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A Phylogenetic Study of the Recent Crinoids, with Special Reference to the Question of Specialization Through the Partial or Complete Suppression of Structural Characters

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A PHYLOGENETIC STUDY OF THE RECENT CRINOIDS, WITH SPECIAL REFERENCE TO THE QUESTION OF SPECIALIZATION THROUGH THE PARTIAL OR COMPLETE SUPPRESSION OF STRUCTURAL CHARACTERS

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CONTENTS

PREFACE

In the study of any group of animals from the systematic standpoint the ultimate aim is the arrangement of the units within the group in a sequence which shall conform as nearly as possible to their relative phylogenetic status.

The consummation of such an arrangement is not always an easy task, for we too commonly fall into the error of over-estimating the comparative value of, and thereby placing too much reliance upon, some single obvious or exaggerated character, instead of taking into consideration and carefully weighing all of the characters presented.

Thus we are prone to place types distinguished by some unique and phylogenetically aberrant feature, though not otherwise remarkable, ahead of others which, more conservative throughout, are except for this single feature more advanced.

The recent crinoids offer a good illustration of the many difficulties in the path of a logical phylogenetic arrangement. The sequence of the families now commonly accepted is, beginning with the most specialized, as follows:

Order Articulata

Pentacrinitidæ (including the Pentacrinitida and the Comatulida)
Apiocrinidæ
Phrynocrinidæ
Bourgueticrinidæ
Holopodidæ

Order Inadunata

Plicatocrinidæ

This sequence has been determined not by an exhaustive study of the characters of each type and a subsequent comparison based upon the results of such a study, but rather by a more or less fortunate application of the doctrine of probabilities, based upon general resemblances.

It is the aim of the present paper to analyze all of the characters employed in the differentiation of the larger groups of recent crinoids, and, on the basis of this analysis, to indicate the true linear phylogenetic interrelationships of the recent types.

THE DETERMINATION OF THE PHYLOGENETIC SIGNIFICANCE OF THE DIFFERENTIAL CHARACTERS EMPLOYED IN SYSTEMATIC WORK

In the systematic study of organisms the differential characters are always employed in pairs, the two components of each pair being contrasted with each other.

Within each group individual pairs have ordinarily only a limited application, serving for the differentiation of certain units, but being quite useless for the differentiation of others.

Thus in every large group a large number of such contrasted pairs of characters must be employed, each of them having a more or less limited value.

A detailed study of the pairs of contrasted characters used in the differentiation of the groups of recent crinoids, and especially of the relation of the two components of each pair to each other, should not only indicate the phylogenetic interrelationships of the various types, but should also show clearly by what broad principle phylogenetic advance, or specialization, has come about.

Therefore in addition to determining the correct phylogenetic status of each of the groups of recent crinoids, an attempt will be made in the present paper to analyze the pairs of contrasted characters in an effort to discover the significance of each of the components, and thereby to indicate along what lines the phylogenetic development of the crinoids has progressed.

THE COURSE TAKEN BY PHYLOGENETIC PROGRESS, OR PROGRESSIVE SPECIALIZATION, AMONG THE CRINOIDS

The dominant feature of the progressive specialization among the crinoids from the earliest times to the present day has always been a process of progressive simplification in structure, the result of a process of progressive atrophy or suppression affecting some part or other of the organism. Thus the more specialized types differ from the more generalized through the atrophy or suppression of some important structural element, while the later groups are differentiated among themselves according to the lines which this atrophy or suppression has followed.

In a broad way this has long been appreciated; we recognize that the (recent) Articulata are distinguished from the Inadunata by the extreme atrophy of their calyx, involving in most cases the complete disappearance of certain essential elements; the comatulids are differentiated from all other (recent) types by the suppression of the column, excepting only the topmost columnal which becomes permanently attached to the calyx; *Holopus* is differentiated from all other (recent) genera through the suppression of the column excepting only the base, upon which directly the calyx rests; the Phrynocrinidæ differ from the Bourgueticrinidæ in the complete suppression of the radicular cirri; and the Bourgueticrinidæ differ from the Phrynocrinidæ in the suppression of the terminal stem plate. But as yet no attempt has been made to apply this principle to all of the differential characters which collectively make up the crinoid whole.

THE APPARENTLY NEW STRUCTURES IN THE LATER CRINOIDS

In the process of development and specialization of the crinoid phylogenetic line no new features have been added; nothing is found in the later and more specialized types that does not occur, usually in a more extended form, in the earlier and more generalized.

There are two apparent exceptions to this statement. The pentacrinites and the comatulids are chiefly remarkable for the great development of cirri, which are unknown in most of the earlier types and which therefore might be assumed to be of relatively recent phylogenetic origin; and most of the later forms possess one or more series of paired plates, of which the outermost is axillary, interpolated between the radials and the arm bases, whereas in the more primitive types the arms are given off directly from the radials.

As is explained further on, in the Articulata the column, after reaching a certain definite length, abruptly ceases further development, and the last formed columnal becomes permanently attached to the calyx. Though the skeletal development of the column ceases abruptly, the growth of the other constituents of the column is not so suddenly arrested, for we notice that the columnal which is attached to the calyx increases in size and gradually becomes more or less differentiated from the other columnals. If the column be very short—in other words if the suppression of the columnar development has been very abrupt—cirri are developed which break through the walls of the enlarged topmost columnal. These cirri, invariably associated with atrophied, dwarfed, or attenuated columns, represent a diffuse lateral diversion of the normally linear longitudinal stem development. The sudden suppression of the development of the skeleton of the column is not correlated with a correspondingly sudden suppression in the development of the other systems which enter into the columnar structure; and the organic adjustment or equilibrium necessitated by the continued development of the organic portions of the column after the inorganic portion has reached its limit is attained by a lateral diversion of this ontogenetic force, resulting in the formation of a varying number of cirri, each of the cirri representing a fractional degenerate derivative from a suppressed column of the normal type, while all of the cirri collectively represent the degree of excess of development possessed by the "soft parts" of the column over that possessed by the skeleton.

In order to understand the significance of the pair of ossicles in the later ten-armed types which occur between the radials and the arm bases it is necessary to bear in mind that the radials are not true calyx plates, but arm plates. The true calyx plates are (1) the basals, corresponding to the genitals in the urchins, and (2) the infrabasals, corresponding to the echinoid oculars. The radials, which always retain traces of an ultimate origin from two fused plates, are in practically all types the basic plates of the arms; but possibly they were originally the second arm plates, for in many of the older types there occur beneath one or more of them, most commonly under the right posterior, small additional plates which separate them from the infrabasals. This small plate beneath the right posterior radial is known as the radianal; in the young comatulid the same plate, which usually appears at a greater or lesser distance from its original position, has almost universally been designated as the anal, though it does not correspond to the anal of the older types.

As the calyx, through specialization by atrophy, decreases in size, the arms which, being composed dorsally of an extension of the heavily calcified dorso-lateral wall of the calyx and ventrally of an extension of the ventral surface of the disk which draws out along these skeletal supports prolongations from the various ring systems about the mouth, are necessarily situated where these two divisions of the body surface join, cannot accompany the radials in their distalward migration. The increasing gap between the radials and the arm bases is therefore filled by a pair of apparently new plates of which the outer, almost invariably axillary, is a double plate, a very close duplication of the radials, but with the two original elements less completely fused, while that between it and the original radial possibly represents the original subradial. The forms with the division series composed of paired ossicles (such as the species of *Endoxocrinus* for example) thus possess between the radials and the arm bases a series of paired plates, the inner plate of each pair resting upon the radial itself, or upon the outer plate of a preceding pair, and the outer plate of each pair being a reduplication of the original radial. Thus these paired plates of which the division series are formed in most of the later crinoids are not in any way new structures, but an adaptation through a system of reduplication, involving a complicated twinning process, of plates of fundamental significance common to all crinoids. The formation of the division series of paired plates is exactly comparable to the formation of the column in the pentacrinites, which involves a continuous linear repetition of the complete original column, each unit corresponding to the original column resting upon a cirriferous nodal as a terminal stem plate, and terminating itself in a cirriferous nodal, which, though in origin and significance a true proximale, never succeeds in attaching itself permanently to the calyx.

Thus upon close analysis neither the cirri nor the paired division series are found to be in reality new structures; the cirri, which occur sporadically in certain of the older types as well as uniformly in many of the later, are always associated with atrophy, dwarfing or attenuation of the column, and are in reality merely the evidence of the diversion of the column-forming substance from its original intent in the direction of the production of imperfect fractional columns, while the paired division series are merely reduplications of the primitive arm base, made necessary by the atrophy of the calyx and the consequent creation of a gap between the radials, of necessity in contact with the true calyx plates, and the arm bases, of necessity situated on the border between the ventral and the lateral surfaces of the animal.

THE CONTRASTING CHARACTERS USED IN DIFFERENTIATING THE GROUPS OF RECENT CRINOIDS, WITH THE FAMILIES EXHIBITING EACH, AND AN EXPLANATION OF THEIR DIFFERENTIAL AND PHYLOGENETIC SIGNIFICANCE

In the following pages, grouped under the headings "I. Calyx, II. Column, III. Disk, IV. Arms, V. Pinnules and VI. General," are listed all of the more important differential characters of broader significance found in the recent crinoids.

These characters are given in contrasting pairs, the more generalized being in each case numbered "1" and the more specialized numbered "2."

In each of these pairs the more specialized character (2) is always derived from the more generalized by a process of degeneration through reduction or more or less complete suppression.

Under each member of each pair are grouped the families presenting the character as described with its bathymetric and thermal distribution, and after each pair the significance of the two contrasting characters is pointed out, as well as the significance of the difference between them.

I. CALYX

1. Calyx in the form of a cup, protecting the viscera dorsally and laterally.

	Bathymetric range	Thermal range
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Calyx forming a platform upon which the viscera rest, more or less supported by the arm bases.

	Bathymetric range	Thermal range
Pentacrinitidæ	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75

In the majority of the older crinoids, as well as in the pentacrinoid young of the comatulids, the visceral mass is protected dorsally and laterally by two or three alternating rings of plates, with the summit of the column covering the opening in the center of the innermost ring.

In the later types, as in the developing young of the comatulids, we see a progressive decrease in the relative size of the calyx plates, as a result of which they become more and more restricted to the dorsal apex, leaving more and more of the lateral portion of the visceral mass exposed, until finally they become so reduced as to serve merely as a platform upon which the dorsal apex of the visceral mass rests, the lateral portions being supported by the arm bases.

The reduction of the crinoid calyx from the primitive condition of a cup entirely enclosing and protecting laterally and dorsally the visceral mass, is obviously specialization by inhibition and progressive suppression of the skeleton forming power; it is correlated with a similar reduction affecting other portions of the skeleton.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	2	80–75	0	1
100–200	1	2	75–70	1	2
200–300	1	2	70–65	0	2
300–400	1	2	65–60	0	2
400–500	1	2	60–55	0	2
500–600	1	4	55–50	0	2
600–700	1	4	50–45	0	2
700–800	1	4	45–40	1	2
800–900	1	3	40–35	1	4
900–1000	1	3	35–30	1	2
1000–1500	1	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	808 fathoms	785 fathoms
Average temperature	{71.0°, 37.5°} Fahr.	50.1° Fahr.

1. Calyx reduced by the moving inward of all the calyx plates, so that they become closely appressed and, their longitudinal axes all being parallel, form a closely knit column upon the summit of which the visceral mass rests.

	Bathymetric range	Thermal range
Phrynocrinidæ (*Naumachocrinus*)	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75

2. Calyx reduced by the eversion and imbrication of the calyx plates, so that eventually they come to form a platform composed of superposed circlets of plates, all the plates in the same circlet lying in the same plane.

	Bathymetric range	Thermal range
Pentacrinitidæ	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ (*Phrynocrinus*)...	508–703	38.1–40.0

One type of calyx reduction consists in the calyx abruptly ceasing growth upon reaching its perfected form, or, in the most extreme cases, closing up after the manner of an umbrella, so that the visceral mass, which continues to grow, is extruded and thus comes to lie, entirely exposed laterally, upon the summit of a short column composed of the much narrowed and more or less aligned calyx plates, supported chiefly by the arm bases.

But more commonly the reduction of the calyx plates takes the course of a progressive retardation in their development whereby they become smaller and smaller in relation to the lateral and dorsal area of the visceral mass, the inner edges of the plates of each circlet, as the circlets decrease in diameter, slipping inward over the outer edges of the plates of the circlet next within.

