PROGRADING GRAVELLY SHORELINE DEPOSITS IN THE EARLY CRETACEOUS YUASA FORMATION, WESTERN KII PENINSULA, SOUTHWEST JAPAN

WATARU MAEJIMA*

Abstract Within the upper part of the Early Cretaceous Yuasa Formation to the southwest of Yuasa, western Kii Peninsula, seven sedimentary facies are distinguished. They make up distinct facies sequences that are interpreted as progradational gravelly shoreline origin. An idealized sequence consists of, in ascending order, (1) poorly sorted sheet conglomerate interpreted as a transgressive lag; (2) alternate succession of thin-bedded sandstone with mudstone partings interpreted as nearshore-offshore transition zone deposits and cross-bedded sandstone interpreted as a remnant of fluvial-influenced sediment influx; (3) bedded sandstone of lower shoreface origin; (4) trough cross-bedded pebbly sandstone interpreted as the deposits of an upper shoreface (zone of wave build-up and zone of swash-surf transition); (5) well sorted, planar-bedded conglomerate and sandstone representing a beach environment (foreshore and backshore); and (6) mudstone-dominated, marsh or lagoonal deposits with (7) an intercalation of poorly sorted, cross-bedded pebbly sandstone of stream channel origin.

Storm-generated deposits are preferentially preserved in the nearshore-offshore transition zone, lower shoreface and backshore facies. In the upper shoreface and foreshore deposits, storm products are almost absent, and are thought to have been completely reworked by ordinary shoaling waves.

The upper Yuasa sediments were deposited along an approximately east-west oriented coastline which received abundant coarse materials from the north through braided streams and was characterized by high wave energy and a low tidal range.

Introduction

Numerous detailed sedimentologic studies have been made on the sandy shoreline deposits in stratigraphic record (MASTERS, 1967; CAMPBELL, 1971; HOBDA, 1974; DICKINSON, 1976; VOS & HOBDA, 1977; RAUTMAN, 1978). On the contrary, gravel-bearing shoreline deposits have been less studied. As examples of these studies, may be cited works by CLIFTON *et al.* (1971), CARTER (1978) and CLIFTON (1981). Even in the cases of these works, however, gravel is a minor constituent, and their beach deposits are almost wholly made up by sand. Shoreline deposits con-

taining much more abundant gravel than these examples are by no means uncommon in geologic record, especially in rocks which were formed in coastal zones where coarse-grained alluvial deposits such as the deposits of alluvial fans or braided streams built into seas.

The Yuasa Formation of Southwest Japan (Figs. 1, 2) is a conglomerate-bearing clastic sequence of Early Cretaceous age. Recently I made facies analysis of the formation and reported a brief summary of paleoenvironmental reconstruction showing that the formation is composed of the deposits of terrestrial and coastal origin and that coarse materials were transported by braided streams into the coast and were worked by wave activity (MAEJIMA, 1980). Roughly, the lower part of the formation is represented by terrestrial deposits, while the upper part is predominated

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* Department of Geosciences, Faculty of Science, Osaka City University, Sumiyoshi-ku, Osaka, 558 Japan.

Fig. 1. Index map of the Cretaceous basin in the Chichibu Belt in the western Kii Peninsula, showing the location of the Yuasa area.

Fig. 2. Geologic sketch map of the Yuasa area. Simplified after MIYAMOTO (1980) and MAEJIMA (1981). X and Y indicate locations where stratigraphic sections shown in Fig. 4 were measured.

by coastal deposits.

This paper describes and interprets facies of the coastal deposits in the upper part of the Yuasa Formation exposed to the southwest of Yuasa (Fig. 2), and provides an example of prograding gravelly shoreline deposits.

Geologic setting

In the western Kii Peninsula, the Cretaceous clastic deposits more than 2000 m thick occupy the east-northeast-trending linear basin in the Chichibu Belt (Fig. 1). Detailed works on the stratigraphy and geologic structure of these deposits have been made by MATSUMOTO (1947) and TANAKA (1956 a, b). The western part of the basin, where the study area is located, is mainly occupied by the Early Cretaceous deposits, while the Late Cretaceous rocks are distributed chiefly in the middle and eastern parts of the basin. They are folded and faulted, and show complex geologic structure (Fig. 2). The Early Cretaceous sequence in the Yuasa area shows lateral changes in lithofacies and biofacies in the north-south direction (TANAKA, 1956 a). Deposits in the northern part of the basin are rich in coarse materials in general. They yield brackish-water molluscs and abundant plant remains as well as marine molluscan fossils. The southern counterpart rather dominates in fine materials and sparsely contains only marine fossils.

