A database approach to fluvial facies models: example results from the Lower Jurassic Kayenta Fm. (SE Utah)

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FAKTS DATABASE

The *Fluvial Architecture Knowledge Transfer System* (FAKTS), is a relational database for the digitization of fluvial architecture (Colombera et al. 2012a); it has been populated with literature- and field-derived data from studies of both modern rivers and their ancient counterparts preserved in the stratigraphic record. The database records all the major features of fluvial architecture, including style of internal organization, geometries, spatial distribution and reciprocal relationships of genetic units. Datasets are classified - either in whole or in part - according to both controlling factors such as climate type and tectonic setting, and context-descriptive characteristics, like river pattern. The stratigraphy of preserved ancient successions is translated into the database schema by subdividing it into geological objects belonging to different scales of observation, nested in a hierarchical fashion: facies units are contained in architectural elements, in turn contained into large-scale depositional elements. Adopted classifications of facies units and architectural elements are largely based on Miall's (1996) schemes.

Code	Legend	Architectural element type
CH		Aggradational channel fill
DA		Downstream accreting macroform
LA		Laterally accreting macroform
DLA		Downstream + laterally accreting macroform
HO		Scour-hollow fill
AC		Abandoned-channel fill
FF		Overbank fines
SF		Sandy sheetflood dominated floodplain
CR		Crevasse channel
CS		Crevasse splay
		Aeolian elements

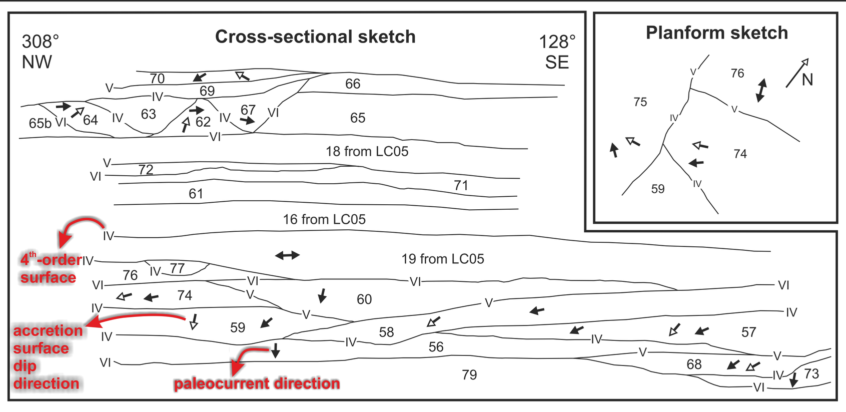
Other architectural element types are included in FAKTS

Code	Legend	Lithofacies type
Gmm		Matrix-supported massive gravel
Gcm		Clast-supported massive gravel
Gh		Horizontally-bedded or imbricated gravel
Gt		Trough cross-stratified gravel
Gp		Planar cross-stratified gravel
St		Trough cross-stratified sand
Sp		Planar cross-stratified sand
Sr		Ripple cross-laminated sand
Sh		Horizontally-bedded sand
Sl		Low-angle cross-bedded sand
Ss		Scour-fill sand
Sm		Massive or faintly laminated sand
Sd		Soft-sediment deformed sand
Fl		Laminated sand, silt and clay
Fm		Massive clay and silt
Fr		Fine-grained root bed
P		Paleosol carbonate

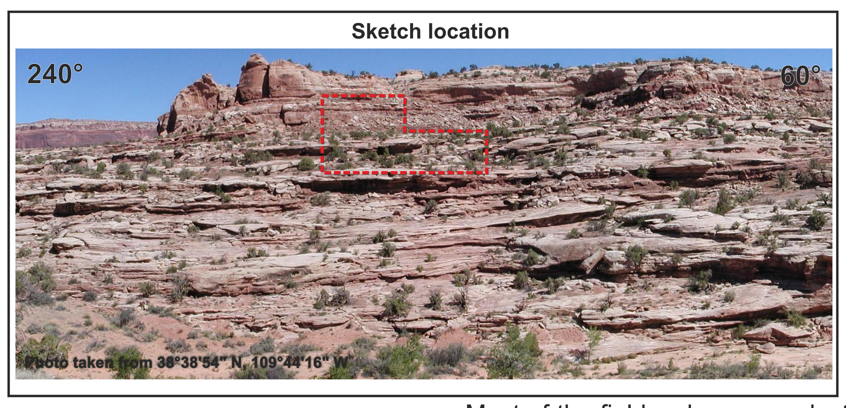
Other facies unit types are included in FAKTS

CASE STUDY

The Lower Jurassic (Sinemurian-Toarcian) **Kayenta Fm.** is a continental assemblage consisting dominantly of coarse- to fine-grained sandstones, interpreted as a broad alluvial plain - with minor aeolian deposition - developed in the overall arid/semiarid climatic context of the Glen Canyon Gp., in the Colorado Plateau province of the United States. Six studies on the Kayenta by other authors (Miall 1988; Bromley 1991; Luttrell 1993; Stephens 1994; North & Taylor 1996; Sanabria 2001) are also included in FAKTS; here mainly purposely-acquired field data from SE Utah (USA) is presented in order to provide examples of the information that can be incorporated into a FAKTS quantitative facies model.



