programs they think deserve more financial support. They have been able to ease some of the strain caused by tight travel and library budgets, furnish equipment that would persuade a promising Ph.D. to accept an appointment or keep a valued professor from accepting a position elsewhere, or speed the establishment of a computing center to serve the entire institution.

It is often assumed that *the* purpose of NSF institutional grants is to offset imbalances caused by grants for research projects. Many times they do perform this function. The addition of a recent doctoral graduate to a small physics department may mean that a college can give a physics major as well as majors in chemistry and biology, and this results in better institutional "balance." Also, the grants often serve as catalysts for the procurement of other funds to support research outside the sciences. Yet, the annual reports show that "balance" and "imbalance" are not easily definable when applied to the total educational and research activities of a university. Concentration of spending upon one activity may mean the deliberate creation of an imbalance in the interest of furthering a special mission which the institution thinks it has. In general, colleges and universities think of the grants as a means of strengthening their science programs—perhaps through trying to achieve a roughly even level of competence, perhaps through concentration of effort in a particular area, perhaps by trying to revive a weak department. Despite the similarity of problems in science confronting higher educational institutions across the country, the problems are always unique on each campus. The very nature of local direction and control of institutional grants means that colleges and universities decide the purposes of the program so far as they are concerned.

The fact that the grants have grown in amount has led to greater attention to their potential value as a means of continuous rebuilding and regeneration of institutional science programs to meet changing social demands. When compared with the first year's annual reports, those on the second year of the program show greater awareness of the possible importance of the grants, more imaginative and less routine administration of them, and more signs of institutional planning for the best use of the funds.

The relations of the federal government and higher education constantly shift and change, and the institutional-grants program shows one of the ways in which they are changing. It is a means of fostering greater national strength in science. At the same time it is an expression of confidence in the initiative of institutions and in their ability to use the resources responsibly for the building of excellence in science.

Massive Extinctions in Biota at the End of Mesozoic Time

Any proposed explanation should account for the profound effect on marine planktonic life of that time.

M. N. Bramlette

The profound and geologically abrupt changes in the earth's biota, particularly those marking the end of Paleozoic and of Mesozoic time, have been the subject of much speculative discussion. A review by Newell (*1*) is one of the more recent and comprehensive on this subject, but does not include the possible explanation suggested here. These great changes primarily reflect a geologically sudden extinction of many important elements of the earth's population—the extinction of some large populations thriving toward the end of Mesozoic time being more demonstrably abrupt than that at the end of the Paleozoic. However, the causes of these major events were not necessarily similar, since the physical condition of the earth and the populations of organisms most affected were not closely similar at these two times. The extinction at the end of the Mesozoic seems, in the fossil record, to be most obviously and strikingly reflected by the planktonic life (plant and animal) of the oceans and by the larger forms dependent on plankton, such as ammonites and belemnites, whose extinction at that time has long been recognized. That so much marine life became extinct solely from a lack of adequate nutrition seems an oversimplification, but evidence that such a lack may have been the critical factor under the probable environmental conditions of that time deserves some consideration.

Among previous explanations, the one suggestion that the extinction occurred as a result of excessive radiation from an exceptional cosmic event might seem intriguing because such radiation could have had widespread and nearly instantaneous effects on life. Loeblich and Tappan (*2*) suggest that such radiation might have induced mutations and more extinctions in the planktonic than in the more protected benthonic foraminifera at the end of the Mesozoic. However, even a thin layer of surface water would serve as an effective blanket, according to Urey (*3*), and, as mentioned by Newell (*1*), the radiation would have affected land plants much more than the record indicates. The suggestion of a climatic change with a reduction in temperature seems to have little support, and the effects of such a change should likewise be most apparent in the fossil land plants rather than in the marine life. Changes in sea level may have adversely affected nearshore marine life, as Newell and others have advocated, but such changes should not have affected the plankton populations to the unusual degree that is evident.

Life in the oceans may include an

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even greater number of individuals (although not of taxa) than that on land because of the much greater surface area and depth of the marine part of the biosphere. Evidence is here summarized that this vast planktonic life was drastically affected at the end of Mesozoic time, and that this effect might be expected from certain physical conditions of the earth at that time which resulted in a reduced supply of detritus, with the required nutrients, to the ocean.

There appears to have been a proliferation of population sizes, as well as of the taxa, among some of the plankton groups during late Mesozoic time. However, that limitation of the population according to Malthusian principle would culminate in wholesale destruction seems improbable without some superimposed adversity, such as a decrease in the supply of nutrients to the ocean waters. The volume of nutrients in the depths of the vast oceanic reservoir might appear nearly inexhaustible to the biologist, but it appears that the supply of nutrients from the ultimate source on land decreased over some millions of years. This condition, however, should not have considerably affected the much greater amount of major inorganic constituents, or salinity, of the oceans. Whether or not the amount of nutrients in the oceans could have decreased to a level below the threshold for support of much of the phytoplankton, as in some laboratory experiments, and thus have resulted in mass extinctions in a geologically brief episode, is a serious and difficult question. This question is considered below after a review of the record of distribution of the fossils and of the environmental conditions which seem significant to any interpretation.

