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STUDY OF GROWTH  
IN RECENT AND FOSSIL INVERTEBRATE EXOSKELETONS  
AND ITS RELATIONSHIP TO TIDAL CYCLES  
IN THE EARTH-MOON SYSTEM

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Principal Investigator: Professor W. B. N. Berry

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Introduction

This study includes development of techniques for discerning growth cycles in fossil pelecypod shells and a tentative morphogenetic classification of those cycles. The recognition of the cycles leads to estimation of the length of the months and years in the pre-historic past based on the relationship between environmental rhythms and the growth cycles. The growth cycles, which are reflected in the shell as growth increments, are closely related to tidal phenomena in many present-day pelecypods. The increments are present in their fossil ancestors, and a considerable body of evidence suggests that in the past these organisms added growth increments in the same relationship to environmental phenomena as in the modern seas.

Technique

Analysis of the shells commences with observation of untreated specimens with the unaided eye and with the microscope using reflected light. The larger growth increments are commonly distinct on the shell surface, but the traces of finer growth layers either are generally obscured by pitting and smoothing of the shell as a result of abrasion or they are too fine to be readily observed.

Featureless and nearly-featureless surfaces have been etched with acid in an attempt to bring out the finer layers, but this technique has not been successful. Although certain growth layers in some shells form especially prominent concentric ridges, the finer layers may be seen on the flanks of such ridges only with great difficulty. Flexible surface replicas of these shells have been made, but they have proven to be of little aid in studying the fine layers. The shells must be sectioned to view the finer growth layers.

After the shells have been studied in reflected light at magnifications up to X200 and, in many cases, photographed, the shells are cut in thin sections in the directions that appear most suitable for the particular shell. Conventional thin sectioning processes do not yield entirely satisfactory results because the molluscan shells tend to break apart as they are polished down to the desired thickness of 15 to 20 microns. This breakage, which is commonly the result of faulty adhesion of the shell to the slide, may be reduced by using a new epoxy resin instead of the resins most commonly in use in cutting thin sections of rocks. Oxidants have been applied to decrease breakage resulting from the flexible proteinous nature of parts of the shell.

The thin sections are examined in polarized light. They are photographed along a traverse connecting the dorsal and ventral shell margins. Then the photographs (actually on the scale of photomicrographs) are joined together to form a composite figure of the shell in thin section. These composites facilitate objective study; when the image of the shell thin section has been projected to a ten by two foot area, it is possible to place one's finger on the likeness of structures only a few microns in size. The resolution quality is considerably superior to that obtained from ordinary lantern slide projectors.

#### The Growth Layers--A Tentative Classification

The following growth layers have been observed in the shells of both fossil and modern pelecypods:

1) Elemental layers, or the smallest growth layers visible through the light microscope. These are (a) cryptocrystalline  $\text{Ca CO}_3$ , (b) an opaque substance, and (c) conchiolin dispersed in an aggregate of microcrystalline  $\text{Ca CO}_3$  (in the form of aragonite). The layers in most of the species examined are arranged in the following sequence, which may be repeated thousands of times during the formation of a single shell: a, b, c, b, c, b, c, b, ; a, b, c, b, . . . . etc. This bundle of eight elemental layers often is visible as a single striation on the shell surface. The number of striations per annual layer suggests diurnal origin. Some species, however, lack such an orderly grouping of elemental layers, the smallest cyclic layer consisting of an alternation of a with either b or c. In these forms, the number of smallest cyclic layers per annual layer is often more or less than 365.

2) Ridge-troughs, or cyclic alternations of concentric ridges and troughs. The component growth layers of the ridges are relatively thin and therefore must result from relatively slow shell growth during time of ridge formation. Ridge-trough cycles have been found to number close to 24, or 12 per annual layer, and the number of component layers per ridge-trough is either close to 15 or in the vicinity of 30. Thus, it seems that the ridge-troughs may be formed monthly or bimonthly with the ridges recording slow growth phases of the tidal cycles. There are, however, at least two species that form concentric ridge-troughs in a manner which obviates environmental connections.

3) Node-troughs. These are similar to concentric ridge-troughs but are confined to radial ribs. Despite the fact that some species have uniquely distributed nodes, many others feature a remarkable coincidence of nodes from one radial rib to another. The component growth striae are thinnest within the nodes. They number close to 30 per node cycle in Trigonia.

4) Annual bands. These are alternations of relatively thin portions of translucent shell, with thicker portions of dark-colored shell. Translucent shell consists chiefly of  $\text{CaCO}_3$  crystals oriented with a high degree of optical parallelism, whereas the dark-colored shell is composed of more irregularly-oriented crystals, mixed with a relatively large amount of brownish conchiolin. The component growth layers of these bands are thickest in the dark-colored portion, and as indicated by study of summer samples of living pelecypods, are deposited during summer seasons of rapid shell growth. Thus, the band cycle has diagnostic microtextural criteria and it is known to be of annual significance.

