Supplemental Information

METHODS DESCRIPTION

We collected field data from the Piceance Basin that were used to reconstruct channel paleohydraulics, including flow depth, fluvial slope, and sediment discharge. Additionally, data were collected to assess lateral migration and avulsion style.

Paleo-flow depth and grain size measurements

Estimates of paleo-flow depth through the Wasatch Formation were obtained by measuring the relief on fully preserved fluvial barforms and channel fill structures. Laterally migrating channels accrete sediment on the inner bank of meander bends, which are recognized as stacked clinothem structures (e.g., Ethridge and Schumm, 1977). When channels are abandoned by avulsion, sediment fills the resulting topographic low. Sediment fill and clinothems may be measured to assess the bankfull geometry of the alluvial channel by measuring the thickness of these deposits.

For this study, 114 measurements of paleo-flow depth were collected using measuring tape across all three Members of the Wasatch Formation. Each measurement comprises a single bar clinothem or channel fill structure, and any given outcrop exposure may possess several individual locations for flow depth measurements. We were careful to select barform features that permitted unambiguous interpretation of the maximum relief. Accordingly, since some units of the Wasatch formation are highly amalgamated, it is often impossible to identify the dimensions of the barforms from the exposure without bias. As a result, sample sizes vary across units. These measurements are provided in the Data Repository file titled DR1.

Channel bed deposits at the toes of bar clinothems were also identified, and interpreted as thalweg deposits. Samples were collected from these deposits, and median grain size was measured using a hand lens and standard grain size card. These measurements are provided in the Data Repository file DR1.

Foreman et al. (2012) also estimated paleo-flow depth throughout the Wasatch Formation, using a dataset of 132 measurements. This data set was combined with data collected from this study, and used to produce an expanded distribution of measured flow depths for each Member of the Wasatch Formation.

Paleo-slope estimate

Trampush et al. (2014) derived an empirical model to assess fluvial slope from a dataset comprising over 400 modern rivers. They show that the best variables for predicting slope are bankfull flow depth and median bed material grain size:

$$logS = \alpha_0 + \alpha_1 logD_{50} + \alpha_2 logH_{bf}, \quad \text{(S1)}$$

where S is the slope, D_{50} is the median bed material grain size, H_{bf} is the bankfull flow depth, and α_0, α_1, and α_2 are constants with associated uncertainty, values given in Trampush et al (2014). We use this framework with the paleo-flow depth and grain size data presented in Data Repository file DR1 to assess paleoslope throughout the Wasatch Formation.

Shield's parameter estimate

Slope and depth are the first-order governing factors that control shear stress on the channel bed. We used our estimates of paleo-flow depth and paleo-slope to produce estimates of shear stress for each Member of the Wasatch Formation. An estimate of the Shield's parameter for sediment transport, normalized by the submerged weight of the sediment particles, is estimated based on median bedload grain size, and an assumed density of 2.65 g/cm^3.

Channel mobility assessment

Chamberlin and Hajek (2019) used bar preservation as an indicator of fluvial reworking. In their framework, a bar is recognized as "fully preserved" if it has a visible clinoform sets with bar-top rollover and hosts upper-bar facies. Partially-preserved or poorly preserved bars lack one or more of these features, but lower-bar facies can still be recognized. Truncated bars are considered partially-preserved, if the structure is capped by an erosional surface. Because recent work suggests that facies associations deposited by free bars under high flow conditions may differ substantially from low-flow conditions, we tallied only bars that we could confidently identify as bank-attached bars, omitting free bars or ambiguous cases.

Drone imagery was used to construct three-dimensional models of three outcrops in the Piceance Basin, one for each Member of the Wasatch Formation. The imagery from these outcrops was interpreted, whereby bar clinothem sets were mapped and classified as partially, poorly, or fully-preserved.

Avulsion style assessment

The basal contact of a fluvial sand body represents an avulsion event that is either preceded abruptly (without crevasse splays) or transitionally (with splays) (Jones and Hajek, 2007). Transitional-style avulsions in an alluvial basin may indicate more active crevassing in the channel-floodplain system (Hajek and Edmonds, 2014), whereas abrupt avulsions indicate less active crevassing.

