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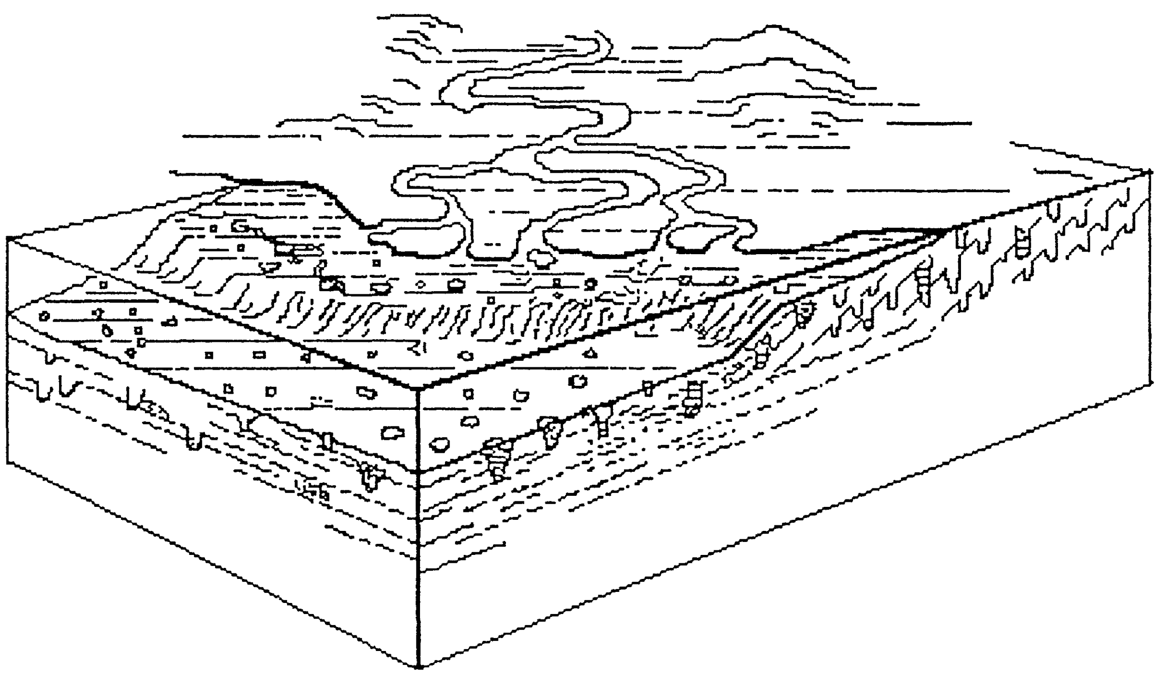
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Arctic Delta Processes

A computer animation and paper models

by
Tau Rho Alpha* and Erk Reimnitz*
Open -file Report 95-843



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Description of Report

* Note: In the diskette version (HyperCard stack) additional information can be viewed by clicking on an asterisk (*) or **bold type.**

This report shows, by means of a computer animation and paper models, how deltas are affected by fresh and salt water currents, topography and location. The report is intended to help students and others visualize how ice shapes and forms a delta. By studying the animations and the paper models, students will come to understand why deltas have different shapes and different interior structures. The diskette version has an animation of arctic delta processes. While both the diskette and paper versions have teacher guide and paper models.

Many people provided help and encouragement in the development of this HyperCard stack, particularly Scott W. Starratt and Art Ford. This report was enhanced by the excellent reviews by Jim Pinkerton and Peter W. Barnes.

Table of Contents for paper version of this report

Description of Report

Requirements for the diskette version are: Apple Computer, Inc., HyperCard 2.2™ software, and an Apple Macintosh™ computer with high-density drive. If you are using System 7, we recommend using at least 3 MB of RAM with 4500K of memory available for HyperCard. 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. The animation is accompanied by sound. If no sound is heard, ensure that the control panel "Sound," which is in the "Control Panels" folder under the "Apple" menu, has the volume set at least to 2.

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 geologic 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 in the Home stack, 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 12/4/1995. OF 95-843-A, paper copy, 27p.; OF 95-843-B, 3.5-in. Macintosh 1.4-MB high-density diskette.

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Deltas

A **delta** is a triangular landform similar to the Greek letter "delta"Δ, composed of clay, silt, and sand called **sediment.** Deltas form where a river flows into a body of standing water. The river divides and subdivides into smaller channels called **distributaries.** The current of the narrow river channel is reduced when it reaches a body of standing water and therefore drops its **sediment load** (of clay, silt and sand.) The coarse particles settle out first and the clay continues farthest into the ocean. A delta will be built only if the sediment load carried by the river is greater than the amount of sediment that can be eroded away by ocean waves and currents.

The shape of a delta varies depending on the configuration of the coastline and the intensity of wave and current action. The Nile River delta has the shape of a triangle with a curving shoreline; it is called an arcuate delta. The Mississippi delta has channels projecting into the ocean; this shape is called a digitate or bird-foot delta. Where waves and currents are strong, sediment is spread along the shore line in both directions from the river mouth and produces a cuspate delta, a pointed delta with curved sides that form sandy spits. If the mouth of the river is in a valley, the delta is long and narrow and is called an estuarine delta. Example of an estuarine delta is the Colorado River delta of North America. For examples of North American deltas see Our Changing Coastlines by Shepard and Wanless, 1971.

River-flooding of fast ice and related Arctic delta processes

Delta-building processes differ greatly between those of classic, well-known open-water conditions in tropical to **temperate** areas and those in the Arctic, where a 2-m (6 ft) thick, smooth ice sheet (**fast ice**) covers the ocean when the rivers reach spring flood-stage in early June. The animation of Arctic Delta flooding highlights what little is known about unique Arctic river-mouth processes. Also see a vedeotape, by Steve Wessells, Erk Reimnitz, Peter Barnes and Ed Kempema, 1993, Drift - Ice as a Geologic Agent.

