GLACIAL, PERIGLACIAL AND GLACIO-VOLCANIC STRUCTURES ON THE ECHUS PLATEAU, 
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Introduction: A complex of sinuous ridges, clearly visible on MOLA imagery, bisects the plateau above Echus Chasma (275°<long<285°W, 0°<lat<5°N). The ridges have lengths of up to 270km with an average height of 100m. They are superimposed upon a Hesperian plateau bounded to the north and west by more recent Amazonian lava flows. Glacial outwash features extend along Echus Chasma at the eastern edge of the Plateau. The geological sequence of lavas, graben, windblown dunes, shallow valleys, canyons and glacial structures is discussed using MOLA, THEMIS and MOC imagery.

The Setting, Echus Chasma and Kasei Vallis: Echus Chasma is situated at the head of Kasei Vallis, part of the Circum-Chryse outflow complex (figure 1).

Figure 1 MOLA shaded relief of Echus Plateau.

The Hesperian terrain of the Echus Plateau extends to altitudes of 2500 m above the western cliffs of Echus Chasma. It is bounded to the north and west by younger Amazonian and Hesperian lava flows from Ascreus Mons. The erosional history has been influenced by surface runoff, massive outflows and possibly glacial erosion. The steep cliffs of Echus Chasma are incised by many tributary canyons of Hesperian age. Dense, shallow valley networks found at the edge of the Echus Plateau above the canyons [1,2,3] predate or are coeval with the deeper dendritic canyons.

A complex of 100 m high, sinuous ridges extend SW-NE across the Echus Plateau.

Figure 2: Themis I band daytime maps covering the Echus Chasma region acquired using JMars.

The Structures on Echus Plateau: The following structures on the plateau are clearly resolved on THEMIS images (Figure 2):

The Sinuous Ridges and Plains- Two main, sinuous ridges cross Echus Plateau (figures 1 & 2). The longest ridge runs for 268 km from an altitude of 2300 m towards the edge of Echus Chasma. Shorter ridge segments appear across the Plain. The dominant ridges exhibit sharp ridge-lines, are up to 12 km broad and have heights of 150 m. Sinuous rilles are observed to parallel some ridges and many of the ridges are cut by graben. THEMIS V band images (36 m) resolve some of the smaller, features into discrete conical hills. The small ridge in Figure 3b is consistent with material flooding around the ridge’s base.
**The Lava Flows** - The Amazonian-Hesperian lava flows define the western and northern boundaries of the Echus Plateau. These have lobate or foliate edges and several show well structured levees. The flows represent tube fed fan units as observed on the slopes of the Tharsis volcanoes [4]. The western flows stop short of the ridged terrain, in some cases butting up against ridges (Figure 4). Faint outlines of older lavas can be seen forming the Plateau floor.

![Figure 3 Ridge structures](image)

Figure 3 Ridge structures a: Themis I band images b: Themis V band

**The Graben** - The northwestern part of the Echus Plateau plateau is dissected by a field of graben 250 km in length, with depths of at least 200 m deep, and 0.5 m to 2 km broad (Figure 5). These extend along a direction N70°E sharing this alignment with the northern canyons in the wall of Echus Chasma. Both appear controlled by an underlying fault system. The major graben trend is radial to central Tharsis, a characteristic shared by many other graben including that of Valles Marineris. The northernmost graben disappear below the younger Amazonian lavas.

![Figure 4 Contacts between lavas and ridge features](image)

Figure 4 Contacts between lavas and ridge features and their relation to the graben field (THEMIS mosaic).

**The Canyons and Rough Terrain** - Canyons extend up to 100 km into the Echus Plateau. Their dendritic shape and rounded ends are indicative of groundwater sapping. The canyon walls show layered structures and crevasse-like faulting paralleling the canyon rims. Narrow, dark slope-streaks running down the cliff and scree are common, possibly the result of granular solids transported downslope by water or vapour [6]. The canyon floors have been flooded by material from Echus Chasma. There is a clear dichotomy between the smooth terrain underlying the sinuous ridges and a 100 km strip of Rough Terrain, extending towards the edge of Echus Chasma. This Rough Terrain stands up to 30 m above the western Plateau and includes networks of shallow channels. The area is overlain by recently formed, small barchan-dunes. The shallow valley networks form part of this Rough Terrain and are resolved into a hummocks a few hundred metres across. The drainage network appears controlled by the hummock alignment. Smooth, 2 km wide channels penetrate this Rough Terrain linking the canyon heads to the smoother Plateau to the west (Figure 6). Near the dichotomy the Rough Terrain breaks up into small, kilometer sized mesa-like structures.

**Possible Origins** - The Echus Plateau displays a wide range of surface features representing volcanic, fluvial, aeolian and glacial morphologies. The smooth terrain associated with the sinuous ridge systems is bounded to the east by Echus Chasma and its canyons. Its southern
edge is formed by the slopes rising to Mariner Valley, while extensive lava flows limit the western and northern boundary. The progress of the Amazonian lava flows appears to have been stopped by sections of the ridge system. Extensive grabens cut both the smooth plains in the northern part of the region and the sinuous ridge systems. The graben have similar alignments to the major canyons and are controlled by underlying Tharsis-centred faults.

