Cretaceous Drowning of Reefs on Mid-Pacific and Japanese Guyots

Abstract. *Reefs dredged on guyots of the Mid-Pacific Mountains and the Japanese Seamounts yield middle Cretaceous fossils, indicating that submergence killed off the fauna of the reefs sometime during the Albian-Cenomanian. Eustatic rise of sea level is probably responsible.*

Cretaceous ages have been determined for several of the seamounts that lie off the coast of Japan (*1, 2*) and for several of the guyots of the Mid-Pacific Mountains (*3–5*), but except for this sparse sampling, the age of the hundreds of seamounts that dot the floor of the northwest Pacific remains unknown. In June 1971, aboard the Scripps Institution of Oceanography ship R.V. *Washington* on Aries V Expedition, en route from Honolulu to Tokyo, we dredged 17 guyots and 2 ridges (*6*). Six of the guyots are part of the Mid-Pacific Mountains, three belong to the Marcus-Wake group, and eight are of the group of seamounts that lie southeast of Japan (Fig. 1). We report here the age of the reefs that cap the guyots sampled, note what appears to be a middle Cretaceous extinction of the reef fauna on many of the guyots of the northwest Pacific, and suggest that the reefs were drowned as the result of a rise in sea level.

The rocks dredged from the Mid-Pacific Mountains and the Japanese guyots (Fig. 2) are remarkably similar to one another. Basalts, hyaloclastites, Cretaceous reef limestone, Cretaceous chalks, Eocene chalks, and Miocene or younger oozes are common to guyots of both groups. The guyots of the Marcus-Wake group (Fig. 2) similarly yielded volcanic rocks, Eocene chalks, and oozes younger than Miocene, but only guyot K of this group contained fossils of Cretaceous age.

We dredged volcanic rocks as either large, blocky chunks or small, rounded fragments set in foraminiferal chalk from guyots A, D, E, F, H, I, J, K, M, Q, and S (Fig. 2) and palagonitized hyaloclastite from guyots D, E, F, H, K, M, and Q. Thin sections of the volcanic rocks show that they belong to the alkali basalt suite, which typically marks the waning stage of volcanism on islands and seamounts. The dredge haul from guyot R, however, yielded one fragment less than 6 cm in diameter of hypersthene-augite andesite, along with one piece of pumice. The andesite pebble most probably is rafted glacial debris, for guyot R lies in an area from which glacial debris has been described (*7*).

The reef limestone is built of well-rounded shell fragments, generally less than 5 mm in diameter, which in places support intact, although partly leached, rudists and solitary corals. The fragments come from rudists, hermatypic corals, bryozoans, coralline algae, echinoids, gastropods, fish as teeth or bones, pelecypods, and agglutinated foraminiferans. Calcareous fragments are composed of low-magnesian calcite, with francolite replacing some fragments of the reef limestones, but more commonly replacing the Eocene and Cretaceous chalks. The fossil fragments of the reef limestones are generally preserved as hollow molds, many of the molds showing a micritic envelope with a thin inner rim of sparry cement, a texture similar to that of rocks cemented in the phreatic zone (*8*), which suggests that the reef limestones have had a similar history of cementation.

Rudists provide the oldest ages determined for any of the reef limestones examined by us. Guyots P and S (Fig. 2) yielded the Albian rudist cf. *Sabinia vivani* (*9*) and guyot N (Fig. 2) an Albian-Cenomanian rudist (*Caprotina* sp. or *Seller* sp.). Guyot P (Fig. 2), in addition to rudist-bearing limestone, yielded chalk with Cenomanian foraminiferans (*Hedbergella* sp. and *Rotalipora* sp.).

The guyots E, F, and M (Fig. 2) gave up reef limestones bearing Late Cretaceous rudists that are too poorly preserved for precise dating of the reefs; however, guyot E (Fig. 2) contains Cenomanian to early Turonian chalk (*Clavihedbergella simplex, Praeglobotruncana helvetica, Rotalipora* cf. *cushmani*, and *R. greenhornesis*), and guyots F and M yielded Cenomanian chalk (*Rotalipora* sp. and *Heterohelix* sp.). Guyot D (Fig. 2), with a reef limestone similar to those discussed above, contains no recognizable rudist fragments, but the dredge haul from D does include Turonian chalk (*Praeglobotruncana helvetica*). Guyots O and R (Fig. 2) contained Late Cretaceous rudists, and the only identifiable foraminiferan, *Globotruncana*, ranges throughout the Late Cretaceous.

