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

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 ^{10}Be 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.

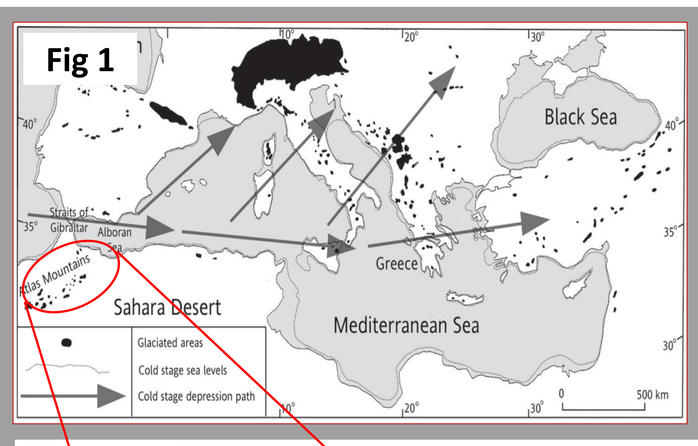
RESULTS:

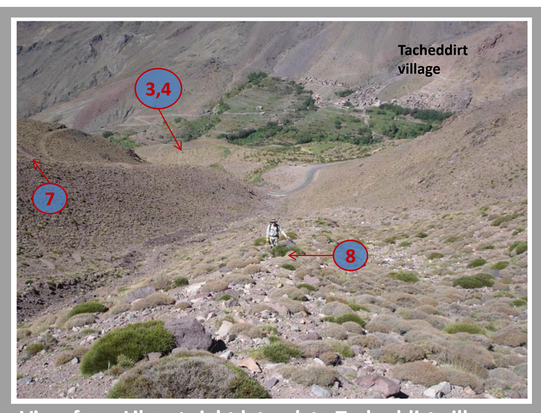
The largest ice field and valley glaciers formed in the Toubkal massif (**yellow circle** Fig 2). The regions studied are outlet glacial valleys of **Mt Aksoual (3912 m) (Fig 3)** and northern slopes of Adrar Adj Mt (3129 m) at **Azib Mzik (Fig 4)**. Three distinct phases of glacial advances are evident within the Last Glacial Cycle.

1.Pre-LGM: the oldest moraines occur at the lowest elevations (~2300 m) with 5 ^{10}Be erratics giving ages ~ 30 to 88 ka (1 outlier)

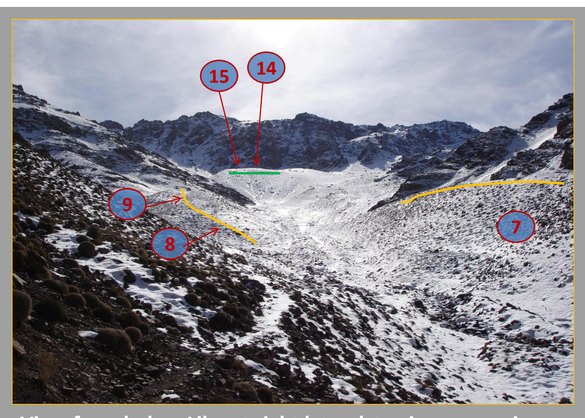
2.LGM: moraines at intermediate elevations (~2500m) with 5 ages ~15.5 to 24.0 ka (2 outliers) associated to the global LGM (~ 22-20 ka) and Termination-1.

3.Late Younger Dryas: youngest and most elevated moraines (~2900m) with 5 ages peaked from 10.1 to 11.9 ka. Typical sequence (Fig3) varies in elevation range due to strong local topo-climatic controls.

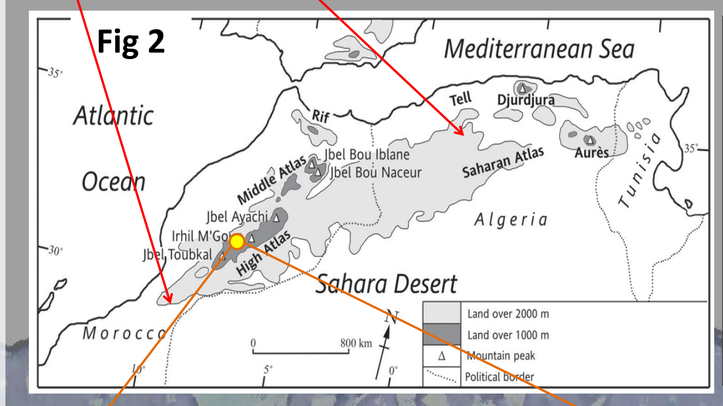




View from Likemt right lateral to Tacheddirt village.