Segment D from outcrop LC06 (Sevenmile Canyon)

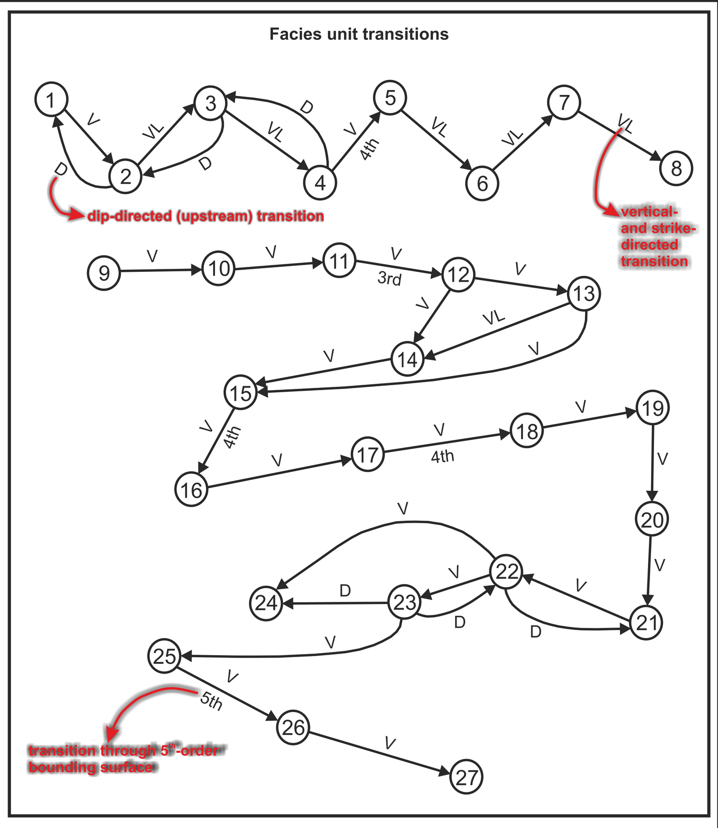


Architectural element properties

AE nr	Type	Thickness	Width	Length
56	CH	1.8	unltd 200	
57	DA	1.2		
58	DA	2.2		
59	DLA	2.4	app 38	
60	CH	1.6		
61	Aeolian D	1.6		
62	LA	1.3	part 7	19
63	CH	2.2		
64	DLA	2.4		part 47
65	Aeolian D	3.0		
66	Aeolian SS	0.8		
67	CH	1.3	14	
68	DA	2.3		
69	AC	1.4	part 26	
70	LA	1.5	part 11	
71	Aeolian ID	1.1		
72	CH	0.7		
73	CH	1.4		
74	DA	1.8	unltd 23	part 110
75	DLA		10	
76	SF	2.0	part 200	
77	CR	1.0	13	
78	DA	1.8		part 140
79	SF	2.3		

Facies unit properties

FU nr	AE nr	Type	Thickness	Width	Length
1	41	Sl	1.1	unltd 65	
2	41	Sl	0.5	part 38	
3	41	Sl	0.45	part 32	part 10
4	41	Sl	0.75	part 31	part 37
5	43	Sl	1.0	part 18	
6	43	St	1.2	part 39	
7	43	Sl	0.9	part 21	
8	43	St	0.7	app 31	
9	5	Gcm	0.1		
10	5	Sm	0.15		
11	5	St	0.4		
12	5	Ss	0.2		
13	5	Ss	0.45	part 2.6	
14	5	St	0.7	part 2.2	
15	5	St	0.6	part 4.3	
16	7	Gp	0.85		unltd 30
17	7	Sl	0.5	part 18	
18	8	Sl	0.45		unltd 21
19	8	Sl	0.8		unltd 21
20	8	Sm	0.2		part 19
21	8	Sl	0.25		part 17
22	8	St	0.5		part 18
23	8	Sd	0.4		part 3.1
24	8	St	0.45		part 18
25	8	Sm	0.3		unltd 15
26	10	St	0.3	unltd 6	
27	10	Sp	0.65	unltd 3	unltd 18
28	10	St	0.4	part 16	
29	11	Gt	0.4		
30	11	St	0.5		
31	11	Gcm	0.9		

