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U.S. DEPARTMENT OF THE INTERIOR
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Sand Dunes

Computer animations and paper models

By

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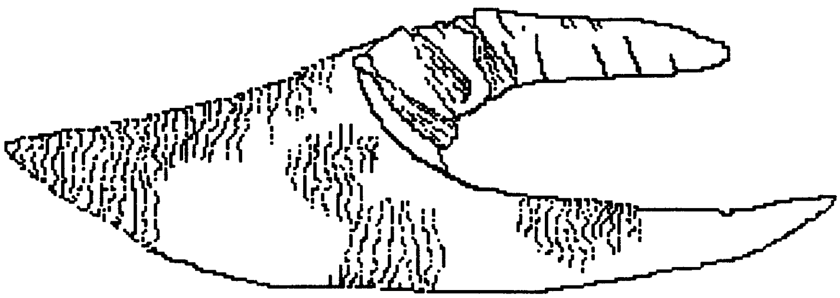
Open-file Report 98-131-A



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Description of Report

This report illustrates, through computer animations and paper models, why sand dunes can develop different forms. By studying the animations and the paper models, students will better understand the evolution of sand dunes,
Included in the paper and diskette versions of this report are templates for making a paper models, instructions for there assembly, and a discussion of development of different forms of sand dunes. In addition, the diskette version includes animations of how different sand dunes develop.

Many people provided help and encouragement in the development of this HyperCard stack, particularly David M. Rubin, Maura Hogan and Sue Priest.

This report was enhanced by reviews from Peter Stauffer and Warren Yeend.

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 or above, 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.

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 March 30, 1998, OF 98-131-A, paper copy, 64 p.; OF 98-131-B, 3.5-in. Macintosh 1.4-MB high-density diskette.

This stack (report) can be down loaded from self-extracting archives, that are on the U.S. Geological Survey's Learning Web site.
The URL address is: < http://www.usgs.gov/education/animations/ >

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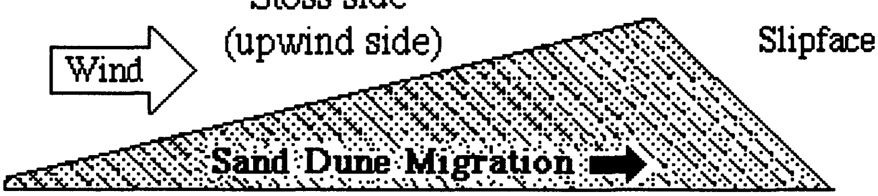
General Introduction to Dunes:

Many areas of the world have specific landforms that result from processes associated with wind. Wind-related processes and deposits are also termed **eolian processes** or deposits (aeolian from the Latin word Aeolus, meaning god of the winds).

A principle **eolian** depositional landform is a sand dune. Sand dunes can develop in any environment in which loose particles of sand are exposed to wind action and are free to migrate and accumulate. Most people think that dunes only form in desert or coastal environments. But dunes can be found in any environment where there is a steady wind regime, a dry (less than 10 inches of rainfall annually) environment, and a supply of loose surface material which is small enough to be transported by the wind. In general sand dunes are not found wet inviroments as wet sand grains adhere (stick) to each other and are not easily moved by wind.Thus a dry/cold windy climate (such as desert or polar environments) favors the formation of dunes. Wind can also move snow. Deposits of wind-driven sand and snow are called niveo-eolian deposits. These deposits occur on an annual basis in cold-climate environments and consist of layers of consolidated snow, which is often recrystallized into small pellets intermingled with layers of sand.

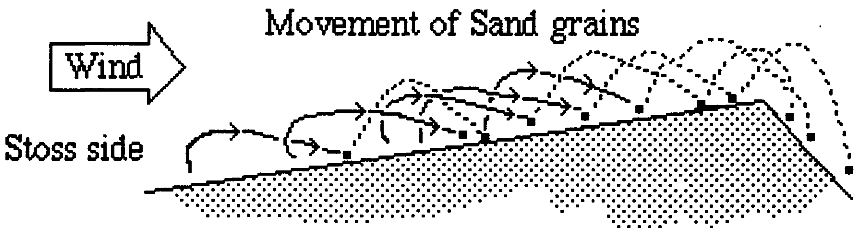
A typical sand dune is created by the transport of sediment (small loose rock particles) by the wind and involves the interaction of the wind and the ground surface. Sand is defined as particles with a size between 2 mm to 0.0625 mm (2 mm equals 0.078 inches). Wind moves sand near the surface, usually within 1 meter of the ground, and carries it only a short distance. Very small particles are transported in suspension by the wind and stay in the air for a relatively long distance. Silt-clay size sediments, particles less than 0.0625 mm, are usually deposited downwind and are called loess. These small sized particles play a minor role in the development of dunes. Dunes begin to form when winds carrying sediment encounter an obstacle that slows the wind. The reduced wind velocity causes the coarsest (largest) fraction of the sediment to fall back to the ground. This build- up of sand creates a larger obstacle that constitutes a wind break, causing more deposition.

If the wind is not strong enough particles of sand may be pushed or rolled along the surface. This process is known as surface creep. Wind speed needs to be greater than 10 miles per hour (16 km) to put sand grains into motion. Sand is transported up the stoss side (upwind side) [see" typical dune" illustration below] of the dune in a series of short-distance jumps called saltation. The sand grains are transported a short distance by the wind then fall back to the ground surface hitting other sand grains in the process causing the sand grains to become airborne. This process of saltation continues as long as the wind is blowing. Upon reaching the top of the dune the sand then rolls down the slipface or the lee ward side of the dune. This continuous process of wind erosion from a source area, the transport of the sand up the stoss side and the deposition of sand on the slip face results in a net downwind migration of the dune. Thus sand dunes grow by several processes: 1) saltation and/or **wind ripples** on stoss slopes, 2) trapping of sand in the slipface, and 3) overtaking of one dune by another.



Typical Sand Dune

A typical dune is 3 to 100 meters high and asymmetricl. The slip face is usually twice as steep as the windward face (stoss slope) of the dune forms an angle relative to a horizontal ground surface, usually around 33 degrees. This is called the **angle of repose**. The stoss slope is usually 10 degrees from a horizontal ground surface. Sand grains deposited on the slipface of dunes form avalanche-like deposits which look like overlapping tongues which become thinner towards the top of the dune. The avalanching of the sand is a result of the oversteepened slipface which is beyond the angle of repose in dry sand.



Saltation

DUNE CLASSIFICATION

Sand dunes may be classified in various ways based on: 1) size and shape of the dune(s), 2) the environment in which they are occur, coastal, desert, or polar, 3) their growth stages, and degree of internal complexity, and 4) the wind direction responsible for there formation.

A simple geomorphological classification groups dunes on the basis of their shape, number of slip faces, and the wind directions that forms them and results in six major groups; 1) Transverse, 2) Oblique, 3) Longitudinal, 4) Barchan, 5) Star, and 6) Parabolic.

Model 1 - Transverse dunes

Transverse dunes occur where there is a plentiful supply of sand. In plan view, transverse dunes form straight to very gently curving ridges. The dunes are aligned perpendicular to the prevailing wind. The winds that form transverse dunes come from two directions, usually 75 to 90 degrees to the dune axis. There is a close relationship between the dune height, width and spacing of transverse dunes. Sediments of transverse dunes are dominated by grainfall and grainflow cross-strata deposited on the lee face and preserved as the dune migrates downwind. **Wind ripple laminae** form a thin set of strata that parallel the slope of the stoss slope and dune crest. Transverse dunes represent approximately 40 percent of the dunes found in the sand seas world wide.

Model 2 - Oblique dunes

Oblique dunes are similar to transverse dunes in that they form straight to very gently curving ridges. The winds that form oblique dunes come from two directions usually 15 to 75 degrees to the dune axis. One of the wind directions is usually dominante (indicated by the larger arrow on the paper model) which results in a sand transport vector perpendicular to the axis of the dune. An excellent review of storm-controlled oblique dunes of the Oregon Coast is presented by Hunter and others, 1983.

Model 3 - Longitudinal dunes

Longitudinal dunes are formed in areas of limited sediment supply but with strong winds. The long dune crests are elongated parallel to the direction of wind flow. The winds that form longitudinal dunes comes from two slightly different directions usually 0 to 15 degrees to the dune axis. Longitudinal dunes called seif dunes (Arabic for 'sword') are usually less than 4 m high but can extend downwind for several kilometers. In large deserts they can reach a height of a 100 m and extend for 120 km.

Model 4 - Barchan dunes

In the absence of vegetation, small individual crescent shaped dunes called barchan dunes are the dominant dune type. The wind regime is characterized by a narrow range of wind directions (15 degrees or less). Barchans occur as isolated dunes in areas of limited sand availability. This is demonstrated by their ability to migrate long distances with only minor changes in form. Barchans are characterized by a crescent shape in plan view with a concave slip face and 'horns' extending downwind. Most barchans range in height between 3 and 10 m. The stoss slope of barchans is convex in profile, with slope angles of 2-10 degrees. Dune height is typically 1/10th of the dune width. As the sand supply increases barchans can coalesce laterally to form transverse dunes. The sediments of barchans like transverse dunes are dominated by grainfall and grainflow cross-strata deposited on the slip face and preserved as the dune migrates downwind. Wind ripple laminae form a thin set of strata that parallel the slope of the stoss slope and dune crest. Barchans comprise only a small percent of global sand sea deposits.

Model 5 - Star dunes

Star dunes are characterized by their large size, pyramidal morphology and radiating sinuous arms. The basal parts of star dunes consist of a broad, gently sloping (5-10 degrees) plinth or apron. They are the largest dunes in many sand seas and may reach heights of more than 300 m. They contain a greater volume of sand than any other dune type and occur in areas which represent depositional centers. Approximately 8.5 percent of all dune types are star type. Star dunes are associated with wind regimes that are multidirectional, or complex, especially in the months in which sand transport occurs. Star dunes are characterized by a pyramidal shape, with three or four arms radiating from a central peak and multiple avalanche faces. Each arm has a sharp sinuous crest, with avalanche faces which alternate in aspect as wind directions change seasonally. The arms may not all be equally developed and many star dunes have dominant or primary arms on a preferred orientation. The upper parts of many star dunes are very steep with slopes at angles of 15-30 degrees. Avalanche face orientation changes seasonally. Many of the claims for the 'world's highest dunes' are related to star dunes.

Model 6 Parabolic dunes

Parabolic dunes are common in many coastal and semi-aird environments. Parabolic dunes are characterized by a U-shape with trailing partly vegetated parallel arms, and an unvegetated active 'nose' or dune front that advances by avalanching. The conditions under which parabolic dunes form are not well known. They seem to be associated with the presence of a moderately developed vegetation cover, and with a unidirectional wind regime. The wind forms a blow out and the sand is carried up the stoss slope. A parabolic dune resembles a barchan dune but its 'horns' point the opposite direction --upwind. The ends of the dune may be anchored by vegetation.

The majority of large dunes are found in sand seas. Sand seas are large regional scale bodies of eolian sand which contain large amounts of sand with significant amounts of interdune sediments. Sand seas have formed principally in two areas: 1) Sahara, Arabian Peninsula, Australia, and South Africa. 2) in the enclosed basins of central Asia. Other smaller sand seas are found in North America. Sand Seas exhibit many different dune types. The following table illustrates the size of dunes found in the larger sand seas. Sand seas can cover a large area, the Rub Al Khali desert (called the Empty Quarter) covers 560,000 square km, this is an area larger than the state of California.

	Mean values		
Location	Spacing (m)	Width (m)	Height (m)
United Arab Emirates	590	440	
Algodones, Calif.	1070	880	50-80
Thar Desert, India	1440	1300	
Simpson, Australia	648	290	11
Namib, Africa	1724	650	34
Grand Erg Oriental, Africa	2070	950	117
SW Kalahari, Africa	435	220	9

Table modified from Lancaster, 1995

The following references will help you gain a better understanding of dune processes in different environments. An excellent review of desert dunes is presented by Lancaster (1995) in Geomorphology of Desert dunes, and McKee (1979) A Study of Global Sand Seas. Nordstrom and others (1990) gives an excellent description of coastal dunes: form and process. Dune development in cold-climate environments is discussed by Runz and Allard (1994) and a bibliography of periglacial sand dunes and sand sheets is presented by Niessen and others (1984). An excellent source for the physics of dune movement can be found in Bagnold (1937, 1941 and Lancaster (1995).

"Booming Dunes" a natural phenomenon

The Kelso Dunes located in San Bernardino County, California contain a very rare phenomenon found in the U. S. -- booming sand (Yeend and others, 1984). The sound-producing sand is commonly termed "desert thunder," "booming sands," or "roaring sands." The sound appears to be the result of the shearing of the grains during avalanching. Deserts in the Middle East, the Sahara, Southern Africa, Chile, and Baja California, possess booming sand. In the Continental U.S. the only other booming dune besides the Kelso Dunes are found in Sand Mountain, Nevada (Lindsay and others, 1976).

ANCIENT EOLIAN DEPOSITS

Sand dunes are among the best known ancient deposits because of their spectacular crossbeds. Today, we can watch sand dunes being formed, we can watch them migrate with the wind, and, with a shovel and a little effort, we can even look at the internal structure of a dune. When we look at a sequence of rocks, how can we tell that we are looking at sand dunes and not a series of rocks that were originally deposited as sediments in the ocean.

We begin with one of the basic principles of geology, uniformitarianism. Simply stated, the principle of uniformitarianism allows us to use observations of features forming today to help us determine how rocks were formed in the past. We might also say that "the present is the key to the past." Using this principle, we can apply our knowledge of how and where sand dunes are being formed today in a search for the deserts of the past. There are several characteristics we can use to help in our identification of fossil sand dunes:

Geologic and Climatic Setting: Due to global atmospheric circulation patterns, most (although not all) deserts are located in inland basins between 10° and 30° latitude, or in some cases, they can be located in moisture-starved regions on the leeward side of mountain ranges. Desert sands are often found interfingering with other desert deposits such as alluvial fans and playa lakes. Depending on geologic controls such as basin size and sand supply, desert deposits can occupy a small basin or a vast, open region. The dune "seas" found in the **Paleozoic** and **Mesozoic** rocks of the southwestern United States (Arizona, Colorado, New Mexico, Utah) cover many square miles.

Stratigraphic Sequence: When you look a fossil dunes, the one feature that jumps out at you is the enormous size of the crossbeds. When you watch a sand dune forming, it is easy to see how the crossbeds form, but when you look at ancient sand dunes you have to visualize the ripples of sand moving up the stross slope of the dune and cascading down the slipface. The crossbeds are separated from each other by bounding surfaces. Geologists have identified three different kinds of bounding surfaces which they use to determine the size of the dune, the direction that the dune was moving, and what the local sand and water supplies were like.

Sedimentology: The sand grains are well sorted (all of the grains are about the same size) and well rounded (most are almost spherical). Most of the grains are made of quartz. The surfaces of the grains are frosted and pitted from the constant collisions between grains as they are moved by the wind. Ancient sand dune deposits in some places are pink, orange, or reddish due to a thin coat of iron oxide (rust) on their surfaces.

Fossils: Because of the nature of deserts, body fossils (skeletons) are rarely found in sand dune deposits. Those rare fossils (including dinosaurs) from desert deposits are often spectacular. We more commonly find trace fossils including trails of footprints, root casts, and the burrows of insects. It is not possible to use fossil evidence to help identify some of the oldest sand dunes because they were formed at a time before terrestrial plants and animals existed.

Some of the oldest desert deposits in the world are more than a billion years old. The most extensive deposits were formed during the late Paleozoic and the Mesozoic. The size and distribution of these ancient deserts was very different from the deserts of today. These differences help to tell us what the climate of the Earth was like in the distant past.

