A relational database for quantifying fluvial sedimentary architecture:
application to discern spatial and temporal trends in Permian and Jurassic fluvial successions from SE Utah, USA

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FAKTS DATABASE

A **relational database** - the **Fluvial Architecture Knowledge Transfer System (FAKTS)** - has been devised as a tool for translating numerical and descriptive data and information about fluvial architecture coming from fieldwork and peer-reviewed literature, from both modern rivers and their ancient counterparts in the stratigraphic record. The stratigraphy of preserved ancient successions is translated into the database schema in form of genetic units belonging to different scales of observation, nested in a hierarchical fashion. Each order of unit is assigned a different table and each object within a table is given a unique numerical identifier that is used to keep track of the relationships between the different objects, both at the same scale (transitions) and also across different scales (containment). Each single dataset is split into a series of stratigraphic windows called subsets that are characterized by homogeneous attributes, such as internal and external controls. Thus, the database scheme records all the major features of fluvial architecture, including style of internal organization, geometries, spatial distribution and reciprocal relationships of genetic units, classifying datasets – either in whole or in part – according to both controlling factors such as climate type and tectonic setting, and context-descriptive characteristics (e.g. channel/river pattern, dominant transport mechanism).

Scientific literature / Field studies → Data entry procedure with fluvial architecture standardization → **DATABASE** → Interrogation → QUANTITATIVE INFORMATION → Comparative studies of fluvial architecture

Flowchart showing the data acquisition-entry-query-analysis/use workflow that has been followed to obtain the quantitative characterization of fluvial successions (Kayenta Fm. and Organ Rock Fm.) described in this poster.

Large scale depositional elements | Architectural elements | Depositional facies

SCALE: 10⁰-10² m

Representation of the main scales of observation and types of geological genetic units translated into the database in the form of tables and entries respectively. Their dimensions, qualitative attributes and relative spatial arrangement are all taken into account by the database schema.

CASE STUDIES

The database has been employed as an instrument for the quantitative description of fluvial architecture of the **Organ Rock and Kayenta Formations** (USA) in order to better characterize and compare these systems in terms of both their spatial and temporal development. Architectural data for the Organ Rock Fm. in SE Utah has been derived from work by Cain (2009). Purposely acquired field-derived data from SE Utah for the Kayenta Fm. have been integrated with results from 6 other works (Miall 1988; Bromley 1991; Luttrell 1993; Stephens 1994; North & Taylor 1996; Sanabria 2001) from all over the Colorado Plateau.

The Organ Rock Fm. (Leonardian-Artinskian) forms a wedge of coarse-grained fluvial deposits that progressively fine southwestwards, intertonguing downstream with aeolian strata.
The Kayenta Fm. (Sinemurian-Toarcian) is a continental assemblage consisting dominantly of coarse- to fine-grained sandstones, interpreted as a broad alluvial plain (with minor aeolian deposition) representing a more pluvial period in the arid climatic context of the Glen Canyon Gp..
Both successions are interpreted as arid or semi-arid terminal fluvial systems, whose internal architecture was apparently controlled by climatic cylicity (Sanabria 2001; Cain 2009; Cain & Mountney 2009; 2011).

When a significant amount of data is stored in the FAKTS database, comparative studies will be mainly conducted – and synthetic models constructed – on the basis of the boundary conditions of the depositional systems; so, these case studies only serve as **examples to show the types of quantitative information resulting from data integration (Kayenta Fm.) and subset comparison (ORF)** .

STRATIGRAPHIC CHART FOR THE SOUTHEAST UTAH REGION
Modified after Cain (2009)

	Formation
JURASSIC	Morrison Formation
	Sommerville Formation
	Curtis Formation
	Entrada Sandstone
	Carmel Formation
	Navajo Sandstone
	Kayenta Formation
	Wingate Sandstone
TRIASSIC	Chinle Formation
	Moenkopi Formation
	White Rim/De Chelly Sandstone
PERMIAN	**Organ Rock Formation**
	Cedar Mesa Sandstone
	Halgaito Shale/lower Cutler beds
PENNSYLVANIAN	Honaker Trail Formation
	Paradox Formation

Above: maps of the regional distribution of the Organ Rock and of the Kayenta Formations.

ORGAN ROCK FM.