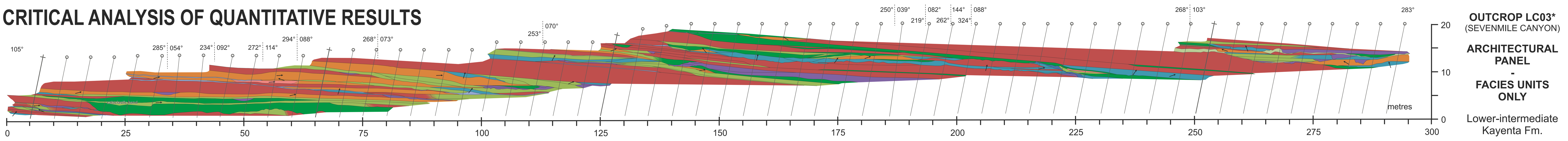


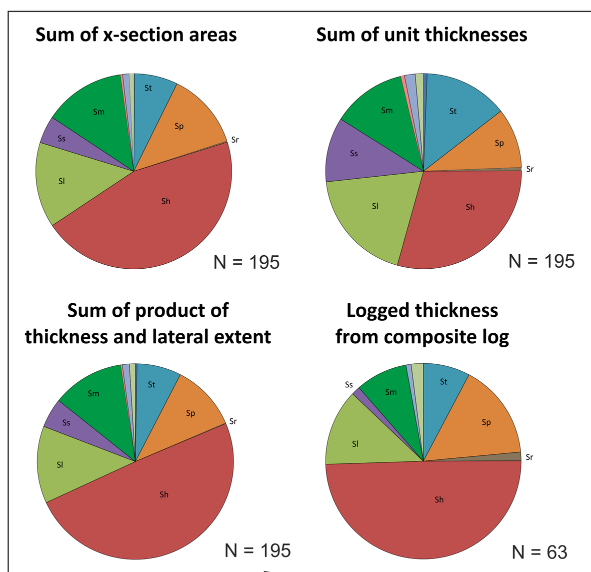
Segment A from outcrop LC09 (Sevenmile Canyon)

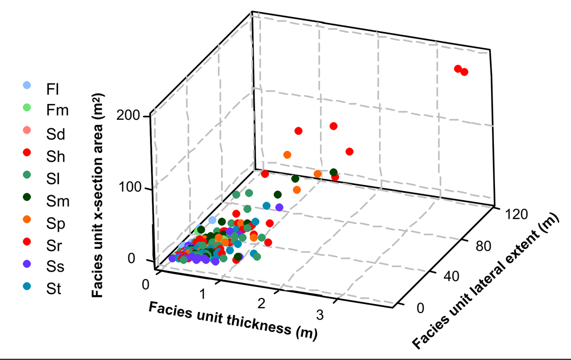
FIELD TECHNIQUES

Most of the fieldwork was conducted in a database-oriented way. Architectural elements were indexed by numerical identifiers, some of their properties were tabulated (element type and dimensions), and their spatial arrangement was sketched - in form of cross-sectional and planform sketches - including bounding surface order (scheme by Miall, 1996) and paleocurrent information . Also facies units were indexed and their properties (facies type, dimensions and element they belong to) tabulated. The reciprocal relationships between facies units were depicted in transition diagrams, storing strike-, dip-, and vertical-directed transitions between facies units, including bounding surface order information. The unique numerical identifiers are used to keep track of the transitions between facies units and of the containment of facies units in architectural elements, similarly to what is done in the database itself. Differently from logging or measuring architectural panels, this field technique does not generate standalone representations, but all the data required are contained, and acquired faster than traditional methods.

CRITICAL ANALYSIS OF QUANTITATIVE RESULTS

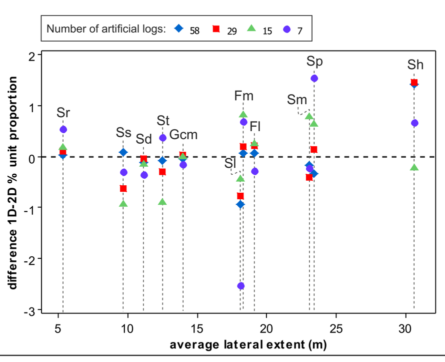




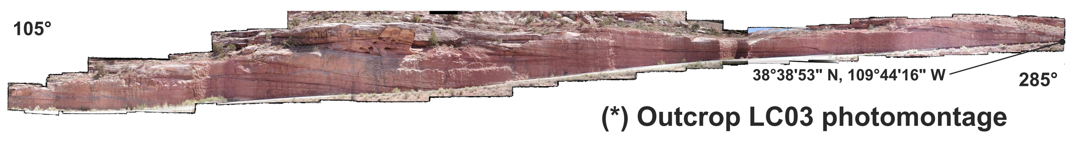


Data-type influence on proportions

The internal organization of genetic packages can be characterized in terms of the objects belonging to lower-order scales. FAKTS allows three scales of observation to be considered, corresponding to hierarchically nested depositional elements, architectural elements, and facies units. As both architectural elements and facies units were considered in this study, the internal organization of architectural elements can be described by the proportion and spatial distribution of facies units within each of them.
Ideally, the aim is to obtain volumetric proportions of genetic units, but in practice, very rarely data on 3D geometries are available, as most of FAKTS data derives from 2D architectural panels, 2D/pseudo-3D borehole-correlation frameworks, and 1D logs.
We assume that considering an architectural panel encompassing both downstream-directed lengths and cross-valley widths (relative to local paleocurrent), i.e. given a sufficient paleocurrent variability, 2D cross-sectional areas of genetic units represent a good estimation of volumetric proportions.
The architectural panel depicted above (outcrop LC03 at Sevenmile Canyon) has been chosen to test the sensitivity of overall facies unit proportions to the method of estimation, whose choice depends on available data types and dataset completeness.
In comparison to areal estimations, proportions that are based on the sum of unit thicknesses tend to return underestimated amounts for the units that have the largest lateral extent (e.g. facies units *Sh* and *Sp*). Therefore, in order to obtain more realistic proportions when the data record on lateral dimensions is incomplete, it is advisable at least to correct summed-thickness proportions according to average lateral dimensions.



