ALLUVIAL FANS AS RECORDERS OF AFRICAN HUMID PERIOD FLOOD HYDROLOGY

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Alluvial fans are cone-shaped depositional landforms that commonly build along mountain fronts, valley sides or at tributary junction settings in uplands or along the margins of uplands. Their sedimentology and geomorphology provide important archives of long-term Quaternary landscape development driven by interplay between tectonics, climate, and rock strength controls. Within this study, we explore the use of alluvial fans as important but overlooked recorders of long-term climate-related Quaternary fluvial landscape development, an issue first highlighted to the FLAG community by Mather et al [1].

Within an alluvial fan, as part of the broader fluvial system, climate controls 1) weathering and erosion processes, influencing sediment supply to the fan, and 2) flood hydrology to and within the fan, driving sediment transport and deposition. Past changes in flood hydrology (palaeohydrology) can be derived from the sedimentology (size and flow depth) and geomorphology (surface slope and channel cross-sectional area) of dated deposits, an approach often applied to river terrace sequences [2]. However, river terraces typically reflect long temporal and large spatial scale integration of palaeofloods and their fluvial sediment. In contrast, alluvial fans offer a more localized, almost in situ, hydrological perspective of climate-related precipitation and flood discharge due to small transport distances over shorter temporal scales. Despite the climate-landscape response insight offered by alluvial fans, palaeohydrological perspectives and their climate relationship are lacking from Quaternary alluvial fan (fluvial) archive research.

In this study, we explore the application of palaeohydrological analysis to a large alluvial fan that has built along the flanks of a volcanic island, Santo Antao. This is the most north westerly positioned island of the Cape Verde archipelago (east-central Atlantic Ocean), some 850 km offshore West Africa. The study location is excellent for alluvial fan palaeohydrological analysis. 1) The island is tectonically quiescent during the Upper Quaternary (stationary oceanic plate setting and marine terrace evidence), meaning fan building is unaffected by uplift. 2) The volcanic island setting provides a clear and simple geological framework for the fan catchment (dipping layered lava flows, cross-cut by dykes) and its depositional area (volcano flank, akin to a mountain front setting). The volcanic bedrock and some minor volcanic events during the Upper Quaternary provide chronological insight into fan building (i.e. dated and spatially extensive volcanic markers and dateable fan material). 3) The coastal setting of the fan means that well constrained eustatic base-level variation is a key control on fan building space, driving fan progradation (falling sea level and lowstands) and shortening / incision (rising sea level and highstands) in concert with global climate changes. 4) The fan has built under a dryland climatic setting, with Cape Verde considered an offshore extension of the Sahara Desert. The dry climate means an easily observable landscape devoid of vegetation, with excellent preservation of fan depositional lobes and their fluvial bar form and channel networks. The Cape Verde location (offshore west Africa) and the Quaternary context of the Sahara Desert is especially interesting since the Quaternary African climate is strongly influenced by precession-related climate changes called 'African Humid Periods' (AHPs). AHP events are driven by wobbling of the Earth's axial spin, which alters atmospheric circulation patterns every ~20 ka, repeatedly bringing elevated hydrological conditions (~5ka duration) to low-mid latitudes of continental Africa, and offshore areas such as Cape Verde.

The study fan (Fig. 1) is located on the SW flank of Santo Antão Island. The fan is ~6 km long with an area of ~11 km^2, fed by a main catchment with an area of ~28 km^2 and relief of 1300 m. A modern active fan lobe occupies a small portion of the distal coastal area of the fan (0.4 km^2), activated annually during late summer / early autumn storms. This active lobe is fed by a deeply incised channel that cuts down through an expansive abandoned relict fan surface. In proximal fan areas the channel is incised by up to 120 m below the surface, forming a narrow (10's of meters wide) slot canyon. Incision decreases to around 10 m in distal fan areas with the canyon widening to several hundreds of meters into distal fan areas. Along the coast, a 10 m high coastal cliff is being cut into the distal most part of the fan. Small streams originating from the coastal cliff cut back into distal and mid parts of the fan as a series deep and narrow at a scale of meters to 10's of meters. The deeply incised channels reveal a fan sediment sequence of up to 100 m thick. Contacts with basalt basement bedrock are only observed in proximal fan areas. A lava flow (not dated) and a 200 ka Ar-Ar dated tephra unit are interbedded with the fan sediments and can be observed across proximal-mid-distal fan settings in various locations. In the most proximal fan areas the fan surface is mantled with a 100 ka tephra.