Due to its downstream termination, the Organ Rock depositional system lends itself to the application of FAKTS for the quantification of proximal to distal variations in facies architecture. In FAKTS, the position (and/or relative distality) of every subset can be stored; subsets can then be clustered into groups of relative distality. Proximal to distal changes in the relative proportion of facies units in the Organ Rock Fm. are obtained from logged depositional facies thicknesses. *Gmm, Fl, Fm* and *P* deposits can be considered as non-reservoir facies, and net-to-gross (NTG) ratios derived.

Proximal region — N = 320, NTG = 0.96
Medial-proximal region — N = 1064, NTG = 0.93
Medial region — N = 2009, NTG = 0.94
Distal region — N = 1777, NTG = 0.95

Organ Rock Fm. facies composition - after log data from Cain 2009 (84 logs)

Legend: G-, Gcm, Gp, Sp, Sh, Sd, Fm, Gmm, Gt, Sr, Sm, Fl, P, Undefined

Cyclicity model for climate as a primary control on deposition
Modified after Cain (2009)

On the basis of a climate-driven cyclicity model proposed by Cain (2009) for the Organ Rock Fm., seven stratigraphic segments have been established as clusters of subsets characterized by inferred relative changes in system humidity. The dataset includes 22 logs; after log-to-log correlation, each log has been subdivided into subsets corresponding to the seven stratigraphic segments. Proportions of facies units for each stratigraphic segment were obtained from the sum of logged depositional facies thicknesses.

The facies organization of the stratigraphic segments is obviously characterized by increases in aeolian facies corresponding with drier episodes, as these facies are used as the main proxies for humidity change. Within the stratigraphic segments corresponding to the drying-upward cycle 1 (DUP-1, segments B, C and D) and to the wetting-upward cycle (WUP, segment E), the proportions of facies that are only fluvial in origin do not show any marked change across the segments.

A substantial change in facies architecture is instead observed between the drying-upward cycle 2 (DUP-2, segments F and G) and the underlying deposits: the uppermost part is characterized by a strong reduction in the proportion of in-channel facies and an increase in the proportion of unconfined-flow facies and soft-sediment deformed deposits, due to changes in the sedimentary style of the medial part of the system.

Legend — Sedimentary Facies: Proximal/medial fluvial facies (FPU); Distal fluvial facies; Aeolian dune facies; Aeolian sandsheet facies. Surfaces: Top of drying-upward cycle (DUP) (max. aridity); Top of wetting-upward (WUP) cycle (max. humidity); Base Organ Rock Formation. WUP Wetting-upward cycle; DUP Drying-upward cycle.

ALL FACIES PROPORTIONS

Facies proportions within the 7 stratigraphic segments established from the climate-driven cyclicity model by Cain (2009).

N = 268 (A, BASE OF SUCCESSION), N = 320 (B), N = 201 (C), N = 289 (D), N = 506 (E), N = 234 (F), N = 54 (G, TOP OF SUCCESSION)

ONLY FLUVIAL FACIES PROPORTIONS

Legend: Gcm, St, Sp, Sr, Sh, Sm, Sd, Fl, Fm, P, Aeolian

Depositional lithofacies and architectural element type codes; modified after Miall (1996).

Code	Depositional facies type
G-	Gravel to boulders – undefined textural and structural properties
S-	Sand – undefined textural and structural properties
F-	Fines (silt, clay) – undefined textural and structural properties
Gmm	Matrix supported massive gravel
Gmg	Matrix supported normally or inversely graded gravel
Gci	Clast supported inversely graded gravel
Gcm	Clast supported massive gravel
Gh	Horizontally-bedded or imbricated gravel
Gt	Through cross-stratified gravel
Gp	Planar cross-stratified gravel
St	Through cross-stratified sand
Sp	Planar cross-stratified sand
Sr	Ripple cross-laminated sand
Sh	Horizontally laminated 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 mud
Fsm	Laminated to massive silt and mud
Fm	Massive mud and silt
Fr	Fine-grained root bed
C	Coal or carbonaceous mud
P	Palaeosol carbonate

Code	Architectural element type – geomorphic significance
CH	Vertically accreting (aggradational) channel (fill)
DA	Downstream accreting macroform
LA	Laterally accreting macroform
DLA	Downstream + laterally accreting or undefined accretion direction macroform
SG	Sediment gravity flow body
HO	Scour hollow fill
LV	Levee
AC	Abandoned channel (fill)
FF	Overbank fines
SF	Sandy unconfined sheetflood dominated floodplain
CR	Crevasse channel
CS	Crevasse splay
LC	Floodplain lake
C	Coal body

COMPARISON ORGAN ROCK FM.-KAYENTA FM.