These two types of calyx reduction are, in a way, parallel to each other; yet the first appears to be of a more primitive character than the second, for the reason that the cessation of calyx growth and development does not begin until after the calyx has reached its perfected form, whereas in reduction by the second method the alteration of the relation of the calyx plates begins, at least in the developing comatulids, in the very early stages before the elimination of the radianal from the radial circlet. Thus it would appear logical to derive the second type from the first by carrying the inhibition of the formation of the calyx further back in the ontogeny or in the phylogeny.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	1	80–75	0	1
100–200	1	1	75–70	1	1
200–300	1	1	70–65	1	1
300–400	1	1	65–60	1	1
400–500	1	1	60–55	1	1
500–600	2	3	55–50	1	1
600–700	2	3	50–45	1	1
700–800	2	3	45–40	1	1
800–900	1	2	40–35	2	3
900–1000	1	2	35–30	1	1
1000–1500	1	1	30–25	1	1
1500–2000	1	1			
2000–3000	1	1			

	1	2
Average depth	777 fathoms	771 fathoms
Average temperature	48.8° Fahr.	50.2° Fahr.

1. Basals present.

	Bathymetric range	Thermal range
Pentacrinitidæ (Atelecrinidæ; Pentacrinitida)	5–1350	36.0–71.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Plicatocrinidæ	266–2575	31.1–43.9

2. No basals.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comatulida, except Atelecrinidæ)	0–2900	28.7–80.0
Holopodidæ	5–120	71.0

In the crinoids, including the developing comatulids, the two sets of plates which appear to be of the greatest importance are the basals and the radials, the former true calyx plates (corresponding to the echinoid genitals) and the latter properly speaking arm plates, though always forming part of the calyx cup.

It is only in types of very late occurrence, and, among the comatulids, very late in the ontogeny, that the basals become atrophied and disappear.

The elimination of the basals from the calyx in the more perfected types indicates phylogenetic advance through suppression of one of the most fundamental crinoid structures.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	2	80–75	0	1
100–200	2	2	75–70	2	2
200–300	3	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	5	1	55–50	2	1
600–700	5	1	50–45	2	1
700–800	5	1	45–40	3	1
800–900	4	1	40–35	5	1
900–1000	4	1	35–30	2	1
1000–1500	3	1	30–25	1	1
1500–2000	2	1			
2000–3000	2	1			

	1	2
Average depth	761 fathoms	713 fathoms
Average temperature	49.0° Fahr.	54.1° Fahr.

1. Five basals.

	Bathymetric range	Thermal range
Pentacrinitidæ	5–1350	36.0–71.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Plicatocrinidæ (*Calamocrinus*)	392–782	38.5–43.9

2. Less than five basals.

	Bathymetric range	Thermal range
Plicatocrinidæ (except *Calamocrinus*)	266–2575	31.1–43.9

The number of the basals in the crinoids, like the number of the corresponding plates, the genitals, in the urchins, appears fundamentally to be five.

Variation from this number, which is always by reduction, appears invariably to be an indication of specialization, for it always occurs in correlation with specialization in other directions.

The reduction in the number of basals from five to three is an example of specialization through suppression; though the reduction is by coalescence and not by loss of two of the original five, and therefore all of the original substance included in the primitive five basals is equally included in the specialized three, the segregation of four into two pairs indicates a suppression of the individuality of the units involved, though without an actual loss of their substance.

Frequency at different depths		
Fathoms	1	2
0–100	2	0
100–200	2	0
200–300	2	1
300–400	3	1
400–500	3	1
500–600	5	1
600–700	5	1
700–800	5	1
800–900	3	1
900–1000	3	1
1000–1500	2	1
1500–2000	1	1
2000–3000	1	1

Frequency at different temperatures		
Degrees Fahrenheit	1	2
80–75	0	0
75–70	2	0
70–65	2	0
65–60	2	0
60–55	2	0
55–50	2	0
50–45	2	0
45–40	3	1
40–35	5	1
35–30	1	0
30–25	1	0

	1	2
Average depth	681 fathoms	936 fathoms
Average temperature	49.8° Fahr.	40.0° Fahr.

1. Basals separate.

	Bathymetric range	Thermal range
Pentacrinitidæ (*Atelecrinus*; Pentacrinitida)	5–1350	36.0–71.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ (*Monachocrinus, Democrinus, Bythocrinus*)	62–2217	37.4–40.5
Plicatocrinidæ (*Calamocrinus, Hyocrinus, Gephyrocrinus, Thalassocrinus*)	392–2575	31.1–43.9

2. Basals fused into a single calcareous element.

	Bathymetric range	Thermal range
Pentacrinitidæ (except *Atelecrinus* and Pentacrinitida)	0–2900	28.7–80.0
Bourgueticrinidæ (*Ilycrinus, Bathycrinus, Rhizocrinus*)	77–2535	30.9–48.7
Plicatocrinidæ (*Ptilocrinus*)	266–2485	35.3

Primarily the basals form each a separate and distinct skeletal element at the head of one of the interradial areas.

But, if through reduction of the calyx in its relation to the visceral mass, or in any other way, the basals lose their intimate connection with the structures lying immediately within them, they also lose more or less their individuality, becoming closely united and forming a single skeletal element, a ring or "rosette," which in extreme cases is functionally little more than a topmost columnal, for which, indeed, it has often been mistaken.

The reduction of the basals and their fusion into a single calcareous element is evidence of the inhibition and suppression of the normal skeleton forming power by which the basal ring primarily develops from five distinct centers in the form of a circlet of five similar large, separate and perfect plates.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	2	80–75	0	1
100–200	2	2	75–70	1	1
200–300	2	3	70–65	1	1
300–400	3	3	65–60	1	1
400–500	3	3	60–55	1	1
500–600	5	3	55–50	1	1
600–700	5	3	50–45	1	2
700–800	5	3	45–40	3	2
800–900	4	3	40–35	5	3
900–1000	4	3	35–30	1	2
1000–1500	3	3	30–25	0	1
1500–2000	2	3			
2000–3000	2	3			

	1	2
Average depth	774 fathoms	846 fathoms
Average temperature	47.1° Fahr.	48.4° Fahr.

1. Infrabasals present as individual plates.

	Bathymetric range	Thermal range
Pentacrinitidæ (*Teliocrinus, Hypalocrinus, Metacrinus, Isocrinus*)	5–1350	36.0–71.0

2. Infrabasals absent, or fused with other plates.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comatulida, and *Endoxocrinus*)	0–2900	28.7–80.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

The infrabasals, which correspond to the oculars of the echinoids, do not appear to be of such fundamental significance as their representatives in that group, for in the earlier crinoids they may or may not be present. But whatever their status in the ancient types may be, they are regarded as either actually or potentially present in the order Articulata, to which all but one of the recent families belong.

Primarily the infrabasals occur as five small plates within (or below) the basal ring, and alternating in position with the basals.

Although potentially present in all the recent families of the Articulata, at best the infrabasals are represented by insignificant plates, invisible exteriorly, in the adults, while usually they are represented only in the very young, or are absent altogether.

The progressive suppression and final elimination of the infrabasals, plates which, so far as we know, are of fundamental importance in the Articulata, is directly correlated with the specialization of the respective types. The Plicatocrinidæ, which belong not to the Articulata but to the Inadunata, represents probably a primarily monocyclic type.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	3	80–75	0	1
100–200	1	3	75–70	1	3
200–300	1	3	70–65	1	2
300–400	1	3	65–60	1	2
400–500	1	3	60–55	1	2
500–600	1	3	55–50	1	2
600–700	1	3	50–45	1	2
700–800	1	3	45–40	1	3
800–900	1	3	40–35	1	3
900–1000	1	3	35–30	0	3
1000–1500	1	3	30–25	0	2
1500–2000	0	3			
2000–3000	0	3			

	1	2
Average depth	568 fathoms	808 fathoms
Average temperature	58.0° Fahr.	50.5° Fahr.

1. Five radials.

	Bathymetric range	Thermal range
Pentacrinitidæ (except *Promachocrinus* and *Thaumatocrinus*)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Ten radials.

	Bathymetric range	Thermal range
Promachocrinus	10–222	28.7
Thaumatocrinus	361–1800	37.4–42.7

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	1	80–75	1	0
100–200	2	1	75–70	3	0
200–300	3	1	70–65	2	0
300–400	3	1	65–60	2	0
400–500	3	1	60–55	2	0
500–600	5	1	55–50	2	0
600–700	5	1	50–45	2	0
700–800	5	1	45–40	3	1
800–900	4	1	40–35	5	1
900–1000	4	1	35–30	3	0
1000–1500	3	1	30–25	2	1
1500–2000	3	1			
2000–3000	3	0			

	1	2
Average depth	822 fathoms	666 fathoms
Average temperature	49.5° Fahr.	35.8° Fahr.

1. Interradials present.

	Bathymetric range	Thermal range
Promachocrinus	10–222	28.7
Thaumatocrinus	361–1800	37.4–42.7

2. Interradials absent.

	Bathymetric range	Thermal range
Pentacrinitidæ (except *Promachocrinus* and *Thaumatocrinus*)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	2	80–75	0	1
100–200	1	2	75–70	0	3
200–300	1	3	70–65	0	2
300–400	1	3	65–60	0	2
400–500	1	3	60–55	0	2
500–600	1	5	55–50	0	2
600–700	1	5	50–45	0	2
700–800	1	5	45–40	1	3
800–900	1	4	40–35	1	5
900–1000	1	4	35–30	0	3
1000–1500	1	3	30–25	1	2
1500–2000	1	3			
2000–3000	0	3			

	1	2
Average depth	666 fathoms	822 fathoms
Average temperature	35.8° Fahr.	49.5° Fahr.

1. Anal *x*, bearing a process, present.

	Bathymetric range	Thermal range
Promachocrinus	10–222	28.7
Thaumatocrinus	361–1800	37.4–42.7

2. Anal *x* absent.

	Bathymetric range	Thermal range
Pentacrinitidæ (except *Promachocrinus* and *Thaumatocrinus*)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

The problem of the so-called interradials in *Promachocrinus* and *Thaumatocrinus* is a very complicated one.

These five interradial radials arise as five simple interradials, corresponding exactly to the interradials of many fossil forms, and that in the posterior interradius gives rise to a process, being the homologue of the anal *x* of fossil types.

These interradial radials being primarily interradials, and the one in the posterior interradius being the representative of anal *x*, it naturally follows that the forms in which they occur present a more primitive type of structure, more nearly similar to the ancient structural types, than those from which they are absent as a result of the progressive simplification of the skeleton by the gradual suppression and elimination of superfluous calcareous elements.

But on the other hand these interradial radials do not retain the status of simple interradials. They grow to an equal size with the true radials, and each gives rise to a post-radial process which, starting as a simple linear series of ossicles, eventually comes to be exactly like that arising from the true radials.

This type of structure is quite unique, and may therefore be considered as an evidence of specialization.

Hence the five interradial radials of *Promachocrinus* and *Thaumatocrinus* must be considered, if viewed in the light of their origin, as indicating a low degree of specialization marked by the retention of the primitive interradials, and of anal *x;* but if viewed in the light of their ultimate condition, as indicating a high degree of specialization.

It may be remarked that in certain fossil types there are analogous cases of doubling of the radials through a transformation into radials of plates originally of quite different significance.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	2	80–75	0	1
100–200	1	2	75–70	0	3
200–300	1	3	70–65	0	2
300–400	1	3	65–60	0	2
400–500	1	3	60–55	0	2
500–600	1	5	55–50	0	2
600–700	1	5	50–45	0	2
700–800	1	5	45–40	1	3
800–900	1	4	40–35	1	5
900–1000	1	4	35–30	0	3
1000–1500	1	3	30–25	1	2
1500–2000	1	3			
2000–3000	0	3			

	1	2
Average depth	666 fathoms	822 fathoms
Average temperature	35.8° Fahr.	49.5° Fahr.

1. Interbrachials present.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comasterinæ, Calometridæ, *Mastigometra*, *Antedon*, *Erythrometra*, Pentacrinitida)	0–1350	36.0–80.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Interbrachials absent.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Comasterinæ, Calometridæ, *Mastigometra*, *Antedon*, *Erythrometra*, Pentacrinitida)	0–2900	28.7–80.0
Apiocrinidæ	565–940	26.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0

Interbrachials, characteristic of most fossil crinoids, occur, usually as small and thin, more or less irregular and poorly developed, plates, in many recent types.

Usually, however, they are quite absent, at least in adults.

The disappearance of the interbrachials is quite in line with the progressive development of the crinoid skeleton through the progressive elimination of the less essential elements.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	3	80–75	1	1
100–200	1	3	75–70	1	3
200–300	2	2	70–65	1	2
300–400	2	2	65–60	1	2
400–500	2	2	60–55	1	2
500–600	2	4	55–50	1	2
600–700	2	4	50–45	1	2
700–800	2	4	45–40	2	2
800–900	2	3	40–35	2	4
900–1000	2	3	35–30	1	2
1000–1500	2	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	750 fathoms	747 fathoms
Average temperature	52.5° Fahr.	51.0° Fahr.

II. COLUMN

1. Entire column present.

	Bathymetric range	Thermal range
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Original column discarded in early life.

