Extent, timing and palaeoclimatic significance of Late Pleistocene and Holocene glaciation in the High Atlas, Morocco

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LATE PLEISTOCENE GLACIERS

INTRODUCTION:
The Atlas Mountains, Morocco (31.1°N, 7.9°W, Fig 1), display extensive and multiple late Pleistocene glaciations. Their extent is significantly larger than that recognised by previous workers. Glacial geomorphological mapping coupled with ¹⁰⁷Be cosmogenic exposure ages of ~20 erratics from 3 valley systems in the highest peaks of the Atlas Mountains, provide new insights on the history and evolution of the largest desert region on Earth.

RESULTS:
The largest ice field and valley glaciers formed in the Toubkal massif (yellow circle, Fig 2). The regions studied are outlet glacial valleys of Mt.Akousal (3912 m) (Fig 3) and northern slopes of Adrar Adj M't (3129 m) at Azib Mzik (Fig 4). Three distinct phases of glacial advances are evident within the Last Glacial Cycle.

1. Pre-LGM: the oldest moraines occur at the lowest elevations (~2300 m) with 5 ¹⁰⁷Be erratics giving ages ~30 to 88 ka (1 outlier)
2. LGM: moraines at intermediate elevations (~2500 m) with 5 ages peaked from 10.1 to 88 ka (~22-20 ka) and Termination-1.75
3. Late Younger Dryas: youngest and most elevated moraines (~2900 m) with 5 ages peaked from 10.1 to 11.9 ka. Typical sequence (Fig 3) varies in elevation range due to strong local topo-climatic controls.

DISCUSSION:
The glacial record of the High Atlas reflects moisture supply to the north-western Sahara Desert indicating shifts between arid and pluvial conditions. The low ELA moraines elevations of 2000-2500 m for the MIS 2-4 glacial advances indicates significantly cooler and wetter climates than today. The new evidence on glacial timing and ELAs in the High Atlas has major implications for moisture transfer between North Atlantic depressions and the West African Monsoon during Pleistocene cold stages. This in turn has important bearing on the strengths of meridional vs. zonal circulation at mid-latitudes during glacial phases.

HOLOCENE GLACIERS & ROCK-SLOPE FAILURE

INTRODUCTION:
To the west of Mt Akousal and its Pleistocene glacial record near the village of Armoud, geomorphic mapping of n’Imserdane valley has identified massive landslide debris intermixed with glacial moraine ridges. The slope derived rock avalanche debris consists of two lobes – unit A at lower valley elevations (~2100 m) underlying Armoud village (~1700 m), and a smaller cross valley lobe, unit-B, at ~2300-2400 m. Three apparent glacial units are defined: #1 on the northern flank, #2, adjacent to avalanche unit-B and #3 at ~2900 above avalanche unit-B (Figs 5 & 6).

RESULTS:
Within the analytical age errors per sample (~0.1 to 0.4 ka) and inherent geologic variability per unit, timing of rock wall collapse and glacial advances are coeval. All 7 of 9 moraine boulder ages and 6 avalanche ages peak between 3.1 to 4.5 ka.

DISCUSSION:
Glacial units (#1,2,3) show distinct moraine morphology. Moraine ages, ~4 ka, appear to be unequivocally mid-late Holocene. However to date, Holocene moraines ages are not observed elsewhere in Toubkal. Absence of Pleistocene age on glacial units may be the result of their modification and/or destruction by repetitive rock-wall failure events from over-steepened flanks following major glacial retreat (10-20 ka). The most recent avalanche, ~4 ka, is likely due to seismic activity (Tizi n’Test fault, 1 km distant and a major fault of Toubkal Massif). Either rockfall events have altered all the glacial record, or specific local parameters enable preservation of Holocene glaciers. The relationship between avalanches and moraine assemblages is complex and the subject of ongoing research.