minerals are associated with it. The general relations appear quite similar to those in New Jersey.

It seems quite remarkable that in New Jersey it should have been formed in such abundance and in crystals of such great size, and that later it should have been almost totally removed. Its disappearance cannot well be ascribed to weathering, for in many instances the casts have been filled with minerals of an early period of deposition. The formation and subsequent removal of the mineral indicate that for it the conditions of chemical stability were satisfied for a brief period only during the processes of general mineral deposition.

ZOOLOGY.—*The correlation between the bathymetrical and the geographical range in the recent crinoids.* AUSTIN H. CLARK, National Museum.

In a paper published about a year ago[1] I remarked that the geographical range of a crinoid species, genus or higher group is approximately proportionate to its bathymetric range, but at that time I did not have the facts upon which I based the deduction in such form as to be able to present them in a convincing manner.

While the bathymetric range of any type can mean but one thing—the number of fathoms (or meters) between the highest and the lowest limit of the zone in which it occurs—the geographical range may be interpreted in two different ways: (1) as the actual area, calculated as the sum of the geographical units within which the type is actually known to occur, or (2) as the area in which the type potentially occurs, that is, the area over which physical conditions are such as to suggest that, if not found at all points within it now, it has or may have, occurred at all points within it at some time in the not remote past.

According to the first method a count is made of the units of area within which the type has actually been taken; the figures are therefore of very varying value for different groups, for many types, undoubtedly with an enormous geographical range, have been taken at only a very few widely scattered localities, while

[1] Internationale Revue der gesamten Hydrobiologie und Hydrographie, Bd. 6, Heft 1, S. 29.

others, with a much more restricted geographical range, have been reported from all points within a very large area.

The second method first of all calls for the determination of some restricted region as the center of distribution, for it makes considerable difference in calculating the potential geographical range of a group like the Thysanometrinæ, occurring from southern Japan southward to the Admiralty Islands, and again in the Caribbean Sea, whether we assume the center of distribution to be the Malayan region, and therefore that the connection between the two localities is westward from the line between southern Japan and the Admiralty Islands, or whether we assume some other center of distribution, and a connection eastward through Oceania and over Central America.

I have elsewhere[2] given my reasons for considering the Malayan region as the center of distribution for the recent (and later fossil) crinoids, explaining the similarity between the fauna of southern Japan and Hawaii and the Caribbean Islands as the result of their present similar isolation from the Malayan region, an isolation which has permitted the persistence on the periphery of the area inhabited by the crinoids as a whole of types which in all the intermediate regions have been extirpated by more efficient competitors of subsequent origin.

If we divide the map of the world into areas measuring 15° on each side, we find that the number of such divisions covering the geographic ranges of each of the families of recent crinoids is as follows:

Capillasterinæ	42	Thysanometrinæ	5
Comactiniinæ	28	Zenometrinæ	19
Comasterinæ	30	Perometrinæ	12
Zygometridæ	12	Heliometrinæ	68
Himerometridæ	22	Bathymetrinæ	12
Stephanometridæ	14	Pentametrocrinidæ	13
Mariametridæ	30	Atelecrinidæ	7
Colobometridæ	31	Pentacrinitida	20
Tropiometridæ	33	Apiocrinidæ	2
Calometridæ	10	Phrynocrinidæ	2
Ptilometrinæ	10	Bourgueticrinidæ	20
Thalassometrinæ	36	Holopodidæ	2
Charitometridæ	18	Plicatocrinidæ	14
Antedoninæ	43		

[2] Internationale Revue der gesamten Hydrobiologie und Hydrographie, Bd. 6, Heft 1, S. 24.

Plotting these together with the maximum range for each family (fig. 1), we notice very little similarity between the two lines. It is interesting to observe, however, that in the left half of the diagram, including all of the better known families, the agreement between the geographical and the bathymetrical ranges

