U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Crinoids

A computer animation and paper model

By
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and
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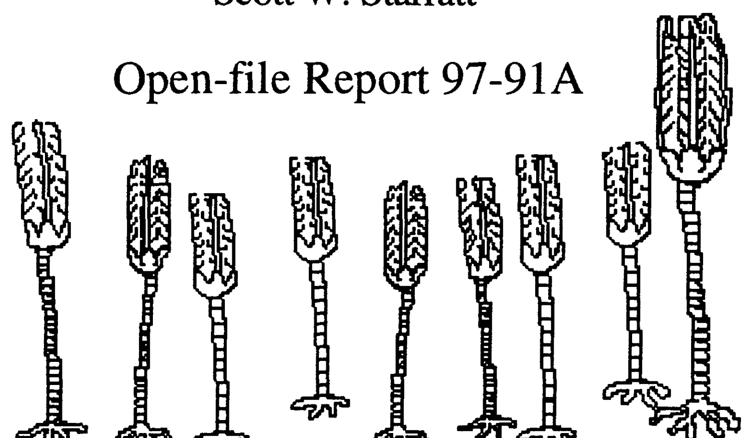
Open-file Report 97-91A



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Description of Report

This report illustrates, through the use of computer animations and a paper model, how crinoids lived and became fossilized. By studying the animations and the paper model, students will better understand the flower-like animal that is referred to as a "sea lily" and its ocean-floor environment.

Included in the paper and diskette versions of this report are templates for making the paper model, instructions for its assembly, and a discussion of crinoids. In addition, the diskette version includes an animation of crinoids on the ocean floor.

Many people provided help and encouragement in the development of this HyperCard stack, particularly Art Ford and David Howell. Thanks are also due to John Junck, Maria Correia, Steve Brewer and Don Buckley, William Ausich, Gary Lane and Charles Messing for incentive and review. This report was enhanced by the excellent reviews by Jim Pinkerton and John Lahr.

Table of Contents for paper version of this report.

Description of Report

Requirements for using the diskette version are: Apple Computer, Inc., HyperCard 2.2™ software and an Apple Macintosh™ computer with an internal disk drive. If you are using System 7, we recommend having at least 8 MB of physical RAM with 4.5MB of memory available for HyperCard.

The animation is accompanied by sound. If no sound is heard, change the memory of HyperCard to 4500K and ensure that the control panel "Sound," which is in the "Control Panels" folder under the "Apple" menu, has the volume set to at least 2. To change the memory available to HyperCard, quit this stack. Highlight the HyperCard program icon and choose "Get Info" from the File Menu. Change the "memory requirements" to 4500K and start this stack again.

Purchasers of the diskette version of this report, which includes all of the text and graphics, can use HyperCard 2.2™ software (not supplied) to change the model (by adding patterns, symbols, colors, etc.) or to transfer the model to other graphics software packages.

To see the entire page (card size: MacPaint), select "Scroll" from the "Go" menu and move the hand pointer in the scroll window. If you are experiencing trouble with user-level buttons, select "message" from the "Go" menu. Type "magic" in the message box and press return. Three more user-level buttons should appear.

The date of this Open File Report is 2/28/1997. OF 97-91-A, paper copy, 57p.; OF 97-91-B, 3.5-in. Macintosh 1.4-MB high-density diskette.

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CRINOIDS -- LILIES OF THE SEA

Alluding to **crinoids** as "lilies of the sea" is a good description of these beautiful occupants of the ocean. The phrase is, however, a misnomer, for they are actually animals, not plants. Crinoids are deep-water relatives of the starfish and sand dollars that are commonly found on most coasts. In this brief introduction to crinoids, we will discuss both the biology and paleontology of these interesting marine organisms.

History of the Crinoids

Crinoids are a diverse and important component of Paleozoic shallow marine faunas. During some intervals of the Paleozoic, the remains of crinoids were a major component of the sediment. Complete crinoids are extremely rare because of the way in which their skeletons are constructed. The crinoid skeleton is made up of numerous calcite plates, all of which are held together by connective tissue. When they die, these skeletons disintegrate because the soft connective tissue decays.

Crinoids are less abundant today than in the past, but at present are represented by more than twenty stalked genera and some ninety genera of unstalked forms. It is these unstalked forms that dominate the crinoid fauna in today's oceans.

Crinoids appear to have originated during the great radiation of the Early Ordovician. A number of echinoderms similar to crinoids originated several million years earlier in the Cambrian, and one of these was probably the ancestor of crinoids. Crinoids evolved rapidly during the early Paleozoic. However, only two groups survived into the late Paleozoic, and only one group survived the mass extinction event that took place at the end of the Paleozoic.

Most modern crinoids are unstalked forms; they have developed great flexibility in their arms which allows them to actively search for good feeding grounds on the ocean floor. The living stalked forms (those that we call "sea lilies") are usually small, with stems that rarely exceed 0.75 meter in length. These crinoids are generally found at depths greater than 100 meters.

All Crinoids Look the same, Don't they ?

A typical stalked Paleozoic crinoid can be divided into three regions, the plated body (also called the calyx, or theca) which encloses most of the vital organs of the animal, the food-gathering arms (brachia) that branch off the side or top of the calyx, and a stem with a group of cirri that attaches the base of the calyx to the substrate. Some crinoids developed an elaborate holdfast, similar to those that attach giant kelp to the seafloor.

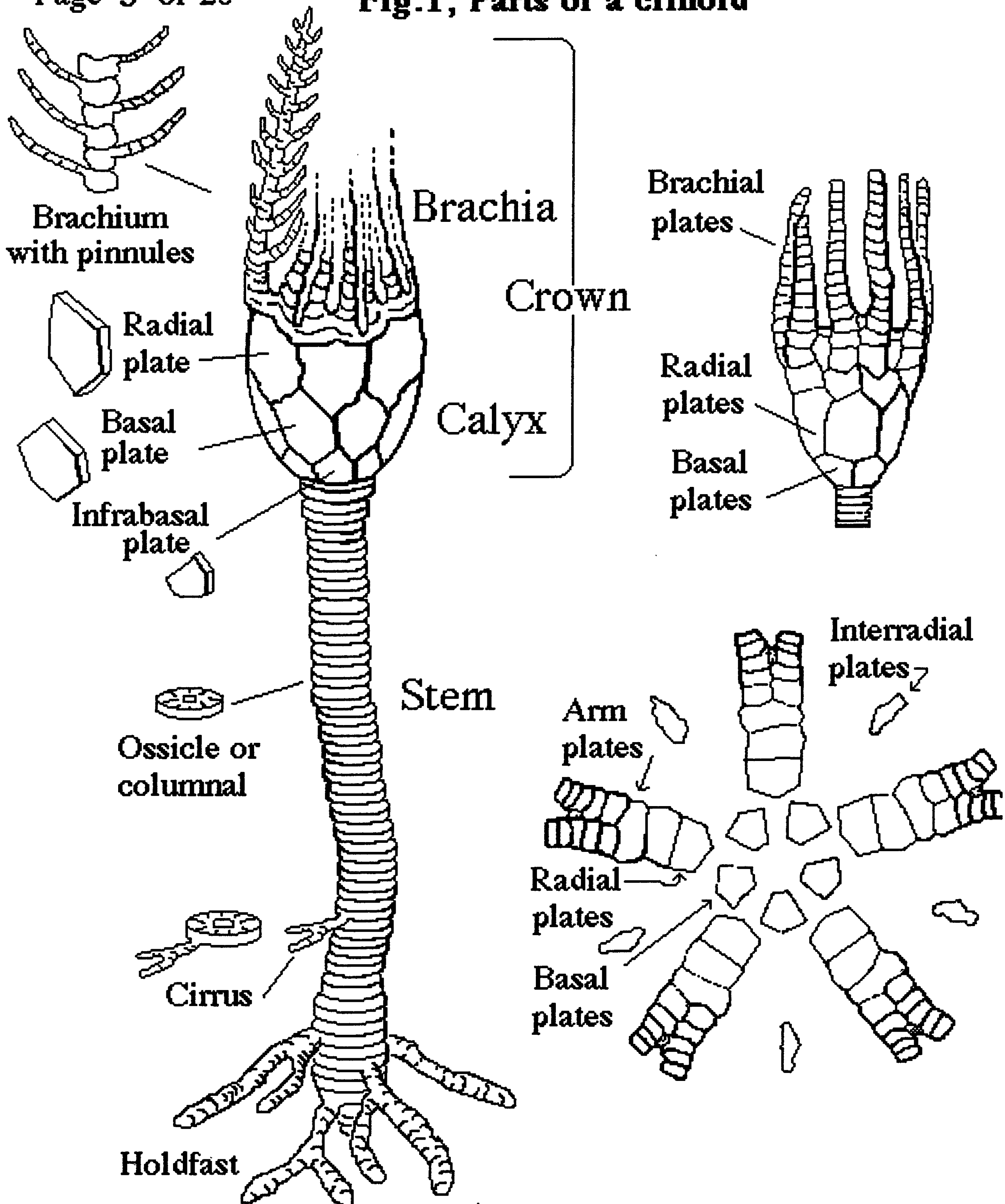
An important distinction among the major groups of crinoids is the number of rows (circlets) of plates in the calyx below the arms. The structure of the arms is also important in identifying the basic groups of crinoids. As you might expect, crinoids are easiest to identify if the calyx is intact.

Like most echinoderms (starfish, sea urchins, sand dollars), crinoids exhibit radial symmetry. Each circlet contains five plates. Most crinoids contain two or three circlets of plates. Their arms are attached to a row of radial plates. The next row of plates are named basal plates. In some cases, the basal plates are attached directly to the stem, but in others there is an additional row of plates called infrabasal plates. In these varieties, the infrabasal plates are attached to the stem. The arms occur in multiples of five. Many of the arms have side branches called pinnules. The top of the calyx is covered by the tegmen, a flexible membrane which has a number of irregular plates embedded within it.

What's inside a crinoid?

Most of the vital organs in crinoids are found in the theca. The mouth is located in the center of the tegmen. Inside the theca is a spirally twisted gut. The anus is also found on the surface of the tegmen, but it is located off to one side. From its location in the center of the theca, the water vascular system sends vessels into each arm. The water vascular system and its external extensions, the tube feet, are responsible for collecting food and moving it from the arms to the mouth. The reproductive structures are located on the arms.

Fig.1, Parts of a crinoid



What's Floating Around in the Soup, or what do Crinoids Eat?

Each arm has a double row of tube feet, and there is a medial food groove between the tube feet. When the crinoid is feeding, the pinnules with tube feet are extended. The tube feet trap bits of detrital material and small organisms on their sticky surfaces. The food is carried to the mouth by a ciliary mucus tract along the food groove. The food grooves in the pinnules join with those in each arm, and in turn, unite to form five primary grooves that cross the tegmen and enter the mouth. When the tube feet are disturbed, they retract into the food groove and are protected by cover plates.

Making New Crinoids

Reproduction occurs as a mass spawning, usually at annual intervals. Prior to spawning, metabolic energy is directed toward the production of gametes. The spawning of one individual usually triggers other individuals nearby to release their gametes. This process insures cross-fertilization and the exchange of genetic material. After the egg is fertilized it develops into a free-swimming larva. This larval stage aids in the dispersal of the generally sedentary crinoids. After a period of several days, the larva settles to the seafloor and begins its new life.

