

**A database for the digitization of the sedimentary architecture  
of fluvial systems: uses in pure and applied research**

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The candidate confirms that the work submitted is his own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated overleaf. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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## Abstract

A relational database has been devised as a tool for the digitization of features relating to the sedimentary and geomorphic architecture of modern rivers and ancient fluvial successions, as derived from either original field studies or published examples. The system has been designed in a way that permits the inclusion of hard and soft data – comprising geometries and spatial and hierarchical relationships – referring to classified genetic units belonging to 3 different hierarchical levels, and assigned to stratigraphic volumes that are categorized in terms of deposystem boundary conditions and descriptive parameters.

Several applications of the quantitative information generated through database interrogation have been explored, with the scope to demonstrate how a database methodology for the storage of sedimentary architecture data can be of use for both pure and applied sedimentary research.

Firstly, an account is given of how the system can be employed for the creation of quantitative fluvial facies models, which summarize information on architectural styles associated with classes of depositional systems. The value of the approach is shown by contrasting results with traditional qualitative models.

Secondly, database output on large-scale fluvial architecture has been used in the context of a comparative study aiming to investigate the role of basin-wide aggradation rates as predictors of fluvial architectural styles. The results contrast with what might be expected by commonly considered stratigraphic models; the main implication is the necessity to reconsider continental sequence stratigraphy models or their domain of applicability. This application further provides an example of how the methodology could be generalized to the study of the sensitivity of architecture to its controls.

Thirdly, database output has been used to conduct a re-evaluation of previously-proposed approaches to the guidance of well-to-well correlations of subsurface fluvial channel bodies, applied in earlier studies. Making use of the same analogue information, a new probabilistic approach has been proposed as a way to inform or rank correlation panels of channel bodies across equally-spaced wells.

Finally, the value of the system as an instrument for constraining object- and pixel-based stochastic structure-imitating models of fluvial sedimentary architecture is collectively demonstrated through a range of example applications employing database output.



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## Abbreviations

1D	one-dimensional
2D	two-dimensional
3D	three-dimensional
DMAKS	Deep-Marine Architecture Knowledge Store
DQI	Data Quality Index
DWAKB	Deep-Water Architecture Knowledge Base
FAKTS	Fluvial Architecture Knowledge Transfer System
GSLIB	Geostatistical Software Library
HAST	High-accommodation systems tract
LAB	Leeder-Allen-Bridge
LAST	Low-accommodation systems tract
MPS	Multiple-point statistics
SIS	Sequential Indicator Simulation
SQL	Structured Query Language
T-PROGS	Transition-Probability Geostatistical Software
UK	United Kingdom
USA	United States of America
WSG	Walloon Subgroup

# 1 Introduction

## 1.1 Rationale

Fluvial sedimentary successions are important both scientifically and economically, since they represent sensitive recorders of environmental conditions in continental settings at the time of deposition and accumulation, and act as hosts for important natural resources including water, metals and hydrocarbons. Hence, sedimentological studies have been extensively carried out on modern rivers and ancient successions to enhance understanding of the facies architecture of fluvial systems, with either the aim of developing new techniques and knowledge with which to decipher the geological record or of establishing predictive models that describe the distribution of sedimentary heterogeneities, which themselves are key fundamental controls that dictate the distribution of natural resources. Key architectural properties targeted by sedimentological studies comprise the proportion, the external and internal geometries, the hierarchical relationships and the spatial arrangement of sedimentary units present in fluvial systems and their preserved successions at a variety of scales. A vast amount of such architectural data have been collected in the last four decades, especially in outcrop studies, and typically rendered available in published form. As the amount of sedimentological and architectural data available has increased over time, so a fundamental issue has become ever more important and significant: the need to ensure that different datasets collected in different ways by different geologists (e.g. 1D vertical graphical log profiles, 2D architectural panels, plan-form morphological information) are somehow stored in a format such that direct comparisons between fundamentally different types of data that were originally collected in different ways can be made in a sensible and informative manner, without requiring extensive literature search and re-processing each time the analyses of given families of data are attempted. This problem is not trivial, though the benefits of developing a solution are potentially considerable: if this problem were overcome the usefulness of the primary data for research would be enhanced, for example through facilitation of synthesis or comparison. Since the solution to this problem requires datasets to converge in a common medium, one approach to tackling this issue is to devise a method to effectively store and retrieve sedimentological data and interpretations. A database-oriented technique that largely fulfils this task has previously been developed for deep-marine depositional systems by Baas et al. (2005), from whose

work inspiration has been drawn for this project. The underlying drive of the current work is to demonstrate how a relational database can practically be employed as a means for the collation of fluvial architecture data, with the aim of ensuring the continuing value of the data for pure and applied science.