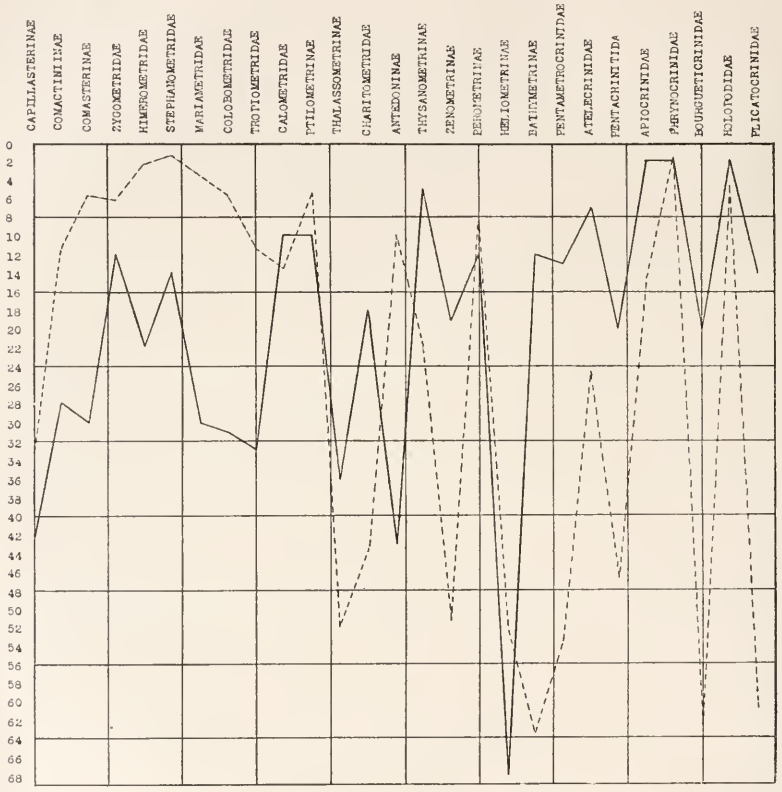

Fig. 1. Comparison between the maximum bathymetric range (. . . .) and the geographical range, expressed as the sum of the areas of 15° on each side within which the families occur (———).

is somewhat closer than in the right half, which includes the rarer types.

There is a very grave source of error in comparing the geographical and the bathymetrical ranges of any animal group by this method, and that is that single observations are always of far

greater value from a bathymetric than from a geographic standpoint, so that, broadly speaking, our knowledge in regard to the bathymetric distribution of animal types is much more detailed than our knowledge of the limits of the geographical range of the same types.

The bathymetric range is measured on a single line assumed to extend perpendicularly downward from the surface to the deepest part of the sea. But the points on this line are determined from observations everywhere. That is, the entire volume, or cubical content, of the ocean basins furnishes data projected upon a single line. For example, a certain type occurs in Alaska in 5 fathoms, in the Crozet Islands in 1600 fathoms, and off Greenland in 300 fathoms; its bathymetric range is, therefore, from 5 to 1600, or 1595, fathoms.

Thus our knowledge of the bathymetric ranges of the larger groups is reasonably complete, as a result of this method of reducing to terms of a single dimension records which, strictly speaking, are taken in three dimensions.

With the geographical ranges calculated as the sum of all the areas measuring 15° on each side within which a given type occurs the case is very different. Investigation has largely been localized within certain restricted areas which, for some reason or other, have proved to be especially interesting, or where exceptional opportunities for study have been presented. Within these areas there are very numerous records all of which, though marking different steps in, and increasing our knowledge of, the bathymetic scale, fall in the same geographical unit, and hence are the geographical equivalent of only a single record.

Intensive study of any one locality increases our knowledge of the bathymetric distribution of all the endemic types, while adding nothing to our knowledge of the geographical distribution of the same types; similarly future investigations in many of the now little known regions of the world will greatly increase our knowledge of the geographical range of many groups, at the same time giving us nothing new in reference to their bathymetrical range.

Thus it is evident that the comparison of the bathymetric ranges of the families of recent crinoids, which for the most

part are known to within a comparatively small limit of error, with the geographical ranges calculated as the sum of the units measuring 15° on each side within which they occur, though apparently perfectly logical, at the present state of our knowledge is not practicable, and cannot give results of value.

If we assume that the Malayan region is the center of distribution of the recent crinoids, a very simple way of expressing the comparative potential geographical range of the several crinoid types becomes possible. If we multiply the number of units of 15° between the meridians bounding the region inhabited by each type by the number of units of 15° between the parallels of latitude bounding the same regions, always reckoning east and west and north and south from the Malayan region, we will obtain for all types (excepting only the Holopodidæ which, alone among the crinoid families, does not occur in the Malayan region) strictly comparable areas expressed in units of 15° on each side, that is, including 225 "square" degrees each.

The geographical ranges of the families of recent crinoids expressed in these units are:

Capillasterinæ	30 × 6 = 180	Thysanometrinæ	18 × 4 = 72
Comactiniinæ	30 × 6 = 180	Zenometrinæ	24 × 10 = 240
Comasterinæ	12 × 6 = 72	Perometrinæ	17 × 4 = 68
Zygometridæ	6 × 5 = 30	Heliometrinæ	24 × 12 = 288
Himerometridæ	10 × 5 = 50	Bathymetrinæ	24 × 10 = 240
Stephanometridæ	9 × 4 = 36	Pentametrocrinidæ	16 × 10 = 160
Mariametridæ	12 × 6 = 72	Atelecrinidæ	20 × 3 = 60
Colobometridæ	20 × 6 = 120	Pentacrinitida	20 × 6 = 120
Tropiometridæ	19 × 6 = 114	Apiocrinidæ	1 × 2 = 2
Calometridæ	5 × 6 = 30	Phrynocrinidæ	6 × 2 = 12
Ptilometrinæ	5 × 5 = 25	Bourgueticrinidæ	16 × 10 = 160
Thalassometrinæ	24 × 8 = 192	Holopodidæ	2 × 2 = 4
Charitometridæ	20 × 6 = 120	Plicatocrinidæ	24 × 9 = 216
Antedoninæ	18 × 6 = 108		

On the accompanying diagram (fig. 2) are shown the maximum bathymetric range of each family of recent crinoids (in a dotted line) and the geographical range calculated according to the method just described (in an unbroken line).

