Murat Avci (b. 1938) received degrees from the University of Ankara, International Institute for Aerial Survey and Earth Sciences, ITC, Deft, Holland including a Masters Degree in Engineering Geology. Murat worked during 1957-1966 in the Turkish Air Forces as a jet engine mechanic on F-84 and F-104 Aircraft's and from 1966-1973 for Mineral Research and Exploration Institute of Turkey as a field geologist. From 1973-1976, Avci worked at the University of Reading, Department of Earth Sciences, as a Research Assistant and taught Air Photo Interpretation and Field Geology. During 1976-1986 at the Department of Geology, University of Ife , Ile-Ife, Nigeria, he worked as a Senior Lecturer in geology and was Head of the Department for three years. Murat has also work for Turkish Aerospace Industries, taught the F110-GE-100 jet engines used on F-16 fighter aircraft, worked as the Training Manager for Bombardier Inc., written 12 scientific papers on earth sciences which were published in internationally recognized scientific journals, and written three papers on F-16 aircraft.

Chapter 29

2004-2006 Murat Avci

The Formation and Mechanisms of the Great Telçeker Earthflow, Mount Ararat, Eastern Turkey

Upper Cretaceous formations, flanking the Southern Slopes of Mount Ararat are suitably stratified together with appropriate lithologies to form ideal conditions for landsliding. Climatic factors were also in the favour of continuous surface erosions and consequent rapid mass movements. As a direct result of these conditions a 5 sq km valley has been carved down, reaching at its equilibrium at a depth of approximately 1000m. The stack of colluvial materials at the valley bottom measures 5-10 metres from which the earthflow was derivated.

During the rapid erosional phase, a large hard rock slab from the Miocene limestone unit at the top was brought down by a slump type landslide and wedged in by splitting the colluvial materials on the valley floor. Excessive loading on the colluvials by continuous addition of materials built up pressure and increased the kinetic energy in the colluvials. At one point, when the stress was released, the 1.2 km long earthflow came into existence.

The slab crept with the earthflow, and the earthflow mechanisms combined with the affects of glaciation and glacial meltdown processes, transformed the slab into a shiplike feature which astonishingly resembled to a man made structure. The etiology of the formation of this Natural Monument is explained in detail.

The study is supplemented with an analytical airphoto interpretation which provided vitally important data. These data enabled to understand the dynamical behavior of the earthflow and also disclosed the intriguing formation of the shiplike feature. At the planning stage, it has been helpful in determining the objectives and judging the validity of the study.

Key Words: Earthflow – Slump – Shiplike landform – Axial Displacement – Natural Monument-– Turkey

I-Introduction.

The Telçeker earthflow is located in the province of Dogubeyazit, 3km to the Southwest of the Turco-Iranian highway; reachable from the Telçeker village, which is approximately 300m East of Üzengili village, at the foot of Mount Ararat, one of the magnificent young volcanic mountains of Eastern Anatolia. However, the Telçeker earthflow is not located in the volcanic part of the mountain, but rather in the flanking Createaceous formations into which mount Ararat was intruded (Fig.1).

