the changes in its excess energy content. In calcite the change in crystal angles with temperature is practically linear up to 600°. This indicates that in quartz the excess in energy content represents an internal reaction or equilibrium condition which eventually causes the inversion. It will be of interest to study other minerals, showing inversion points, with respect to their energy content and crystallographical and optical properties at different temperatures; also to ascertain the form of the curves near the melting points.

PALAEONTOLOGY.—*The systematic position of the Crinoid family Plicatocrinidae.* AUSTIN H. CLARK, National Museum.

In the preparation of the section dealing with the Crinoidea in the new edition (1913) of Eastman's translation of Zittel's *Palaeontologie*, Springer and Clark[1] were unable to come to a satisfactory conclusion regarding the proper systematic position of the family Plicatocrinidae (as defined by us including the genera *Plicatocrinus, Hyocrinus, Gephyrocrinus, Thalassocrinus, Ptilocrinus* and *Calamocrinus*), which we tentatively placed among the Crinoidea Articulata, just beyond the comatulids, the young of which the species in this family greatly resemble.

The Articulata include all of the other recent crinoids so far discovered and this fact, together with the close resemblance of the species of Plicatocrinidae to the young of the comatulids, was largely responsible for our placing this family here. But the species of the Plicatocrinidae differ from all of the other forms included in the Articulata in a number of most important and fundamental features.

1. The tegmen is entirely covered with a pavement of solid plates.

2. The orals are always present; they are not plane or spherical triangles, as they are in all of the (comparatively few) species of Articulata which possess them, but their edges are turned upwards so that instead of presenting five sharp angles to the mouth they

[1] When this paper was prepared and sent to press Mr. Springer was absent from Washington, but he returned to the city just before its publication. After a discussion of the subject matter he requested me to add a note stating that he is in complete accord with my conclusions as herein expressed.

meet above it in five sharp parallel edges, as do the orals of the stalked young of the macrophreate comatulids.

3. The calyx is more or less asymmetrical; the two posterior radials may be enlarged, as in *Calamocrinus*, or there may be a very small basal just to the right of the anal area, as in *Hyocrinus*. In the young of the comatulids the two posterior radials may be larger than the others, and there is always a radianal, situated more or less to the right hand side of the posterior interradius.

4. The dorsal cup is very large, entirely enclosing the visceral mass dorsally and laterally; this condition is identical with that found in the young of the comatulids, but only occurs in the adults of the Articulata in the highly aberrant *Marsupites*.

5. The plates of the dorsal cup are very thin, entirely lacking the extensive inward calcareous development so characteristic of all the other species of the Articulata; in this the Plicatocrinidae agree with the young of the comatulids, and with the highly aberrant pelagic comatulids *Marsupites* and *Uintacrinus*.

6. Instead of occupying the entire distal edge of the radials as in the Articulata (excepting only the highly aberrant *Marsupites*), the arm bases occupy only a small part, as in the stalked young of the comatulids.

7. There are no infrabasals.

8. There are no pinnules on the arm bases; proximal pinnules are, except in a few very exceptional instances among the comatulids, always present in the Articulata; but they are absent in the young of the comatulids until a considerable size is attained.

9. Tho the pinnules have essentially the same basal structure as those of the Articulata, they are in all ways more generalized, and suggest in many ways ramules or degenerate arm branches rather than perfect pinnules of the Articulata type; in this they resemble the pinnules of the very young comatulids, or of the growing tip of the arm in larger specimens.

10. The apex of the dorsal cup shows a tendency to form a concavity for the reception of the column.

11. The column lacks all trace of the modified columnal known as the proximale, but adds new segments at its summit thruout life; in this respect the column resembles that of the young coma-

tulids before the appearance of the final stem segment, which eventually will come to form the centrodorsal.

12. There are no cirri; the column is attached by a heavy terminal stem plate as in the young of the comatulids.

A few words of explanation regarding the column of the Articulata may not be out of place here. The column of the Articulata (entirely absent in the Comatulida Innatantes, the one suborder of comatulids not represented in the recent seas) is entirely different from that of any other crinoids for, instead of growing continuously thruout life thru the formation of columnals just under the crown, it possesses a definite growth limit at which further increase in the number of columnals abruptly ceases, and the last columnal to be formed becomes attached to the calyx by close suture (usually fusing with the infrabasals), enlarges, and becomes the so-called proximale which is, to all intents and purposes, an apical calyx plate. Immediately below this enlarged columnal or proximale is another more or less modified columnal to which it is attached by a modified close suture, the so-called stem syzygy which, except for a superficial resemblance, has nothing in common with the brachial syzygies.

The typical form of the column in the Articulata is seen in the young of the comatulids at the time of the formation of the centrodorsal; but this typical form persists in the adults only in the genus *Thiolericrinus*, and in the family Phrynocrinidae. In such types as the Apiocrinidae the proximale is so enormously enlarged that it involves with itself in this process a considerable number of the columnals beneath it, so that a cone shaped series of enlarged columnals is formed, each of which is a reduplication, progressively less perfect, of the proximale just beneath the calyx. Essentially the same state of affairs is seen in the Bourgueticrinidae, especially in the recent genus *Ilycrinus*. In the comatulids (excepting in the Innatantes, which never possess one) the column is discarded at the stem syzygy between the proximale and the columnal just beneath it.