	Bathymetric range	Thermal range
Pentacrinidæ	0–2900	28.7–80.0

Whatever may be said of crinoids as a whole, or of echinoderms as a class, the column is an essential feature of the structure of the Articulata, to which all of the recent crinoids except those of the family Plicatocrinidæ belong, and of the Inadunata, which includes that family.

The absence of the column, or the atrophy and rejection of the larval stem, therefore, is clear evidence of specialization.

The rejection of the column in the young and the subsequent adoption of a so-called free existence, is an example of specialization through the suppression of an originally fundamental structure.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	1	80–75	0	1
100-200	2	1	75–70	2	1
200–300	2	1	70–65	1	1
300–400	2	1	65–60	1	1
400–500	2	1	60–55	1	1
500–600	4	1	55–50	1	1
600–700	4	1	50–45	1	1
700–800	4	1	45–40	2	1
800–900	3	1	40–35	4	1
900–1000	3	1	35–30	2	1
1000–1500	2	1	30–25	1	1
1500–2000	2	1			
2000–3000	2	1			

	1	2
Average depth	785 fathoms	808 fathoms
Average temperature	47.5° Fahr.	52.5° Fahr.

1. Column jointed.

	Bathymetric range	Thermal range
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Plicatocrinidæ	266–2575	31.1–43.9

2. Column unjointed.

	Bathymetric range	Thermal range
Holopodidæ	5–120	71.0

Not only are the Articulata and the Inadunata fundamentally provided with a column, but that column is primarily composed of numerous short ossicles united end to end in the form of a long jointed stem.

The reduction of this jointed column to a simple calcareous base is therefore a form of specialization over the original condition, as is evident from a study of the earlier types, and from a study of the developing young.

The reduction of the primitive long jointed column to a single spreading base is evidently an example of specialization through suppression of the normal stem forming power.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	1	80–75	0	0
100–200	1	1	75–70	1	1
200–300	2	0	70–65	1	0
300–400	2	0	65–60	1	0
400–500	2	0	60–55	1	0
500–600	4	0	55–50	1	0
600–700	4	0	50–45	1	0
700–800	4	0	45–40	2	0
800–900	3	0	40–35	4	0
900–1000	3	0	35–30	2	0
1000–1500	2	0	30–25	1	0
1500–2000	2	0			
2000–3000	2	0			

	1	2
Average depth	828 fathoms	60 fathoms
Average temperature	45.8° Fahr.	71.0° Fahr.

1. Column composed of short cylindrical ossicles bearing radial crenellæ on their articular faces.

	Bathymetric range	Thermal range
Plicatocrinidæ	266–2575	31.1–43.9

2. Column not composed of short cylindrical ossicles bearing radial crenellæ on their articular faces.

	Bathymetric range	Thermal range
(Pentacrinitidæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0

In all primitive types, and in practically all of the Palæozoic crinoids, the column is composed of a great number of short cylindrical ossicles with their circular articular faces marked with radial crenellæ.

But in most of the families of the Articulata, and in a few of the earlier forms, such for instance as the Platycrinidæ, the column, in addition to a marked decrease in the number of the columnals, has been greatly reduced in volume through the reduction in size of each of the component ossicles which, instead of being circular in cross section, have become elliptical, the long axes of the ellipses representing the diameter of the original circle, and the difference in length between the two axes indicating the amount of calcareous matter lost; rigidity is maintained in this (the so-called "bourgueticrinoid") type of column by a difference in the direction of the long axes of the ellipses at either end of each columnal whereby the column as a whole forms a series of spirals.

The bourgueticrinoid type of column, with its relatively few columnals, each of the minimum volume compatible with the necessary rigidity, is a good instance of specialization through the gradual suppression of the skeleton forming power of the animal.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	0	3	80–75	0	1
100–200	0	3	75–70	0	3
200–300	1	2	70–65	0	2
300–400	1	2	65–60	0	2
400–500	1	2	60–55	0	2
500–600	1	4	55–50	0	2
600–700	1	4	50–45	0	2
700–800	1	4	45–40	1	2
800–900	1	3	40–35	1	4
900–1000	1	3	35–30	1	2
1000–1500	1	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	936 fathoms	747 fathoms
Average temperature	37.5° Fahr.	51.0° Fahr.

1. Column composed of a single type of columnals, without a proximale or nodals.

	Bathymetric range	Thermal range
Plicatocrinidæ	266–2575	31.1–43.9
Apiocrinidæ (*Carpenterocrinus*)	565	38.1

2. Column including modified columnals, a proximale or nodals.

	Bathymetric range	Thermal range
Pentacrinitidæ	0–2900	28.7–80.0
Apiocrinidæ (*Proisocrinus*)	940	36.7
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75

In the primitive crinoids, and in the very young (phytocrinoid stage) of the comatulids, the column is composed of an indefinite number of similar ossicles, which continuously increases during the life of the individual.

In the Articulata, however, the column typically, after attaining a certain definite number of columnals and reaching a certain definite length, abruptly ceases further growth, and the topmost columnal becomes attached to the calyx by close suture, developing into what is, to all intents and purposes, an apical calyx plate, the so-called proximale. The so-called centrodorsal of the comatulids is such a proximale below which the original column has been discarded. In the pentacrinites the early growth is exactly as in the comatulids, but the proximale never becomes attached to the calyx; instead, new columnals are formed between it and the crown and a new stem is formed for which the original proximale serves as a terminal stem plate, and a second proximale appears beneath the calyx; this process continuing, a series of so-called nodals is formed, each of which represents, so to speak, an attempt of the column to limit itself to a definite length and to cease all further growth. In the Bourgueticrinidæ, and in most of the Apiocrinidæ, the original proximale is reduplicated, so that just beneath the calyx there is found a more or less conical structure composed of a series of proximales which increase in perfection to that just beneath the calyx.

The abrupt limitation in the growth of the column, and the formation of a proximale which becomes rigidly attached to the calyx, preventing the formation of additional columnals between it and the calyx, in contrast to the primitive method of continuous stem growth during life, is specialization through inhibition and definite limitation of the skeleton forming power of the column.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	0	2	80–75	0	1
100–200	0	2	75–70	0	2
200–300	1	2	70–65	0	2
300–400	1	2	65–60	0	2
400–500	1	2	60–55	0	2
500–600	2	3	55–50	0	2
600–700	1	3	50–45	0	2
700–800	1	3	45–40	1	2
800–900	1	2	40–35	2	4
900–1000	1	3	35–30	1	2
1000–1500	1	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	904 fathoms	797 fathoms
Average temperature	37.5° Fahr.	50.1° Fahr.

1. Column terminating in an expanded terminal stem plate.

	Bathymetric range	Thermal range
(Pentacrinitidæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Column without a terminal stem plate.

	Bathymetric range	Thermal range
Bourgueticrinidæ	62–2690	29.1–70.75

The columns of the earlier crinoids typically (though by no means always) terminated in an expanded base composed of a number of enlarged columnals which, in later types, became simplified as a single terminal stem plate from which the column more or less abruptly arises.

The presence of a terminal stem plate appears to be of fundamental significance, and therefore any type without it must be considered as possessing a highly specialized type of column.

The absence of a terminal stem plate indicates specialization through suppression of a fundamentally important skeletal structure.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	1	80–75	1	0
100–200	2	1	75–70	2	1
200–300	2	1	70–65	1	1
300–400	2	1	65–60	1	1
400–500	2	1	60–55	1	1
500–600	4	1	55–50	1	1
600–700	4	1	50–45	1	1
700–800	4	1	45–40	2	1
800–900	3	1	40–35	4	1
900–1000	3	1	35–30	2	1
1000–1500	2	1	30–25	1	1
1500–2000	2	1			
2000–3000	2	1			

	1	2
Average depth	785 fathoms	808 fathoms
Average temperature	52.0° Fahr.	44.8° Fahr.

1. Radicular cirri present.

	Bathymetric range	Thermal range
Bourgueticrinidæ	62–2690	29.1–70.75

2. Radicular cirri absent.

	Bathymetric range	Thermal range
(Pentacrinitidæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

Combined with a broad spreading base composed of a mass of swollen, distorted and overgrown columnals, the early crinoids commonly possessed stout and massive radicular cirri, which were very irregular in position, and equally irregular in structure. In the Articulata this type of stem base occurs only in fossil species belonging to the family Apiocrinidæ, though a suggestion of it is found in the young of certain macrophreate comatulids, particularly those belonging to the genus *Hathrometra;* elsewhere one or other of the root systems has been suppressed.

The presence of radicular cirri appears to be of the same fundamental significance as the presence of a terminal stem plate, and therefore any type without it must be considered as possessing a highly specialized type of column.

The absence of radicular cirri, just as the absence of a terminal stem plate, indicates specialization through suppression of a fundamentally important skeletal structure.

The recent crinoids possess either radicular cirri or a terminal stem plate, but never both combined as do many of the earlier types; one or the other is always suppressed. As the suppression of either is equally an evidence of specialization, it naturally follows that we have here, in the presence or absence of the radicular cirri and the correlated absence or presence of the terminal stem plate, two categories each of which is the complement of the other, while both represent an equivalent stage in phylogenetic advancement.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	2	80–75	0	1
100–200	1	2	75–70	1	2
200–300	1	2	70–65	1	1
300–400	1	2	65–60	1	1
400–500	1	2	60–55	1	1
500–600	1	4	55–50	1	1
600–700	1	4	50–45	1	1
700–800	1	4	45–40	1	2
800–900	1	3	40–35	1	4
900–1000	1	3	35–30	1	2
1000–1500	1	2	30–25	1	1
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	808 fathoms	785 fathoms
Average temperature	44.8° Fahr.	52.0° Fahr.

1. Cirri absent.

	Bathymetric range	Thermal range
Apiocrinidæ (*Carpenterocrinus*)	565	38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Cirri present.

	Bathymetric range	Thermal range
Pentacrinitidæ	0–2900	28.7–80.0
Apiocrinidæ (*Proisocrinus*)	940	36.7

The cirri, in contrast to the radicular cirri, properly speaking are structures primarily associated with the calyx and not with the column, though always arising from the latter. They are always associated with the existence of a proximale, or modified proximal columnal, upon which they are situated, and hence are almost entirely confined to the Articulata.

The presence of cirri is always correlated with a great reduction in the size and number of constituent elements of the column, and in the relative size and number of skeletal elements of the calyx.

While undoubtedly a new structure, the cirri by their presence always indicate a very high degree of reduction in the skeleton of the calyx and of the column, and hence are always an index of specialization through suppression of skeletal development.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	1	80–75	0	1
100–200	2	1	75–70	2	1
200–300	2	1	70–65	1	1
300–400	2	1	65–60	1	1
400–500	2	1	60–55	1	1
500–600	4	1	55–50	1	1
600–700	3	1	50–45	1	1
700–800	3	1	45–40	2	1
800–900	2	1	40–35	4	2
900–1000	2	2	35–30	2	1
1000–1500	2	1	30–25	1	1
1500–2000	2	1			
2000–3000	2	1			

	1	2
Average depth	783 fathoms	818 fathoms
Average temperature	47.5° Fahr.	51.3° Fahr.

III. DISK

1. Disk entirely covered with plates.

	Bathymetric range	Thermal range
Pentacrinitidæ (Zygometridæ, Calometridæ, Pentacrinitida)	0–1350	36.0–80.0
? Apiocrinidæ	565–940	36.7–38.1
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Disk naked, or with scattered granules.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comatulida, except Zygometridæ and Calometridæ) .	0–2900	28.7–80.0
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75

In the earlier crinoids belonging to the order Camerata, as in the very young of the comatulids, the disk is always entirely covered with plates, which form a solid pavement over it.

Only in the later types, chiefly in the Articulata, does this disk armament become less and less complete, eventually disappearing altogether.

The partially plated or unplated disks of many of the later crinoids furnish an example of specialization through suppression of a fundamental primitive character.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	2	80–75	1	1
100–200	2	2	75–70	2	2
200–300	2	2	70–65	1	2
300–400	2	2	65–60	1	2
400–500	2	2	60–55	1	2
500–600	3	3	55–50	1	2
600–700	3	3	50–45	1	2
700–800	3	3	45–40	2	2
800–900	3	2	40–35	3	3
900–1000	3	2	35–30	1	2
1000–1500	2	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	707 fathoms	791 fathoms
Average temperature	52.8° Fahr.	50.7° Fahr.

1. Orals present.

	Bathymetric range	Thermal range
Pentacrinitidæ (Calometridæ, Pentacrinitida)	0–1350	36.0–80.0
? Apiocrinidæ	565–940	36.7–38.1
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Orals absent.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comatulida, except Calometridæ)	0–2900	28.7–80.0
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75

Correlated with the presence of a solid plating over the surface of the disk is the presence of large and definite oral plates surrounding the mouth.