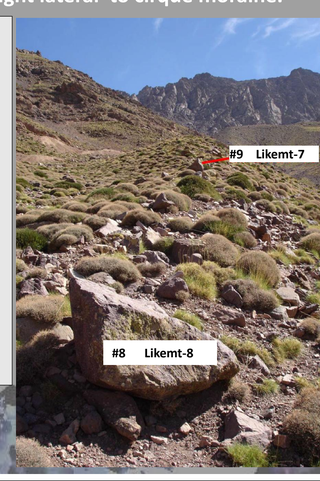


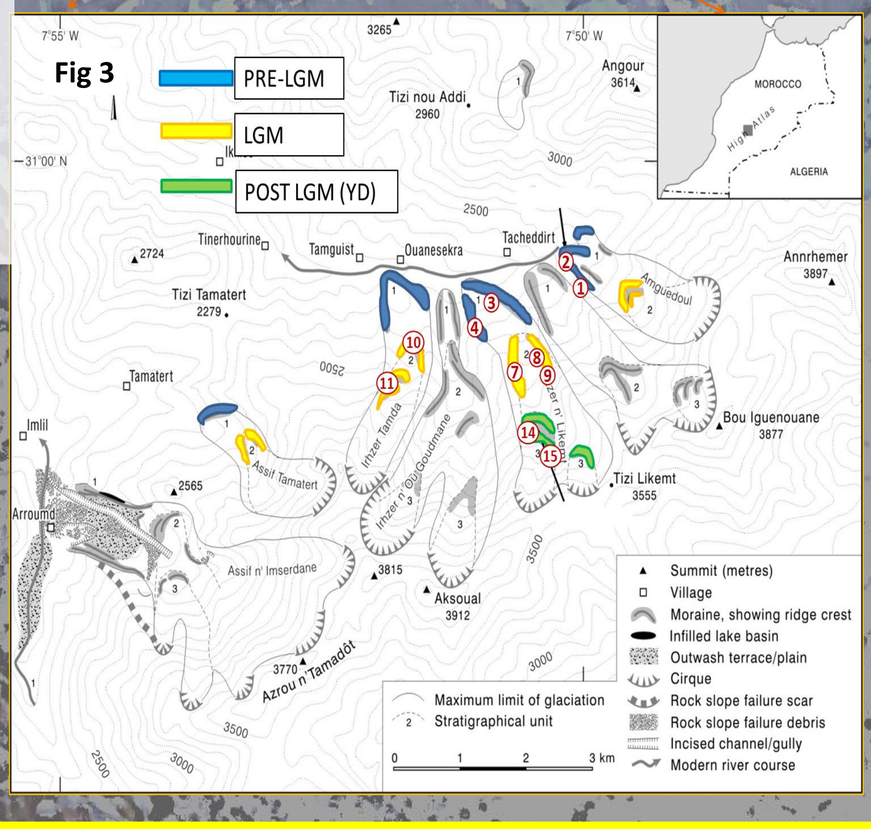
View from below Likemt right lateral to cirque moraine.

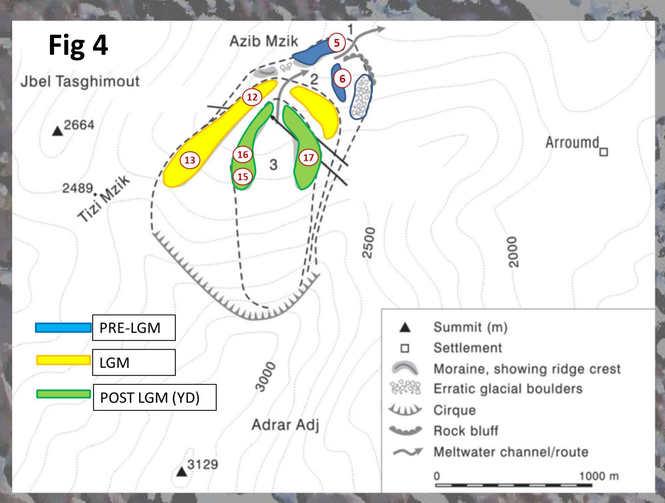


DISCUSSION:

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 moraine 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 pluvial phases.