The Yuasa Formation forms the lowest member of the Early Cretaceous succession in the northern region (Fig. 3), and unconformably overlies the pre-Cretaceous sedimentary, igneous and metamorphic rocks (MATSUMOTO, 1947; TANAKA, 1956 a; MAEJIMA 1978) which are tectonically much more disturbed than the Cretaceous rocks. The Yuasa Formation is conformably overlain by the Arida Formation which is, in turn, discon-

	Northern Region	Southern Region
Lower Cretaceous	Nishihiro Formation	Izeki Formation
	Arida Formation	Arida Formation
	Yuasa Formation	Kitadani Formation
	Pre-Cretaceous Sedimentary, Igneous, and Metamorphic Rocks	

Fig. 3. Lithostratigraphy of the Lower Cretaceous in the Yuasa area. Wavy line indicates unconformity. Simplified after TANAKA (1956a).

Fig. 4. Stratigraphic sections of the Yuasa Formation with gross environmental interpretation. Locations of the sections are shown in Fig. 2. Detailed measurement was carried out through the intervals shown in the section X. Numbered vertical bars indicate position of logs shown in Fig. 5.

formably overlain by the Nishihiro Formation. In the southern region, the time equivalents to the Yuasa and Nishihiro Formations have been named the Kitadani and Izeke Formations, respectively (MATSUMOTO, 1947; TANAKA, 1956 a) (Fig. 3). The Arida Formation yields abundant ammonite fossils (MATSUMOTO, 1947; TANAKA, 1956 a; OBATA & OGAWA, 1976), and the Barremian age has been assigned to the middle and upper parts of the formation (OBATA & OGAWA, 1976; OBATA & MATSUMOTO, 1977). The other formations in the Yuasa area are barren of reliable index fossils. However, based on the stratigraphic position and the fossil content,

the Nishihiro and Izeke Formations have been considered to be Aptian to Albian in age (TANAKA, 1956 a; OBATA & MATSUMOTO, 1977), and the Yuasa and Kitadani Formations to be of Hauterivian age (MATSUMOTO *et al.*, 1982).

The Yuasa Formation consists of alternating conglomerate, sandstone and mudstone, and ranges in thickness from 25 to more than 200 m, thickening toward the south. The formation yields brackish molluscs and abundant fossil plants, and has been considered to be mainly of marginal marine origin (TANAKA, 1956 a). Fig. 4 shows the simplified lithologic columns through the Yuasa Formation along the coasts to the west and southwest of Yuasa (for locations, see Fig. 2). In these areas, the lower part of the formation consists of poorly sorted conglomerate and interbedded sandstone and mudstone. The upper part is mainly composed of intensely bioturbated mudstone with sandstone intercalations and well-sorted conglomerate and sandstone.

Sedimentary facies

Fig. 5 shows examples of detailed stratigraphic sections of the upper part of the Yuasa Formation measured along the study outcrops. Based on association of lithology, sedimentary structures and biological features, seven sedimentary facies (denoted as A to G) are distinguished within these deposits.

Facies A. Poorly sorted, cross-bedded pebbly sandstone

Facies A is made up by 1 to 1.5 m thick, medium- to very coarse-grained, commonly pebbly sandstone (Plate I, Fig. 1). The basal surfaces of the sandstones are sharp and erosional. Up to 20 cm deep scours are frequently observed. Pebbles are locally concentrated on the basal surfaces. Sandstones are rather poorly sorted, and pebbles do not form discrete layers. Internally trough cross bedding is predominated. Thickness of trough sets ranges 10 to 40 cm. Planar cross-bedded sets also occur but are rare. Paleocurrent azimuths are almost unidirectional, directed to the south-southwest (Fig. 6). Biological in-

fluences are consistently absent in the whole of this facies.

Facies B. Bioturbated mudstone and sandstone

This facies is composed dominantly of massive or thinly laminated black mudstone with intercalations of sandstone beds. Mudstones are up to 2 m thick. Sandstone beds are commonly less than 0.3 m thick. Intense biological influences are the characteristic feature throughout this facies. Many of mudstones are intensely bioturbated. Burrows are abundant, mostly unornamented. Such mudstones frequently contain scattered or irregularly concentrated sand- and granule-size grains. Some sandstones are also intensely turbated to show no traces of primary physical

structures. These sandstones are commonly muddy and sometimes contain scattered granules. Sandstones free from thorough bioturbation are either ripple-laminated or parallel-laminated.

