British Society for Geomorphology (BSG) 2013 Grant Report 21st February 2014

Name: Mitch D'Arcy

Institution: Imperial College London, United Kingdom

Project: Alluvial fans as sensitive recorders of climate change in eastern California, USA

Amount received: £972.00

1. Summary

I proposed a 3-week field campaign to the Owens Valley and Death Valley areas of eastern California, to investigate how mountain catchment-alluvial fan systems record information about past glacial-interglacial climate changes in sediment flux, grain size distribution, depositional length, and other sedimentological measurements. In addition to financial support from the BSG, I was also fortunate enough to receive funding from the Geological Society of London with any additional costs covered by my PhD supervisor's Royal Society funds. Therefore I was able to proceed with the field campaign to California earlier than originally planned, returning in December 2013, in order to benefit from the better weather and earlier collection of data. I was also able to extend the field campaign to 26 days in total, compared to the 18 days originally planned, which allowed me to visit more locations and collect significantly more data.

My proposal was to study the grain size trends preserved in alluvial fans in both Owens and Death Valleys, and the extent to which their stratigraphy and sedimentology recorded climate and climate change. I also planned to explore the sediment sources and processes in the parent catchments that may determine climatic sensitivity. I was successful in my field objectives, and was pleased to study 11 alluvial fan systems in total, including 381 study locations during this trip.

In Death Valley, my initial proposal was to study the Indian Creek and Hanaupah Canyon alluvial fan systems of Death Valley. I measured the Indian Creek alluvial fan as planned, collecting detailed down-fan transects on two dated surfaces, with 72 sampling sites in total. The Hanaupah Canyon fan was inaccessible due to storm washouts, so I decided to study two alternative, well-dated alluvial fans accessible in northern Death Valley: the Big Dip and Red Wall fans, which I had planned as my reserve choices. Here I collected targeted sedimentological data from a further 88 localities (Fig. 1). As a result of the grant money I received I was able to extend the trip and measure an additional 8 well-dated alluvial fan systems in neighbouring Owens Valley as well, including detailed data collection about sediment sources in parent catchments with a variety of characteristics.

My analysis of the field data is still ongoing at this stage, however I have already established some very encouraging early findings, and this report describes my preliminary results.

2. Results

   a. Alluvial fan systems in Death Valley

I mapped and collected detailed sedimentological data on three alluvial fan systems in Death Valley; the Indian Creek, Big Dip, and Red Wall fans, which have been dated in detail using cosmogenic nuclides and radiocarbon techniques by others [*Frankel et al*., 2007a,b]. These fans are dominated by stream-flow depositional processes and all have well-exposed late Pleistocene surfaces (~70 ka in age, representing the glacial climate) and Holocene surfaces (representing interglacial conditions), allowing a comparison to be made between fan processes under different climatic conditions. I collected grain size and sedimentological measurements at 160 localities in total, providing detailed down-fan transects along glacial and interglacial surfaces on each fan (Fig. 1A). I am still processing the field data at this early stage, however I do now have an excellent data set with which I will perform one of the first detailed, empirical tests of theoretical hypotheses about catchment-fan system sensitivity to climate change, over the coming months. In the field, I observed significant and encouraging differences between fan deposits from glacial and interglacial periods (Fig. 1B,C).

