of the closure of the old rift (Gondwanan) basins and the emergence of new extensional structures and marginal downwarpings, as India drifted northwards. Diverse tectono-sedimentary settings range from active margins in a subduction zone-island arc collisional framework operating along the northern (Himalayan) and eastern (Arakan-Yoma) boundaries, extending to the Andaman-Nicobar island complex; transgressions followed along reactivated rifts with the gradual spreading of epicontinental seas in downwarped areas including continental plate margins; fluvio-lacustrine facies are represented by the terminal phase of Gondwana sedimentation in senile rifts and the initiation of a latest Cretaceous volcano-sedimentary sequence with the eruption of the Deccan basalts. One of the most spectacular features of the Indian Cretaceous is the development and preservation of a regolith yielding dinosaur nests on the shield basement and blanketed by the Deccan lava flows.

Principal tectonic events

Tectonic events in the Indian Cretaceous are firmly controlled by the

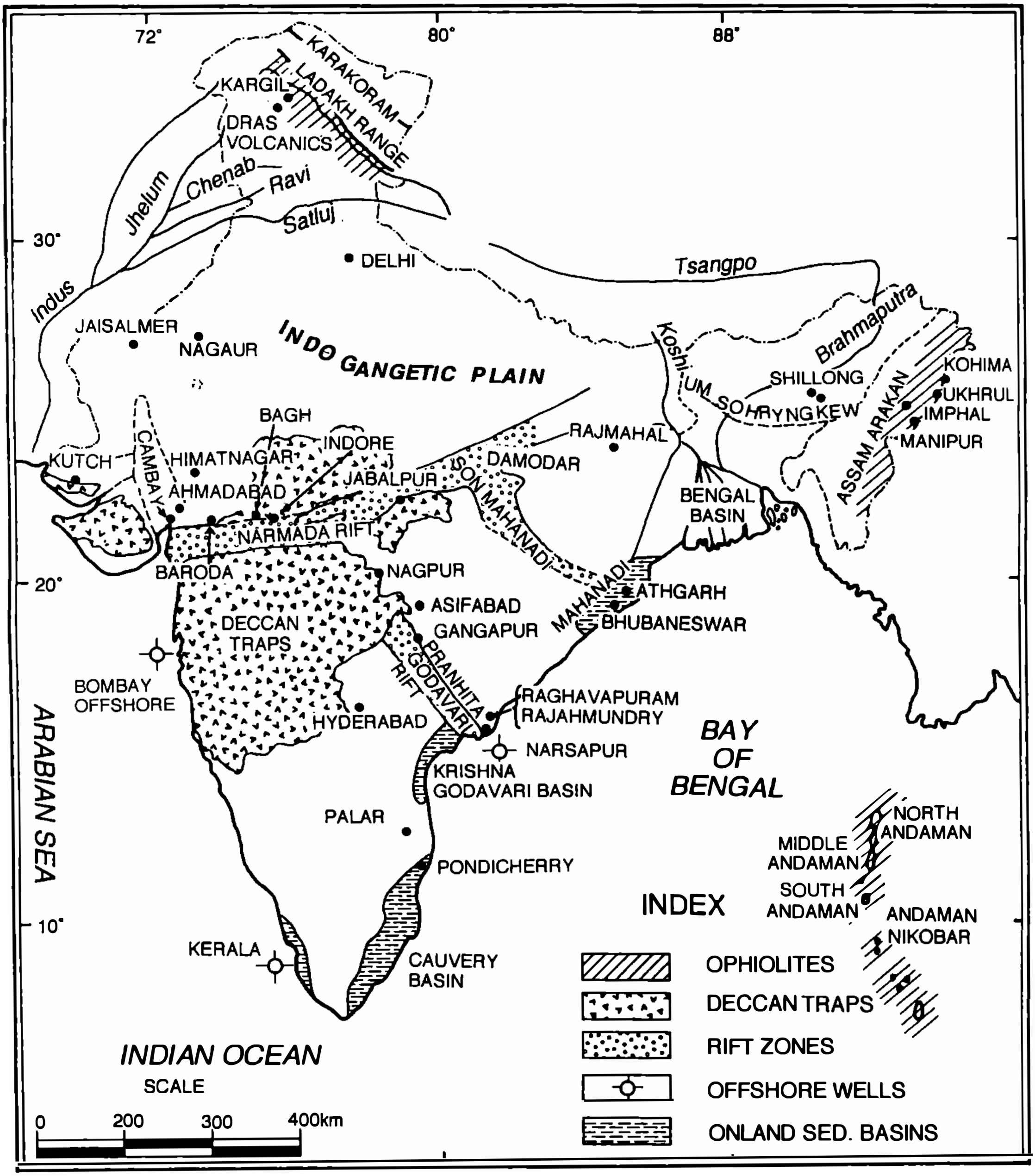

Fig. 1. Principal structural features of the Indian peninsula that were influential during the Cretaceous.