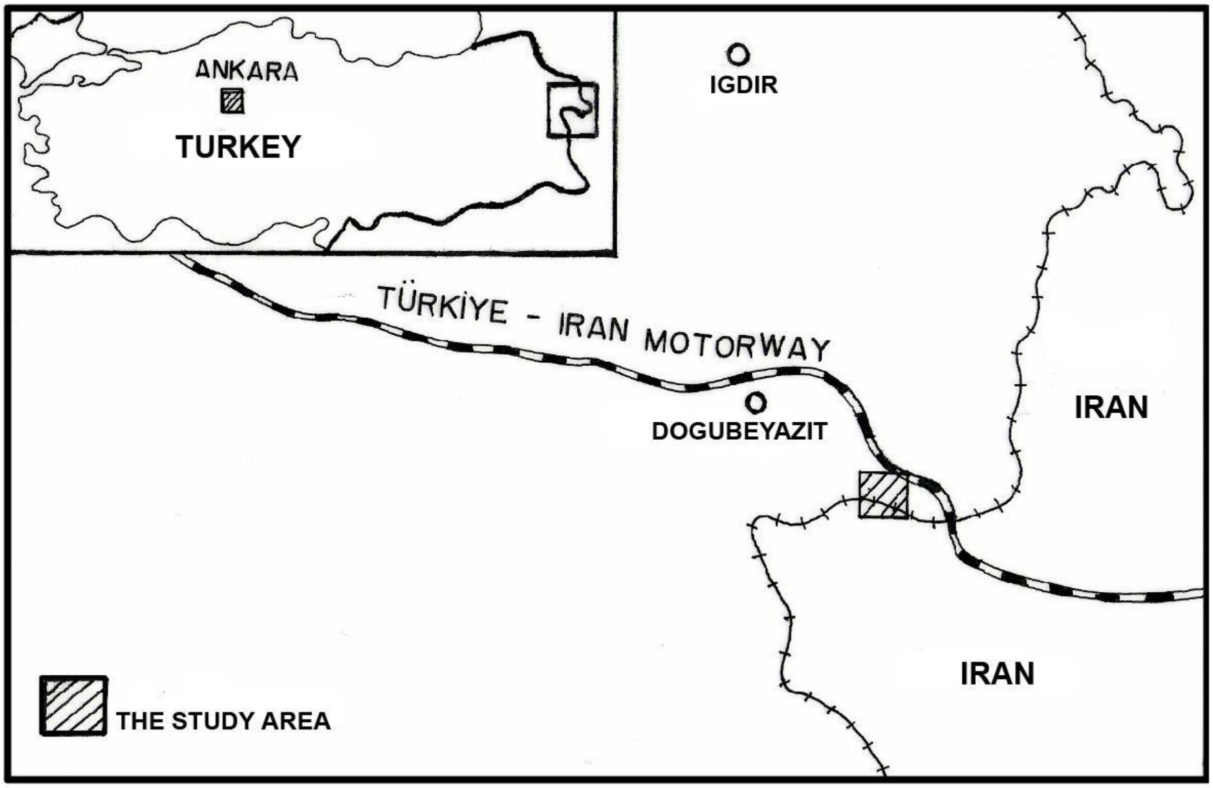

Figure 1. Location map of the study area

This study aims to describe the development and formation of the Telçeker earthflow which is a great earthflow when measured and compared with the other great landslides in the world. However, it is not only worthy studying it because of its size but also for a special feature that it carries on its shoulders. This feature resembles to a ship and is assumed to be the Noah's Ark, symbolizing a story mentioned in the world's three major celestial religion books. For this reason, it has attracted both religious and none religious professionals who had visited the area and proposed views on this **Natural Monument** since the beginning of the 19th century. However, except confidential technical reports of MTA, Turkey, the first significant research around Mount Ararat was carried out by Blumental(1959). But the area became more topical after the publication of an aerial photograph in a local weekly magazine (Life Magazine) in 1959, in Turkey which contained the great earthflow and the shiplike feature on it.

The primary purpose of this study is to make a comprehensive analysis of Telçeker earthflow, a secondary aim is to clarify how the tantalizing shiplike feature was formed in the earthflow. This combination made for an intriguing and stimulating study.

Yılmaz Güner (1986) carried out a detail study concentrating specifically on the shiplike Feature. Güner described the earthflow as a mudflow; his thesis on the formation of the feature was equally unpersuasive. However, he did at least silence the superstitious elements by defining the formation of the feature as an erosional event. According to his analysis, the shiplike feature is a residiual hill, an outcropping of the ophiolitic bedrock at the bottom of the valley and that this residual hill was carved by the mudflow along its edges and consequently shaped it into its present form. Although Güner's approach is a rational one, his technical diagnosis is not necessarily correct in defining the formation of the feature. It is however the premise of this article that the geomechanical processes that he has proposed are in fact not possible in this context. First of all, the landslide type is an earthflow rather than a mudflow. This is definite, both from aerial photographs and from evidences on the ground. Secondly, the idea of a residual hill is not tenable in the light of the lithological characteristics of the site and the type of progressive mass movement mechanics prevalent in the area. Additionally, the feature is formed in a valley more than 1000m deep with no topographic anomalies. The rock types and their mode of stratification encourage instability when there is enough water, either from rain or from melting snow. Nor are there volcanic dykes or monadnock types of landform development in the area. All of these facts point to the unlikelyhood of a residual hill remaining in a regular and well stratified rock formation after a thousand metres of downcutting. Additionally, a small hill could not have survived intact against the power of a great earthflow such as this,moving like a river of rock and sweeping everything before it.

