Floodplain development based on selective preservation of sediments, Squamish River, British Columbia

Gary J. Brierley and Edward J. Hickin
Department of Geography and The Institute for Quaternary Research, Simon Fraser University, Burnaby, B.C., Canada, V5A 1S6

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ABSTRACT


In the conventional model of floodplain sediment accumulation, mechanisms of floodplain growth are differentiated into lateral and vertical accretion processes, in which within-channel deposits are capped by overbank deposits. In the high-energy, gravel-based Squamish River, sediments laid down on bar surfaces are composed of trough and planar cross-bedded coarse sands. These sequences contrast incongruously with adjacent floodplain deposits which are composed in large part of vertically accreted fine sands atop coarse alluvial gravels. Using element analysis it is inferred that bar platform sediments are stripped away by chute channels, which are subsequently infilled with lower-energy deposits. From this, a model of floodplain growth based on selective preservation of bar platform sands and preferential preservation of vertically accreted deposits is proposed. This mechanism of sediment replacement occurs independent of channel planform type.

Introduction

Floodplains are sediment sinks adjacent to river channels in which eroded and sorted sediments accumulate and are reworked by various processes, producing an array of sedimentary forms. In the conventional model of floodplain sediment accumulation, mechanisms of floodplain growth are differentiated into lateral and vertical accretion processes, in which within-channel deposits are capped by overbank deposits. These are referred to as bottom-stratum and top-stratum deposits, respectively. The relative abundance of these depositional units which make up floodplains is conditioned largely by environmental setting and the history of geomorphic events.

Wolman and Leopold (1957) pointed out the difficulty in reconciling substantial overbank deposits with regular recurrence intervals of bankfull discharge and considered top-stratum deposits to make up only 20% of floodplain sediments. These findings have been confirmed in many studies (e.g. Lattman, 1960; Allen, 1965). In contrast, other authors have noted the prominence of overbank deposits in migrating channel regimes (e.g. Schumm and Lichty, 1963; Schmudde, 1963; Blake and Ollier, 1971; Chappell et al., 1992) and the floodplains of streams which exhibit little or no lateral migration may be composed largely of vertical accretion deposits (e.g. Ritter et al., 1973; Nanson and Young, 1981). In some settings, major floods may remove coarse-grained floodplain sediments, with replacement by either bar and chute fill deposits.
(e.g. Baker, 1977) or vertical accretion deposits (e.g. Schumm and Lichty, 1963; Burkham, 1972; Nanson, 1986; Ritter and Blakley, 1986). Indeed, floodplain sediments initially deposited by one mechanism often are reworked and redeposited by others (Schmulde, 1963; Schumm and Lichty, 1963; Sigafoos, 1964; Brakenridge, 1984; Hereford, 1984).

As such, although floodplains are composed solely of combinations of laterally and vertically accreted deposits, a wide range of floodplain types has been described, leading Nanson (1986, p. 1467) to comment that “... rather than a single model of floodplain formation, there is an array of processes leading to different floodplain types in different environments.” In this paper an alternative mechanism of floodplain growth is demonstrated for the high-energy, gravel-based Squamish River, in southwestern British Columbia.

In order to understand mechanisms of floodplain sediment accumulation it is necessary to link principles of floodplain sedimentology and fluvial geomorphology. This is

![Diagram of the Squamish River basin](image)

Fig. 1. Regional setting of the Squamish River. Inset top right: Mean monthly discharge of the Squamish River at Brackendale (1955-1987). Inset bottom left: Longitudinal profile of the Squamish River.
achieved using three-dimensional element analysis (Miall, 1985, 1988a–c; Miall and Turner-Peterson, 1989; Brierley, 1991b). Elements are defined in geomorphic terms, thereby providing insight into the associations among sedimentary forms, processes responsible for them, and their environment of deposition.

In this study an elemental approach is used to characterize the fluvial sedimentology of a 20 km reach of the Squamish River in which channel planform changes progressively down-valley from braided to meandering. By comparison of deposits laid down on contemporary bars with those sediments incorporated and preserved in the adjacent floodplain, it is shown that chute channels frequently rework bar platform deposits and are subsequently filled in by much lower-energy, finer sand deposits. This mechanism of sediment replacement results in floodplain sediments dominated by low-energy, vertically accreted deposits atop coarse alluvial gravels. This mechanism occurs independently of channel planform.