These orals dwindle in size with the disintegration of the pavement on the surface of the disk, finally, like that pavement, disappearing altogether.

The disappearance of orals is an example of specialization through the suppression of a fundamental feature, and is quite comparable to the disappearance of the disk plating, with which, in a general way, it is associated.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	2	80–75	1	1
100–200	2	2	75–70	2	2
200–300	2	2	70–65	1	2
300–400	2	2	65–60	1	2
400–500	2	2	60–55	1	2
500–600	3	3	55–50	1	2
600–700	3	3	50–45	1	2
700–800	3	3	45–40	2	2
800–900	3	2	40–35	3	3
900–1000	3	2	35–30	1	2
1000–1500	2	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	707 fathoms	791 fathoms
Average temperature	52.8° Fahr.	50.7° Fahr.

1. Orals of different sizes.

	Bathymetric range	Thermal range
Plicatocrinidæ	266–2575	31.1–43.9

2. All five orals of the same size.

	Bathymetric range	Thermal range
Pentacrinitidæ	0–2900	28.7–80.0
Holopodidæ	5–120	71.0

In the older crinoids, in which as a rule the posterior interradius was enlarged and modified by the inclusion of plates not occurring in the other interradii, the posterior oral was as a rule larger than the other four.

In the later types which, through the suppression of features causing the differentiation of the anal interradius, exhibit a very nearly perfect pentamerous symmetry, the orals are commonly all of the same size.

The similarity of the orals is always associated with, and is an index of, a suppression of certain constituent parts of the original calyx structure, and is almost invariably associated with a reduction in the size of the orals themselves.

Frequency at different depths		
Fathoms	1	2
0–100	0	2
100–200	0	2
200–300	1	1
300–400	1	1
400–500	1	1
500–600	1	1
600–700	1	1
700–800	1	1
800–900	1	1
900–1000	1	1
1000–1500	1	1
1500–2000	1	1
2000–3000	1	1

Frequency at different temperatures		
Degrees Fahrenheit	1	2
80–75	0	1
75–70	0	2
70–65	0	1
65–60	0	1
60–55	0	1
55–50	0	1
50–45	0	1
45–40	1	1
40–35	1	1
35–30	1	1
30–25	0	1

	1	2
Average depth	936 fathoms	713 fathoms
Average temperature	37.5° Fahr.	54.2° Fahr.

1. Orals with their inner edges upturned.

	Bathymetric range	Thermal range
Pentacrinitidæ (Calometridæ)	0–333	52.9–75.7
Plicatocrinidæ (except *Ptilocrinus*)	392–2575	31.1–43.9

2. Orals a spherical triangle.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Calometridæ)	0–2900	28.7–80.0
Holopodidæ	5–120	71.0
Plicatocrinidæ (*Ptilocrinus*)	266–2485	35.3

In the earlier crinoids (except the Flexibilia) the orals were relatively thick plates lying in the tegmen, of which they formed part of the plated surface, and hence they acquired more or less the form of spherical triangles of very appreciable thickness. The disintegration of the orals, following that of the pavement of the disk, took place from the periphery of the oral circlet, gradually working toward the center. As the orals became thinner and thinner dorso-ventrally it naturally resulted that their edges bordering the ambulacral grooves, which were the last portions to be affected, became prominent, standing up above the general surface as thin blade-like borders parallel to the dorsoventral axis of the disk of gradually increasing height, the orals eventually disappearing not as horizontal plates lying in the tegmen but as five trough-like structures surrounding the mouth with their angles in apposition, and with their longest dimension, representing the long dimension of the trough, parallel to the dorsoventral axis. Orals of this type are characteristic of the pentacrinoid young of the macrophreate comatulids.

But while the reduction and disappearance of the orals after their complete formation as skeletal structures characteristic of the adults took this course, reduction of the orals gradually was shoved further and further back into the ontogeny of the later types so that it set in before the orals commenced to thicken. Cessation of development of the orals at this stage leaves them in the form of very thin plates lying in, and conforming in contour to, the inner angles of the interambulacral areas.

Thus the presence of thin orals lying in and conforming in contour to the inner angles of the interambulacral areas is an indication of an advanced stage of suppression of those plates, which has been shoved far forward into the ontogeny. So far as we know the orals of the stalked young of the oligophreate comatulids never develop further than this point.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	2	80–75	1	1
100–200	1	2	75–70	1	2
200–300	1	2	70–65	1	1
300–400	2	2	65–60	1	1
400–500	1	2	60–55	1	1
500–600	1	2	55–60	1	1
600–700	1	2	50–45	0	1
700–800	1	2	45–40	1	1
800–900	1	2	40–35	1	2
900–1000	1	2	35–30	1	1
1000–1500	1	2	30–25	0	1
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	596 fathoms	808 fathoms
Average temperature	{37.5° / 65.0°} Fahr.	52.9° Fahr.

1. Mouth central.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Comasteridæ, and the five largest genera of Heliometrinæ)	0–2900	28.7–80.0
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Mouth more or less excentric.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comasteridæ, and the five largest genera of Heliometrinæ)	0–1062	28.7–80.0

One of the most invariable features of crinoidal structure, a necessary corollary of the primitive and fundamental pentamerous symmetry of these animals, is the central position of the mouth upon the disk.

Only in a very few types, and in these only very late in the ontogeny, do we find the mouth in an excentric position.

The migration of the mouth to an excentric position indicates a high degree of specialization which, like many similar features, is of more or less sporadic occurrence. The migration of the mouth toward an excentric position indicates the gradual suppression of the primitive and fundamental pentamerous symmetry of the crinoids.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	3	1	80–75	1	1
100–200	3	1	75–70	3	1
200–300	3	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	4	1	55–50	2	1
600–700	4	1	50–45	2	1
700–800	4	1	45–40	3	1
800–900	3	1	40–35	4	1
900–1000	3	1	35–30	3	1
1000–1500	3	1	30–25	2	1
1500–2000	3	0			
2000–3000	3	0			

	1	2
Average depth	775 fathoms	568 fathoms
Average temperature	50.0° Fahr.	52.5° Fahr.

IV. ARMS

1. Arms composed of a linear series of ossicles, without IBr series.

	Bathymetric range	Thermal range
Pentacrinitidæ (Pentametrocrinidæ and part of Atelecrinidæ)	103–1800	33.5–60.6
Plicatocrinidæ (except *Calamocrinus*)	266–2575	31.1–43.9

2. Arms dividing one or more times, or, if undivided, with IBr series.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Pentametrocrinidæ and part of Atelecrinidæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ (*Calamocrinus*)	392–782	38.5–43.9

Whatever may have been the ultimate origin of the crinoid arm as a structure, the immediate ancestor of the recent types certainly possessed arms composed of an undifferentiated linear series of ossicles.

Subsequently this simple type of arm became modified through the interpolation between the arm base and the radial of the so-called IBr series, a pair of ossicles which is in reality a more or less perfect reduplication of the radial (corresponding to the IBr_2) and the infraradial (corresponding to the IBr_1).

The presence of IBr series is rendered possible only by a very considerable reduction in the development of the calyx. The arms arise from the border of the disk, and are outgrowths of which the dorsal skeletal structures are derivatives from the skeletal structures of the sides of the calyx cup, while the ventral structures, the ambulacral grooves, water, blood, muscle and ventral nerve systems, are outgrowths from the corresponding structures on the disk which have extended themselves outward over the dorsal skeletal structures as a support. Being in part derived from the lateral body wall and in part an outgrowth from the ventral surface, the arms necessarily must maintain their original position on the edge of the disk. In the reduction of the calyx from the primitive condition of a cup entirely enclosing the visceral mass dorsally and laterally to the form of a small cap covering only the dorsal pole of the visceral mass, or of a platform upon which the visceral mass rests, the arms, as much a part of the disk as of the dorsal skeletal structure, are unable to maintain their original connection with the now greatly reduced radials. The growing gap between the arm bases and the radials is filled not by a dorsalward extension of the arm bases, but by the formation of an entirely new pair of plates, the IBr series, between the radials and the arm bases, which serve to maintain the connection, and which are in origin and in structure a more or less perfect reduplication of the now atrophied radial and infraradial (or possibly infrabasal). The presence of IBr series is therefore a certain indication of the suppression of other more extensive skeletal structures, and is therefore an indication of specialization through suppression. In this respect the presence of IBr series is of the same significance as the presence of cirri, which always indicate and accompany a suppression of development in the column. As the specialization of the column through suppression of its growth is correlated with the specialization of the calyx through suppression of its development, it is only natural that we should find the development of cirri more or less closely correlated with the development of IBr (and additional comparable) series.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	0	3	80–75	0	1
100–200	1	3	75–70	0	3
200–300	2	2	70–65	0	2
300–400	2	3	65–60	1	2
400–500	2	3	60–55	1	2
500–600	2	5	55–50	1	2
600–700	2	5	50–45	1	2
700–800	2	5	45–40	2	3
800–900	2	3	40–35	2	5
900–1000	2	3	35–30	2	2
1000–1500	2	2	30–25	0	2
1500–2000	2	2			
2000–3000	1	2			

	1	2
Average depth	795 fathoms	723 fathoms
Average temperature	37.0° Fahr.	42.9° Fahr.

1. Arms with IBr series in which the outer element is axillary.

	Bathymetric range	Thermal range
Pentacrinitidæ (except *Eudiocrinus* and *Metacrinus*)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Bourgueticrinidæ (*Ilycrinus, Bathycrinus, Monachocrinus*)	743–2690	30.9–40.0
Holopodidæ	5–120	71.0

2. Arms with IBr series in which the outer element is not axillary.

	Bathymetric range	Thermal range
Pentacrinitidæ (*Eudiocrinus* and *Metacrinus*)	22–630	39.5–71.0
Bourgueticrinidæ (*Democrinus, Bythocrinus, Rhizocrinus*)	61–1300	31.8–48.7

In the course of the development of the IBr series it came about that the outer element (the IBr_2) is normally axillary, bearing two exactly similar arms instead of a single arm as in the case of an arm-bearing radial.

Occasionally it happens that the IBr_2 is not axillary, but gives rise to a linear series of ossicles, like the primitive radial. A more or less common meristic variation in many diverse types, this feature has in others become fixed and invariable.

The reduction of the IBr_2 from its normal condition of an axillary to an ossicle giving rise to a simple linear series of ossicles, with the resultant loss of half of the number of arms, is an illustration of specialization through suppression.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	2	80–75	1	0
100–200	2	2	75–70	2	1
200–300	1	2	70–65	1	1
300–400	1	2	65–60	1	1
400–500	1	2	60–55	1	1
500–600	2	2	55–50	1	1
600–700	2	2	50–45	1	2
700–800	3	1	45–40	1	2
800–900	3	1	40–35	3	2
900–1000	3	1	35–30	2	1
1000–1500	2	1	30–25	1	0
1500–2000	2	0			
2000–3000	2	0			

	1	2
Average depth	865 fathoms	483 fathoms
Average temperature	50.5° Fahr.	50.0° Fahr.

1. The first bifurcation is at a more or less indefinite distance beyond the second post-radial ossicle.

	Bathymetric range	Thermal range
Pentacrinitidæ (*Metacrinus*)	30–630	39.5–71.0
Phrynocrinidæ	508–703	38.1–40.0
Plicatocrinidæ	266–2575	31.1–43.9

2. The first bifurcation is on the second post-radial ossicle.

	Bathymetric range	Thermal range
Pentacrinitidæ (except *Metacrinus*)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0

In the earlier crinoid types, especially before the formation of definite IBr series, the bifurcation of the arms commenced at a more or less indefinite distance from the radials.

Later the number of plates intervening between the radials and the first axillary became reduced to one only.

The reduction of the number of plates between the radials and the first axillary from several to one only indicates specialization through the suppression of useless skeletal structures.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	3	80–75	0	1
100–200	1	3	75–70	1	3
200–300	2	2	70–65	1	2
300–400	2	2	65–60	1	2
400–500	2	2	60–55	1	2
500–600	3	3	55–50	1	2
600–700	3	3	50–45	1	2
700–800	2	3	45–40	2	2
800–900	1	3	40–35	3	3
900–1000	1	3	35–30	1	2
1000–1500	1	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	700 fathoms	756 fathoms
Average temperature	49.1° Fahr.	51.6° Fahr.

1. A suture (or pseudo-syzygy) between the ossicles of the IBr series.

	Bathymetric range	Thermal range
Pentacrinitidæ (*Comatula, Comaster,* Zygometridæ, Pentacrinitida)	0–1350	36.0–80.0
Phrynocrinidæ	508–703	38.1–40.0
Plicatocrinidæ	266–2575	31.1–43.9

2. A ligamentous articulation (or synarthry) between the ossicles of the IBr series.

	Bathymetric range	Thermal range
Pentacrinitidæ (except *Comatula, Comaster,* Zygometridæ, Pentacrinitida)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0

So far as can be ascertained, the union between the plates of the IBr series in the earlier crinoids was by means of a more or less featureless suture.

