EPSC Abstracts
Vol. 8, EPSC2013-194, 2013
European Planetary Science Congress 2013

Sub-ice lake scenario for Chaotic Terrains on Mars

M. Roda (1), R. Govers (1) and T. E. Zegers (1)
(1) Universiteit Utrecht, Fac. of Geosciences Budapestlaan 4, 3584 CD Utrecht, The Netherlands (m.roda@uu.nl)

Abstract

A 2D time-dependent thermo-mechanical model, including ice–water phase change and sedimentation process, is developed to study the effects of planetary heat loss and sedimentation rate on the time scale for melting and on the mechanical and hydrological stability of sub-ice lake scenario. The results show that planetary heat loss greater than 25 mW/m^2 and sedimentation rates between 0.1 and 0.001 mm/yr are able to produce stable melting process, reaching a water thickness greater than 1.3 km. These parameters fully agree with the estimates obtained by geological and morphological observations. Afterwards, the water stored within the crater can be rapidly discharged toward the surface through fractures in the sediment cap. The consequent collapse would be 1.3–1.5 km, which agrees with the amount subsidence observed for Aram Chaos.

1. Model setup

The 2D thermo-mechanical time-dependent model was developed using COMSOL Multiphysics®. The physics is solved using the coupled equations for conservation of energy and conservation of momentum. To describe the mechanical behavior of the system during progressive sedimentation and melting the linear elasticity is applied to the sediments–ice–water system. Since the deformation occurring in the bedrock is negligible, it is treated as non deformable. The ductile behavior of ice, active for long time scale, is not taken into account. The initial geometry of the system is characterized by a crater 4 km deep and 100 km wide occurs within a portion of basaltic material 20 km thick. Ice layer 2 km thick occurs within the crater. The surface temperature is fixed at 233 K. This temperature, which represent the present-day mean annual temperature at equator of Mars, would be also representative for the mean annual temperature during early Mars history. Three constant planetary heat losses are applied at the bottom side of the model: 10, 25 and 40 mW/m^2. Free slip condition is imposed along the crater boundaries while a body load is applied at the sediment domain, growing with the thickness of sediments trough time. Since the sedimentation rate could affect the stability of the sediment–ice–water system, we tested three different sedimentation rates: 0.1, 0.01 and 0.001 mm/yr.

2. Results

The combined effects of thermal insulation of overburden and planetary heat loss induce the modification in the thermal state, with temperature increase and melting of ice layer (Fig. 1). The melting does not occur for planetary heat loss of 10 mW/m^2 because of the faint heating from below that is not able to contrast the cooling effect induced by the surface temperature. For 25 mW/m^2 the steady state solution is reached for a water thickness of 1.6–1.7 km while for 40 mW/m^2 the complete melting of the ice layer occurs. When the melting occurs, the sedimentation rate has a primary role on the control of melting time.

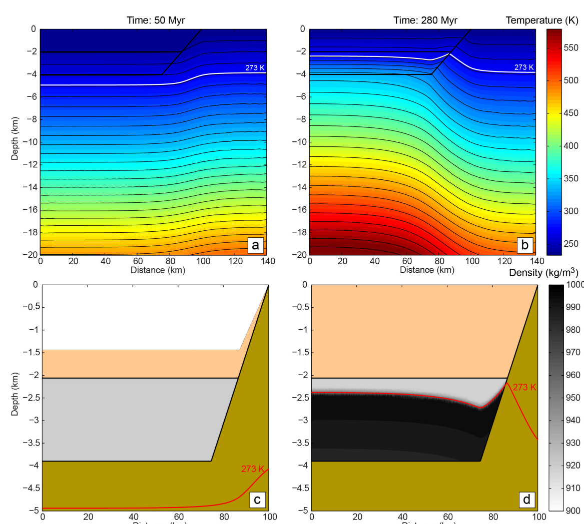

Figure 1: Results for melting process at two different time steps: 50 and 280 Myr. a) and b): temperature fields; c) and d): ice-water density. Simulation: 25 mW/m^2 and 0.01 mm/yr.

