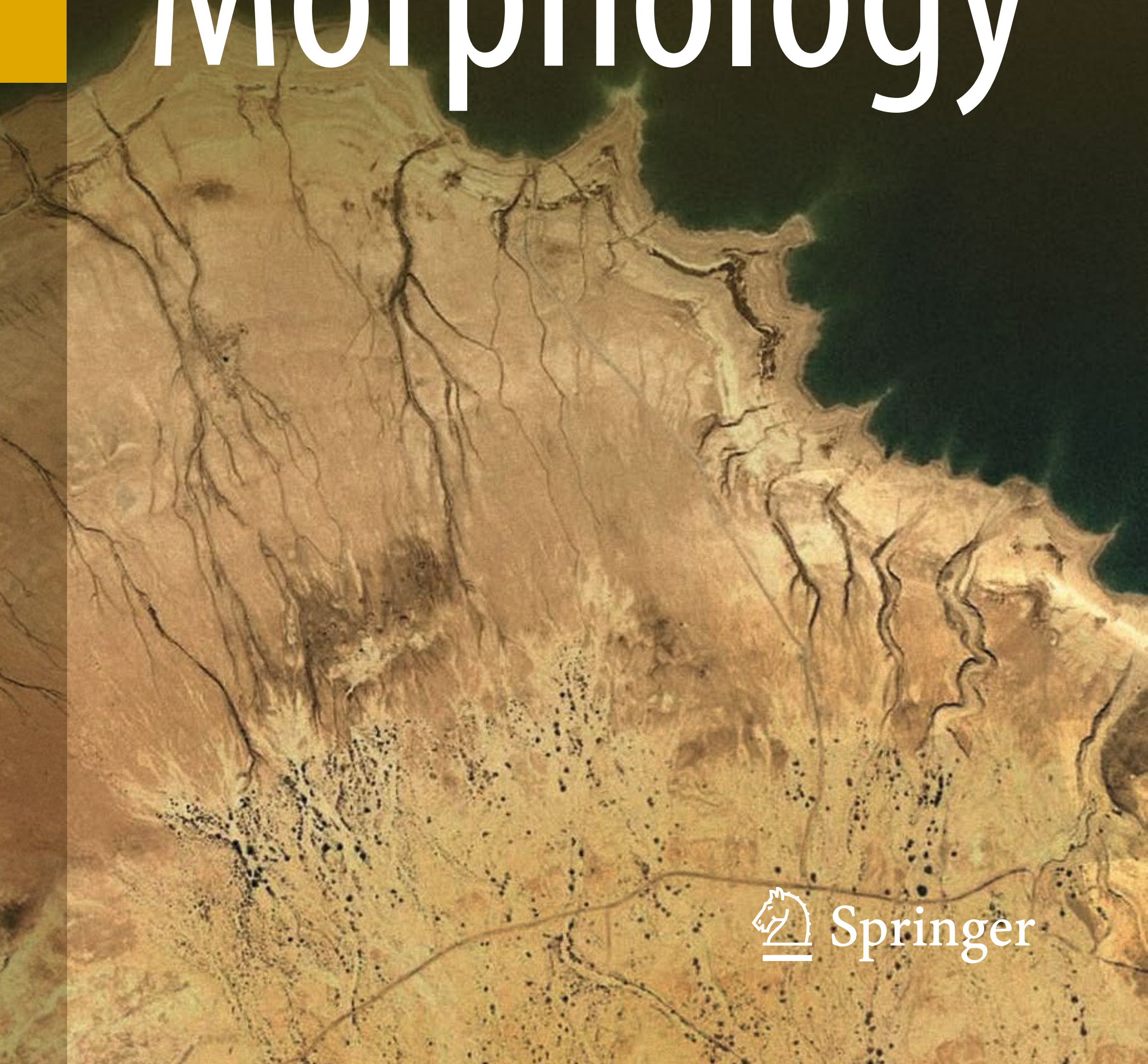
Dan Bowman

Principles of Alluvial Fan Morphology



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Front cover: Aerial view of the distal front of the Ze'elim alluvial fan, prograding toward the receding Dead Sea, the Rift Valley, Israel. The drainage pattern changes from diverging and aggrading at the alluvial fan front (lower part of photo) to a converging and entrenching dendritic system on the exposed coastal area (the upper part of photo). (Map data Google Earth, DigitalGlobe, CC BY-4.0)

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*This volume is devoted to my
mother Trude Schneider Bowman
and to my father Dr. Robert Schneider
from Eger (Cheb) Czechoslovakia,
who was killed by the British Navy
when entering Palestine on board of
the refugee vessel "Tiger Hill" and to
my stepfather Dr. Ernst Bowman, to whom
I owe my education. We were all escaping the
Nazi regime.*