This suture in the later types became developed into a very distinctive ligamentous articulation known as the synarthry, composed of two lateral ligament bundles separated by a strong dorsoventral ridge running entirely across the apposed articular faces.

The development of a union composed of large and definite ligament bundles from a union of scattered and diffuse fibers occupying a much greater surface indicates a great reduction in the skeleton whereby the original fibers have been collected and compressed into compact bundles, and is therefore an indication of development by suppression of the skeleton forming power.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	3	80–75	1	1
100–200	1	3	75–70	1	3
200–300	2	2	70–65	1	2
300–400	2	2	65–60	1	2
400–500	2	2	60–55	1	2
500–600	3	3	55–50	1	2
600–700	3	3	50–45	1	2
700–800	3	3	45–40	2	2
800–900	2	3	40–35	3	3
900–1000	2	3	35–30	1	2
1000–1500	2	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	740 fathoms	755 fathoms
Average temperature	51.3° Fahr.	51.6° Fahr.

1. Division series composed of an irregular number of ossicles.

	Bathymetric range	Thermal range
Pentacrinitidæ (*Metacrinus, Isocrinus*)	5–667	39.5–71.0
Phrynocrinidæ	508–703	38.1–40.0
Plicatocrinidæ	266–2575	31.1–43.9

2. All of the division series composed of a fixed number of segments.

	Bathymetric range	Thermal range
Pentacrinitidæ (except *Metacrinus* and *Isocrinus*)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0

Like the first division series, the succeeding division series in the more primitive crinoid types were composed of a variable and irregular number of ossicles.

After the evolution of the IBr system, of two ossicles only, interpolated between the radials and the arm bases, this system, as the calyx continued to decrease in size, became developed and extended so as to supplant all of the succeeding division series.

The substitution of the primitive division series of a variable and irregular number of ossicles by a system made up of units of two ossicles each, resulting in a great diminution in the number of elements necessary to support a given number of ultimate arm branches, is an example of specialization through suppression of superfluous skeletal elements.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	3	80–75	0	1
100–200	1	3	75–70	1	3
200–300	2	2	70–65	1	2
300–400	2	2	65–60	1	2
400–500	2	2	60–55	1	2
500–600	3	3	55–50	1	2
600–700	3	3	50–45	1	2
700–800	2	3	45–40	2	2
800–900	1	3	40–35	3	3
900–1000	1	3	35–30	1	2
1000–1500	1	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	698 fathoms	756 fathoms
Average temperature	49.1° Fahr.	51.6° Fahr.

1. The arms occupy only a portion of the distal border of the radials.

	Bathymetric range	Thermal range
Pentacrinitidæ (certain genera of Calometridæ)	0–333	52.9–75.7
Plicatocrinidæ	266–2575	31.1–43.9

2. The arms occupy the entire distal border of the radials.

	Bathymetric range	Thermal range
Pentacrinitidæ (except certain genera of Calometridæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0

In the primitive crinoids and in the young of the comatulids the calyx more or less extensively encloses the visceral mass dorsally and laterally, and the arms occupy only a relatively small part of the distal border of the radials.

But in the more specialized types and in the fully grown comatulids the reduction in size of the calyx and its retreat toward the dorsal pole causes the arms, which always remain of approximately the same relative proportions, gradually to come to occupy the entire distal border of the radials.

The occupation by the arm bases of the entire distal border of the radials is an indication of the reduction in size of the radials and other calyx plates, and hence must be regarded as indicating specialization through suppression or atrophy of the skeletal structures.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	3	80–75	1	1
100–200	1	3	75–70	1	3
200–300	2	2	70–65	1	2
300–400	2	2	65–60	1	2
400–500	1	2	60–55	1	2
500–600	1	4	55–50	1	2
600–700	1	4	50–45	0	2
700–800	1	4	45–40	1	2
800–900	1	3	40–35	1	4
900–1000	1	3	35–30	1	2
1000–1500	1	2	30–25	0	2
1500–2000	1	2			
2000–3000	1	2			

	1	2
Average depth	612 fathoms	747 fathoms
Average temperature	{37.5°, 65.0°} Fahr.	51.0° Fahr.

1. All the arms of equal length.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Comasteridæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Plicatocrinidæ	266–2575	31.1–43.9

2. The posterior arms dwarfed.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comasteridæ)	0–830	44.5–80.0
Holopodidæ	5–120	71.0

The crinoids being primarily and fundamentally pentamerous, all five of their arms (or groups of arms) are primarily of equal size and length.

But in certain types the posterior arms (in the Palæozoic usually the anterior), particularly the left posterior, are more or less dwarfed or atrophied, this resulting in a more or less marked bilateral symmetry in which the anteroposterior axis may pass either through the left posterior arm and the right anterior interambulacral area, or through the anterior arm and the posterior interambulacral area.

The dwarfing or atrophy of one or both of the posterior arms is specialization through partial suppression of the normal arm development.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	2	80–75	1	1
100–200	2	2	75–70	2	2
200–300	3	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	5	1	55–50	2	1
600–700	5	1	50–45	2	1
700–800	5	1	45–40	3	1
800–900	4	1	40–35	5	0
900–1000	4	0	35–30	3	0
1000–1500	3	0	30–25	2	0
1500–2000	3	0			
2000–3000	3	0			

	1	2
Average depth	822 fathoms	359 fathoms
Average temperature	48.6° Fahr.	61.4° Fahr.

1. All the arms terminate in a growing tip.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Comasteridæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Some of the arms terminate in a pair of pinnules.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comasteridæ)	0–830	44.5–80.0

Normally in the crinoids the arms grow continually throughout life, and the arms therefore always terminate in a growing tip.

But in case arm growth is arrested it frequently happens that a definite perfected arm type is acquired which terminates in a pair of pinnules and is capable of no further development.

The presence of (posterior) arms terminating in a pair of pinnules indicates specialization through more or less extensive suppression of the normal arm growth.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	3	1	80–75	1	1
100–200	3	1	75–70	3	1
200–300	2	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	5	1	55–50	2	1
600–700	5	1	50–45	2	1
700–800	5	1	45–40	3	1
800–900	3	1	40–35	5	0
900–1000	3	0	35–30	2	0
1000–1500	2	0	30–25	2	0
1500–2000	2	0			
2000–3000	2	0			

	1	2
Average depth	723 fathoms	450 fathoms
Average temperature	42.9° Fahr.	60.0° Fahr.

1. All the arms are provided with ambulacral grooves.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Comasteridæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. The posterior arms are without ambulacral grooves.

	Bathymetric range	Thermal range
Comasteridæ	0–830	44.5–80.0

In the crinoids all of the arms are normally provided ventrally with ambulacral grooves.

From the posterior arms of certain types, which always are correlatively more or less dwarfed, these ambulacral grooves may be absent.

The absence of ambulacral grooves on the posterior arms (which may involve as many as three of the five radii) indicates specialization through the suppression of one of the most fundamental elements of the arm structure.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	3	1	80–75	1	1
100–200	3	1	75–70	3	1
200–300	2	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	5	1	55–50	2	1
600–700	5	1	50–45	2	1
700–800	5	1	45–40	3	1
800–900	3	1	40–35	5	0
900–1000	3	0	35–30	2	0
1000–1500	2	0	30–25	2	0
1500–2000	2	0			
2000–3000	2	0			

	1	2
Average depth	723 fathoms	450 fathoms
Average temperature	42.9° Fahr.	60.0° Fahr.

V. PINNULES

1. Pinnules, at least the proximal, more or less sharply triangular in cross section.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Macrophreata)	0–1600	34.2–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Pinnules circular or elliptical in cross section.

	Bathymetric range	Thermal range
Pentacrinitidæ (Macrophreata)	0–2900	28.7–79.1

In all of the earlier crinoids in which the structure of the pinnules can be made out these organs are found to be prismatic in form and more or less sharply triangular in cross section, the ambulacral groove occupying a side opposite to a sharp (dorsal) ridge.

In a few highly specialized types the pinnules, instead of being strongly prismatic and triangular in cross section, are more or less cylindrical and circular or elliptical in cross section, with very slender segments and swollen joints.

In the change from the prismatic to the cylindrical type the pinnules lose a very large part of the calcareous substance, becoming very slender; and hence we may look upon this change as correlated with an increasing suppression of the skeleton forming power.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	3	1	80–75	1	1
100–200	3	1	75–70	3	1
200–300	3	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	5	1	55–50	2	1
600–700	5	1	50–45	2	1
700–800	5	1	45–40	3	1
800–900	4	1	40–35	5	1
900–1000	4	1	35–30	3	1
1000–1500	3	1	30–25	1	1
1500–2000	3	1			
2000–3000	2	1			

	1	2
Average depth	754 fathoms	808 fathoms
Average temperature	50.4° Fahr.	52.5° Fahr.

1. All of the pinnules similar.

	Bathymetric range	Thermal range
Pentacrinitidæ (Ptilometrinæ, Atelecrinidæ, Pentacrinitida)	0–1350	36.0–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. The proximal pinnules modified.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comatulida, except Ptilometrinæ and Atelecrinidæ)	0–2900	28.7–80.0

So far as we know the earlier crinoids, like the young comatulids before the appearance of P_1, had all the pinnules similar, except in the cases in which the proximal segments of the lower pinnules were embedded in the calyx wall, when these were enlarged and broadened.

But in the dominant types to-day the proximal pinnules are almost always modified, having lost their original significance and adopted instead the function of slender tactile or stout protective organs.

The modification of the proximal pinnules is always associated with the loss not only of the ambulacral grooves and the associated structures, but also of the genital organs; and it therefore is possible to consider it as an indication of specialization through suppression of all of the functions of pinnules, which has permitted a radical change in their structure.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	3	1	80–75	1	1
100–200	3	1	75–70	3	1
200–300	3	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	5	1	55–50	2	1
600–700	5	1	50–45	2	1
700–800	5	1	45–40	3	1
800–900	4	1	40–35	5	1
900–1000	4	1	35–30	2	1
1000–1500	3	1	30–25	1	1
1500–2000	2	1			
2000–3000	2	1			

	1	2
Average depth	621 fathoms	808 fathoms
Average temperature	51.1° Fahr.	52.5° Fahr.

1. Pinnulation of the arm bases more or less deficient.

	Bathymetric range	Thermal range
Pentacrinitidæ (part of Capillasterinæ, Colobometridæ, Zenometrinæ, Pentametrocrinidæ and Atelecrinidæ, and all of the Perometrinæ)	0–1050	37.0–80.0
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Plicatocrinidæ	266–2575	31.1–43.9

2. All of the proximal pinnules present.

	Bathymetric range	Thermal range
Pentacrinitidæ (except part of Capillasterinæ, Colobometridæ, Zenometrinæ, Pentametrocrinidæ, and Atelecrinidæ, and the Perometrinæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Holopodidæ	5–120	71.0

In the earlier crinoids all of the pinnules were commonly present, but with the decrease in the size of the visceral mass and the corresponding increase in the size and in the length of the arms which we are, in a general way, able to trace from the earlier to the later types, the arm bases became more or less crowded together, so that the development of pinnules on the earlier brachials became impossible.

With the further reduction of the calyx, which chiefly involved the turning outward of the radials so that ultimately they attained a position at right angles to instead of parallel with the dorsoventral axis of the animal, the arms progressively became more and more widely separated, and then, step by step, the proximal pinnules were again able to develop.

Although originally the crinoids possessed all of the proximal pinnules, the primitive condition of the immediate ancestors of the groups to which the recent types belong was a deficient pinnulation of the arm bases. As the reappearance of the pinnules on the arm bases was made possible by, and is therefore directly correlated with, the more advanced stages in the reduction of the calyx, perfection of the proximal pinnulation is in reality an evidence of specialization through a reduction of the more fundamental elements of the skeleton.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	2	80–75	1	1
100–200	2	2	75–70	2	2
200–300	3	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	4	2	55–50	2	1
600–700	4	2	50–45	2	1
700–800	4	2	45–40	3	1
800–900	3	2	40–35	4	2
900–1000	3	2	35–30	2	1
1000–1500	3	1	30–25	1	1
1500–2000	2	1			
2000–3000	2	1			

	1	2
Average depth	763 fathoms	722 fathoms
Average temperature	50.7° Fahr.	52.9° Fahr.

1. Side- and covering-plates highly developed.

	Bathymetric range	Thermal range
Pentacrinitidæ (Calometridæ, Thalassometridæ, Charitometridæ, and Pentacrinitida)	0–1600	34.2–75.7
Apiocrinidæ	565–940	36.7–38.1
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Side- and covering-plates rudimentary.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Calometridæ, Thalassometridæ, Charitometridæ, and Pentacrinitida) ...	0–2900	28.7–80.0
Phrynocrinidæ	508–703	38.1–40.0

Side- and covering-plates, in one form or another, are of almost universal occurrence among the earlier crinoids.