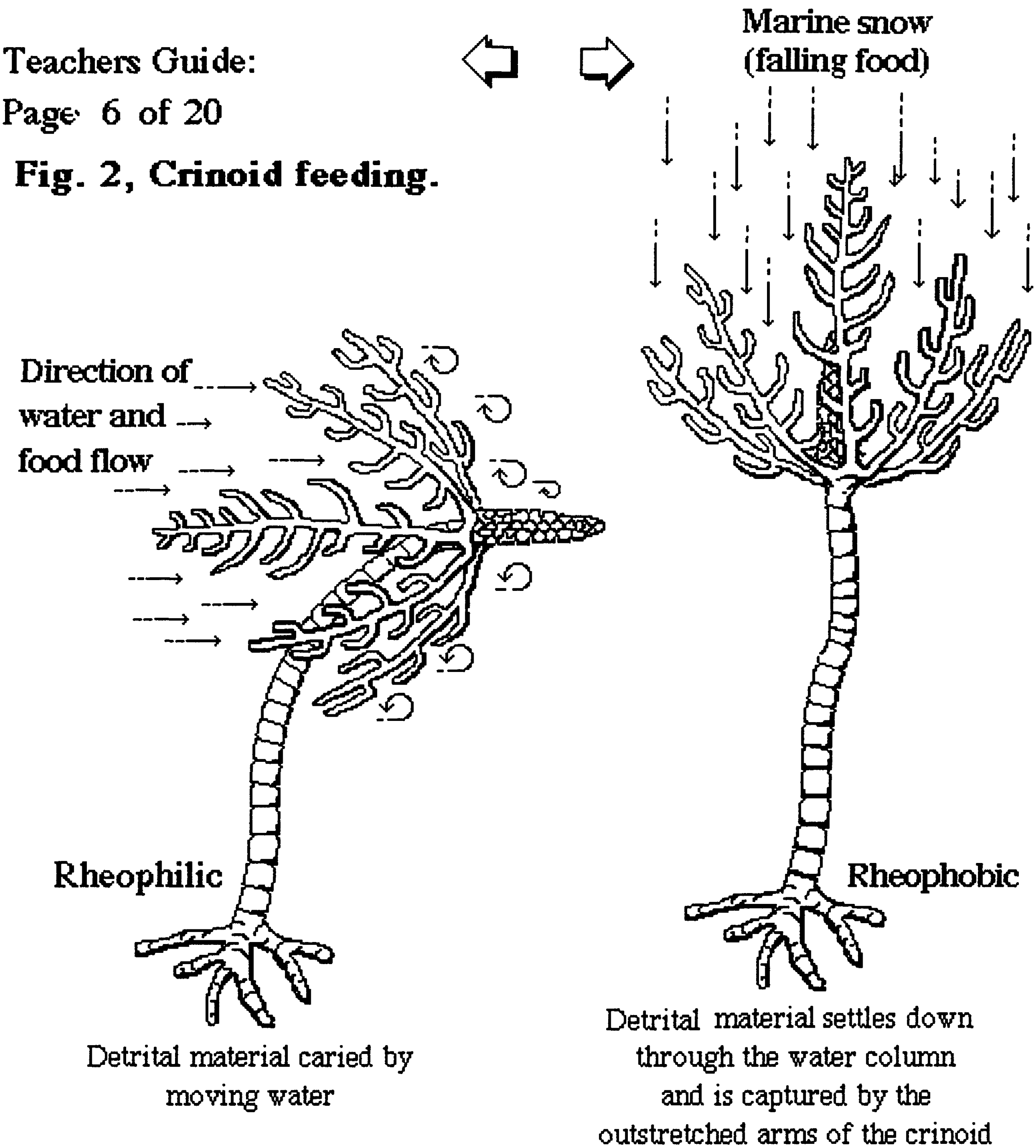
Where are Crinoids Found and How do they Live ?

Although crinoids are still alive in modern seas, they have evolved significantly in the recent geologic past. Part of the group with stalks has moved from shallow to deeper water environments, while the remainder have lost their stems and become mobile. These unattached forms are quite common today, and can be found living at most depths. The stalked forms are normally found only below 100 m. Because they are uncommon in shallow water and are usually only abundant in inaccessible regions, little was known about their biology until recently. Observations made while SCUBA diving have illuminated many adaptations and rekindled discussions of the form and function of ancient crinoids.

Present-day forms are commonly divided into two feeding types: rheophobic (current avoiding) and rheophilic (current seeking). Rheophobic crinoids live in regions of the ocean in which there is little movement of the water. They rely entirely on gravity feeding, taking only the detrital material that filters down through the water column. These forms lie on the bottom, their arms outstretched to form a horizontal collecting bowl, capturing the organic particles falling within. Some rheophobic forms live in the deep ocean, collecting detrital material that may have fallen thousands of meters through the water column. These forms do not consume nearly as much food as their rheophilic relatives. To compensate for this reduced rate of food intake, the metabolic and growth rates of rheophobic crinoids are probably less than those of their rheophilic relatives.

Rheophilic crinoids are usually found in relatively shallow, current-swept waters. During the day individuals may hide in cavities, but come out at night to feed, climbing with their cirri to a elevated location, and unfurling their arms. The arms are spread out in a vertical filtration fan, with the mouth facing away from the current. The filtration fan exposes the maximal cross-sectional area of the food gathering surface and also creates a baffle that slows the flow of the food-bearing water by creating a series of eddies. The reduced speed of the current and eddies created by the outstretched arms and pinnules aid the tube feet to extract food from the water. This system is remarkably efficient for extracting food particles from the current.

Fig. 2, Crinoid feeding.



Fossil Crinoids

A number of diverse crinoid faunas are preserved within rocks of the United States. The Crawfordsville Limestone of Indiana is full of stalks and calyxes that were deposited in quiet, poorly aerated waters. Based on morphology, these crinoids were probably rheophobes.

Crinoids from the Mississippian Burlington Limestone of Missouri are thought to have been rheophilic. The stems are strong and flexible. This flexibility allowed the crown to vary its attitude from horizontal to vertical, depending on the velocity of the current.

The most diverse echinoderm fauna, which includes a large number of crinoids, is found in the Middle Ordovician Bromide Formation of Oklahoma. The crinoids lived in a variety of shallow, warm water environments, ranging from 3 to 75 m. deep. They were most abundant on a substrate of lime mud and skeletal debris.

These Paleozoic crinoid gardens were stratified or tiered in order to take advantage of food resources at a number of different heights above the seafloor. Just as giraffes are able to take advantage of the leaves in tall trees, the crinoids with long stems could take advantage of bits of food floating more than a meter above the seafloor.

During the Mesozoic, a group of crinoids with crowns more than 80 cm in diameter and stems more than 15 m long evolved. There are two explanations of the need for these extremely long stems. The long stem may have served as a tether for the kite-like crown. By changing its orientation in the current, the crinoid was able to move its crown up and down in the water column, stopping where it found the most food.

The second explanation is more interesting. Rather than growing up from the seafloor to take advantage of food-rich levels in the water column, this group of crinoids was pseudoplanktonic, floating along attached to driftwood. From these "islands of life," they could take advantage of the plankton in the surface waters of the ocean. Crinoids are not the only organisms found attached to fossil driftwood. There is fossil evidence that the surface of driftwood was entirely covered by clams, snails, bryozoans, and other invertebrates. The long stems of these crinoids allowed them escape the competition for food on the driftwood and to drift near the ocean surface, several meters away from the invertebrate metropolis.

Why are Complete Crinoid Fossils so Rare?

The likelihood of a crinoid being preserved (and you finding it) is controlled by several factors. These include (1) how many individual crinoids there were, (2) what type of environment the organisms lived in, and more importantly what kind of environment they died in, and (3) what happened to them after they were buried.

Many crinoids are thought to have lived in shallow "gardens". These clumps or mounds were found on shallow carbonate-rich banks in warm tropical ocean. Diversity varied from garden to garden. Other crinoids inhabited the sometimes muddier water between the gardens.

After the crinoids died, they were usually broken apart by the action of waves and scavengers. The individual components first became lighter as the organic material inside them decayed; they then became heavier as seawater replaced the organic matter. Individual plates were then transported by wave and current action to the muds surrounding the crinoid gardens. Some Mississippian limestones are made up almost entirely of crinoid plates and ossicles.

For a fossil crinoid to be preserved, it needs to be buried in a quiet, oxygen-poor environment. In an oxygen-rich environment bacteria begin to break down the connective tissue that holds the plates together, soon after a crinoid dies. In some cases scavengers may also feed on the recently deceased animal. These bacteria and predators require oxygen to survive, so if the crinoid dies in an environment in which these organisms cannot live, then there is a greater chance that it will be preserved intact, rather than as a group of plates.

The second requirement is deposition in a quiet environment. Waves and currents tend to break apart and destroy all of the sediment particles that they carry, including fossils. If the crinoid is deposited in a quiet place away from fast-moving water, then there is a better chance of it being preserved.

These two factors are the main reason that there are so few complete examples of crinoids. Most of those that we do have were preserved in fine-grained oxygen-poor muds that accumulated in a low energy environment. In the Paleozoic, these environments included lagoons and some of the areas between the crinoid gardens; in the Mesozoic, the best examples of pseudoplanktonic crinoids (many still attached to their driftwood anchors) come from fine-grained, low-oxygen deep sea muds.

When one considers all the things that can go wrong in the process of fossilization, it is not surprising that there are so few examples of complete crinoids.

Why study Crinoids?

From a biological point of view, crinoids are interesting because of their well developed, highly adaptable feeding system. Few other animals possess such a finely tuned food-filtering system. While most crinoids were firmly anchored to the sea floor, some have developed the ability to move using modified cirri. Still others managed to hitch a ride on passing pieces of driftwood.

Crinoids are useful to geologists because they can be used to help tell geologic time. They are particularly useful for this purpose in the middle part of the Paleozoic because they evolved quickly. Short periods of geologic time were characterized by one or two unique species. When you find fossils of these species, you know where you are in geologic time.

Questions

What aspects of crinoid anatomy illustrate their similarity to more common echinoderms such as starfish and sand dollars?

Where do you think crinoids are found today?

Why do you think that crinoids were much more abundant in the past than they are today?

How do fossils provide evidence of how life and environmental conditions change?

Can you give examples of changing natural systems that exceed the limits of organisms to naturally adapt?

How has man changed the natural systems of the Earth so that species cannot adapt to these changes?

Can you give examples of what man's overpopulation will do to life and environmental conditions?

Glossary

Basal plates The circlet of plates (five) farthest from the mouth of a crinoid. These plates are attached to the stem of the crinoid. In some crinoids, a row of infrabasal plates lies between the basal plates and the stem. See figure 1.

Brachia -- Another name for the arms of a crinoid. The brachia are made up of brachial plates. See figure 1.

Bryozoan -- A member of the phylum Bryozoa, characterized by colonial growth, a calcareous skeleton, and a U-shaped digestive tract with mouth and anus.

Crinoid -- Marine invertebrates of the class Crinoidea, including the sea lilies and feather stars, having feathery, radiating arms and a stem which attaches to a surface.

Calcite -- Mineral (calcium carbonate) that forms the external skeletons of many invertebrates including corals, bryozoans, echinoderms, mollusks, and brachiopods.

Calyx -- The cup-shaped body of the crinoid; contains the internal organs. See figure 1.

Cambrian Period -- The oldest period of the Paleozoic era. Extends from 570 to 500 million years ago. Named after Cambria, the Roman name for Wales, where rocks of this age were first studied.