SAMPLE #	SAMPLE NAME	VALLEY	10Be conc (atoms/g-Q) x 1E6	10Be error	% ERR	ALT (m)	LAT (deg)	shldg	Min exposure age (ka)	Error analytical (ka)	Error total (ka)	AMS LAB
Glacial Unit 3		**pre-LGM**										
1	AMEG-1	Ameguedoul	(36Cl)						87.3		9.1	SUERC
2	AMEG-2	Ameguedoul	1.91	0.056	2.9%	2480	31.16	0.961	88.1	2.7	8.3	SUERC
3	LIKEMT-9	Irhzer Likemt	0.561	0.019	3.3%	2309	31.15	0.950	28.2	0.9	2.7	ANSTO
4	LIKEMT-10	Irhzer Likemt	0.202	0.009	4.5%	2274	31.15	0.945	*10.4*	*0.5*	*1.0*	ANSTO
5	AM-2	Azib Mzik	0.796	0.029	3.6%	2063	31.13	0.942	48.3	1.8	4.6	SUERC
6	AM-3	Azib Mzik	0.552	0.019	3.5%	2063	31.13	0.884	35.5	1.3	3.4	SUERC
Glacial Unit 2		**LGM**										
7	LIKEMT-5	Irhzer Likemt	0.147	0.005	3.3%	2553	31.14	0.961	*6.3*	*0.2*	*0.6*	ANSTO
8	LIKEMT-7	Irhzer Likemt	0.114	0.008	7.4%	2583	31.14	0.937	*4.8*	*0.4*	*0.5*	ANSTO
9	LIKEMT-8	Irhzer Likemt	0.481	0.018	3.7%	2576	31.14	0.937	21.6	0.8	1.9	ANSTO
10	TAM-2	Irhzer Tamda	0.237	0.008	3.3%	2154	31.15	0.821	15.5	0.5	1.5	SUERC
11	TAM-4	Irhzer Tamda	(36Cl)						16.5		1.8	SUERC
12	AM-7	Azib Mzik	0.435	0.015	3.5%	2125	31.13	0.965	24.0	0.9	2.3	SUERC
13	AM-10	Azib Mzik	0.241	0.006	2.7%	2122	31.13	0.711	19.6	0.5	1.3	ANSTO
Glacial Unit 1		**YD**										
14	LIKEMT-1	Irhzer Likemt	0.352	0.019	5.3%	2940	31.14	0.976	11.7	0.6	1.2	SUERC
15	LIKEMT-2	Irhzer Likemt	0.347	0.013	3.7%	2940	31.14	0.976	11.9	0.5	1.1	ANSTO
16	AM-4	Azib Mzik	0.155	0.008	4.8%	2023	31.13	0.913	10.5	0.5	1.0	SUERC
17	AM-8	Azib Mzik	0.173	0.007	3.8%	2129	31.13	0.941	10.1	0.4	1.0	SUERC
18	AM-9	Azib Mzik	0.192	0.009	4.4%	2079	31.13	0.933	11.5	0.5	1.1	SUERC

Samples were processed and measured at SUERC and ANSTO. All ^{10}Be exposure ages based on ^{10}Be/^{9}Be ratios normalised to NIST-SRM-4325 with ^{10}Be/Be = 27, 900x10^{-15} and a production rate of 4.60 at/g/y using Stone scaling.

HOLOCENE GLACIERS & ROCK- SLOPE FAILURE

INTRODUCTION:

To the west of Mt Akousal and its Pleistocene glacial record near the village of Arrmoud, 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) underlying Arrmoud village (~1700), 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 ~2500 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.

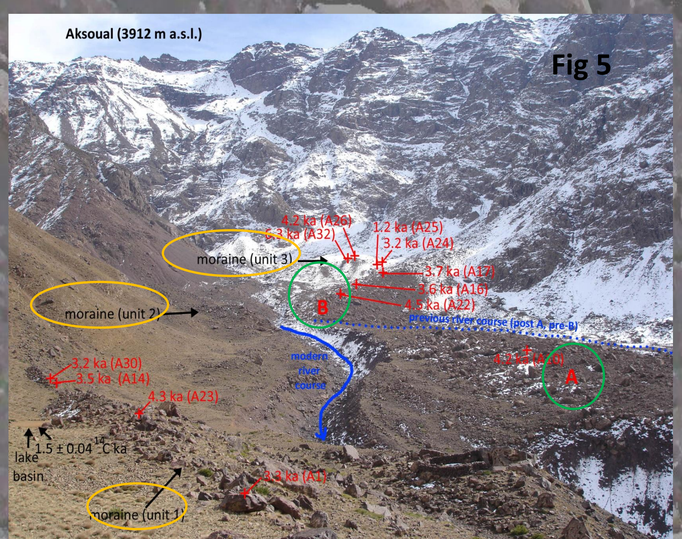
Arrmoud Glacial Unit #3 (youngest?) - sample A25