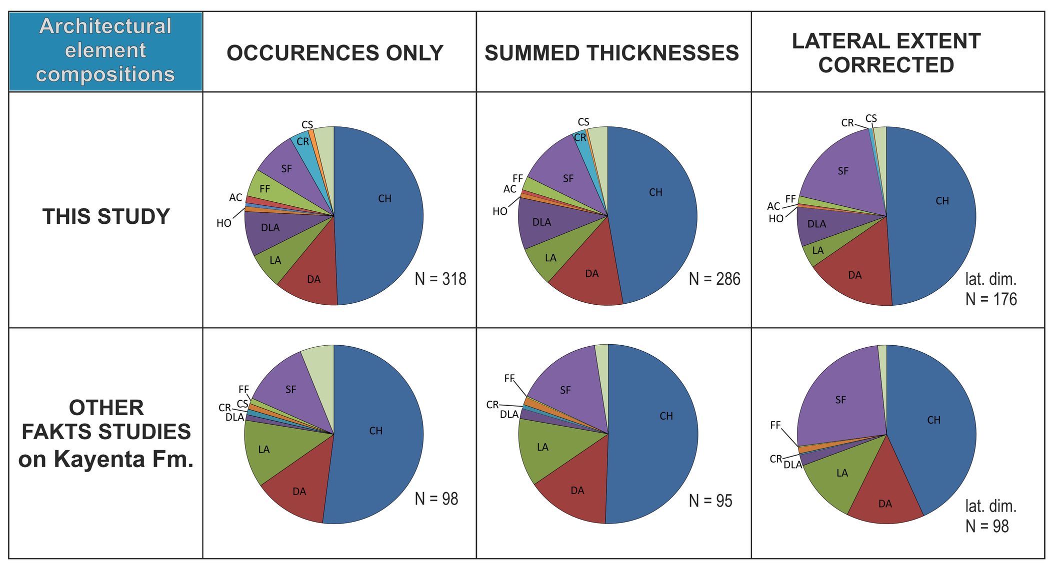
As represented above 58 artificial logs have been traced across the panel; four of them spanning the entire stratigraphy have been chosen to obtain a composite log from which facies proportions can be estimated by 'logged' thicknesses. In this case, units with the largest lateral extent (e.g. facies units *Sh* and *Sp*) are overestimated, probably due to their higher probability to be logged, as suggested by the plot of the differences in facies proportions relative to area-based estimations against unit mean lateral dimension.

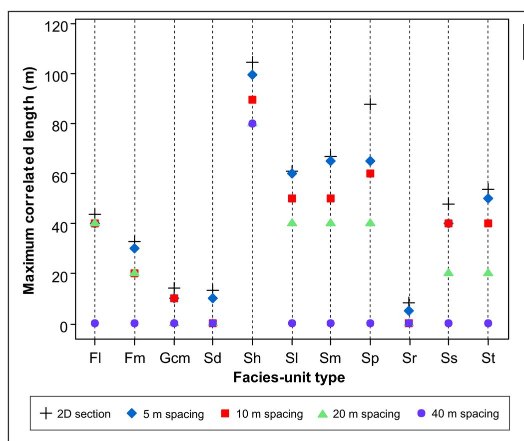


(*) Outcrop LC03 photomontage

Interpretation influence on proportions

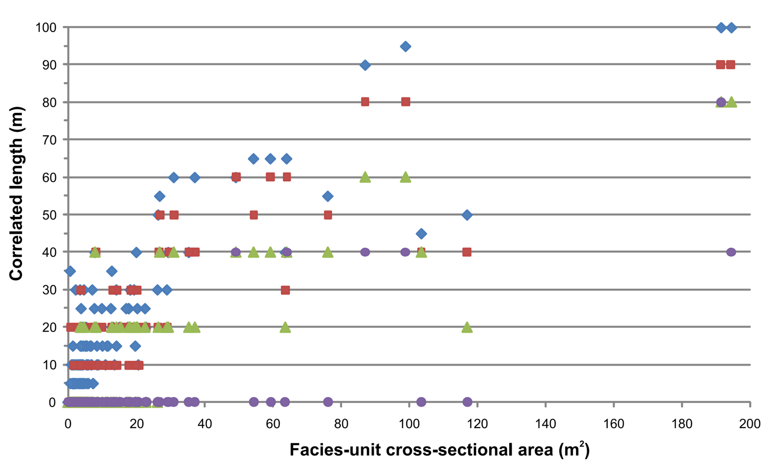
Other factors may influence the outcome of genetic-unit proportion computations, namely the quality of the interpretations, the use of different classification schemes and the resulting process of translation into FAKTS classes.
Below, we present a comparison between overall architectural element proportions obtained from this study and proportions obtained by all the other six FAKTS studies of the Kayenta Fm. together. For example, only some authors distinguish *DLA* barforms from *LA* and *DA* elements; this results in an underestimation in *DLA* elements and an overestimation in *LA* elements, with respect to this study.