rifting of India from Madagascar and eastern Africa and its northerly drift towards Asia (Sahni, 1984). Against this overall background, however, several other regional tectonic events have played major roles in influencing magmatism, volcanism and sedimentation.

(a) With the northerly drift of India in the Cretaceous-early Tertiary and the subduction of the oceanic lithosphere and the underthrusting of the Indian plate beneath the Tibetan block, the Tethys gradually closed. The subduction resulted in a plutonic-volcanic island arc confluent with the Kohistan belt of Pakistan, termed the Ladakh magmatic arc in the Indian region (Thakur, 1987). The granites of the Ladakh batholith range from the Cretaceous (103±3 Ma) to the early Tertiary (60-40 Ma). The Kohistan-Ladakh plutonic-volcanic arc provided an active sedimentary source for the 4000-m-thick Indus Formation, which concurrently developed in the arc-trench gap lying to the south of the magmatic arc. This thick sequence includes ophiolite melanges comprising the Shergol and Nidar ophiolites, the Nidan flysch, and blue schist rocks sandwiched between the Indus Formation and the Zanskar Tethys Himalaya, interpreted by Thakur (1987) as representing an accretionary prism. The ophiolite suite also demarcates the northeastern and eastern boundary of the Indian plate. The Naga-Manipur ophiolite belt trends southwards in discontinuous and poorly mapped outcrops and contains interbedded radiolarites, nannoplankton, and planktonic foraminifers, which suggests an age ranging from the Campanian to Maastrichtian. Across the Bay of Bengal, in the Andaman and Nicobar island, the oldest rocks exposed are represented by the Port Meadow Formation. The lithology here consists of a chert-spilite association deposited in a developing oceanic trench, and based on the radiolarites is considered to be Cenomanian in age.

(b) Three major transgressive phases are recognised during the Cretaceous, and these appear to be controlled by distinct tectonic events.

1) Marginal downwarping of the southeastern coast of India during the Early Cretaceous led to what is popularly known as the development of the "east coast Gondwana basins" (Raju et al., 1991). The pre-Aptian history of these basins is based on palynological assemblages although some beds are known to yield poorly preserved foraminifers. In the Krishna-Godavari and Cauvery

basins, the Raghavapuram Shale, Sivaganga Beds are considered to be Barremian in age. In the above basins, the Albian to Maastrichtian biochronology has been established on the basis of rich planktonic and benthic foraminiferal assemblages with the recognition of all the stages extending from the Albian to the Maastrichtian.

The sedimentary sequence of the Cauvery basin yields diverse fossils including echinoids, brachiopods, ammonites, inoceramids and, towards the top, dinosaurs in a regressive phase of Maastrichtian age.

2) Another well-studied transgressive sequence of Cenomanian-Turonian age occurs confined to the western Narbada river rift zone. These richly fossiliferous deposits known as the Bagh Beds also grade upwards in the Maastrichtian to dinosaur eggshell-yielding sandy carbonates known as the Lameta Formation.

3) Deposits of epicontinental seas occur in the Jaisalmer region of Rajasthan confluent with the Sindhu Sea, traversing Pakistan, and in the northeastern extremity of the Indian plate in Begal, Assam and Meghalaya forming part of the Bangla seaway (Sahni and Kumar, 1974). The Meghalaya sections at UM Shorengkew are the most interesting as an iridium anomaly has been recognised across the Cretaceous-Tertiary boundary section established on the basis of planktonic foraminiferal biostratigraphy (Bhandari et al., 1987). Further south, in the Bengal basin subcrops, the presence of *Aquilapollenites* was reported from Maastrichtian sediments and the taxa has since been reported from other sections, including the offshore wells in the Krishna-Godavari basin and in an intracratonic setting at Jabalpur from the Deccan basalt volcano-sedimentary beds (intertrappeans).