In the young pentacrinite the proximale is formed exactly as in the young comatulid; but the great excess of column growth induces the formation of new columnals between the proximale and

the calyx before the proximale has time to become attached; the proximale therefore becomes pushed away from the calyx, but exactly as in the case of the comatulids, cirri are protruded from it, and it becomes united to the columnal just below it by a stem syzygy, these two columnals now forming what is known as a nodal and an infranodal, the nodal (with the cirri) being in origin a true proximale, and the infranodal the columnal just beneath the true proximale. Following the formation of this first nodal the pentacrinite proceeds to grow an entirely new column, of which the first nodal represents the terminal stem plate; this second column grows to a definite length, and then the same nodal forming process is repeated. Each pentacrinite nodal with the series of internodals beneath it, therefore, is morphologically the equivalent of the entire column in such types as the Apiocrinidae, Phrynocrinidae, or the comatulids.

In the adult pentacrinites only nodals are formed just beneath the calyx, so that here we have a series of reduplicated proximales, just as in the Apiocrinidae; but none of these nodals become attached to the calyx, for they are constantly being pushed away from the calyx by the formation of new nodals. At a little distance from the calyx intercalated columnals begin to appear between them, with the nearest of which they always unite themselves by syzygy, so that at a somewhat greater distance from the crown the nodals (proximales), united by syzygy to the infranodals, with which they form syzygial pairs, become regularly spaced, forming the typical pentacrinite column as we commonly find it.

In the bourgueticrinoid type of column any two of the columnals may be united by stem syzygy; these double columnals are rare in the distal portion of the column, but increase in frequency toward the crown. Each of these syzygially united pairs of columnals represents an effort to form a proximale which, thru excessive stem growth, has been thrust away from the calyx exactly as in the case of the pentacrinites. In addition to these there is just under the crown a definite series of proximales, corresponding to the continuously growing and indefinite series found in the pentacrinites. To emphasize the essential similarity of the

columns of the pentacrinites and of the Bourgueticrinidae it may be mentioned that the earliest nodals in the young pentacrinite column resemble far more the syzygially united columns in the bourgueticrinoid column than they do the nodals of the adult, for they are much elongated, and the cirri are usually defective, three, two, or sometimes only one, in number.

It is evident that the structure of the Plicatocrinidae in all of its details corresponds very closely to that of the young comatulids before the appearance of the columnal which is eventually to form the centrodorsal; it is also evident that this family can scarcely find a logical position among the Articulata, from all of the other forms in which it differs so radically.

The order Inadunata of Wachsmuth and Springer includes Crinoidea in which the arms are free above the radials; the dorsal cup is limited to radials, basals, infrabasals (when present) and anal plates; no interradials nor interbrachials occur except at the posterior (anal) side, and the brachials are never incorporated in the cup; all the plates of the cup are united by close suture; the mouth is subtegminal; the column is circular in section (with very rare exceptions), without a proximale.

It is at once evident that the Plicatocrinidae agree with the members of this order far better than they do with those of the Articulata, differing only in a lack of a distinct differentiation of the posterior area, and in the possession of open food grooves and an open mouth. But in the Encrinidae, which are referred to this order, the posterior area is in no way different from the others, while in at least three of the recent genera of the Plicatocrinidae it is not quite the same, so that this difference is very slight. In many of the fossil Inadunata we do not know the disk; while among recent types the genera of the Plicatocrinidae have the deepest food grooves and the nearest approach to a subtegminal mouth; it may be that in reality this apparent difference is nonexistent.

A rapid survey of the various families of the Inadunata— in the suborder Larviformia the Stephanocrinidae, Pisocrinidae, Haplocrinidae, Allegecrinidae, Synbathocrinidae and Cupressocrinidae, and in the suborder Fistulata the Hybocrinidae, Heterocrinidae,

Anomalocrinidae, Cremacrinidae, Catillocrinidae, Belemnocrinidae, Dendrocrinidae, Crotalocrinidae, Cyathocrinidae, Botryocrinidae and Poteriocrinidae—cannot fail to give the impression that there is certainly more than a superficial similarity between these types and the Plicatocrinidae. As an interesting point it may be noticed that the systematic interrelationships within the family order Inadunata are decidedly heterogeneous, and the same character is clearly reflected within the family Plicatocrinidae.

While the Plicatocrinidae, broadly speaking, may be said to agree perfectly with these families collectively—that is to say the characters presented by the component species may all be matched in the order Inadunata and in no other order—the family cannot definitely be assigned to any certain position. Therefore the most logical position for the Plicatocrinidae appears to me to be within the order Inadunata, at the end of the series of families, beyond the Poteriocrinidae.

Long ago (1899) Dr. F. A. Bather reached the conclusion that the Plicatocrinidae (which he divided into Plicatocrinidae and the Hyocrinidae) were really inadunate forms, and he accordingly included them in the Inadunata, which he considered as comprising the Hybocrinidae, the Stephanocrinidae, the Heterocrinidae, the Calceocrinidae, the Pisocrinidae, the Catillocrinidae, the Zophocrinidae, the Haplocrinidae, the Allegecrinidae, the Synbathocrinidae, the Belemnocrinidae, the Plicatocrinidae, the Hyocrinidae and the Saccocomidae.

Of the four great orders of crinoids, two, the Camerata and the Flexibilia, range from the Ordovician thru the Carboniferous. The Inadunata began in the Ordovician, one (possibly two) families persisting to the Permian, and one to the Trias, in which horizon the stalked pentacrinites were already developed. The Articulata began, so far as we can ascertain, in the Trias, and all of the fossil types (excepting only the Thiollericrinidae and the Eugeniacrinidae) persist in the recent seas. It is thus not at all surprising that we should find in the recent seas, in addition to the dominant Articulata, a remnant of the Inadunata.