THE DESERT SOUTHWEST: ONCE A DESERT, (ALMOST) ALWAYS A DESERT

Choose just about any highway route between San Francisco or Los Angeles and Denver and you will pass through at least one of the desert regions of the United States. If you pick the right route, you will even see sand dunes. As you pass through these modern deserts (being careful to avoid the occasional jackrabbit), you are also passing over the remnants of a much larger and older desert. If you have ever looked at pictures of Zion National Park or Glen Canyon Dam, you have seen the rocks of this ancient desert.

During the Jurassic (the middle part of the Age of Dinosaurs, when Apatosaurus and Allosaurus ruled the American West), a great sea of sand dunes stretched from eastern California near Las Vegas, Nevada northeastward through Utah into Wyoming. This desert once extended more than 1000 kilometers from north to south and 400 kilometers from east to west. In some places the paleo-sand dunes are more than 900 meters thick. This desert was so big that the rocks that remain today have been given different names in different regions. Outside of Las Vegas it is called the Aztec Sandstone; throughout much or Utah, as well as northern Arizona and western Colorado it is known as the Navajo Sandstone; near its northern limits in Wyoming and northern Utah this golden sandstone is called the Nugget Sandstone.

The sediment that comprises the Navajo Sandstone is well-rounded, well sorted frosted quartz. The average size of a sand grain is 0.2 millimeter. During the Jurassic, this sand formed dunes with individual crossbeds as long as 15 meters. These crossbeds typically range from 5 to 10 meters thick and dip at about 20°. Some crossbeds have dips that are even greater. Fossils are rare in these deposits. There are a few examples of pterosaur and dinosaur tracks. Bipedal dinosaur skeletons are even rarer. In the wetter interdune areas, freshwater crustaceans have been preserved.

The evidence that supports the theory that the spectacular crossbeds of the Navajo Sandstone were formed in an eolian environment is presented below.

1) The immense thickness of individual crossbedded units (some more than 30 meters thick) as well as the overall size of the paleodesert (from California to Wyoming)

2) The high angle at which the crossbeds dip (some greater than 20°).

3) The rapid change in the direction of sand movement is similar to what is observed in desert regions today.

4) Mudcracks in the interdune deposits that indicates exposure to air for some period of time.

5) The most significant evidence is the presence of the fossils and tracks of freshwater invertebrates and dinosaurs and their relatives in these deposits.

When taken together all of these lines of evidence indicate that the Navajo Sandstone and it equivalent stratigraphic units, the Nugget Sandstone and Aztec Sandstone were all part of a sea of sand dunes that covered much of the western United States during the Age of the Dinosaurs.

WHAT'S IN IT FOR ME?

Dunes and sand sheets develop under a range of climatic and environmental conditions. Sand dunes occur along sandy ocean beaches, lake shores, in arid and polar deserts and in semi-arid continental regions. Dunes play an important role in many ecosystems and are very important indicators of environmental change. Many areas of the world are now experiencing land degradation (desertification) where the area becomes drier. More than 100 nations are at risk. Moving dunes may engulf agricultural areas, settlements and transportation corridors, decreasing arable land for grazing and agriculture and disrupting transportation. Coastal dunes are important for coastal stability. A climatic or human disturbance to the supply of sand blown from adjacent beaches may alter beach processes and cause coastal erosion. Thus the formation of new dunes or the reactivating of old dunes due to climatic changes and/or humane disturbances may threaten the world's coastlines and reduce or change agricultural land into marginal cropland or useless deserts.

WHERE TO SEE MODERN AND ANCIENT EOLIAN DEPOSITS

Modern Eolian Deposits
Algodones dune field, CA
Coral Sand Dunes State Park, UT
Death Valley National Park, CA
Indiana Dunes National Seashore, IN
Kelso Dunes, CA
Kobuk Dunes, AK
Sand Mountain, Highway 50, east of Fallon, NV
Oregon Dunes National Seashore, OR
White Sands National Mounument, NM

Ancient Eolian Deposits
Arches National Park, UT
Canyonlands National Park, UT
Grand Canyon National Park, AZ
Valley of Fire State Park, NV
Zion National Park, UT

QUESTIONS

Where are sand dunes found near your house or city?

Where are sand dunes found in your state?

What kind of sand (mineral) makes up these sand dunes?

How strong does the wind (windspeed) need to be in order to move sand?

When sand is transported by wind what is this geologic process called?

What is the upwind side of a sand dune called?

What is the downwind side of a sand dune called?

What is the angle of repose for dry sand? Is this angle the same for wet sand?

Why is it hard to climb (walk) up a slip face?

Why are fossils rarely found in sand dunes deposits?

Glossary

Angle of repose: The maximum angle of slope at which a material such as sand remains stable. Some times called critical slope.

Bedding planes: Planes which visibily separate individual layers of rock or sediments.

Cross-beds: Inclined and often lenticular, beds between the main bedding planes. The arrangement of laminations of strata to the planes of stratification.

Desert: An area of low rainfall, less than 10 inches a year.

Eolian: The erosive action of the wind, and the deposits which are due to the transporting action of the wind.

Eolian processes: Erosion and deposition of sediments do to wind action.

Mesozoic Era: The middle time interval (Era) between the Paleozoic and Cenozoic Eras. The Mesozoic lasted from 245 to 65 million years ago and is commonly referred to as the "Age of Dinosaurs."

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."

Wind ripple: Wave like forms on a sand surface, an inch or so in height, lying at right angles to the wind.

Wind ripple laminae: A layer in a sedimentary rock less than 1cm. in thickness that is separable from other layers above and below.

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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 of Earth and Space Science as recommended in the National Science Education Standards. Some of these concepts for grades 5-8 and 9-12 are:

Grades 5 - 8

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

+ Animals have adapted to unique environments.

Grades 9 - 12

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

+Human activities can enhance the potential for hazards. Students should understand the risks associated with natural and man-made hazards.

+ Humans use many natural systems as resources. Changing the natural system can affect the quality of resources humans use, i.e. drinking, water pollution.

+ Each element moves among reservoirs in the solid Earth. Understanding chemical reactions and geochemical cycles is important for maintaining the health of natural envirnments.

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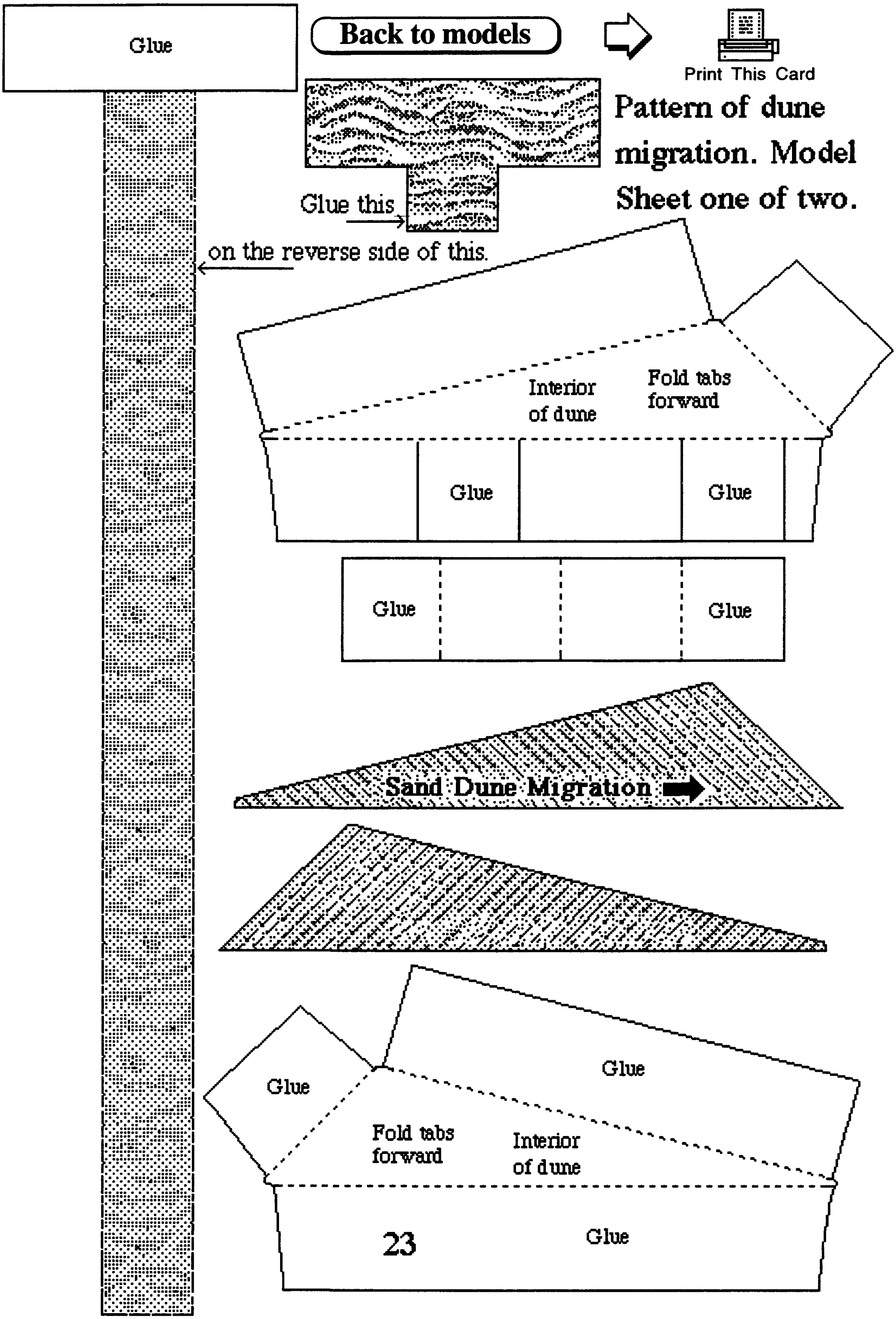
Pattern of dune migration. Model Sheet one of two.



Pattern of dune migration.
Base

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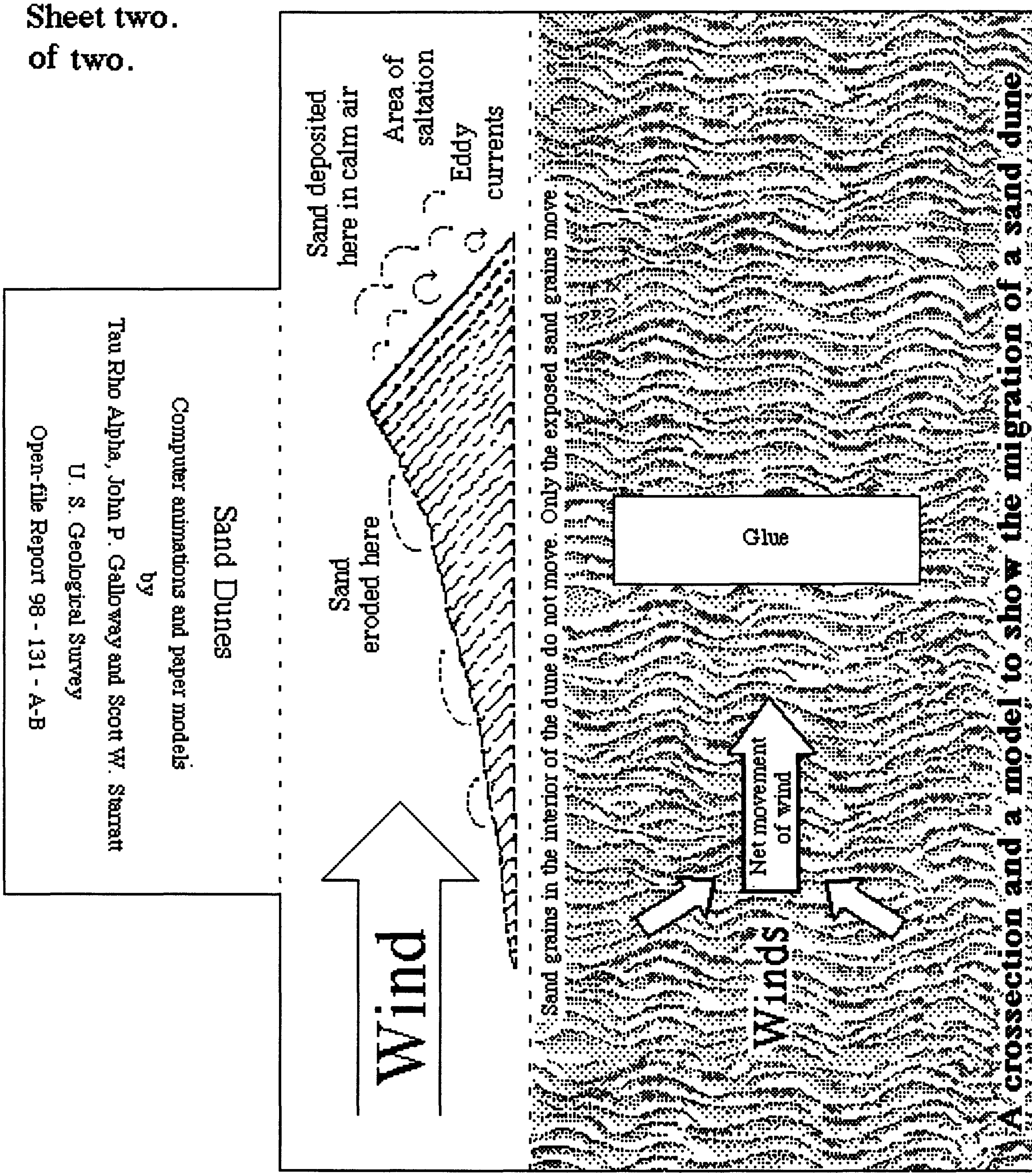
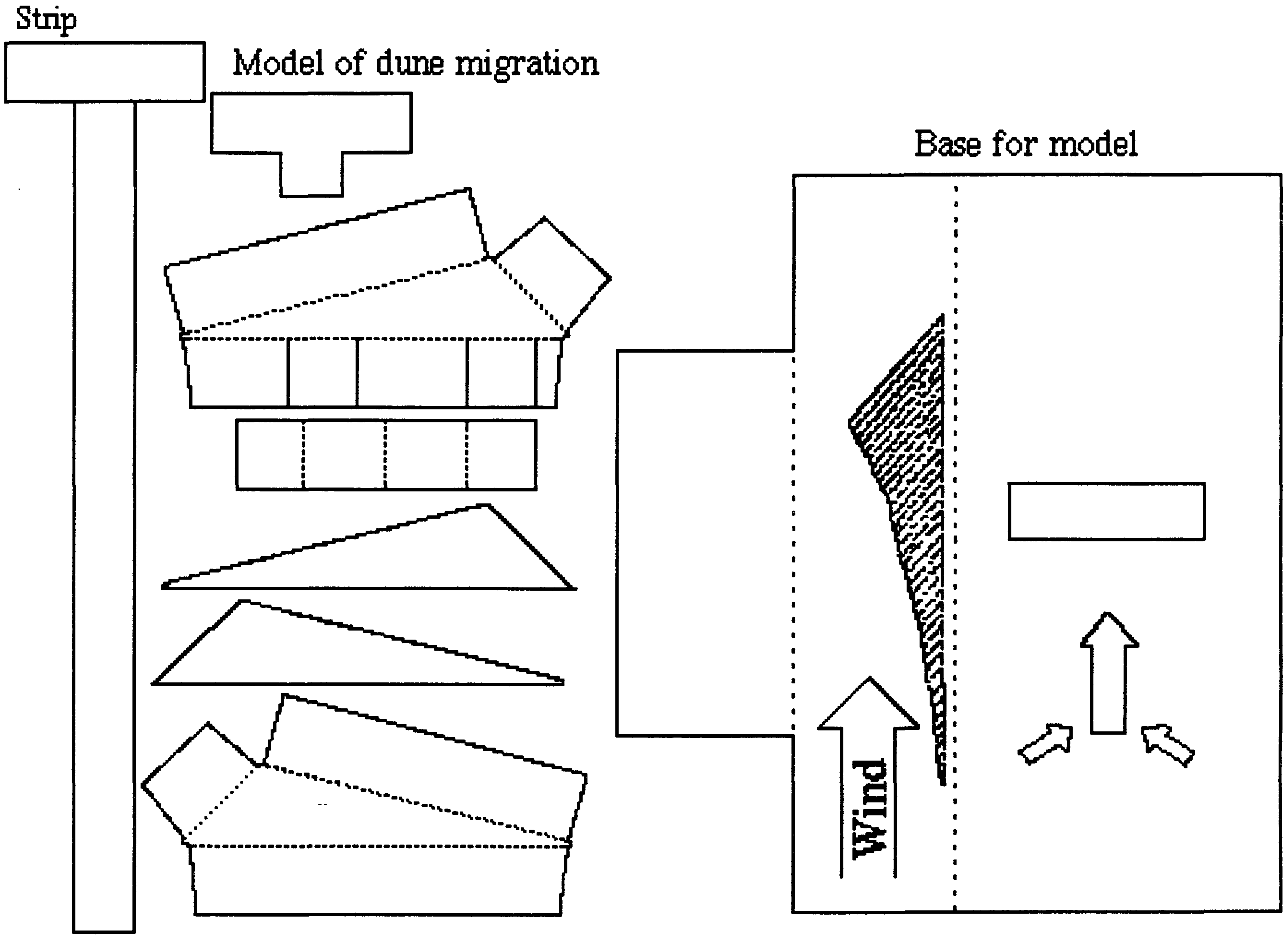
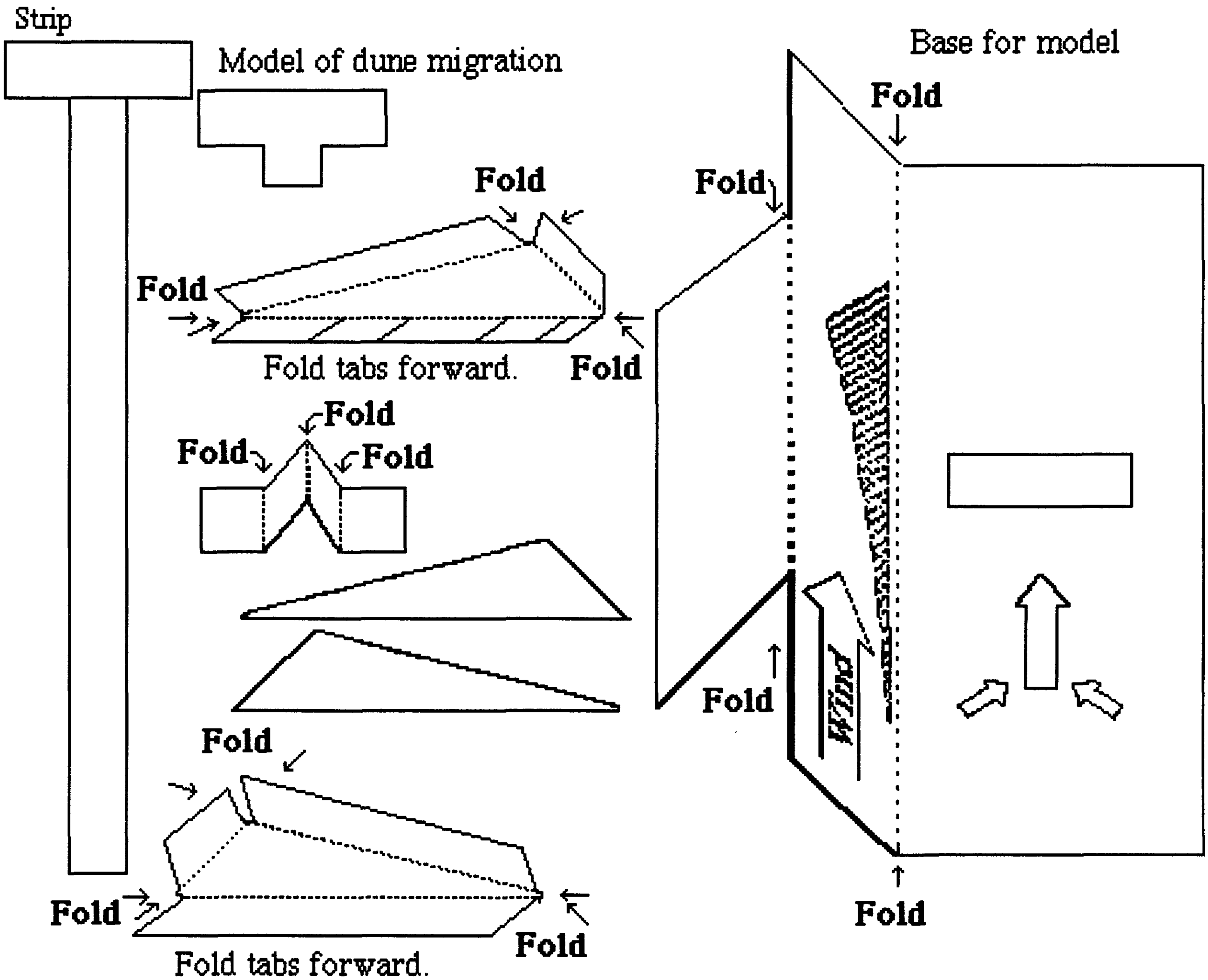
Sheet two.
of two.



