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Geomorphic elements on modern distributive fluvial systems

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ABSTRACT

Analysis of over 400 fluvial megafans (>30 km in length) in aggradational continental sedimentary basins reveals that geomorphic channel and floodplain changes on these distributive fluvial systems (DFS) generally behave in predictable ways with increasing distance from the apex. These changes can include: a decrease in discharge, a decrease in bed material transport and calibre of sediment, a decrease in stream power, an overall decrease in channel width, an overall decrease in channel depth, an increase in avulsive behaviour, and sinuosity becomes more variable.

Three generic geomorphic element models are proposed – reflecting observed changes in channel behaviour – based on measurable changes in channel width and planform characteristics with increasing distance downstream. The three models are derived from (1) a single braided channel that bifurcates downstream into low sinuosity channels; (2) a dominant, sinuous, single-thread channel that anabranches and bifurcates with distance downstream, creating smaller channels with varying sinuosity; and (3) a dominant multi-thread channel that anabranches and bifurcates with distance downstream, creating smaller channels with varying sinuosity.

The changes in fluvial behaviour and landforms on DFS are in response to variable discharge and sediment supply ratios from the upstream catchment. In contrast to examples described in hydrogeomorphological literature for tributary fluvial systems where channel dimensions tend to increase downstream, observations from DFS suggest that – where the formative DFS channel does not retain the same dimensions – intrinsic geomorphic thresholds lead to the breakdown of the main trunk channel into smaller anabranching and distributary channels with distance downstream; in some instances the majority of channelised flow at the DFS termination may even be disintegrated. The observed range of termination types and floodplain soils for each DFS type are interchangeable dependent on local conditions. The modern geomorphic elements and floodplain soils are dependent on climate in the upstream catchment and in the downstream receiving sedimentary basin.

1. Introduction

1.1. What are DFS?

Distributive fluvial systems (DFS) are composed of a radial network of channels and associated deposits dispersed below an apex where a river emerges from valley confinement and enters a sedimentary basin (Weissmann et al., 2010). The term 'distributive' does not necessarily imply coeval flow in all channels of the radial network. These DFS have been referred to as megafans, alluvial fans and fluvial fans in geomorphic and sedimentological literature, although their distinction is perhaps arbitrary along a continuum of DFS scales (Hartley et al., 2010; Weissmann et al., 2010, 2011). Crucially, aggradational fluvial and alluvial systems that display distributive planforms under the most recent (Quaternary) climate regimes dominate depositional form in modern continental sedimentary basins (Hartley et al., 2010; Weissmann et al., 2010, 2011).

In this paper, *tributary* refers to a stream that discharges into, or joins, a larger river; *distributary* refers to a channel branch that directs flow away from, and does not rejoin, the main channel as opposed to anabranching channel planforms. Likewise, the term *avulsion* or *avulsive behaviour* refers to the (tendency for) lateral displacement of a stream from its main channel into a new course across its floodplain (Allaby, 2008).

1.2. Why are DFS important?

The identification of DFS as dominant Quaternary geomorphic features in many modern, aggradational continental sedimentary basins challenges the accepted wisdom that tributary fluvial system landforms and deposits predominate in the modern and ancient sedimentary and geomorphological records. This is reflected by fluvial geomorphology research and corresponding published literature, which since the 1960s and '70s, has been driven by engineers needing to understand river,

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floodplain and hillslope processes for channel design and hazard mitigation purposes; however, it has been primarily been concerned with disseminating data collected from tributary fluvial systems. With the advent of geographical information systems (GIS) and GoogleEarth© imagery the recognition of large-scale fluvial systems like DFS has become apparent. As a result, several fundamental fluvial geomorphic concepts need to be reconsidered to better encompass the range of behaviour and characteristics of all fluvial systems — from tributary to distributary.

In addition, the analyses of Weissmann et al. (2010, 2011) and Hartley et al. (2010) revealed that DFS are present in both endorheic (internally drained) and exorheic (externally drained) basins in all tectonic and climatic settings. In effect, models that are developed to account for variations in the distribution of geomorphic features on modern DFS – which dominate aggradational sedimentary basin-fill – can be useful as a generic guide for the interpretation of the recent alluvial sedimentary record, regardless of setting.

1.3. Aims

This paper characterises observed modern geomorphic elements (defined here as topographic landforms and channel-scale barforms created by fluvial processes) on DFS and provides three generic DFS geomorphic models. Each DFS type is distinguishable by specific geomorphic elements and the corresponding distribution and scale of these elements, spatially within the specific DFS type, and with increasing distance downstream from the DFS apex. A discussion of the variability of geomorphic elements on DFS over time highlights the difficulty in untangling the relative influences of climatic- or tectonic-scale processes and internally-driven processes. Primary consideration is given to the potential for qualitative and quantitative descriptions of DFS in understanding the primary differences in behaviour between tributary and distributary fluvial systems to facilitate the development of new geomorphic models.