Preface

Alluvial fans have been studied and restudied by many researches worldwide, amounting to an inventory of hundreds of publications and more, many of which have been studied while preparing this volume. The challenge was to bring together the knowledge dispersed widely in the literature, including regional case studies. The manifold aspects addressed in the present volume – morphology, processes, systems, ratios, rates, temporal aspects, controlling factors, and human impacts – should provide a useful basis for understanding alluvial fans. A selection of papers has been attached to each chapter for additional, more focused reading. The complex interdependence of the fan morphology and the mechanism of sediment transport and distribution along confined channelized flows or unconfined surfaces needs, for example, additional reading.

This volume is intended to serve students in earth sciences, engineers, and planners. Of significant help was my experience in lecturing the Alluvial Fan course at Ben-Gurion University of the Negev, Israel, including field trips to the Dead Sea rift with its multiple examples of alluvial fans in different stages of evolution.

Efforts have been made in the past to summarize various aspects of alluvial fans. This volume is an attempt to submit the principles of the great bulk of material in a textbook mode. The following are the main former reviews, summary papers, conference proceedings, and special volumes devoted to alluvial fans:

Blair TC, McPherson JG (1994) Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages. J Sediment Res 64A:450–489

Blair TC, McPherson JG (2009) Processes and forms of alluvial fans. In: Parsons AJ, Abrahams AD (eds) Geomorphology of desert environments, 2nd edn. Springer, New York, pp 413–467

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Ethridge, FG (1985) Modern alluvial fans and deltas in recognition of fluvial depositional systems and their resource potential. In: Flores RM, Ethridg FG, Miall AD, Galloway WE, Fouch TD (eds), SEPM short course. Tulsa, SEPM, 19, pp. 101–143

French RH (1987) Hydraulic processes on alluvial fans. Developments in Water Science 31, Elsevier, Amsterdam

Giles P, Nichols G, Wilford D (eds) (2010) Alluvial fans: from reconstructing past environments to identifying contemporary hazards. Geomorphology 115(3–4)

Harvey AM (2011) Drylands alluvial fans. In: Thomas DSG (ed) Arid Zone Geomorphology: process, form and change in drylands, 3rd edn. Wiley, Chichester, pp. 333–371

Harvey AM, Mather AE, Stokes M (2005) Alluvial fans: Morphology, Sedimentology, Dynamics. Geological Society, London, Special publications vol. 251, London

Nilsen TH (1985) Modern and ancient alluvial fan deposits. Benchmark papers in geology series, Van Nostrand Reinhold, New York, 372 p

Nilsen TH, Moore TE (1984) Bibliography of alluvial-fan deposits. Geo Books, Norwich

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Stock JD (2013) Waters divided: a history of alluvial fan research and a view of its future. In: Shroder JF, Wohl E (eds) Treatise on geomorphology, vol 9, fluvial geomorphology. Academic Press, Elsevier, San Diego

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Thanks to Ruth, my friend for life, who brought the desert morphology into our home by her aquarelle paintings which I, Michal, Ehud, and Tomer endlessly enjoyed.

I am grateful for the permissions granted to all the republished figures.

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Contents

Definitions and Setting

1

Abstract

The alluvial fan is a sediment storage in form of a prism by the mountain front, above a local base-level. Fans show in plan-view a triangular cone-shaped form, bridging in between highly erosive upland catchments and down-fan valleys. To form fans requires (a) an elevational difference and (b) a sharp change in the alluvial geometry when exiting the mountain front. Fan deltas are subaerial alluvial fans that prograde into a standing water body often as Gilbert-type fan deltas, recognizable by a tripartite internal geometry. Distinction should be made between mountain-front fans and tributary-junction fans.

Keywords

Playa · Fluvial geometry · Base-level · Triangular facet · Bajada · Apex · Fan embayment · Mid-fan · Toe · Pediment · Terminal fan · Accommodation space · Fan delta · Gilbert-type fan delta · Mountain-front fan · Tributary-junction fan

Drew created the term *alluvial fan* in 1873. The alluvial fan morphology bridges between the highly erosive upland catchments, where channels are confined and the sediment is produced and the down-fan basins or valley floors where channels can spread and the material is finally deposited. The classic alluvial fan type is a three-dimensional distributive stream deposit at the mountain feet, below a front escarpment (Fig. 1.1), piled up and stored on the way down to an ultimate sink. The initial condition for depositing alluvial fans requires *elevational differences* as between mountains and adjacent intermontane basins which operate as an *accommodation space* for sediment accumulation. A fault system may control the accommodation space and cause tilting and differential subsidence of the basin. Rise of a marine or a lacustrine base-level will likewise create an accommodation for alluvial sedimentation. Fans typically veneer mountain fronts of internally drained closed basins which are tectonic troughs, often with a salt terminal lake or with an extreme flat valley floor called *playa*.