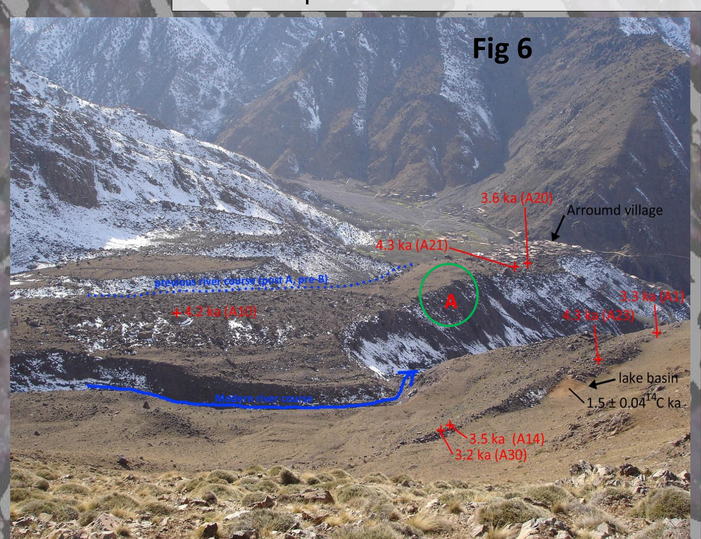
Arrmound Glacial Unit #1 3.1 to 4.3 ka

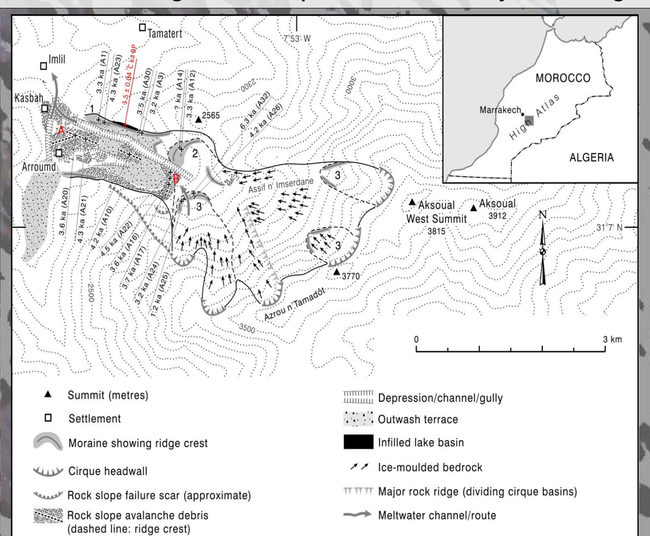
SAMPLE #	10Be conc (atoms/g-Q)x(1E6)	10Be error	% error	ALT (m)	LAT (deg)	shldg	Min exposure age (ka)	Error analytical (ka)	Error total (ka)	AMS LAB
ROCK AVALANCHE A										
A10	0.076	0.004	5.9	2167	31.13	0.974	4.2	0.2	0.4	ANSTO
A20	0.062	0.004	5.7	2071	31.13	0.980	3.6	0.2	0.4	ANSTO
A21	0.073	0.004	5.1	2070	31.13	0.980	4.3	0.2	0.4	ANSTO
ROCK AVALANCHE B										
A16	0.068	0.003	3.7	2222	31.12	0.951	3.6	0.1	0.3	ANSTO
A17	0.072	0.003	4.1	2260	31.12	0.950	3.7	0.2	0.4	ANSTO
A22	0.084	0.003	4.1	2217	31.12	0.951	4.5	0.2	0.4	ANSTO
GLACIAL UNIT 1										
A1	0.055	0.003	6.1	2125	31.12	0.973	3.3	0.2	0.3	SUERC
A3	0.051	0.006	11.7	2133	31.12	0.928	3.1	0.4	0.5	SUERC
A23	0.077	0.005	6.2	2125	31.12	0.969	4.3	0.3	0.5	ANSTO
A30	0.063	0.010	15.8	2135	31.13	0.928	3.5	0.6	0.6	ANSTO
GLACIAL UNIT 2										
A12	(36Cl)						3.3		0.5	SUERC
GLACIAL UNIT 3										
A24	0.066	0.002	3.7	2354	31.12	0.925	3.2	0.1	0.3	ANSTO
A25	0.026	0.001	5.2	2368	31.12	0.925	1.2	0.1	0.1	ANSTO
A26	0.086	0.004	5.1	2356	31.12	0.925	4.2	0.2	0.4	ANSTO
A32	0.128	0.006	4.7	2350	31.12	0.925	6.3	0.3	0.6	ANSTO

DISCUSSION:

Glacial units (#1,2,3) show distinct moraine morphology. Moraine ages, ~ 4ka, *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 (10-20ka). 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 rock-fall 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.







Avalanche (rock slope failure) debris lobe above Arrmoud village (samples A20 & A21)