4) The Cretaceous in India is marked by stupendous continental flood basalt activity represented by an earlier and eastern eruptive activity known as the Rajmahal traps (upper limit is approximately 115 Ma) and by another, later event on the western margin constituting the Deccan basalts. The latter are estimated to be 2000-3000 m in thickness, with a possible original areal extent encompassing about 1×10^6 km^2. The Deccan traps are now considered to have been an intense, rapidly erupting pile of lava flows straddling the Cretaceous-Tertiary boundary, which include thin sedimentary highly fossiliferous horizons

in the basal sections. These include the remains of excellently preserved, silicified plant material along with diverse vertebrate remains, including dinosaurs and palaeoryctid mammals. The Deccan lava flows have blanketed the underlying freshwater deposits of Maastrichtian age (Lameta Formation) resulting in the rare preservation of dinosaur nesting sites confined to a specific lithology (pedogenically modified freshwater limestones) than can be traced in discontinuous bands for more than 800 km along strike. The Lameta Formation has also yielded microfossils such as charophytes, ostracods, as well as pulmonate gastropods, unionid bivalves, fish, amphibians, pelomedusid turtles, snakes, crocodiles, and dinosaurs. The beds are considered to be semiarid alluvial plain deposits, pedogenically modified resulting in the formation of massive calcretes and variegated mottled nodular beds.

5) Lower Cretaceous sediments are also known to occur in Gondwana rift basins which were sites of active deposition from the Permian to Jurassic. For example, in the Pranhita-Godavari graben (Gangapur Beds) and the Narbada rift zone, Lower Cretaceous plant-bearing beds (*Ptilophyllum* flora) occurs as the capping rock of the grabens during the waning and terminal phase of Gondwana sedimentation. The *Ptilophyllum* flora provides an important datum to correlate other subcontinental section in different tectonic settings: intertrappean of the Rajmehal traps; marginal basins on the west coast (Umia Beds), Kutch and on the east coast (Athgarh Sandstone) or Orissa. In fact the *Ptilophyllum* assemblage is also found in several small intracratonic basins dispersed in central peninsular India.

Marine-nonmarine correlation sites

Given the extensive distribution of Cretaceous sediments and their diverse nature, it is not surprising that several localities exist wherein it is possible to make correlations between nonmarine and marine sequences. In the Early Cretaceous there were several upper Gondwana basins along the west coast (Kutch) and along the east coast (Raju et al., 1991) where benthic marine invertebrates occur along with floral assemblages. In fact, the admixed assemblages have divided scientific opinion as to the original nature of the basins, whether these are coastal marine with transported vegetal matter or freshwater with occasional marine incursions. Sedimentological and basinal studies undertaken so far have not fully resolved the issue. By far the best data for marine-nonmarine correlations has been obtained from a number of oil exploratory wells drilled by the Oil and Natural Gas Commission of India, but this information is largely proprietary in nature. In spite of this, several publications (Bhandari et al., 1983) have highlighted the advances made in the subcontinental correlation of the Cretaceous basins.

The outcrop/subcrop data from Krishna-Godavery basins along the east coast extending from the Albian to the Maastrichtian has strong palynological input along with information from marine microfossils. Of particular interest in this regard, is the data from offshore wells drilled near Rajahmundhry where Campanian-Maastrichtian planktonic foraminiferal zones are associated with interbedded thin Deccan trap flows (Narsapur Deep Well). From these sections palynological studies have established the presence of diagnostic palynoassemblages that include *Aquilapollenites*. This association has led to the successful correlation of several other coeval sections along the eastern margin of the Indian plate. Using this information, it has been possible to correlate inland continental sections (Padwar and Ranipur Deccan intertrappean sections; Sahni and Jolly, 1990) yielding *Aquilapollenites*.

Charophyte and fish assemblages from various localities fringing the Deccan traps have also been used for making marine-nonmarine correlations as some of the taxa have been found in association with foraminifer-rich intertrappeans, such as those found at Duddukuru near Rajahmundry on the Godavari delta.

Economic resources

In spite of its great areal extent, there are as yet no major economic resources that have been recovered from the Indian Cretaceous. It is true that some oil and gas shows have been detected in oil exploratory wells drilled by the Oil and Natural Gas Commission in the east coast offshore region. However, one of the practical problems faced by petroleum geologists is that

Cretaceous sedimentary basins lie beneath the thick pile of Deccan basalts thus hard to reach.