Changes in the plant and animal life on land were at a more nearly normal rate during late Cretaceous time. Even the conspicuous example of the extinction of the dinosaurs is not demonstrably such a sudden and wholesale destruction of thriving populations. Perhaps, too, a degree of circular reasoning is involved in the case of the dinosaurs, as certain strata, for whose ages adequate supplementary paleontologic evidence is lacking, have been reassigned from Cenozoic to late Mesozoic when some dinosaur remains have been discovered in them. The dinosaur remains are sparse, and synchroneity of the enclosing strata is commonly not well established from other evidence.

Record of the Fossil Plankton

The succession shown in Fig. 1 for the distribution of calcareous nannoplankton is evident from the direct superposition of strata in Alabama, and is similarly clear for the Danian resting directly on the earlier strata in Denmark and France. The correlation and age assignments agree with those from most recent studies of the foraminifera and other groups of fossils. Samples containing vast numbers of nannoplankton (dominantly protophyta) from the indicated taxa were taken from within a few meters below and above the top of the Mesozoic strata (upper Maestrichtian and the equivalent in Alabama). The skeletal remains of the marine calcareous plankton (nannoplankton and planktonic foraminifera) constitute about one-half the total in these chalk formations—countless millions of the "nanofossils" (averaging less than 10 microns) occurring in a few cubic centimeters of the chalk. The distribution of the identified taxa of nannoplankton shown in Fig. 1 is fairly representative of other known regions.

A surprisingly similar distribution, with a comparable number of extinctions at this same time, of the taxa of planktonic foraminifera is shown by unpublished results of several investigators of this group of fossils, and is indicated in part by Bolli, Loeblich, and Tappan (*4*) and by Berggren (*5*). The sparsity of preserved fossils from other groups of plankton, such as the radiolarians, diatoms, and dinoflagellates or "hystrichospherids," in strata of these ages precludes an equally clear comparison, although the meager evidence does suggest that marked extinctions occurred at the end of the Mesozoic. Among the larger forms of marine life which have preservable hard parts and are dependent on the smaller plankton, the complete extinction at that time of the belemnites and of the large, diversified, and long-existent group of ammonites is well known.

The data on calcareous nannoplankton and planktonic foraminifera are now adequate to indicate this worldwide extinction of most of the distinctive taxa, and to show that the extinction of these large populations was so abrupt that the stratal record of transition still remains obscure. A record, even though an abbreviated one, will doubtless be found which shows diminished numbers of Cretaceous taxa and individuals associated with progenitors of the few early Cenozoic forms. Although some stratal discontinuity is commonly found at this horizon, much evidence indicates that the hiatus was not a long one in geological time, particularly because any large record of deposition missing in some areas should be represented by sedimentation elsewhere. The hiatus thus may involve many thousands of years but probably much less than a million; comparable changes in the fossil record normally require some millions of years. Such a long period of existence during Mesozoic time is indicated for many of the planktonic taxa which became extinct at the close of that era. It required several million years also for the meager assemblages of the nannoplankton and planktonic foraminifera surviving into the earliest Cenozoic to develop diversification comparable to that found in the late Mesozoic.

Significance of Land Conditions

There is no dispute with the principle of uniformitarianism in the view that the relative rate or intensity of the normal processes produced very different net results over much of the earth for long periods of time. In late Mesozoic time it seems that there were environmental factors which should have greatly reduced the supply of nutrients to the oceans, nearly all of which must be derived from the land surface. The character of the nearshore sedimentary deposits of the late Mesozoic indicates an almost senile earth for that time—or better termed a "hibernating" earth, because of the return to unusual vigor during the late Tertiary to Recent time. Some of the evidence is summarized below which suggests that the earth was not stirring with the usual amount of orogeny, uplifts, and erosion with the resulting supply of detritus to the oceans. No complete change in these conditions is probable; only an appreciable diminution from normal need be assumed, because there now exist large oceanic areas, for instance in the central north Pacific, where nutrients are inadequate for a prolific microplankton.