Some mudstones and muddy sandstones yield abundant brackish-water molluscan fossils such as oysters (Plate I, Fig. 2). They are either scattered throughout a bed or concentrated to form laterally discontinuous layers which are commonly 1 to 2 cm, sometimes 15 to 20 cm, thick. Mudstones generally contains abundant plant remains. Many of them are small and appear to be imprints of leaves, stems and roots of grass. Large plant remains are also present in places. In some horizons, coaly layers are intercalated. They are thin

Fig. 5. Examples of the detailed section in the upper part of the Yuasa Formation measured along the coast to the southwest of Yuasa (labeled X in Fig. 2), showing textural, stratification and biologic characteristics of the facies (notated A to G on the left side of each log). Stratigraphic position of individual logs is shown in Fig. 4.

(commonly less than 3 cm thick) and laterally impersistent.

Facies C. Well-sorted, planar-bedded sandstone and conglomerate

This facies consists of about 3 to 6 m thick, well-sorted, medium-to very coarse-grained sandstone and granule to pebble conglomerate.

The upper part of this facies is dominated by sandstone with some granules and pebbles (Plate I, Figs. 3, 4). Pebbles are well segregated from sand into laterally continuous, thin planar layers that are commonly less than 10 cm, mostly 1 to 5 cm, thick. In places, pebble layers can be traced more than 5 m laterally. Sandstones are internally planar-laminated due to textural variation. Stratification throughout this part of the facies is almost parallel. In places, however, low angle discordances in lamination are present, which generally do not exceed 5°.

The middle part is represented by pebble accumulation (Plate I, Fig. 5), and sandstone is uncommon. The pebbles show a high degree of segregation into planar beds of different clast size, ranging in thickness from 5 to 50 cm.

The lower part is composed of interbedded conglomerate and sandstone. As in the upper part, pebbles are well segregated from sand into discrete beds of 5 to 20 cm thick, and bedding is mostly planar. Sandstones are also planar-laminated. The conglomerate beds and individual lamina sets in the sandstone are either uniform in thickness or slightly wedge-shaped in cross section due to low angle (commonly less than 10°) discordances. Inclination direction of stratification in this part is predominantly toward the south (Fig. 6).

In general, grain size gradually increases upward from the lower part into the middle part, and then rather abruptly decreases into the upper part. Pebble imbrication is rather poorly defined, but, where evident, the flatter pebbles are imbricated inclining to a southerly direction (Plate I, Fig. 4).

Biological features are almost absent in the whole of this facies, but very rarely *Ophiomorpha* burrows occur in the lower part.

On the outcrops studied, facies C is lacking in mudstone at all with only one exception. As shown in a detailed log (Fig. 5—3), a 40 cm thick mudstone with scattered sand-

Fig. 6. Paleocurrent rose diagrams. Notations as follows; N: number of readings, L: vector magnitude, p: significance of Rayleigh test.

and granule-size grains occurs between the upper and middle parts. A lenticular sandstone bed, 5 cm thick, is intercalated. The mudstone contains abundant plant debris, and is intensely bioturbated. Burrows are abundant.

Facies D. Cross-bedded pebbly sandstone

Facies D is composed of as much as 6 m thick, dominantly medium- to coarse-grained sandstone. Pebbles are common, either scattered throughout the sandstone or segregated into layers, and increase in abundance upward. In general, pebble size also increases upward. The predominant sedimentary structure is medium-scale trough cross bedding in about 10 to 50 cm thick sets (Plate I, Figs. 6, 7). Individual troughs are 0.5 to more than 2 m wide. Some differences in textural and stratification characteristics are revealed between the upper one-third of the facies (about 2 m thick) and the lower remainder.

The upper part of the facies is made up of coarse- to very coarse-grained sandstone with abundant granules and pebbles. Sediment sorting is rather poor compared with that in the lower part, but is much better than in the pebbly sandstones of facies A. The upper part is wholly cross-bedded (Fig. 5). Paleocurrent azimuths are weakly bimodal. Cross bedding dips predominantly southward (Fig. 6). Some foresets dip to the east to form a less distinct secondary mode.

The lower part of the facies is mainly composed of trough cross-bedded, medium-grained sandstone with pebbles. Pebbles are well segregated from sand and tend to be concentrated on the basal surfaces of troughs. Paleocurrent azimuths are quite different from those in the upper part. The southerly mode is not significant, and foresets dip predominantly northward, almost in the opposite direction to that of the primary mode in the upper part (Fig. 6). The easterly mode is present, but is less conspicuous than in the upper part. Some parallel-laminated beds of 10 to 30 cm thick occur in the lower part (Fig. 5). These beds are made up of fine-grained (rarely medium-grained) sandstone.

Pebbles are rare, and are, when present, well segregated from sand to form thin and persistent layers. Internal lamination is defined by textural variation.

Facies D is generally unfossiliferous; molluscs including oysters are present in a few horizons. Bioturbation is likewise uncommon, although a few burrows (including *Ophiomorpha*-like ones) are discernible.