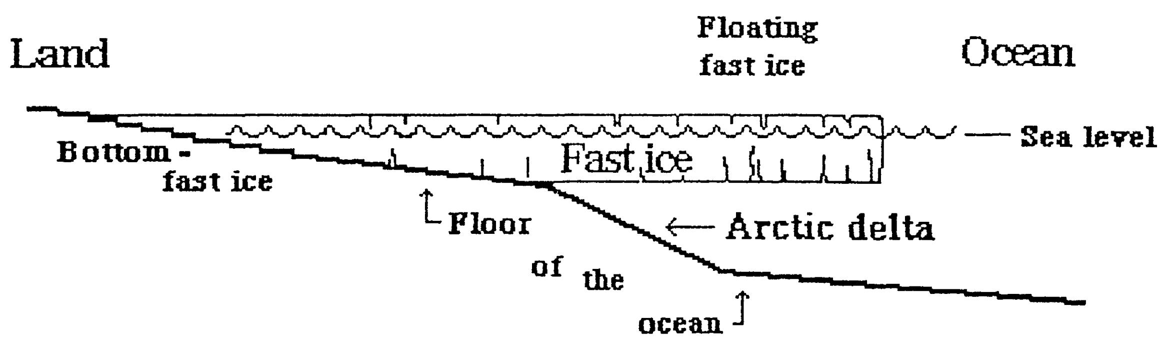


Fig. 1 Profile of an Arctic delta

The **morphology** of arctic to sub-arctic deltas in North America is characterized by extensive shallow [<2 m(6 ft)] platforms extending as much as 10-20 kilometers (6-12 miles) from delta shores (Reimnitz and Bruder, 1972; Dupré, 1982). These platforms are not crossed by channels deeper than the thickness of the fast ice [2m(6 ft)], and therefore river distributaries can not freely discharge into the sea during spring floods. Instead of flowing under the ice, the river water during spring flood must flow out over the fast ice, as shown in the animation. The flood-water front advances at a rate of several kilometers per hour, and reaches its maximum extent within several days.

During this stage of the spring flood, there is as much as 1m (3 ft) or even more freshwater on top of 2 m (6 ft) of fast ice, which in turn is resting on the sea bed or floating on salt water. Both liquids may be at their respective freezing points. This arrangement of an ice layer sandwiched between two layers of water is unstable. The ice sheet is driven upward by its **buoyancy**.

Cracks weak zones and perforations in the ice, where present, allow the surface water to drain and the ice to rise over a period of a few days. The shore-fast ice extends as a continuous sheet far beyond the regions flooded by river water. These regions, however, are inhabited by seals, who make breathing holes for themselves and maintain them throughout the winter. During wintertime, the vents are concealed by drifting snow. Seals use these holes to climb out onto the ice surface, once the sun begins to warm the air and there is no danger from polar bears. When swiftly spreading river water encounters these holes it drains in vertically oriented **axial jets** with a swirling motion called **strudel** (Reimnitz and Bruder, 1972). The rushing water enlarges these vents to 10 or even 30 meters in diameter. Strudel also form along cracks in the ice. Cracks formed by tidal action exist primarily along the contact between the ice resting directly on the seafloor in regions shallower than 2 m and the floating ice heaving offshore. Therefore strudel are concentrated along this contact line, the 2-m **isobath.** Elswhere in the **inundated** region the sea ice may crack under the sheer weight of flood waters opening more draniage pathways.

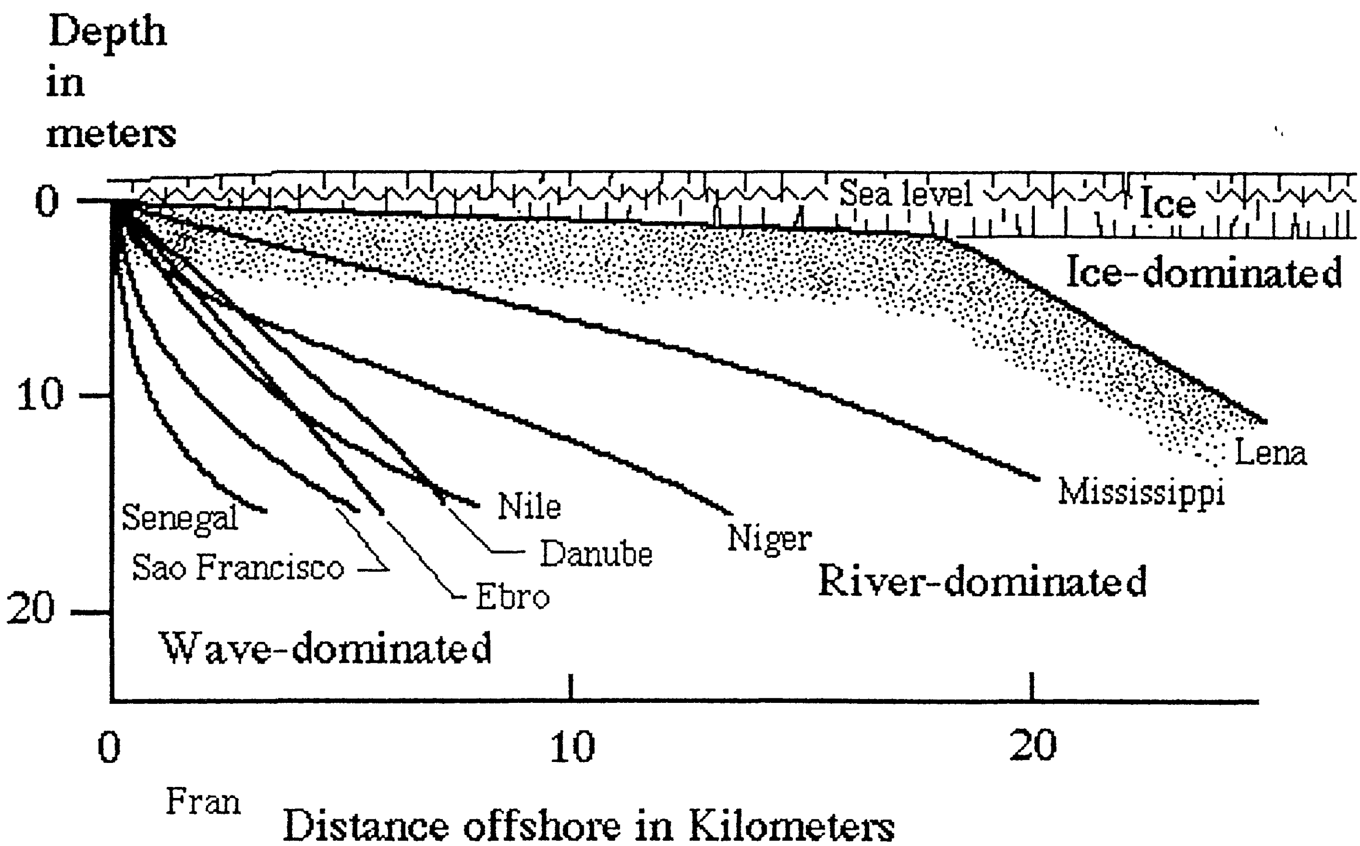
Water depths in the arctic regions flooded by rivers are less than 5 to 8 meters (15 to 24 ft). Therefore one would expect that the swirling flow of axial jets would produce scour marks on the seafloor which they do. Steep-walled **strudel-scour craters** indeed are formed by the water jets, as delineated in hydrographic surveys and examined by divers (Reimnitz, et al., 1974; Reimnitz and Kempema, 1983). Craters 20 meters (65 feet) in diameter and 7.5 meters (25 ft) deep below the surrounding seafloor have been observed. The craters form during a 7 to 10-day period, and fill in from **sediment bedload-transport** within 3 years (Reimnitz and Kempema, 1983). The resulting scour depression sediment fill becomes a permanent and characteristic part of Arctic deltaic deposits, as seen in **seismic reflection records** (Reimnitz and others, 1974). For the construction of buried pipelines crossing the coastal zone, the threat of strudel excavation of big craters poses the most serious and costly design constraint.

