Abstract

Effects of Strongly Seasonal and Yearly Variable Precipitation Patterns on Fluvial Facies: Tropics and Subtropics

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This paper focuses on the effects of strongly seasonal and yearly variable precipitation patterns, present in large parts of tropics and subtropics. Specifically it explores the effects on river systems, what concerns their dynamics, and the resultant sedimentary facies and architectural properties. These precipitation patterns are controlled by the annual and inter-annual variations in the Hadley Cell or Inter-Tropical Convergence Zone, and the resultant monsoon circulation and tropical-subtropical cyclones. The outer margin of this zone fluctuates seasonally between 30-35° of latitude, and the inner margin occurs within 5-10° of latitude, bordering the perennially wet rainforest zone.

The strongly seasonal and yearly variable precipitation pattern promotes the occurrence of intense rainfall events, where up to 100% of the mean annual precipitation may occur in a few months, or just a few downpours. Intense rainfall is likely to cause flooding with characteristically high flow velocities, and the typically rapid rise, sharp peak and rapid decline of the flood hydrograph. Rivers in such climate zones transmit up to 100% of their water and sediment discharge during these high intensity events, and may remain dry or transmit discharges below the effective discharge (discharge below sediment transport threshold) during rest of the year or for a multiple years. However, the intensity and duration of the flooding events and the proportion of the water and sediment transmitted during high magnitude floods varies considerably, depending on the annual and inter-annual precipitation distribution or peakedness (kurtosis).

Climates where most of the annual precipitation falls in a few downpours that last from only hours to days, transform rivers into particularly flashy systems that transmit nearly 100% of their water and sediment discharge during high-intensity floods. As a result, deposits of such rivers resemble flashflood or megaflood deposits rather than any fluvial facies models (Fig. 1). They consist of more than 80-100% of Froude transcritical and supercritical sedimentary structures, such as parallel or planar laminations, convex-up low-angle bedforms, scour and fill structures and humpback or sigmoidal cross strata, as a result of the high flow velocities and sharp-peaked flood hydrograph. Another effect of the high flow velocities and the sharp-peaked flood hydrograph is high sediment flux and locally high deposition rates, as seen by the abundance of gradational, aggradational (climbing) varieties of the Froude transcritical and supercritical bedforms, as well as simple, multi-meter thick accretion packages (Fig. 1). The latter occur instead of well-developed macroforms, and indicate in many cases low-angle downstream accretion. These sets resemble very rapid deposition due to flow expansion in downstream direction across previous flood deposits. The locally high channel bed aggradation rates promote avulsions rather than channel migration. As a result, the channel lithosomes form amalgamated, in places tabular channel fill units that are massive or uniform in appearance, due to the amalgamation, the lack of lithofacies and accretion direction variability, and occurrence of thick low-angle accretion sets (Fig. 1).

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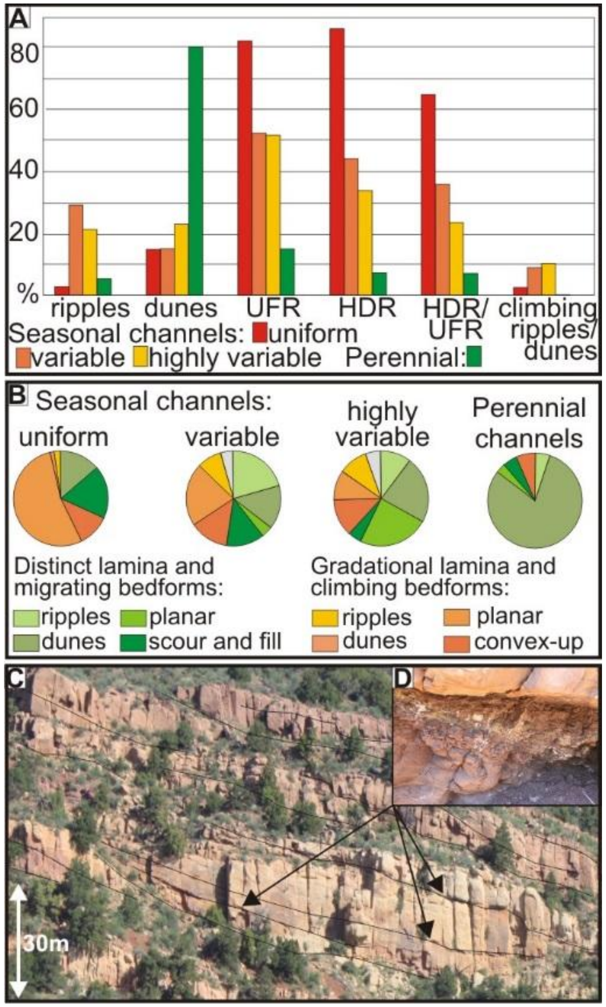

Figure. 1. Comparison of facies in flashy and perennial rivers (A) by channel types and (B) by specific sedimentary structures. Some channel fills have a vary uniform appearance due to thick, simple downstream accreting bars (C). In-channel terrestrial bioturbation and pedogenic modification indicates that channels were dry at times (D). UFR – upper flow regime, HDR – high deposition rate.