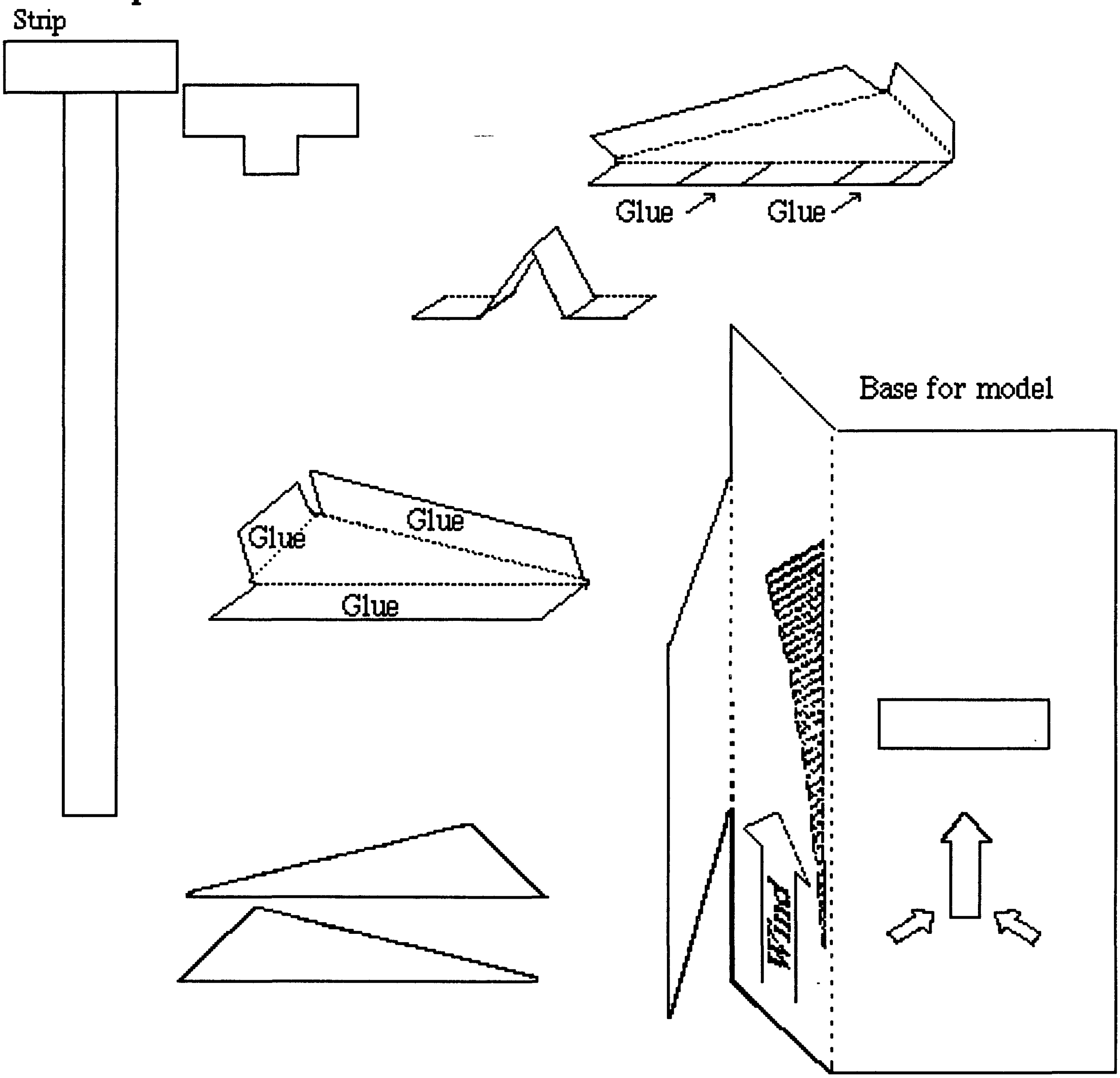
Cut out model and base.



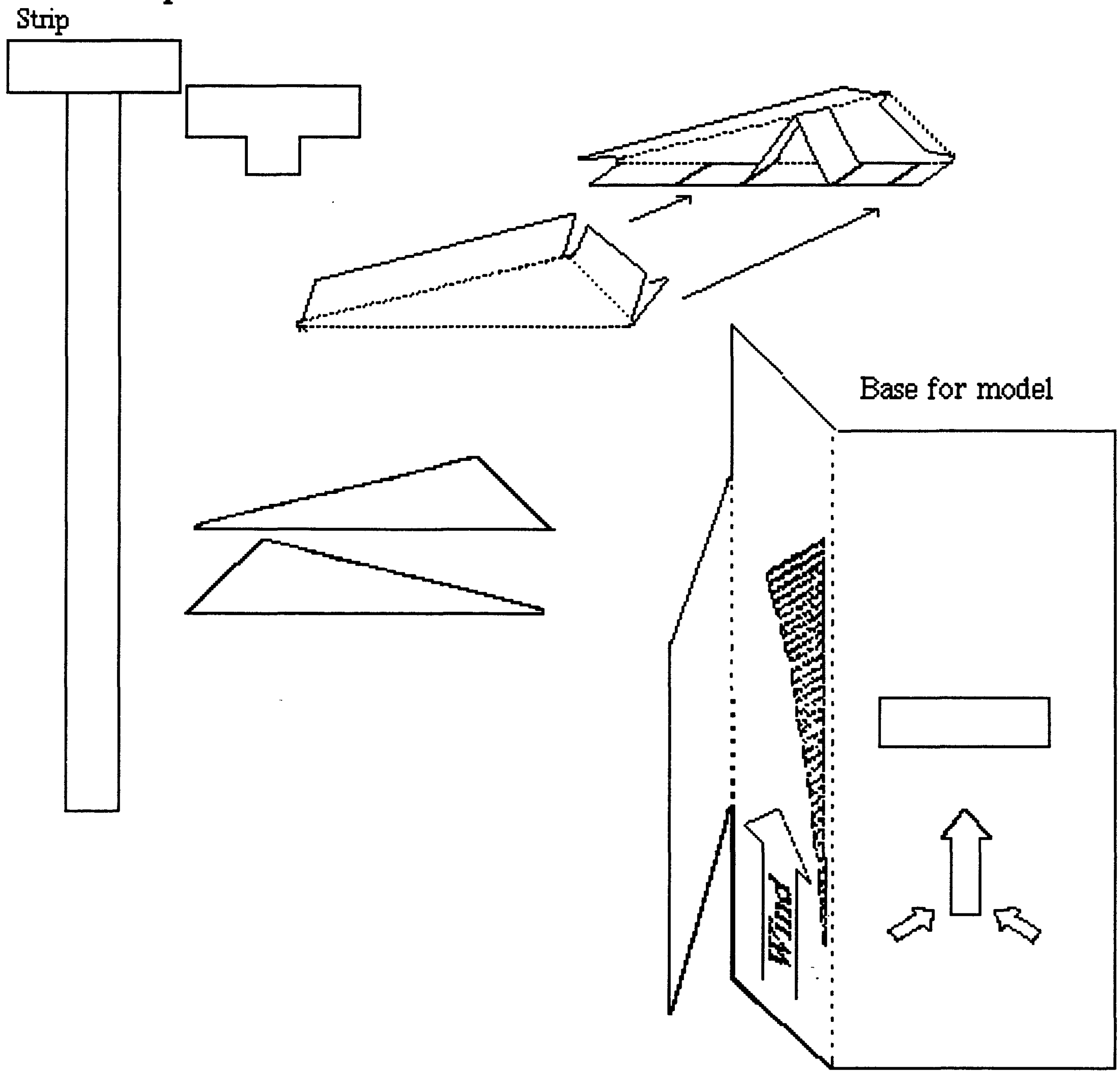
Fold model and base.



Glue parts of model.

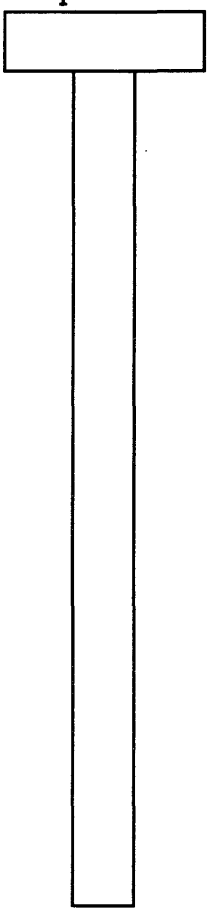


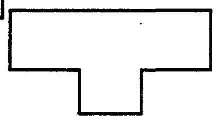
Attach parts of model.



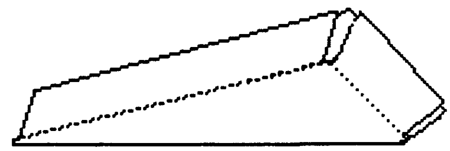
Glue and attach parts of model.

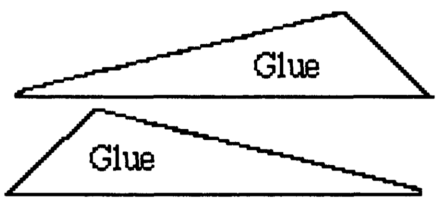
Strip



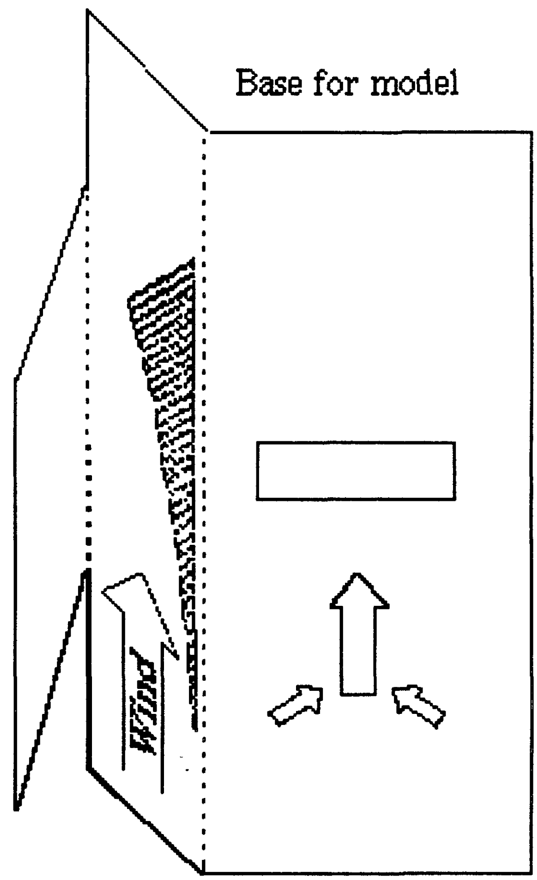


Glue other side of "T" shape.