The flow of water toward the strudel hole carves out radial channel patterns on the ice surface. These become visible from the air 1-2 weeks after the spring flood has subsided and the fast ice drained. Now the fast-ice cover is again on the sea surface. A study of aerial photos of one small Alaskan river delta after drainage of the fast ice revealed more than two of these spider-like patterns per square kilometer of ice cover. That density would represent the density of new scour craters formed on the sea bed per year. Nothing is known about the whereabouts of the scour excavation products (mud and sand), except that they are not found in the form of **levees** surrounding craters.

Other Background Information

A number of other questions are raised by the few scientific observations of river break-up in the Arctic. For example, numerous reports attributed the sediment load commonly observed on Arctic pack ice to surface deposition by rivers during spring floods. Arnborg et al. (1967) reported that 62% of the total annual suspended inorganic sediment load of Arctic Alaska's largest river is transported seaward during the initial 13 days of flooding. Such deposition by river floods on sea ice are not reliably documented, in fact, other reports describe the lack of such flood deposits (Reimnitz and Bruder, 1972) In any case, the fate of the fast ice that was initially flooded by rivers is unknown. The ice seems to melt in place before long-distance drift occurs on Arctic continental shelves. Thus the question of whether or not flood-deposits occur on the fast ice would be irrelevant for long-range sediment transport. Another unanswered question is how the scour craters achieve their large size in such short time intervals, while the subsurface in large regions should be hard permafrost. Ice crystals are known to grow where two fluids with different salinities and therefore different freezing temperatures mix. Could such ice crystals, carried downward with the flow, cause bottom abrasion?

The most fundamental and significant question is raised when the forms of temperate deltas are compared with the forms of arctic deltas covered seasonally by fast ice. This comparison is shown in figure 2 (next page) and the paper model. The conformity of the base of the fast ice with the top of the 2-meter bench (Reimnitz and Bruder, 1972) and the seaward break in slope at this 2-meter thickness, suggest a cause and effect relationship. Reimnitz and Bruder (1972) speculated that 2 meter fast ice causes a current-flow intensification between ice and ocean floor during peak river discharge, moving sediment seaward. The few sub-ice current measurements available for the time of river breakup do not show increase in current flow. Another possible explanation is that ice -growth reduces the cross section for tidal currents, causing current-winnowing and planation of the 2 meter bench. Loss of recording current meters under the fast ice in shallow water is to blame for this remaining question.



Comparison of the profiles of seven temperate deltas by Wright and Coleman (1973) with the typical profile of an ice-dominated delta, exemplified by that of the Lena River of Siberia. Profiles of other arctic deltas are very similar.

Fig. 2 Comparison of river delta profiles.

What's in it for me?

A delta provides many sources of food for mankind. Historically these large fertile lands supported large agricultural populations.

Many deltas provide access to the continental interior for supply and trade.

Deltas provide harbors and shelter for vessels.

New land is created by the growth of a delta. The Mississippi River delta grows at a rate of 200 feet or 60 meters per year.

A delta and its estuaries provide permanent and temporary homes for fish and wildlife.

Deltas filter out pollutants, improving the quality of water for living things.

Questions for further study

Deltas are composed mostly of clay, silt, and sand. What is the word that represents these materials?

Why is sediment deposited at the mouth of the river ?

What are the branches of the river called that flow through the delta?

Why do rivers flowing into the open ocean have difficulties forming deltas?

What is the largest river in North America that flows northward? What sea or ocean is its delta in.

What is the longest river in Africa? What geometric shape is its delta? What Greek letter has this shape?

What is the name of the 2-m (6 ft) thick ice that is attached to the delta (shore), rests on the seafloor to the 2-m (6 ft) isobath and then floats as it continues out to sea?

After the spring flood, the fast ice has holes in it which are surrounded by spider-like patterns. What is the name of these ice holes. Would this be a safe place to visit?

Glossary

Axial jets: Jets of water flowing in a vertical direction.

Bedload transport: The transportation of solid material at or near the bottom of the stream.

Buoyancy: Capacity to remain afloat.

Delta: The flat triangular-shaped land at the mouth of a river.

Distributaries, or distributary stream: A divergent stream flowing away from the main stream and not returning to the main stream.

Fast ice: Sea ice that forms along and remains attached to the coast.

Inundated: A flood covering land or ice that is not normally submerged.

Isobath: A line on a chart that connects points of equal water depth. The two-meter isobath is the contact between the fast ice resting on the seafloor and the floating fast ice further offshore.

Levee: An embankment of sediment.

Glossary Cont.

Morphology: Study of the structure, development, and form of the earth's surface.

Sediment: Solid material that originates from the weathering of rocks and is transported by air, water, and ice.

Sediment bedload-transport: Part of the sediment load that is not in suspension but is moved along the stream bed, such as boulders, pebbles, gravel and even sand.

Sediment load: The solid material that is transported by a stream or river.