The correspondence between the bathymetric range and the geographical range as thus calculated is very striking, bringing

our very forcibly the fact that the potential geographical range of a given group is proportionate to its bathymetrical range.

It will be noticed that, in the comparison between the bathymetrical and the geographical ranges as given on the diagram, 3000 fathoms in depth is the equivalent of 256 × 225, or 6400, square

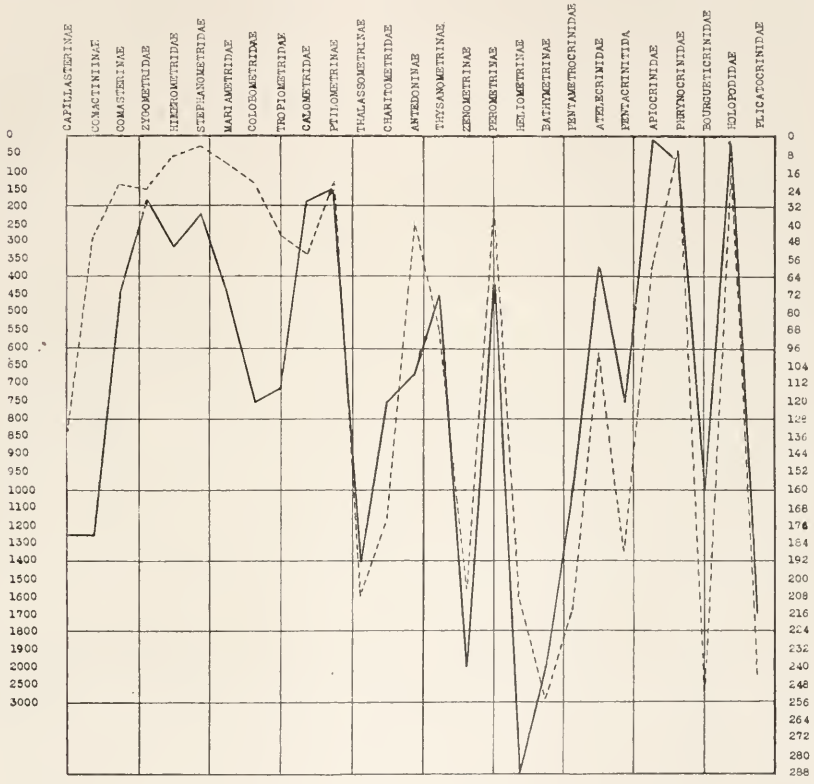

Fig. 2. Comparison between the maximum bathymetric range (. . . . .) and the geographical range expressed, in units of 15° square (225 square degrees), as the product of the number of degrees on the equator between the meridians passing through the limits of the distribution West and East of the Malayan region, times the number of degrees between the Parallels of Latitude bounding the area of occurrence of the Families of Recent Crinoids (———).

degrees; therefore every fathom of increase in the bathymetric range of a given type implies an increase of approximately 2.13 square degrees in the geographical range, and every increase of

100 fathoms in the bathymetric range is correlated with an increase of 213.33 square degrees in the geographical range.

In the families confined to comparatively warm water the geographical range is somewhat greater than the bathymetrical range, when 100 fathoms is considered as the equivalent of 213.33 square degrees, while in the families confined to cold water, and the families represented in the polar regions, the reverse is the case. This indicates that the curve representing the decrease in area of the units measuring 15° on each side from the equator to the poles is less marked than the curve representing the difference in the temperature between the surface water and that of the abysses (which plays a very important part in the bathymetrical distribution of marine organisms) from the equator to the poles.

This method of comparing the bathymetrical and the geographical range of marine organisms which at no time during their developmental history are pelagic takes no account of the land masses within the geographical areas as calculated. These land masses appear to be negligible; in other words, we appear to be justified in considering them as everywhere potentially habitable by the crinoids occurring along their shores as far as the meridians of longitude and the parallels of latitude to which these crinoids now extend.

The great tropical currents flowing northward, the Gulf Stream and the Kuro-Siwo, do not act as distributors of crinoids as they do of other types of organisms, for the reason that the littoral forms which might be supposed to extend their range along the shores washed by them, but which are confined within a very limited range of temperature and of salinity, cannot survive the conditions in the winter, when the currents in the northernmost part of their course move southward and off shore, and when further southward their inshore border is chilled and freshened by drainage from the land.