No large regions of unusual aridity appear to have caused a reduction in the supply of detritus in the late Mesozoic—apparently there was at that time even less aridity indicated by the strata than is normal for the earth. With normal rainfall and stream-flow from topographically reduced land surfaces,

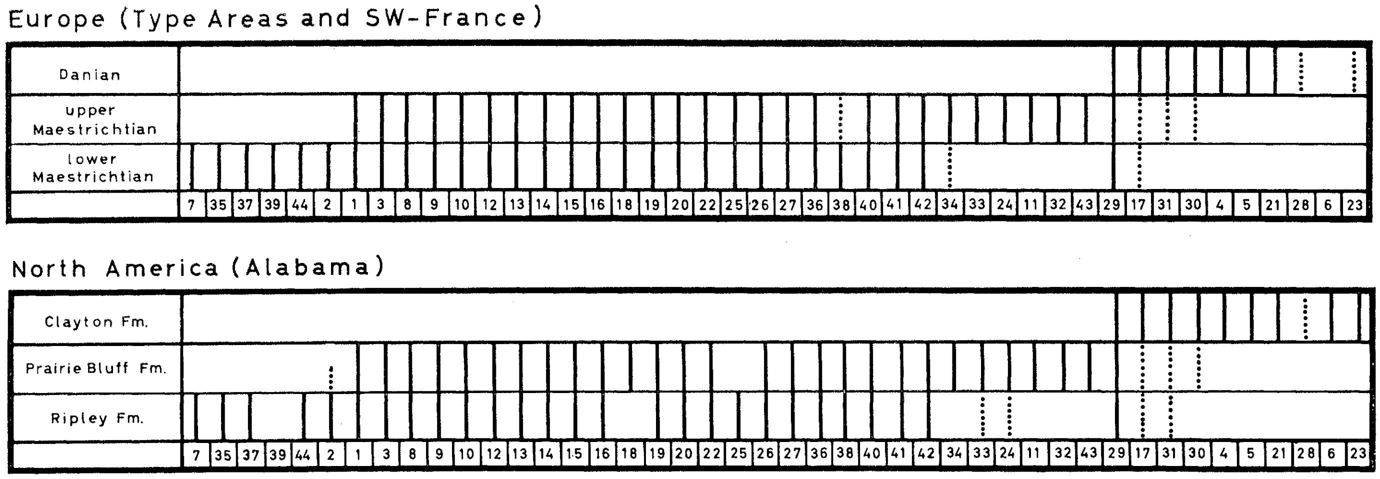

Fig. 1. Distribution of calcareous nannoplankton in stratigraphic arrangement, showing change at top of Maestrichtian, and equivalent in Alabama. Numerals correspond to names of taxa as given by Bramlette and Martini (*9*), where this illustration first appeared.

the amount of eroded detritus would be reduced, and in time the resulting old soils would have been depleted of nutrients, including the "soil extracts" containing such organic compounds as thiamine and vitamin B_{12}.

There is evidence over large parts of the earth that erosion and supply of detritus (presumably including the unrecognizable "soil extracts" which are so valuable in plankton cultures) were abnormally low in late Mesozoic time, although a stratal record of that particular time is lacking or is covered by later deposits in yet larger areas.

Most of northern Europe has marine chalk deposits of late Mesozoic age, indicating relatively little supply of land-derived detritus into these marginal sea deposits, and the same is true for much of southern Europe and northern Africa. Chalk accumulation around much of the Gulf of Mexico at this time likewise implies that little detritus was derived from most of the central part of North America, and a similar condition is indicated for western Australia.

Some regions with marine deposits of this age have extensive accumulations of richly glauconitic sediments rather than chalk, and these, too, indicate that the supply of detritus was reduced, so that the slowly accumlating glauconite formed a large proportion of the sediments. Although occurring in strata of many places and ages, such highly glauconitic sediments are conspicuous in most of the strata of latest Mesozoic age along the east coast of the United States, and even in considerable areas of "never quiet" California. In the Crimea, W. A. Berggren reports (*6*), "The contact is characterized by abundant glauconite, immediately underlain by one to three meters of glauconitic sands with abundant oyster remains." In the major geosyncline of northern South America, Hedberg (*7*) reports glauconitic sediments only in the formation assigned to the latest Mesozoic and early Cenozoic, which suggests a reduced supply of sediment even in such a trough of generally rapid accumulation. Marine strata of this age in western Equatorial Africa are reported by Reyment (*8*) to be interbedded with extensive coal deposits, which may be evidence of some reduction of sedimentation.

Search of the literature for adequate descriptions of other areas in the latest Mesozoic and earliest Cenozoic remains to be done. Certainly there are some regions with deposits of this age, however, which indicate very active erosion and sedimentation, but, to repeat, only a subnormal supply from large areas of land should in time affect all the open oceans. One example of very active uplift and erosion during this period is known in the Rocky Mountain region, but most of the detritus accumulated in the same general region, much of it in non-marine basins, and presumably relatively little of that part supplied to the adjacent inland sea would have reached the open oceans.