Seismic reflection record: Recording of sound waves generated by an energy source such as a air gun or electric charge and reflected from sub-bottom layers during geophysical surveys.

Strudel: Vertical jets of water flowing down through holes or cracks in the ice.

Strudel-scour crater: Craters on the floor of the ocean made by vertical jets of water.

Temperate: Temperature that is moderate or mild such as found in the middle latitudes.

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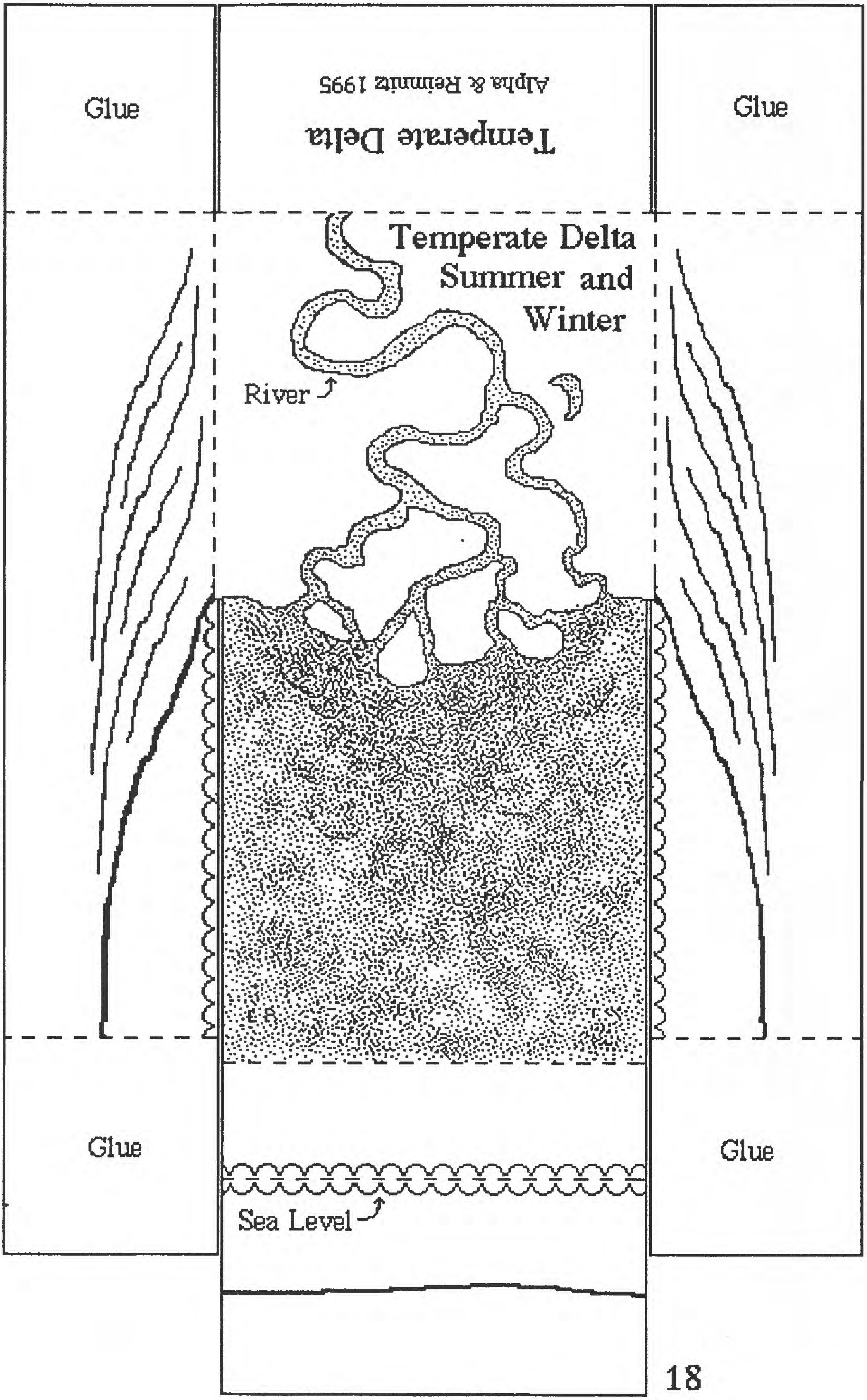

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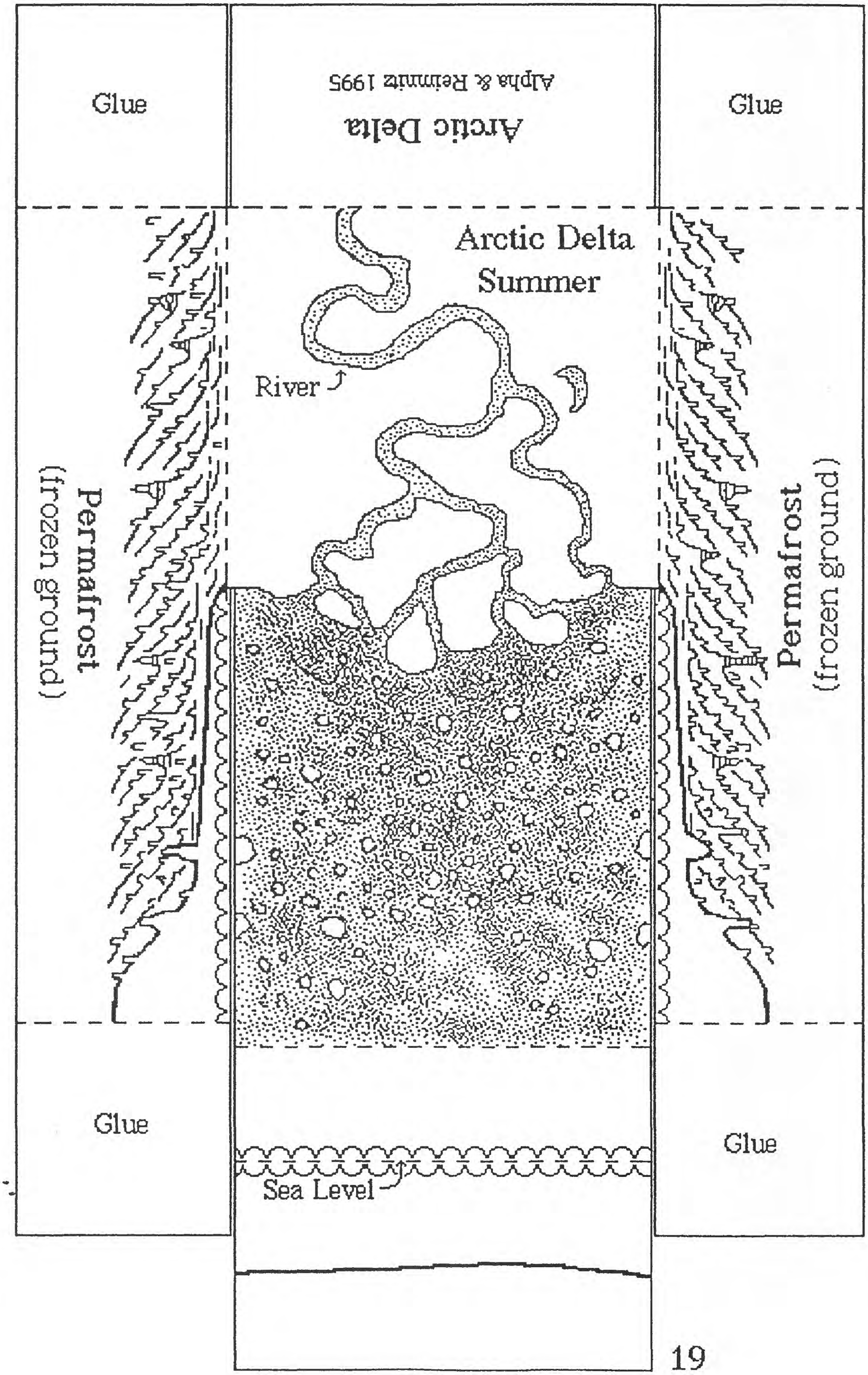
Cut out temperate delta outline. Fold dashed lines.