The reefs of the Mid-Pacific Mountains and the Japanese Seamounts (Fig. 2) prove to be middle Cretaceous, wherever their ages can be determined within narrow limits. The reef faunas from guyots Hess (*3*), Cape Johnson (*3*), Horizon (*4, 5, 10*), N, P, and S (Fig. 2) contain fossils that are Aptian or younger and Cenomanian or older. Dredge hauls from guyots D, E, F, M, and P that contain reef limestones with fossils whose range could be determined no more precisely than Late Cretaceous suggest the same thing. Planktonic, foraminiferal chalk occurs on these guyots. Such chalk can only be deposited on the top of a guyot after it has subsided and the fauna of the reef have died; therefore, the age of the chalk fixes the minimum age of the reef limestone. The reef limestone of guyots D and E therefore must be Turonian or older, and that of guyots F, M, and P Cenomanian or older.

Thus, of the 16 guyots (Fig. 2) successfully dredged among the Japanese Seamounts and the Mid-Pacific Mountains, 13 bear Late Cretaceous reef

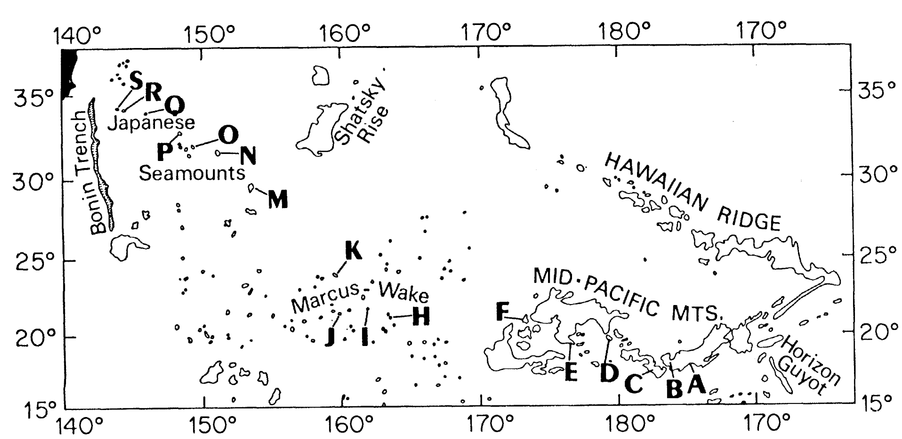

Fig. 1. Chart showing the location of guyots dredged during the Aries V Expedition.

faunas. Ten of these guyots supported reefs whose age is Turonian or older, yet Aptian or younger, and no other reefs that are demonstrably younger than Turonian or older than Aptian.

The Late Cretaceous reef limestones of guyots O, R, and Siseov (*2*) may be younger than Turonian or older than Aptian, but we see nothing to suggest that this is so. Lithologically, the reef limestone that we dredged from guyots O and R is similar to the Albian-Cenomanian limestones of nearby guyots. The tops of guyots O and R have the same approximate depth as nearby guyots of Albian-Cenomanian age. If guyots O and R had formed at a time other than Albian-Cenomanian, their summits would probably have different depths, and so we speculate that guyots O and R also formed during the Albian-Cenomanian.

Guyots A, B, and Q yielded only Cenozoic chalks; however, luck plays as important a part as skill in dredging, and so these guyots may yet give up Albian-Cenomanian fossils to future investigators.

The relation that emerges then, wherever one finds fossils with a limited range of age, is Albian to Cenomanian reef limestones, overlain by Late Cretaceous chalks and Cenozoic chalk and ooze (*11*).

Undoubtedly, some guyots will prove to be exceptions to this simplified scheme of guyot evolution, but we suggest that because most of the guyots of the Japanese Seamounts have similar depths, they will have the same age of formation. Many of the guyots of the Mid-Pacific Mountains probably also supported Albian-Cenomanian reefs; however, some of the guyots of the Mid-Pacific Mountains, especially some of those in the east, may owe their origin to the events that produced the Line Islands chain of seamounts, and therefore some of these guyots might be expected to have an age other than Albian-Cenomanian.

The guyots (H, I, J, and K) of the Marcus-Wake group (Fig. 2) present a special problem. These guyots yielded only Eocene chalk, some of which contained pieces of volcanic rock, suggesting that the Eocene chalks may have been deposited on a platform carved in volcanic rock; however, because Danian and Paleocene sediments are generally absent or thinly developed in the Pacific (*11*), the significance of the Eocene chalks is uncertain. The dredge haul from guyot K, however, did contain a small quantity of chalk, which included Late Cretaceous *Globotruncana* foraminiferans and a single intensely leached coral, suggesting that this guyot, at least, might date from the Cretaceous. The evidence is not compelling for either hypothesis, and the age of the Marcus-Wake group is best left for further investigation.