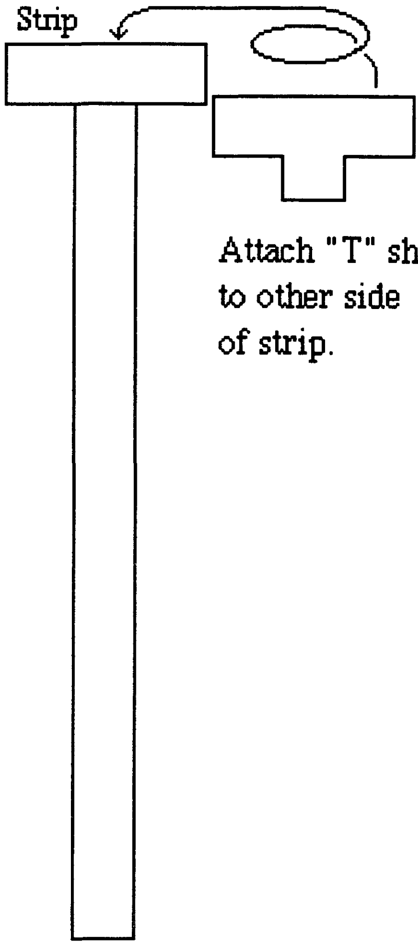




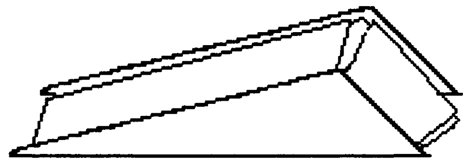
Base for model



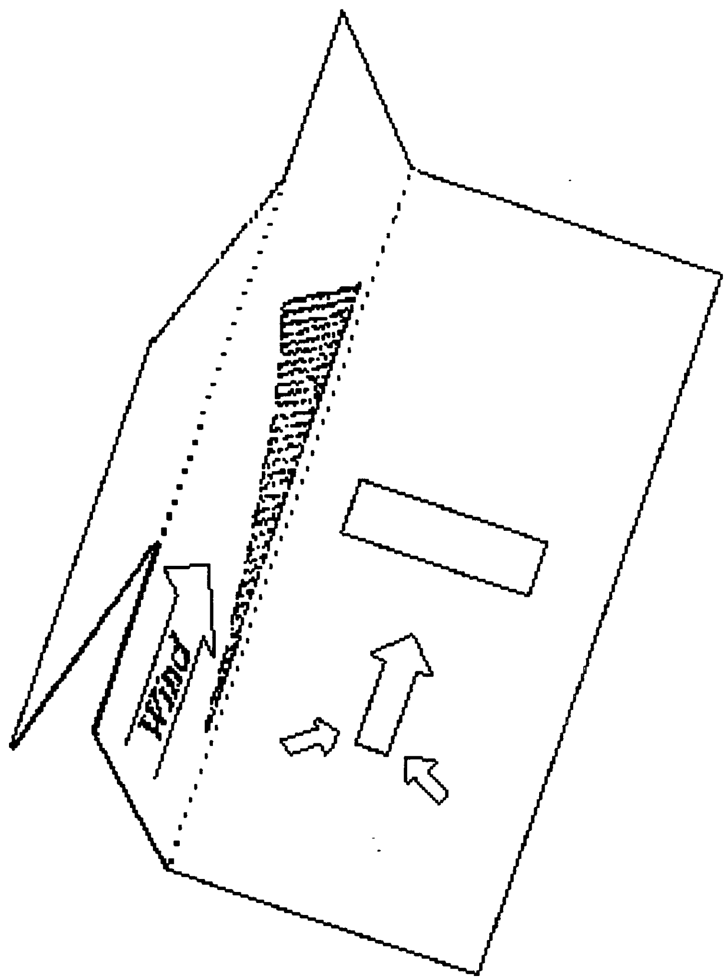
Glue and attach parts of model.



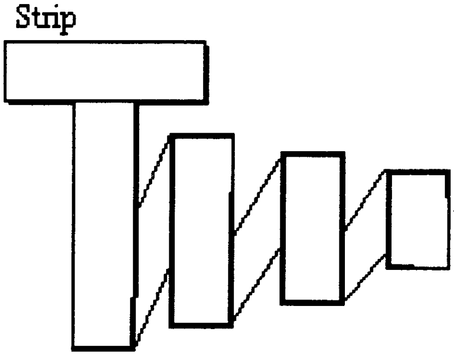
Attach "T" shape
to other side
of strip.

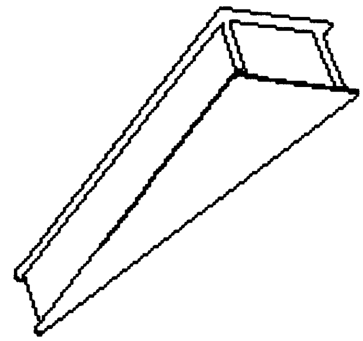


Attach sides to model.

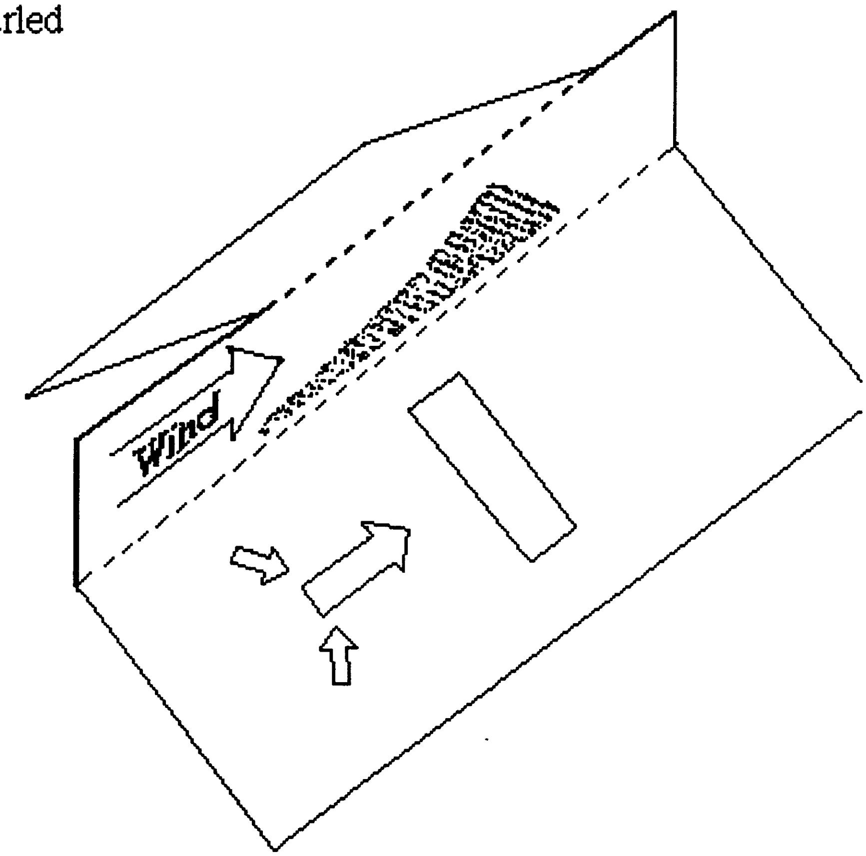


Curl strip

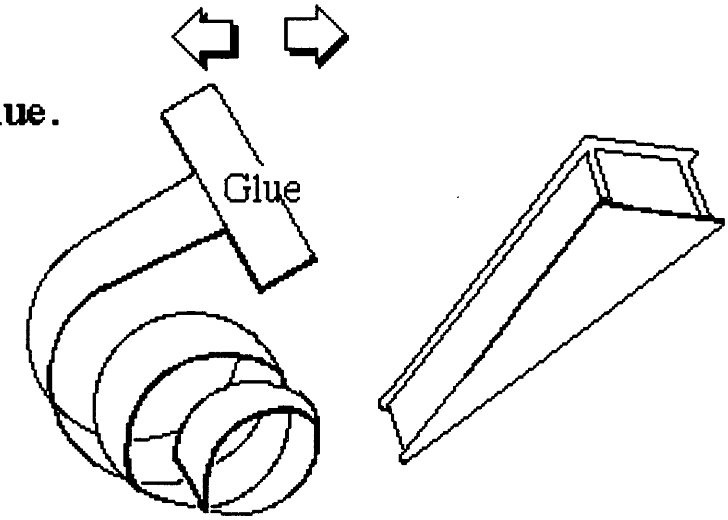




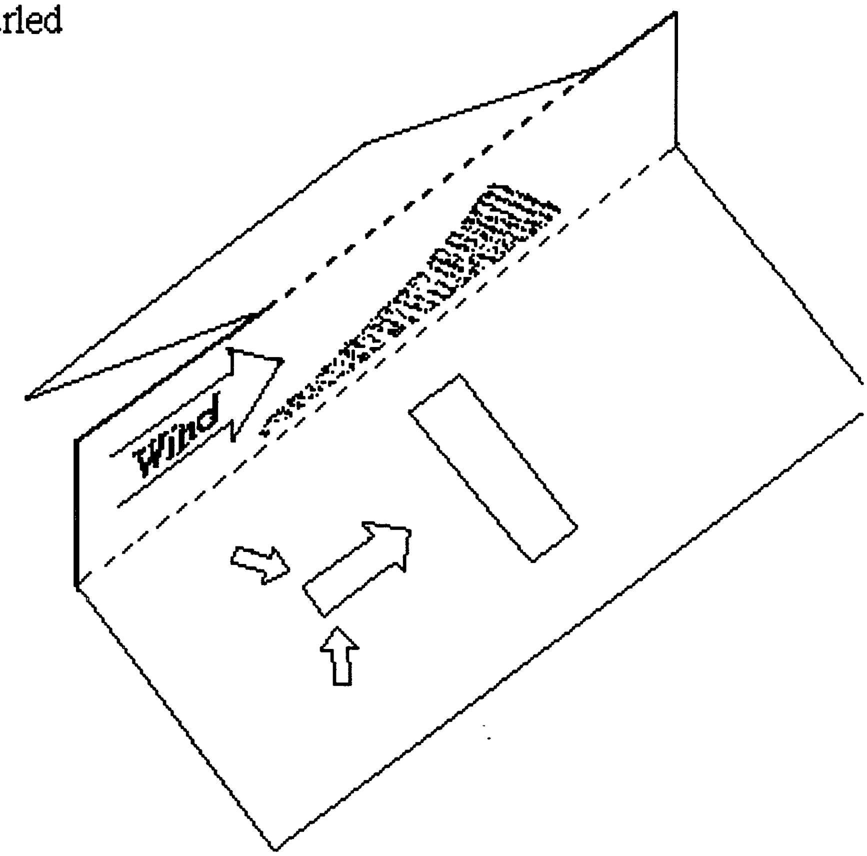
The more the strip is curled or rolled the better the sand dune migration model works.



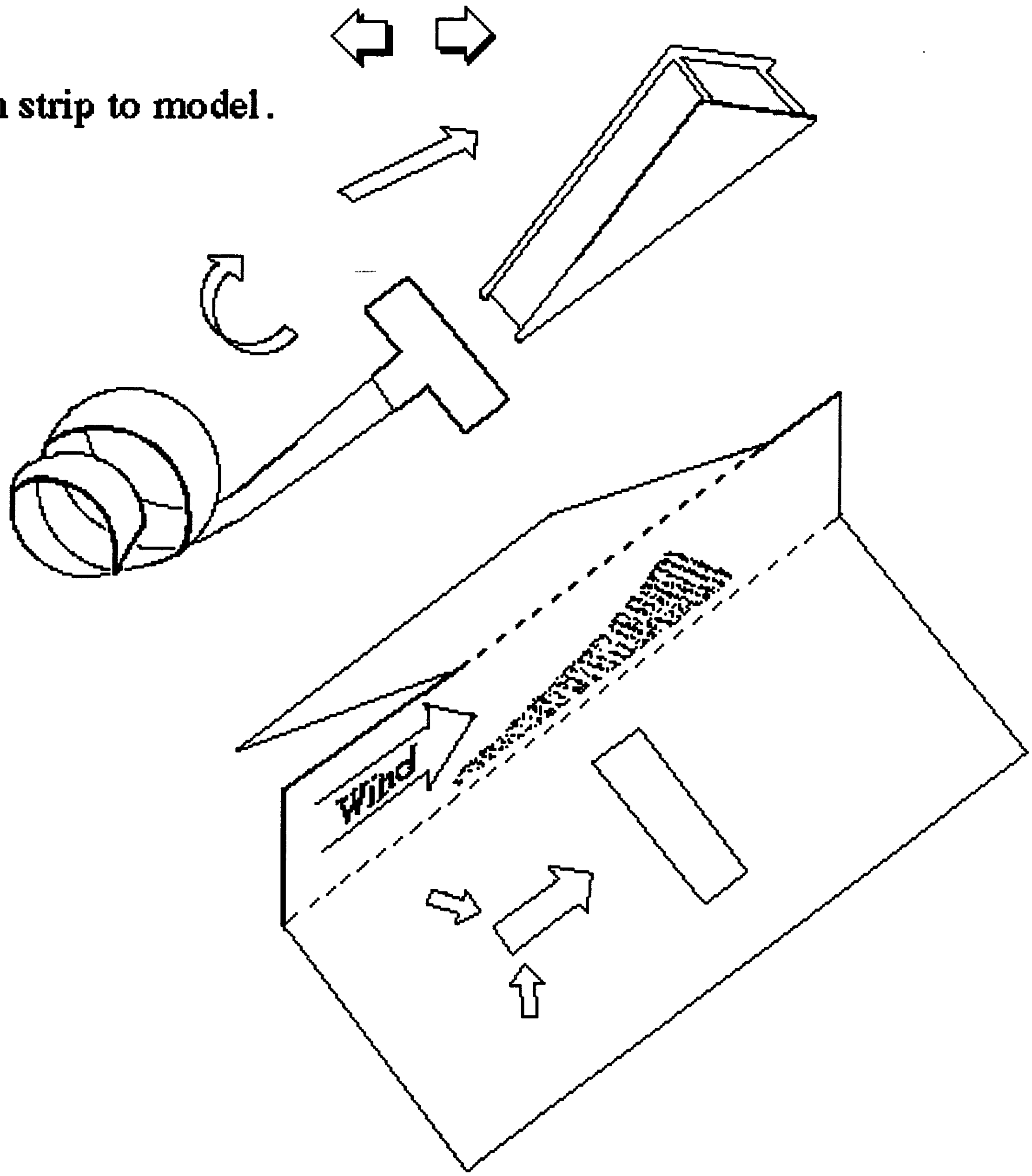
Curl strip and glue.