A close field check of the edges of the shiplike feature shows that it is not under the earthflow materials but rather overlies them. For all these reasons, it is clear that the feature was not a residual hill but was something floating on the earthflow.

Aerial photographs provided vital information in understanding the development and formation of the Telçeker earthflow with its shiplike feature. The key observation was the identification of the axial displacement between the feature's long axis and the direction of the earthflow, leading to the assumption that the feature was indeed an object floating on the earthflow rather than a fixed object protruding from the valley floor. This observation has been the criteria to decide in carrying out this study. The Telçeker earthflow itself has a good picture of a classical earthflow example, but the formation of the shiplike feature gives it a special importance because it created this **Natural Monument**.

II- Geological setting.

There are three main rock formations involved in the Telçeker earthflow. The oldest rock unit in the area is the Upper Cretaceous ophiolites which outcrops in and around the valley floor. The ophiolites are highly altered serpentinite, purplish reddish limestones and conglomeratic sandstones. The unit bears a high clay content and because of this holds up the water seeping through the overlying pervious colluvial materials and thus creates the appropriate **slide surface** for the earthflow. The ophiolites are overlayed by the greenish grey marl, sandstone, claystone and clayey limestone intercalated Eocene series. The harder layers are varied in thickness (maximum 50cm) and embrittled by faulting and folding. They are easily removed and transported by external forces and thus provide the greater part of the earthflow materials. With its high clay content, this unit played an important role in the formation of the great earthflow by lubricating the colluvial materials when collaborated with water.

The youngest and the highest rock unit is the 4-5m. Thick Miocene fossiliferous limestones overlying the easily removed soft Eocene layers. This unit is horizontal or slightly tilted and broken into heavy blocks. This stratification creates a high degree of instability. Water seeps through the joints and reaches the soft, clayey Eocene layer, which then causes the blocks to be moved down by slides, falls and slumps. Limestone blocks are the heaviest component of the colluvial deposit. The shiplike feature for example is a large block which detached from the sheer cliff of this unit by slumping.

It is difficult to determine the interior lithology of the shiplike feature in the field, because during the slumping and wedging process, it picket up many rock fragments from the colluvials. Enigün's geophysical investigation (1988) did not yield significant information. Drilling at several strategic points would have allowed a clear look at the interior structure and material of the feature but this would be difficult and expensive. There is a strong assumption that the shiplike feature is a block of layer from the Miocene limestone unit at the top as there is no other thick and consolidated rock that could create such a landform and withstand the hard erosive conditions prevailing in the area. On the other hand, from the engineering standpoint, the important thing is the rigid rock slab which is the main factor to create a landform such as this.

The colluvial materials are loose Quaternary deposits derived from the surrounding rock units by means of different types of erosional processes and deposited at the valley floor up to a variable thickness of 5-10 metres. The great earthflow containing the shiplike feature is originated from this colluvials.

Before the Telçeker earthflow took place, the whole area was covered by snow and there was glacier formation until the late Quaternary. The higher areas such as the fossiliferous limestone at 2400m was covered by ice that did not melt even in warm seasons. Thus the shiplike landform slumped down with glacier on its back. Repeated freez and-melt cycles during the seasons partially consolidated the loose colluvial materials by physical and chemical erosional processes and smoothened the topography of the irregularly deposited colluvials in the basin. However, the topography of the younger earthflow is distinguishable from nonaffected areas by the anomalies created by sliding. Glacial landforms such as glacier caves, cirque lakes and moraines are still visible in the area.

III- Evolution of the Erosional Processes and Formation of the Telçeker Earthflow.