Hamilton (*3*), in his discussion of the extinctions of the Mid-Pacific Mountains, concludes that submergence brought on by local sinking of the ocean floor caused the death of organisms. We agree that submergence caused the death of the Albian-Cenomanian reef-dwelling fauna of the Mid-Pacific Mountains, but expand the thesis to include the Japanese Seamounts, and propose that eustatic rise of sea level caused the drownings. The breadth of the area involved is great, stretching from Horizon Guyot in the east to guyot R in the west, and so the submergence is not local, as assumed by Hamilton (*3*), but involves a considerable portion of the Pacific plate. The concept of plate tectonics suggests no process whereby such a large segment of the oceanic crust might founder, yet it does suggest mechanisms that would cause sea level to fluctuate, for instance, a change in the rate of spreading (*12*) or in the configuration of the ridges causing a change in the volume of the oceanic ridges, and consequently a change in the volume of the water displaced (*12, 13*). Other mechanisms have been proposed that correlate fluctuations of sea level with tectonic processes (*14*) and climatic change (*15*). We have no evidence bearing on the cause of fluctuating sea level, but simply accept that sea level changes in the middle Cretaceous appear to have been global (*16, 17*).

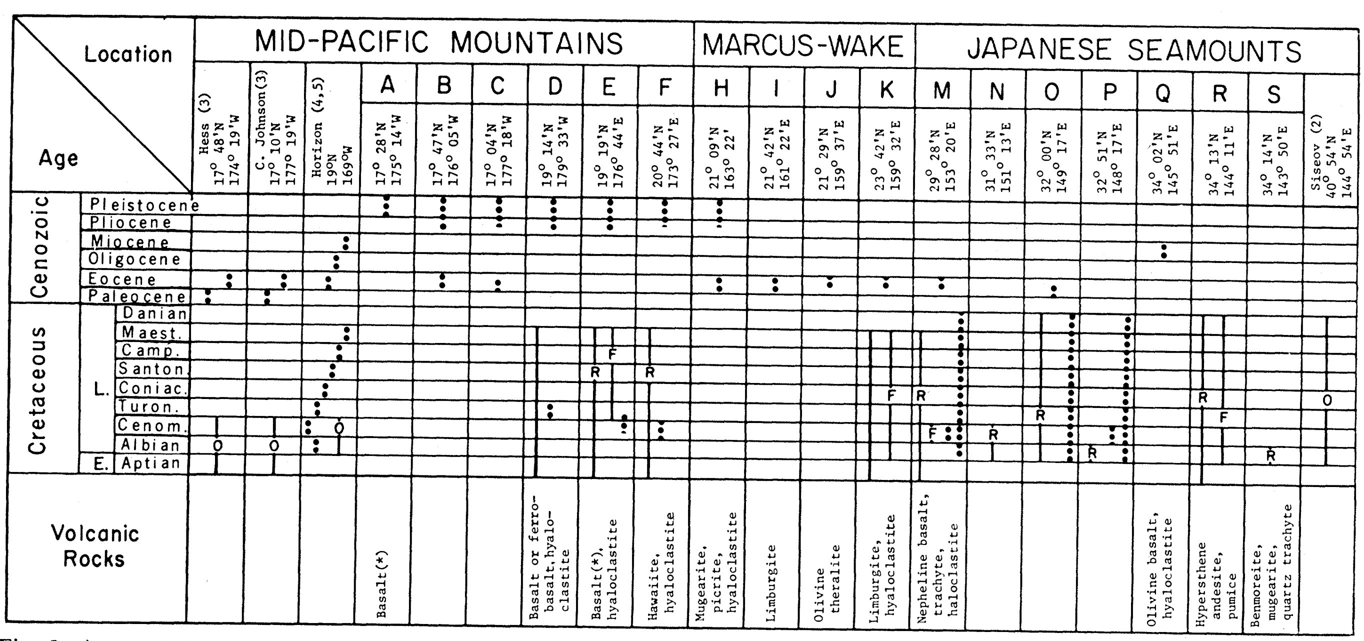

Fig. 2. Age and lithology of various guyots of the Mid-Pacific Mountains, Marcus-Wake guyots, and Japanese Seamounts dredged during the Aries V Expedition (letters) and various other expeditions (names). Solid lines indicate reef limestone; the length of the line specifies the range as determined from rudists (*R*), other megafossils (*O*), or planktonic foraminifera (*F*). The dotted lines denote pelagic chalk or ooze. An asterisk denotes rocks examined in hand specimens only. Cape Johnson (*3*) and *C* are the same guyot, separated here to show the results of the Aries V Expedition. The subdivisions of the Late (*L.*) Cretaceous that are abbreviated above are: Maestrichtian, Campanian, Santonian, Coniacian, Turonian, and Cenomanian.