In certain of the later and more specialized types the development of the plates has been more or less completely suppressed.

In this we see a clear example of specialization through suppression of a fundamental structure.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	2	1	80–75	1	1
100–200	2	1	75–70	2	1
200–300	3	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	4	2	55–50	2	1
600–700	4	2	50–45	2	1
700–800	4	2	45–40	3	1
800–900	4	1	40–35	4	2
900–1000	4	1	35–30	3	1
1000–1500	3	1	30–25	1	1
1500–2000	3	1			
2000–3000	2	1			

	1	2
Average depth	794 fathoms	778 fathoms
Average temperature	50.0° Fahr.	51.2° Fahr.

1. All of the pinnules beyond the oral provided with ambulacral grooves.

	Bathymetric range	Thermal range
Pentacrinitidæ (except Comasteridæ and Charitometridæ)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

2. Some or all of the pinnules on certain arms without ambulacral grooves.

	Bathymetric range	Thermal range
Pentacrinitidæ (Comasteridæ, Charitometridæ)	0–1200	39.5–80.0

Primarily all the pinnules on a crinoid arm are similar, and all are provided with ambulacral grooves. In many of the later types, however, the ambulacral grooves on the proximal pinnules have been suppressed.

In other late types not only have the ambulacral furrows and associated structures been suppressed on the proximal pinnules, but also they have disappeared from the genital, and in many cases from all, the pinnules.

The disappearance of the ambulacral grooves and associated structures from the genital and distal pinnules is an instance of specialization through suppression of a fundamental structure.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	3	1	80–75	1	1
100–200	3	1	75–70	3	1
200–300	3	1	70–65	2	1
300–400	3	1	65–60	2	1
400–500	3	1	60–55	2	1
500–600	5	1	55–50	2	1
600–700	5	1	50–45	2	1
700–800	5	1	45–40	3	1
800–900	4	1	40–35	5	1
900–1000	4	1	35–30	3	0
1000–1500	3	1	30–25	2	0
1500–2000	3	0			
2000–3000	3	0			

	1	2
Average depth	822 fathoms	568 fathoms
Average temperature	49.5° Fahr.	57.5° Fahr.

VI. GENERAL

1. Skeleton composed of more than a million ossicles.

	Bathymetric range	Thermal range
Pentacrinitidæ (part of Capillasterinæ, Comasterinæ, Zygometridæ, Himerometridæ, Mariametridæ, Colobometridæ, and Heliometrinæ, and Pentacrinitida)	0–1350	28.7–80.0

2. Skeleton composed of less than a million ossicles.

	Bathymetric range	Thermal range
Pentacrinitidæ (except part of Capillasterinæ, Comasterinæ, Zygometridæ, Himerometridæ, Mariametridæ, Colobometridæ, and Heliometrinæ, and Pentacrinitida)	0–2900	28.7–80.0
Apiocrinidæ	565–940	36.7–38.1
Phrynocrinidæ	508–703	38.1–40.0
Bourgueticrinidæ	62–2690	29.1–70.75
Holopodidæ	5–120	71.0
Plicatocrinidæ	266–2575	31.1–43.9

In the older crinoids the skeleton was usually composed of an enormous number of ossicles.

In the later and more specialized types the individual skeletal elements are as a rule very much less in number.

This is a good example of specialization through suppression.

Frequency at different depths			Frequency at different temperatures		
Fathoms	1	2	Degrees Fahrenheit	1	2
0–100	1	3	80–75	1	1
100–200	1	3	75–70	1	3
200–300	1	3	70–65	1	2
300–400	1	3	65–60	1	2
400–500	1	3	60–55	1	2
500–600	1	5	55–50	1	2
600–700	1	5	50–45	1	2
700–800	1	5	45–40	1	3
800–900	1	4	40–35	1	5
900–1000	1	4	35–30	1	3
1000–1500	1	3	30–25	1	2
1500–2000	0	3			
2000–3000	0	3			

	1	2
Average depth	568 fathoms	822 fathoms
Average temperature	52.5° Fahr.	49.5° Fahr.

THE FAMILIES OF RECENT CRINOIDS, WITH THE CHARACTERS, AS PREVIOUSLY GIVEN, PRESENTED BY EACH

In the following pages each of the families including recent crinoids is given, together with the characters as just described which it presents.

PENTACRINITIDÆ

Calyx

2. Calyx forming a platform upon which the viscera rest, more or less supported by the arm bases.
2. Calyx reduced by the eversion and imbrication of the calyx plates.
    1. Basals present (minority).
    2. Basals absent (majority).
1. Five basals.
    1. Basals separate (minority).
    2. Basals fused into a single calcareous plate (majority).
    1. Infrabasals present as individual plates (minority).
    2. Infrabasals absent, or fused with other plates (majority).
    1. Five radials (majority).
    2. Ten radials (minority).
    1. Interradials present (minority).
    2. Interradials absent (majority).
    1. Anal *x*, bearing a process, present (minority).
    2. Anal *x*, bearing a process, absent (majority).
    1. Interbrachials present (large minority).
    2. Interbrachials absent (small majority).

Column

2. Original column discarded in early life.
2. Column not composed of short cylindrical ossicles with radial crenellæ.
2. Column including modified columnals, a proximale or nodals.

(1. Column terminating in an expanded terminal stem plate.)

(2. Radicular cirri absent.)

2. Cirri present.

Disk

    1. Disk entirely covered with plates (minority).
    2. Disk naked, or with scattered granules (majority).
    1. Orals present (minority).
    2. Orals absent (majority).
2. All five orals of the same size.
    1. Orals with their inner edges upturned (minority).
    2. Orals a spherical triangle (majority).
    1. Mouth central (majority).
    2. Mouth more or less excentric (minority).

Arms

1. Arms composed of a linear series of ossicles, without IBr series (minority).
2. Arms dividing one or more times, or, if undivided, with IBr series (majority).
1. Arms with IBr series in which the outer element is axillary (majority).
2. Arms with IBr series in which the outer element is not axillary (minority).
1. The first bifurcation is at a more or less indefinite distance beyond the second post-radial ossicle (minority).
2. The first bifurcation is on the second post-radial ossicle (majority).
1. A suture between the ossicles of the IBr series (minority).
2. A ligamentous articulation in the IBr series (majority).
1. Division series composed of an irregular number of elements (minority).
2. Division series composed of a fixed number of elements (majority).
1. The arms occupy only a portion of the border of the radials (minority).
2. The arms occupy the entire distal border of the radials (majority).
1. All the arms of equal length (majority).
2. The posterior arms dwarfed (minority).
1. All the arms terminate in a growing tip (majority).
2. Some of the arms end in a pair of pinnules (minority).
1. All of the arms are provided with ambulacral grooves (majority).
2. The posterior arms are without ambulacral grooves (minority).

Pinnules

1. Pinnules, at least the proximal, more or less sharply triangular in cross section (majority).
2. Pinnules circular or elliptical in cross section (minority).
1. All of the pinnules similar (minority).
2. The proximal pinnules modified (majority).
1. Pinnulation of the arm bases more or less deficient (minority).
2. All of the proximal pinnules present (majority).
1. Side- and covering-plates highly developed (minority).

2. Side- and covering-plates rudimentary (majority).
1. All of the pinnules beyond the oral provided with ambulacral grooves (majority).
2. Some or all of the pinnules on certain arms without ambulacral grooves (minority).

General

1. Skeleton composed of more than a million ossicles (minority).
2. Skeleton composed of less than a million ossicles (majority).

APIOCRINIDÆ

Calyx

2. Calyx forming a platform upon which the viscera rest more or less supported by the arm bases.
2. Calyx reduced by the eversion and imbrication of the calyx plates.
1. Basals present.
1. Five basals.
1. Basals separate.
1. Five radials.
2. Interradials absent.
2. Anal *x* absent.
2. Interbrachials absent.

Column

1. Entire column present.
1. Column jointed.
2. Column not composed of short cylindrical ossicles with radial crenellæ.
   1. Column composed of a single type of columnals, without a proximale or nodals (half).
   2. Column including modified columnals, a proximale or nodals (half).
1. Column terminating in an expanded terminal stem plate.
2. Radicular cirri absent.
   1. Cirri absent (half).
   2. Cirri present (half).

Arms.

2. Arms dividing one or more times, with IBr series.
1. Arms with IBr series in which the outer element is axillary.
2. The first bifurcation is on the second post-radial ossicle.

2. A ligamentous articulation between the ossicles of the IBr series.
2. Division series composed of a fixed number of ossicles.
2. The arms occupy the entire distal border of the radials.
1. All the arms of equal length.
1. All the arms terminate in a growing tip.
1. All the arms are provided with ambulacral grooves.

Pinnules

1. Pinnules more or less sharply triangular in cross section.
1. All of the pinnules similar.
2. All of the proximal pinnules present.
1. Side- and covering-plates highly developed.
1. All of the pinnules provided with ambulacral grooves.

General

2. Skeleton composed of less than a million ossicles.

PHRYNOCRINIDÆ

Calyx

2. Calyx forming a platform upon which the viscera rest, more or less supported by the arm bases.
    1. Calyx reduced by the moving inward of all the calyx plates (half).
    2. Calyx reduced by the eversion and imbrication of the calyx plates (half).
1. Basals present.
1. Five basals.
1. Basals separate.
1. Five radials.
2. Interradials absent.
2. Anal *x* absent.
2. Interbrachials absent.

Column

1. Entire column present.
1. Column jointed.
2. Column not composed of short cylindrical ossicles with radial crenellæ.
2. Column including modified columnals, a proximale or nodals.
1. Column terminating in an expanded terminal stem plate.
2. Radicular cirri absent.
1. Cirri absent.

Disk

2. Disk naked.
2. Orals absent.
1. Mouth central.

Arms

2. Arms dividing one or more times, but without IBr series.
1. The first bifurcation is at a more or less indefinite distance beyond the second post-radial ossicle.
1. A suture between the ossicles of the IBr series.
1. Division series composed of an irregular number of ossicles.
2. The arms occupy the entire distal border of the radials.
1. All the arms of equal length.
1. All the arms terminating in a growing tip.
1. All the arms provided with ambulacral grooves.

Pinnules

1. Pinnules more or less sharply triangular in cross section.
1. All of the pinnules similar.
1. Pinnulation of the arm bases more or less deficient.
2. Side- and covering-plates rudimentary.
1. All of the pinnules provided with ambulacral grooves.

General

2. Skeleton composed of less than a million ossicles.

BOURGUETICRINIDÆ

Calyx

2. Calyx forming a platform upon which the viscera rest, more or less supported by the arm bases.
1. Calyx reduced by the moving inward of all the calyx plates.
1. Basals present.
1. Five basals.
    1. Basals separate (half).
    2. Basals fused into a single calcareous element (half).
2. No infrabasals.
1. Five radials.
2. Interradials absent.
2. Anal *x* absent.
2. Interbrachials absent.

Column

1. Entire column present.
1. Column jointed.
2. Column not composed of short cylindrical ossicles with radial crenellæ.
2. Column including modified columnals, a proximale or nodals.
2. Column without a terminal stem plate.
1. Radicular cirri present.
1. Cirri absent.

Disk

2. Disk naked.
2. Orals absent.
1. Mouth central.

Arms

2. Arms with IBr series.
1. Arms with IBr series in which the outer element is axillary.
2. The first bifurcation is on the second post-radial ossicle.
2. A ligamentous articulation between the ossicles of the IBr series.
2. Division series composed of a fixed number of ossicles.
2. The arms occupy the entire distal border of the radials.
1. All the arms are of equal length.
1. All the arms terminate in a growing tip.

Pinnules

1. Pinnules more or less sharply triangular in cross section.
1. All of the pinnules similar.
1. Pinnulation of the arm bases more or less deficient.
1. Side- and covering-plates highly developed.
1. All of the pinnules provided with ambulacral grooves.

General

2. Skeleton composed of less than a million ossicles.

HOLOPODIDÆ

Calyx

1. Calyx in the form of a cup, protecting the viscera dorsally and laterally.
2. No basals.
2. No infrabasals.

1. Five radials.
2. Interradials absent.
2. Anal *x* absent.
2. Interbrachials absent.

Column

1. Entire column present.
2. Column unjointed.
2. Column not composed of short cylindrical ossicles with radial crenellæ.
1. Column terminating in an expanded terminal stem plate.
2. Radicular cirri absent.
1. Cirri absent.

Disk

1. Disk entirely covered with plates.
1. Orals present.
2. All five orals of the same size.
2. Orals a spherical triangle.
1. Mouth central.