The chronology of the major features in the region is fairly clear:

1. Formation of the Echus Plateau
2. Formation of Echus Chasma and ponding above Kasei Vallis
3. Evolution of Echus Plateau
   a. Formation of shallow valley networks in southern part of region
   b. Canyons and dendritic channels form and dissect rough terrain
   c. Formation of central smooth plains
   d. Ridge formation
4. Lavas encroach from west and north
5. Major impacts form lobate craters

The individual ridge systems while coeval with the plains and valley networks may not necessarily share a single formation mechanism. In the section which follows possible mechanisms contributing to the geomorphology of the plateau are discussed and the most probable cause of ridge formation identified.

**Aeolian** - The southern Plateau has a high albedo possibly due to blown dust infilling low areas between the ridges or some other resurfacing. Clusters of 1 km linear dunes are visible throughout the western plateau, largely confined to the floors of craters and graben. The Rough Terrain is covered by recent small scale barchan dunes driven by the predominantly south westerly winds of the region. The larger scale rounded features in the Rough Terrain, controlling the drainage of the dune systems, predate the shallow valleys (Figure 7).

**Surface Flow and Groundwater** - The dominant fluvial erosional features are Echus Chasma and its tributary canyons. The shallow valley networks formed after Echus Chasma but prior to completion of the formation of its tributary canyons. The Rough Terrain is pierced by kilometer-wide, corridors leading to heads of the major canyons. These canyons exhibit the rounded, theatre-shaped, head walls associated with groundwater sapping rather than surface flow [7]. The dichotomy between the smooth, western Plateau and Rough Terrain may be the result of shallow water deposition behind the slightly elevated lip of Echus Chasma. This water could have formed during a wetter
period or the melting snout of a receding glacier. The meltwaters then drained into Echus Chasma via flat corridors and tributary canyons. The smooth plateau terrain is similar to the Vastitas Borealis Formation which has been ascribed to sedimentary deposition from ponded outflows and a northern ocean [8]. This smooth terrain could also represent glacial till deposited beneath a glacier. The graben complex could result from groundwater sapping processes [9] controlled by deeper fault structures. However there is no evidence for surface flows from the graben.

**Glacial**- Gravel deposits in subglacial tunnels (eskers) are the most obvious glacial analogue to the ridge systems [10]. Terrestrial eskers are up to several hundred kilometers long, with widths of up to 6 km and heights of 200 m [11]. In a glacial scenario the Rough Terrain represents material pushed up ahead of the glacial snout. Glacial meltwater later eroded this material to form complex, shallow drainage channels in the outwash region. The shallow valleys could also have formed due to basal melting within the glacier. The larger dune-like structures in the Rough Terrain represent drumlins and kaimes, left as a glacier retreated [12].

The Echus Plateau represents a “kipuka” or island around which the later Amazonian lavas flowed. Perhaps the flows encountered a remnant ice sheet/glacier extending from the base of the Tharsis/Thaumasia uplands. Theatformation of such a glacial remnant is supported by evidence of basal scouring by ice on the floors of the Kasei Valley and Echus Chasma [13, 14].

**Volcanic**- The Echus Plateau kipuka is bounded by flows to the north and west and floored by older flows sharing the general trend of the ridges. The few eruption sites on the Echus Plateau take the form of small, isolated cones some of which occur in the northern graben. The ridges are older than the surrounding Amazonian lava flows which butt up to their sides. In a volcanic model the main ridges represent intrusions of magma from rifts and graben. The larger ridges show indications of summit vents. The observed sharp spines and the beaded appearance of the ridges are expected from rift eruptions. The sharply defined ridge boundaries and the flooded cones represent lava, or possibly mud flows, pooling around the ridge bases. Rille systems paralleling the large ridges represent small lava tubes draining the lava lakes surrounding the ridge vents.

**Conclusions:** The Echus Plateau shows a wide variety of structures representing aeolian, volcanic fluvial and glacial formation mechanisms. The shallow valleys and the dichotomy between the ridged plains and the rough terrain provide strong evidence for the existence of a small glacier on the Echus Plateau in the Late Hesperian - Early Amazonian period. The sinuous ridges’ size, shape and sharp crests, and the presence of outlying cones’ are best explained by rift eruptions similar to those associated with the Deccan Traps, though on a smaller scale [15]. The presence of both volcanic and glacial structures on the Echus Plateau raises the possibility that sub-glacial volcanic events occurred below a remnant ice cap or glacier forming the ridge systems. Sub-glacial eruptions would result in tabular mesa-like structures (tuyas) and long, flattened Moberg ridges [16].

Further high resolution visible, infrared and radar imaging is required targeting the sinuous ridges and drumlin features in the Rough Terrain to confirm the existence of glacial formations in the region.

**References:**