Late Mesozoic and Cenozoic sedimentation along oceanic island margins: analog to continental margins

Oceanic islands
Sedimentation
Eustasy
Bottom current
Continental margin sedimentation

Iles océaniques
Sédimentation
Eustasie
Courant de fond
Sédimentation marge continentale

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ABSTRACT

The depositional environments along Pacific island margins have been used as analogs to elucidate depositional processes along continental margins. They are controlled by their tectonic and volcanic, climatic, hydrographic and biologic evolution. Intervals of low eustatic sea levels led to be displacement of shallow water sediments (with their contents of neritic fossils) into the adjacent deep-sea basins. Eight erosional pulses when neritic fossils were displaced into the deep-sea, can be discerned in the central Pacific during the past 130 MY. Velocities of oceanic bottom water currents which affected island margin sedimentation, were slow in the Cretaceous Pacific, but they eroded sediments in intermediate water depths since Maastrichtian time. Mechanical erosion seems to have generated most hiatuses. The temporal distribution of the abundance of displaced pelagic fossils reveals the development of vigorous current regimes during the past 42-44 MY within in the meso- and bathypelagic parts of the Pacific water column. This is considered important for an understanding of the distribution and development of pelagic oxygen-deficient depositional environments.

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RÉSUMÉ

Sédimentation sur les marges des îles océaniques : analogie avec les marges continentales.

On étudie la sédimentation sur les marges continentales à la lumière des résultats obtenus sur les marges des îles du Pacifique. Celle-ci est contrôlée par leur évolution tectonique, volcanique, climatique, hydrographique et biologique. Les périodes de bas niveau eustatique sont caractérisées par un déplacement des sédiments d'eau peu profonde vers les bassins profonds adjacents. Dans le Pacifique central, depuis 130 mA, on caractérise ainsi huit phases d'érosion avec déplacement des faunes néritiques vers les bassins. La vitesse des courants océaniques de fond était faible au Crétacé, mais a augmenté suffisamment dans les profondeurs intermédiaires depuis le Maestrichtien pour éroder les sédiments et générer des hiatus. La distribution temporelle des faunes pélagiques remaniées montre l'instauration d'un régime de forts courants depuis 44-42 mA agissant dans les environnements méso- et bathypélagiques.
Ces observations ont des conséquences importantes pour l'étude de la distribution et du développement des environnements pélagiques déficitaires en oxygène.

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INTRODUCTION

Continental margins trail one of the most important geological and tectonic boundaries on our globe : the transition from oceanic to continental basement. Because of the difference in the basement compositions this transition zone is accompanied by a large gradient of the relief of the crust's surface. The movements of the marine water masses in the transitional zone between the coasts of the continental land masses and the pelagic environment are affected by the presence of this physical obstacle. It results in margin-specific constructive and destructive depositional processes, which often lead to the downslope displacement of sedimentary components. Reworking and displacement processes can be studied best by means of benthonic fossils assemblages because of their depth zonation which is well developed and known from neritic regions reaching into the photic zone. However, reworking effects also most other sediment components such as shell material produced by the oceanic plankton and terrigenous particles. There are many continental margins where reworked and displaced sediments are considerably more abundant than those which still rest on the location of their primary deposition.

Because of the complicated vertical tectonic movements of continental margins with time (Watts, Ryan, 1976), it is often difficult to decide if tectonic on sedimentary processes caused the displacement of entire sedimentary sequences or of individual sedimentary components. In this study evidence for large scale vertical and horizontal displacement of sediments along the slopes and flanks of oceanic islands and structural highs in the Pacific Ocean will be used to discuss the temporal variability of sea level fluctuations and of meso- and bathypelagic current regimes. Oceanic islands, shelfs slopes and rises represent physical obstacles for the bypassing oceanic water masses generating phenomena in many ways analog to those which can be observed along continental margins, but they are less complex. New data (Thiede *et al.*, in press) from the flanks of submarine elevations in the central Pacific Ocean collected by the Deep-Sea Drilling Project allow to discuss some important aspects of displacement processes in the central Pacific Ocean, which are important for the understanding of Mesozoic and Cenozoic sea level fluctuations as well as the evolution of oxygen-deficient depositional environments in the oceans (Dean *et al.*, in press).