Arms

2. Arms dividing once, with IBr series.
1. Arms with IBr series in which the outer element is axillary.
2. The first bifurcation is on the second post-radial ossicle.
2. A ligamentous articulation between the elements of the IBr series.
2. Division series composed of a fixed number of ossicles.
2. The arms occupy the entire distal border of the radials.
2. The posterior arms are dwarfed.
1. All the arms terminate in a growing tip.
1. All the arms are provided with ambulacral grooves.

Pinnules

1. Pinnules more or less sharply triangular in cross section.
1. All of the pinnules similar.
2. All of the proximal pinnules present.
1. Side- and covering-plates highly developed.
1. All of the pinnules provided with ambulacral grooves.

General

2. Skeleton composed of less than a million ossicles.

PLICATOCRINIDÆ

Calyx

1. Calyx in the form of a cup, protecting the visceral mass dorsally and laterally.
1. Basals present.
   1. Five basals (minority).
   2. Three basals (majority).
   1. Basals separate (majority).
   2. Basals fused into a single calcareous element (minority).
2. No infrabasals.
1. Five radials.
2. Interradials absent.
2. Anal *x* absent.
1. Interbrachials present.

Column

1. Entire column present.
1. Column jointed.
1. Column composed of short cylindrical columnals with radial crenellæ.
1. Column composed of a single type of columnals, without a proximale or nodals.
1. Column terminating in an expanded terminal stem plate.
2. Radicular cirri absent.
1. Cirri absent.

Disk

1. Disk entirely covered with plates.
1. Orals present.
1. Orals of different sizes.
   2. Orals a spherical triangle (minority).
   1. Orals with upturned inner edges (majority).
1. Mouth central.

Arms

   1. Arms composed of a linear series of ossicles, without IBr series (majority).
   2. Arms dividing one or more times, without IBr series (minority).
1. The first bifurcation is at a more or less indefinite distance from the second post-radial ossicle.
1. A suture between the first two post-radial ossicles.

1. Division series composed of an irregular number of ossicles.
1. The arms occupy only a portion of the distal border of the radials.
1. All the arms are of equal length.
1. All the arms terminate in a growing tip.
1. All the arms are provided with ambulacral grooves.

Pinnules

1. Pinnules more or less sharply triangular in cross section.
1. All of the pinnules similar.
1. Pinnulation of the arm bases more or less deficient.
1. Side- and covering-plates highly developed.
1. All of the pinnules provided with ambulacral grooves.

General

2. Skeleton composed of less than a million ossicles.

THE OCCURRENCE IN THE VARIOUS FAMILIES OF BOTH COMPONENTS OF CONTRASTING PAIRS

Excepting for the Holopodidæ, which is represented in the existing seas by only a single species, all of the families of recent crinoids agree in exhibiting, in closely related genera included in them, both of the contrasted characters in a greater or lesser number of pairs.

The number of entire pairs included in the various families is apparently proportionate to the known recent representation of each family. It is largest in the Pentacrinitidæ, which includes by far the greater part of all the existing types.

In detail the contrasted pairs in each family are as follows:

PENTACRINITIDÆ

I. *Calyx*

The presence or absence of basals.
The individual occurrence, or fusion, of the basals.
The presence or absence of infrabasals.
The occurrence of five or ten radials.
The presence or absence of interradials.
The presence or absence of anal *x*.
The presence or absence of interbrachials.

III. *Disk*

The presence or absence of plating on the disk.

The presence or absence of orals.

The condition of the orals, whether with or without upturned edges.

The central or excentric position of the mouth.

IV. *Arms*

The structure of the arms, whether a linear series of ossicles without IBr series, or dividing one or more times, or with IBr series.

The condition of the IBr_2, whether axillary or not.

The position of the first post-radial axillary, whether on the second post-radial plate or beyond.

The type of the union between the plates of the IBr series, whether a suture (pseudo-syzygy) or a synarthry.

The condition of the division series, including a definite or an indefinite number of plates.

The condition of the union between the radials and the arm bases, whether or not the latter occupy the entire distal border of the former.

The equality or inequality in the length of the arms.

The definite or indefinite termination of the arms.

The presence or absence of ambulacral grooves on all the arms.

V. *Pinnules*

The prismatic or cylindrical form of the pinnules.

The presence or absence of differentiation of the proximal pinnules.

The development or non-development of side- and covering-plates.

The presence or absence of ambulacral grooves on all the pinnules.

VI. *General*

The presence of more or less than a million skeletal elements.

PLICATOCRINIDÆ

I. *Calyx*

Five or fewer basals.

The individual occurrence, or fusion, of the basals.

III. *Disk*

The condition of the orals, whether with or without upturned edges.

IV. *Arms*

The structure of the arms, whether a linear series of ossicles without IBr series, or dividing one or more times, or with IBr series.

BOURGUETICRINIDÆ

I. *Calyx*

The individual occurrence, or fusion, of the basals.

IV. *Arms*

The condition of the IBr_2, whether axillary or not.

APIOCRINIDÆ

II. *Column*

The presence or absence of nodals.
The presence or absence of cirri.

PHRYNOCRINIDÆ

I. *Calyx*

The method of reduction of the calyx.

THE CRINOID FAMILIES CONSIDERED AS THE SUM OF THE CONTRASTED CHARACTERS EXHIBITED BY THEM

If we take each crinoid family, and, for each of the structural divisions given (Calyx, Column, Disk, Arms, Pinnules and General Structure), add the primitive characters (1) and the specialized characters (2), the difference between the two totals will give us an index of the relative condition of specialization of each of the different structural units.

The figures are as follows:

PENTACRINITIDÆ

Calyx	8 (1)	9 (2)	difference	1 (2)
Column	1 (1)	5 (2)	"	4 (2)
Disk	4 (1)	5 (2)	"	1 (2)
Arms	9 (1)	9 (2)	"	0
Pinnules	5 (1)	5 (2)	"	0
General	1 (1)	1 (2)	"	0
	28 (1)	34 (2)	difference	6 (2)

APIOCRINIDÆ

Calyx	4 (1)	5 (2)	difference 1 (2)
Column	5 (1)	4 (2)	" 1 (1)
Arms	4 (1)	5 (2)	" 1 (2)
Pinnules	4 (1)	1 (2)	" 3 (1)
General	0	1 (2)	" 1 (2)
	17 (1)	16 (2)	difference 1 (1)

PHRYNOCRINIDÆ

Calyx	5 (1)	5 (2)	difference 0
Column	4 (1)	3 (2)	" 1 (1)
Disk	1 (1)	2 (2)	" 1 (2)
Arms	6 (1)	2 (2)	" 4 (1)
Pinnules	4 (1)	1 (2)	" 3 (1)
General	0	1 (2)	" 1 (2)
	20 (1)	14 (2)	difference 6 (1)

BOURGUETICRINIDÆ

Calyx	5 (1)	6 (2)	difference 1 (2)
Column	4 (1)	3 (2)	" 1 (1)
Disk	1 (1)	2 (2)	" 1 (2)
Arms	3 (1)	5 (2)	" 2 (2)
Pinnules	5 (1)	0	" 5 (1)
General	0	1 (2)	" 1 (2)
	18 (1)	17 (2)	difference 1 (1)

HOLOPODIDÆ

Calyx	2 (1)	5 (2)	difference 3 (2)
Column	3 (1)	3 (2)	" 0
Disk	3 (1)	2 (2)	" 1 (1)
Arms	3 (1)	6 (2)	" 3 (2)
Pinnules	4 (1)	1 (2)	" 3 (1)
General	0	1 (2)	" 1 (2)
	15 (1)	18 (2)	difference 3 (2)

PLICATOCRINIDÆ

Calyx	6 (1)	5 (2)	difference 1 (1)
Column	6 (1)	1 (2)	" 5 (1)
Disk	5 (1)	1 (2)	" 4 (1)
Arms	8 (1)	1 (2)	" 7 (1)
Pinnules	5 (1)	0	" 5 (1)
General	0	1 (2)	" 1 (2)
	30 (1)	9 (2)	difference 21 (1)

In this connection the Pentacrinitidæ deserve more detailed examination. Very many characters are represented in this exceedingly large and very heterogeneous group by both components of the contrasted pairs, one of which is found in a—usually large—majority, while the other occurs in a—usually small—minority of the genera.

In the preceding lists the totals represent all of the characters under each heading; hence many characters in this family are given in the totals for both (1) and (2); such characters are neutral so far as their effect upon the general total is concerned.

If we eliminate this neutralization of one of the components of a pair by the other by considering only the components of each pair which are either represented alone or in the majority of the genera our results will naturally be somewhat different.

This method will give us the average state of specialization to which the family has attained, through eliminating the influence of a few conservative types which by the other method are accorded far more than their true phylogenetic importance.

	Total of all the characters	Total of the majority components, or the components singly represented, of each pair	Total of all the characters	Total of the majority components, or the components singly represented, of each pair		Total of all the characters	Total of the majority components, or the components singly represented, of each pair
Calyx	8 (1)	2 (1)	9 (2)	8 (2)	difference	1 (2)	6 (2)
Column	1 (1)	1 (1)	5 (2)	5 (2)	difference	4 (2)	4 (2)
Disk	4 (1)	1 (1)	5 (2)	4 (2)	difference	1 (2)	3 (2)
Arms	9 (1)	4 (1)	9 (2)	5 (2)	difference	0	1 (2)
Pinnules	5 (1)	2 (1)	5 (2)	3 (2)	difference	0	1 (2)
General	1 (1)	0	1 (2)	1 (2)	difference	0	1 (2)
	28 (1)	10 (1)	34 (2)	26 (2)	difference	6 (2)	16 (2)

THE TRUE PHYLOGENETIC SEQUENCE OF THE CRINOID FAMILIES HAVING RECENT REPRESENTATIVES

Judged on the basis of the preceding tables, the proper phylogenetic sequence of the crinoid families including recent species is as follows:

Pentacrinitidæ	28 (1)	[10 (1)]	34 (2)	[26 (2)]	difference	6 (2)	[16 (2)]
Holopodidæ	15 (1)		18 (2)		"	3 (2)	
Bourgueticrinidæ	18 (1)		17 (2)		"	1 (1)	
Apiocrinidæ	17 (1)		16 (2)		"	1 (1)	
Phrynocrinidæ	20 (1)		14 (2)		"	6 (1)	
Plicatocrinidæ	30 (1)		9 (2)		"	21 (1)	
	128 (1)	[110 (1)]	108 (2)	[100 (2)]	difference	20 (1)	[10 (1)]

According to the table just given the true phylogenetic arrangement of the families of recent crinoids, together with their relative positions in the scale of phylogenetic advancement, reckoning from the Plicatocrinidæ as the least specialized type, is as follows:

Pentacrinitidæ	+6 (+16)	or 30 (40)
Holopodidæ	+3	or 24
Bourgueticrinidæ	—1	or 20+
Apiocrinidæ	—1	or 20—
Phrynocrinidæ	—6	or 15
Plicatocrinidæ	—21	or 1

THE RELATIVE SPECIALIZATION OF EACH STRUCTURAL UNIT IN THE CRINOID FAMILIES INCLUDING RECENT SPECIES

In the various families the several structural units are not necessarily correlated in the amount of specialization they exhibit. The sequence in each family, as deduced from the preceding tables, is as follows, the most specialized structural unit being in each case placed at the head of the list, and units of equal value being bracketed.

Pentacrinitidæ	Apiocrinidæ	Phrynocrinidæ	Bourgueticrinidæ	Holopodidæ	Plicatocrinidæ
Column	{Calyx	Disk	Arms	Arms	General
Calyx	Arms}	General	Calyx	Calyx	Calyx
Disk	General	Calyx	Disk	General	Disk
{Arms	Column	Column	General	Column	Column
Pinnules	Pinnules	Pinnules	Column	Disk	Pinnules
General}	(No disk)	Arms	Pinnules	Pinnules	Arms

THE PHYLOGENETIC SEQUENCE OF THE RECENT CRINOIDS ON THE BASIS OF THE RELATIVE SPECIALIZATION OF EACH OF ITS COMPONENT STRUCTURAL UNITS

If we take each structural unit and in each family assign to it a number (from 1 to 6) according to its condition of specialization in reference to all the other families (if of the same value in two or more families giving it the same number in each), the family showing the lowest total will be the one which, as the sum total of all these structural units, is the most specialized.

The figures are given in the following table; the figure 1 indicates the maximum specialization for each structural unit, and the figure 6 the minimum.

	Calyx.	Column.	Disk.	Arms.	Pinnules.	General.	Total.
Holopodidæ	1	2	3	1	2	1	10
Pentacrinitidæ	2	1	1	4	1	2	11
Apiocrinidæ	4	3	0	3	2	1	13
Bourgueticrinidæ	3	4	2	2	3	1	15
Phrynocrinidæ	5	4	2	5	2	1	19
Plicatocrinidæ	6	5	4	6	3	1	25

If, however, we consider the Pentacrinitidæ on the basis of the average specialization, that is, if we consider each of the pairs of characters of which it exhibits both components on the basis of the majority representation alone, disregarding the small minority representation, this family easily takes precedence over the Holopodidæ.