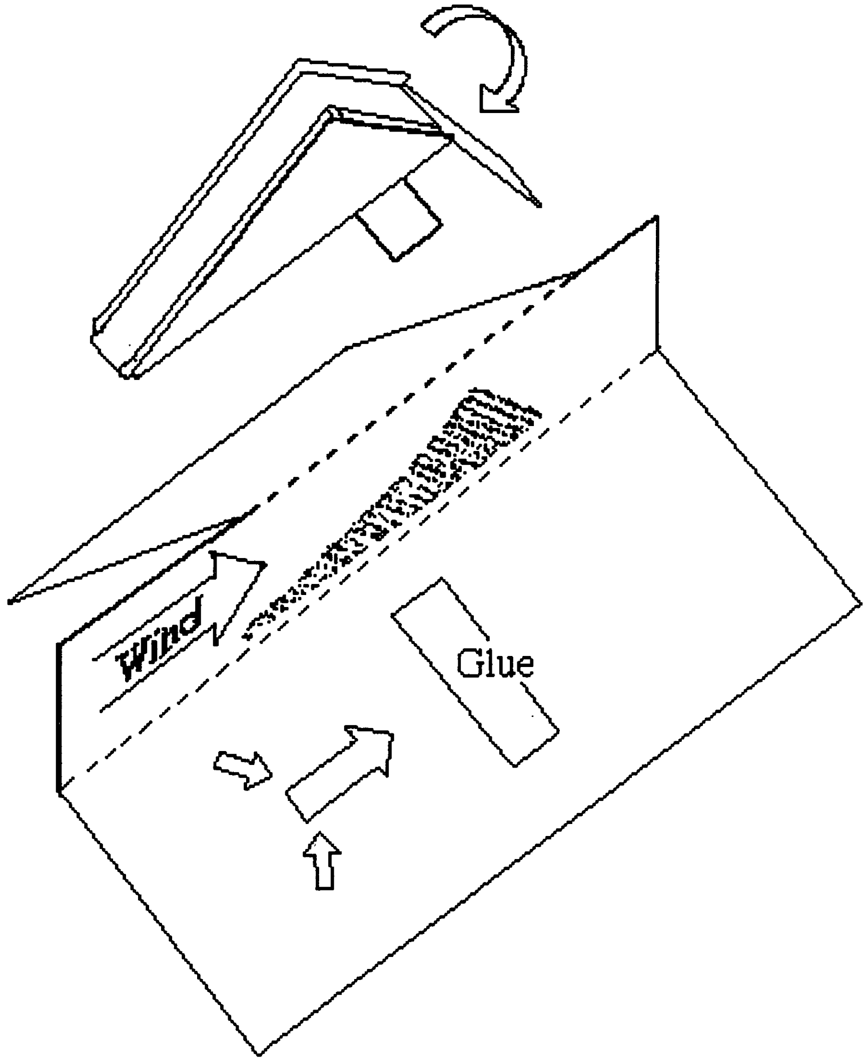
The more the strip is curled
or rolled the better the
sand dune migration
model works.



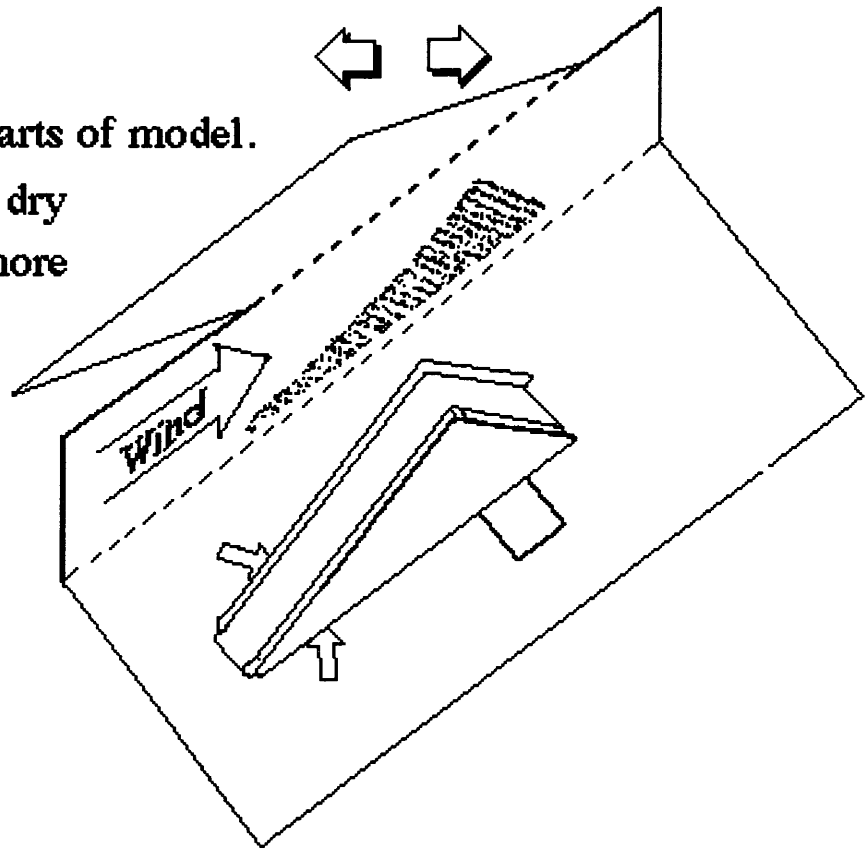
Attach strip to model.



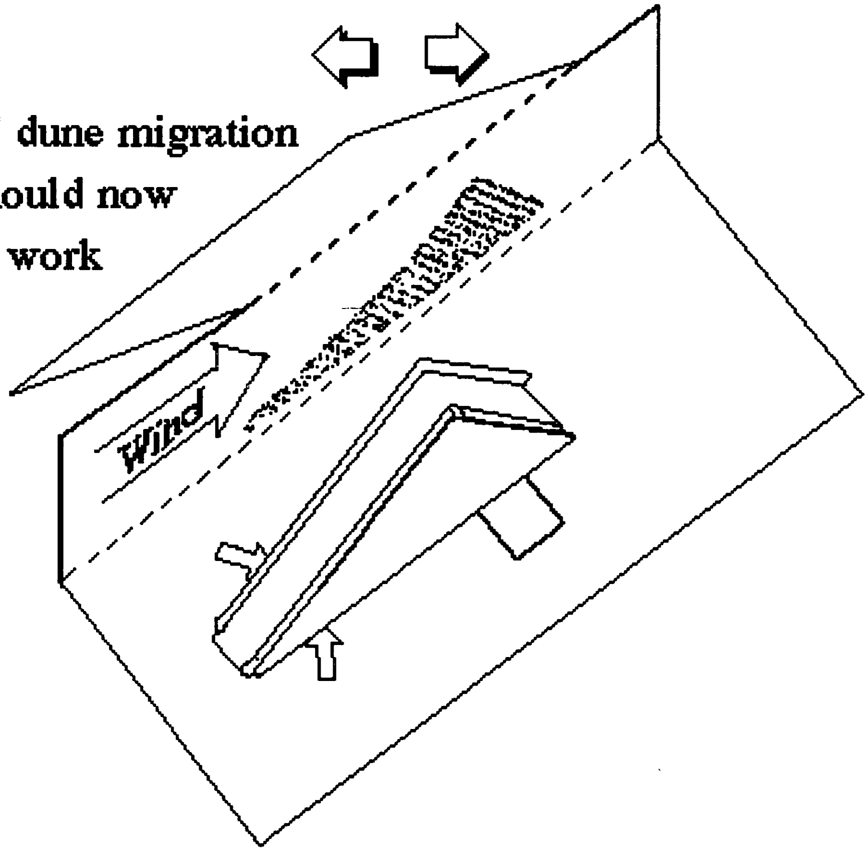
Glue and attach parts of model.



Attach parts of model.
Let glue dry
five or more
minutes.



The sand dune migration model should now look and work like this.



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Model of transverse dunes

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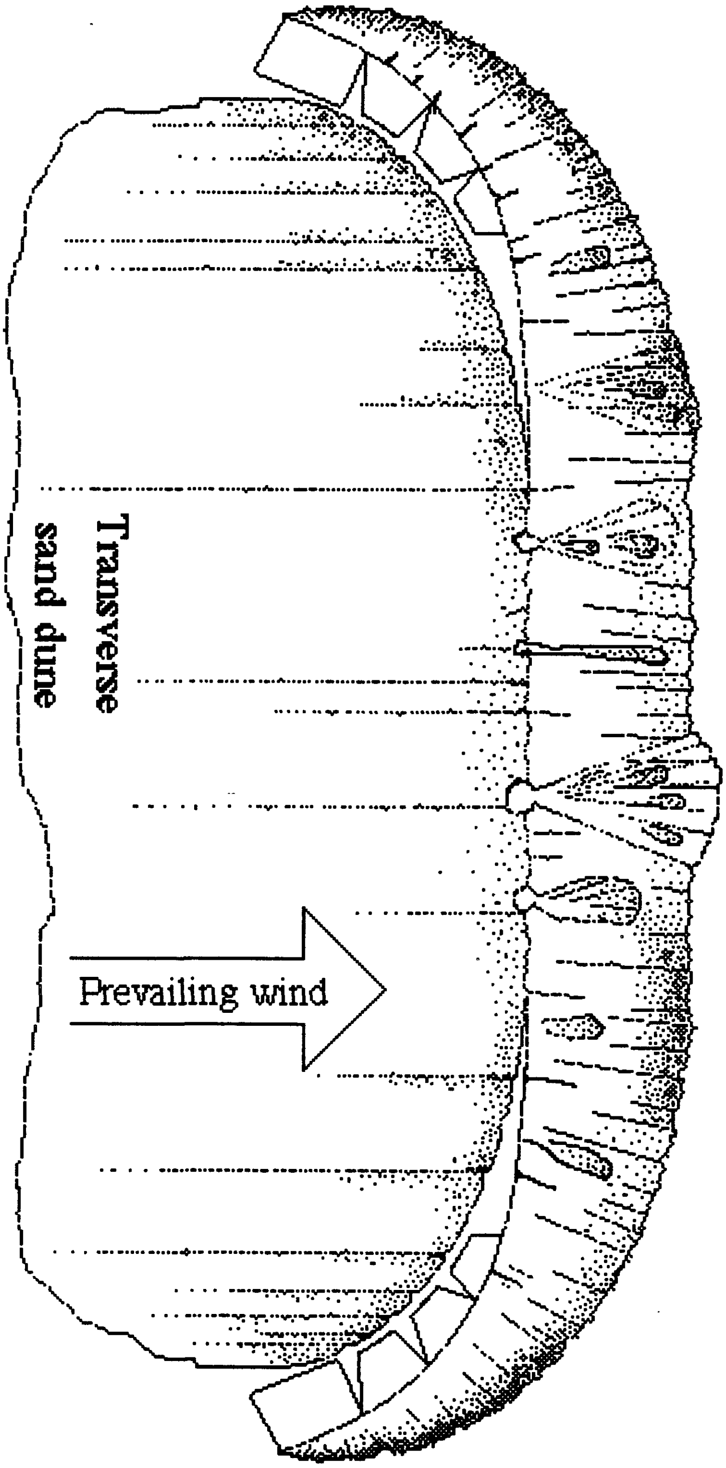
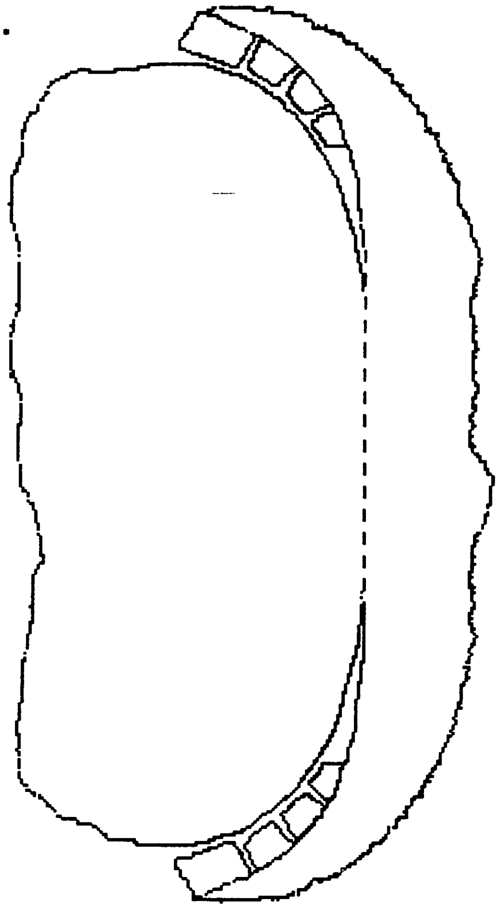
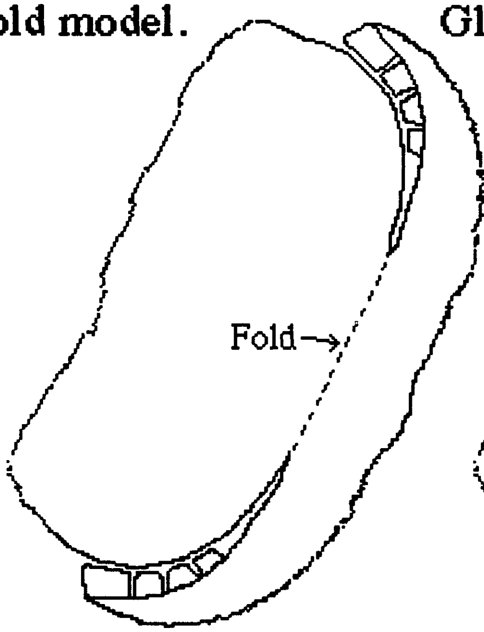


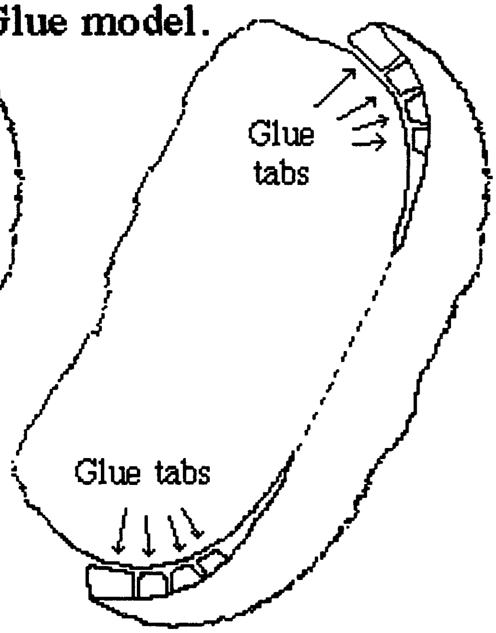
Cut out model .



Fold model.



Glue model.