During the same simulations performed for the melting we analyzed the stability of system in terms of mechanical stress of the overburden. Since the small relaxation time of ice (2 years) compared to the sediments (103 years), the mechanical behavior of ice layer is mainly viscous for the entire simulation time. For this reason we treated only the elastic mechanical stability of the sediment cap. The stress field, obtained using Mises criterion, indicates a general compressive regime operating within the overburden, generated by sliding of sediments lying along the crater rim (Fig. 2). The area of maximum stress concentration is located between the rim and the crater floor, which represents the area with highest probability of fracturing (Fig. 2b). In general, the stress increases with the sediments thickness and water through time and in some areas it can exceed 12 MPa (sediments strength for compressive regime). For the low and medium sedimentation rates (0.001–0.01 mm/yr) the strength limit is exceeded when the molten layer reaches a thickness 1.2-1.4 km while for the highest rate (0.1 mm/yr) and low planetary heat loss (25 mW/m^2) the water thickness is less then 1 km.

3. Conclusions

Numerical simulations of sub-ice lake scenario, applied to Aram Chaos, indicate that planetary heat loss, together with the thermal insulation induced by overburden, are able to generate large melting of buried ice layer in a reasonable time scale. Planetary heat loss greater than 25 mW/m^2 and sedimentation rates between 0.1 and 0.001 mm/yr are the best working conditions to produce a stable melting process until to reach a water thickness greater than 1 km within 1 Gyr. These geological parameters fully agree with the estimates obtained by geological and morphological observations. Sub-ice lake scenario is a valid mechanism involving non-climatic processes (planetary heat loss and thermal insulation of overburden) to explain the occurrence of large amount of water needed to carve the outflow channels in a very short time scale, as required by a general cold climate characterizing the early Mars.

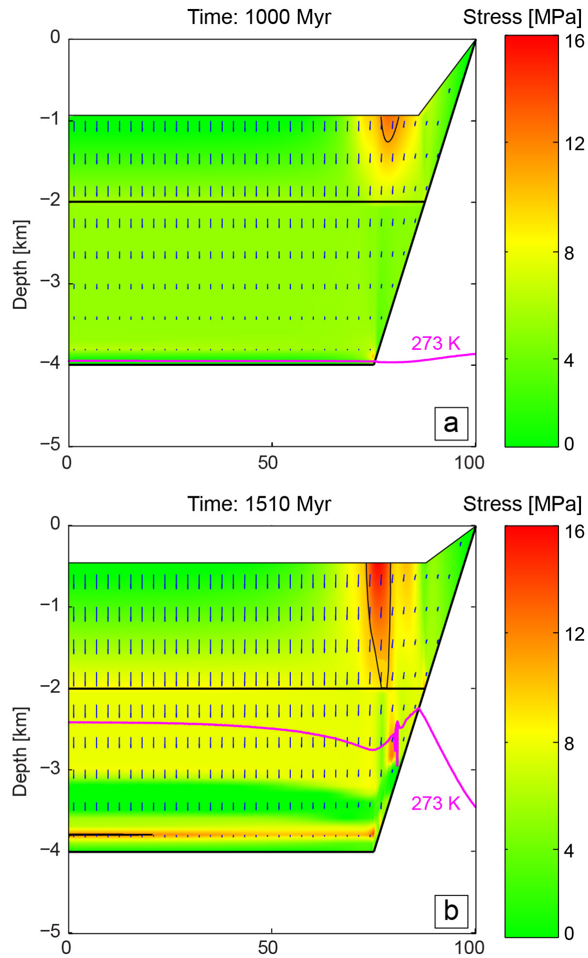

Figure 2: Mises-stress map at two different time steps: 120 and 250 Myr. Black arrows represent the displacement field vectors and the pink contour is the 273 K isotherm. Simulation: 25 mW/m^2 and 0.001 mm/yr.

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