DISPLACEMENT OF NERITIC FOSSILS INTO THE DEEP SEA

Displaced neritic fossils, which are found in pelagic sediments, are easily recognized regardless if the material is contemporaneous or older than the host sediment. They can tell us about the nature and presence of past neritic depositional environments. They allow us to date these environments, and to describe the mode of transport, and, in some instances, the nature of the transport path. There are many records of the displacement of neritic fossils across continental margins (see for example Fig. 1), but because of the isostatic movements, of hiatuses and of the sparse sample coverage of the outer and deeper continental margins, it is presently impossible to establish a comprehensive and complete record of the source region of such material and of the processes leading to its displacement. However, we can turn to the open ocean and look there for evidence of displacement of shallow water derived fossils.

Recently a search has been made in the reports of deep-sea drill sites in the tropical and subtropical Pacific Ocean (Fig. 2) in the hope of establishing temporal and spatial patterns in the distribution of contemporaneous, as well as non-coeval neritic fossils which have been reworked from shoal areas (Thiede *et al.*, in press). The sediments described from the sites with reworked fossils in the central Pacific Ocean (Fig. 2) span over a wide range in time (from late Jurassic/early Cretaceous to Quaternary) and depth (< 1.5-> 6 km) ; most of them are located on the Mesozoic part of the Pacific Plate (Pitman *et al.*, 1974), and all of them penetrated pelagic sedimentary sequences. Because of the random regional distribution of the drill site locations over such a wide area, a bias towards one single deep-sea basin or towards one very specialized, depositional environment can be excluded. The occurrence and age distribution of neritic displaced fossils (Fig. 3) in many deep-sea drill sites of the western central Pacific Ocean came as a surprise, because these sites are presently distant from extensive land areas. However, it has been known for some time that many of the submarine rises and platforms observed in the western central Pacific Ocean once reached close to or above the sea surface (Matthews *et al.*, 1974 ; Hamilton, 1956 ; Heezen *et al.*, 1973) that they can have acted as source areas for the displaced material.

Evidence for displacement of shallow water carbonate

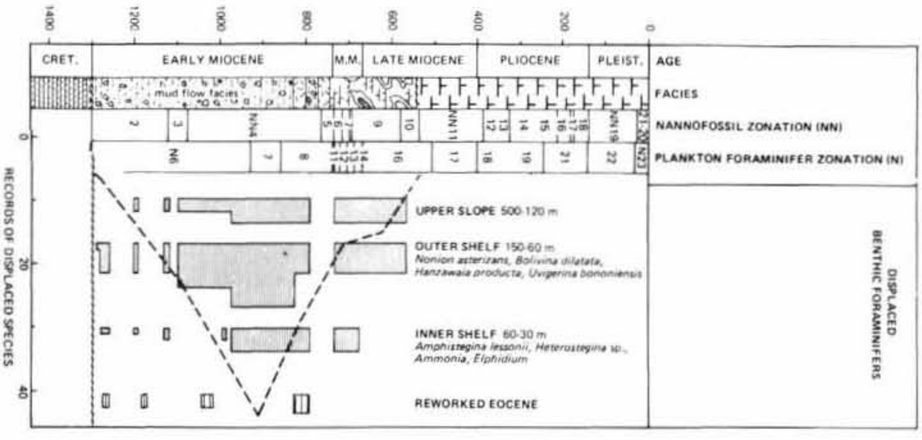
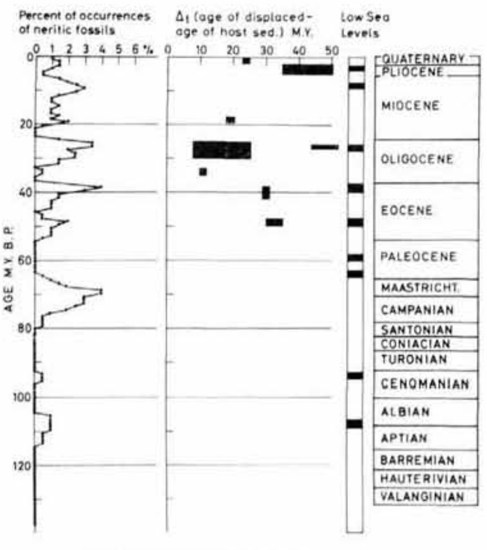


Figure 1
Deep-Sea Drilling Project site 397 in the northeast Atlantic Ocean off northwest Africa (2,900 m water depth). Distribution of displaced shelf benthonic foraminifers in Neogene sediments (after Lutze, in Von Rad et al., *1979).*