A triangular valley is formed and enlarged by different erosional processes that work at the upper slopes and downcut at the only outlet of the triangle. While the valley was enlarging, the materials detached from the slopes were mainly accumulated in a thick colluvial layer on the valley floor rather than being transported away. There are two reasons for this. First, there is only one narrow outlet to the valley. Second, there were frequent large landslides because of climate, the rock types and their stratification.

The valley covers approximately an area of about five square kilometres. When the process of downcutting reached the ophiolitic formations at the bottom, the incision slowed down because the material of this unit is impervious; the water ran over instead of cutting down. As a result, the valley profile lowered and valley bottom levelled out. But while downcutting decreased, the backward erosion on the upper slopes continued resulting in more accumulation of material than was transported. Material stacked up for tens of metres above the impervious ophiolitic bedrock unit. As time passed, the erosional cycle continued in the valley. In connection with aggravating climatic variation, four levels of landslides have developed in and around the crescent shaped valley root; the fourth of these was the great earthflow bearing the shiplike landform.

The slides from the fossiliferous limestones unit at the top were mostly of the slumping type because of the hard, jointed limestone blocks overlying the soft, easily crumbled Eocene unit. Once a limestone block detached from the sheer cliff, it would easily crush the softer lower unit and slide down along a rotational sliding surface without deforming the top hard layer, specifically, if the detached block is as large as at the dimensions of the shiplike feature measuring 150mx50mx4m. This is how the shiplike landform was initially slid down as a large layer from the upper fossiliferous limestone formation and crept downward until it became a part of the colluvial materials and stationed over the lower ophiolitic unit.

Slumping is a common landslide type in this kind of stratification in all over the world (i.e. compact, hard and pervious lithology above and soft, impervious lithology below), provided that the water agent is available. In this way, the shiplike landform detached and crept down until it became part of the colluvial materials which accumulated in the cone shaped valley. The narrow end of the cone was the only outlet to drain water from this small basin. As materials piled up in the upper sections of the valley, a constant pressure is being supplied on to the colluvial materials which caused the development of a kinetic energy. While the energy increased in the materials by constant loading, the seeped water trough the colluvials, on the other hand, held by the ophiolitic bedrock, prepared the needed sliding surface for the earthflow to happen. Preceding the great slide, the load at the upper mid valley was fed by several small slide tributaries from above which they later joined at a central area and flowed down as one great slide creating the present Telçeker earthflow.

The aerial photographs show clearly that the great Telçeker earthflow itself took place in two stages, separated by minutes or a few hours. The clear boundary line between the two flows is seen in figure 2, at point S. Possibly, tremors from the first flow triggered the second which followed the same curve, sweeping material from the older slide in front of it, materials that might have been still well saturated with water. The flow ran 1.2 km past the only outlet of the basin. Two hundred metres before it stopped, the flow made a turn of almost 90 degrees to the East; exactly at the point where it crosses the Dogu Beyazit fault line. The fault was there long before the earthflow, which simply adapted itself to the existing topography. Meanwhile, the shiplike feature was carried and shaped within the older section of the flow. Although the surface characteristics of the two flow stages are similar, they are

distinguishable by the slight difference in flow direction and the surface texture.

It is interesting to note that all the smaller slide tributaries from different parts of the valley floor moved down at the same time though they were distant from each other- suggests a regional triggering agent along the following lines: First, a period of heavy precipitation and/or excessive snow melt followed by an earthquake tremor (quite common in this region). This combination could have initiated all the initial flows and consequently the main (Telçeker) flow.

Anyhow, the lithology and climate in the area are synchronous to produce varied examples of landslides. For example, an incomplete slumping can be observed in figure 2 PS, developed before and independent of Telçeker earthflow. The arrows indicate the circular trace of a slump-type landslide which occurred in the homogeneous part of the ophiolites. The block in view was rotated at its circular sliding surface for several metres but left no apparent topographic anomaly. Because, it is clear that the sliding cycle of the slumping process was incomplete, probably because of some obstruction in the foot area. While it stood at its position as a potential slump, the Telçeker earthflow material moved in and covered this foot area (R), creating a natural retaining wall which prevented further slumping.

