an extensive volume of Io's interior be molten.

The electric currents discussed by Gold (*1*) apparently do not provide more than a small part of the observed heat flow. Furthermore, there is no evidence that they produce the very-high-temperature gases that he suggested. Temporary local concentrations of current through volcanoes cannot play a role in the impulsive acceleration of material in the plumes, for example, by sputtering, to velocities of the order of 5 km sec^{-1} that appear to be required to explain the observed clouds of neutral sodium and potassium about Io (*18*). Herbert and Lichtenstein (*19*) concluded that charge storage falls far short of being adequate to support such temporary concentrations of current (lightning).

A. F. COOK
Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138
E. M. SHOEMAKER
U.S. Geological Survey, Flagstaff, Arizona 86001
B. A. SMITH
Department of Planetary Sciences, University of Arizona, Tucson 85721
G. E. DANIELSON
Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena 91125
T. V. JOHNSON, S. P. SYNNOTT
Jet Propulsion Laboratory, California Institute of Technology, Pasadena 91103

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15 December 1980

Reworked Neritic Fossils in Upper Mesozoic and Cenozoic Central Pacific Deep-Sea Sediments Monitor Sea-Level Changes

Abstract. *Upper Mesozoic and Cenozoic pelagic sediments in the central Pacific Ocean contain occasional horizons with reworked and displaced fossils produced by organisms that once lived in neritic shallow-water environments. The flux of neritic fossils was restricted to eight intervals of low eustatic sea level during Late Mesozoic and Cenozoic times. They were eroded from shoals along the flanks of volcanic highs which often supported tropical islands and which since then have subsided.*

Displaced neritic fossils that are found in pelagic sediments are easily recognized regardless of whether the material is contemporaneous with or older than the host sediment. These fossils can tell us much about the nature and presence of former neritic depositional environments (shoals or coastal regions of small and large oceanic islands) which may not exist anymore because of the subsidence of the oceanic crust with time. They allow us to determine the date of existence and subsidence of these environments and to describe the mode of transport and in some instances the morphology of the transport path. Recently a search has been carried out in the reports of deep-sea drilling sites (*1*) in the tropical and subtropical Pacific Ocean (Fig. 1) to establish temporal (*2*) and spatial patterns in the distribution of reworked and displaced contemporaneous as well as noncoeval neritic fossils. The sediments that have been described as containing reworked fossils (Fig. 1) in the central Pacific Ocean span a wide time (from late Jurassic–early Cretaceous to Quaternary) and depth range (1.5 to 6 km). Because of the poor coring record of the sites drilled during the early phases of the Deep Sea Drilling Project (DSDP) and the long-lasting hiatuses that have been encountered, the deep-sea basin sites from the central Pacific Ocean are underrepresented as compared with the elevated areas. The sites are spread over the entire western subtropical and tropical Pacific Ocean (Fig. 1) where the sea floor is predominantly of Jurassic, Cretaceous, and early Tertiary age and which, because of the slow northward movement of the Pacific plate, has remained in the tropical and subtropical Pacific Ocean (*3*). Because of the distribution of the drilling site locations over such a wide area, a bias toward one single deep-sea basin or toward one very specialized, depositional environment can be excluded.

The occurrence, frequency, and age distribution of displaced fossils derived from shallow-water environments (Fig. 2) in many of the western central Pacific deep-sea drilling sites was surprising as these sites are presently located at a distance 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 once reached close to or above the sea surface. The shallow-water carbonate rocks that have been dredged from the flanks of these features (*4, 5*) at several hundred to several thousand meters of water depth (*6*) indicate possible source localities for the displaced material. Evidence for the displacement of shallow-water carbonate fossils from their neritic depositional environment into the adjacent deep sea is widespread, both with respect to space and time. Most of the occurrences reveal the displacement of sediments of approximately the same age as the host sediment, whereas evidence for erosional events cutting into sections considerably older than the time of displacement have been found in only very few locations. These sites are situated in the vicinity of the Tuamotu Islands (site 76), the Line Islands (site 165), the Emperor Seamounts (site 309), and at site 462 in the Nauru Basin (*7*). These are areas where extensive reworking of shallow-water sediments has been recorded in deep-sea drilling sites (Fig. 2). The occurrence of noncoeval neritic fossils is also restricted to Cenozoic sediments. The maximum difference between the age of the reworked material and the time of displacement is 50 × 10^6 years in the late Oligocene deposits of site 462 (*8*).