EXAMINATION OF EACH OF THE STRUCTURAL UNITS IN DETAIL

A critical study of each structural unit, on the basis of the contrasted characters as previously given, is of considerable interest.

In the following tables each of these units is listed separately, the families in each case being arranged according to their relative specialization in regard to the unit under consideration, with the most specialized at the head of the list.

When the total is the same in two families, the one which possesses the higher number of specialized characters (or the lesser number of generalized characters) is given precedence. Families with identical totals are bracketed.

Calyx

1. Holopodidæ	2 (1)	5 (2)	difference	3 (2)
2. Pentacrinitidæ	8 (1)	9 (2)	"	1 (2)
3. Bourgueticrinidæ	5 (1)	6 (2)	"	1 (2)
4. Apiocrinidæ	4 (1)	5 (2)	"	1 (2)
5. Phrynocrinidæ	5 (1)	5 (2)	"	0
6. Plicatocrinidæ	6 (1)	5 (2)	"	1 (1)
	30 (1)	35 (2)	difference	5 (2)

Column

1. Pentacrinitidæ	1 (1)	5 (2)	difference	4 (2)
2. Holopodidæ	3 (1)	3 (2)	"	0
3. Apiocrinidæ	5 (1)	4 (2)	"	1 (1)
4. {Phrynocrinidæ	4 (1)	3 (2)	"	1 (1)
4. {Bourgueticrinidæ	4 (1)	3 (2)	"	1 (1)
5. Plicatocrinidæ	6 (1)	1 (2)	"	5 (1)
	23 (1)	19 (2)	difference	4 (1)

Disk

1.	Pentacrinitidæ	4 (1)	5 (2)	difference	1 (2)
2.	Phrynocrinidæ	1 (1)	2 (2)	"	1 (2)
	Bourgueticrinidæ	1 (1)	2 (2)	"	1 (2)
3.	Holopodidæ	3 (1)	2 (2)	"	1 (1)
4.	Plicatocrinidæ	5 (1)	1 (2)	"	4 (1)
5.	Apiocrinidæ	.....	.....		.....
		14 (1)	12 (2)	difference	2 (1)

Arms

1.	Holopodidæ	3 (1)	6 (2)	difference	3 (2)
2.	Bourgueticrinidæ	3 (1)	5 (2)	"	2 (2)
3.	Apiocrinidæ	4 (1)	5 (2)	"	1 (2)
4.	Pentacrinitidæ	9 (1)	9 (2)	"	0
5.	Phrynocrinidæ	6 (1)	2 (2)	"	4 (1)
6.	Plicatocrinidæ	8 (1)	1 (2)	"	7 (1)
		33 (1)	28 (2)	difference	5 (1)

Pinnules

1.	Pentacrinitidæ	5 (1)	5 (2)	difference	0
2.	Apiocrinidæ	4 (1)	1 (2)	"	3 (1)
	Phrynocrinidæ	4 (1)	1 (2)	"	3 (1)
	Holopodidæ	4 (1)	1 (2)	"	3 (1)
3.	Bourgueticrinidæ	5 (1)	0	"	5 (1)
	Plicatocrinidæ	5 (1)	0	"	5 (1)
		27 (1)	8 (2)	difference	19 (1)

General

1.	Apiocrinidæ	0	1 (2)	difference	1 (2)
	Phrynocrinidæ	0	1 (2)	"	1 (2)
	Bourgueticrinidæ	0	1 (2)	"	1 (2)
	Holopodidæ	0	1 (2)	"	1 (2)
	Plicatocrinidæ	0	1 (2)	"	1 (2)
2.	Pentacrinitidæ	1 (1)	1 (2)	"	0
		1 (1)	6 (2)	difference	5 (2)

As shown by the preceding tables, the relative condition of specialization of the various structural units is as follows:

General	1 (1)	6 (2)	difference	5 (2)
Calyx	30 (1)	35 (2)	"	5 (2)
Disk	14 (1)	12 (2)	"	2 (1)
Column	23 (1)	19 (2)	"	4 (1)
Arms	33 (1)	28 (2)	"	5 (1)
Pinnules	27 (1)	8 (2)	"	19 (1)
	128 (1)	108 (2)	difference	20 (1)

This, however, is not a strictly correct presentation of the case.

In dealing with the families we considered in each the same number of contrasted characters and, with a few exceptions, each pair was represented in each family, so that the totals were directly comparable.

But the number of the contrasted pairs considered in the various structural units varies very greatly, running from 1 to 10. As there are six families, the actual number of pairs and the actual number of characters for each structural unit is as follows:

Structural unit	Pairs of contrasted characters	Total number of pairs in all the families	Total number of characters considered
Calyx	10	60	120
Arms	9	54	108
Column	7	42	84
Disk	5	30	60
Pinnules	5	30	60
General Structure	1	6	12

Thus in order to raise the figures for all the structural units in all the families to the same relative value it is necessary to multiply each by the following numbers:

Calyx	10 x 63 x 6—3780	Disk	5 x 126 x 6—3780
Arms	9 x 70 x 6—3780	Pinnules	5 x 126 x 6—3780
Column	7 x 90 x 6—3780	General	1 x 630 x 6—3780

Applying these multiples to the table (the figures of which already include the multiple 6) we have:

General	630 (1)	3780 (2)	difference	3150 (2)
Calyx	1890 (1)	2205 (2)	"	315 (2)
Disk	1764 (1)	1512 (2)	"	252 (1)
Arms	2310 (1)	1960 (2)	"	350 (1)
Column	2070 (1)	1710 (2)	"	360 (1)
Pinnules	3402 (1)	1008 (2)	"	2394 (1)

In terms of the least specialized structural unit (the pinnules) this gives us the following ratios of specialization:

	According to the first table		According to the second table	
General	+5	24	+3150	5544
Calyx	+5	24	+315	2709
Disk	—2	17	—252	2142
Arms	—5	14	—350	2044
Column	—4	15	—360	2034
Pinnules	—19	1	—2394	1

THE CORRECTED RELATIVE SEQUENCE OF THE RECENT CRINOIDS ON THE BASIS OF THE RELATIVE SPECIALIZATION OF EACH OF ITS COMPONENT STRUCTURAL UNITS

In order to appreciate correctly the phylogenetic sequence of the recent crinoids on the basis of the relative specialization of each of its component structural units, it is necessary to apply as a correction the foregoing figures, representing the relative state of the specialization of each structural unit in terms of the least specialized.

To do this we may make use of the table given on p. 63, modified so that the least specialized structural unit will be indicated by the number 1, and the most specialized by the number 6 (that is, with the figures reversed), multiplying each number by the relative value of the structural unit under consideration in terms of the pinnules.

Applying both sets of figures given above, we get the following tables:

Applying the figures of the first table:

	Calyx	Column	Disk	Arms	Pinnules	General	Total	Relative standing of the families, the Plicatocrinidæ being taken as 100
Holopodidæ	144	60	34	84	2	48	372	312
Pentacrinitidæ	120	75	68	42	3	24	332	279
Bourgueticrinidæ	96	30	51	70	1	48	296	248
Apiocrinidæ	72	45	0	56	2	48	223	187
Phrynocrinidæ	48	30	51	28	2	48	207	174
Plicatocrinidæ	24	15	17	14	1	48	119	100

Applying the figures of the second table:

	Calyx	Column	Disk	Arms	Pinnules	General	Total	Relative standing of the families, the Plicatocrinidæ being taken as 100
Holopodidæ	16254	8136	4284	12264	2	11088	52028	259
Pentacrinitidæ	13545	10170	8568	6132	3	5544	43962	219
Bourgueticrinidæ	10836	4068	6426	10220	1	11088	42639	213
Apiocrinidæ	8127	6102	0	8176	2	11088	33495	167
Phrynocrinidæ	5418	4068	6426	4088	2	11088	31090	155
Plicatocrinidæ	2709	2034	2142	2044	1	11088	20018	100

The figures upon which these tables are based are:

Holopodidæ	6	4	2	6	2	2	22
Pentacrinitidæ	5	5	4	3	3	1	21
Apiocrinidæ	3	3	0	4	2	2	14
Bourgueticrinidæ	4	2	3	5	1	2	17
Phrynocrinidæ	2	2	3	2	2	2	13
Plicatocrinidæ	1	1	1	1	1	2	7

It will be seen that these corrected figures give the same sequence of families as the table summarizing the characters in each family (p. 60), except that the Holopodidæ come before the Pentacrinitidæ.

It differs from the sequence of the families on the basis of the uncorrected figures for the structural units in that the position of the Bourgueticrinidæ and the Apiocrinidæ is reversed.

If we judge the phylogenetic status of the Pentacrinitidæ on the basis of its average development, by considering only the character in each pair having the majority representation and leaving out of consideration the primitive features exhibited only by a negligible percentage of the species, the Pentacrinitidæ occupy a position well in advance of that of the Holopodidæ.

The Bourgueticrinidæ and the Apiocrinidæ undoubtedly are on very nearly the same plane, as is evident on even a superficial survey of their fossil species. Judging from the general structure of the recent genera the disk of the recent Apiocrinidæ, as yet not known, is probably more like that of the stalked pentacrinites than like that of the Bourgueticrinidæ or of the comatulids; if so, this would emphasize the phylogenetically advanced position of the Bourgueticrinidæ.

From the three tables showing the relative phylogenetic status of the crinoid families including recent species we get the following differences between each family and the family below it:

	From the table on p. 60	From the table on p. 64 (1st)	From the table on p. 64 (2nd)
Pentacrinitidæ	6	33	40
Holopodidæ	4	31	6
Bourgueticrinidæ	0	61	46
Apiocrinidæ	5	13	12
Phrynocrinidæ	14	74	55
Plicatocrinidæ	0	0	0

This indicates that there is a very broad phylogenetic gap between the Plicatocrinidæ (belonging to the Inadunata) and the remaining families (all of which belong to the Articulata). There is another broad gap between the Bourgueticrinidæ and the Apiocrinidæ.

Thus it would appear that the crinoid families represented in the recent seas, on the basis of their recent representation, fall into three well marked groups separated by broad phylogenetic gaps, as follows:

Group 1	Group 2	Group 3
Pentacrinitidæ Holopodidæ Bourgueticrinidæ	Apiocrinidæ Phrynocrinidæ	Plicatocrinidæ

THE RELATION BETWEEN PHYLOGENETIC DEVELOPMENT AND BATHYMETRICAL AND THERMAL DISTRIBUTION

The relationship of phylogenetic development to depth and to temperature presents a problem of considerable interest.

In the following table is given the amount of excess of the more primitive (1) or the more specialized (2) characters in each of the thirty-seven contrasted pairs.

Depth. Excess of		Temperature. Excess of		Depth. Excess of		Temperature. Excess of	
1	2	1	2	1	2	1	2
768	..	..	25.2	..	15	..	2.2
463	..	..	17.1	..	23	..	2.1
382	..	..	17.1	..	23	..	1.4
273	..	..	16.7	..	35	..	1.4
273	..	..	13.7	..	54	..	1.3
254	..	..	13.7	..	56	..	1.2
223	..	..	13.5	..	58	..	0.3
207	..	..	12.8	..	72	0.5	..
189	..	..	12.6	..	84	*0.5	..
156	..	..	8.0	..	84	1.5	..
107	..	..	7.2	..	135	2.1	..
72	..	..	5.9	..	156	2.1	..
48	..	..	5.1	..	156	3.0	..
41	..	..	5.0	..	187	7.2	..
23	..	..	3.8	..	212	7.5	..
23	..	..	*3.3	..	240	*8.3	..
16	..	..	2.5	..	254	9.8	..
6	..	..	2.5	..	255	13.7	..
..	3	..	2.5	..	..	..	..

In the temperature column the three figures marked with an asterisk (*) represent the difference between two sharply marked nodes in a single character pair.

These double nodes all fall under the more primitive characters (1). The difference between each element of the three double nodes and the average under the more specialized characters (2) are:

1	2
12.1	15.4
14.0	13.5
20.9	12.6

In the bathymetric distribution the more primitive components of the character pairs exceed the more specialized in 18 cases, while the reverse is true in 19 cases.

In the thermal distribution the more specialized components of the character pairs exceed the more primitive in 26 cases, the reverse being true in 11 cases.

The excess in depth of the primitive characters over that of the specialized is 1422 fathoms, each of the 18 primitive characters having an average depth of 196 fathoms, as against 110 fathoms for each of the 19 specialized characters.

The excess in temperature of the specialized characters over that of the primitive is 141.9°, each of the 26 specialized characters having an average temperature of 7.6°, as against 5.1° for each of the 11 primitive characters.

Thus it appears that, taken collectively, the specialized characters are developed in shallower and warmer water than the more primitive.