## 1.2 Aims and Objectives

The fundamental aim of this Thesis is to demonstrate how a database system for the digitization of fluvial sedimentary and geomorphological architecture can be applied to the wider scope of sedimentary research to address a series of recognized research questions, which those working on problems in fluvial sedimentology and stratigraphy have hitherto not been able to address due to the lack of an appropriate tool for sophisticated data analysis. Ultimately, this is achieved in the current work by employing a novel and innovative database system in example applications relevant to both pure and applied fluvial research, which demonstrates how such a methodology has the potential to advance scientific knowledge and refine subsurface-related practices. In achieving this overarching aim, each illustrative application represents a stand-alone piece of research (a sub-project), which itself attempts to answer a series of specific research questions. Many of the research targets pursued in the context of each sub-project are included in the following list and these represent the specific objectives of this Thesis:

- Identify what architectural characteristics of fluvial depositional systems need to be considered and are deemed appropriate and suitable for inclusion in a database. Devise efficient ways to standardize the related forms of data and encapsulate them in a suitable and versatile digitized format.
- Develop novel and innovative approaches to the quantitative characterization of the depositional architecture of specific classes of fluvial depositional systems, typified by facies models (*sensu* Walker 1984). Refined approaches to the development of quantitative facies models could help identify and tackle related research questions, to which some consideration is given in this work; in particular, attention is given to broad research objectives concerning for example the recognition of classes of fluvial systems that are the most appropriate for facies model categorization and which yield the greatest predictive power or the validation of rock-record interpretations by comparison with the facies organization of modern systems for which system and unit classifications are straightforward.



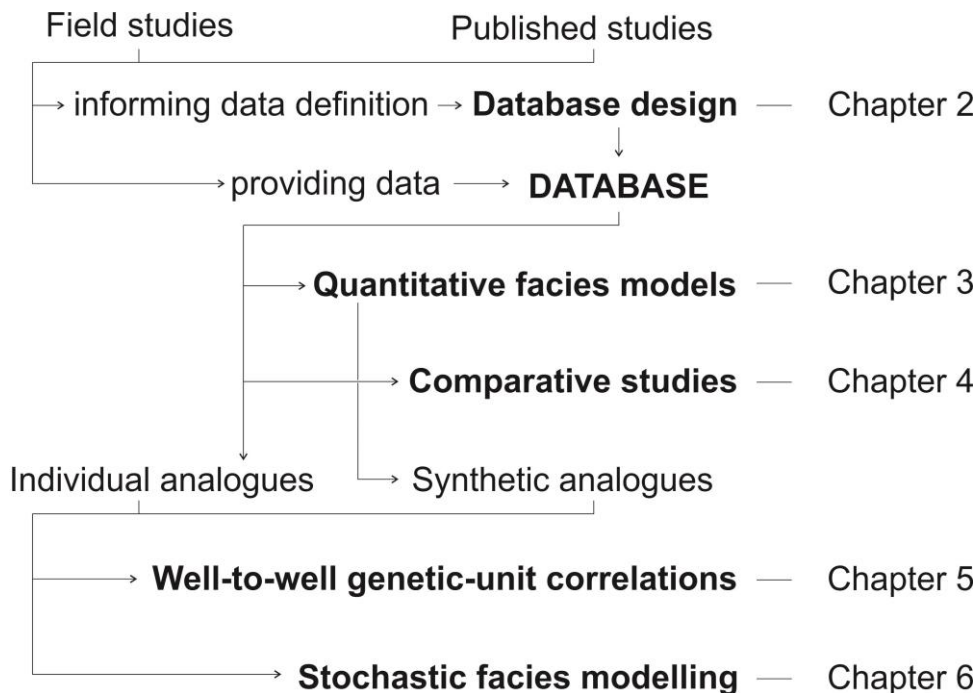
- Improve understanding of the preserved architectural signature arising from both autogenic and allogenic factors that act to control depositional architecture, which can be explored through quantitative comparative studies. Particular focus is given to the investigation of the role of aggradation rate as a predictor of large-scale fluvial architecture by testing whether consistent relationships between changes in rates of basin-wide aggradation and architectural styles are shown across different systems regardless of the different controls determining changes in aggradation rate. One of the main aims of the work is to test the validity of current assumptions that are implicitly embedded in popular sequence stratigraphic models involving the notion that changes in channel-deposit density and geometry are a diagnostic indicator of changes in rates of creation of accommodation space.
- Test the predictive value of empirical relationships that are commonly referred to for forecasting the lateral extent of fluvial-channel sandstone bodies in subsurface successions of economic interest; an additional related objective is to present alternative empirical relationships to further constrain deterministic models of large-scale fluvial architecture in the subsurface.
- Devise a method for quantitatively ranking the geological realism of alternative interpretations of well-to-well correlation panels involving the lateral tracing of fluvial channel complexes across a constantly-spaced well array, by comparing the correlation panels with ideal models incorporating likelihood of channel-complex penetration and correlation based on database geometrical information.
- Set up a database practice that provides straightforward constraints to stochastic models of subsurface fluvial sedimentary architecture at various scales. Specific objectives of this work relate to the establishment of procedures that permit (i) obtaining constraints to object-based models that consider hierarchical and spatial relationships, and (ii) the exploitation of an object-oriented database for the derivation of parameters for conditioning pixel-based simulations.