Occurrences of displaced contemporaneous carbonate fossils derived from shallow water have been observed in sediments ranging from Barremian-Aptian to Quaternary in age (Fig. 2). The earliest event occurred 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 toward the Cretaceous-Tertiary boundary, 65×10^6 years ago. The Paleocene deposits show no evidence for reworked shallow-water carbonates; this may be the result of the many extensive hiatuses that developed during erosive events in the deep sea. In the Cenozoic, the flux of shallow-water components to the deep sea was important during the early Eocene, late Eocene, late Oligocene, late Miocene, and the Plio-Pleistocene. It is particularly notable that the influx of shallow-water carbonate fossil debris during the entire time span considered here (approximately the past 130×10^6 years) occurred in pulses reflecting a sequence of episodic events rather than as a continuous process.

The composition of the shallow-water carbonate fossil debris displaced into the deep sea changed considerably with time. The Cretaceous events eroded mainly remains of coralline and green algae, large benthonic foraminifers (*Asterorbis, Pseudorbitoides, Sulperculina,* and *Vaughanina*), corals, ostracods, echinoids, bryozoans, and mollusks (especially bivalves such as *Inoceramus* and rudists). Rich Mesozoic shallow-water fossil assemblages have been found at sites 171, 317A, and 462. The Tertiary and Quaternary events, inasmuch as they did not cut into any upper Mesozoic sedimentary strata, resulted in a transfer to the deep sea of fossil assemblages which consisted mainly of coralline algae, large and small benthonic foraminifers (*Assilina, Amphistegina, Asterocyclina, Discocyclina, Elphidium, Heterostegina, Lepidocyclina, Miogypsinoides, Nummulites,* and *Operculina*), corals, bryozoans, ostracods, bivalves, and echinoderms. Diverse and abundant Cenozoic shallow-water fossil assemblages have been found at sites 165, 318, and 462. The displaced mollusks, corals, and other macrofossils are usually fragmented, but they may occur as clasts several centimeters in diameter in horizons enriched in reworked material and are therefore easily observed in the relatively fine-grained, deep-sea sediments.

The survey of reworked and displaced benthonic fossils derived from shallow water in the late Mesozoic and Cenozoic pelagic sediments of the central Pacific is

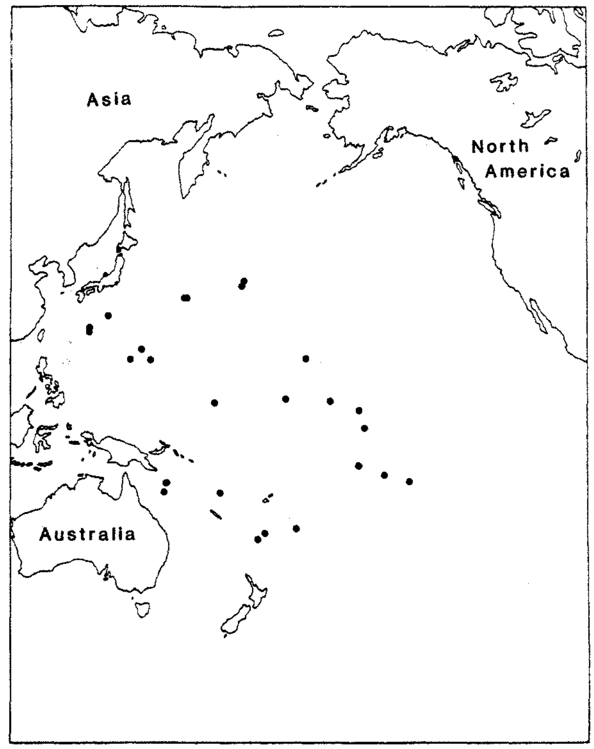

Fig. 1. Locations of deep-sea drilling sites with good coring records and displaced neritic fossils in the tropical and subtropical Pacific Ocean.