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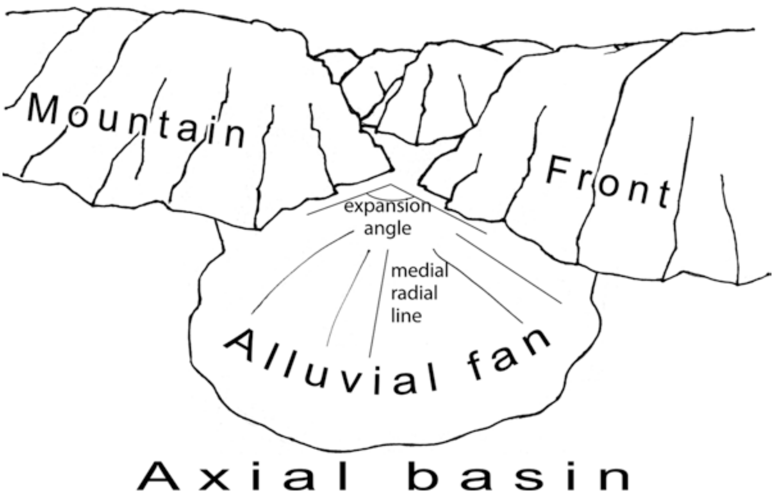

Fig. 1.1 An alluvial fan located at the feet of a mountain front

Each fan has its upstream *sourcing drainage basin* from which water and sediments are funneled through a confined mountain stream, whether perennial, intermittent, or ephemeral. From the point where the channel issues toward the valley, flows expand and become free to swing laterally, to braid and to form a distributive triangular network. Such branching systems are typically associated with environments of net deposition. The classical alluvial fan resembles a cone with an expansion angle, radiating downslope from a sharp termination of the mountainous relief, making a convex pattern of downslope bowing contours. Debris flows, landslides, and talus cones often demonstrate similar conical fan-shaped landforms. A *medial radial line* often splits fans into two halves. Because of confinement problems along their boundaries, not all alluvial fans are semi-conical shaped.

Alluvial fans are the outcome of the erosional response to a rising relief. The fans compose a sediment storage in the form of a prism by the mountain front and serve as a periodic buffer for sediments and water in their move from mountainous erosive catchments. The alluvial fan environment is often hundreds of meters above the *local terminal base-level*. The bedrock slopes along the range front display *triangular facets* between the fan outlets, i.e., triangular mountain-front bedrock slopes between the V-shaped valleys (Figs. 1.2 and 1.3). The magnitude of the facets depends mainly on the width of the drainage basins. Between long and narrow drainage basins, the facets are small and closely spaced.

The term *terminal fan* (Tunbridge 1984) has been suggested for fluvial distributary ephemeral systems in arid and semiarid environments, where high evaporation and percolation into the channel bed make a significant downstream reduction in discharge. The flow splits into smaller distributaries and causes runoff to vanish gradually (Kelly and Olsen 1993; Nichols and Fisher 2007). The morphological,

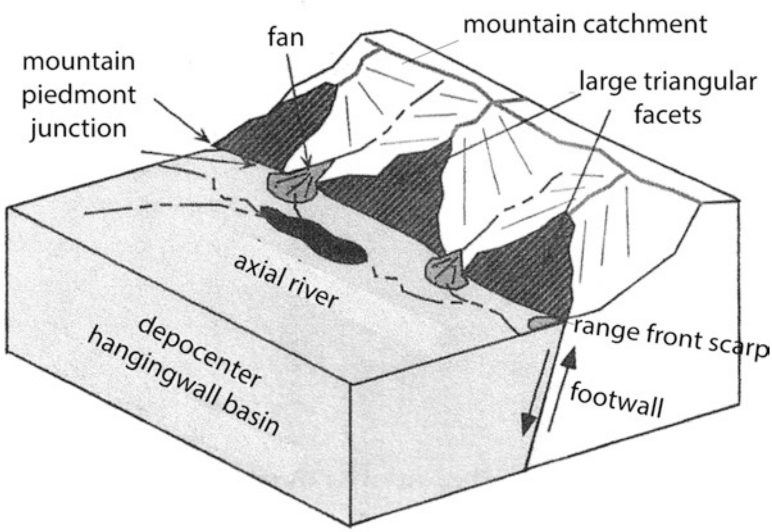

Fig. 1.2 Typical alluvial fans location along a normal fault at a range front. Sourcing drainage basins are entrenched in the mountainous footwall. Triangular facets indicate the mountain front. The fans prograde towards the axial river in the hanging wall basin. (Modified after Burbank and Anderson 2011)