Ciliary -- Microscopic hairs capable of rhythmical motion.

Cirrus (pl. cirri) -- Any of the flexible, root-like, jointed appendages attached to the side of the stem of a crinoid. See figure 1.

Crown -- Consists of the arms (brachia) and the calyx. See figure 1.

Detrital material -- Inorganic material (mineral grains) and Organic material (plankton, pieces of decaying plants and animals) that falls through the water column. Crinoids filter this material out of the water using their arms.
See figure 2.

Glossary

Fauna -- Animals as a whole, esp. those of a specific region or period.

Gametes -- Male and female reproductive cells.

Genus (pl. genera) --The level of taxonomic classification between family (larger group) and species (smaller group).

Infrabasal plates -- Row of plates in the calyx that lies between the basal plates and the first ossicle of the stem.

Limestone -- Rock consisting mainly of calcium carbonate, usually in the form of calcite.

Marine snow -- Detrital material composed of bodies of microplankton, fecal pellets, and other organic material raining down through the water column.

Mass extinction -- A time interval during which the rate at which organisms become extinct greatly exceeds the normal rate for a given interval of geologic time, usually a million years. The background extinction rate for the past 570 million years is between three and ten families of organisms per million years.

Mesozoic Era -- The interval of geologic time that lasted from about 245 million years ago to about 65 million years ago. Literally means "middle life." Also commonly referred to as the "Age of the Dinosaurs."

Mississippian Period -- The interval of geologic time that lasted from about 360 million years ago to about 320 million years ago. Rocks of this age in the eastern United States are characterized by extensive shallow reef deposits. Named for the State of Mississippi, in which extensive deposits of this age are found.

Glossary

Morphology -- Study of the structure and form of living organisms.

Ordovician Period -- The interval of geologic time that lasted from about 505 million years ago to about 438 million years ago. Named for the Orduvies, a tribe in ancient Wales.

Paleontology -- The study of fossils.

Paleozoic Era -- The interval of geologic time that lasted from about 570 million years ago to about 245 million years ago. Literally means "ancient life."

Pinnules -- Slender, unbranched, jointed, lateral extensions off of the arms of some crinoids.

Plahlctic -- Organisms that move chiefly by floating along on ocean currents.

Pseudoplanktonic -- The mode of life in which an organism attaches itself to a floating object, commonly driftwood, and is transported along with the object. A pseudoplanktonic mode of life allowed some crinoids to exploit an ecological niche that they were unable to utilize while anchored on the sea floor.

Radial symmetry -- The arrangement of the body of an organism in a radial pattern, with a point in the middle, and structures, such as the arms of a starfish radiating outward from that point.

Radial plates -- The circlet of plates (five) that lies between the basal plates and the arms of a crinoid. See figure.

Glossary

Radiation -- An increase in the diversity of a group of organisms, often occurs following an extinction event.

Rheophilic -- Current loving. Rheophilic crinoids prefer to live in an environment swept by ocean currents.

Rheophobic -- Rheophobic crinoids prefer environments where there is little or no ocean current activity.

Substrate -- Surface to which the crinoid is attached. This may include rocks, coral reefs, or, in the case of pseudoplanktonic crinoids, a floating log.

Tegmen -- The ventral surface of a crinoid body covered by a non-calcareous skin. The mouth of the crinoid is located in the center, and the anus off to one side of the tegmen.

Theca -- Another commonly used word for calyx.

Tier -- One of a series of rows placed above another.

Tube feet -- Hundreds of tubes connected to the water vascular system. In starfish and sea urchins (two close relatives of the crinoids), tube feet are used for movement and feeding. In the crinoid, they have been adapted to help move the food trapped by the arms to the mouth.

Water vascular system -- A system of interconnected fluid-filled tubes characteristic of echinoderms. This system is responsible for movement and feeding in starfish and sea urchins and for the movement of food from the arms to the mouth of crinoids.

References

Boardman, R.S, Cheetham, A.H., and Rowell, A.J., 1987, Fossil invertebrates: Blackwell Scientific Publications, Palo Alto, 713 p.

This book is considered by many to be the best textbook for college level invertebrate paleontology courses. The information on evolution, biology, and ecology are all up-to-date. Many of the illustrations are black-and white photographs.

Broadhead, T.W., and Waters, J.A., 1980, Echinoderms: Notes for a short course: University of Tennessee, Department of Geological Sciences, Studies in Geology 3, 235 p. (Available from the Paleontological Society)

A collection of short articles by experts in the field. A little advanced, even for introductory college courses, but a good source of illustrations.

Clarkson, E.N.K., 1993, Invertebrate palaeontology and evolution, 3rd ed.: Chapman and Hall, London, 434 p.

The third edition of this book has many improvements over the first two. The text is still a little dry, but the illustrations are excellent.

Cowen, R., 1990, History of life: Blackwell Scientific publications, Boston, 470 p.

More biological in its approach than Boardman and others (1987), it emphasizes ecology and organismal interaction rather than systematics.

Lane, N.G., 1992, Life of the past, 3rd. ed.: Macmillan Publishing Company, New York, 334 p.

An introductory text suitable for high school or non-science majors in college. One of the authors (sws) has used it for an introductory college-level class.

McKerrow, W.D., ed., 1978, The ecology of fossils: An illustrated guide: The MIT Press, Cambridge, 384 p.

One of the best books illustrating how fossils fit into their respective paleoenvironments. Illustrated with numerous maps and block diagrams.

References

McKinney, F.M., 1991, Exercises in invertebrate paleontology: Blackwell Scientific Publications, Boston, 272 p.
This book is intended to be used with a collection of fossils making many of the exercises difficult to complete if fossils are not available.

McKinney, M.L., 1993, Evolution of life: Processes, patterns, and prospects: Prentice Hall, New Jersey, 415 p.
A non-systematic approach to the history. Falls somewhere between Cowen (1990) and Lane (1992) in terms of level of complexity.

Moore, R.C., Lalicker, C.G., and Fischer, A.G., 1952, Invertebrate fossils: McGraw-Hill Book Company, Inc. New York, 766 p. (out of print, but occasionally available in used bookstores)
For many years this was the textbook used in invertebrate paleontology courses at many colleges and universities. The most useful aspect of this book today are the excellent illustrations.

Murray, J.W., ed., 1985, Atlas of invertebrate macrofossils: Halsted Press, John Wiley and Sons, Inc., New York, 241 p.
As the name suggests, this book is meant to be used as a reference. It is probably the best technical source of photographs of fossils.

Nield, E.W., and Tucker, V.C.T., 1985, Palaeontology: An introduction: Pergamon Press, Oxford, 178 p.
Similar to Lane (1992) in level of complexity, although the approach is taxonomic.

Shimer, H.W., and Shrock, R.R., 1944, Index fossils of North America: John Wiley and Sons, Inc., New York, 837 p. (Long out of print)
This is an excellent book for amateurs interested in invertebrate paleontology.

Stearn, C., and Carroll, R., 1989, Paleontology: The record of life: John Wiley and Sons, Inc., New York, 453 p.
Another introductory textbook that falls somewhere between Cowen (1990) and Lane (1992) in degree of complexity.

Fundamental Concepts

"SCIENTIFIC LITERACY FOR ALL STUDENTS is a National goal. The National Science Education Standards are a contribution toward achieving that goal." (Draft, November 1994, National Science Education Standards, prepared by the National Research Council, National Academy of Science)

After building this model and reading the text all students should have developed a basic understanding of the following fundamental concepts for Earth and Space Science as recommended in the National Science Education Standards. Some of these fundamental concepts for grades 5-8 and 9-12 are highlighted below.

Grades 5 - 8

+ Fossils provide important evidence of how life and environmental conditions have changed.

+ The Earth processes we see today are similar to those that occurred in the past.

Grades 9 - 12

+ Populations of organisms evolve over time.

+ Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations.

+ Creativity , imagination, and a good knowledge base are all required in the work of science and engineering.

+ Changing natural systems can exceed the limits of organisms to adapt naturally or humans to adapt technologically.

Additional Models and Animations

Alpha, Tau Rho, 1989, How to construct two paper models showing the effects of glacial ice on a mountain valley: U. S. Geological Survey Open-File Report 89-190 A&B (Available as a 3.5-in. MACINTOSH disk or a 30-p. report)

Alpha, Tau Rho, Lahr, John C., and Wagner, Linda F., 1989, How to construct a paper model showing the motion that occurred on the San Andreas fault during the Loma Prieta, California, earthquake of October 17, 1989: U. S. Geological Survey Open-File Report 89-640A&B (Available as a 3.5-in. MACINTOSH disk or a 10-p. report)

Alpha, Tau Rho, and Lahr, John C., 1990, How to construct seven paper models that describe faulting of the Earth: U. S. Geological Survey Open-File Report 90-257 A&B (Available as a 3.5-in. MACINTOSH disk or a 40-p. report)

Alpha, Tau Rho, 1991, How to construct four paper models that describe island coral reefs: U. S. Geological Survey Open-File Report 91-131A&B (Available as a 3.5-in. MACINTOSH disk or a 19-p. report)

Additional Models and Animations

Alpha, Tau Rho , and Gordon, Leslie C., 1991, Make your own paper model of a volcano: U.S. Geological Survey Open-File Report 91-115A&B (Available as a 3.5. MACINTOSH disk or a 4-p. report)

Alpha, Tau Rho, Page, Robert A., and Gordon, Leslie C., 1992, Earthquake effects, a computer animation and paper model: U. S. Geological Survey Open-File Report 92-200A&B (Available as a 3.5-in. MACINTOSH disk or a 4-p. report)

Alpha, Tau Rho, Starratt, Scott W. and Chang, Cecily C., 1993, Make your own Earth and tectonic globes: U. S. Geological Survey Open-File Report 93-380A&B (Available as a 3.5-in. MACINTOSH disk or a 14-p. report)

Alpha, Tau Rho, and Stein, Ross S., 1994, Make your own paper model of the Northridge, California, earthquake, January 17, 1994: U. S. Geological Survey Open-File Report 94-143 4-p.

Alpha, Tau Rho, and Stein, Ross S., 1994, The Northridge, California, Earthquake of January 17, 1994: A computer animation and paper model: U. S. Geological Survey Open-File Report 94-214A&B. (Available as a 3.5-in. MACINTOSH disk or a 30-p. report).