The Dalmiapuram Limestone of the Cauvery basin and the Lameta Limestone of central peninsular India provide adequate material for regional cement industries.

Some gold and platinum enrichment has been observed along the Naga-Manipur ophiolite tract, but no commercial exploitation occurs.

Standard European stages in India

Most Cretaceous stages can be identified in the Indian sections. Expectedly, however, it is not always possible to directly constrain the stages in India with the same rigour and resolution in the absence of index taxa and the inherent problems of dealing with essentially different palaeobiogeographical provinces, particularly during the drift phase of India. Marine zonation attempted on the basis of planktonic foraminifers by Raju et al. (1991) for the east coast Gondwanas appears to be well constrained. On the other hand, plant-bearing continental deposits that occurred in small isolated basins in the Early Cretaceous are difficult to correlate solely on the basis of the *Ptilophyllum* flora, which is long-ranging and possibly facies-controlled. Hence the presence of Neocomian strata assigned to such basins may need to be revised.

For the Campanian-Maastrichtian, zonation based on planktonic foraminifers and nannoplankton is reliable and has been used for the delineation of the Campanian-Maastrichtian boundary.

Ammonite zonation has also been used for defining the Cenomanian in the Bagh Beds and Cauvery basin.

Environmental changes

So far, there are hardly any well-documented data recording major environmental changes in the Indian Cretaceous. Most studies have focussed on depositional environments for individual basins rather than integrating the data in a generalised scheme for the entire Cretaceous. Perhaps the best documented example of Late Cretaceous environments and palaeoclimates comes from the Lameta Formation (Tandon et al., 1990). Based on detailed sedimentological studies, Tandon et al. have demonstrated semiarid alluvial plain conditions during Lameta time with the recognition of dessication features, shrinkage cracks, honeycomb calcretes and sheetwash deposits. The fact that the Lameta limestones contain dinosaur nests in widely separated outcrops is of potential importance in deducing palaeoclimates and nesting habitats for the dinosaurs. In the overlying Deccan intertrappeans, extremely well preserved silicified plant remains suggest more tropical conditions (Bande et al., 1986). However, this palaeoenvironmental change needs to be better documented.

References

Bande, M.B., Chandra, A., Venkatachala, B.S. and Mehrotra, R.C. 1986. Deccan intertrappean floristics and its stratigraphic implications. *Proceedings of the symposium on the Palaeocene of India,* 83-123 (Birbal Sahni Institute of Palaeobotany, Lucknow).

Bhandari, L.L., Venkatachala, B.S., Kumar, R., Swamy, S.N., Garga, P. and Srivastava, D.C. (eds.) 1983. Petroliferous basins of India. *Petroleum Asia Journal,* 1-189.

Bhandari, N., Shukla, P.N. and Pandey, J. 1987. Iridium enrichment at the Cretaceous-Tertiary boundary at Meghalaya. *Current Science* 56, 1003-1004.

Raju, D.S.N., Ravindran, C.N., Mishra, P.K. and Singh, J. 1991. Cretaceous and Cenozoic foraminiferal zonal framework for the east coast sedimentary basins of India. *Geoscience Journal* 12, 156-175.

Sahni, A. 1984. Cretaceous-Paleocene terrestrial faunas of India: lack of faunal endemism during drifting. *Science* 226, 441-443.

Sahni, A. and Jolly, A. (eds.) 1990. *Cretaceous event stratigraphy and correlation of the Indian nonmarine strata,* 125 pp. (IGCP 216/245 Workshop Contributions, Chandigarh).

Sahni, A. and Kumar, V. 1974. Palaeogene palaeobiogeography of the Indian subcontinent. *Palaeogeography, Palaeoclimatology, Palaeoecology* 15, 209-226.

Tandon, S.K., Verma, V.K., Jhingran, V., Sood, A., Kumar, S., Kohli, R.P. and Mittal, S. 1990. The Lameta Beds of Jabalpur, central India: deposits of fluvial and pedogenically modified semiarid fan-palustrine flat system. *IGCP 216/245 Workshop Contributions, Chandigarh* (eds. Sahni, A. and Jolly, A.), 27-30.

Thakur, V.C. 1987. Development of major structures across the northwestern Himalaya, India. *Tectonophysics* 137, 1-13.