### **1.3 Thesis outline**

This Thesis commences with a discussion of how best to capture and record data relating to sedimentary architecture in the digital form of a relational database. This involves an overview of the devised database structure and of the form and geological significance of its output (Chapter 2). Different fields of application of the

database output are then explored in the following four chapters. Necessarily, there are connections between the applications; for example, the practice related to the compilation of a quantitative fluvial facies model (Chapter 3) is inherently linked with subsurface-related practices (Chapters 5 and 6), as the database facies modelling approach may find direct application to the generation of a synthetic analogue with which to inform deterministic or stochastic hydrocarbon reservoir models. Significantly, each chapter represents a self-contained piece of research and was therefore conceived as an independent published or publishable work; as a result, the Thesis lacks general introductory and discussion sections that have traditionally been present in works of this type; instead, the scientific background, aims and objective and discussion of each sub-project are given separately in each chapter. Importantly, the content of the chapters are the result of work that was not carried out in a temporal order that corresponds with the numbering order of the chapters. Furthermore, the database was populated progressively and incrementally while the different applications that comprise the various chapters were being explored; for example, results from Chapter 3 incorporate more data than most of the results in Chapter 6.

An overview of each single chapter is given in the following paragraphs, and relationships involving data and information presented or used in each of them are summarized graphically in figure 1.1.



**Figure 1.1:** flowchart depicting the relationships between original field- and literature-derived data or database output information and the use made of data and information in each chapter.

**Chapter 2** concentrates on the description of the process of digitization of fluvial sedimentary architecture and its storage within the framework of a relational database. This chapter first focuses on the database structure and on the process of standardization needed to ensure that the recorded case studies are comparable; it then considers a range of example output and discusses possible applications. The chapter provides an account on how the system captures and quantifies basic architectural attributes like genetic unit types, geometries, reciprocal spatial and hierarchical relationships, and on how it tackles problems connected to data standards; some of these problems arise especially from the need to include interpretative classes, as does, for example, the fact that adopted classifications inevitably reflect only current understanding. The chapter concludes by giving an insight into the potential applications of database output, which are treated in greater detail in the following chapters.

In **Chapter 3** attention is given to a practice involving the use of the architectural database in the compilation of fluvial facies models. The generation of quantitatively-justified fluvial facies models is demonstrated through a series of example models based on the synthesis of database-derived information from sets of relevant depositional systems. The methodology finds application to various research problems: it can be used, for example, to determine what classes of depositional systems are most suitable for facies modelling, or to answer the need for provision of sedimentological 'general summaries' that constitute more flexible references than traditional idealized sedimentary graphic logs or block diagrams. The value of these database-derived facies models as quantitative synthetic analogues to subsurface systems is considered in greater detail in Chapters 5 and 6.

The development of quantitative fluvial facies models as obtained by following the procedure outlined in Chapter 3 also permits the quantitative appreciation and definition of the type of architectural characteristics that may be associated with given system boundary conditions. Architectural differences across models cannot necessarily be taken as diagnostic of the specific controls on which the models are categorized, as many different allogenic factors typically interplay with autogenic dynamics in a complex manner, resulting in a wide variety of architectural styles; however, distinctive architectural styles and trends emerging from the generalized models can be used to address certain specific research hypotheses. The application of the architectural knowledge base to study the importance of rates of creation of accommodation as a factor with predictive value is presented in **Chapter 4**, within which a comparative study is carried out between several case histories

for which both sedimentary architecture and rates of floodplain aggradation are constrained. A primary outcome of this work is, in effect, a test of common physical stratigraphy models relating architectural properties to accommodation; as such, emphasis is given to the implications that results of this study may have for continental sequence stratigraphy.