Additional Models and Animations

Alpha, Tau Rho, Starratt, Scott W., Hendley, James W., II, 1994, Make your own paper fossils, a computer animation and paper models: U.S. Geological Survey Open-File Report 94-667A&B. (Available on 3.5 MACINTOSH disk or a 42 p. report)

Alpha, Tau Rho, Galloway, John P., Bonito, Mark V., 1995, Sea-Floor Spreading, a computer animation and paper model: U.S. Geological Survey Open-File Report 95-573A&B. (Available on 3.5 MACINTOSH disk or a 35 p. report)

Alpha, Tau Rho, and Reimnitz, Erk, 1995, Arctic Delta Processes, a computer animation and paper models: U.S. Geological Survey Open-File Report 95-843A&B. (Available on 3.5 MACINTOSH disk or a 27 p. report)

Alpha, Tau Rho, and Galloway, John P., 1996, Ocean Trenches, a computer animation and paper model: U.S. Geological Survey Open-File Report 96-76A&B. (Available on 3.5 MACINTOSH disk or a 41 p. report)

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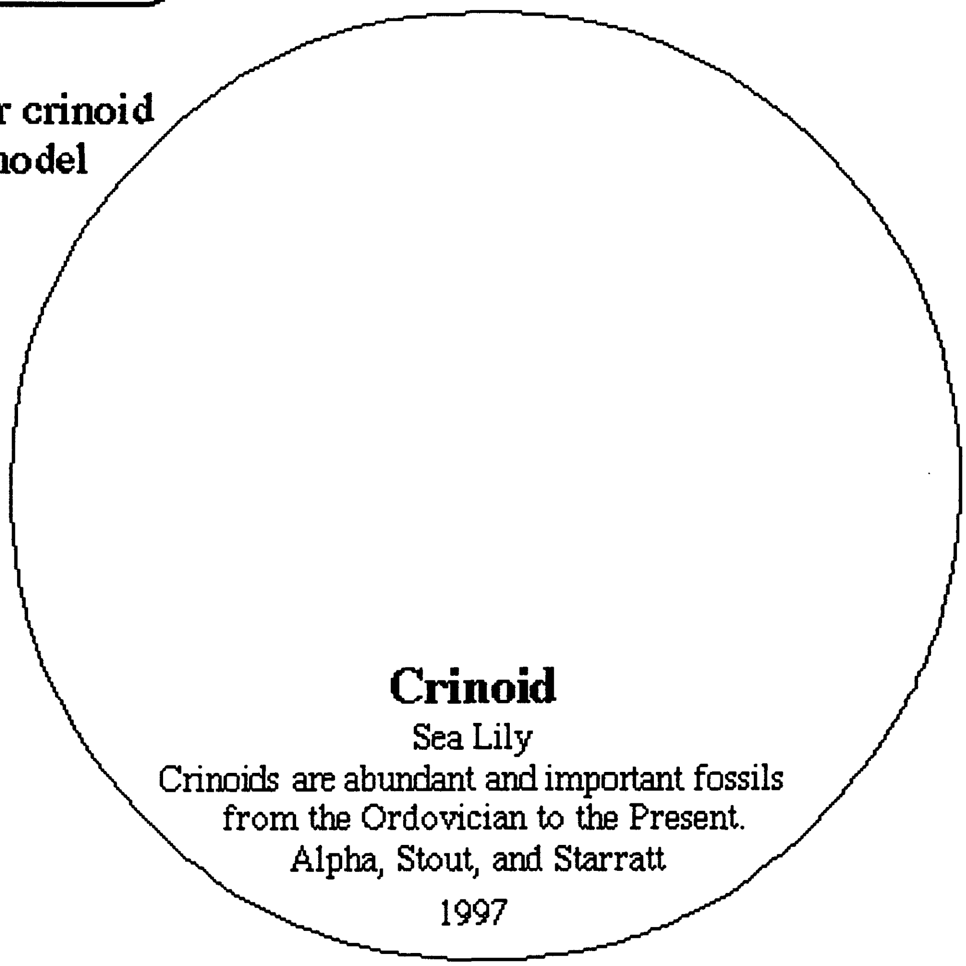
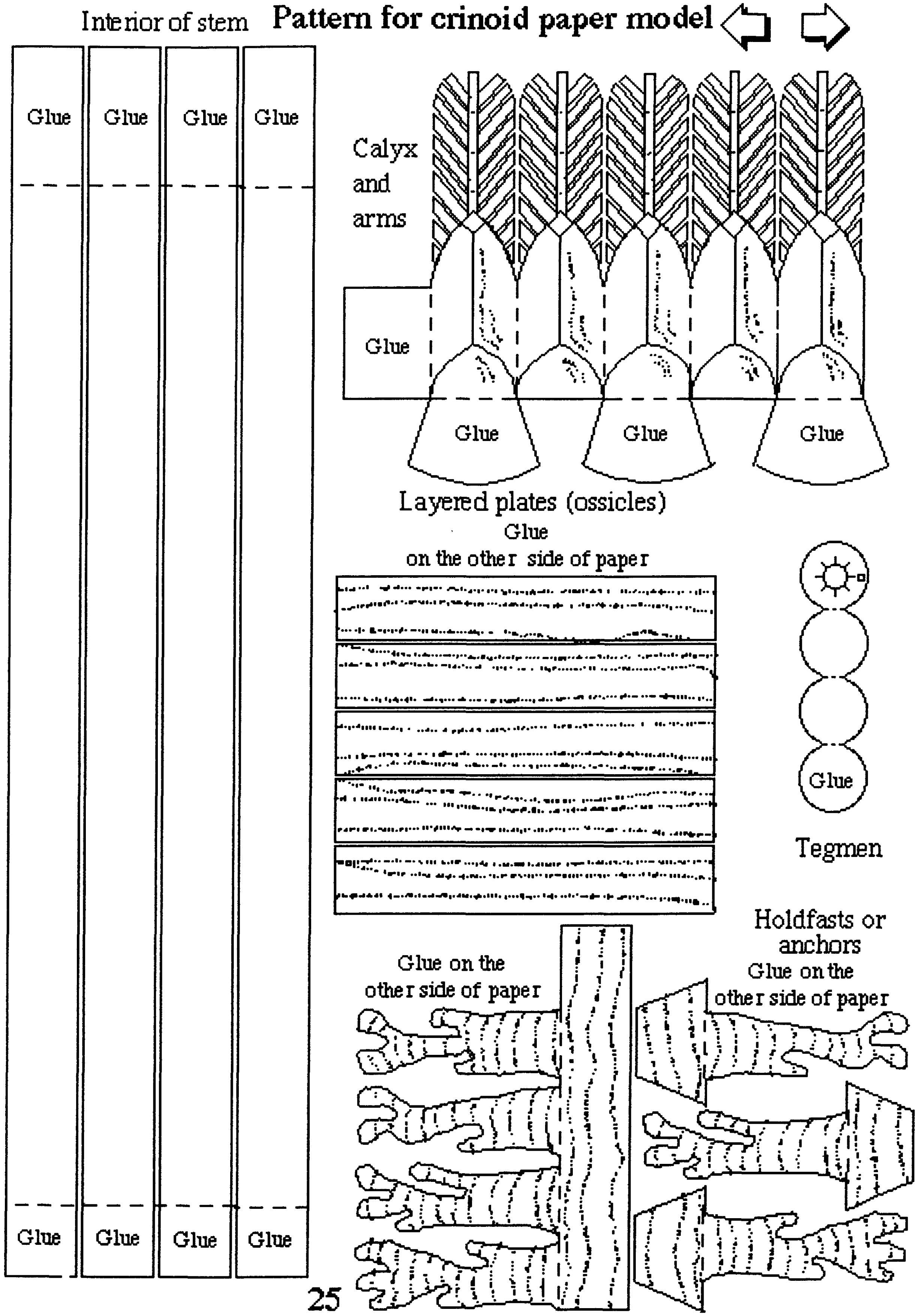
Paper Model instructions

Base for crinoid paper model

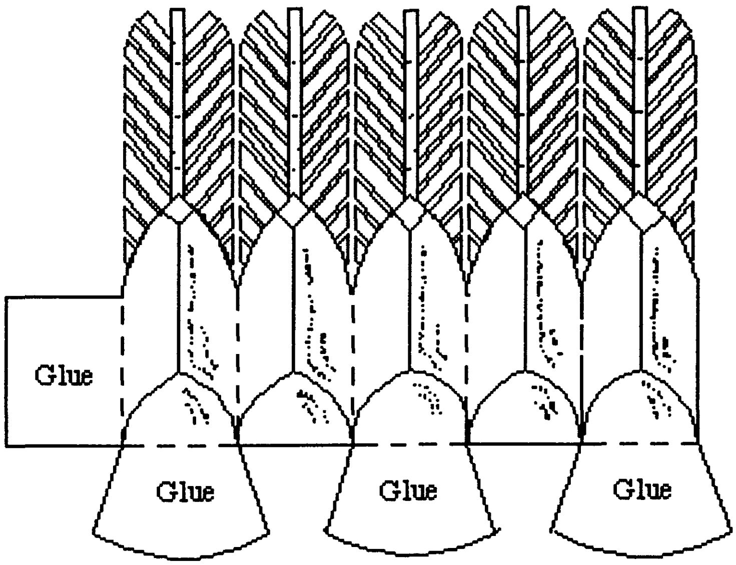
Cut out base of crinoid



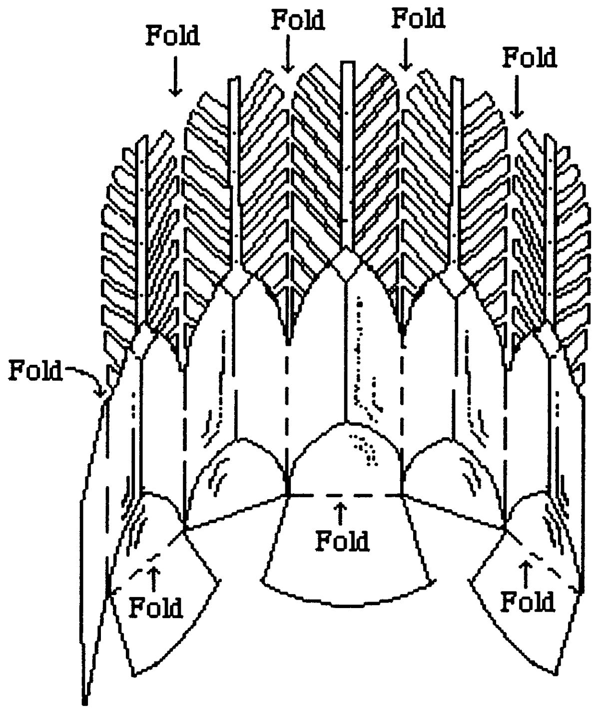
Pattern for crinoid paper model



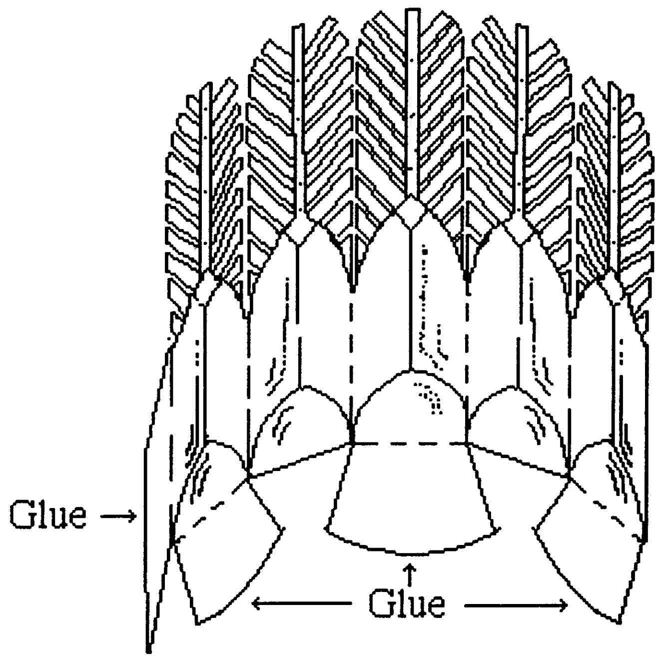
Cut out calyx.



