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Experimental alluvial fans: Advances in understanding of fan dynamics and processes

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ABSTRACT

Alluvial fans are depositional systems that develop because of a disparity between the upstream and downstream sediment transport capacity of a system, usually at the base of mountain fronts as rivers emerge from the constrained mountain area onto the plain. They are dynamic landforms that are prone to abrupt changes on a geomorphological (decades to centuries) time scale, while also being long-term deposition features that preserve sedimentary strata and are sensitive indictors of environmental change. The complexity of interactions between catchment characteristics, climate, tectonics, internal system feedbacks, and environmental processes on field alluvial fans means that it is difficult to isolate individual variables in a field setting; therefore, the controlled conditions afforded by experimental models has provided a novel technique to overcome some of these complexities. The use of experimental models of alluvial fans has a long history and these have been implemented over a range of different research areas utilising various experimental designs. Using this technique, important advances have been made in determining the primary factors influencing fan slope, understanding of avulsion dynamics, identifying autogenic processes driving change on fan systems independent of any change in external conditions, and the mechanics of flow and flood risk on alluvial fans, to name a few. However, experiments cannot be carried out in isolation. Thus, combining the findings from experimental alluvial fans with field research and numerical modelling is important and, likewise, using these techniques to inform experimental design. If this can be achieved, there is potential for future experimental developments to explore key alluvial fan issues such as stratigraphic preservation potential and simulating extra terrestrial fan systems.

1. Introduction

Experimental models have been used in alluvial fan research for over 50 years, with experiments covering aspects of alluvial fan morphology and dynamics in areas such as flow process understanding, flood hazard simulation, sequence stratigraphy, and identifying autogenic signals. These have demonstrated a general experience that the tendencies observed in small-scale experimental fans are relevant to field-scale trends (Davies et al., 2003) and, more recently, have been used to parameterise and verify numerical models. The controlled conditions afforded by experiments allow isolation of individual variables and processes that would not be possible through field monitoring alone.

Alluvial fans are sedimentary deposits formed at the base of mountain fronts as rivers emerge out of the mountain range (Bull, 1977; Fig. 1) or at the river mouth where it flows into a large valley or water body. Spreading their loads in a radiating pattern from a single apex, alluvial fans form conical bodies typically with slightly concave long profiles and convex cross-profiles (Clevis et al., 2003). In fluvial systems, alluvial fans can act as important controls on sediment transfer, acting as an interface between the sediment production areas of the upland catchments and the transitory and depositional lowland regions. They therefore provide a valuable record of environmental change. Blair and McPherson (1994) classified alluvial fan styles based on process combinations; they surmised that alluvial fans can be divided into two main categories on the basis of their dominant primary processes and resultant mechanical behaviour: fluvially formed fans, composed from sediment moved by the force of water; and debris-flow fans, in which sediment is transported by gravity acting directly on the materials. Fluvial-formed fans tend to be larger with lower gradients, while debris-flow fans are smaller in size and steeper. This paper will specifically focus on experiments related to fluvial-formed fans.

Alluvial fans have a global distribution and form in a diverse range of climatic and tectonic regimes. In all climatic environments, alluvial fans represent critical sites of sediment routing in mountainous watersheds and may play an important buffering role in mountain geomorphic or sediment systems. They trap the bulk of the coarse sediment delivered from the mountain catchment, and therefore affect the sediment dynamics downstream, either in relation to distal fluvial systems or to sedimentary basin environments (Harvey, 2005). Alluvial fans represent small-scale coupled transport/depositional systems and therefore provide the ideal opportunity to explore the relationships between the dominant surface processes, sediment transport, and morphology. The constant reworking of alluvial fans at geomorphological time scales