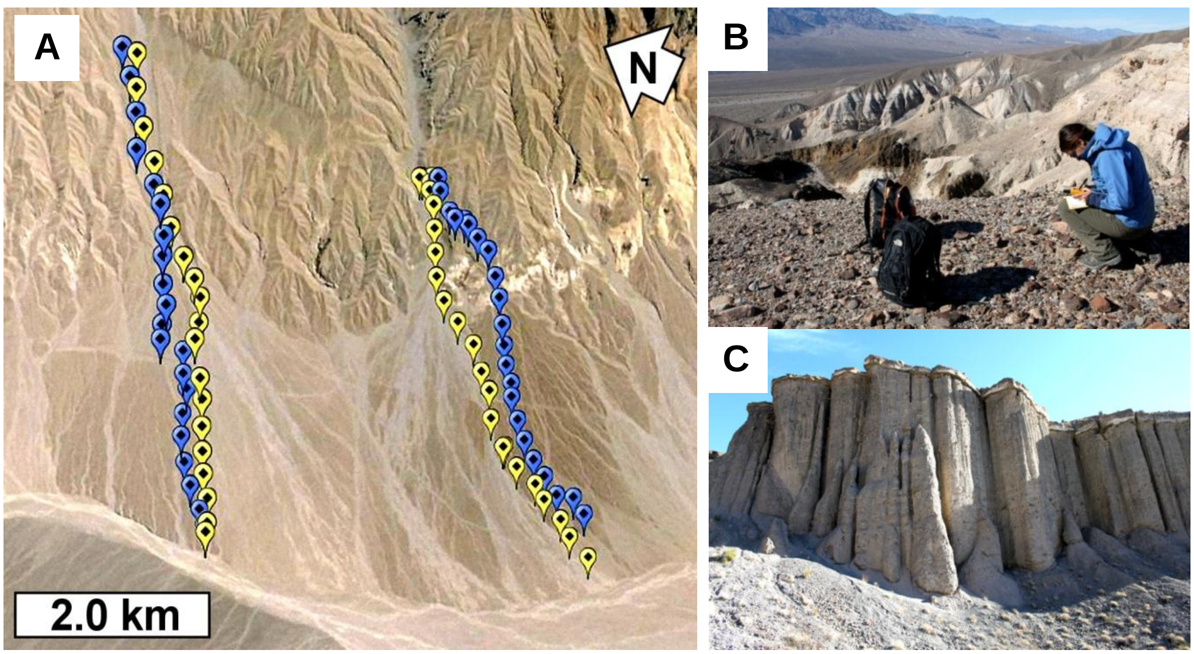

Fig. 1 (A) The Big Dip and Red Wall alluvial fans of northern Death Valley, California. My field localities are shown as placemarks (yellow = Holocene deposits; blue = ~70 ka late Pleistocene deposits); I have completed detailed down-fan transects with which I can now compare the sediment export and down-fan fining signals between interglacial and glacial surfaces. Landscape evolution models predict that this data may be sensitive to glacial-interglacial climate changes, which are well-constrained in the southwest USA. Below are field photographs from the Red Wall fan. (B) The well dated late Pleistocene fan surface (foreground) and has been deeply incised by Holocene channels (background), indicating a large change in fan dynamics correlated with the Pleistocene-Holocene climatic transition. (C) Well exposed incised sections through the fan deposits allowed us to collect sedimentological data through the fan stratigraphy as well as across preserved surfaces. These sections have not been described or reported by others before and offer a unique 3D view of alluvial fan sediments in Death Valley.

b. Alluvial fan systems in Owens Valley

I was also able to extend the field campaign and study additional alluvial fan systems in neighbouring Owens Valley, California, along the frontal Sierra Nevada adjacent to the town of Independence. These alluvial fans have also been well-dated by previous workers using cosmogenic nuclides [*Zehfuss et al*., 2001; *Dühnforth et al*., 2007; *Le et al*., 2007]. They are much more debris flow dominated than the Death Valley fans, and so this larger data set allows me to compare the effects of climate change on fan systems with different sediment transport dynamics. I have measured the grain size, sediment flux and depositional morphology of debris flow deposits on alluvial fan surfaces with ages spanning back through the last glacial-interglacial cycle. Again, I am still in the process of typing up and analysing the data I collected in the field, however initial results show that these metrics are highly sensitive to past climate change. For example, Fig. 2 shows the temporal variation in mean d84 (upper quartile) grain size of sediment from debris flow channels on a number of fan surfaces. This is compared with the Devil's Hole terrestrial oxygen isotope record from southern Nevada [*Winograd et al*., 2006]. This data shows, for the first time, that the grain size distribution of debris flow deposits is highly correlated with palaeoclimate records in this area, over at least 10^{4-5} year timescales, becoming significantly coarser in the Holocene compared to the last glacial period. I have collected a range of targeted sediment supply data from the parent catchments, including input from lateral glacial moraines, landslides and hillslope scree. Next, I will use this data to investigate the origins of the observed grain size signals, and also their relationships with variables including catchment size and extent of past glaciation. My early findings also reveal that it is possible to invert the stratigraphic record of alluvial fans to extract a terrestrial palaeoclimate record, and they underscore the importance of further research into debris flow stratigraphy.