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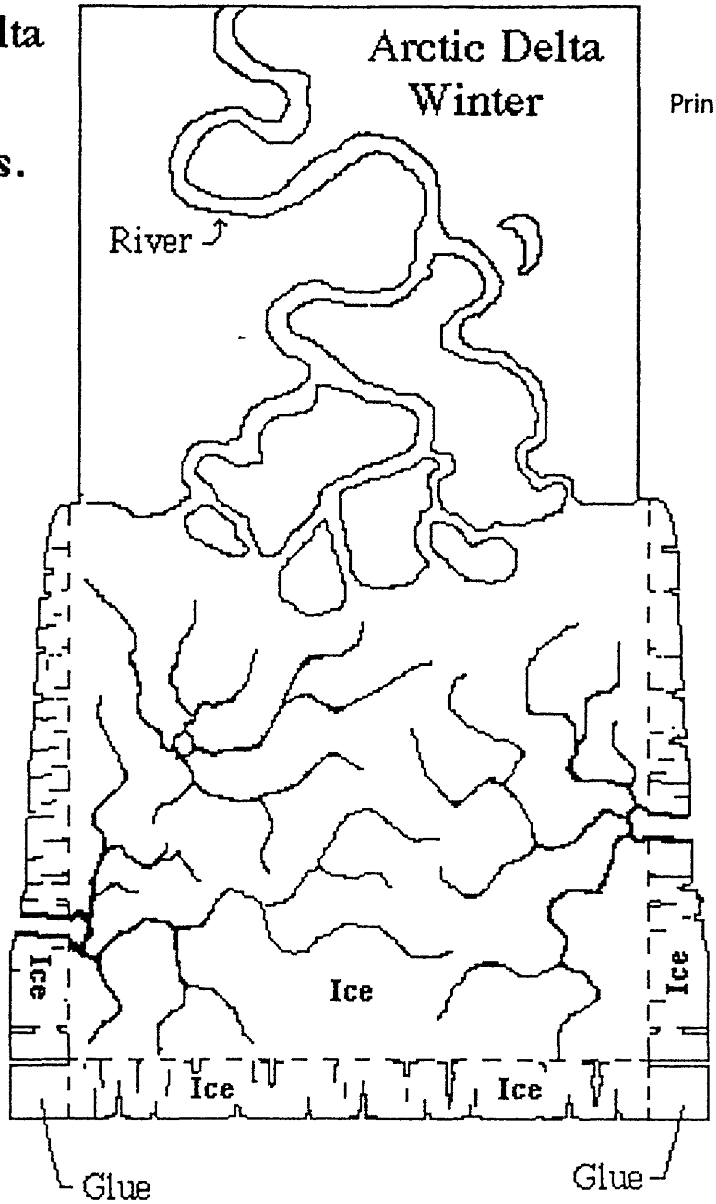
Cut out arctic delta summer outline. Fold dashed lines.

Cut out arctic delta winter outline. Fold dashed lines.