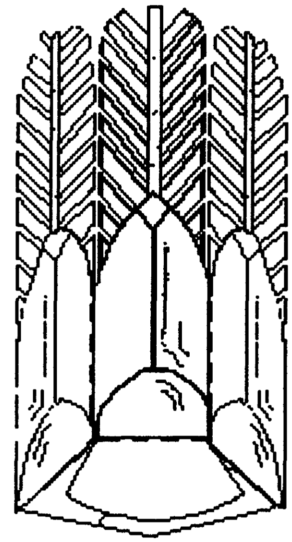
Fold pattern along dashed lines



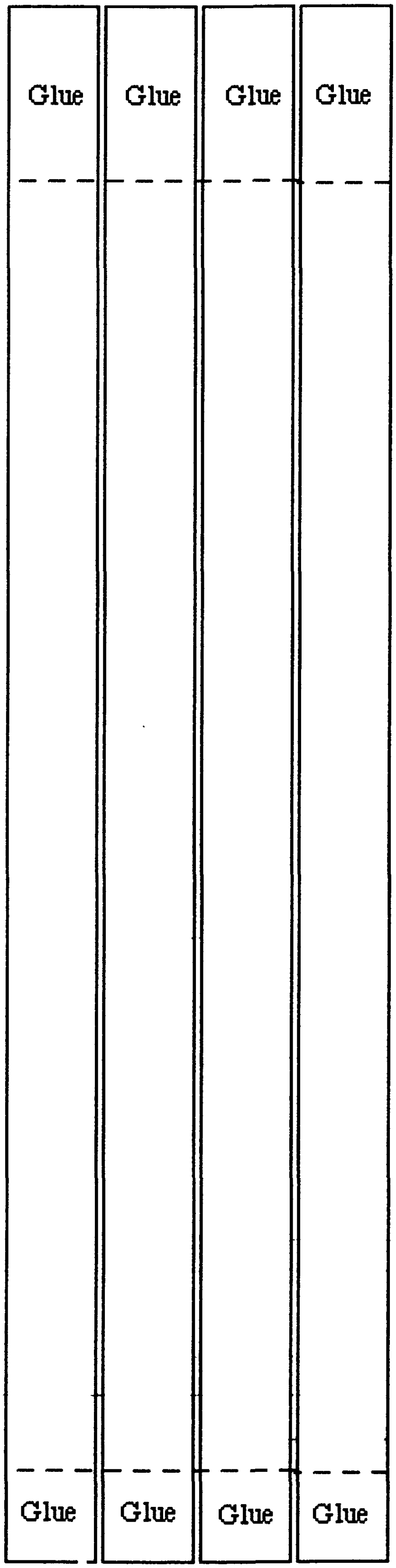
Glue tabs of calyx



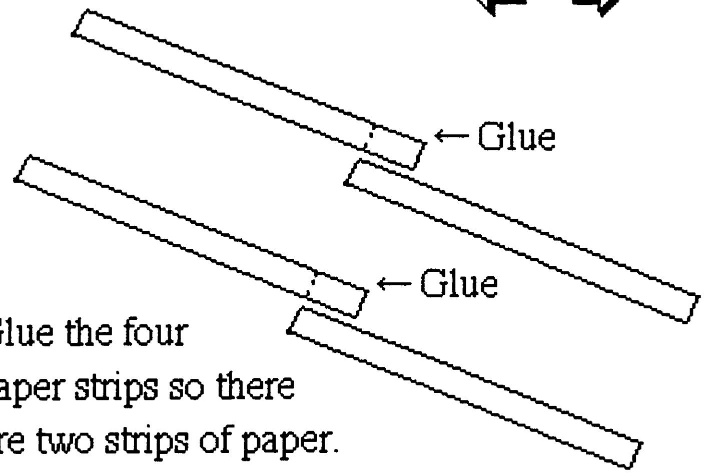
Calyx should look like this.



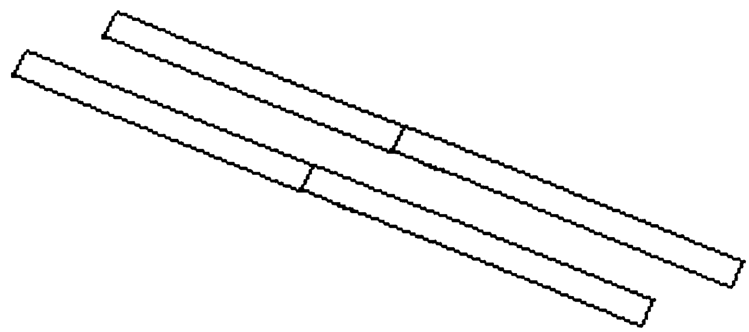
Interior of stem

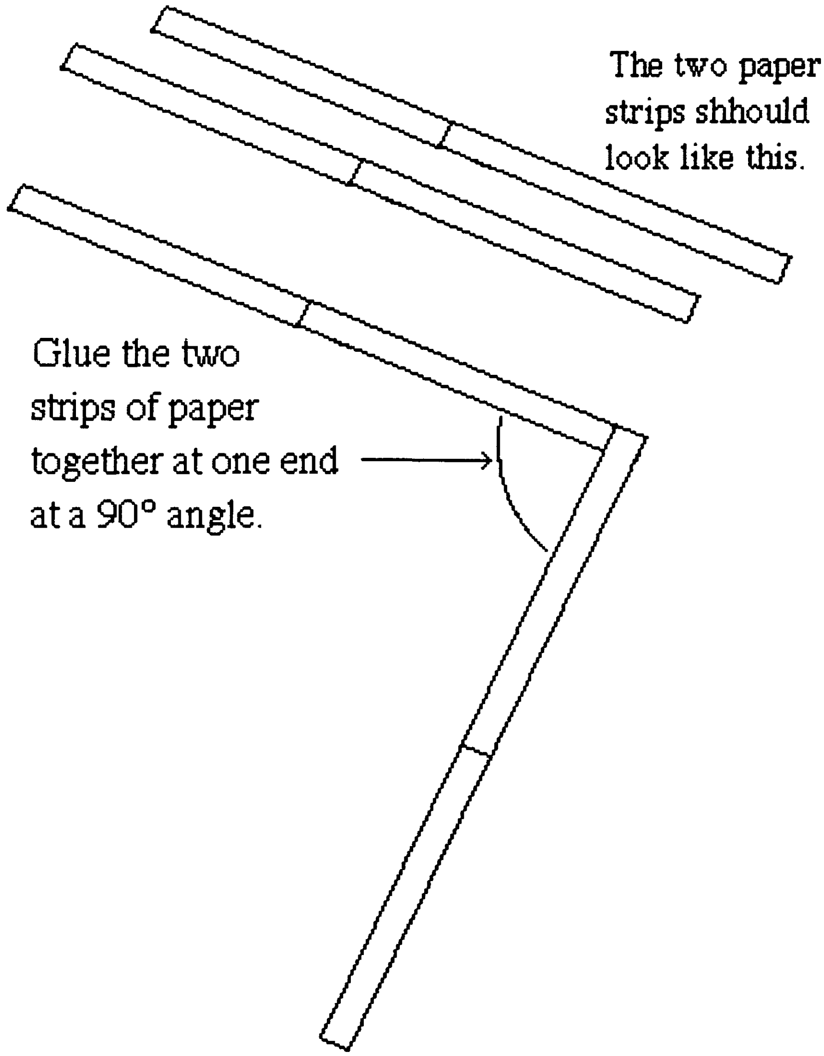


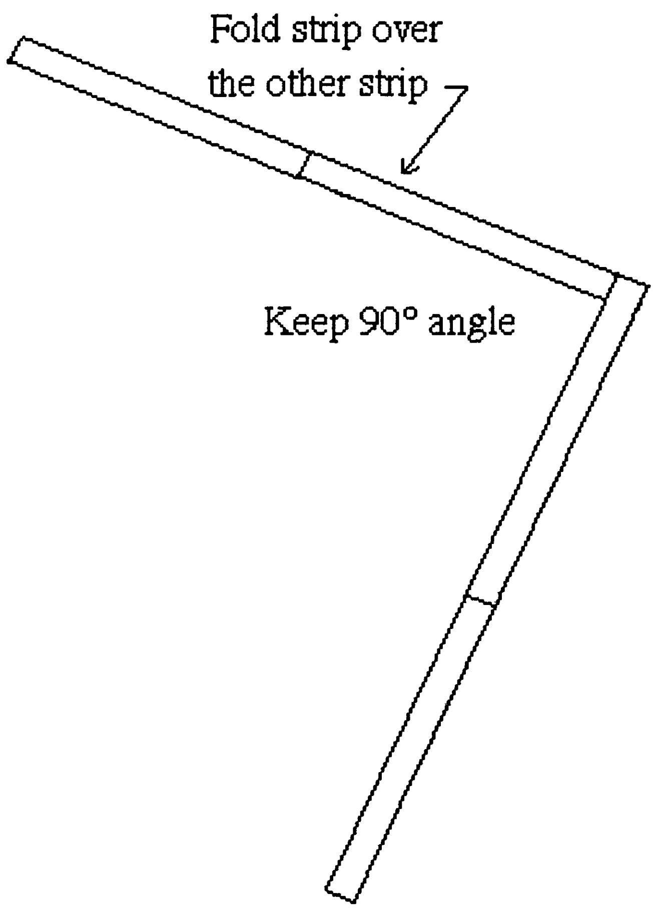
Cut out interior of stem.