The Cretaceous System of Australia

Mary E. Dettmann

Department of Botany, University of Queensland, Brisbane, Queensland 4072, Australia

Overview of Cretaceous of Australia

The Cretaceous System is represented in Australia by sedimentary sequences in 22 of the continent's 23 Mesozoic depositional basins (Fig. 1), and by volcanics that are principally concentrated along the eastern coast and in the southeast. The sediments, which collectively span the Cretaceous, were deposited in environments ranging from offshore-marine to fluvial/lacustrine.

Rocks

Lower Cretaceous sequences represented in western margin basins comprise fluvial/ lacustrine sandstone-dominated and/or mixed sandstone and fine-grained arenaceous and argillaceous units of fluvial/ lacustrine and coastal and marine shelf origin. Overlying mid-to Upper Cretaceous sediments are radiolarites and carbonates that were deposited in shelf and open marine environments. Lower Cretaceous sediments in southern margin basins reflect high to low energy alluvial

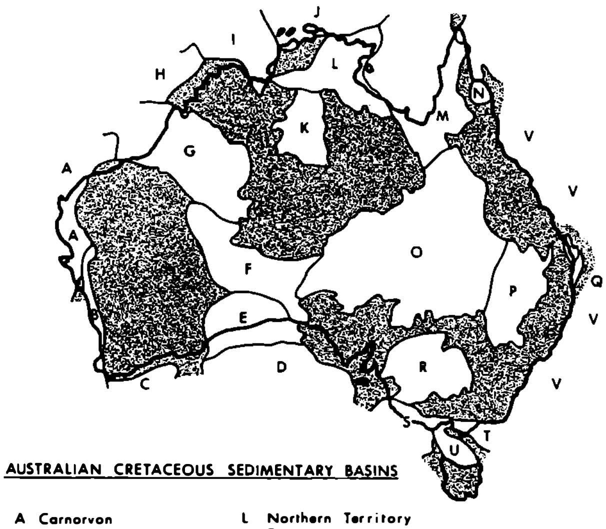

Fig. 1. Australian Cretaceous sedimentary basins.

deposition in fault-bounded rift valleys. Disconformably overlying sediments comprise coastal plain and marginal marine coals, siltstones, mudstones and minor sandstones. On the northeastern margin coal-bearing clastics and volcanogenic sediments were deposited in several basins during the Early and mid-Cretaceous in coastal, marine shelf and marine environments. In interior basins Cretaceous successions have at their bases mixed clastic rocks with coarse-grained fluvial facies around basin margins, and finer grained lacustrine counterparts in axial areas. Overlying sediments are siltstone- and mud-dominated and were deposited in marginal marine to shallow marine environments. These are capped by a thick highly volcanic lithic unit which is coal-bearing and which marks the cessation of deposition during the mid-Cretaceous. The relative position of the marine and nonmarine sequences is related to advancement or retreat of coastlines, from sea level oscillations, and from tectonic displacements associated with progressive isolation of Australia from the Gondwanan assembly.

Tectonic regimes

Throughout the Early Cretaceous a magmatic arc lay landward of a Chilean-type subduction zone along the convergent Pacific margin of Eastern Gondwana (Veevers, 1991). The arc and related subduction zone had moved landward through the Permian and Early Mesozoic and reached its terminal position in the mid-Cretaceous along the present Queensland coast, Lord Howe Rise, and New Zealand (Fig. 2). The spreading ridge between India and Australia-

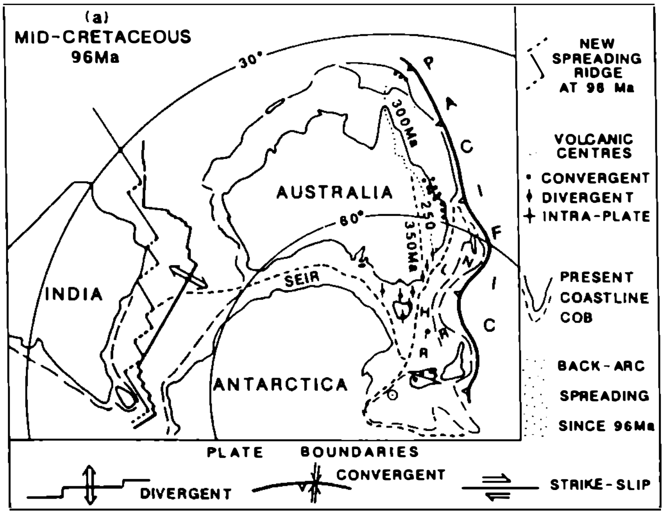

Fig. 2. Mid-Cretaceous plate configuration with Chilean-type subduction at the southwest Pacific margin.