In Chapters 5 and 6 attention is turned to the use of the architectural database as a predictive tool in subsurface-related practices.

In **Chapter 5**, the analogy concept is applied to the derivation of probability-based models that can be used to assess the likelihood of well correlation panels in which fluvial channel complexes are traced laterally across wells. The chapter explains, from first principles, how the method allows a quality-check of subsurface deterministic models to be performed by comparing correlation patterns with the ones expected for an analogue system on a probabilistic basis; results highlight how this approach has implications concerning the possibility to better predict the distribution, size and static connectivity of reservoir-quality genetic units.

In **Chapter 6**, methodologies are outlined that employ the database output to variably condition object- and pixel-based structure-imitating stochastic simulations of fluvial sedimentary architecture. Outcrop-analogue databases have long been applied to derive simple geometrical constraints to object-based models; this chapter deals with the improvements in conditioning determined by the database capacity to provide information about spatial and hierarchical relationships, object connectivity and stacking patterns, resulting in a wider variety of constraints to object- (or event-) and pixel-oriented simulations.

Finally, **Chapter 7** firstly provides a brief summary of the work, presenting conclusions in response to the Thesis aims stated above. Possible further improvements of the method and areas of future research are also discussed; in particular, this concluding chapter highlights the portability of the database applications treated in this Thesis to other clastic (and arguably carbonate) depositional systems, which makes this work valuable as a point of reference for a possible generalization of the approach.

## **2 A relational database for the digitization of fluvial architecture: concepts and example applications**

### **2.1 Summary**

Depositional facies models of fluvial architecture permit straightforward categorization of deposits, but are necessarily simplistic. Here a complementary database methodology is described, which is designed to encapsulate the inherent complexity of fluvial systems and their preserved deposits. The database is implemented as a series of tables (characterising qualitative and quantitative architectural and geomorphological properties and system attributes) populated with data derived from peer-reviewed studies of both modern rivers and ancient fluvial successions, and from other reliable sources. Architectural properties (geometries, internal organization, spatial distribution and reciprocal relationships of lithosomes) are assigned to 3 different orders of genetic bodies organized in a hierarchical framework, ultimately belonging to stratigraphic volumes that are homogeneous in terms of their controlling factors and internal parameters. Interrogation of the database generates a varied suite of quantitative information, whose principal applications include: (i) the quantitative comparison of fluvial architecture to evaluate the relative importance of intrinsic and extrinsic controls; (ii) development of quantitatively justified fluvial depositional models through the integration of data from multiple sources; (iii) development of better constraints on the workflows used to infer borehole correlations and to condition stochastic models of subsurface architecture; (iv) identification of appropriate modern and ancient analogues for hydrocarbon reservoirs.

### **2.2 Introduction**

Fluvial architecture can be defined as the ensemble of geometries, internal organization, proportions, spatial distribution and reciprocal relationships of genetic bodies within fluvial successions (Allen 1978; Miall 1996). These features are expressed over a wide range of scales, and an intimate relationship exists between fluvial forms and the associated sediment deposits generated as a product of their migration and accumulation (Bridge 2006). From an applied perspective,

characterizing and predicting subsurface fluvial architecture is important because it aids determination of heterogeneity and interconnectedness of reservoir-quality rocks. As a result, many conceptual models that attempt to account for complexity in fluvial stratigraphic architecture based on both autogenic fluvial system behaviour and response to allogenic controls have been proposed as reference points to guide interpretation and prediction (e.g. Walker & James 1992; Bridge 2006).