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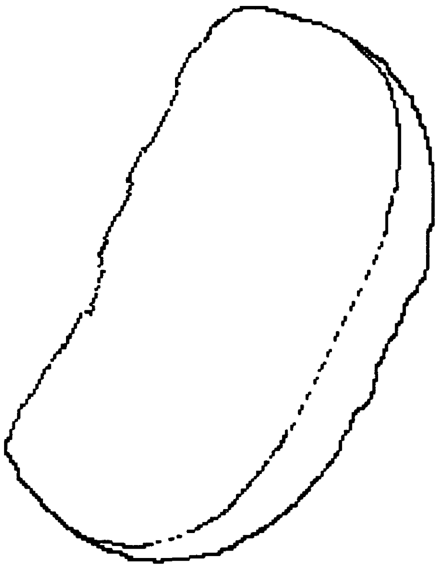
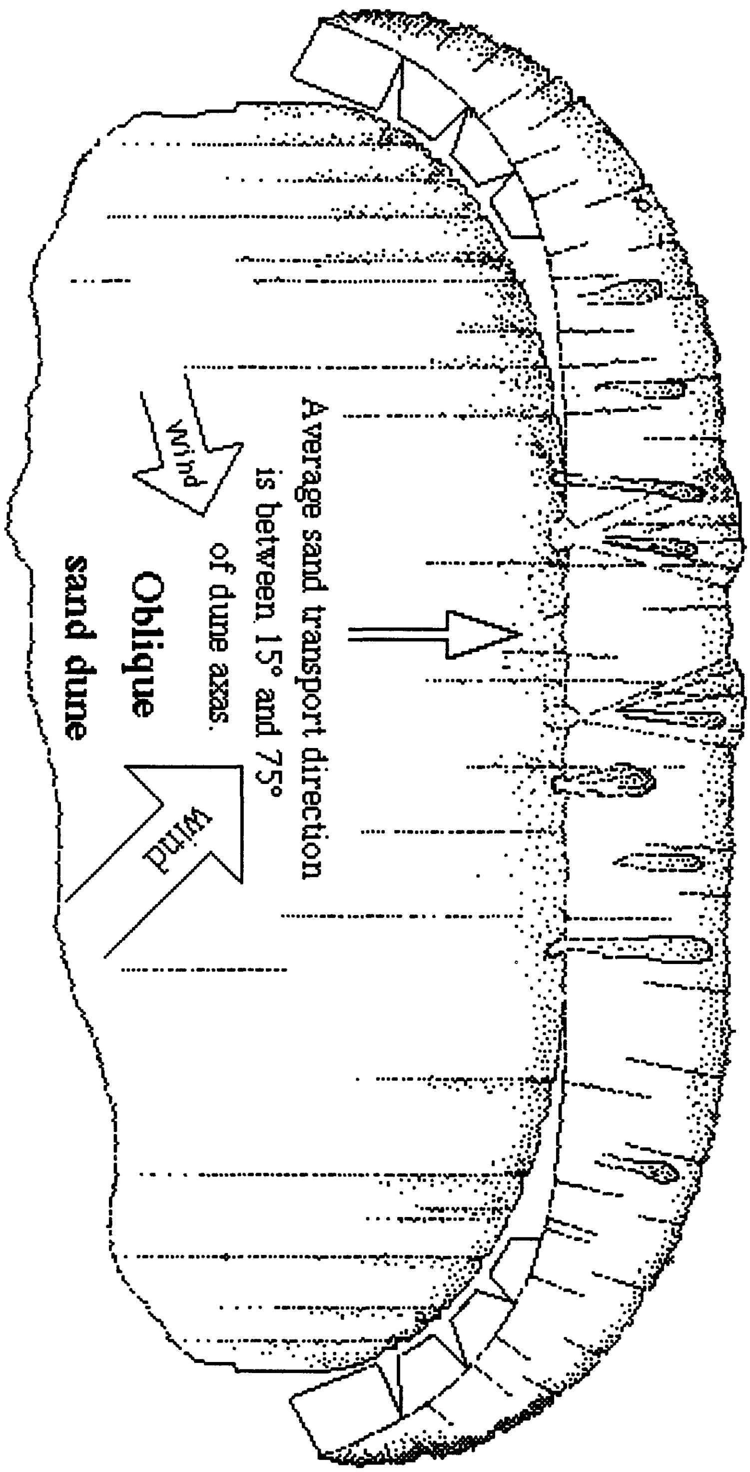
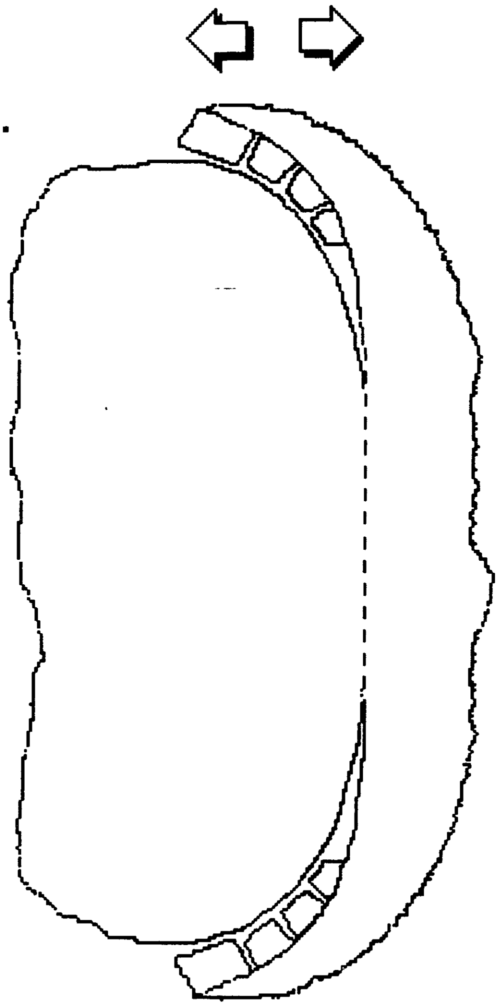
Finished transverse dune model should look like this.



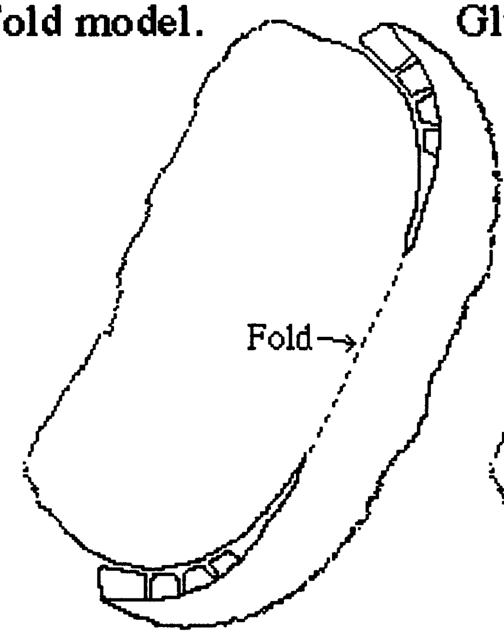
Model of oblique dune.



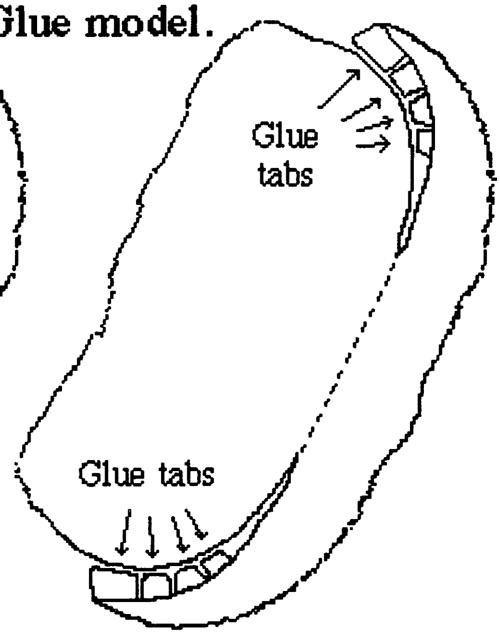
Cut out model.



Fold model.



Glue model.



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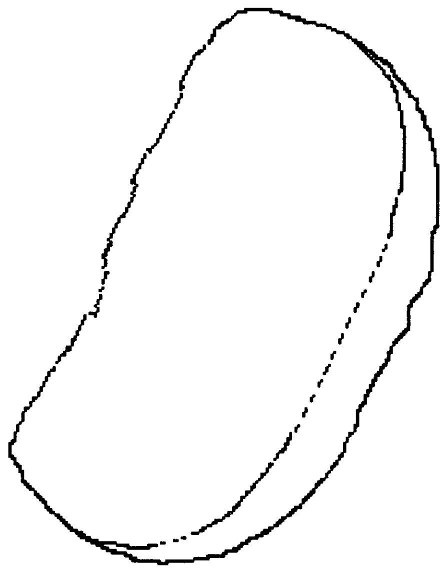
Finished oblique dune model should look like this.



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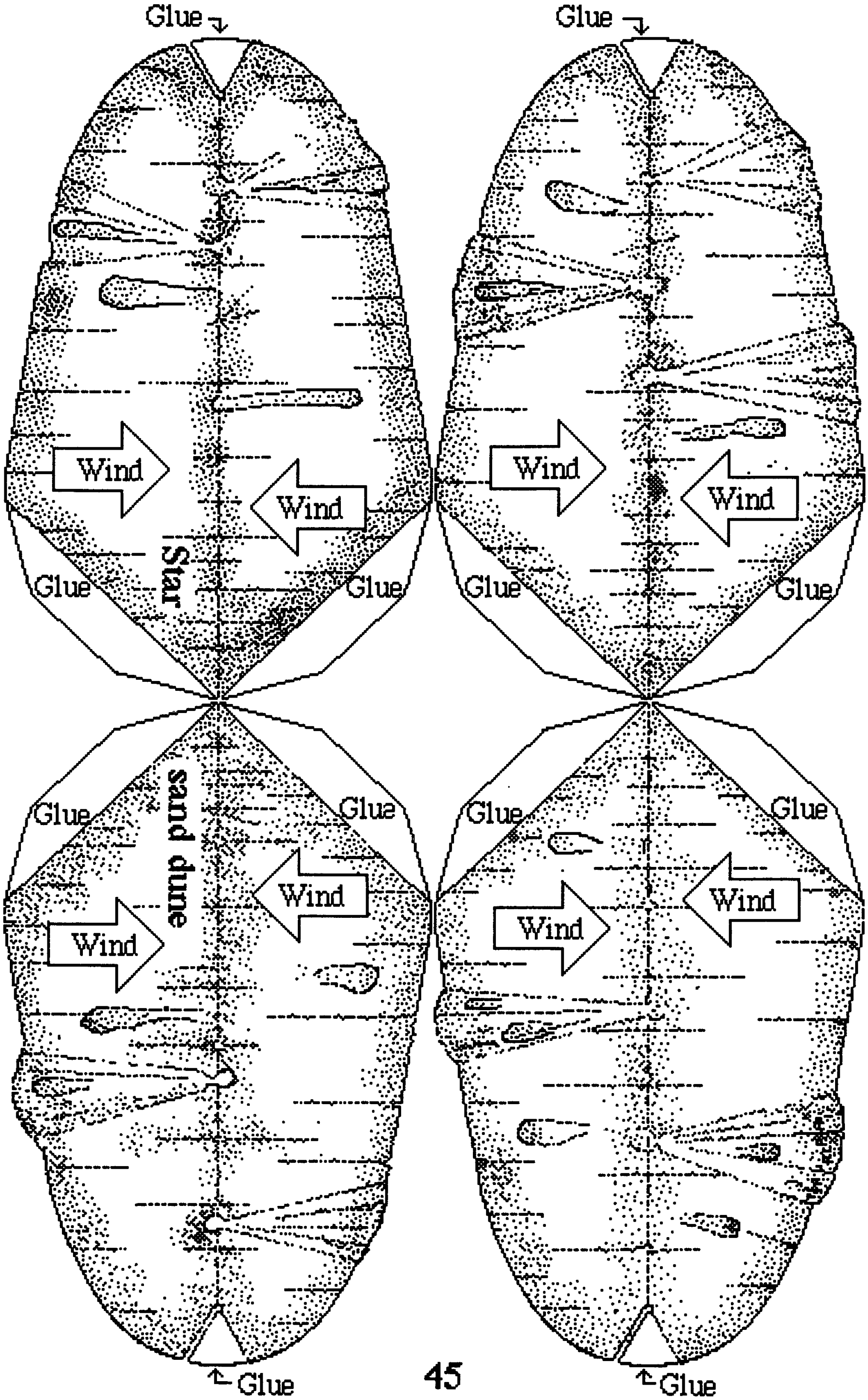
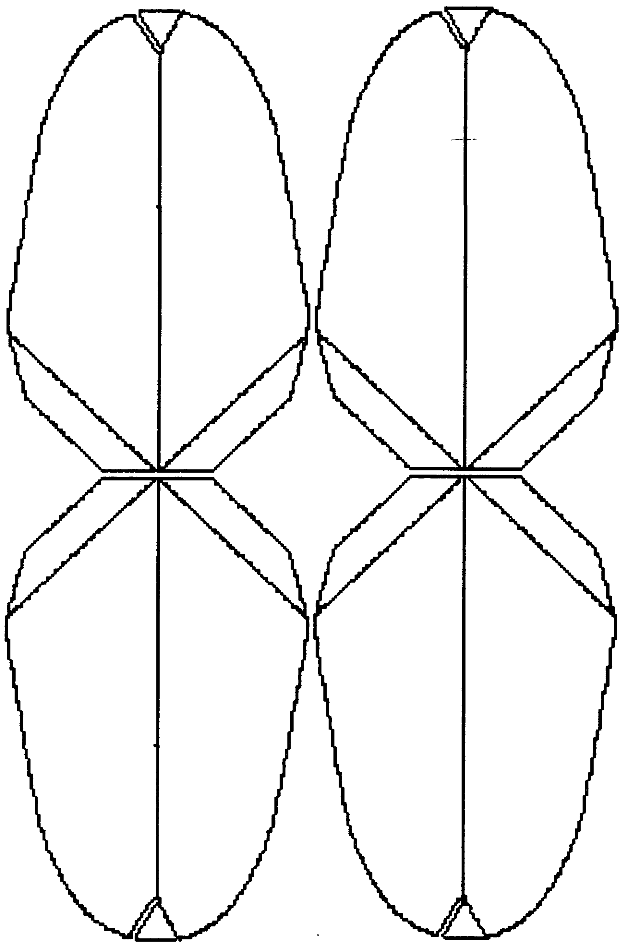
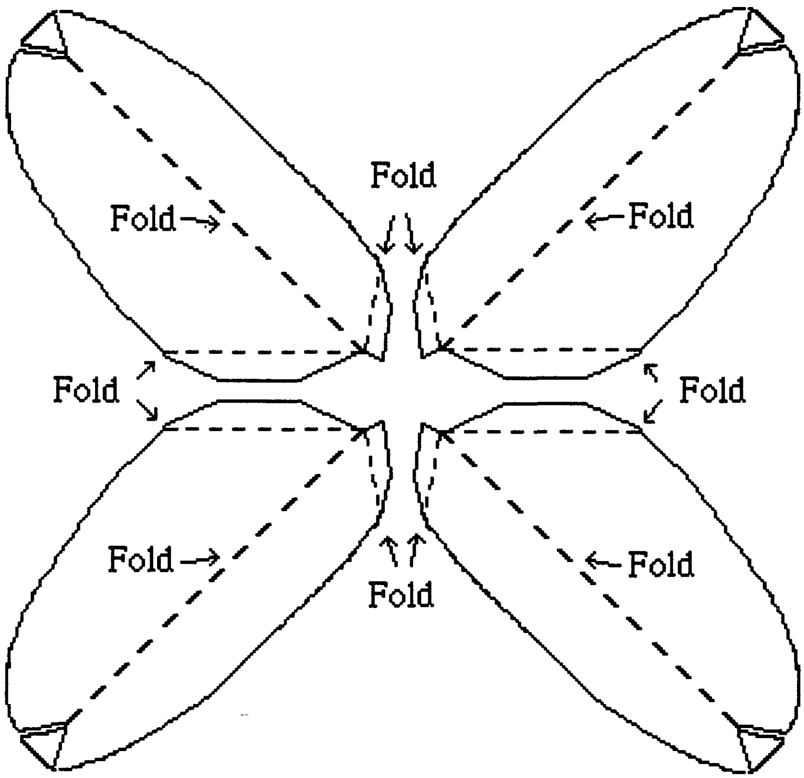
Model of star dune.