Facies E. Bedded sandstone

This facies consists of 10 to 40 cm thick beds of fine- to medium-grained sandstone (Plate II, Fig. 1). Pebbles are uncommon, decreasing in abundance and in size downward. Individual beds are separated by erosional bounding surfaces on which coarse to very coarse sand grains, granules and pebbles are frequently concentrated. The bounding surfaces are generally flat to slightly undulose, but can be sometimes irregular.

Many of the beds are parallel-laminated throughout. In some cases, lamination is gently cross-stratified at very low angle. Lamination is defined by textural variation or rarely by concentration of small, fragmented plant debris. Ripple lamination occurs at the top of some beds, especially thicker ones.

Bioturbation is intense in some beds, and causes partial disruption of primary physical structures. Horizontal burrows are, in places, abundant (Plate II, Fig. 2). Vertical burrows are uncommon, and, when present, are mostly defined by isolated tubular concentrations of coarse to very coarse sand grains or granules. Biological influences are almost restricted to the upper part of individual beds.

Facies F. Sandstone with mudstone interbeds

Common presence of mudstone interbeds differentiates this facies from the other facies composed of sandstone and conglomerate. Two kinds of constituents are recognized within this facies. One is trough cross-bedded sandstone, and the other is thin-bedded sandstone with mudstone interbeds. They alternately succeed (Plate II, Fig. 3).

Trough cross-bedded sandstone (Plate II, Fig. 4) forms 1 to 2 m thick units. Sandstone is medium- to coarse-grained, sometimes

granular. Some pebbles and fragmented oyster shells are contained, and tend to be concentrated toward the base of troughs. Individual trough sets are 5 to 30 cm thick. These sets are grouped into cosets of 0.2 to 1.2 m thick. Some cosets are characterized by an undulose, erosional basal surface. In places, thin (less than 2 cm thick), impersistent mudstone partings or drapes are present. Paleocurrent azimuths are somewhat diverse. Foresets dip predominantly south or southeast (Fig. 6). Within each unit, however, foreset azimuths are generally unidirectional. Biological influences are generally uncommon in the trough cross-bedded sandstones although vertical burrows such as *Ophiomorpha* occur in some beds. In places, burrows are truncated by basal erosional surfaces of trough cosets.

Thin-bedded sandstone forms as thick as 1 m units. Individual sandstone beds are up to 20 cm thick. The upper surfaces of sandstone beds show straight- to slightly sinuous-crested ripple form (Plate II, Fig. 5). Internally, sandstones are either ripple-laminated or parallel-laminated. Isolated or laterally persistent mudstone drapes sometimes occur within ripple-laminated sandstone to form flaser and wavy bedding. Mudstone interbeds are commonly less than 3 cm thick, and laterally pinch out in some cases. Exceptionally mudstone reaches about 20 cm thick. Mudstone is either massive or thinly laminated, and sometimes contains sandy streaks and ripple-formed thin (less than 2 cm thick) sandstone layers. Bioturbation is rather intense in mudstone interbeds, and lamination is frequently destroyed.

Facies G. Poorly sorted, sheet conglomerate

This facies is made up exclusively of very poorly sorted conglomerate with a sharp and erosional basal surface (Plate II, Fig. 6). The basal surface in most places is planar and shows little, if any, local relief. The conglomerate bed is thin (generally less than 30 cm thick) and laterally continuous, showing sheet-like nature. The beds are internally massive, and granules and pebbles of up to 6 cm in diameter are disorderly concentrated

in fine- to coarse-grained sand matrix. In places, the beds contain scattered fragments of molluscan shells, particularly of oysters.

Facies sequence

Seven facies described above make up a distinct facies sequence. At least five sequences are recognized. Although all of these sequences are incomplete and lack two or three components, integration of systematic vertical succession of facies within each incomplete sequence leads to construct an idealized facies sequence that is shown in Fig. 7—A.

The base of the sequence is marked by a sharp and erosional surface truncating underlying deposits. A thin conglomerate of facies G of the basal part of the sequence is succeeded by sandstone and mudstone of facies F which, in turn, is overlain by bedded sandstone of facies E. Facies E sandstone grades up into pebbly sandstone of facies D which is overlain with a sharp and planar truncation surface by sandstone and conglomerate of facies C. Grain size gradually increases upward from facies F to the middle part of facies C, and then abruptly decreases into the upper part of facies C. The sequence is capped by mudstone-dominated facies B in which pebbly sandstone of facies A is intercalated with an erosional basal surface.