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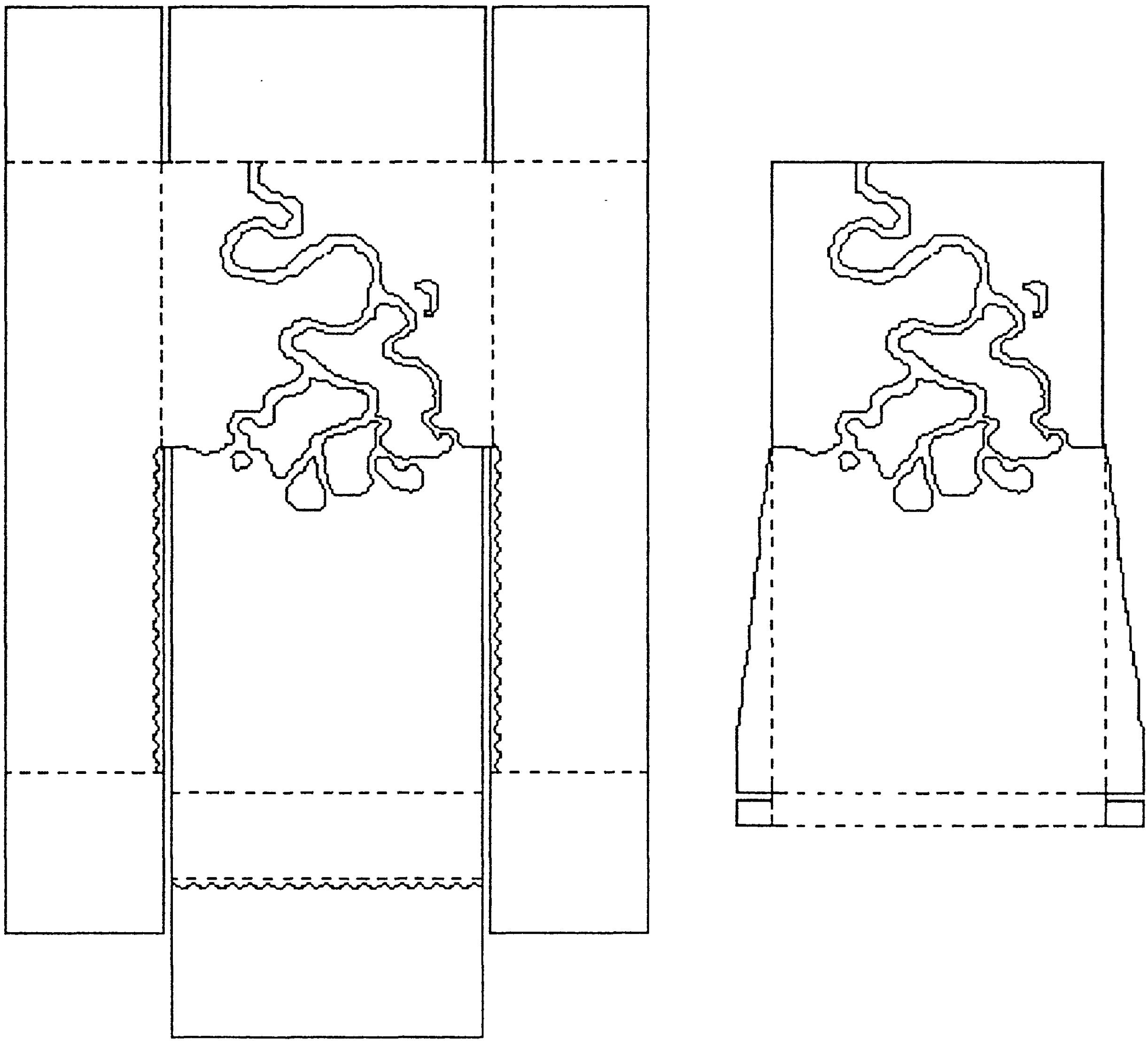
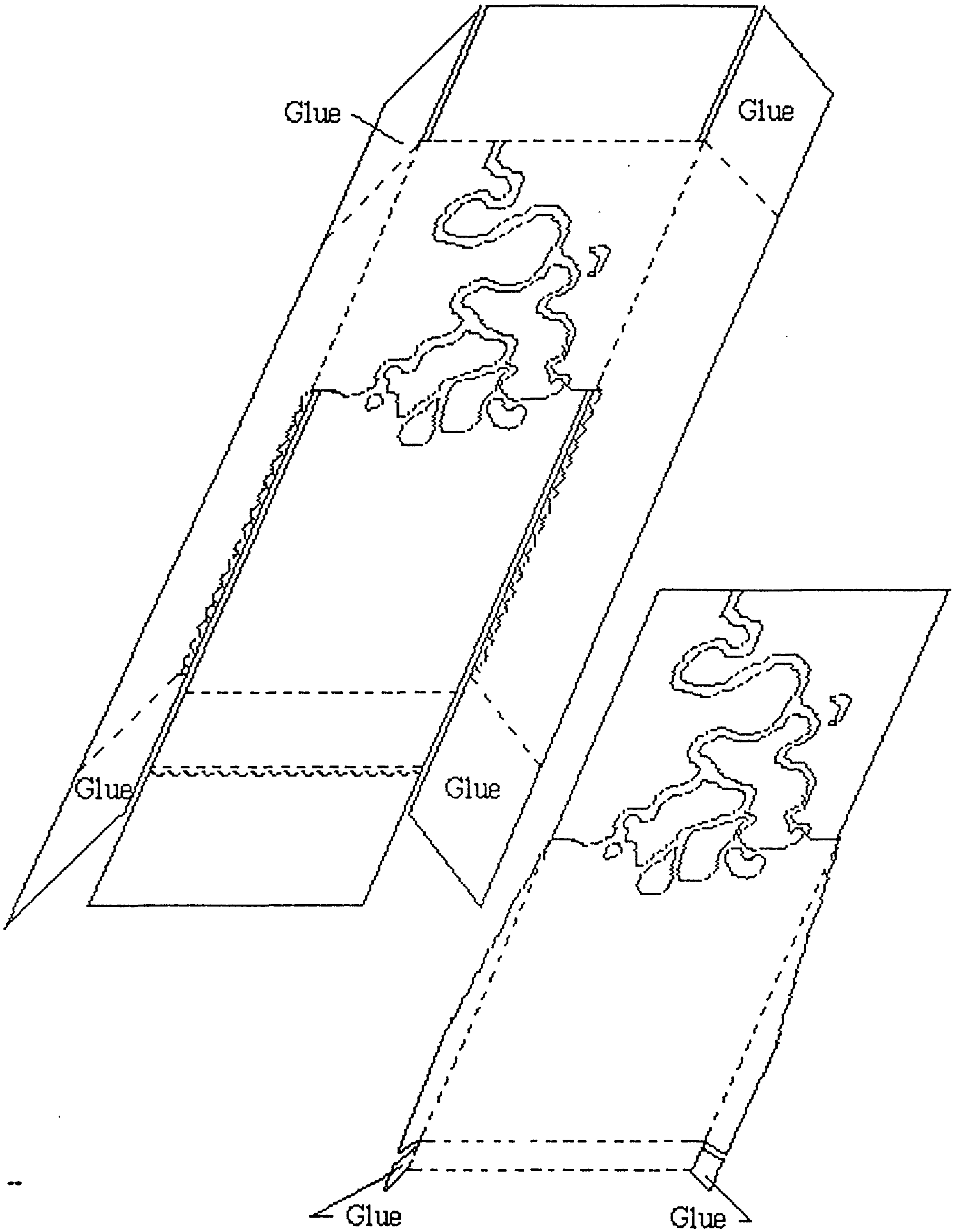
Step 1, Cut out temperate delta, arctic delta, and arctic delta winter models.