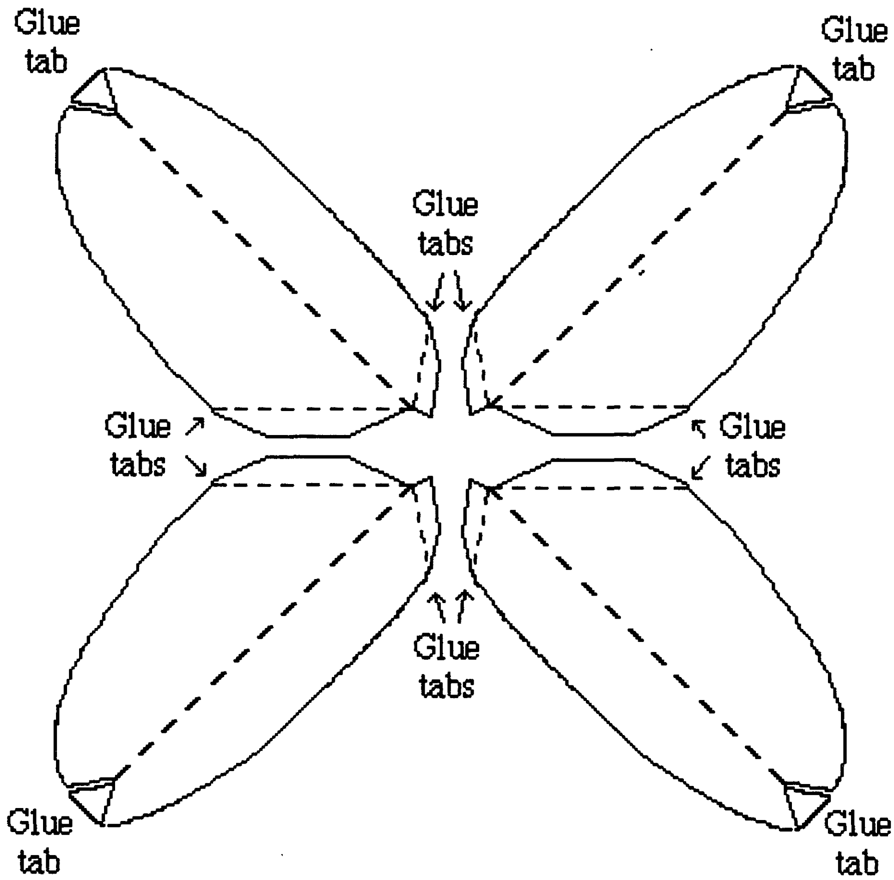
Cut out arms of star dune.



Fold arms of star dune.



Glue model.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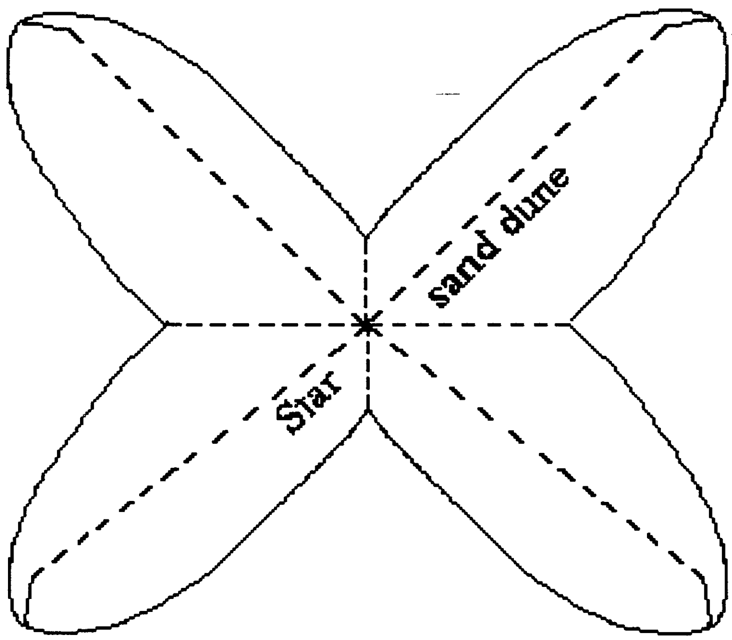
Finished star dune model should look like this.



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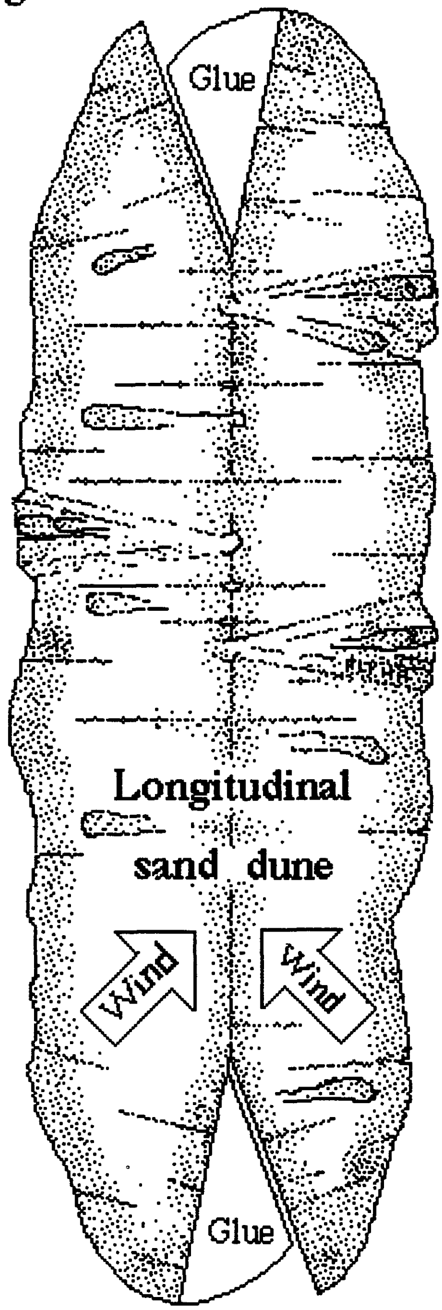
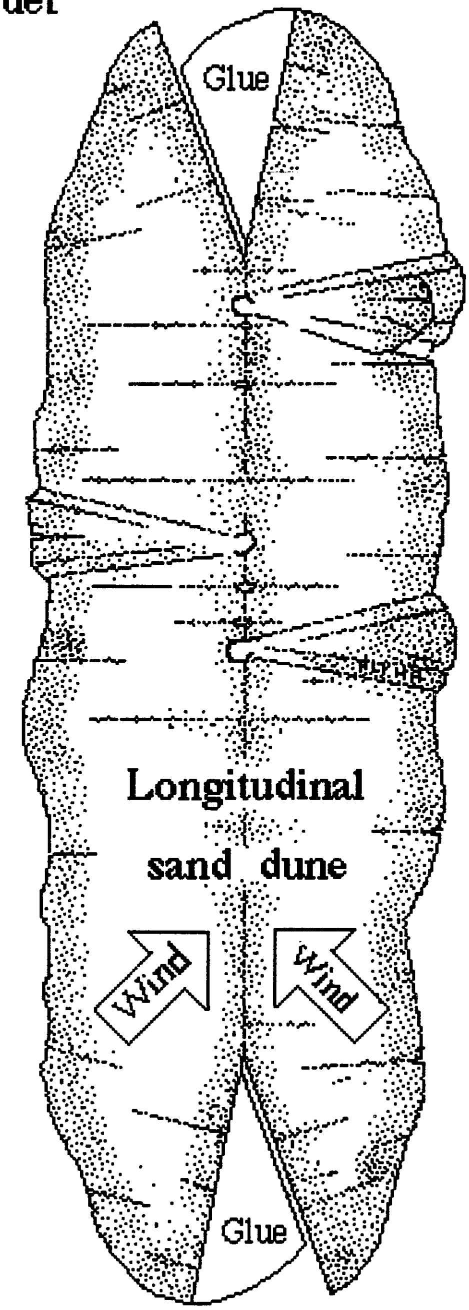
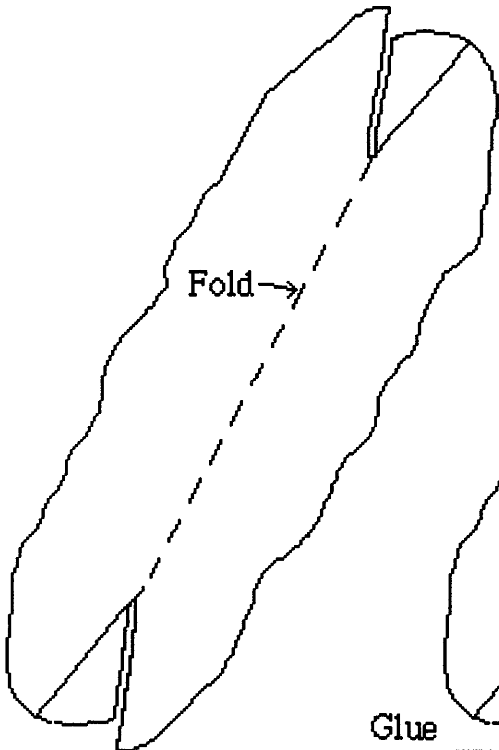
Model of longitudinal dune.



Cut out model



Fold model.



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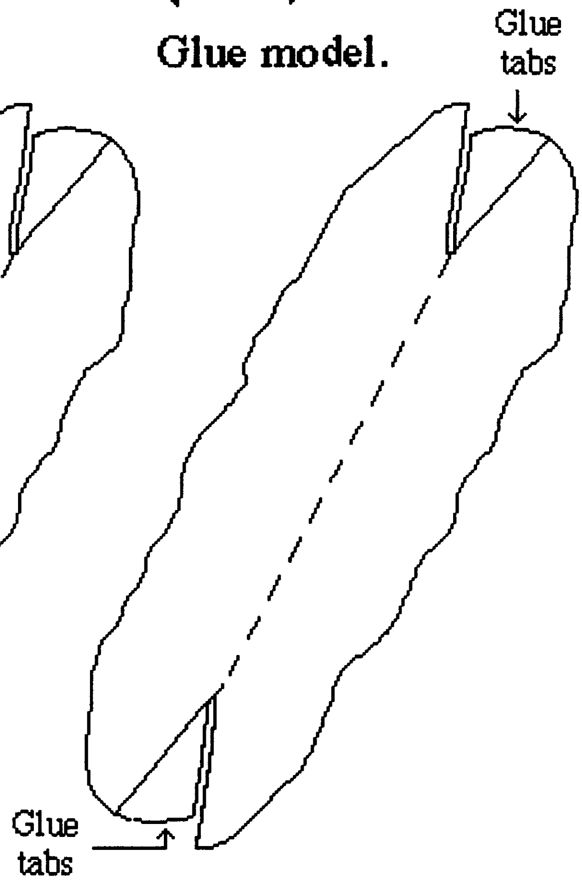

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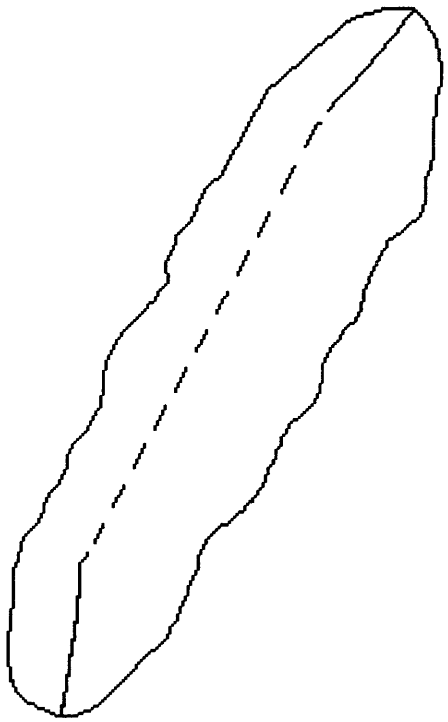
Finished longitudinal dune model should look like this.



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Model of barchan dune.

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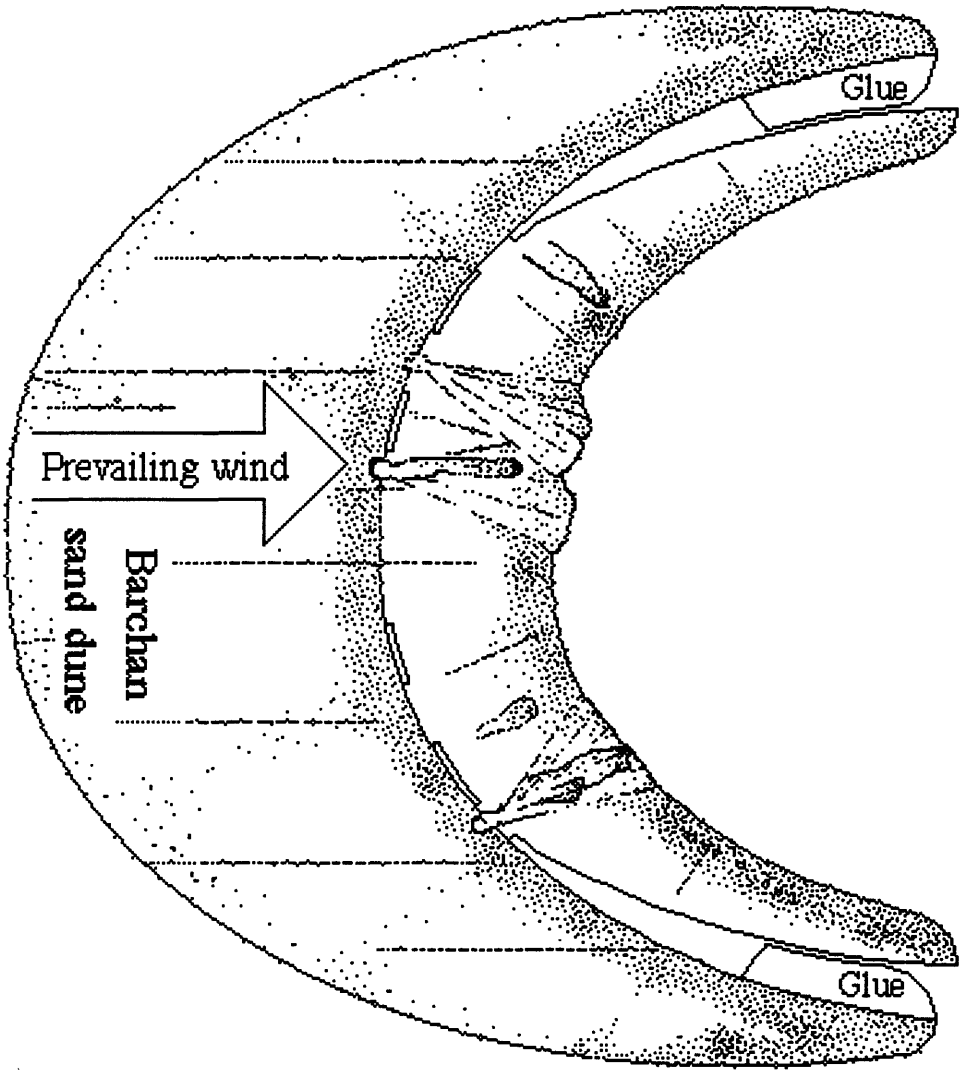
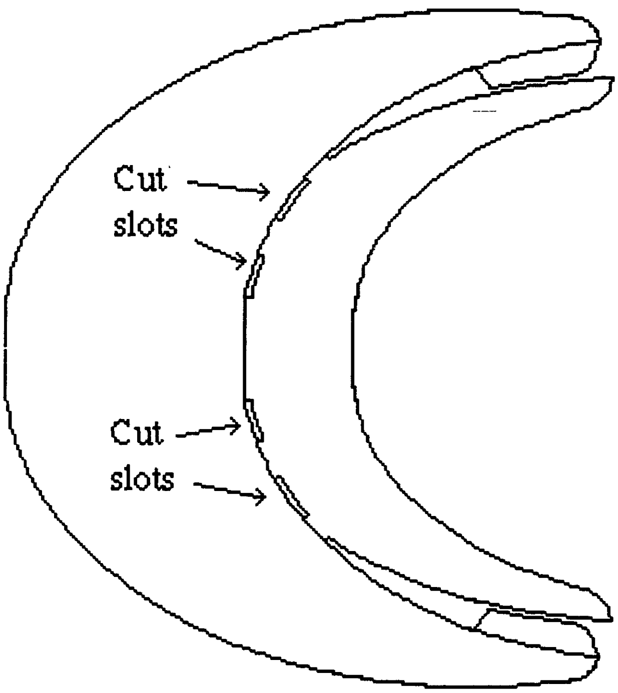
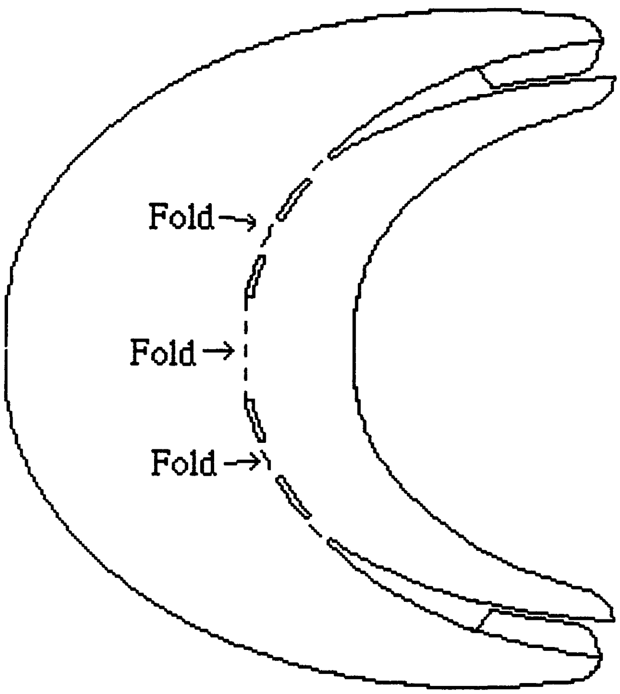


Cut out model



Fold model.