Land conditions that evidently resulted in abnormally low supplies of detritus to many parts of the oceans should thus with time have affected the available nutrients of the entire volume of the ocean waters. The difficult problem is posed, however, as to whether a long period of decreasing supply could culminate in a sudden extinction of much of the protophyta which formed the base of important food chains throughout the oceans. The relation of the time factor of geological events to that of laboratory experiments is too commonly an imponderable one.

Laboratory Experiments and Generalities

Some laboratory experiments show that cultures of phytoplankton may thrive in normal growth and rate of proliferation as they consume unreplenished nutrients in the medium until threshold conditions are reached that cause a sudden death of all. This likewise occurs in some cultures which include populations of more than one group, because the requirements, or limiting ones, are similar for many forms. Whether such results could be meaningful for the vast expanse of oceans would certainly seem very doubtful, except that some thousands of years for extension of the results upon plankton life would appear almost as brief in the geological record as the time involved in the laboratory experiments.

Much evidence indicates that the oceans were more uniform, at least with respect to surface water temperatures, in the late Cretaceous than at present, probably with an associated decrease in intensity of upwelling and other currents, and thus the conditions were then somewhat more comparable to those of a laboratory culture. If the indicated conditions could have resulted in widespread threshold effects on most of the phytoplankton, the disastrous consequences for many higher forms of life in the food chain of the oceans would surely have followed in a geological time so brief as to appear synchronous.

Consideration of this problem obviously should include data on other groups of fossils, but information on the significant aspects seems inadequate, or needs analysis by specialists on these fossils. The interesting histograms of Newell (*1*), showing the changes with time in the number of families within larger groups, suggest the magnitude of the event at the end of the Mesozoic. Possible causes should be reflected better, however, by an analysis of such changes shown in populous groups of similar habitat within these higher phylogenetic groupings. For example, Newell's histograms show the extinction of all the many families of ammonites at the end of the Mesozoic, a phenomenon which appears to be of particular causal significance because all of these ammonites seem to have belonged to the marine nekton. In contrast, his histogram on families of foraminifera shows little change at this time because the very populous planktonic taxa which became extinct are classed in only a few of the many families considered. The families of crinoids plotted likewise include family groups of planktonic, benthonic, and deep- and shallow-water habitats, and separate consideration of these groups should prove interesting.

Among the benthonic "shallow-water" forms, the *Rudistae* are conspicuous as a large group which became extinct at the end of the Mesozoic. Perhaps it is significant that the sessile rudistids seem most commonly to have existed on a calcareous substrate, which suggests a water environment with detritus and nutrient supply more nearly comparable with the open ocean than with that of those nearshore organisms which lived on a substrate of clastic detritus. The latter environment should have had a more nearly adequate food supply near shore even if less food reached the open oceans. One test of this possibility might be whether those taxa of corals commonly associated with rudistids were comparably affected.

Certain geochemical tests could, perhaps, prove significant for this or some other explanation—possibly by revealing differences between critical minor elements in clays or in the phosphatic skeletal remains of fish of the latest Maestrichtian and the clays or skeletal remains from earlier Maestrichtian strata of the same area—if diagenetic changes have not obscured any original differences in these constituents. In any case, some aspects of this discussion seem to bear on the ultimate solution of this intriguing and important problem in earth history.

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10. I thank my colleagues, W. R. Riedel and F. L. Parker, for valued criticisms and suggestions.

Appendix

An explanation should be added on the usage of certain terms involved in the rules of stratigraphic nomenclature. The abrupt extinctions of a surprisingly large part of Mesozoic marine life took place prior to deposition of the strata of the Danian Stage and are commonly interpreted as occurring at the end of Mesozoic time. Others, however, place the Danian in the latest Mesozoic—in which case this marked change would have occurred within latest Mesozoic time. Paleontologic aspects of this problem have received extensive review recently by Berggren (*1*).

The Danian was originally assigned by Desor (1846) to the Mesozoic (*2*). Rules of priority in nomenclature are essential, and Desor's name for the Danian Stage should remain fixed. Such rules are not applicable, however, to Desor's placement of these Danian strata in the Cretaceous (upper Mesozoic). Precise limits at a type locality were not indicated by d'Halloy (1822) in his original designation of the Cretaceous (*3*), but the indicated Cretaceous strata in France have been generally accepted as including equivalents of the strata of the type Maestrichtian, which therefore was included as an upper stage of the Cretaceous. Priority would place the Danian Stage as an uppermost stage of the Cretaceous only if evidence indicated that the type Danian strata were equivalent in age to part of the chalk of the originally designated Cretaceous in France—and there seems little or no evidence for this. The Cretaceous System and other time-stratigraphic units would have little meaning as such if strata placed in them by correlations extended to the type locality from elsewhere were not subject to necessary adjustments, when and if justified by additional evidence (which, it is hoped, will eventually include consistent radiometric evidence).

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