Step 2, Fold and glue
temperate delta, arctic delta, and arctic delta winter models.



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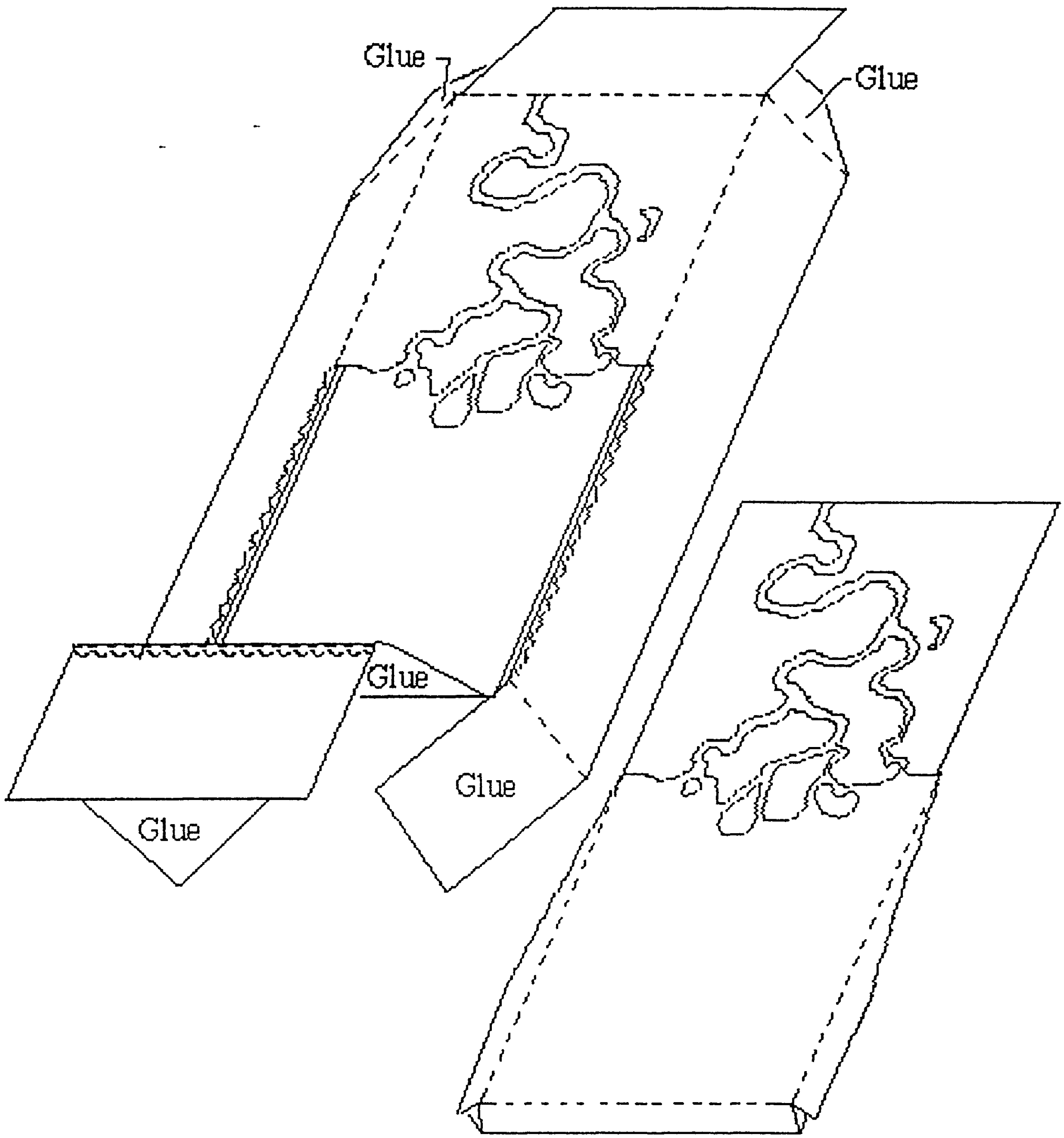

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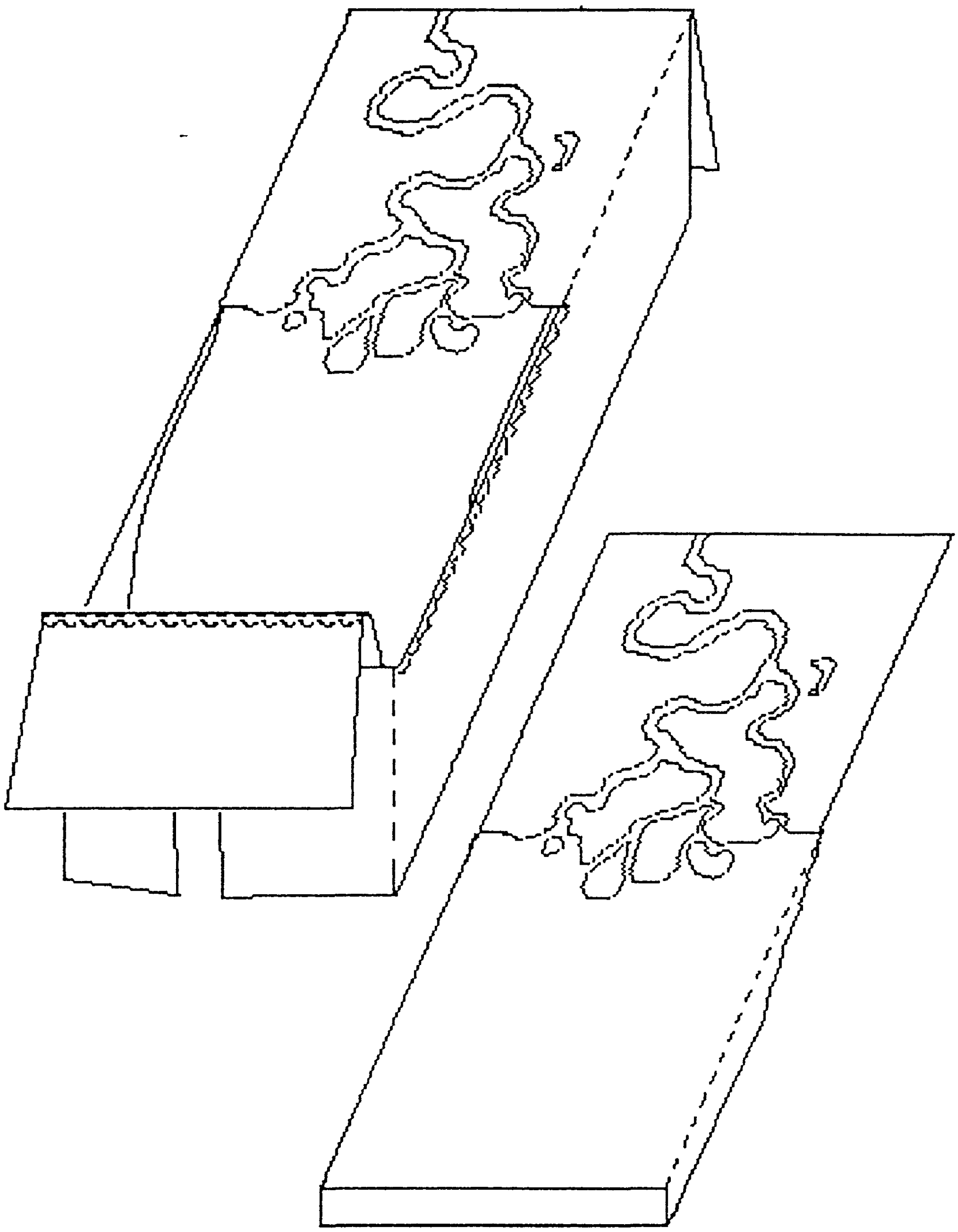