2. Modern DFS types and generic geomorphology from remotely sensed imagery

Remotely sensed imagery was examined in a GIS platform in order to derive maps of generalized geomorphic elements on each type of DFS and to examine the generic behaviour of DFS in more detail. For each DFS, Landsat imagery at 15-, 30- and 60-m resolution (NASA, 2003) (panchromatic, multispectral, and thermal, respectively) and DEM data at 30-m resolution (NASA, 2003) were mosaicked and combined in a GIS-based data file and analyzed to produce layers of slope, aspect, and surface curvature (ESRI, 2011). In addition, the multispectral nature of the data enabled the inference of information regarding surface geomorphic and roughness characteristics and vegetation type and density. Where necessary, this data set was augmented with Google Earth© imagery (Hartley et al., 2010; Weissmann et al., 2010, 2011).

This study refines the analysis of over 400 large (>30 km in length) DFS by Hartley et al. (2010) where dominant channel planform type was used to identify six different DFS types (Fig. 1): (I) a single braided channel that bifurcates downstream into low sinuosity channels, (II) a single dominant braided channel, (III) a single braided channel that increases in sinuosity downstream, (IV) a dominant single sinuous channel system, (V) a single sinuous channel that bifurcates into smaller sinuous channels downstream, and (VI) multiple sinuous channels with no dominant single channel. This paper attempts to describe the variability between and within generic DFS types in order to define characteristic geomorphic elements for specific DFS types.

2.1. Generic DFS geomorphology

Previous research has shown that downstream channel changes on DFS can include: a decrease in discharge, a decrease in bed material transport and calibre of sediment, a decrease in stream power, an overall decrease in channel width, and an overall decrease in channel depth (but this is not as systematic as decrease in width) (Friend, 1978; Kelly and Olsen, 1993; Stanistreet et al., 1993; DeCelles and Cavazza, 1999; Horton and DeCelles, 2001; Shukla et al., 2001; Assine, 2005; Nichols and Fisher, 2007; Chakraborty and Ghosh, 2010; Ralph and Hesse, 2010).

In the present analysis of satellite imagery, approximately 10% of recognisable DFS only could be observed with low resolutions on Google Earth©, or were too anthropogenically modified to identify geomorphic element style; these were therefore excluded from the present assessment of DFS geomorphology and behaviour. Observations and measurements of the location of changes in channel morphology were taken from 25% of the remaining database to represent an equal number of planform types, the range in DFS scale, climatic and tectonic settings, and termination type. Measurements from this representative sample of the range of modern DFS confirm that active channel width generally tends to decrease with increasing distance from apex to toe; this observation applies to all planform types in climatic settings ranging from arid polar and desert regimes, to humid subtropical and continental regimes (Table 1). We also observe that, with increasing distance from the apex, DFS tend to display an increase in avulsive behaviour (as evidenced by the increase in associated geomorphic elements, such as abandoned palaeochannels, described in subsequent sections) and highly variable sinuosity (Table 1).

Deposition within the active channel belt on the active accretionary DFS lobe (sensu Schumm et al., 1987; Chakraborty et al., 2009; Chakraborty and Ghosh, 2010) leads to the development of the formative features of DFS; these features are described in this study as geomorphic elements and will be used here as discriminatory criteria within and between DFS types (Table 2). Distinguishing criteria for DFS types include:

- Active-channel geomorphic features such as point bars and braid bars, which are relatively unvegetated.
- Areas prone to frequent avulsions or levee breaches — which may have ponds and marshes with dense vegetation and areas of standing water with interconnected waterways.
- Relict geomorphic features, including oxbow lakes, scroll bars, abandoned channels, and meander cutoffs. We note here that although there may be some flooding from the main channel belt into these regions, the abandoned features do not have interconnected waterways but are rather isolated features in the floodplain.
- Channels initiating on the DFS surface. These channels that tend to form small tributary networks of underfit channels within palaeochannel belts result in reworking the abandoned channel-belt deposits.
- The degree of pedogenic modification. This characteristic differs between different depositional regions on DFS. For instance, because of the active deposition and migration of bars and channels in proximal regions of the active DFS lobe, floodplain deposits will comprise weakly developed, immature soils; in contrast, exposed floodplain surfaces on abandoned DFS lobes will be subject to pedogenic modification and subsequent soil development (Hartley et al., in press).

The DFS termination types can vary depending on the climate in the sedimentary basins. Hartley et al. (2010) showed that the range of DFS termination types includes playas, lakes, aeolian dune fields, an axial fluvial system, wetlands, or a marine coast. For instance, the style of DFS termination in dryland climates is driven primarily by the type of drainage system in the basin; endorheic basin DFS terminate in perennial lakes or playas or dissipate in dune fields, whereas exorheic basin DFS terminate as tributary fans to an axial drainage system. As a result, the sedimentary lithofacies in dryland DFS terminations will show the increased dominance of evaporation and aeolian dunes downstream with precipitation of evaporate minerals, along with desiccation cracks and aeolian deposits in the distal areas. The presence and dominance of an axial system are dependent on the climate in