

# Remarkably extensive Early Holocene glaciation in Turkey

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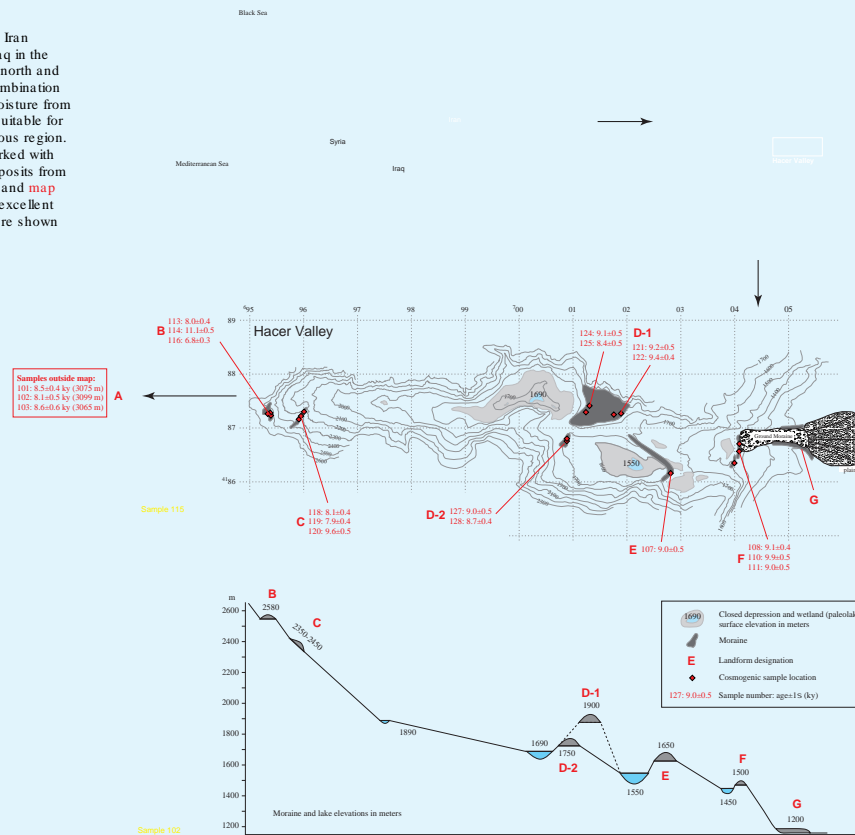
## DESCRIPTION

We conducted a detailed glacial-geological study in Aladaglar (in the High Taurus, central Turkey, 37°45'N, 35°15'E). We mapped and dated six large, well-preserved moraines in Hacer Valley (1510-2580 m), and one on the summit plateau (3080 m) [see [table](#) below and [map](#) in the center]. From the position of the moraines [see [profile](#)], we calculated changes in the equilibrium line altitude (DELA, a measure of the extent of glaciation) and in the temperature. The large sizes and low elevations of the lowest moraines hinted at their origin during the Last Glacial Maximum (LGM), at the end of the Pleistocene, about 20 ky ago. But cosmogenic <sup>36</sup>Cl dating [see [METHODS](#)] of boulders [see [photographs](#)] from tops of these moraines [see [map](#)] has yielded surprising results: all moraines, from the most extensive to the least, have early Holocene ages, ranging from 9.3 ± 0.4 ky (calendar years) for the lowest moraine in the valley, to 8.3 ± 0.3 ky for the plateau moraine [see [table](#)]. The positions of the moraines indicate a decrease of the ELA by up to 1 km and the corresponding decrease of temperature, assuming no changes in the rate and seasonality of precipitation, by up to 7°C [see [table](#)]. This result is important and surprising because: (1) the moraines have similar ages, but different DELAs, which indicates a fast climate change; (2) these DELAs are typical of the LGM, which indicates a remarkably big climate change; and (3) all moraines have early Holocene ages, which suggests that the contemporary glacial climate was as severe as that of the LGM elsewhere. These findings prompt an important question: Is this an isolated occurrence or a regional pattern? An isolated occurrence could be explained by anomalous local climatic or glaciological conditions. But ubiquitous extensive and young glacial deposits would imply that the early Holocene regional climate was much more severe than previously thought. And our results may have important implications for the study of human evolution in this 'cradle of civilization'. An extensive early-Holocene glaciation implies that paleoclimate might have played an important role in the evolution of early human civilizations. The deglaciation ages reported here coincide broadly with the transition from nomadic to settled life style, with the spread of agriculture, and with the dispersal of early Indo-European languages.