CENTRAL PACIFIC OCEAN

Figure 2
Locations of deep-sea drill sites with good coring records and displaced neritic and non-contemporaneous pelagic fossils in the tropical and subtropical Pacific Ocean (after Thiede et al., *in press).*



CENTRAL PACIFIC OCEAN

Figure 3
Occurrence and age of displaced shallow water fossils in drill sites from the subtropical and tropical Pacific Ocean. Occurrence is expressed in percent of total observations of displaced material. Δt_{max} *is the maximum time difference between the age of the reworked and displaced shallow water fossils and host sediment. The ages of low eustatic sea level stands have been marked according to Vail* et al., *1977.*

fossils from their neritic depositional environment into the adjacent deep-sea has been found spread over wide intervals in space and time (Fig. 3). In most cases the displaced sediment is about the same age as the host sediment ; evidence for erosional events cutting into sections considerably older than the time of displacement are not common. The sites with such records lie close to the Tuamotu Islands (site 76), the Line Islands (site 165), and the Emperor Seamounts (site 309), and include site 462 in the Nauru Basin (Schlanger, Premoli-Silva, in press). These deposits are Cenozoic in age and they are situated in areas where extensive reworking of shallow water sediments has been recorded in deep-sea drill sites.

Displaced contemporaneous shallow water derived carbonate fossils have been observed in sediments ranging from Barremian-Aptian to Quaternary in age (Fig. 3). The earliest event was in Barremian-Albian time, the next one during the Cenomanian. Intensive displacement of shallow water carbonates took place during Campanian and Maastrichtian time, but decreased sharply towards the Cretaceous-Tertiary boundary. The Paleocene deposits gave no evidence for reworked shallow water carbonates in the central Pacific Ocean, but this might be the result of many and extensive hiatuses that developed during erosive events in the deep-sea at that time. The flux of shallow water components was particularly important during the early Eocene, late Eocene, late Oligocene, late Miocene and during the Plio-Pleistocene. It seems particularly notable that the influx of shallow water carbonate fossil debris during the entire time span considered here occurred in pulses and that it rather represented a sequence of episodic events than a continuous process.

The occurrences of neritic fossils in central Pacific Ocean pelagic sediments (Fig. 3) document the repeated injection of shallow water derived debris into the adjacent deep-sea basins. This occurred throughout the late Mesozoic and the entire Cenozoic as a sequence of short-lived episodic events. These are separated from each other by intervals when less or no shallow water derived benthonic fossil material reached the floor of the deep-sea basins. The events, except the Campanian-Maastrichtian one, coincided with low eustatic sea level stands (Vail *et al.*, 1977), and represent, therefore, probably the product of erosional processes at sea level during those intervals. The Campanian-Maastrichtian event is a special case because it is the most important one of the late Mesozoic paleoenvironment, but it apparently did not coincide with very low eustatic sea levels (Vail *et al.*, 1977 ; McCoy, Zimmermann, 1977). This interval was coeval to a major phase of wide-spread volcanic activity (Natland, 1976 ; Jackson, Schlanger, 1976) in the central Pacific Ocean. This volcanic activity led to the deposition of volcanic ashes in the Mariana Basin (site 199), along the Line Islands (sites 165, 315, 316) and on Horizon Guyot (sites 171 and 313) in the Mid-Pacific Mountains. The occurrence of neritic fossil debris in central Pacific Ocean deep-sea sediments which is apparently not coeval to its time of redeposition, is restricted entirely to the Cenozoic parts of a few drill sites, for example sites 76, 165, 209, 315 and 462. These sites are located on old oceanic crusts. Subsidence did not generate important differences in paleodepth of deposition during the later part of the Mesozoic and during Cenozoic. Erosion during low eustatic sea level stands, therefore, was able to reach the older strata.