Environmental interpretation

The upper part of the Yuasa Formation under study contains abundant plant debris, coaly layers, brackish-water molluscan fossils and marine trace fossils including *Ophiomorpha* that is an indicator of littoral and shallow sublittoral environments (WEIMER & HOYT, 1964; KENNEDY & SELLWOOD, 1970; DIKE, 1972), and is interpreted as coastal deposits. The idealized facies sequence (Fig. 7—A) shows a coarsening-upward nature. The coaly layers are restricted to the top component of the sequence (facies B). Brackish shells and plant remains are also most common in this part of the sequence. On the contrary, marine trace fossils increase down the sequence. Each sequence, there-

Fig. 7. (A) Idealized facies sequence with paleoenvironmental interpretations. Paleocurrent pattern is highly schematical. (B) Schematic representation of the terminology of the zones of a shoreline profile.

fore, appears to represent a regressive or progradational episod. The shoreline was approximately oriented east-west with seaward side to the south. This paleogeography is inferred from southerly flowing paleocurrents in the fluvial deposits in the lower part of the Yuasa Formation (MAEJIMA, 1980) and from general lithofacies and biofacies changes in the Cretaceous rocks in the Yuasa area (TANAKA, 1956 a, b).

Many studies on the processes and products in modern coastal zones provide a framework for environmental interpretation of the components of the facies sequence. Based on these studies, detailed interpretation of the facies is discussed (Fig. 7—A, B).

Facies A.

The pebbly sandstone of facies A may be attributed to fluvial sedimentation. Cross bedding with unimodal paleocurrent pattern

flowing down the inferred paleoslope and lack of marine or brackish-water fossils support the fluvial interpretation for facies A. The erosional bases suggest channel scour, and locally concentrated pebbles on the basal surfaces may represent channel lag deposits. The cross-bedded sandstone resting on the channel floor was resulted from deposition by migrating dunes within channels. The facies A pebbly sandstones avoid any indications of lateral point bar accretion or channel bar formation, and are interpreted as the deposits filling stream channels.

Facies B.

Predominance of mudstone, intense bioturbation and fossil contents indicate that facies B was originated chiefly in a low-energy, paralic environment. Abundant plant remains and coaly layers may represent deposition in coastal marshes. Some mudstones and muddy sandstones containing abundant brackish-water molluscan fossils may be interpreted as the deposits of coastal lagoons.

Facies C.

The well-sorted, planar-bedded conglomerate and sandstone contain many features indicative of a beach environment. A high degree of segregation of pebbles from sand or into beds of different clast size is a distinctive feature of gravels worked by waves (CLIFTON, 1973). Gently seaward-inclined planar bedding with low angle discordances is well documented from present-day beach deposits (McKEE, 1957; PANIN, 1967; CLIFTON *et al.*, 1971; DICKINSON *et al.*, 1972; HOWARD & REINECK, 1981) and is explained by processes of swash action (CLIFTON *et al.*, 1971; HARMS, 1975). Imbrication of pebbles dipping in a seaward direction is also well known as a typical feature of beach gravels (TWEHOFEL, 1939; CAILLEUX, 1945; BLUCK, 1967). A beach interpretation for this facies is supported by presence of marine burrows (*Ophiomorpha*) and the overlying marsh or lagoonal deposits.

Recently MAEJIMA (1982) studied the textural and stratification characteristics of sediments across a modern gravelly beach in Southwest Japan, and showed that the sediments coarsen up a foreshore into a zone of

foreshore-backshore transition which is marked by a low ridge at the berm crest and then abruptly fine into a backshore and that the dip of stratification becomes gentle and less diverse from a foreshore to a backshore. Vertical changes in grain size and in bedding characteristics through the facies C are closely comparable with such trends in across-beach sediment characteristics, and facies C is explained to represent beach progradation. The interbedded conglomerate and sandstone of the lower part, in which sediments coarsen up and discordances in bedding are frequent, are interpreted as having formed chiefly in a foreshore with swash the predominant process. The conglomerate of the middle part, in which the coarsest sediments are found, may probably represent a low ridge at the berm crest on the seaward margin of a backshore, onto which the coarser pebbles were transported and accumulated by swash uprush during high water periods. The sandstone-dominated, almost parallel-bedded upper part may be attributed to deposition in a rather flat area of a backshore which was flooded and subjected to wave action only during storm periods.

Assuming that loading compaction has been negligible, the thickness of foreshore deposits may provide an evidence of a maximum tidal range. The interbedded conglomerate and sandstone of the lower part that is attributed to foreshore sedimentation are 1 to 2 m thick, and the tidal range may be estimated to have been no more than 2 m. If the rate of progradation was not great enough as compared with the rate of basin subsidence, the tidal range was probably much less than 2 m.