Jones and Hajek (2007) provide criteria for classifying avulsions as "stratigraphically abrupt" or "stratigraphically transitional." Abrupt avulsions are recognized by a fluvial sandbody emplaced directly above fine-grained floodplain sediments, indicating incision into the antecedent floodplain surface. In contrast, transitional avulsions are recognized by a fluvial sandbody preceded by a thickening sequence of crevasse-splay sandstones. These criteria were used to classify avulsions based on field observations in all three Members of the Wasatch Formation.

DATA SOURCES AND STATISTICAL ANALYSES

Flow depth measurements ($n = 132$) published in Foreman et al. (2012) were aggregated with new flow depth measurements collected for this study ($n = 114$) and collectively used to analyze the paleoflow depth for each of the three Members in the Wasatch Formation (Figure 3, first column). With the null hypothesis that the mean flow depth is the same for all three members, a Kruskall-Wallace test and paired Conover-Iman tests with a Bonferroni correction were conducted (Table 1). None of these tests reject the null hypothesis.

At every outcrop, flow depth measurements collected for this study were paired with median grain size estimates. For each outcrop or channel belt where both grain size data and paleo-flow depth data were present, Equation S1 was used to estimate the paleoslope. These data are presented in Figure 3, second column. With the null hypothesis that the paleo-slope is the same for all three members, a Kruskall-Wallis test and paired Conover-Iman tests with a Bonferroni correction was conducted (Table 1). None of these tests reject the null hypothesis.

At the three outcrops where drone imagery was acquired to classify barforms (i.e., as described above), fully preserved and partially-preserved bars were tallied. The relative proportion of fully preserved bars was calculated from these tallies, and the variance in this proportion was estimated via bootstrapping (Figure 3, Table 1). Bootstrapping entails subsampling the dataset with replacement, and estimating a parameter for each subsample. The standard deviation of subsamples approximates the standard deviation of the parameter itself.With the null hypothesis that the proportion of fully preserved versus partially preserved bars was the same in all three members, a χ^2 test was conducted. This test rejected the null hypothesis.

Avulsion deposits were classified according to the criteria in Jones and Hajek (2007), as described above, tallied as transitional and abrupt. The relative proportion of transitional avulsions was calculated from these tallies, and the variance in this proportion was estimated via bootstrapping (Figure 3, Table 1). With the null hypothesis that the proportion of fully preserved versus partially preserved bars was the same in all three members, a χ^2 test was conducted. This test rejected the null hypothesis.

DATA FORMAT AND RATIONALE

All field data from all sources is aggregated into Data Repository File DR1. DR1 is organized in "long data" format, where every row constitutes an observation, and every column is a variable. For each individual field observation, we include:

(1) The date of collection.
(2) A hierarchical set of identifiers, so that observations can be grouped by location, grouped by sets of related observations (a single channel story in an outcrop), or by data origin (data supplied from different field campaigns or from literature values).
(3) Location information, including latitude, longitude, and elevation, with the appropriate geographic projection.
(4) The stratigraphic member.
(5) A categorical variable that indicates the sedimentary structure being assessed. Examples include "bar" for bar clinothems, and "channel" for channel-fill structures.
(6) A categorical variable indicating what property is being measured. Examples include "thickness" for measurements of a sand-body or bar clinothem thickness, "sample" for grain size estimates sample, or "dimensions" for a paired length and width measurement.
(7) The numerical measurement value(s). Some measurement types like "dimensions" have two quantities, (e.g. length and width).
(8) The units for each measurement value.
(9) Observations and interpretations, for example of transitional versus abrupt avulsions, or fully versus partially preserved bars.

(10) Additional categorical variables were collected, including the texture and composition of rock samples, a standardized description of samples, and image file names. Additional variables of auto-generated ID codes were used for some analyses and labeling.

In this way, the data may be grouped and analyzed according to location, stratigraphic member, outcrop group, or structure type. For example, all paleo-flow depth data derived from bar clinothems from the Atwell Gulch member can be accessed by filtering for rows where 'formation' is "atwell_gulch" and then filtering for where 'structure' is "bar." If an average is desired, "meas_a" would then be averaged from the resulting filtered list.