THE INTERMEDIATE WATER PALEOENVIRONMENT : THE DISPLACEMENT OF PELAGIC SEDIMENTS

Circulation patterns and current velocities of the intermediate oceanic water masses through time are not yet studied in sufficient detail. They are of high interest, because the ocean appears to have gone through stages of relatively quiescent intermediate and bottom water regimes when oxygen deficient depositional environments developed. Anoxic sediment facies are observed along many continental margins (Tissot *et al.*, 1979 ; Arthur, Natland, 1979) where paleoenvironments were especially favorable for the preservation of anoxic sediment facies. Several models have been invoked (Thiede, van Andel, 1977) to explain these occurrences which, however, do not account for the fact that most observations of "black shale" occurrences in the world ocean (Arthur, Natland, 1979) have been made in Cretaceous sediments (the Jurassic has not yet been sampled sufficiently). It has therefore been tried to evaluate the temporal patterns of mechanical transport in the pelagic realm through observations of displaced pelagic fossils (Thiede *et al.*, in press). Sedimentary structures in deep-sea drill cores often indicate the presence of bottom water currents, but the amount of reworking and displacement of contemporaneous biogenic components is difficult to detect and to assess. However, if fossils considerably older than the time of deposition are included into the deep-sea sediments, their presence can be used as an unequivocal argument for current transport. The properties of the eroded sediments and of the transported sediment particles are evidence for the strength of the current regimes. In Figure 4 we have plotted, therefore, only observations of non-contemporaneous reworked fossils.

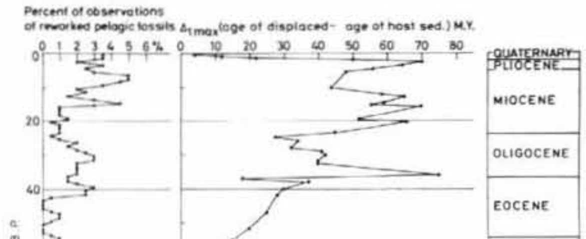


Figure 4

Occurrence of non-contemporaneous reworked pelagic fossils in drill sites from the central Pacific Ocean (cf. Fig. 2). Occurrence is expressed in percent of total observations of reworked non-contemporaneous pelagic fossils, Δt_{max} is the maximum time difference between the age of the reworked fossils and of the host sediment.

The most surprising feature of the distributions of reworked non-contemporaneous pelagic fossils in the central Pacific Ocean (Fig. 4) was the almost complete lack of such redeposited pelagic fossil material in the Mesozoic sections. Most of the drill sites evaluated here are located on structural highs ; their sediments are composed often of calcareous sections suggesting that they have been located above the relatively shallow late Mesozoic CCD (Thierstein, 1979). Also diagenetic processes which have altered the late Mesozoic pelagic carbonate limestone (Schlanger, Douglas, 1974) cannot explain to complete absence of reworked old pelagic fossils in the late Mesozoic central Pacific Ocean sediments, but the number of observations remained modest until late middle Eocene (44-42 MY B.P.) time when a major erosive episode began in the intermediate water masses of the central Pacific Ocean. The planktonic foraminiferal faunas of many sites bear ample evidence of wide-spread reworking of Eocene to Cretaceous faunas (Krasheninnikov, in press). The past 40 MY have been a time of constant reworking of deep-sea sediments (Fig. 4) with peaks of erosive events approximately 40 MY B.P., 30-32 MY B.P., 14-15 MY B.P., 7-8 MY B.P. and during the past 5 MY. The percentage of observations from the intervals 10-13 MY B.P. and in particular from 15-25 MY B.P. and 33-38 MY B.P. are relatively small.

The age difference of the reworked material to the time of displacement can in general range between O (which means the reworking of contemporaneous or pene-contemporaneous deposits) and a maximum value which is determined by the difference in age of the oldest eroded sediments and the time of deposition of the reworked components. It seems to be characteristic for the central Pacific Ocean that there was apparently no age difference between reworked and host sediments in most of the Mesozoic parts of the penetrated sedimentary section and that — if any — only coeval sediments have been reworked.