The interpretation of the uncommon mudstone intercalated between the upper and middle parts is not certain. It may indicate deposition in a body of standing water. Such a body of water was probably formed by blocking a small stream crossing the beach due to ridge formation at the seaward margin of the backshore.

Facies D.

Trough cross bedding, *Ophiomorpha*-like burrows and position in a facies sequence indicate

that this facies was originated in a shallow marine environment close to a beach, where sediments had been intensely reworked by physical processes, that is an upper shoreface. Upward increase in conglomerate and in pebble size suggests shoreline progradation. Trough cross bedding is the predominant sedimentary structure throughout this facies, but the direction of cross bedding is quite different between the upper and lower parts of the facies. This implies that individual parts were originated in different sites within an upper shoreface environment and that predominant hydraulic processes were different between these two sites. In the progradational setting, the upper part represents the shallower area in an upper shoreface than the lower part.

The seaward direction of cross bedding in the upper part may be interpreted as resulting from rip currents or seaward water movement in the transition between swash and surf. Off modern beaches, rip currents are well known to form under high wave conditions (McKENZIE, 1958; COOK, 1970; DAVIS & FOX, 1972), and rip current deposits show seaward-dipping trough cross bedding (DAVIDSON-ARNOTT & GREENWOOD, 1976; HUNTER *et al.*, 1979). In the inner portion of the surf zone in the modern high-energy coast, dunes are formed by the interaction of swash and surf and migrate in a offshore direction to produce also seaward-dipping trough cross bedding (CLIFTON *et al.*, 1971). Large rip currents, however, probably did not form so frequently, because a gravelly beach has a steep beachface slope (KING, 1959; SHEPARD, 1963), and much of the water is returned seaward by reflected waves and rip currents are poorly developed in such a steep beach (COOK, 1970). Thus the interaction of swash and surf were probably much responsible to forming the offshore-dipping cross bedding, although rip current origin cannot be excluded. The east-west directed minor modes are interpreted as having formed by longshore currents.

In contrast to the upper part, the lower part is dominated by northward-dipping

trough cross bedding. These trough sets indicate deposition from dunes which almost exclusively migrated toward the inferred shoreward direction. High degree of segregation of pebbles into thin layers shows that sediments were sufficiently worked by waves. Hence, dune generation and their landward migration are thought to have been caused by wave-generated currents. The environment of deposition of the lower part is closely comparable with the zone of wave build-up in the high-energy, non-barred coast of Oregon studied by CLIFTON *et al.* (1971), where landward facing dunes are the dominant bed form and migrate toward the shore.

Facies E.

Partial disruption of lamination due to bioturbation, finer grain size than in facies D and scarcity of pebbles indicate that facies E was accumulated in deeper water than the overlying upper shoreface deposits (facies D) but not in water deep enough that physical sedimentary structures were completely destroyed by biological activity. Consequently a lower shoreface environment is suggested for this facies. Parallel- and ripple-laminated fine-grained sands similar to this facies are recorded in the modern lower shoreface (KUMAR & SANDERS, 1976; DAVIDSON-ARNOTT & GREENWOOD, 1976; GREENWOOD & MITTLER, 1979). Ancient deposits comparable with this facies have been described and attributed to lower shoreface (VOS & HOB-DAY, 1977; ROEP *et al.*, 1979; BRENCHELY & NEWALL, 1980; CLIFTON, 1981).

The erosional surfaces bounding the beds may be interpreted as forming during intense storm wave surge, when sea bottom was eroded and sediments were kept in turbulent suspension. The coarse materials concentrated on these bounding surfaces may represent a lag deposit as regarded so by KUMAR & SANDERS (1976) in modern and ancient shoreface storm deposits. The parallel-laminated sandstone, a predominant component of this facies, is inferred to be a product of deposition of suspended sediments in the waning stage of the storm, when wave surge currents were strong enough to produce sheet flow deposits.

Low angle truncation resembles hummocky cross stratification that is believed to be of storm origin (HARMS, 1975; DOTT & BOURGEOIS, 1982).

Ripple lamination is restricted to the top of the beds, and is interpreted as representing minor reworking of sediments during the fair-weather period or the terminal stage of the storm. Bioturbation and burrows in the upper part of the beds are also thought as the products during the fair-weather condition. These low-energy records are absent in some beds. It is probably due to erosion and resuspension of the substrate by a following storm.

Facies F.