Channel-fill (CH) W/T aspect ratios

Scatter-plot of width:thickness aspect ratios for CH elements; including total and apparent widths only (incomplete width measurements associated with partial exposure have not been included).

Kayenta (37) · ORF (79)

Architectural element proportions

Overall Organ Rock Fm. — N = 397
CH 77.45%, FF 9.81%, AC 0.25%, DA 0.08%, LA 1.54%, CS 0.60%

Overall Kayenta Fm. — N = 260
CH 52.1%, LA 11.6%, DA 13.4%, SF 13.1%, DLA 5.1%, CR 1.2%, SG 0.3%, AC 0.2%, HO 1.2%, FF 0.4%, SF 1.6%

Legend: CH, HO, DA, AC, CR, FF, SG, LA, DLA, SF, CS

Proportions of facies overlying CH erosional channel-bases

Right: proportions (number) of facies occurring at the erosive base of channel-fills (right), obtained selecting only facies units belonging to CH element and overlying 4th or higher order bounding surfaces.

Organ Rock Fm. — N = 33
Kayenta Fm. — N = 114

Facies proportions within CH elements
Organ Rock Fm. — N = 133
Kayenta Fm. — N = 339
Legend: Fm, Fl, St, Sp, Sr, Sh, Sl, Gcm, Gmm, Gh, Gt

Below: bar-charts representing percentages of vertical facies transitions within CH elements.

Facies vertical transitions within CH elements
Organ Rock Fm. / Kayenta Fm.
Percentage of vertical transitions

Legend – upper facies units: Fm, Fl, St, Sp, Sr, Sh, Sl, Sm, Sd, Gcm, Gmm, Gh, Gt
N (K) = 263 · N (ORF) = 133

Facies unit proportions
Overall Organ Rock Fm. — N = 4632
Overall Kayenta Fm. — N = 761

Proportions of genetic units computed as the product of occurrences and average element thickness (architectural elements) or summed measured thicknesses (facies units); ORF data from Cain (2009) and Kayenta data from own fieldwork integrated with data from Miall (1988), Bromley (1991), Luttrell (1993), Stephens (1994), North & Taylor (1996), and Sanabria (2001).

With FAKTS, individual and co-occurring features of fluvial architecture can be compared quantitatively, allowing objective comparisons between systems to be made.

The internal organization of genetic packages can be characterized in terms of the objects belonging to lower-order scales. Information on genetic unit internal organization includes compositions and spatial distributions, respectively described by relative proportions and trends in transitions of lower-order building blocks. Further insight into genetic unit spatial arrangement can be obtained relating the occurrence of given genetic units to the order of their bounding surfaces (cf. Miall 1996). For a fuller understanding on fluvial architecture, information on the internal organization of genetic units can be coupled with information on their geometry and dimensions.

In comparison with the Organ Rock Fm., the Kayenta Fm. is characterized by a smaller volume of non-fluvial deposits. The Kayenta fluvial domain has a larger in-channel:floodplain ratio, associated with less frequent and narrower aggradational channel-fills, with more frequent downstream- and laterally-accreting barforms, and with a tendency to develop more sandy sheetflood-dominated elements rather than fine-grained floodplain elements.

The apparent absence of *Sl* and *Ss* facies within the Organ Rock Fm. and its larger amount of *Sh* and *Sm* facies in comparison to the Kayenta Fm. are probably the result of different facies codes and field practices (inclusion of low-angle lamination into horizontal plane beds and no recognition of scour fills, for the ORF). This demonstrates that care must be taken when combining data from different case studies or making dataset comparisons.

CONCLUSIONS

Architectural data from the Organ Rock and Kayenta Formations have been used to demonstrate the ability of FAKTS to **describe fluvial architecture and its spatial and temporal variability in a quantitative way**. Once a larger number of classified case studies are digitized, quantitatively justified comparative studies will be performed to **test architectural sensitivity to different external and internal controlling factors**, in order to improve our understanding of fluvial architecture in different settings. Other FAKTS far-reaching objectives include (1) the **compilation of synthetic depositional models**, obtainable through dataset integration, with which we aim to overcome traditional depositional and facies models, and (2) the production of output – tailored to external controls and internal parameters – which can be used to **assist the prediction of subsurface reservoir architecture** through deterministic and stochastic models.

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