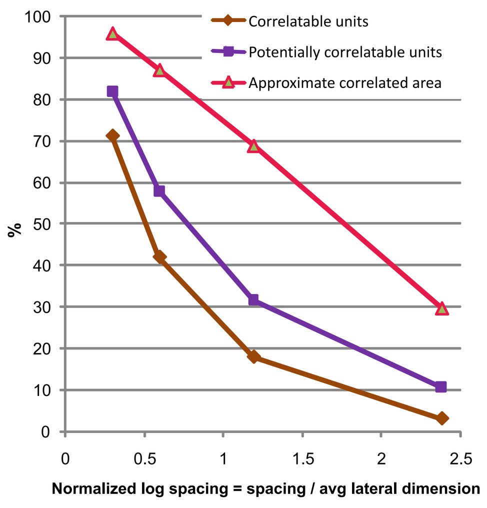


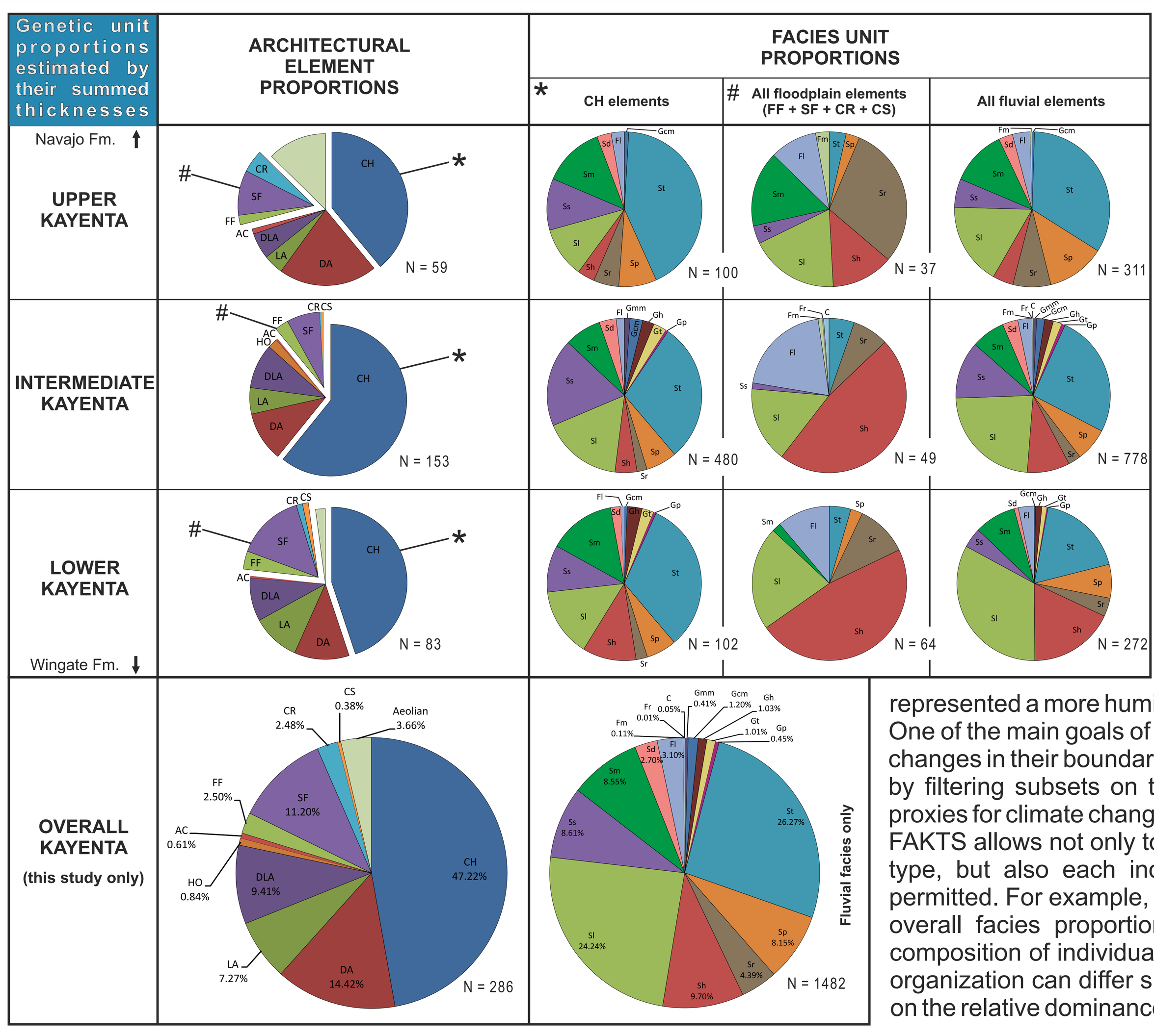


Log-spacing influence on dimensions

The database structure can be exploited for objective evaluations of the density/spacing of observations on both system characterization and interpretations. For example, it is possible to show how 1D data spacing affects the perception of genetic unit dimensions and their correlability.
To demonstrate this, the 58 artificial logs traced across the panel have been entered in a replica of the FAKTS structure, in which the specification of subset sampling spacing is implemented and several possible realizations for the same dataset included. It is then possible to determine the optimal spacing for obtaining a good estimation of dimension distribution and associated descriptive statistics. In order to make not only different setting, but also different scales comparable, the results can be presented according to a normalised dimensionless spacing, for example defined as spacing divided by the average lateral dimension of the type of genetic unit considered. In this case, with increasing spacing, the number of units we correlate decreases exponentially, but the excess approximation of the area (in turn approximating the volume) decreases linearly.