Field setting

The Squamish River is a high-energy, gravel-based river, 60 km north of Vancouver in southwestern British Columbia, Canada (Fig. 1). Over 150 km long, the river has a drainage basin area of almost 3600 km². During the Holocene the Squamish River has moved, sorted and redistributed glacially and slope-derived sediments within its high-relief fjord setting. Abundant sediments supplied from slope failures on Mount Cayley (Fig. 1) have imposed a braided channel planform down-valley. In contrast, base level control associated with Cheekye Fan adjacent to Mount Garibaldi has imposed downstream channel control on the meandering reach. The 20 km study reach focuses on the planform transition reach, in which there is a change in bar type from mid-channel and bank attached compound bars to lateral and point bars (Fig. 2).

In the study reach, channel sinuosity increases down-valley from 1.1 to 1.5, while the braiding parameter (measured as number of bars and islands per meander wavelength) decreases from 3.7 to 0.7. $D_{50}$ values for the gravel population on contemporary bars decrease down-valley in a regular manner from in excess of 100 mm to less than 50 mm (Brierley and Hickin, 1985). Valley slope diminishes from about 0.006 to 0.001, while valley width
doubles from about 1 km to 2 km. In this reach, channel shifting is prevalent, bend migration is very rapid, and log jams are abundant.

Annual precipitation in Squamish exceeds 2000 mm. Annual runoff is highly seasonal, and average monthly discharge of the Squamish River at Brackendale ranges from 90 m$^3$ s$^{-1}$ in March to over 500 m$^3$ s$^{-1}$ in July (Fig. 1). In an average year the river delivers about 2 million metric tons of sand and silt to the Squamish Delta in Howe Sound (Hickin, 1989). Occasional fall floods are especially severe; an event in October 1984 had a maximum instantaneous discharge of 2610 m$^3$ s$^{-1}$, and brought about significant channel changes in some reaches (Hickin and Sichingabula, 1988). Floodplain vegetation is mixed coniferous and deciduous woodland, with a well-developed lower canopy.

**Floodplain growth of the Squamish River**

To evaluate both contemporary bar sediments and preserved floodplain sediments of the Squamish River, a three-fold sampling procedure was employed. Contemporary bar deposits were evaluated in a number of pit transects, sediments were exposed in trenches dug perpendicular to the main channel at the bar/floodplain margin, and bank exposures were examined at regular down-valley intervals. Sampling in the channel marginal zone had several advantages in that the relationship between known depositional environments and their sediments could be evaluated by comparing contemporary bar sequences with adjacent floodplain deposits.

Whenever possible, pits, trenches and bank exposures were dug to gravel depth, and sediment sequences were analysed at both facies and element scales. Particles sizes were recorded for each individual bedding unit. Specific sampling site locations and procedures for sediment analysis are described elsewhere (Brierley, 1991a, b).

Bar sedimentology relates directly to the spatial distribution of morphostratigraphic units, with different within-bar trends by bar type (Brierley, 1991a; Fig. 3). Fluvial morphostratigraphic units are defined as three-di-
mensional morphologic features on bar surfaces which are associated directly with specific sediment sequences. Four morphostratigraphic units are observed on Squamish River bars, namely bar platform, chute channel, ridge and remnant floodplain units. Unvegetated bar platforms are the major features of contemporary river bars. Their facies composition differs markedly from the other morphostratigraphic units, with trough and planar cross-bedded coarse sands dominant, frequently with upward-fining particle size trends. In contrast, other morphostratigraphic units are characterized by lower-energy facies composed primarily of medium-fine to fine sands. All four types of morphostratigraphic unit are observed on each bar type, although their scales and spatial associations differ.