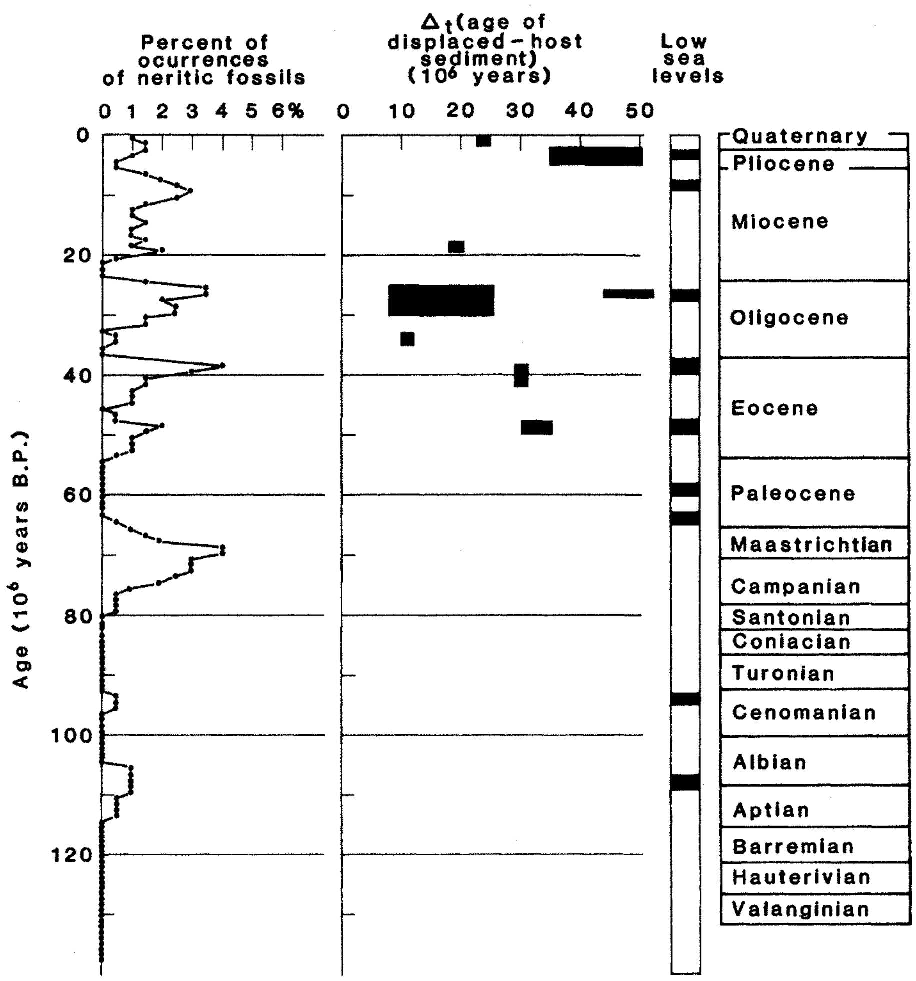

Fig. 2. Occurrence and age of displaced shallow-water fossils in drill sites from the subtropical and tropical central Pacific Ocean. Occurrence is expressed as a percentage out of a total of 218 observations; $\Delta_{f\,max}$ is the maximum time difference between the age of reworked and displaced shallow-water fossils and the host sediment. The ages of low eustatic sea-level stands have been marked according to (*10*).

by no means complete. But the collected data (a total of 218 observations) come from 25 deep-sea drilling sites during ten legs of DSDP's D/V *Glomar Challenger* and are therefore a representative set of observations. The reworked and displaced shallow-water benthonic fossils found in deep-sea sediments bear evidence of the former nature of the many depositional environments of shoals that once reached into the photic zone and were the locale of extensive carbonate deposition (*4, 5*). Most of the central Pacific guyots have been found to be made up of lower and upper Cretaceous carbonates (*6*) and volcanic rocks of highly variable composition (*9*). It has been assumed that most of the late Mesozoic tropical and subtropical (*3*) Pacific shallow-water carbonate environments have ceased to exist as a result of submergence due to rapid eustatic sea-level rises (*4*).