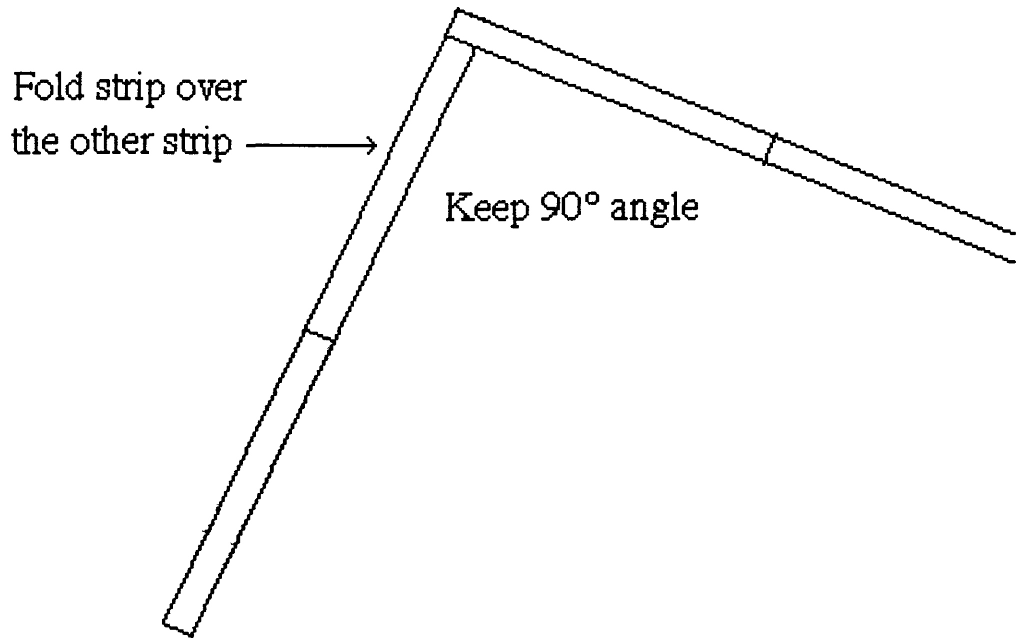


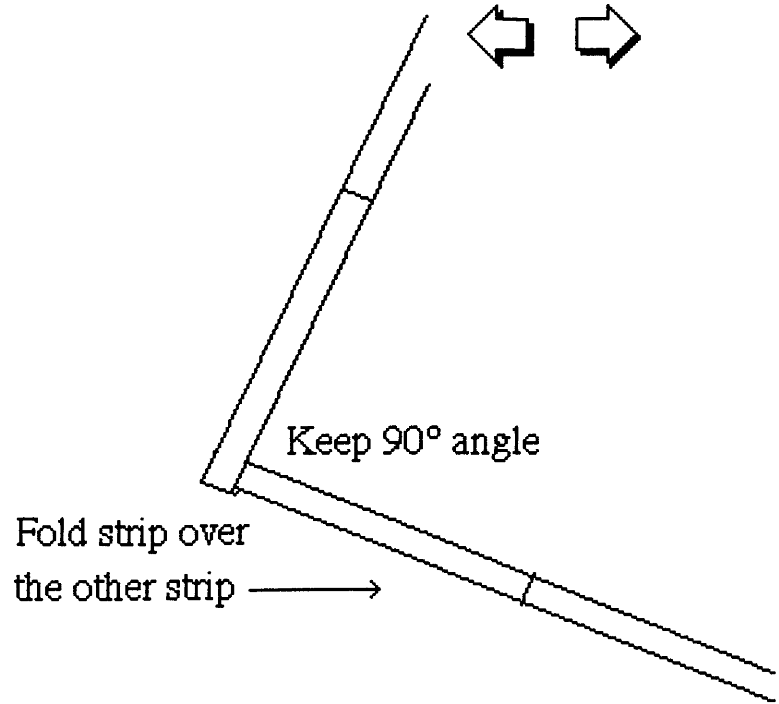
Glue the four paper strips so there are two strips of paper.



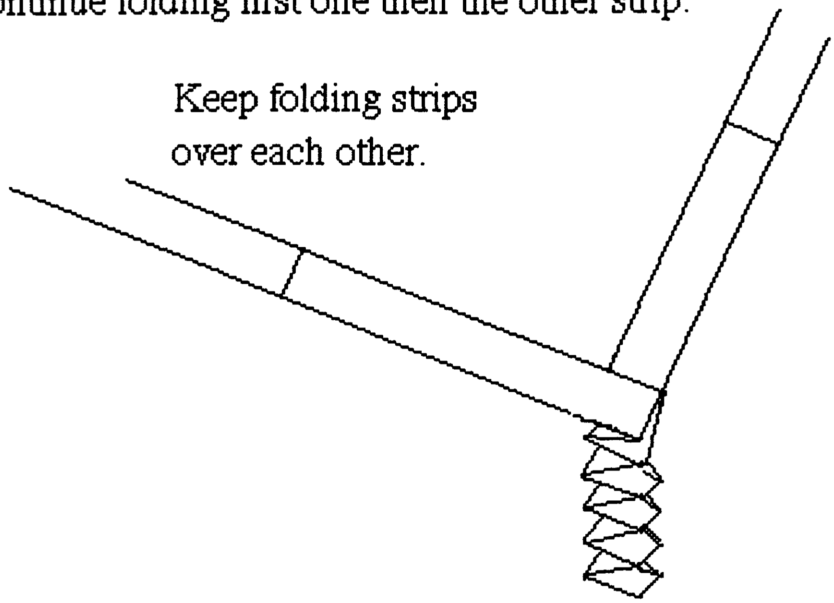

The two paper strips shhould look like this.
Glue the two strips of paper together at one end at a 90° angle.

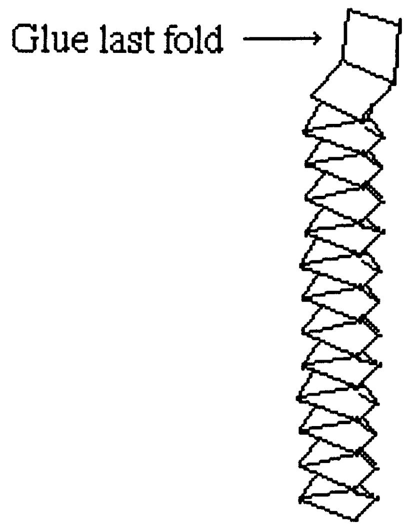

Fold strip over
the other strip
Keep 90° angle


Fold strip over
the other strip
Keep 90° angle


Keep 90° angle
Fold strip over
the other strip

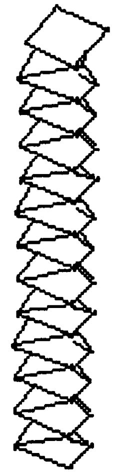
Continue folding first one then the other strip.



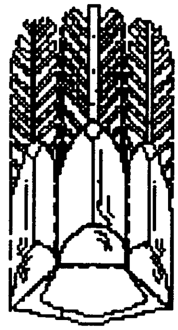

Glue last fold

Interior of stem should look like this.

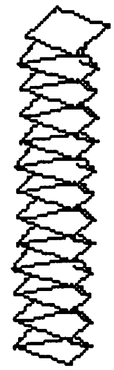
When finished folding the two strips over each other, they should look like this.



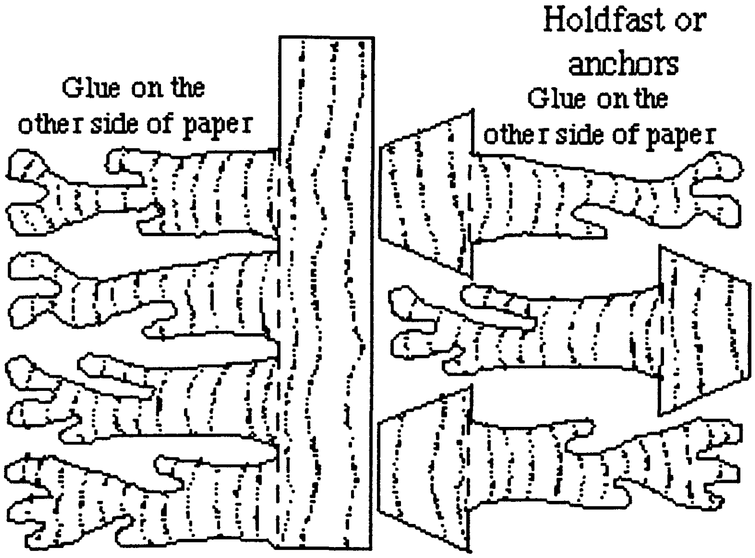
Calyx
previously
assembled.



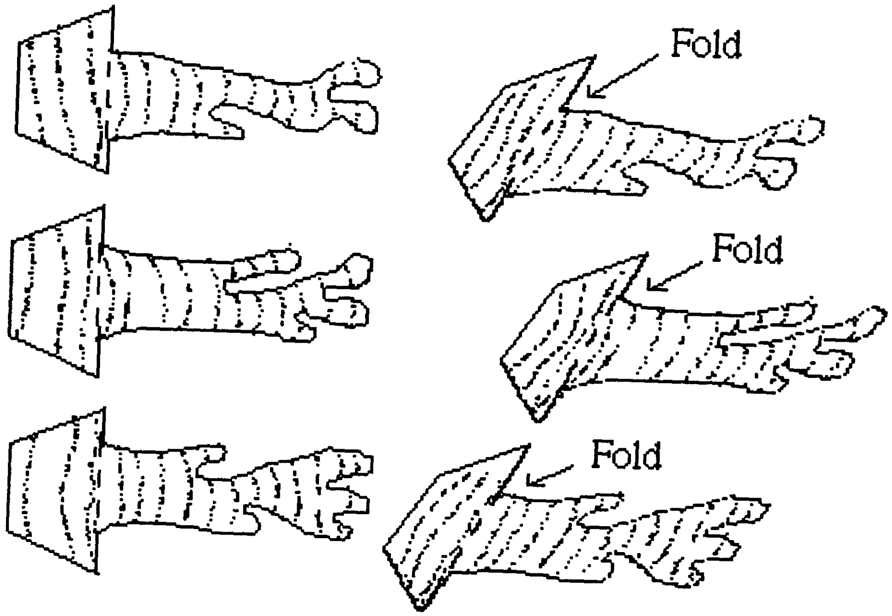
Interior
of stem.

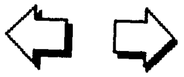


Cut out holdfast of crinoid.

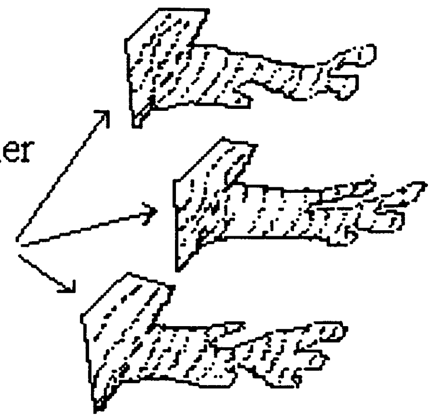


Cut out and glue these three holdfast to the interior of stem first.

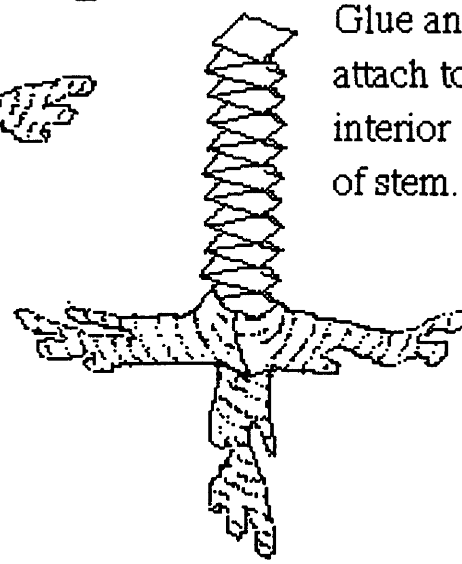

Fold
Fold
Fold



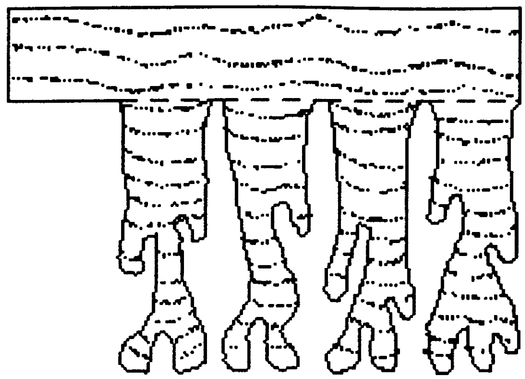
Glue other other side of paper.



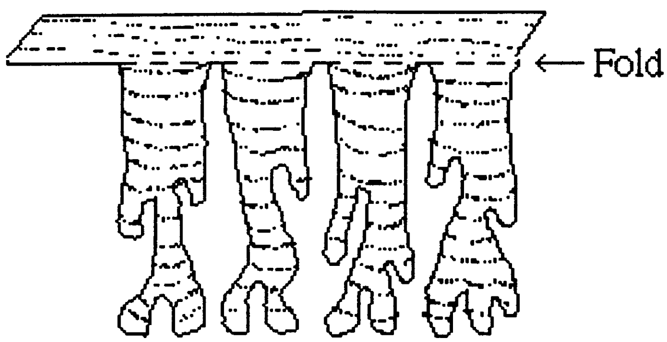
Glue and attach to interior of stem.