Antarctica had generated the early Indian Ocean since spreading started in the Valanginian when the South Pole was situated in the Ross Sea region of Antarctica and Australia was spread between latitudes of 70-80°S and 30-40°S. These events highlighted the last phases of the Innamincka regime which was replaced by the Potoroo regime in the Cenomanian (Veevers, 1991). The change in regime was marked by: a) a change in the rate and pattern of plate divergence on the west such that India moved northward behind a rapidly maturing Indian Ocean, and the margins commenced accumulating carbonate following the establishment of a thermohaline circulation; b) a change in plate divergence pattern on the south such that 360 km of Early Cretaceous continental extension in a 700 km wide rift valley dominated in the east by alkaline volcanic detritus was replaced by seafloor spreading from the Southeast Indian Ridge; c) a change from Chilean-type subduction on the east to Mariana-type subduction entailing back arc spreading between Australia and Lord Howe Rise/Norfolk Ridge/New Zealand, marked by mid-Cretaceous alkaline volcanics (Veevers, 1991).

Palaeogeography

During the Cretaceous Australia separated from the Gondwanan assembly, with seafloor spreading commencing in the earliest Cretaceous on the north-western margin (Fig. 3) and progressing anticlockwise around the continent; by the close of the Cretaceous Australia was isolated except for land connections with Antarctica in the southeast (Fig. 4). The Early

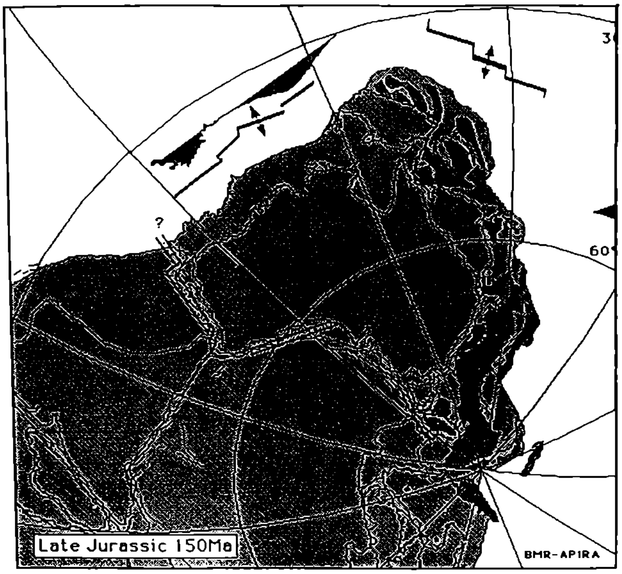

Fig. 3. Palaeogeography of Eastern Gondwana for Late Jurassic-earliest Cretaceous.

Cretaceous phase of seafloor spreading on the western coast was associated with formation of the Indian Ocean and break away in the Valanginian of Greater India from Australia. At this time the sea encroached into the Eromanga basin from the north; maximum flooding was during the Aptian-Albian when seaways connected all major basins in eastern Australia and when the interior basins of Western Australia were linked to the proto-Indian ocean via the western part of the widening rift valley to the south. Several areas of emergent land are interpreted in New Guinea and associated continental fragments. By the Cenomanian the epicontinental seas had retreated from all interior basins, but the sea had penetrated the southern rift valley to the western portion of the Otway Basin. At this time brackish conditions developed in the Gippsland Basin heralding initiation of the proto-Tasman Sea (Fig. 5). The eastern Indonesian continental fragments were detached from northeastern Australia by oblique extension. The widespread drainage