On compound bars of the braided reach, morphostratigraphic units exhibit no characteristic spatial pattern, resulting in complex within-bar trends in facies and particle size characteristics. Sediment trends are much better defined on point bars in the meandering reach, with both down-bar and lateral trends in facies and particle size characteristics. The primary control on observed within-bar sediment trends on all bar types is exerted by the activity of chute channels. These actively rework bar platform sediments, scouring to the depth of basal channel framework gravels. As such, contemporary bars of the Squamish River are dominated by discontinuous sheets of
Fig. 5. Representative photographs of floodplain sedimentology of the Squamish River. (a) Vertically accreted fine sands are observed directly atop basal channel framework gravels in this braided reach floodplain exposure. Sediments are 3.5 m deep. (b) Selectively preserved bar platform sands beneath overbank deposits in the meandering reach. Upward-fining trough cross-bedded and rippled sands contrast markedly with the darker fine sand/silts above. These have lighter coloured proximal top-stratum (flood cycle) deposits atop. (c) 4 m pit dug in the ridge/swale sequence of a laterally confined point bar. Note the sharply tilted swale contacts at the base of the pit side wall. The floodplain is composed in large part of vertically accreted fine sands.
coarse sands laid down on bar platforms, with finer-grained deposits laid down in dissecting chute channels and on marginal ridges and occasional remnant floodplain units.

To examine broader scale elemental sedimentology of the floodplain, sediment sequences were examined in 9 trenches, up to 26 m in length, dug perpendicular to the main channel at bar/floodplain margins, and in regularly spaced longitudinal bank exposures (up to 210 m in length). Elements are defined on the basis of their geometry, position in the sediment sequences, their bounding surface and their associated sedimentology. In this study, elements simply represent morphostratigraphic units observed and analysed in vertical sediment exposures.

Two element-scale floodplain sedimentology models are proposed for the Squamish River (Brierley, 1991b; Fig. 4). In the first model, floodplain sequences marginal to contemporary bars are dominated by chute, ridge and top-stratum deposits (up to 3 m thick), with minimal preservation of bar platform sands (Fig. 5a). The latter occur as remnant units of planar or trough cross-bedded coarse sands at the base of sediment sequences. As observed on contemporary bars, bar platform sands are removed during flood stages and replaced by lower-energy depositional sequences, especially in chute channels. In many instances these chute channels have scoured to basal channel gravel depth. Sediments infilling chute channels and their adjoining ridges are composed of vertically accreted fine sands (up to 2 m deep), with up to 1.5 m of top-stratum (flood-cycle and sand wedge) deposits atop (Fig. 6). As such, floodplain sediments in trenches and bank exposures immediately adjacent to contemporary river bars contrast markedly with deposits observed on the bars themselves. While the former are dominated by fine sand, lower-energy facies, the latter are composed primarily of coarse sand, high-energy facies.

In the second model of the floodplain sedimentology of the Squamish River, channel avulsion has resulted in preservation of up to
2 m thick sequences of bar platform units composed of coarse sand. These are preserved beneath uniform sequences of fine sands, up to 2.5 m thick, which were deposited in a distal floodplain environment. Subsequent avulsion has resulted in placement of proximal top-stratum deposits above these distal top-stratum units. The former are composed of flood cycle sequences up to 3 m thick (Fig. 5b).

Bar platform sands also are preferentially preserved beneath vertically accreted top-stratum deposits adjacent to a point bar in a laterally confined bend. As this bend impinges against a bedrock bluff, inhibiting bend migration (Hickin and Sichingabula, 1988), no chute channels are observed, and bar platform deposits are laterally continuous, with overbank deposits of fine sands atop, away from the main channel (Fig. 5c). These sediment sequences are typical of those ascribed to a meandering planform style (e.g. Allen, 1965), but are atypical for floodplain sequences of the Squamish River in which distal top-stratum elements are not observed in mid sediment sequence. This implies that the mechanism of bar platform preservation is tied to chute channel processes.