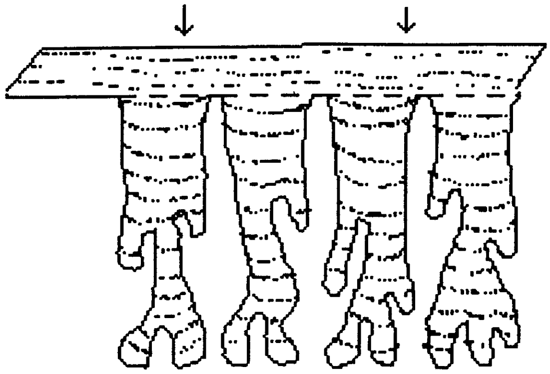
Use a lot of glue.
Let glue dry.



Cut out
holdfast pattern.

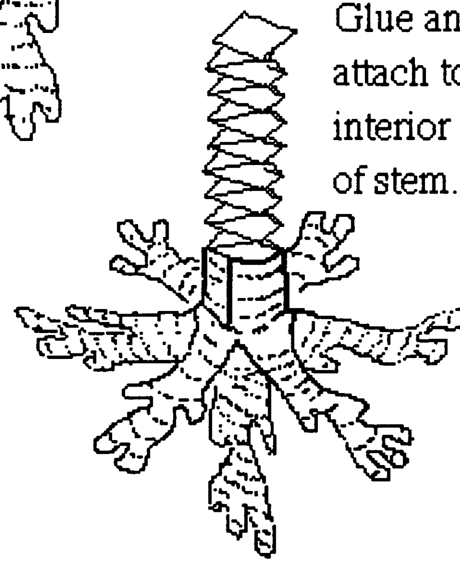


Glue other side of paper pattern.



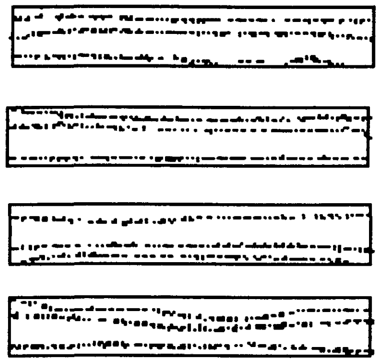
Use a lot of glue.

Let glue dry.



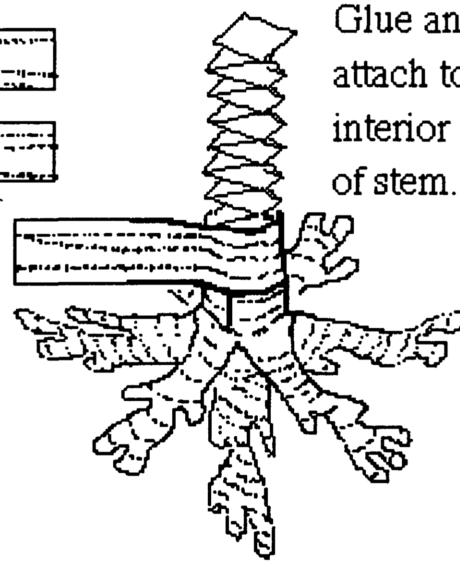
Glue and
attach to
interior
of stem.

Cut out layered plates (ossicles)

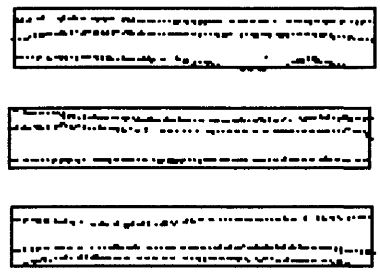


Glue layered plates on the other side of paper

Glue and attach to interior of stem.

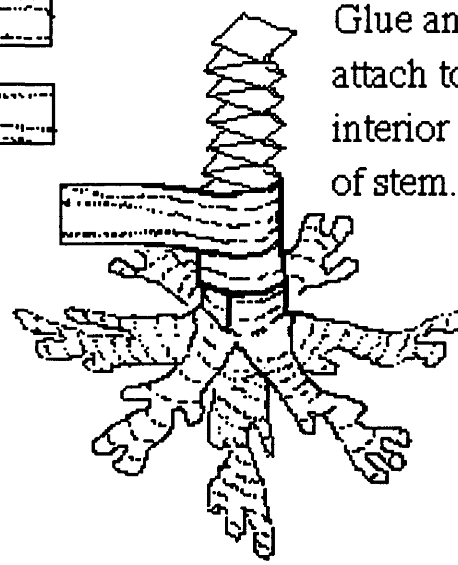


Use a lot of glue.
Let glue dry.



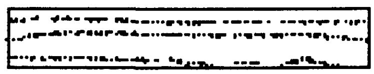
Glue layered plates on the other side of paper

Glue and attach to interior of stem.

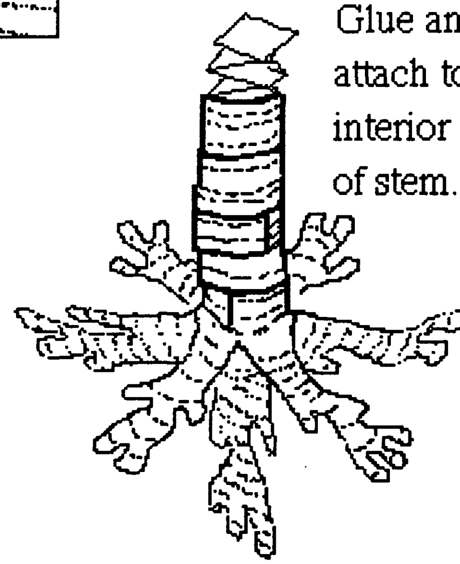


Use a lot of glue.
Let glue dry.

Glue layered plates on the other side of paper

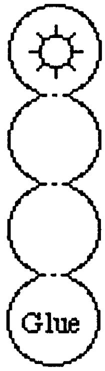


Glue and attach to interior of stem.

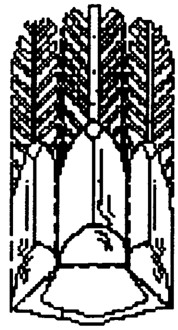


Use a lot of glue.
Let glue dry.

Cut out tegmen

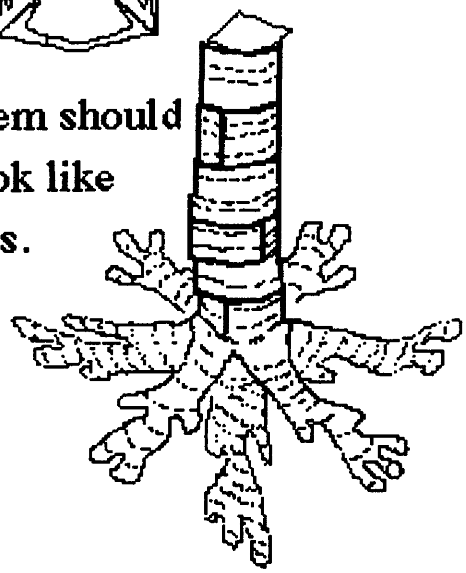


Tegmen



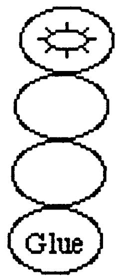
Calyx previously assembled.

Stem should look like this.

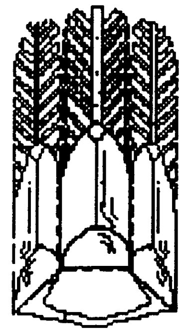


Use a lot of glue.
Let glue dry.

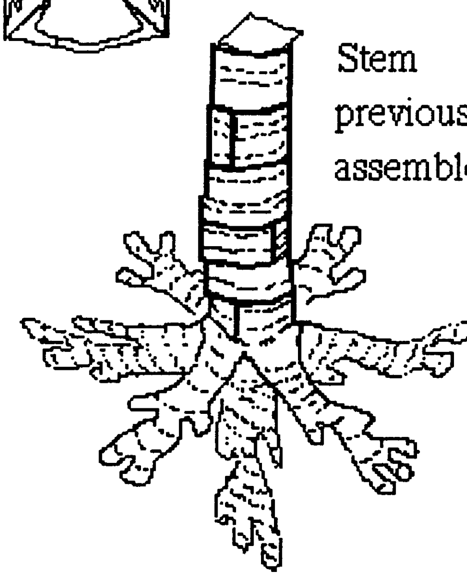
Fold tegmen



Tegmen

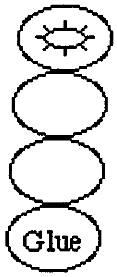


Calyx previously assembled.

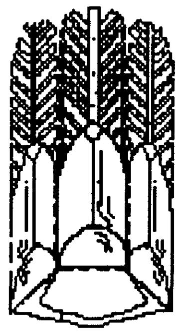


Stem previously assembled.

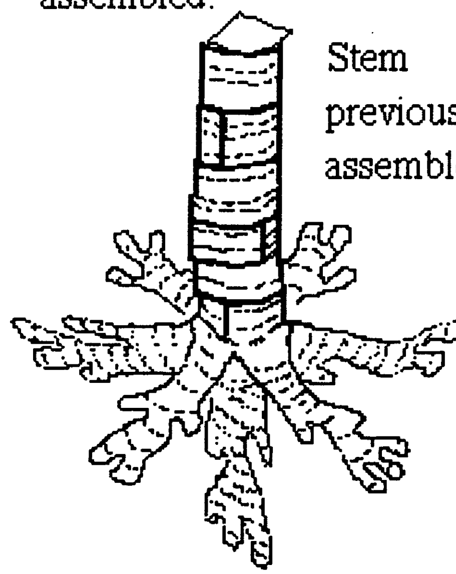
Glue tegmen



Tegmen

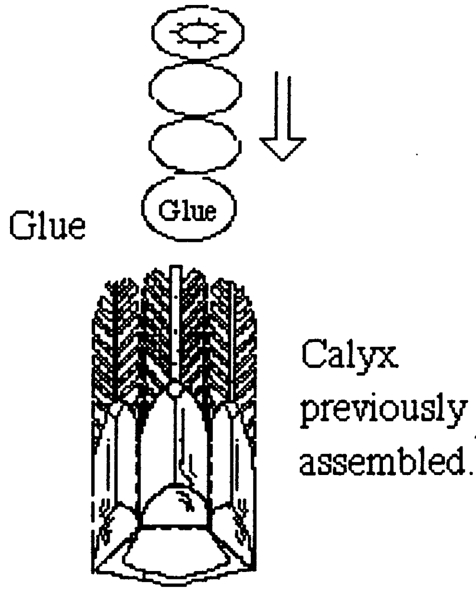


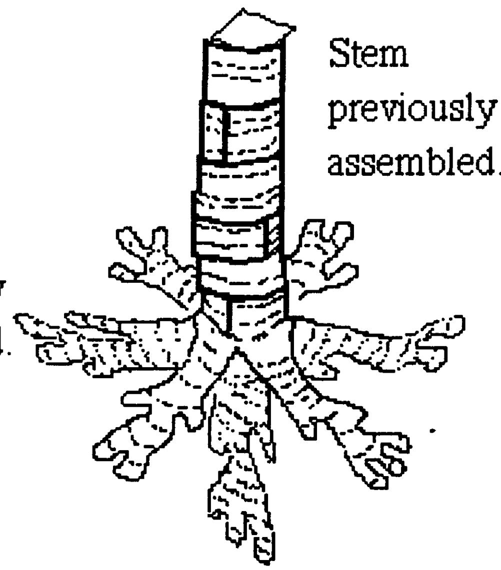
Calyx
previously
assembled.