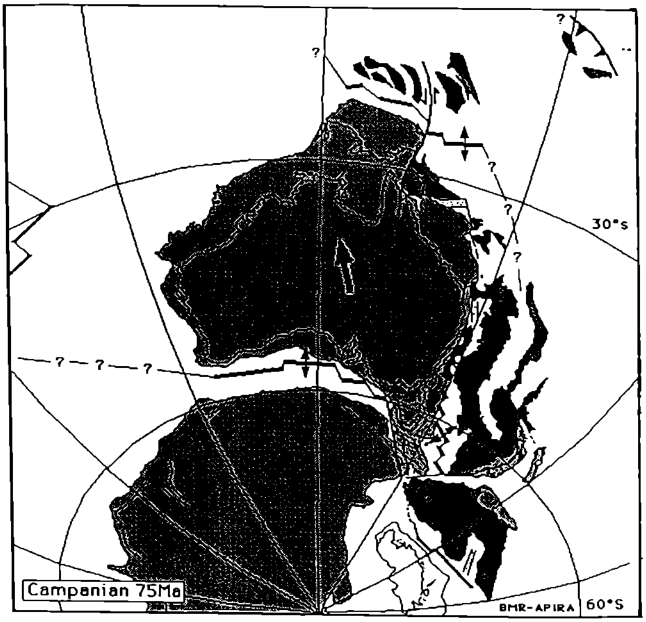

Fig. 4. Palaeogeography of Eastern Gondwana for Campanian.

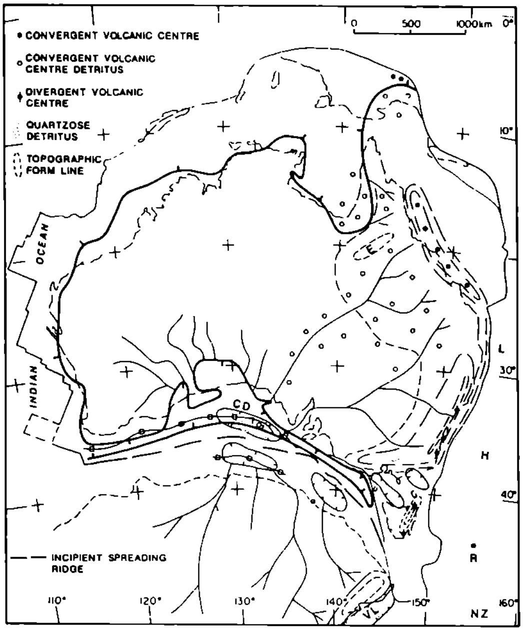

Fig. 5. Interpreted later Cretaceous (Campanian, 80 Ma) palaeogeography, from Veevers (1984, Fig. 147F). The Mount Howie Sandstone shown by dots and palaeoslope by arrow (Wopfner, 1963; Forbes, 1972). Shoreline in eastern Glippsland from Frakes *et al.* (1987). Juvenile Southeast Indian Ocean from Veevers (1987). B - Bass Basin; G - Gippsland Basin; O - Otway Basin.

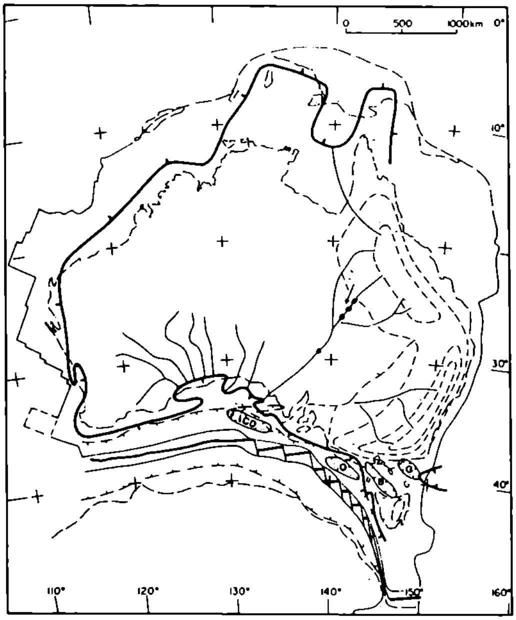

Fig. 6. Interpreted Cenomanian palaeogeography from Veevers (1984, Fig. 147D). Retreat of the epeiric sea during general uplift of the platform and marked uplift and denudation of the eastern margin to establish centripetal drainage into the Australia-Antarctic depression. Line with squares marks axis of magnetic trough (Veevers, 1987). CD - Ceduna depocentre; E - Euroka arch; VL - Victoria Land Basin (Cooper and Davey, 1985).

pattern and environmental changes that occurred during the Cenomanian are believed to reflect the change from the Innamincka to the Potoroo tectonic regime. The latter heralded the onset of intense uplift and denudation along the eastern margin; rapid accumulation of volcanic detritus from the terminal Chilean-type arc along the Queensland coast; replacement of volcanic detritus by quartzose sediment in the southeast rift valley system; and carbonate deposition in the basins of the western margin (Veevers, 1991). For the remainder of the Late Cretaceous much of Australia was emergent. Australia and Antarctica were linked through Tasmania which separated the embryonic Southern Ocean on the west from the advancing Tasman Sea to the east. Sited on the landbridge were lake systems of the Gippsland and Bass Basins. Seafloor spreading continued in the south, and rifting was initiated in the north-east where emergent areas linked Australia to Papua New Guinea and New Caledonia (Fig. 6).