Elevation (m)	<sup>36</sup> Cl age (ky)	DELA (m)	DT (°C)
3080	8.3 ± 0.3	---	---
2580	8.6 ± 1.8	510	3.3
2310	8.6 ± 0.8	610	4.0
1920	9.1 ± 0.3	---	---
1745	8.9 ± 0.3	900	5.8
1636	9.0 ± 0.5	950	6.2
1510	9.3 ± 0.4	1060	6.9
ca. 1200	not dated	1190	7.7

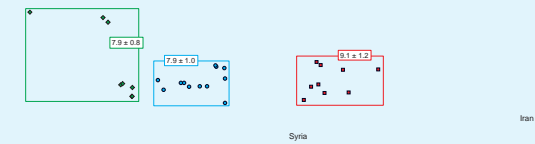
## GEOGRAPHIC SETTING

Nearly continuous mountains of Turkey and Iran separate the low lying areas of Syria and Iraq in the south from Anatolia and Persia in the west, north and east (see [digital image](#) on the right). The combination of high elevations, low temperatures and moisture from the Mediterranean Sea created conditions suitable for extensive glaciers throughout the mountainous region. We studied glacial deposits at locations marked with red dots. Here, we report ages of glacial deposits from Aladaglar (see [digital image](#) on the far right and [map](#) below), where numerous moraines contain excellent material for cosmogenic dating (examples are shown in [photographs](#) below).



## HYPOTHESIS

Glaciation of the Aladaglar was contemporary with the Neolithic Revolution - the transition from nomadic to settled life style and from hunting-gathering to agriculture. These early communities were vulnerable to climatic extremes, especially droughts and floods, which have been proposed as the main factors that slowed development. We propose that glaciation might have played a more direct role in human migration, by blocking passages through mountains. Our calculations show Early Holocene ELAs at ~2500 m and ice margins as low as ~1500 m in Aladaglar ([image](#) on the right). Similarly low glacial limits elsewhere ([map](#) below) could separate the cradle of civilization (Iraq, Syria) from the areas to the west, north and east, thus slowing human dispersion. Radiocarbon dating of archeological sites (boxed areas in [map](#) below) show that sedentary life style and agriculture crossed the Turkish mountains between 9 ky and 8 ky ago, at the same time when glaciers disappeared from Aladaglar. Continuing work in other recently glaciated areas (red dots in the second [image](#) to the left) will test the hypothesis of a connection between glaciation and human development.



Areas with potential for glaciers during Early Holocene time, calculated by extrapolating the results from Aladaglar. Dark blue - calculated ELA at the surface (roughly equivalent to zero July isotherm); light blue - extrapolated potential ice margin elevation (probably overestimated; better calculations are in progress). Boxes are basal dates from archeological sites (data from L. Thissen, 2004, CANeW 14C databases and 14C charts, Anatolia, 10,000 - 5000 cal BC).

## METHODS

Samples were collected from top surfaces of boulders and bedrock. They were cleaned and ground, and size fraction 0.25-1.00 mm was leached overnight in deionized water, and dried. Samples were dissolved in nitric acid in the presence of <sup>35</sup>Cl-enriched carrier in a high-pressure bomb. AgCl was precipitated and purified of sulfur. The ratios <sup>36</sup>Cl/Cl and <sup>35</sup>Cl/<sup>37</sup>Cl were determined on AgCl targets by accelerator mass spectrometry. Aliquots of rocks were powdered and analyzed for major and trace elements by a combination of X-ray fluorescence spectrometry, inductively coupled plasma mass spectrometry, and neutron activation analysis. Total Cl was calculated from the <sup>35</sup>Cl/<sup>37</sup>Cl values.

Cosmogenic <sup>36</sup>Cl surface exposure ages were calculated using a new approach that is being implemented in the ICRONUS software (Zreda et al., 2005, ICRONUS meets CRONUS-Earth: Improved calculations for cosmogenic dating methods-from neutron intensity to previously ignored correction factors, Goldschmidt Conference, Moscow, Idaho, May 2005), with the following production rates: 75.4±3.7 atoms <sup>36</sup>Cl (g Ca)<sup>-1</sup> yr<sup>-1</sup>, 155±12 atoms <sup>36</sup>Cl (g K)<sup>-1</sup> yr<sup>-1</sup>, and 664±39 neutrons (g air)<sup>-1</sup> yr<sup>-1</sup>. These standard production rates are normalized to sea level, high latitudes and modern magnetic field, and include corrections for local environmental factors (topographic shielding, snow cover, tectonic and neotectonic movement, climatic factors, and any other factors that affect local cosmic-ray intensity). Production rates at sample sites were calculated using these standard production rates modified by the corrections appropriate at the sample sites. Uncertainties of the <sup>36</sup>Cl ages, a combination of analytical errors and systematic errors associated with production rate calculations, are estimated to be less than ten percent.