IV- How The Shiplike Feature Was Formed

Slumps are landslide types which usually take place along a circular plane; the slid material is not transported far but is heaped at the root of the scarp. The circular sliding motion is somewhat similar to the motion of a human being trying to sit down while his back is against a wall. During this motion, the body moves down while the legs are bent like a hinge to prevent loss of balance. During the sliding process, the underlying soft unit (because of its homogeneity) is isotropically squeezed down, (representing the legs), it absorbs, and slows down the pressurising energy of the upper consolidated heavy unit (the body) which consequently prevents its unbalanced collapse and deformation. Similarly in slumps, if the top layer is a consolidated rock layer, it is usually not deformed after the slide has occurred. This is exactly what happened when a huge rock layer first detached and slid down from the overlying fossiliferous limestone unit at the top.The shiplike feature is a piece of undeformed remnant of the hard limestone, brought down by a slump type landslide.

Figure 2. Aerial photograph of the great earthflow (Noah's ark highlighted)

However, the slab did not look as it does now until it went through several processes as follows: It apparently detached along an ellipsoidal weakness line concordant to the sheer cliff side (fig.3). Several other conditions contributed to the slump: the removal of the underlying unit by erosion, a period of heavy rain, snow or ice melt, seepage through the present joints and/or an earthquake tremor. After the slump took place, the slablike rock block slid down with the glacier at its back to the valley floor and stuck in the thick colluvial deposits like a wedge; it may have received its first shipshape sculpturing during this wedging stage. It stabilized there in the heavy colluvial materials with other smaller sized materials from the local rock formations.