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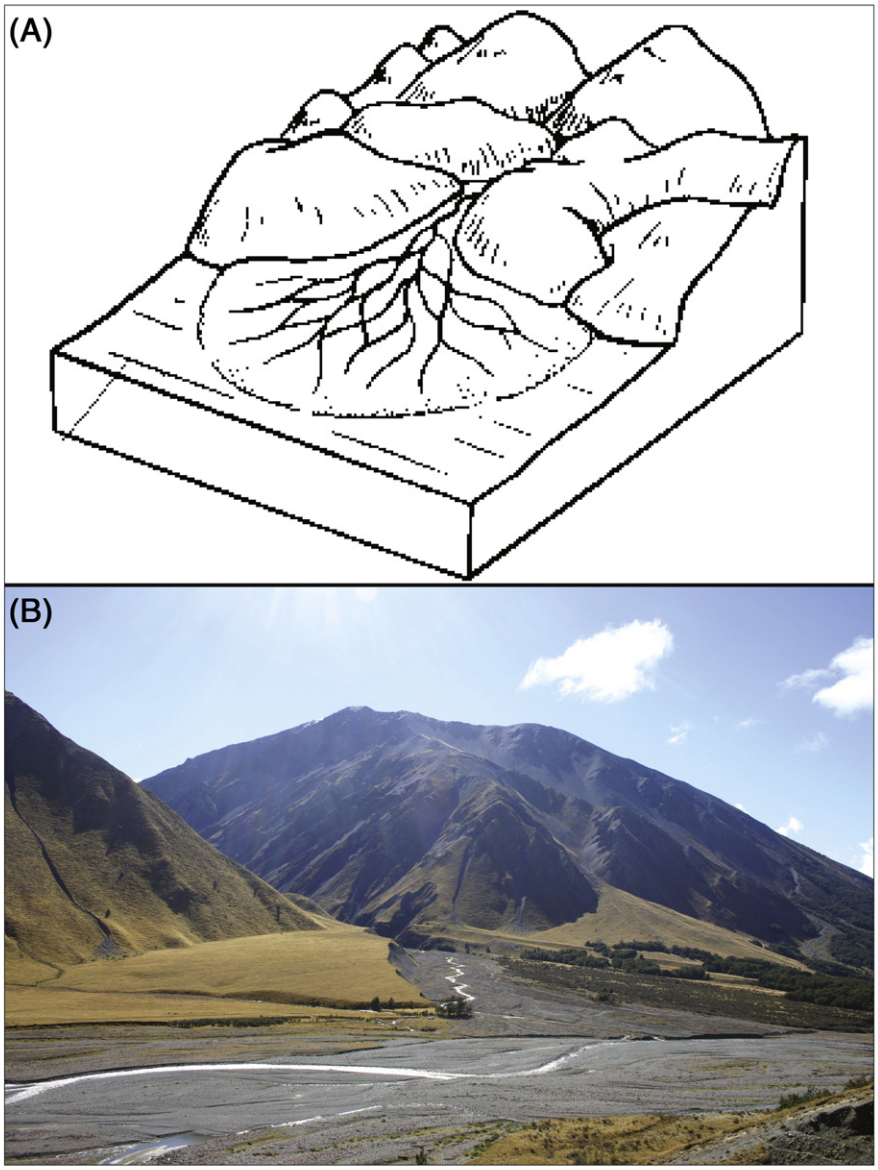

Fig. 1. (A) Conceptual diagram of an alluvial fan (after Rachocki, 1981); (B) Centre Creek, a fluvial-formed alluvial fan in the South Island of New Zealand (photo by L. Clarke).

(decades to centuries in duration) combined with the dynamic response of alluvial fans to changing input conditions and the resulting, often abrupt, change in flow conditions has led to investigation into the hazard posed by alluvial fans and attempting to predict flow paths for engineering purposes (e.g., FEMA, 2000, 2003).

Understanding alluvial fan response and evolution requires knowledge of the alluvial fan morphology, the processes operating on the fans, and how these alter in different spatial and temporal settings. These are dependent on allogenic (forces external to the fan system such as catchment characteristics, tectonics, climate, and base-level change) and autogenic (internally derived thresholds within the fan system) controls. A complex interaction of these forcing occur as an alluvial fan evolves and, the often chaotic preservation of stratigraphic sequences, makes it difficult to isolate individual impacts of one from the other in a field setting. The ability to control boundary and input conditions, as well as the ease of monitoring surface conditions and topography offered by experimental work, can provide an ideal solution. Despite the long history of research into alluvial fans it was not until the 1960s that this changed from a study of the landform itself to attempts to understand the significance of process-form relationships (Blissenbach, 1964; Bull, 1964, 1977; Denny, 1965, 1967; Hooke, 1967, 1968). From these early studies, the importance of using experimental modelling to isolate complex variables during alluvial fan evolution was emphasised, and it started a strong tradition of physical modelling in alluvial fan research. The aim of this paper is to review how experimental work has led to the development of theory and process understanding on alluvial fans, explore the variety of experiments that have been undertaken, and to assess how these findings have influenced field and numerical modelling studies, as well as think to the future of experimental work in alluvial fan research.

2. A history of experimental work on alluvial fans

2.1. The pioneers

Experimental studies of alluvial fans date back to the 1960s with the work of Roger Hooke (Hooke, 1967, 1968; Hooke and Rohrer, 1979). These early investigations examined fan morphology and explored the different mechanisms of sediment transport on the fan comparing fans created in a laboratory environment with examples from Death Valley, California. Although the findings from these experimental fans were compared to natural alluvial fans, they were not scale models