Douglas *et al.* (*17*), using paleontological arguments, recognize a worldwide rise of Cretaceous sea level that began with a major pulse in the Albian and climaxed near the end of the Turonian. Larson and Pitman (*18*), tracing rates of spreading by magnetic lineations, propose a rapid increase of spreading 110 to 95 million years ago in the Pacific and Atlantic oceans, which would cause a dramatic rise of sea level. Thus, geophysical and paleontological arguments indicate a rapid rise of sea level, starting 110 to 100 million years ago, which we conclude ultimately caused the drowning of the reef faunas of the Mid-Pacific Mountains and the Japanese Seamounts during Albian-Cenomanian times. These drownings are probably part of a larger phenomenon and should correlate with the middle Cretaceous transgressions that exterminated coral-rudist reef communities throughout the world (*17*).

J. L. MATTHEWS
Scripps Institution of Oceanography, La Jolla, California 92037
B. C. HEEZEN
Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964
R. CATALANO
Istituto di Geologia, Universite di Palermo, Corso Tukory 131, Italia
A. COOGAN
Kent State University, Kent, Ohio 44240
M. THARP
Columbia University, New York 10027
J. NATLAND
Scripps Institution of Oceanography
M. RAWSON
Columbia University, New York 10027

References and Notes

1. M. Ozima, I. Kaneoka, S. Aramahi, *Earth Planet. Sci. Lett.* **8**, 237 (1970); I. Kaneoka, *Geochem. J.* **5**, 113 (1971).
2. R. Tsuchi and H. Kagami, *Rec. Oceanogr. Works Jap.* **9**, 1 (1967).
3. E. Hamilton, *Geol. Soc. Am. Mem. 64* (1956).
4. P. Lonsdale, W. R. Normark, A. Newman, *Bull. Geol. Soc. Am.* **83**, 289 (1972).
5. E. L. Winterer *et al.*, *Initial Reports of the Deep Sea Drilling Project* (Government Printing Office, Washington, D.C., 1973), vol. 17, p. 919.
6. B. Heezen, J. Matthews, R. Catalano, M. Tharp, M. Rawson, *Geol. Soc. Am. Abstr. Cordilleran Sect. Meet. Honolulu* (1972), p. 169.
7. J. R. Conolly and M. Ewing, *Geol. Soc. Am. Mem. 126* (1970), p. 219.
8. K. O. Emery, J. I. Tracey, Jr., H. S. Ladd, *U.S. Geol. Surv. Prof. Pap. 260-A* (1954); S. O. Schlanger, *U.S. Geol. Surv. Prof. Pap. 260-BB* (1963); R. Bathurst, in *Approaches to Paleoecology*, J. Imbrie and N. Newell, Eds. (Wiley, New York, 1964), p. 357; R. Bathurst, *J. Geol.* **5**, 15 (1966); G. Friedman, *J. Sediment. Petrol.* **34**, 777 (1964).
9. R. H. Palmer, *Occas. Pap. Calif. Acad. Sci.* **14**, 74 (1928).
10. The age of the Albian chalk indicated by the dotted line (Fig. 2) is based on foraminiferans dug from cracks in dredged volcanic rocks; the chalk probably dates from the volcanic inception of the seamount (*4*). The solid line indicates the occurrence of shallow-water fossils encountered during the drilling of hole 171 by the *Glomar Challenger*, Leg 17 (*5*). These fossils must be Cenomanian or older, because Cenomanian chalks overlie them. Cores from Leg 17 show that the chalk was deposited almost without interruption throughout the remainder of the Late Cretaceous. The dotted lines (Fig. 2) are thus shown as segments to differentiate them from the chalks of other guyots, where the length of the dotted line indicates the range of the contained fossils.
11. No Danian or Paleocene chalks were dredged from any of the guyots sampled during the Aries V Expedition. Sediments of this age are absent or only thinly developed elsewhere in the Pacific Ocean (*5*). A lowering of fertility rates and a rise of solution levels may explain this lack of sediment (*5*, *19*).
12. J. Sclater, R. Anderson, M. Bell, *J. Geophys. Res.* **76**, 7898 (1971).
13. A. Hallom, *Am. J. Sci.* **261**, 397 (1963); H. W. Menard and S. M. Smith, *J. Geophys. Res.* **71**, 4305 (1966); K. L. Russel, *Nature (Lond.)* **218**, 861 (1969); J. W. Valentine and E. M. Moores, *ibid.* **228**, 657 (1970).
14. K. J. Hsü, *Am. J. Sci.* **263**, 97 (1965); R. L. Grasty, *Nature (Lond.)* **216**, 779 (1967); W. B. Joyner, *J. Geophys. Res.* **72**, 4977 (1967); P. E. Damon, in *Late Cenozoic Glacial Ages*, K. K. Turekian, Ed. (Yale Univ. Press, New Haven, Conn., 1971), p. 13.
15. H. R. Wanless and F. P. Shepard, *Bull. Geol. Soc. Am.* **47**, 1177 (1936); R. W. Fairbridge, in *Physics and Chemistry of the Earth*, L. H. Ahrens, F. Press, K. Rankama, S. K. Runcorn, Eds. (Pergamon, New York, 1961), vol. 4, p. 99.
16. E. Suess, *La Face de la Terre* (Colin, Paris, 1912), p. 835, J. H. F. Umbgrove, *The Pulse of the Earth* (Nijhoff's, The Hague, Netherlands, 1947), p. 92.
17. R. Douglas, M. Moullade, A. Nairn, in *Continental Drift*, D. Tarling, Ed. (Academic Press, London, 1973), p. 511.
18. R. Larson and W. C. Pitman, *Bull. Geol. Soc. Am.* **83**, 3645 (1972).
19. M. N. Bramlette, *Science* **148**, 1696 (1965); W. H. Berger, *Bull. Geol. Soc. Am.* **81**, 1381 (1970).
20. Partially supported by ONR contract USN N 00014-69-A-0200-6006. We thank R. Douglas, L. Winterer, R. Jarrard, and R. Moberly for their criticism and suggestions.