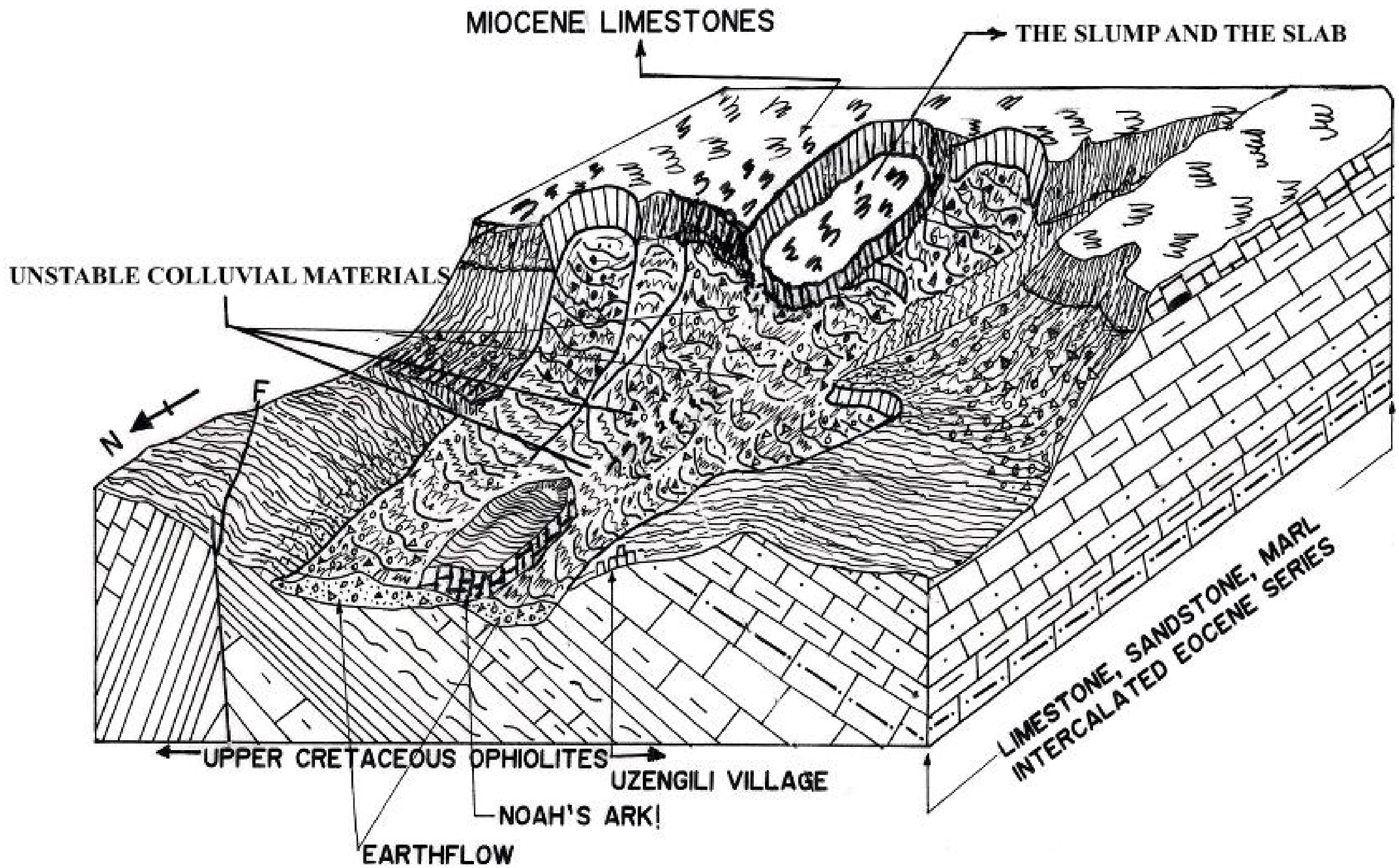

Figure 3. Geology and geomorphological evolution of the site (not to scale)

The slab finished its rapid movement after the slumping, but it continued creeping slowly downward within the colluvials as it was a large and heavy block compare to its proximity and did not stop until the great earthflow took place. While it was slowly wedging down into the colluvials, the colluvial deposition continued behind it; after several hundred years, but before the earthflow took place, it was completely surrounded and became a part of the colluvial deposits on the valley floor.

When the first part of the main earthflow started moving, the slab with the glacier at its back slid down like a large raft floating on a river. But this solid huge mass did not slide at the same rate as the other parts of the earthflow: it was a large piece relative to the other materials of the earthflow and thus moved at its own rate, somewhat more slowly. The slab floated on the earthflow as if on a liquid environment and even oscillated about at its transverse axis. Sometimes it pitched into the earthflow materials and levelled again. The jigsaw scars at the front of the feature were scraped by the rock blocks contained in the earthflow materials during this oscillating movements (fig. 4 J).The slab did not slide for a great distance: it hit bottom from time to time and finally stopped when it grounded firmly at its present position as seen on the aerial photograph. It of course ended up at a higher level relative to the moving earthflow materials. On the aerial photograph there is some printed information that is important support for the theories put forward in this study: that the shiplike feature is not a stationary feature but a piece of the earthflow behaving in a special way. This printed information is the diplacement between the feature's long axis (fig. 2, A-B) and the earthflow's flow direction axis (C-D).

There is 20 degrees of deviation in between these two axes. The explanation for this deviation follows: The shiplike feature moved for a while with the earthflow and then grounded (fig.3, see bottom); however the earthflow continued flowing, trying to carry the feature further; but the feature was grounded and could only be pivoted a bit on its vertical axis; this action caused it to be displaced 20 degrees from the earthflow flow direction.

The identification of this axial displacement and related mechanisms were succeded because of the three dimensional overview capability of airphoto interpretation techniques. In the case, this was not possible the nature of the shiplike feature and the detailed description of the Telçeker earthflow could not have been possible and this study would not be worth carrying out.

It is difficult to estimate the detachment point of the slab as the limestone unit was retreating all the time. However, at present, the slab is 2.5km. away from the scar. It slid from a height of 2500 metres and now rests at 1900metres. It may have been transported approximately 2km.after it was detached. In any event, it is certain that this feature is not a ship or any such manmade artefact, although behaved very much like a ship within the earthflow. For example, either during the push by the earthflow, and resistance by rocking, or oscillation at its transverse axis, the "backbone" of the "ship" was broken in several places (fig.4).

Figure 4. Ground photograph of part of the earthflow and the feature

During both the creeping and the fixed stages of the feature, the earthflow materials flowed faster than the slab and carved it from left and right, somewhat shaping it into a shuttle like form. This is the same principal as sandbar development in a river, except that a sandbar is two dimensional, whereas the shiplike feature is three dimensional (150mx50mx4m) which is why it is so deceptive.