The thin sandstone beds separated by suspension mud suggest that sand was introduced and deposited intermittently, probably related to storms. Common occurrence of ripples indicates that velocities of wave surge currents were low enough even in storm periods or waning stages of storms not to produce abundant sheet flow deposits. Between times of sand deposition, that is in fair-weather periods, agitation due to wave surge was not sufficient to keep fine materials in suspension completely, then suspension mud was deposited over the rippled sand bed to form the intervening mud layers or drapes. Abundant horizontal burrows (probably of sediment feeders) and intense bioturbation also indicate rather quiet conditions between times of sand deposition. As is evident from these interpretations and from the position in the facies sequence, the thin-bedded sandstone with mudstone interbeds represents deposition in a deeper area than the preceding five facies (facies A to E), and a nearshore-offshore transition zone is inferred.

Interpretation of depositional processes of the trough cross-bedded sandstone in this facies is not entirely clear. Pebbles and trough cross bedding that may have been formed by dune migration indicate deposition under much higher energy condition than the thin-bedded sandstone. *Ophiomorpha* also excludes conditions of quiet water. However, thin mudstone partings or drapes and close

association with thin-bedded sandstone show that deposition of the cross-bedded sandstone took place in water as deep as the thin-bedded sandstone. Dominantly offshore-directed paleocurrents and fragmented oyster shells suggest that sediments were transported offshore by strong currents from an area close to the shore. On the process of deposition of trough cross-bedded sandstone, several possibilities can be noted:

1. The unusually severe storms caused enormously large rip currents which extended and transported sediments into enough depth below the level of significant wave surge. However, substantial thickness, mudstone partings or drapes and truncated burrows suggest that the cross-bedded sandstone unit was resulted from multistoried events within some long-term periods. It is difficult to suppose that unusually severe storms were frequent in some periods which were alternated with periods of almost absence of such unusual storms.

2. Tidal inlets deeply incised into near-shore deposits. But dominantly offshore-directed paleocurrents argue against tidal origin. Tidal channels should show oppositely directed bipolar flows. Furthermore, facies C suggests that tidal range was not great during the time of deposition.

3. Fluvial activity extended down into such a depth to cause sediment influx. This seems to be a more favourable explanation than the preceding two cases. According to brief summary of paleoenvironmental reconstruction of the Yuasa Formation (MAEJIMA, 1980), sediments were supplied into the coast from neighbouring uplands by braided streams which were capable of transporting abundant coarse materials. When streams were in extreme flood stage, outflow from a mouth of a stream channel was probably quite strong and may have transported coarse materials even below the level of significant wave agitation. Materials deposited in a shallower zone may have been almost completely reworked by wave action. If this interpretation is correct, alternate occurrence of the thin-bedded sandstone unit and the cross-

bedded sandstone unit is explained as follows: during the time when a stream channel or channel system had shifted away laterally, fluvial processes did not extend into this depth but only marine processes acted to form thin sandstone beds and mudstone partings.

Facies G.

The conglomerate of this facies is interpreted to be a transgressive lag deposit because of its position between deeper water deposits above and shallower water or paralic deposits below. As the sea transgresses, coastal erosion takes place to produce the erosional surface (SWIFT, 1968), on which clasts too large to be significantly driven in landward direction by shoaling waves are concentrated.

Conclusion and discussion

The upper part of the Early Cretaceous Yuasa Formation is interpreted as the non-barred, high energy, gravelly shoreline deposits. In the study intervals, several regressive sequences are recognized. Transgressive episodes are restricted to erosional surfaces and thin lag deposits. Absence of transgressive sequences may be due to coastal erosion during transgression as noted by SWIFT (1968) and RYER (1977). The idealized facies sequence (Fig. 7—A) represents diverse environments near a shoreline, that is, in ascending order, nearshore-offshore transition zone, lower shoreface, upper shoreface, beach (foreshore and backshore) and paralic zone. Thus the sequence is explained in terms of shoreline progradation.

The sediments were transported by braided streams and were deposited in the coast characterized by rather high wave energy and a low tidal range. Wave-induced strong currents during storms must have been responsible for sediment influx into the shoreface or deeper area. Storm waves may also have eroded and resuspended the shoreface substrate and have flooded over the backshore to plane off the beach. Deposition of suspended sediments in the shoreface probably took place in the waning stages of the storms. Storm records are well preserved in the deposits of

the transition zone (thin sandstone beds), lower shoreface (erosional surfaces and parallel-laminated sandstone) and backshore (planar-bedded sandstone and well segregated pebbles). After storms ceased, shoaling waves reworked the sediments and returned the materials landward. Sediment reworking by ordinary shoaling waves must have been especially intense in the upper shoreface, where storm-generated sediments were almost completely reworked to form onshore migrating dunes. Large swells were probably commonplace on the coast. Modification by waves was also strong in the foreshore and the seaward margin of the backshore, and gravels were piled up the beach face to form a ridge on the berm crest. Only minor rippling in the lower shoreface and suspension settling in the transition zone were caused during fair-weather periods, as well as reworking by biological activity at some depth below the sediment surface. The major part of the backshore was also probably free from significant modification during fair-weather periods. Furthermore next-coming storm waves may have easily eroded the surficial sediments. Thus the storm-generated deposits are preferentially preserved in these facies.