The architecture of fluvial systems is controlled by a number of intrinsic (intrabasinal) factors that are ultimately linked through a series of dependent variables to extrinsic (extrabasinal) controls that are themselves commonly considered in terms of climate, tectonics, eustatically-driven base-level changes (Miall 1996; Bridge 2006 and references therein), and hinterland geology. Although field-based models relating changes in fluvial architecture to changes in boundary conditions have been developed (e.g. fluvial sequence models of Shanley & McCabe 1993 and Wright & Marriot 1993), fluvial architecture is known to record complex interactions between allogenic and autogenic controls. Recognizing the relative importance of the different factors is not straightforward, and suggestions of control-response relationships of supposed general applicability and validity from single field studies can be misleading. For this reason, numerical models (e.g. Leeder 1978; Allen 1978; Bridge & Leeder 1979; Mackey & Bridge 1995; Heller & Paola 1996), and physical laboratory models (e.g. Peakall et al. 1996; Ashworth et al. 1999; Sheets et al. 2002; Hickson et al. 2005) have become popular instruments for enhancing understanding of relations between controls on fluvial systems and their preserved architecture, since the role of individual factors can be isolated. However, these techniques also have limitations, for example due to conditioning and scaling problems.

Schemes based on planform channel/river pattern, type of dominant sediment load, and dominant grain size (e.g. Orton & Reading 1993) have been proposed for the classification of fluvial systems. Although such schemes have been used as conceptual frameworks for subsurface interpretations (Allen 1965a; Galloway 1981), their descriptive value is limited given the wide range of natural variability known for fluvial systems (Miall 1985), and their predictive power is therefore relatively poor. End-member styles of fluvial geomorphology have been used as a basis for classifying facies models, which attempt to summarize the types of facies, facies associations, and facies relationships that tend to occur in a particular environment. The development of such facies models results from a process of distillation of many real-world examples; a facies model ideally acts as a norm for comparison, a basis for interpretation, a guide for future observations and a predictor for new geological situations (Walker 1984). Examples of popular fluvial

facies models include the ones proposed by Miall (1985; 1996) for different fluvial environments, each with its own architectural style. However, the usefulness of such facies models is restricted by their qualitative nature (North 1996), which renders them of limited use in quantitative subsurface prediction.

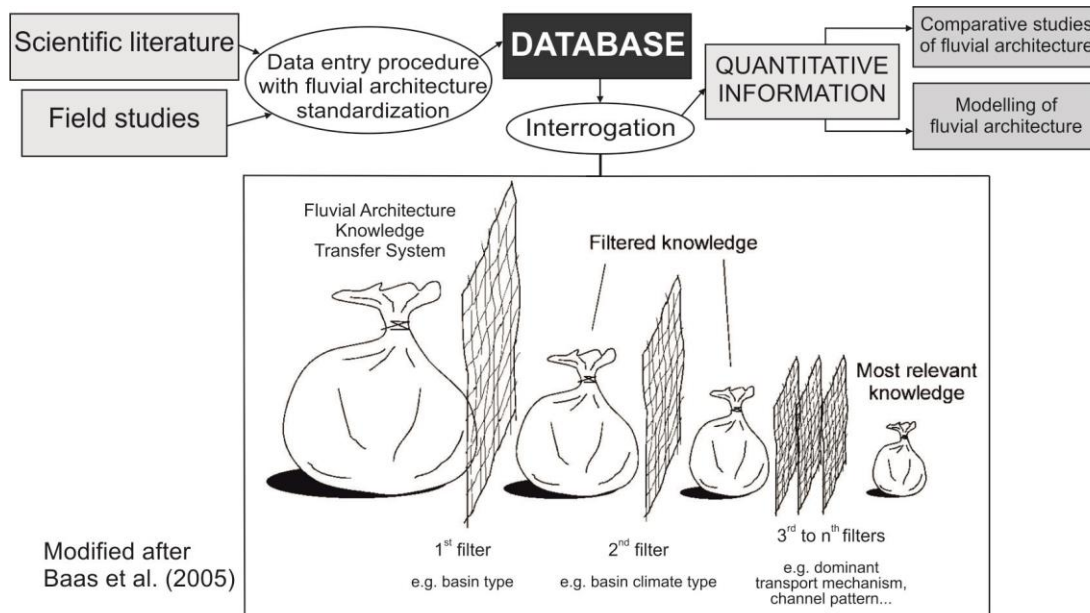
Ancient outcrop and modern river analogues considered closely comparable to subsurface depositional systems are commonly chosen on the basis of similar environmental characteristics and controlling parameters, and these are commonly investigated with the aim of providing quantitative information regarding reservoir character. However, the analogue approach has serious shortcomings (Bridge 2006), most notably the difficulty in reliably and confidently matching outcrop or surface interpretations to subsurface models.