The occurrences of neritic fossils in central Pacific pelagic sediments (Fig. 2) document the repeated injection of debris derived from shallow water into the adjacent deep-sea basins throughout the late Mesozoic and the entire Cenozoic as a sequence of short-lived episodic events separated by intervals when little or no benthonic fossil material derived from shallow water reached the floor of the deep-sea basins. With the exception of the Campanian-Maastrichtian event, there is a correlation with low eustatic sea-level stands (*10*). The displaced fossils are therefore probably the product of erosional processes at or close to 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 (Fig. 2). This event apparently did not coincide with very low eustatic sea levels (*10, 11*), but it was coeval with a major phase of widespread volcanic activity (*9*) in the central Pacific which led to the deposition of volcanic ashes in the Mariana Basin (site 199), along the Line Islands (sites 165, 315, and 316), and on Horizon Guyot (sites 171 and 313) in the Mid-Pacific Mountains. The occurrence of neritic fossil debris in central Pacific deep-sea sediments that is not coeval with its time of redeposition is apparently restricted entirely to the Cenozoic intervals of a few drilling sites (Fig. 2), for example, sites 76, 165, 209, 315, and 462. They occurred during a time span when sea level is believed to have fallen persistently from its upper Cretaceous high approximately 500 m above the modern sea surface (*12*).

The data from the tropical and subtropical central Pacific Ocean are important for the explanation of the onlap of coastal deposits in marine sequences which, based on seismic data, have been described from continental margins; these deposits are believed by some to be the result of true sea-level fluctuations (*10*), but others (*12*) have related them to changes in the rate of sea level fall. All the sites in the central Pacific Ocean are located on oceanic crust or on aseismic rises of volcanic origin. Their depositional record is therefore a priori not linked to events along continental margins in a very direct way. The repeated and episodic injection of neritic fossils from shallow areas that are located adjacent to certain deep-sea drilling sites (Fig. 1) in the central Pacific and the erosion of noncoeval neritic sediments are more easily understood under the assumption of short-lived true eustatic sea-level fluctuations (*10*), which affected simultaneously the shallow areas close to continental margins and which have modulated the long-term trend of falling sea level since late Cretaceous times.

JØRN THIEDE

Department of Geology, University of Oslo, Post Office Box 1047, Blindern, Oslo 3, Norway

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11 July 1980; revised 9 December 1980

Stable Lead Isotopes as a Tracer in Coastal Waters

Abstract. *The natural abundances of the stable isotopes of lead are used to identify natural and industrial sources of lead in the coastal waters of British Columbia, Canada. The* $^{206}Pb/^{207}Pb$ *ratios, used to characterize the lead source, had values of* ~ *1.24 for coastal oceanic water,* ~ *1.22 for fjord waters receiving lead from mine tailings, and* ~ *1.163 for waters near urban centers. The lead concentration data are in agreement with presently accepted seawater values.*

The concentrations and sources of lead in seawater are poorly known, because of gross contamination by industrial artifact lead during sampling, handling, and analysis (*1*). We report here a number of stable lead isotopic compositions and lead concentrations determined for seawater collected during a survey along the coastline of British Columbia, an area characterized by a relatively small number of lead sources.

Lead may be characterized by its stable isotopic composition. There exists a systematic variation in the natural abundance of the stable isotopes ^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb, found in common lead, which reflects the geological evolution or age of the ore body, or both (*2*). The latter three isotopes are derived radiogenically from ^{238}U, ^{235}U, and ^{232}Th, respectively, whereas ^{204}Pb has remained essentially constant with geologic time. This radiogenesis and incorporation in an ore body are not halted until the ore is segregated within the earth's crust. Thus the isotopic composition established in the ore at crystallization will depend, in simple cases at least, upon the uranium/lead and thorium/lead ratios of the source material. Hence, old lead ores tend to contain the least ^{206}Pb and ^{207}Pb, whereas the youngest ores are enriched in these radiogenic products. Soils, rivers, and oceans received the most recent additions to these products and thus tend to be more radiogenic (hence called "modern lead") than ore leads. The simultaneous measurement of ^{204}Pb, ^{206}Pb, and ^{207}Pb provides characteristic (but not necessarily unique) ratios with which to identify the lead source. The ratio $^{206}Pb/^{207}Pb$ is often used as an indicator in comparing lead sources (*3, 4*).

0036-8075/81/0327-1424$00.50/0