Only since Maastrichtian time when fossils from upper Campanian deposits were incorporated into the chalks and calcareous oozes, a major age difference began to develop. The maximal age difference between the age of the oldest reworked fossil components and the host sediment increased in a regular fashion from Maastrichtian to approximately 38 MY B.P. in late Eocene time. Between late Eocene and late Pliocene-early Pleistocene the maximum age difference fluctuated between > 20 and > 70 MY. High age differences (Fig. 4) are reached in late Eocene and early Oligocene time, and during early to middle Miocene and the end of the Pliocene, whereas minimal values are confined to times when the number of observations of reworked pelagic material was less. A drastic decrease of the maximum difference in age of the reworked sediment components and the host sediment during early and late Pleistocene seems to be a general feature of the redeposition of pelagic deposits in the central Pacific Ocean (Rea, Thiede, in press). The distribution of non-coeval reworked pelagic sediment components in the central Pacific Ocean revealed a large difference between the Mesozoic and the Cenozoic strata (Fig. 4). Maastrichtian events which reworked the immediately underlying Campanian sediments represent obviously the beginning of current regimes in the intermediate water masses of the Pacific Ocean. They were not only able to transport and displace coeval sediments, but also to erode into the underlying older sediments. These observations have been made in undisturbed pelagic sedimentary sequences ; they do not include evidence from turbidity currents slumps or slides which are not easily related to deep-sea current regimes. This is different from the South Atlantic paleoenvironment, where pelagic sediments as old as Coniacian have been displaced into deposits of Santonian age (Premoli-Silva, Boersma, 1977). The large quantitative difference of occurrences of planktonic fossils during pre-Maastrichtian and Maastrichtian-Pleistocene time seems to point to a fundamental change of the depositional paleoenvironment of the deep central Pacific Ocean and probably of the world ocean in general. The coincidence of the lack of non-coeval reworked pelagic fossil material and of the repeated development of oxygen deficient depositional environments between 80-120 MY B.P. in the Pacific suggest the possibility of a very quiet and sluggish bottom water circulation. It is documented by their laminated sediments (Dean *et al.*, in press). It also seems to support the interpretation that a wide area of the pre-Campanian central Pacific Ocean has not experienced bottom water currents strong enough, and with high enough speeds to be able to erode older strata, and to transport the resuspended sediment particles. Relatively rapidly flowing currents seem to have been confined to the upper few hundred meters of the water column, especially close to the equatorial divergence (as presented by Dean *et al.* during this colloquium). The percentages of occurrences of reworked non-coeval pelagic fossils (Fig. 4) remained modest from Maastrichtian to late middle Eocene times. Minor peaks during late Paleocene and early middle Eocene represent short-lived erosive events of a modest scale. The remainder of the Cenozoic was characterized by depositional paleoenvironments, where erosion in intermediate water depths was the rule and not the exception. The coincidence of times of important reworking with major changes of the oceanic bottom water temperature regimes as deduced from the δO^{18} ratios of the benthonic foraminifers (Savin, 1977 ; Vincent, Berger, in press) suggests that these episodes represent major revolutions of the bottom water current regimes due to the advection of cold polar bottom waters (Shackleton, Kennett, 1975). It is not clear if pre-late middle Eocene reworking events can be explained by the formation of modest quantities of polar bottom waters much earlier than presumed hitherto, or if another mode of thermohaline deep sea circulation has to be considered.

The age distribution of the reworked and displaced, non-coeval pelagic fossils and the difference between age of reworked components and time of redeposition in the central Pacific Ocean is particularly interesting (Fig. 4). In the central Pacific Ocean the maximum age difference approached zero during Maastrichtian time, but increased fairly regularly throughout the Cenozoic to the Early Pleistocene. The regular increase must mean that the entire sediment column which had been laid down since initiation of this erosive regime in early Maastrichtian time, was subject to continuous erosion and redeposition. Deviations from the regular increase of the maximum time difference between the age of the reworked material and of the time of redeposition have been observed during early and late Oligocene as well as during late Miocene and Quaternary. Minima on this curve (Fig. 4) coincide with episodes of high pelagic accumulation rates (Van Andel *et al.*, 1975 ; Worsley, Davies, 1979), maxima with low accumulation rates and with the development of important hiatuses in the western central Pacific Ocean (Moore *et al.*, 1978). The presence of reworked and displaced non-coeval fossils in deep-sea sediments are caused by mechanical erosion rather than non-deposition or dissolution.

CONCLUSIONS

1) The depositional environments along continental margins respond to tectonic, hydrographic, atmospheric and biologic processes. The hydrographic processes can be subdivided according to water depths into shallow, intermediate and deep ones. In this study sedimentary records from the margins of oceanic islands have been evaluated as analogs to continental margins.

2) The most important process affecting the shallow water masses are eustatic sea level fluctuations. Neritic fossils were transported episodically from continental shelves and from guyots and shoals into the adjacent deep-sea during times of low eustatic level stands in the central Pacific. Erosional events reworking non-coeval, neritic deposits which are considerably older than the age of redeposition, are confined to the Cenozoic.

3) The most important processes in the bathyal depositional environment are related to deep ocean current regimes. Oceanic meso- and bathypelagic water current regimes were very sluggish during the Mesozoic until the end of the Campanian in the Pacific. Anoxic sediment facies along the outer continental margins and in the pelagic realm persisted episodically during the Cretaceous until an erosive bottom water current regime develops during the Maastrichtian and throughout the Tertiary.

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