An innovative method for overcoming the existing limitations of depositional models, facies models and the analogy concept has been proposed by Baas et al. (2005) for deep-marine clastic sedimentary systems. The approach involves the collation, within a relational database, of literature-derived data and information regarding the architecture of these depositional systems and their internal and external parameters. Quantitative analysis of data stored in the database allows objective comparisons between systems to be made (which can be especially helpful in the choice of appropriate analogues and in the assessment of the importance of controlling factors) and the creation of synthetic idealized depositional models for ranges of external controls and internal parameters.

A significant amount of data on fluvial architecture has been gathered and made available in peer-reviewed publications over the past four decades, with primary data available in different forms, including sedimentological logs, architectural panels, and plots of dimensional parameters. However, many studies focus on just a single aspect of fluvial architecture and are centred on a narrow range of physical or conceptual scales.

The aim of this chapter is to introduce a methodology for the incorporation of available data relating to modern and ancient fluvial systems into a relational database, named the Fluvial Architecture Knowledge Transfer System (FAKTS). Through the development of this tool, we aim to devise a system capable of combining partial information derived from many individual studies in order to gain insight into the nature of recurring controls that act to dictate fluvial architecture (Figure 2.1). Specific objectives of this work are: (i) to outline the conceptual and logical schemes of the database, providing a brief explanation of its main components; (ii) to show in which form we can obtain quantitative information by

querying the database; (iii) to demonstrate how this quantitative information can be useful for both research and applied interests.



**Figure 2.1:** flow chart illustrating the data acquisition-entry-query-analysis-use workflow described in this work. The cartoon for the 'database interrogation' stage (modified after Baas et al. 2005) depicts how the application of multiple data filters leads to the extraction of the most relevant data.

## 2.3 FAKTS: approach and implementation

### 2.3.1 Approach

The use of databases as instruments for the collection, storage and analysis of data and information on sedimentary architecture has demonstrated their potential use in a range of pure and applied sedimentary research applications (Dreyer et al. 1993; Baas et al. 2005; Gibling 2006). In contrast to other databases holding content on sedimentary architecture (Dreyer et al. 1993; Baas et al. 2005), the database approach discussed herein (FAKTS) allows the digitization of all the architectural properties of individual features (depositional elements, architectural elements, facies units) of fluvial architecture, instead of just storing quantitative summary data. The scales commonly recognized in fluvial stratigraphy are particularly suited to description in a hierarchical way (Miall 1985; 1996; Leeder 1993; Bridge 2003). Thus, in FAKTS, the stratigraphy of preserved ancient successions and the geomorphic and sedimentary architecture of modern rivers are translated into the database schema by subdividing them into geological objects that are common to both the stratigraphic and geomorphic realms and which belong to different scales



of observation nested in a hierarchical fashion. Each single dataset is split into a series of stratigraphic windows or planform segments (named *subsets*) characterized by having the same attribute values, with attributes describing internal features of the systems and their external controls. Each subset is broken down at the largest scale into depositional elements defined as channel-complexes and floodplain segments with distinct geometrical properties. Each depositional element can be subdivided into a suite of architectural elements, which in turn can be further subdivided into the depositional facies from which they are constructed. The spatial relationships between these elements are stored as transitions along the vertical, cross-gradient and down-gradient directions. So, all significant aspects of fluvial architecture – genetic packages, geometries, relative proportions, relationships and internal properties – are accounted for in the database conceptual model (entities and relationships; Chen 1976) and resulting logical model (tables, attributes and relationships). The approach adopted for feature definition and representation is summarized below.

### **2.3.2 Data definition and standardization**

One of the key aspects of FAKTS is the classification of each case study example and parts thereof on the basis of traditional classification schemes (e.g. dominant transport mechanism, channel/river pattern), external controlling factors (e.g. description of climatic and tectonic context), and associated dependent variables (e.g. basin vegetation type and density, suspended sediment load component).

This context-descriptive information is linked to combinations of quantitative (hard) and qualitative (soft) data which describe fluvial architecture. Soft data stemming from interpretations (typically acquired from the published literature, though also from direct outcrop study) are used for defining the types of constituent units that build sedimentary architecture (assigned to predefined sets of classes; e.g. facies type) and some of their features (e.g. bounding surface order). These soft data are related to hard data, which are derived from measurement or observation (e.g. dimensional parameters, spatial relationships, grain size). Since we rely on interpretations, a standardization of fluvial architecture is required for consistency: common classifications are used, and a set of rules and criteria that define a procedure for translating the source data into FAKTS has been established to keep both data definition and data entry practice as objective and coherent as possible.