Such channel lithosomes occur in modern climates with a considerable variability in mean annual precipitation, from only 100 mm to more than 750mm, with a seasonal (monsoonal) to decadal (ephemeral) recurrence frequency. Common to all the examples is that the total annual precipitation falls in a few downpours that last from hours to a few days generating high-discharge sharp-peaked flooding events.

In contrast, where the mean annual precipitation is distributed over weeks or months, rivers transmit efficient discharge longer (e.g. for a full or partial monsoon season), and experience high discharge variability. Peak discharges, that cause high-magnitude flood events, and deposition of Froude transcritical and supercritical sedimentary structures, may last for a few days only, and alternate with longer periods of lower-magnitude floods and non-flood discharge. As a result, a smaller proportion of the total sediment budget is transported during the peak flood, and thus the proportion of gradational and climbing Froude transcritical and supercritical structures is lower. During the less intense phases of flood or at non-flood discharges, cross strata and ripples form, and in some cases barforms and channels can migrate more systematically. High-intensity peak floods may not occur during every flood season, but rather have a longer return period of up to decades. The resultant channel fill lithosomes display laterally and vertically highly variable sedimentary facies, lithologies and geometries, reflecting the changing flood stages (see also Fielding et al., 2009; Allen et al., 2013). The proportion of Froude transcritical and supercritical sedimentary structures is still high (ca 50% in available examples), whereas the proportion of the high-deposition rate features is considerably lower. Also, the proportion of cross strata, that is the dominant feature of sandy perennial river deposits, is considerably higher (25-40% in the available examples). Where the upper flow regime and high-deposition rate features dominate, the macroforms are thick, simple downstream accretion sets, whereas in other places better developed macroforms occur with a component of lateral accretion. Note that in modern systems with such lithosomes the mean annual precipitation also varies significantly, from 100 mm to more than 1000 mm.

These two types of seasonal or ephemeral rivers are end members of a continuum of channel lithosomes that may present any transitional or intermediate characteristics. Additional features common in rivers with seasonal and yearly variable discharge are thick soft-clast conglomerates that indicate high flow velocities and high deposition rates, but also channel bank collapse that is likely to occur when ground becomes oversaturated during the floods. In-channel terrestrial bioturbation and pedogenic modification is common where the channels stay dry for sustained periods. In other places channels contain higher soil moisture than the surrounding floodplain, and in-channel vegetation is common.

Although with higher cross-strata content, the highly variable lithosomes are distinct from perennial fluvial facies models that are characteristically dominated by cross stratified sandstones (e.g. 80-100% Fig. 1), lack in-channel bioturbation, have conglomerates as thin lags along erosion surfaces, and have better developed and multi-directional accretion sets.

Both end-members of the variable-discharge rivers occur in tropical and sub-tropical climate zones, in monsoonal as well as in dryer climate zones, and are seasonal (mostly yearly flood recurrence) to ephemeral (multi-year or decadal flood recurrence). Thus we link their occurrence to the annual and inter-annual variability of precipitation and intense rainfall, rather than to mean annual precipitation or temperature, or even the flood recurrence frequency. However, intermittently dry channels are likely to occur only in climates where evapotranspiration exceeds precipitation, but they may occur across sub-humid to arid climates. Also, in-channel vegetation is more likely to occur in sub-humid rather than arid areas (see Fielding et al., 2009).

Another common aspect of variable-discharge rivers is that they tend to form fluvial megafans, if they have large enough mountainous drainage basins in tropics and subtropics (see Leier et al. 2005). This behavior is also linked to the discharge peakedness (kurtosis) and resultant locally high deposition rates that promote aggradation and channel avulsions across an alluvial plane. Fluvial megafans build architecture with predictable lateral and vertical channel and floodplain facies transitions and proportions. This is due to the active aggradation and avulsions in these systems and the resultant downstream decrease in water and sediment discharge. Fluvial megafans trap large volumes of (coarse) sediment that would otherwise reach the oceanic basins. The variable-discharge rivers that do not build fluvial megafans are likely to have a large coarse sediment yield, due to the high erosion power during flooding, as well as the initiation of landslides due to oversaturation, especially in areas with sparse vegetation. Moreover, the gradational and climbing sedimentary structures indicate transport and deposition of sand sized particles from suspension, rather than bedload. Suspension transport may considerably increase output of coarse sediment from variable-discharge rivers.

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