Ancient shoreline deposits containing substantial amounts of gravel have been less well studied than almost entirely sandy ones. A few studies contain examples of non-barred coast of the Pleistocene (CLIFTON *et al.*, 1971) and the Miocene (CARTER, 1978) ages and of barred coast of the Miocene age (CLIFTON 1981). They are consistently interpreted as the products under high wave energy and a low tidal range as in the Cretaceous example in this paper. But they are much less abundant in gravel than the Yuasa example. The deposits of beach origin in the upper Yuasa Formation are predominated in gravel, while the beach facies in the other examples are almost wholly made up by sand. The shoreface deposits of the Yuasa example are also more abundant in gravel.

Ancient gravelly shoreline deposits must have formed where gravel-bearing alluvial systems were built into microtidal and high

wave-energy seas. Under such setting, the role of alluvial processes should have been important also at the shoreline. In the flood stages, outflows from the mouth of stream channels may have introduced abundant coarse materials into the shoreface or deeper site. Some of these deposits may be preserved in rock record if they were accumulated in depth below the level of significant wave reworking. In the Yuasa example, such deposits are preserved as intercalations within the nearshore-offshore transition zone deposits.

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紀伊半島西部の前期白亜紀湯浅層中の礫質海浜堆積相

前 島 渉

(要 旨)

紀伊半島西部の湯浅南西に分布する湯浅層(白亜紀前期)の上部には7種の堆積相が識別される。これらの堆積相は一定の累重関係を示し、数個の堆積サイクルをつくる。各堆積相の現世堆積物との比較・古流向などから、個々のサイクルは礫質海浜のプログラデーションによる産物と考えられる。理想的なサイクルの構成と各堆積相の堆積場は次のとおりである。下位より、(1)軽微な浸食基底面をもつ、極めて分級の悪いシート状礫岩(海進時の残留堆積物)；(2)泥岩をはさんで薄く成層する砂岩(海浜—沖合漸移帯)と斜交層理の発達する礫まじり砂岩(漸移帯へ流入して保存された、近接する河口からの碎屑物)；(3)主に平行葉理を示す成層砂岩(沖浜下部)；(4)トラフ型斜交層理が卓越する礫質砂岩(沖浜上部)；(5)平板状に成層し、しばしば低角度の楔型斜交層

理を示すきわめて分級の良い礫岩・砂岩(前浜および後浜)；(6)薄い砂岩をはさみ、強い生物擾乱作用を受けた泥岩(沼沢地またはラグーン)およびその中に狹在される；(7)分級が悪く斜交層理の発達する礫質砂岩(河川チャネル)。

暴浪起源の堆積物は、海浜—沖合漸移帯・沖浜下部・後浜の堆積相に良く保存されている。沖浜上部・前浜では、暴浪時の産物は静穏期の日常的波浪作用によりほぼ完全に再動されてしまったと考えられる。

湯浅層上部の地層は、主として網状河川により北方からもたらされた物質がほぼ東西方向に延びた海浜に沿って堆積したものである。堆積当時の海浜では、波浪エネルギーが高く、潮位差は小さかったと推定される。

Explanation of Plate

Plate I

1. Cross-bedded pebbly sandstone of facies A, resting on an erosional basal surface.
2. Oyster shells and burrows in the intensely bioturbated mudstone of facies B.
3. Sandstone-dominated upper part of facies C showing planar parallel stratification.
4. Well segregated, imbricated pebbles in the upper part of facies C. Scale tape is 30 cm long.
5. Planar-bedded, well sorted conglomerate of the middle part of facies C. Note high degree of segregation of pebbles into different clast size. Scale is in centimeters.
6. Trough cross-bedded pebbly sandstone. Lower part of facies D. Pebbles tend to be concentrated on the bases of troughs to form thin and lenticular layers.
7. Trough cross bedding in the lowest part of facies D.

Plate II

1. Bedded sandstone of facies E. Note an erosional surfaces on which coarse materials are concentrated.
2. Dense network of horizontal burrows at the top of a sandstone bed in facies E.
3. Alternate succession of thin-bedded sandstone with mudstone interbeds and thick, cross-bedded sandstone, facies F.
4. Cross bedding in thick sandstone in facies F.
5. Slightly sinuous-crested ripples on a thin sandstone bed in facies F.
6. Poorly sorted sheet conglomerate of facies G, erosively resting on the mudstone of facies B.