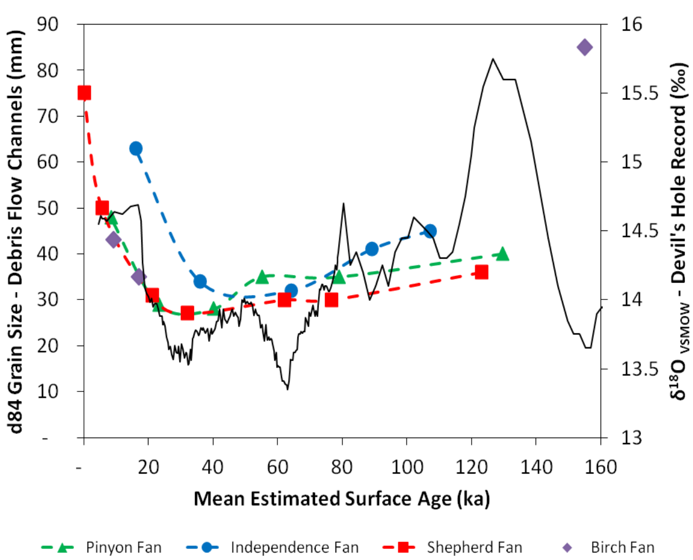

Figure 2. The temporal variation in mean d84 (upper quartile) grain size of sediment from debris flow channel deposits on four alluvial fans, Owens Valley, California. The Devil's Hole terrestrial oxygen isotope curve is also shown as a palaeoclimate record [*Winograd et al*., 2006]. Error bars have been omitted pending a complete uncertainty analysis. On these alluvial fans, grain size in debris flow deposits is highly correlated with past climate changes, in a similar way for unconnected catchment-fan systems. Once processed, our complete data set will include 8 catchment-fan systems from Owens Valley, with a variety of characteristics. For example, the Independence catchment was highly glaciated at the LGM, the Pinyon catchment was moderately glaciated and the Shepherd catchment was only very slightly glaciated. These differences may be expressed in the climatic signal preserved by debris flow grain size.

c. Alluvial fan chronostratigraphies

In addition to collecting data from more alluvial fans than originally planned, I also made an unexpected observation. I observed large weathering fractures dissecting surface boulders on the alluvial fan surfaces under investigation. I have been able to use the detailed surface age constraints available to calibrate the rate at which these fractures widen over time. As shown in Fig. 3, I have identified, for the first time, a strong and linear correlation between mean fracture width and the mean ages of the alluvial fan surface on which they are observed. This strong age dependency is a function of the long-term weathering rate at our field sites, and I am currently developing this as a new approach for estimating the exposure ages of sedimentary surfaces in arid landscapes. I have also been able to use this age relationship to build new chronostratigraphies for previously-undated alluvial fans in Owens Valley.