5) Variation of the shape of the whole shell. Specimens of Myalina (Carboniferous) are constricted periodically five to six times along the dorso-ventral axis. On the average, thirteen ridge-troughs are comprised by a constriction cycle. Interpretation of this growth cycle as an expression of annual environmental variation may be strengthened by the fact that similar constrictions are known to be formed annually in certain living Japanese pelecypods.

6) Disturbance rings. These are units of translucent shell which as seen with the unaided eye are somewhat similar to the winter increments. They tend to occur erratically with respect to the annual band cycle and

their number per shell varies greatly with environment and species. It can be observed in thin section that the disturbance rings are not only thinner than the winter growth units but have crinkled contacts with the normal shell growth units. Disturbance rings can be recognized even when they occur in the midst of the winter phase of the annual band cycle. Occasionally, some detrital quartz sand is found within the disturbance rings. These observations lead to the conclusion that disturbance rings are reflective of storms.

#### Some Recent Determinations

The techniques for study of growth increments in fossil pelecypod shells and the classification of the shell growth layers discussed above have been used as the basis for recognition of annual, monthly, bi-monthly, and diurnal growth cycles in such shells. The majority of the fossil specimens examined have been preserved in such a manner that only single cycles or parts of cycles may be studied. Numbers of shells must be examined carefully before finding shells in which an unbroken succession of the several component layers that comprise the larger-scale layers may be observed and counted. Data are tabulated in Table 1 for the materials studied in the past semi-annual period that have proven well-enough preserved to obtain counts of shell growth increments over several cycles.

Myalina subundata appears to be especially promising as an index to the number of months per year during the Carboniferous. The 19.5 periodicity observed in the samples of Astartella concentrica may not be a true reflection of days per month in the Carboniferous. The forty ridge-troughs observed in its shells probably correlate with rhythms of less than annual magnitude. Whether the rhythms were monthly or fortnightly, or not controlled by the environment, can only be conjectured.

As figures given in earlier reports on the project have indicated, the year in the Cretaceous was apparently composed of 12.5 lunar months and this period is probably equivalent to 401 synodic days. The present data (see Table 1) continue to support the earlier conclusions concerning months per year and days per month during the Cretaceous. At present, the shells examined suggest an average of  $31.8 \pm 1.35$  synodic days for the Cretaceous lunar month.

### Questions for further research

The observed range in possible number of days per months as determined from the study of growth layers in fossil pelecypod shells does raise some questions of interpretation. For example, are anomalous layers present that are being counted as normal growth layers? Such layers could result in the relatively high count seen in Crassatellites vadosus No. 3. Are there omissions of diurnal layers that are expressed in the relatively low count observed in Trigonia thoracia? Are these anomalies and omissions simply the result of some activity in the specific organism studied and not generally present throughout whole populations? May these anomalous numbers be reflective of some special environmental phenomenon? May the fossil forms exhibiting such anomalous numbers of small-scale layers be averaged in a count to ascertain an arithmetic mean number of days? These questions will be pursued as the study of the fossil materials continues.

### Growth Experiments

Growth experiments are proceeding as planned and outlined in earlier reports. Juveniles of local pelecypod species are living in a total of fifty aquarium tanks, supplied with water from the nearby ocean continuously pumped through the tank system. The tanks are being kept under a variety of light-dark and simulated tidal cycles. Juveniles of some other species--those more closely related to the fossil species being examined in this study--are to be included in the growth experiments.

### Conclusions

In conclusion, the examination of the fossil shells indicates a slow and continual decrease in number of months per year, from 13 in the Carboniferous (approximately 300 million years ago), to 12.5 in the Cretaceous (approximately 100 million years ago), to 12 at the present time. Further, there appear to have been somewhat more synodic days per month in the Cretaceous than at present. This evidence suggests that changes in distribution of angular momentum have taken place within the earth-moon system.

Personnel: Professor W. B. N. Berry - Principal Investigator;  
Richard Barker - Post Graduate Research Paleontologist.

TABLE 1

<u>Geological Period</u>	<u>Locality</u>	<u>Fossil</u>	<u>Apparent days per month</u>	<u>Apparent months per year</u>
Carboniferous (270-350 mya)	Wayland Fm., Tex.	<u>Myalina subquadrata</u> #1		13 mos.
	" "	" " #2		13 mos.
Late Cretaceous (70-100 mya)	Graham Fm., Tex.	<u>Astartella concentrica</u>	19.5 (?)	
	Ripley Fm., Tenn.	<u>Corbula crassiplicata</u> #1	32	
	" "	" " #2	32	
	" "	<u>Crassatellites vadosus</u> #1	33	
	" "	" " #2	31	401 days
	" "	" " #3	34	
	" "	<u>Glycymeris lacertosa</u>		12.5
Ripley Fm., Tex.	<u>Trigonia thoracica</u>	28		
Waco Fm., Tex.		<u>Plicatula dentonensis</u>	33.5	
		<u>Lima</u> sp. #1		12.5
" "	" " #2			12.5
Cody Fm., Wyo.		<u>Lucina subundata</u>	31.1	