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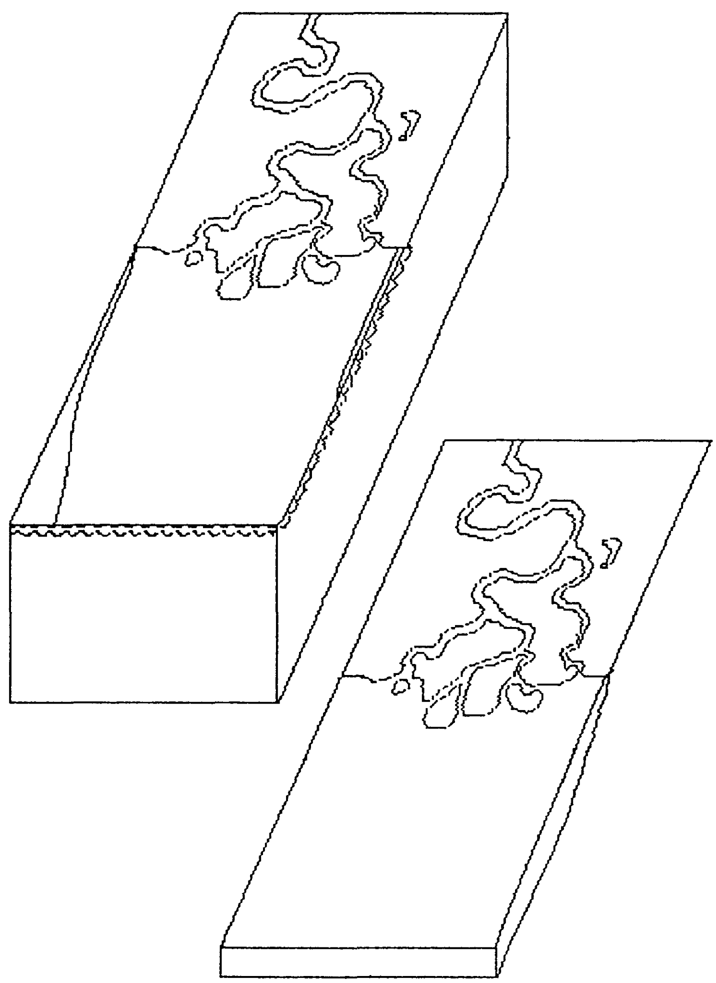

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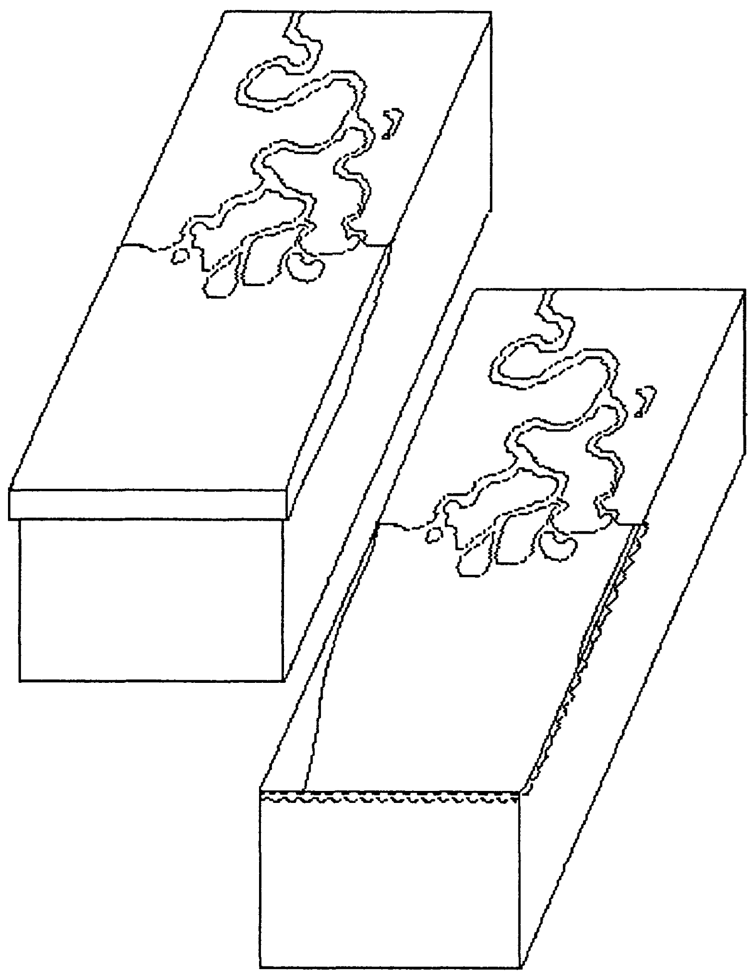

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Finished temperate delta should look like this.