However, at the early stage, the processes which formed the slab into a perfect shiplike feature had not yet been completed. For example, in its present shape, both the center and the edges are raised as in a real ship with a lower area in between; this is how a ship would look if it were burried and then emerged again. There is a rational explanation for this shape. Remember that the slab had an ice cap when it moved down. We know that the edges were partially tilted up, both during its wedging into the colluvials and also later by the pushing of the rapidly moving, heavy earthflow materials during the main flow.

However, the fine work of sculpturing of the slab (Fig. 5 a, b, c, d) happened during the glacier melt. When the earthflow was finished, the ice on the slab started melting both because the slab with the glacier moved down to warmer level and also because the climate warmed up regionally. The land along the edges of the slab was more exposed due to its higher position and so the ice melted faster there, the glacier retreated faster. Because of this, the slab edges were less exposed to water, dripping from the edge of the ice; this reduced the effect of dissolution, condensation and compaction along the edges of the slab and thus the edges remained high.

The depression between the edges and the bulging centre of the formation came about because of the effect of ice melting on the slab's calcareous material. The melting did not start at the bottom centre of the glacier where it would have been cold, but rather at the upper surface and at its edges. After melting started, running water flowed over the glacier surface toward the edges where it joined with the water melting at the edge. The water then ran from the ice edges under the lower surface of the glacier and dripped on the slab between the edges and the centre of the slab.

While the melting continued, the edge of the glacier retreated towards the centre and the drainage line around the glacier from dripping water also moved toward the centre. During this long, slow retreat, these areas were diagenesed by physical and chemical dissolution, and by the process of condensation and compaction. In this way, the areas between the centre and edges were worn down and subsided. Why then the centre remained raised? These slow processes might have taken hundred of years, continuing until the glacier became very small and thin, about the size of the current raised area. This small piece of ice would then melt quickly and disappear in a short period of time: because of this, the centre was not exposed to water action long enough to be diagenesed like the subsided sections and it thus remained higher.

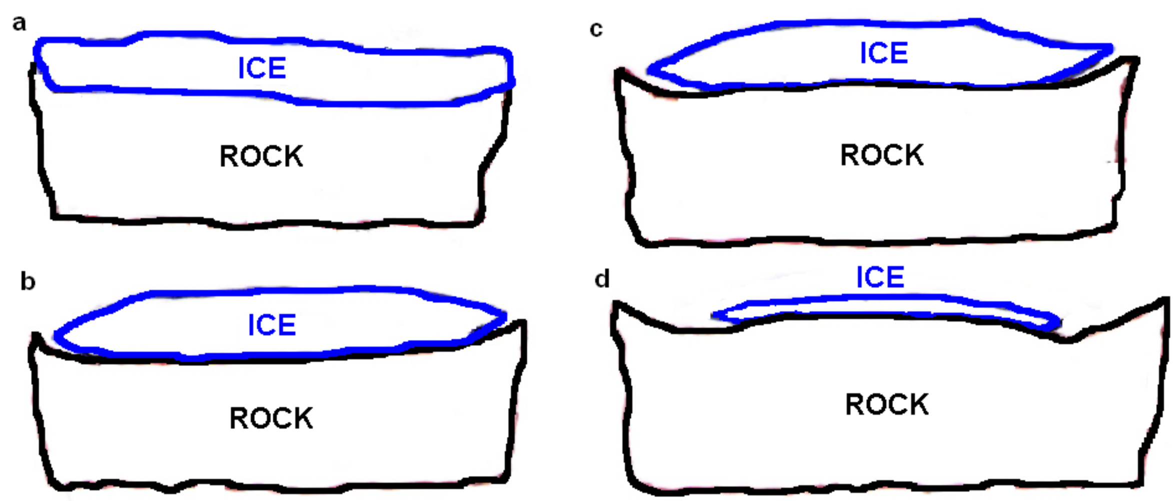

Figure 5. The cross sections showing the final sculpturing stages of the feature

The outcome of all these processes was the formation of this near perfect **Natural Monument,** this shiplike feature, or **Noah's Ark** as it is commonly known.

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