Fig. 1. Oblique drone imagery of A) relict fan surface, noting fluvial bars and channels and B) modern active lobe with recent flow evidence.

The fan surface forms the focus of our palaeohydrological investigations. The surface appears to comprise a single level, lacking in any altitudinally separated surface levels often observed on alluvial fans subject to base-level changes (e.g. tectonics). This surface comprises a network of low relief (<3.5 m) distributive cobble-boulder fluvial bars and channels. Mapping of the channels using satellite imagery reveals that the surface forms 3 lobes, a proximal lobe and two adjacent mid-distal fan lobes. Field survey along transects across the fan surface confirms the separate lobes with lobate convex surface forms being enhanced by deep channel / stream incision in the topographic lows around the separate lobe margins. Preliminary ^{3}He cosmogenic exposure dating of bar form boulders sampled in different locations across the fan surface suggests lobes are associated with different AHP periods. The proximal lobe appears to have formed between 10-20 ka (AHP1), with the mid-distal fan lobes forming between 50-60 ka (AHP 2) and 80-90 ka (AHP3). This is chronology and AHP climate association is currently being refined with additional sampling and dating.

For palaeohydrological analysis we use a competence based palaeoflood discharge quantification approach developed by Clarke [3] called the ‘maximum boulder size’ method. The approach calculates the minimum force needed to move a boulder. It requires field and remote sensing data inputs: triaxial boulder dimensions; relict flow width, slope, and roughness; and the lithology (density) of the clasts. Force is partly a function of the channel slope. To apply the method, we selected a range of proximal-distal fan surface locations, most of which coincide with our ^{3}He sampling sites and incorporate the x3 AHP-related lobes. At each location, we used a drone to image a 200x200 m area from which we used Agisoft/Metashape structure from motion software to build a 3D digital surface model (Fig. 2A). This mapping provided a high-resolution topography from which we could obtain multiple slope and width measurements from different channel and barform morphologies for palaeohydrological modelling data inputs. Within the drone surveyed areas we collected clast size data, measuring the a, b, c axes of the 10 visibly largest boulders across a given unit barform (Fig. 2B). Boulders were all basalt lithologies, so we used an average density value of 2.9 g/cm^3. We also hand surveyed the area for field-based slope and width measurements.

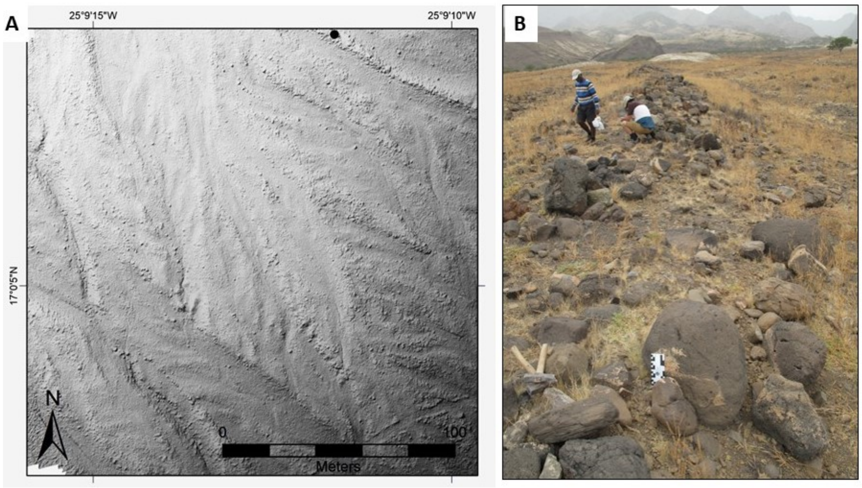

Fig. 2. A) Drone surveyed surface example. B) Boulder measurements from bar form.

Within our presentation we will discuss 1) the challenges of applying competence palaehydrological analysis to alluvial fan settings and 2) make some preliminary interpretation and discussion points concerning the palaeoflood discharge results and their relevance to wider AHP hydrological understanding and research.

REFERENCES

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