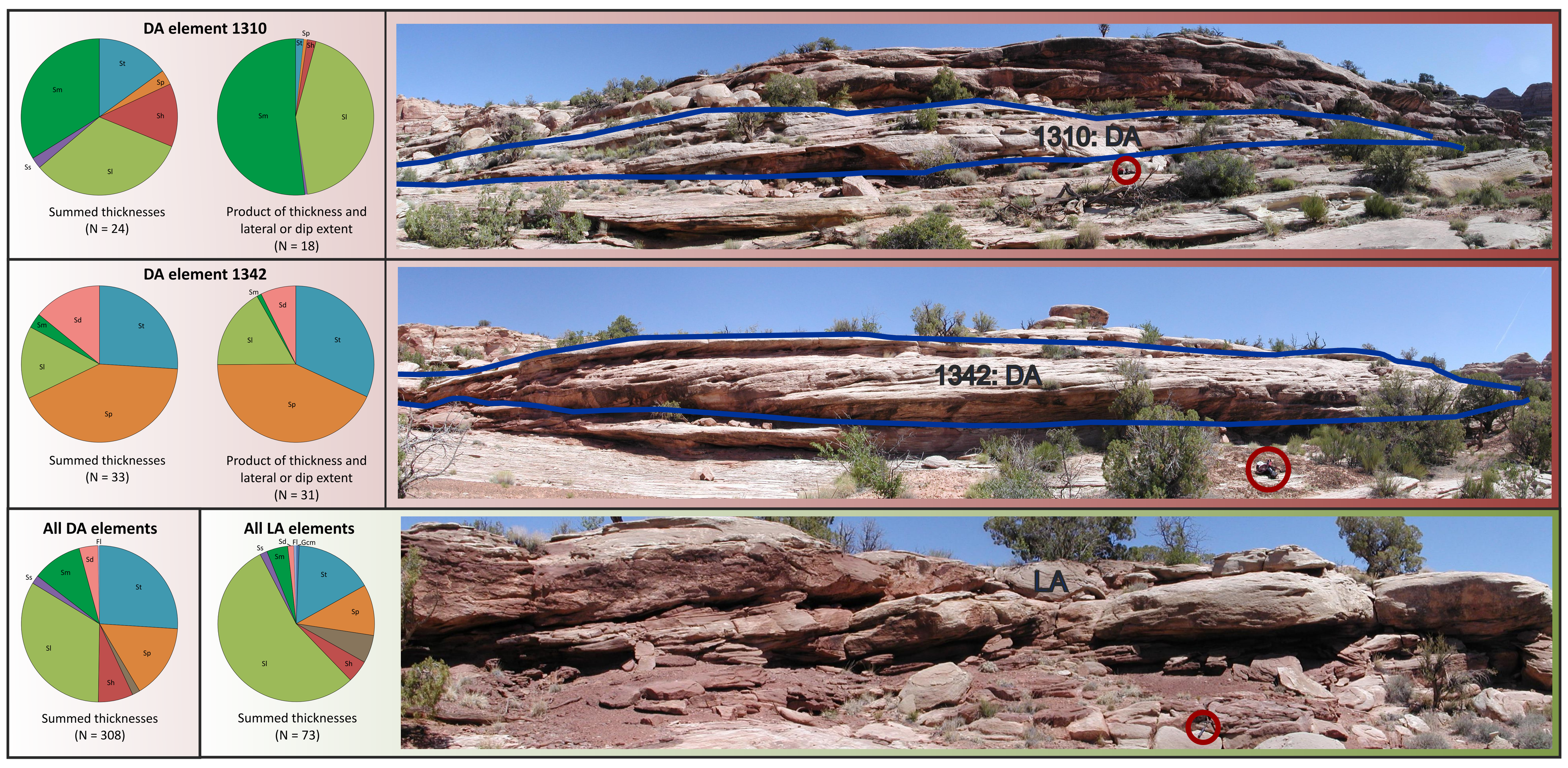






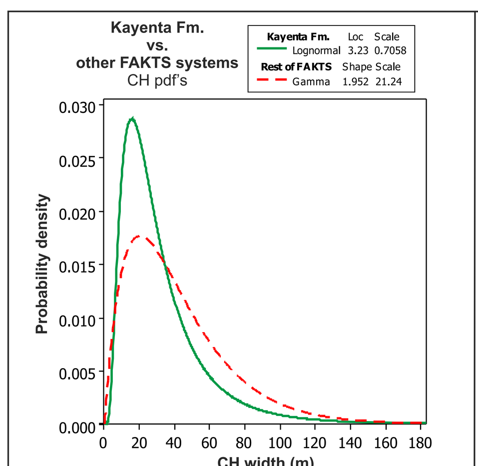
GENETIC-UNIT PROPORTIONS

The subsets into which the digitized stratigraphy is subdivided allow the attribution of temporal and spatial relative relationships, so that a representation of sedimentary trends in time and space can be derived.
Since only data from a part of SE Utah is included in this study, the spatial variability of the Kayenta fluvial system, for example in terms of proximal to distal variations, cannot be appropriately represented, although it would be a key feature in a complete FAKTS quantitative depositional model.
On the left, it is shown how architectural element and facies proportions as well as facies proportions within selected architectural elements vary across a tripartite Kayenta stratigraphy. We could use such database output to gain insights on temporally-varying controlling factors on the depositional system by means of quantitative objective comparisons, inferring variations in controls from changes in architecture. For example, comparing the three stratigraphic segments, it appears that the intermediate portion of the Kayenta Fm. is characterized by no aeolian deposits, a larger amount of *CH* elements, which are also more poorly sorted, and more frequent fine deposits within floodplain. This may suggest that in the long term the intermediate Kayenta Fm. represented a more humid Ma-scale interval.
One of the main goals of FAKTS is to understand how architectural features respond to changes in their boundary conditions. This can be achieved by analysing output derived by filtering subsets on their attributes, but it requires constraints (e.g. independent proxies for climate change) that are not available for this dataset.