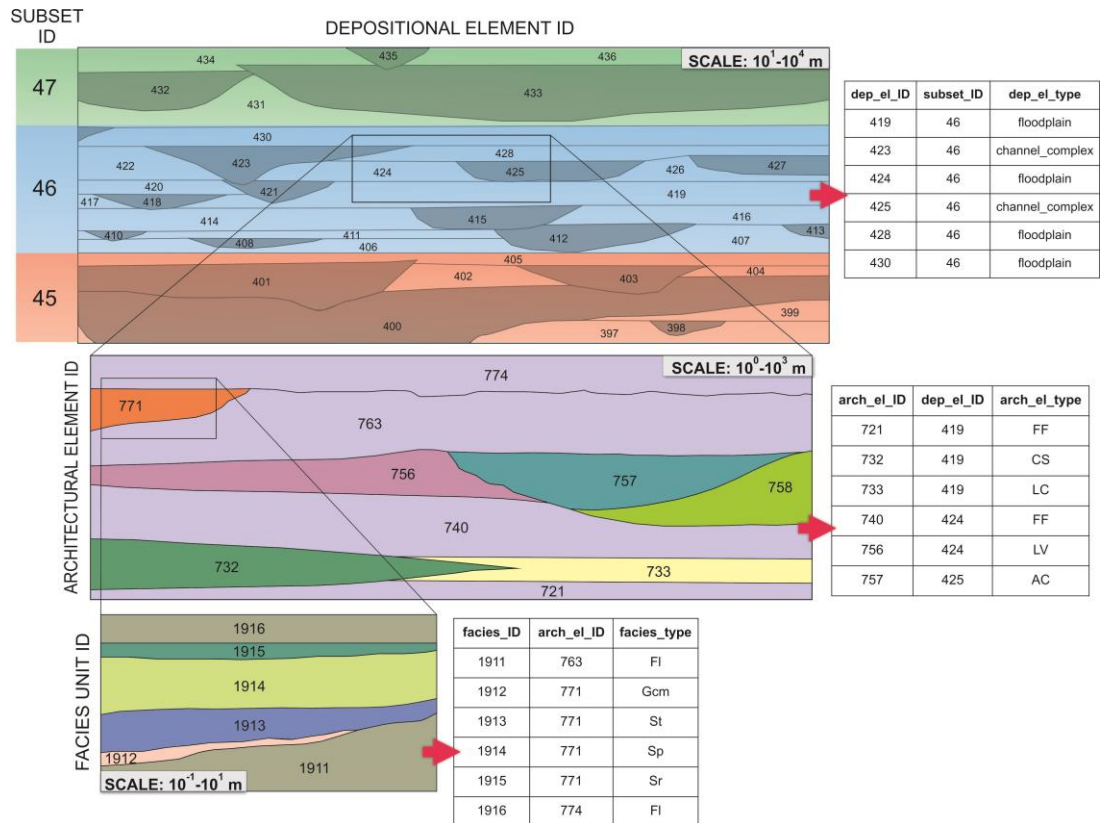
Fluvial systems are subdivided at the largest scale into subsets that have no given geological meaning, but are instead defined according to the two following types of criteria.

Each representation of data about a geological subject (e.g. outcrop sketch, cross-section, log, correlation panel) that is named/numbered separately in the source work, is assigned a single subset. If data about one subject are originally split in the source work (e.g. sedimentological logs and architectural panels in separate figures but covering the same outcrop), the original datasets are merged into one single subset, and the associated type of spatial observation is the result of their composition.

Each dataset that is characterized by demonstrated or inferred changes in some of the attributes is split to obtain subsets with homogeneous attributes, thereby defining subsets as stratigraphic windows or planform segments with homogeneous attributes and no given scale. For example, outcrop panel stratigraphy can be subdivided into subsets on the basis of inferred basinal climate type. An alternative example is the distinction of modern river planform subsets on the basis of channel pattern.

These two criteria are not mutually exclusive and can be combined, for example where many outcrop profiles are considered, each being subdivided into several subsets on the basis of inferred changes in external parameters and controls.

Depositional elements are simply classified as *channel-complex* or *floodplain* elements. Channel-complexes represent channel-bodies (and their infills) that are defined on the basis of flexible but unambiguous geometrical criteria (see appendix A), and are not related to any particular genetic significance or spatial or temporal scale (cf. Dalrymple 2001; Gibling 2006); they range from the infills of individual channels cutting through the floodplain to compound, multi-storey valley-fills. This definition facilitates the inclusion of datasets that are poorly characterized in terms of the geological meaning of these objects and their bounding surfaces, and this is especially the case for most subsurface datasets. Floodplain depositional elements are also defined on the basis of unambiguous geometrical criteria, and their segmentation is subsequent to channel-complex definition, as floodplain deposits are subdivided according to the lateral arrangement of channel-complexes (see the hypothetical example in figure 2.2).