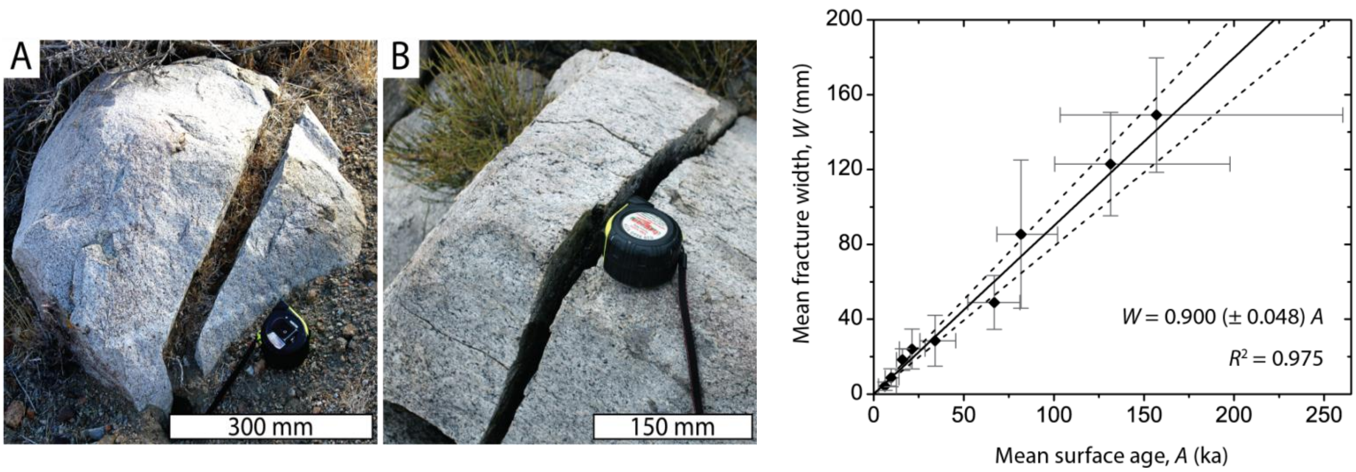

Figure 3. (A and B) Examples of vertical fractures dissecting granitic boulders on debris flow surfaces in Owens Valley. The fractures measured cut completely through the clasts and have planar, polished faces. (C) The relationship between surface exposure age and the mean widths of fractures observed on each surface. Error bars include the standard deviations of fracture widths and cosmogenic age estimates from each surface. These averages have been calculated from over 250 fracture measurements on surfaces with 66 ^{10}Be exposure age estimates between them, distributed across four alluvial fans. There is a strong, linear correlation, with fractures widening with age at a constant rate of approximately 0.9 mm ka^{-1}. This age dependency means that fracture widths can be exploited as a simple and effective method for dating debris flow surfaces in this study area.

3. Outcomes and Future Research Plans

Over the coming months I will continue to process my field data and analyse the results. I have a large data set from eastern California with which I can test current theoretical models, which predict that the sedimentology and grain size characteristics of alluvial fan surfaces may be sensitive to climatic change [e.g., *Allen et al*., 2013; *Armitage et al*., 2013]. My initial data (e.g., Fig. 2) show a clear climatic signal in grain size data from alluvial fans, and this has important implications for our understanding of landscape sensitivity to climate, as well as our interpretation of sedimentological field data and future design of landscape evolution models. I will also continue to develop my new approach to dating sedimentary surfaces in arid landscapes, by calibrating the rate at which weathering fractures develop on exposed surfaces. This has the further benefit of allowing me to report a number of detailed new chronostratigraphies for previously un-dated alluvial fan systems. I am therefore beginning to plan a number of geomorphological and stratigraphic papers arising from this field campaign, and have been accepted for 3 presentations at the coming EGU meeting. The financial support from the BSG has been instrumental in allowing me to collect this field data, and I hope that it will form part of a future submission to *Earth Surface Processes and Landforms*.

4. Use of BSG funds.

I requested a total of £972.00 from the BSG to help with the costs of car hire and petrol expenses, and motel accommodation for two people, during the field campaign. As I received an additional grant, I was able to extend the field trip to collect a stronger data set. This increased the costs of the field campaign compared to my initial estimates, so I have allocated the BSG grant of £972.00 to the costs of: (i) the initial car rental cost (£471.77 in total), all of the petrol expenses during the trip (US $686.60 in total, equivalent to £415.58), and with the remainder going towards the motel costs (which came to a total of £1,328.36). Copies of all receipts are attached. The remaining costs of the field campaign, including the motel costs not covered and other expenses, will be reimbursed by our additional grant money and my supervisor's personal research funds from the Royal Society.

5. References

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