FAKTS allows not only to characterize the internal composition of a given genetic unit type, but also each individual unit, so that observation of distinctive features is permitted. For example, as shown below, not only we are able to compare the internal overall facies proportions of *DA* and *LA* elements, we can also investigate the composition of individual *DA* elements. It appears in this case that the internal facies organization can differ significantly, likely depending, as suggested by the lithofacies, on the relative dominance of upper (e.g. DA 1310) or lower (e.g. DA 1342) flow regime.

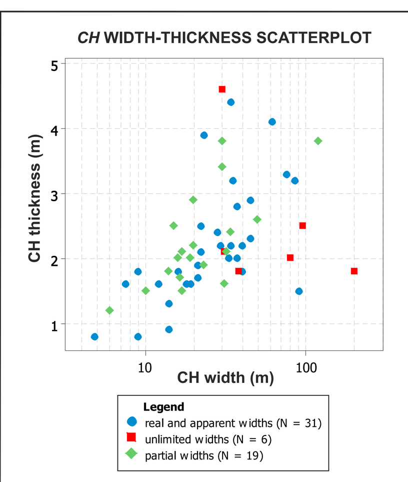


GENETIC-UNIT DIMENSIONS

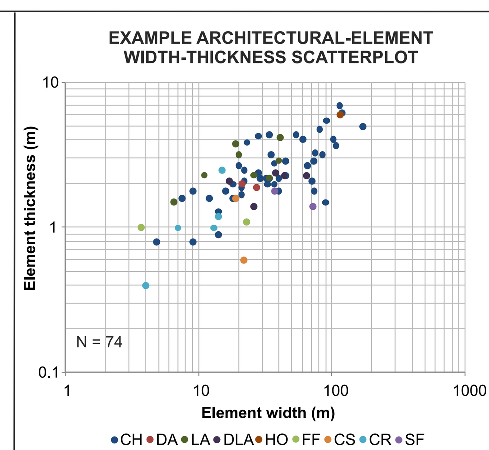
FAKTS quantitative depositional model would include also descriptors of dimensions and geometries of genetic units, possibly presenting figures from both the overall dataset and from its subdivision into spatial and temporal segments. The output is generally presented in form of frequency distributions or distribution functions of given parameters and scatterplots of dimensional parameters, from which aspect ratios can be derived. Cross-valley widths and downstream lengths are classified according to the completeness of the observations into complete, partial and unlimited dimensions (Geehan & Underwood 1993), since some observations are truncated at one limit of the observation window (partial lengths), whereas some others at both ends (unlimited lengths), or as apparent widths in case the observation is oblique to the local paleocurrent. Partial and unlimited widths are useful for (i) obtaining more realistic unit proportions and (ii) constraining to a minimum value the largest dimensional parameters.



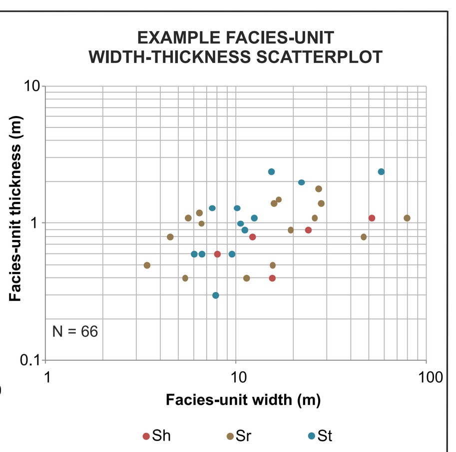
CH width probability density functions for the Kayenta Fm. case study and all the other FAKTS case studies.



Scatterplot of *CH* width/thickness aspect ratios; partial and unlimited widths are included.

