

## **Tufa deposits sheltered by Inland notches as indicators of Quaternary denudation rates**

Nurit Shtober-Zisu (1), Anton Vaks (2), Hani Amasha (3), and Amos Frumkin (4)

(1) Department of Israel Studies, University of Haifa, Haifa, Israel (nshtober@research.haifa.ac.il), (2) Geological Survey of Israel, Jerusalem, Israel (antonv@gsi.gov.il), (3) Department of Geography and Environmental Studies, University of Haifa, Haifa, Israel (haninotch@gmail.com), (4) Institute of Earth Sciences, Hebrew University, Jerusalem, Israel (amos.frumkin@mail.huji.ac.il)

Denudation is the long-term sum of processes that cause the wearing away of the Earth's surface by weathering and erosion. As denudation of carbonate terrains involves mainly karstic dissolution, Israel is a natural laboratory for the study of denudation rates because of its carbonate terrain and steep precipitation gradient, ranging from >1000 mm in the north to less than 100 mm in the south.

Several studies on denudation rates in Israel provide contradictory evidences. Ryb et al [1] found that denudation rates in the Mediterranean climate zone are  $21 \pm 7$  mm per ky, whereas Bar et al [2] showed much lower rates on the long-term scale (Oligocene-present). In this study we determined minimal ages of formation of Inland notches [3] using U-Th dating of tufa deposits developed under the notches' visors or covering notches' cavity beds. The ages of tufa were used to determine the relative slope denudation rates on Mt. Carmel (Israel) that receives annual precipitation rates of 700 mm.

Inland notches are elongated concave-shape indentations that develop on the carbonate rocky cliffs of mountainous zones. These unique features formed as a result of the interaction between specific lithological and weathering factors, emphasizing the importance of climate upon denudation. Inland notches form because the most porous cavity bed retreats at a faster rate compared to the slower subaerial dissolution of the visor bed, until a critical point is reached where the visor collapses. Notches are most common in semi-arid and in Mediterranean climates, mainly in areas with annual rainfall of between 400 mm and 850 mm. Occasionally, tufa stalactites and stalagmites grow within the cavity of the notch.

The Carmel tufa deposits that grew under the notches visors and on the cavity back-wall were dated by U-Th at the Geological Survey of Israel using ion exchange column chemistry and MC-ICP-MS techniques modified after Vaks et al [4]. In each notch the oldest tufa layer was dated giving the minimum age of the surface formation. Six layers from four tufa samples were dated giving ages spanning from  $13,636 \pm 834$  ky to  $37,562 \pm 2,397$  ky, implying that the minimal age of these notches is last glacial period, or last deglaciation.

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2. Bar, O., et al., The uplift history of the Arabian Plateau as inferred from geomorphologic analysis of its northwestern edge. *Tectonophysics*, 2016. 671: 9-23.
3. Shtober-Zisu, N., et al., Inland notches: Implications for subaerial formation of karstic landforms—An example from the carbonate slopes of Mt. Carmel, Israel. *Geomorphology*, 2015. 229: 85-99.
4. Vaks, A., et al., Paleoclimate and location of the border between Mediterranean climate region and the Saharo-Arabian Desert as revealed by speleothems from the northern Negev Desert, Israel *Earth and Planetary Science Letters*, 2006. 249(3-4): 384-399.