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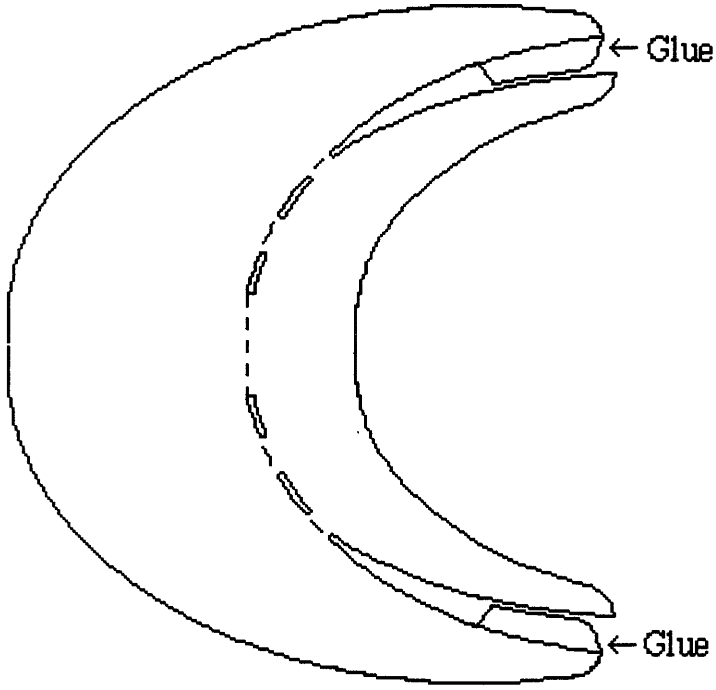

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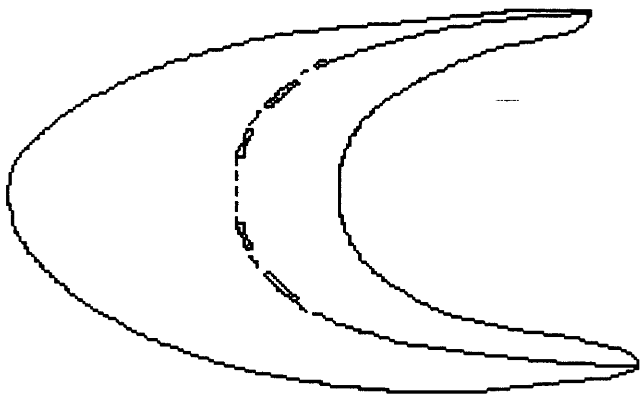
Finished barchan dune model should look like this.



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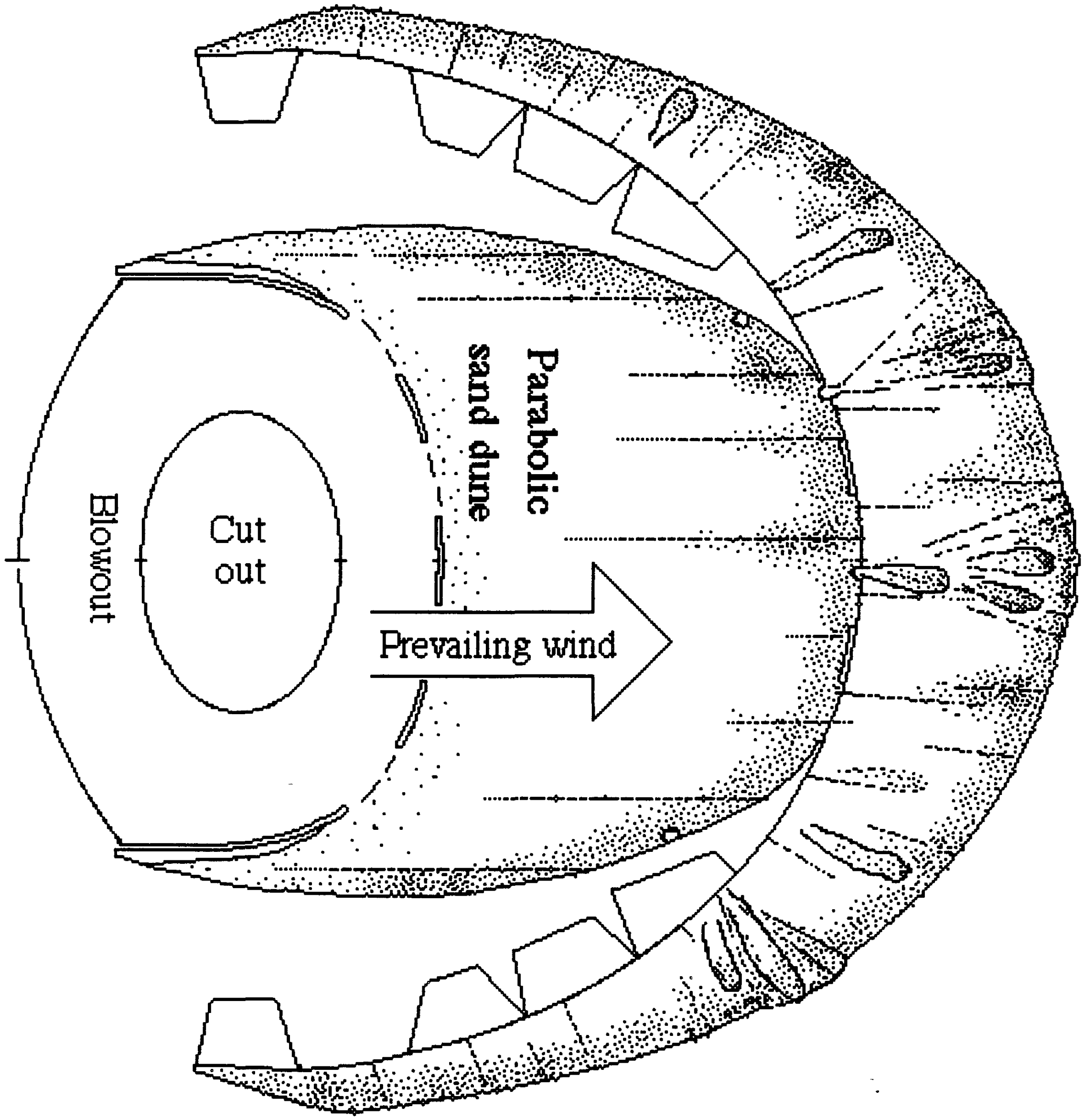
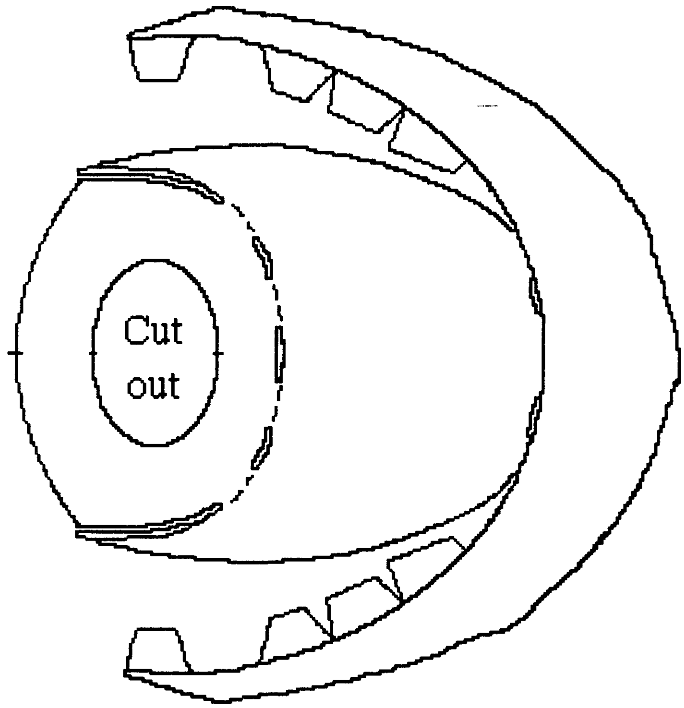
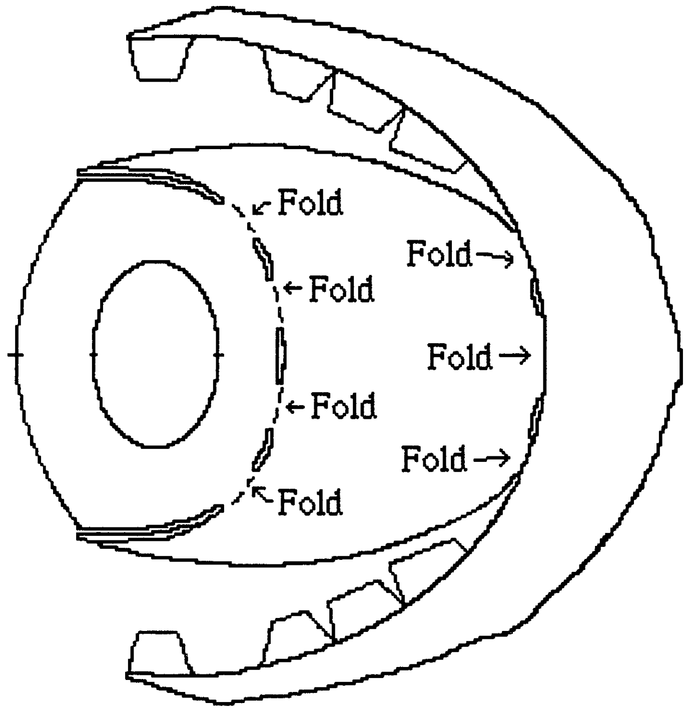
Model of parabolic dune



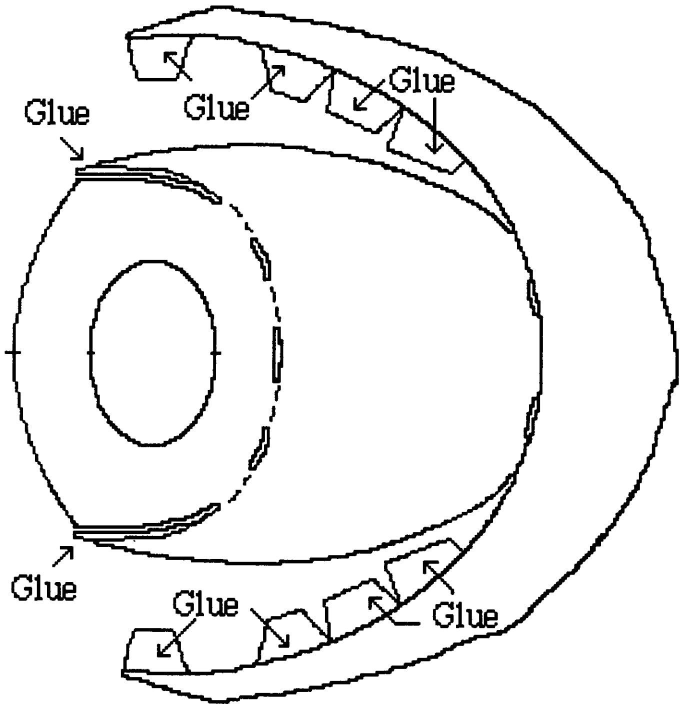
Cut out model



Fold model.



Glue model.



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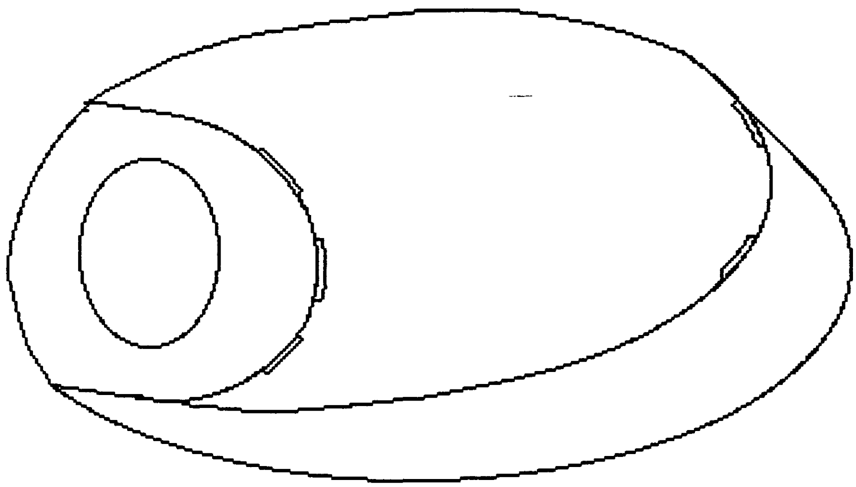
Finished parabolic dune model should look like this.



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Quit

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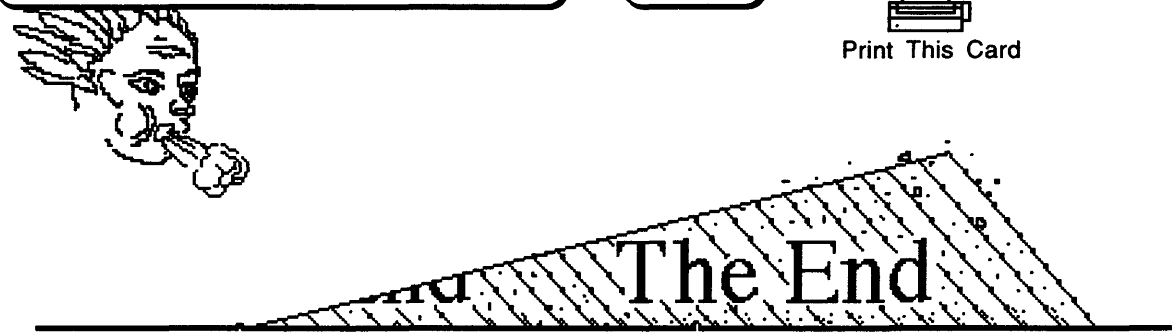

Alpha, Galloway and Starratt

Sand Dunes

Sand Dunes

Sand Dunes

By

Tau Rho Alpha, John P. Galloway and Scott W. Starratt

U .S. Geological Survey

Open-File Report 98-131-B

Cover for disk