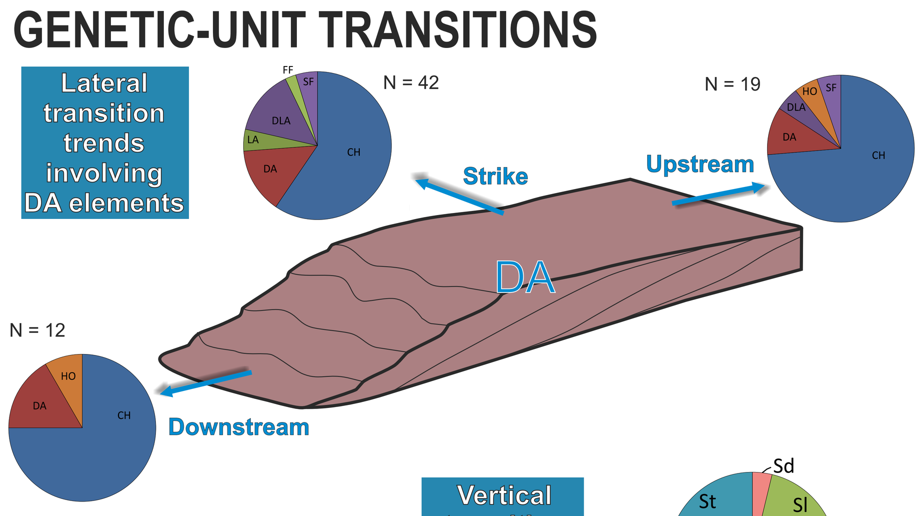


Width/thickness scatterplot for different architectural-element types; only complete widths are included.

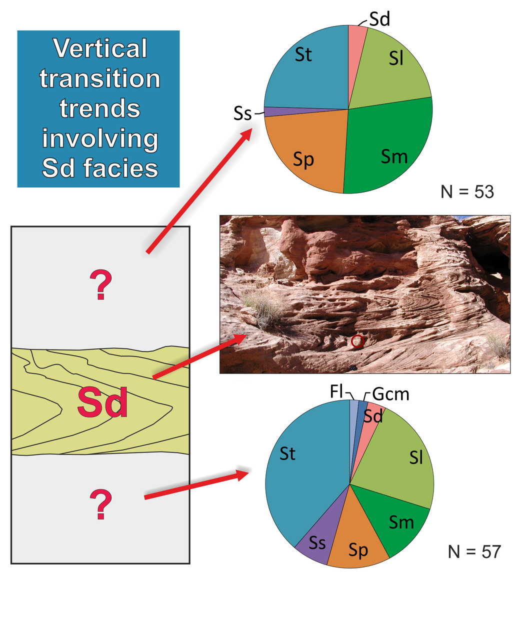


Width/thickness scatterplot for three different facies-unit types; only complete widths are included.

GENETIC-UNIT TRANSITIONS



Quantitative depositional models must take into account the reciprocal relationships between genetic units. Direct database output describing these relations is represented by transition count matrices. From the matrices we can derive specific information about individual genetic units, predicting the likelihood of lateral and vertical occurrences in the way shown in these examples. Filtering transitions on the type of higher-order genetic units in which they occur and on the bounding-surface orders across which they occur permits the fuller characterization of the internal organization of the genetic packages.



CONCLUSIONS

Depositional models are often found as qualitative descriptions of the depositional features of individual case histories; supposedly through a process of synthesis, models for the classification of fluvial systems have been elaborated (e.g. facies models; Miall 1996). Such schemes are used as conceptual frameworks for subsurface interpretations, but they lack quantitative information, therefore their predictive power is relatively poor.

Here we present a database approach that is able to generate quantitative depositional models that account for all the essential features of fluvial architecture. In this case, we show partial information from a quantitative model for the Kayenta Fm; however, the application of multiple filters to the data enables the generation of **synthetic models** (cf. Baas et al. 2005) of fluvial depositional systems, constructed by integrating data from modern and ancient fluvial systems. Thus, we aim to be able to generate facies models classified according to controlling factors (e.g. basin climate type) or context-descriptive parameters (e.g. river pattern).

The database output presented here demonstrates that FAKTS has a wider range of applications: FAKTS has also potential impact on fluvial geology research as an instrument for:

i) improving our understanding of fluvial architecture in different settings and testing sensitivity to different controlling factors;

ii) assisting prediction of subsurface reservoir architecture through deterministic or stochastic models (Colombera et al. 2012b).

REFERENCES

BAAS J.,, MCCAFFREY W.D., KNIPE R.J. (2005) Petr. Geosc. 11, 309-320.
BROMLEY M.H. (1991) Sed. Geol. 73, 77-99.
COLOMBERA L., MOUNTNEY N.P., MCCAFFREY W.D. (2012a) Petr. Geosc. 18, 129-140.
COLOMBERA L., FELLETTI F., MOUNTNEY N.P., MCCAFFREY W.D. (2012b) AAPG Bull. 96, 2143-2166.
GEEHAN G., UNDERWOOD J. (1993) IAS Spec. Publ. 15: 205-212.
LUTTRELL P.R. (1993) Sed. Geol. 85, 411-434.
MIALL A.D. (1988) Sed. Geol. 55, 233-262.
MIALL A.D. (1996) The geology of fluvial deposits: sedimentary facies, basin analysis and petroleum geology. Springer-Verlag.
NORTH C.P., TAYLOR K.S. (1996) AAPG Bull. 80, 811-830.
SANABRIA D.I. (2001) Sedimentology and Sequence Stratigraphy of the Lower Jurassic Kayenta Formation, Colorado Plateau, USA. PhD Thesis, Rice University, Houston.
STEPHENS M. (1994) Sed. Geol. 90, 179-211.

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