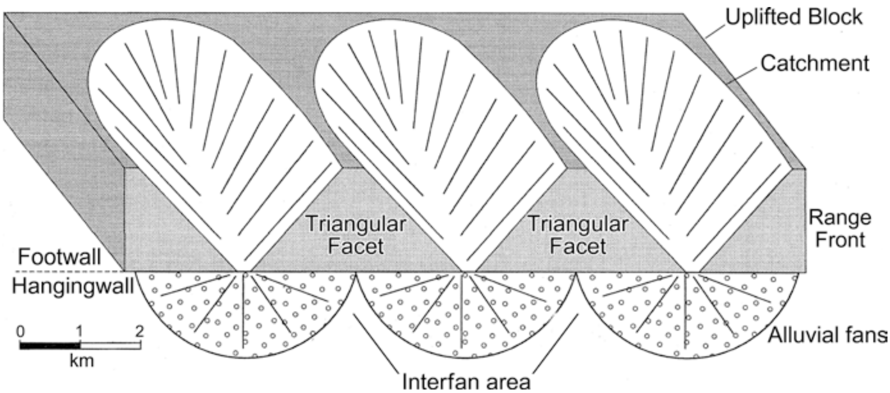

Fig. 1.3 Typical alluvial fan location along a range front. The triangular facets may retain partly the initial fault plane. They owe their size to the spacing of the channels. (Modified after Blair 1999)

sedimentological, stratigraphical, and dynamic characteristics which have been related to terminal fans (Friend 1978; Olsen 1987; Abdullatif 1989; Kelly and Olsen 1993; Friend et al. 1999; Arzani 2007; Stephen and Mountney 2009) are those typical to alluvial fans. The terminal fan concept does not contribute to an improved understanding of the alluvial fan environment. It seems unjustified to use the *terminal fan* concept as a distinctive fan model, a conclusion also shared by North and Warwick (2007).

Alluvial fan evolution is often triggered by thrusting (Fig. 1.4). Deformation pulses may uplift and rejuvenate the source areas. Long periods of mountain uplift and sinking of the nearby basins are important for maintaining the elevational differences and allowing continuous fan sourcing. Fan progradation is controlled by the ratio of subsidence of the accommodation space to the sediment supply from the hinterland. If the rate of sediment delivery and the flux from the source basin exceeds the subsidence, fans will overflow and prograde (Clevis et al. 2004). Fans may prograde tens of kilometers away from the active thrust front. Increase in accommodation space by subsidence will confine the accumulation of fans closer to the mountain front.

Alluvial fans can be distally confined by an axial river and laterally by neighboring fans or stay unconfined (Fig. 1.5). Alluvial fans may thus appear individually uncoalesced as a well-defined single unit with interfan areas drained by channels sourced from the mountain front. Fans may alternatively show lateral

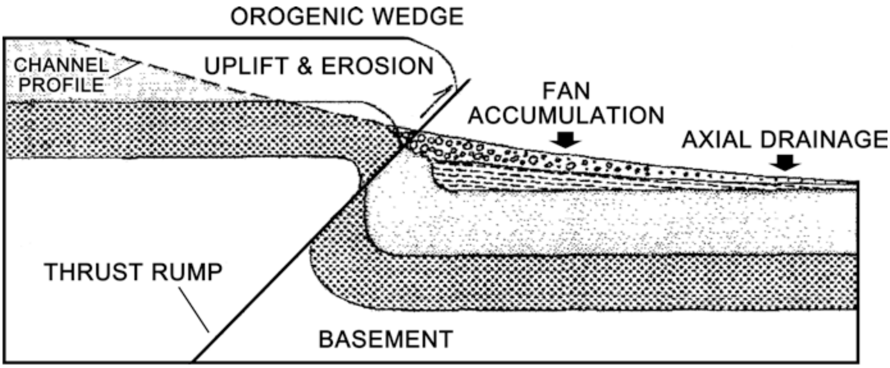

Fig. 1.4 The location of alluvial fans in front of a foreland uplift following unroofing. The uplifted orogenic wedge above the thrust ramp includes the sourcing drainage basins. (Modified from Decelles et al. 1991)