15 August 1973; revised 26 November 1973 ■

Lymphocyte Antigenicity Loss with Retention of Responsiveness

Abstract. *During culturing at 22°C for more than 4 days, human peripheral blood lymphocytes lose their ability to stimulate allogeneic lymphocytes in mixed lymphocyte cultures. The cells retain their ability to respond to allogeneic lymphocytes or phytohemagglutinin for up to 10 days of culturing. The findings are relevant to reports on successful transplantation of cultured skin.*

Lymphocytes respond to alloantigenic differences in vitro by transformation into blast cells (*1*). A curious fact has been that lymphocytes also act as the most effective stimulating cells to induce such transformation. It could be asked whether there is some special relation between the "recognizing" sites and the "recognized" antigens on lymphocytes. We describe here the surprising finding that, upon aging in vitro, lymphocytes lose their ability to stimulate allogeneic cells while they retain their physiological ability to respond. The stimulating antigenic structures may therefore be labile in tissue culture, as has been suggested by the work of Summerlin on cultured skin (*2*).

Peripheral blood lymphocytes containing less than 5 percent granulocytes were separated from heparinized blood of healthy unrelated volunteers by Ficoll-Hypaque gradient centrifugation. Cells were first cultured at 22°C in McCoy's medium for varying numbers of days as indicated below; cell viability after this preliminary culturing (preculture), as determined by trypan blue exclusion, was greater than 80 percent in all instances prior to use in transformation experiments. The cells were adjusted to a concentration of 10^6 per milliliter; cells stained with trypan blue and thus shown to be nonviable were not counted. Mixed lymphocyte culture (MLC) tests were done in triplicate as described by micromethods (*3*)

Table 1. Effect of preliminary culturing of lymphocytes on their responsiveness to PHA. Phytohemagglutinin (25 μg in 0.01 ml volume) was added to 100,000 responding cells in 0.1 ml volume. After 3 days of incubation at 37°C, [^{3}H]thymidine (0.8 μc in 0.02 ml) was added, and the cultures were precipitated after additional incubation overnight. Lymphocytes from 86 persons were tested.

Preculture (days)	Radioactivity [(count/min) ± S.E.]		Ratios in individual experiments
	PHA stimulation	Background	
0	74723 ± 4294	1583 ± 140	75 ± 13
3	68816 ± 5661	619 ± 287	180 ± 49
4	51727 ± 5700	443 ± 69	162 ± 30
6	21205 ± 7540	460 ± 193	63 ± 6
7	25840 ± 3819	254 ± 37	82 ± 11
10	18788 ± 5147	252 ± 123	98 ± 22
16	1485 ± 265	147 ± 35	11 ± 5