Economic Cretaceous resources

a) Coal sequences are represented in the mid-Cretaceous of interior basins; in the Lower to mid-Cretaceous of northeastern basins; in the Lower and Upper Cretaceous of southeastern basins and in the Lower Cretaceous of the Perth Basin. Numerous coalfields were mined during the last century in northeastern and southeastern basins, but only one (Burrum field, Maryborough Basin) is currently in operation.

b) Oil Shale deposits are widespread in the late Albian Toolebuc Formation, Eromanga Basin, but at this stage are not economically viable.
c) Liquid and gas hydrocarbon fields in Bass Strait are believed to have been sourced in part from the Upper Cretaceous Latrobe Group, Gippsland Basin. Several hydrocarbon fields in the Otway Basin are in Lower and Upper Cretaceous sediments. There are numerous small fields in the Lower Cretaceous of the Eromanga Basin. Additionally source rocks have been identified in Lower and Upper Cretaceous sequences of southern and western margin basins.
d) Bauxite mined in northern Queensland may be of Cretaceous age.

Principal environments of Australian Cretaceous

Depositional environments ranged from fluvial/lacustrine to offshore marine and were controlled by tectonic regime with an overprint of world sea levels and climate. A major change in tectonic regime occurred in the Cenomanian, and resulted in changes in drainage patterns with consequent retreat of the sea from interior basins and deposition mainly concentrated in marginal basins. Climatic warming throughout the Cretaceous is suggested by oxygen isotope temperatures and faunas and floras from the marine and terrestrial realms. Earliest Cretaceous climates were temperate with cool temperatures (0-12°C) and high precipitation levels in southern regions where winter freezing may have occurred during the Aptian. A warming trend occurred in the Albian with palaeotemperatures of 12-16°C in the marine realm. Sea water temperatures of 16-28°C during Turonian-Maastrichtian times verify that the warming trend continued into the Late Cretaceous.

References

Audley-Charles, M.G. 1990. Evolution of the southern margin of Tethys (North Australian region) from early Permian to late Cretaceous. In *Gondwana and Tethys* (eds. Audley-Charles, M.G. and Hallam, A.), *Geological Society Special Publication* 37, 79-100.

BMR Palaeogeographic Group. 1990. *Australia: Evolution of a Continent.*

Bureau of Mineral Resources, Australia 97 pp.

Burger, D. 1990. *Australian Phanerozoic timescales. 9. Cretaceous. Geochronological charts and explanatory text.* Bureau of Mineral Resources, Australia Record 1989/39, 36 pp.

Dettmann, M.E. Molnar, R.E., Douglas, J.G. et al. 1992. Australian Cretaceous terrestrial faunas and floras: biostratigraphic and biogeographic implications. *Cretaceous Research* 13, 207-262.

Fielding, C.R. 1992. A review of Cretaceous coal bearing sequences in Australia. *Geological Society of America, Special Paper* 267, 303-324.

Frakes, L.A. and Krassay, A.A. 1992. Discovery of probable ice-rafting in the Late Mesozoic of the Northern Territory and Queensland. *Australian Journal of Earth Sciences* 39, 115-119.

Haig, D.W. and Lynch, D.A. 1993. A late early Albian marine transgressive pulse over northeastern Australia, precursor to epeiric basin anoxia; Foraminiferal evidence. *Marine Micropalaeontology* 22, 311-362.

Pigram, C.J. and Symonds, P.A. 1991. A review of the timing of the major tectonic events in the New Guinea orogen. *Journal of Southeast Asian Earth Sciences* 6, 307-318.

Tarling, D.H. 1990. Gondwanaland and the evolution of the Indian Ocean. In *Gondwana and Tethys* (eds. Audley-Charles, M.G. and Hallam, A.), *Geological Society Special Publication* 37, 61-77.

Veevers, J.J. 1991. Mid-Cretaceous tectonic climax, Late Cretaceous recovery, and Cainozoic relaxation in the Australian region. *Geological Society of Australia, Special Publication* 18, 1-14.