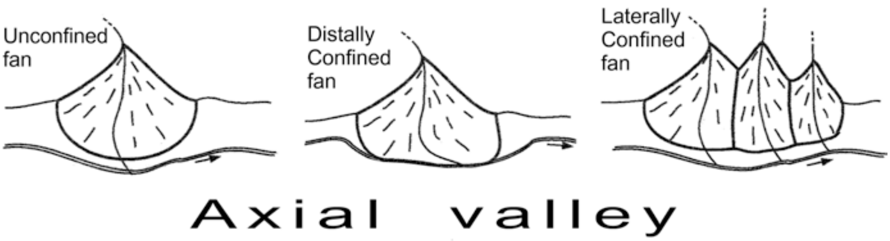

Fig. 1.5 Categorization of alluvial fan confinement. (After Crosta and Frattini 2004)

coalescing with neighboring fans or with the axial basin deposits. Closely spaced alluvial fans may interfinger but not merge, each remaining an individual structure. The narrower the spacing between the catchment outlets, the more the fans become coalesced. Fully merged alluvial fans are called *bajada* (Eckis 1928) and lack a fan-shaped form. It may attain lengths of over 100 km and a thickness of a few tens to a few hundreds of meters, composing a continuous depositional apron. The convexity of its individual fan cones is lost, and contour lines become parallel and linear (Blair and McPherson 2009). Topographically, alluvial fans display typical half-circular contours and show typical convex cross profiles parallel to the mountains (Figs. 1.6 and 1.7) with the central part of the fans almost invariably higher because of more deposition (Hooke and Rohrer 1979). The typical

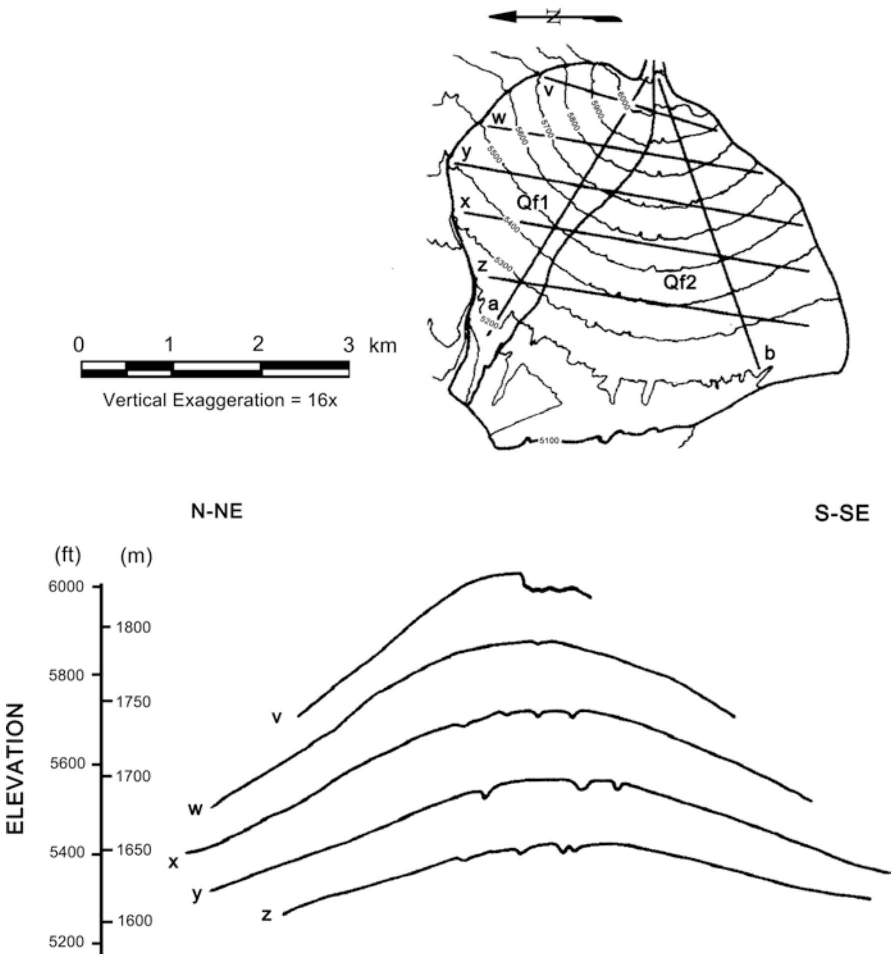

Fig. 1.6 Characteristic convex cross-fan profiles of Cedar Creek alluvial fan. (Following Ritter et al. 1993)