Discussion

Vertical stacking of elements is consistent throughout the study reach, and the two floodplain sedimentology models apply in both the braided and meandering reaches. A mechanism of selective preservation of bar platform deposits is proposed in which these units are preferentially preserved beneath distal overbank elements. The latter accumulate above bar platform sands following channel avulsion. Under conditions of more gradual channel migration, however, bar platform sands are stripped away by chute channels, and replaced by fine sands. The coarse sand which makes up contemporary bar platforms is flushed through the system and accumulates on the delta. Various sources of evidence support this assertion:

(1) During a June 1986 flood event, the dune field making up the bar platform of a point bar was mobilized in its entirety, and the configuration of dunes and avalanche faces on the bar were completely altered. Following passage of this event, the only sediments preserved on the floodplain adjacent to a point bar were fine sands accreted to ridges during the waning flood stage (Fig. 7). Any medium or coarse sands which accumulated during this event were subsequently removed. The fine sands and silts deposited on the ridge are the only sediments deposited during this event.
which have any longer term preservation potential.

(2) At the river mouth, boils on the water surface caused by dune fields. Materials convected to the surface are coarse sands (sampled by Rood and Hickin, 1989). When the main channel was dredged prior to dyking, a large volume of coarse sand was removed from the channel.

(3) Drilling by Swan Wooster Engineering and Simon Fraser University has yielded sediment cores from the delta to depths of 50 m, and all show substantial amounts of coarse sand.

Although similar mechanisms for removal of coarse sand and gravel facies have been described elsewhere (e.g. McGowen and Garner, 1970; Alexander and Nunnally, 1972; Bluck, 1976; Baker, 1977; Brakenridge, 1984), their replacement by lower energy deposits which dominate the floodplain has not previously been described. In the Squamish River system, coarse sands on bar platforms seemingly are transitory evidence of sediment pulses, mobilized during flood events and replaced at bar margins by lower-energy deposits during waning flood stages. The pronounced seasonal variability in discharge of the Squamish River probably promotes this process, as sediments accumulated at lower discharge stages are regularly mobilized during freshet (snow melt) flood events.

Bar platforms are the least vegetated and most accessible depositional unit in a river system. Given their abundance on bar surface, coarse sands appear to be the dominant contemporary sediment unit of the Squamish River. This impression is highly misleading as an analogy in floodplain modelling, as fine sands dominate the floodplain. Although considerable amounts of coarse sand have been deposited in both distributary channels and estuarine environments of the delta, coarse sands make up only a small proportion of the overall depositional suite of the Squamish River system.

Summary and implications

Given the high energy, dynamic geomorphic setting of the Squamish Valley, floodplain sediments do not meet intuitive expectations. Bottom-stratum deposits, which have been shown to be preferentially preserved under certain environmental conditions (e.g. Cant and Walker, 1978; Mader, 1985) are only partially preserved in the Squamish River floodplain, and channel framework gravels predominantly are transitional upwards to fine sand, top-stratum deposits. From analysis of trench and bank exposures it is evident that chute channels have partially removed bar platform sands and replaced them with lower-energy, chute channel infills. The abundant coarse sands which make up active bar surfaces are largely flushed through the system and stored in the delta. The following implications can be made:

(1) There is a need for greater input from geomorphology into floodplain sedimentology if mechanisms of floodplain growth and preservation potential of sediment units are to be understood. This is particularly relevant with increased interest in Holocene floodplain research and studies of environmental change. Since elements are defined specifically in geomorphic terms, they provide an ideal framework for sediment analysis.

(2) The fact that elements stack in identical vertical sequence in both the braided and meandering planform reaches indicates that processes are operating in a similar fashion independent of planform style. Chute channel reworking of bar platform deposits is associated with lateral and down-valley migration of the main channel(s). Bar platform sands also are preserved beneath distal overbank sediments, associated with channel avulsion, in each of the planform reaches. As such, the preservation potential of individual sediment units relates directly to the local scale geomorphic history of the floodplain.

(3) Given this mechanism of sediment re-
working, the distinction between within-channel and overbank mechanisms of floodplain growth has even less relevance than previously has been thought. Better terms may be "constructive" (flowing water) and "passive" (slackwater) sediments, reflecting tractive and suspended deposits respectively. Passive deposits dominate large parts of the Squamish River floodplain. The prominence of these fine sands certainly is contrary to intuitive expectations in the high-energy braided reach.

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