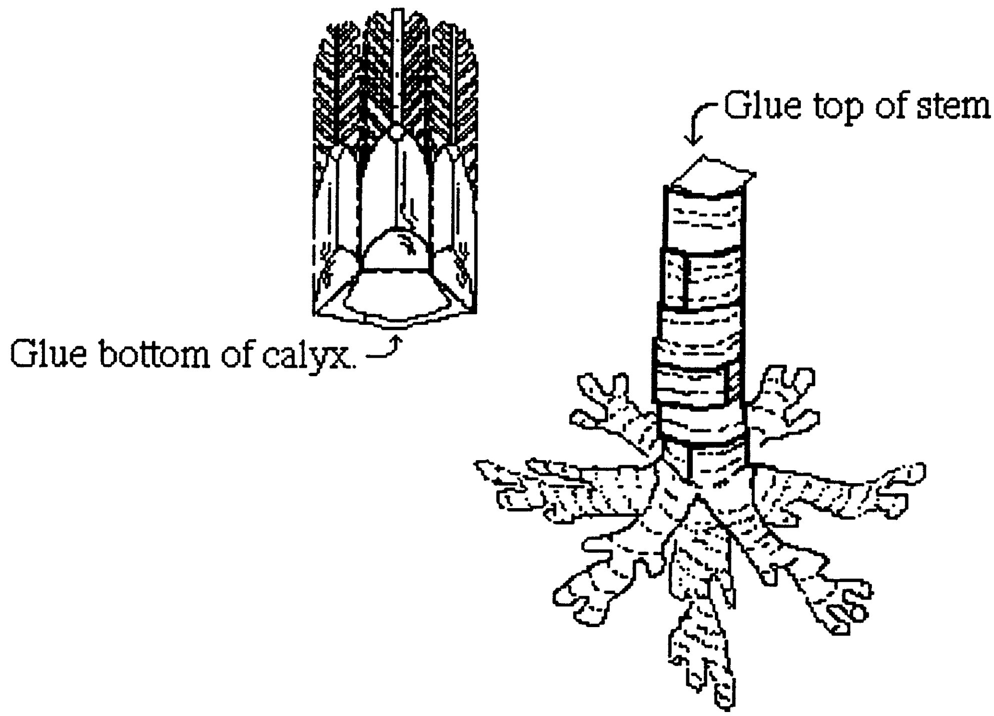


Stem
previously
assembled.

Glue tegmen inside calyx.

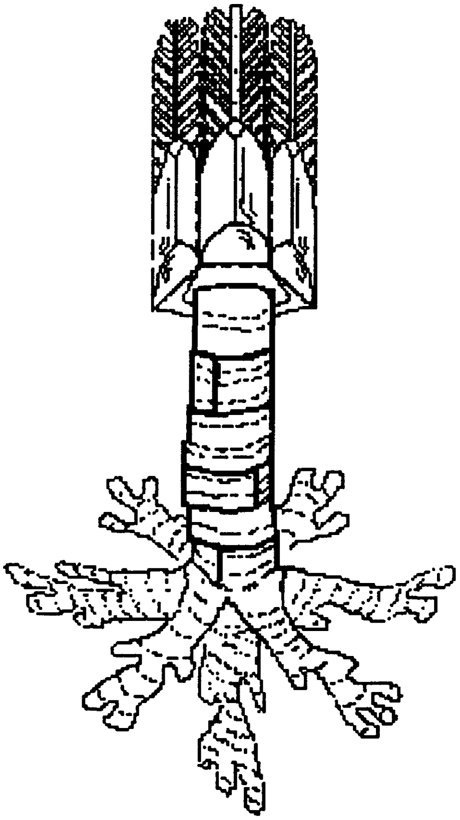




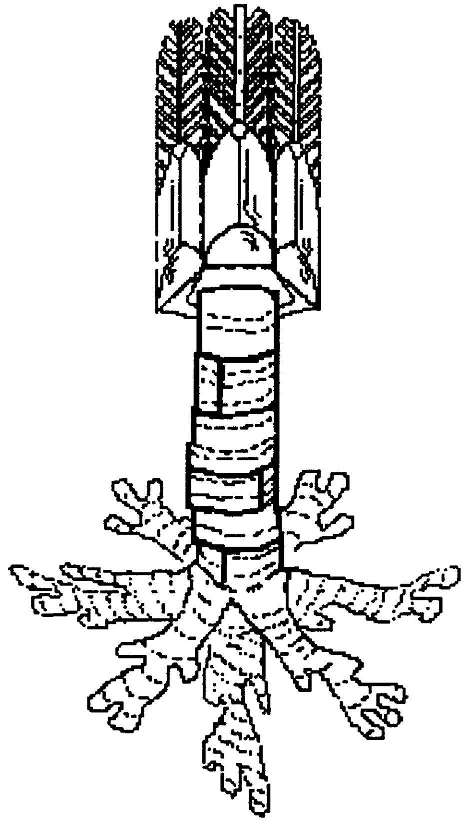

Glue top of stem.
Glue bottom of calyx.

Attach calyx to stem.

Let glue dry.



Crinoid should look something like this.



Glue the other side of crinoid's holdfast.

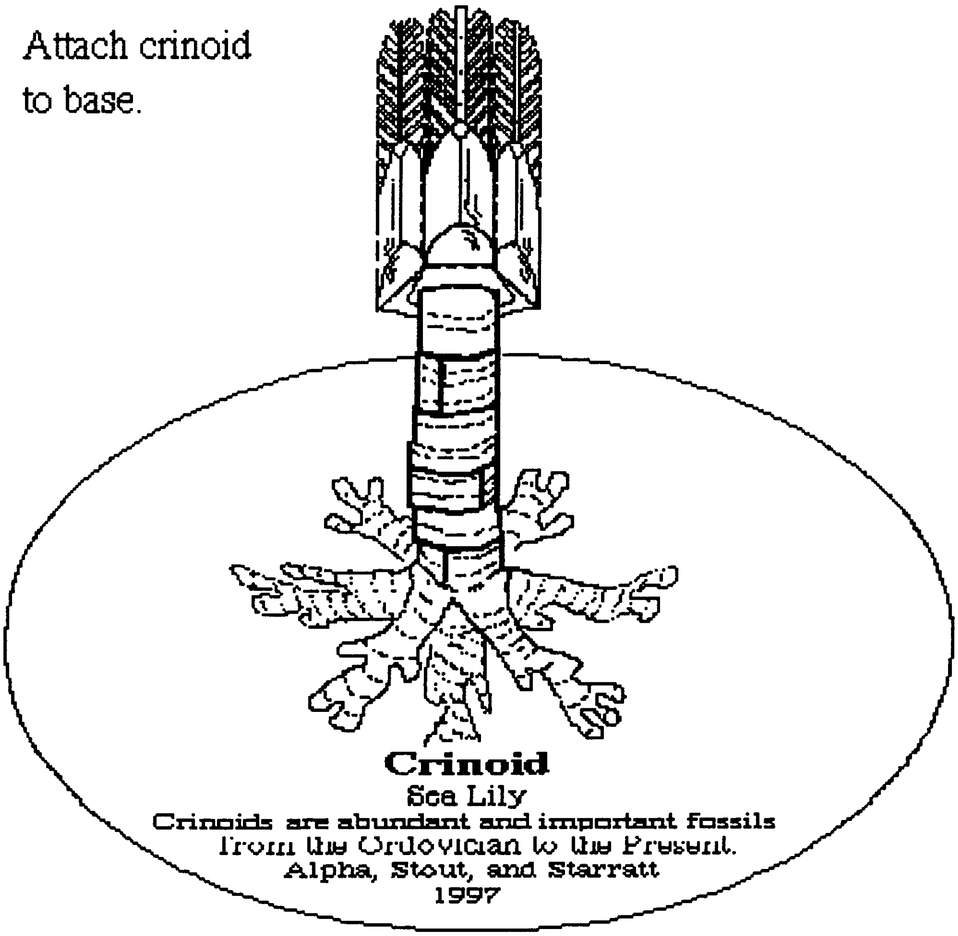
Previously cut out base.

Crinoid

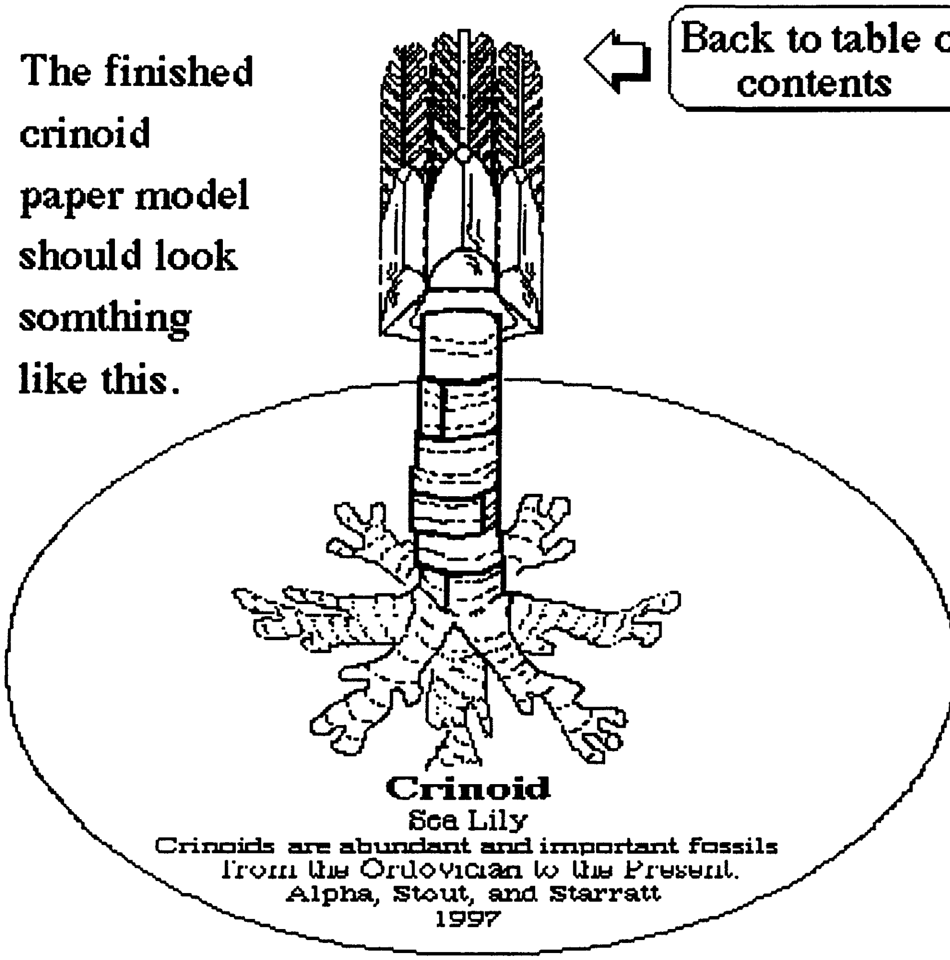
Sea Lily

Crinoids are abundant and important fossils
from the Ordovician to the Present.
Alpha, Stout, and Starratt
1997

Attach crinoid
to base.



The finished crinoid paper model should look somthing like this.



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The End