**Figure 2.2:** hypothetical example showing object indexing of subsets, depositional elements, architectural elements and facies units and illustrating how the nested containment of each order of objects is implemented in the tables by making use of the unique indices. Facies types follow Miall's (1996) classification; architectural element types follow a classification that is purposely defined for FAKTS database, and derives from Miall's (1996) scheme.

Following Miall's (1985; 1996) concepts, architectural elements are defined as components of a fluvial depositional system with the characteristic facies associations that compose individual elements interpretable in terms of sub-environments. FAKTS is designed for storing architectural element types classified according to both Miall's (1996) classification and also to a classification derived by modifying some Miall's classes (table 2.1) in order to make them more consistent in terms of their geomorphological expression, so that working with datasets from modern rivers is easier. Architectural elements described according to any other alternative scheme are translated into both classifications following the criteria outlined by Miall (1996) for their definition.

**Table 2.1:** Architectural element type classification adopted in FAKTS; codes are modified after Miall (1996).

<b>Code</b>	<b>Architectural element type – geomorphic significance</b>
CH	Vertically accreting (aggradational) channel (fill)
DA	Downstream accreting macroform
LA	Laterally accreting macroform
DLA	Downstream + laterally accreting macroform and 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

In FAKTS, facies units are defined as genetic bodies characterized by homogeneous lithofacies type down to the centimetre-scale, bounded by second- or higher-order (Miall 1996) bounding surfaces. Lithofacies types are based on textural and structural characters; facies classification follows Miall's (1996) scheme, with minor additions (e.g. texture-only classes – gravel to boulder, sand, fines – for cases where information regarding sedimentary structures is not provided) (table 2.2). Both facies type and architectural element type classifications can be expanded and edited at any time: classes can be added as they are recognized, and others deleted in order to keep the new classes mutually exclusive.

**Table 2.2:** Lithofacies classification adopted in FAKTS; modified after Miall (1996).

Code	Characteristics
G-	Gravel deposits with undefined structure and undefined additional textural characteristics. Gravel-grade sediment (granule to boulder) usually constitutes the majority of the unit by volume, as the graded or massive structure of bi- or pluri-modal matrix-supported conglomerates/gravels is very likely to be recognized.
Gmm	Matrix-supported, massive or crudely-bedded gravel.
Gmg	Matrix-supported, graded gravel.
Gcm	Clast-supported, massive gravel.
Gci	Clast-supported, inversely-graded gravel.
Gh	Clast-supported, horizontally- or crudely-bedded gravel; possibly imbricated.
Gt	Trough cross-stratified gravel.
Gp	Planar cross-stratified gravel.
S-	Sand deposits with undefined structure. Sand-grade sediment must constitute the majority of the package by volume.
St	Trough cross-stratified sand.
Sp	Planar cross-stratified sand.
Sr	Current ripple cross-laminated sand.
Sh	Horizontally-bedded sand.
Sl	Low-angle (<15°) cross-bedded sand.
Ss	Faintly laminated/cross-bedded, massive or graded sandy fill of a shallow scour.
Sm	Massive sand; possibly locally graded or faintly laminated.
Sd	Soft-sediment deformed sand.
Sw	Symmetrical ripple cross-laminated sand.
F-	Fine-grained (silt/clay) deposits with undefined structure. Fine-grained sediment must constitute the majority of the package by volume.
Fl	Interlaminated very-fine sand, silt and clay; thin cross-laminated sandy lenses may be included into these heterolithic packages.
Fsm	Laminated to massive silt and clay.
Fm	Massive clay.
Fr	Fine-grained root bed.
P	Pedogenic carbonate.
C	Coal or highly carbonaceous mud.

### 2.3.3 Implementation

FAKTS is implemented in the open source *MySQL* database management system, with *HeidiSQL* software being used as a front-end tool for managing database editing, data entry and interrogation. In a manner similar to that employed in the sister database for deep marine depositional systems (DWAKB in Baas et al. 2005),

each entity type (e.g., a facies unit) is assigned a table containing a set of predefined attributes (fields) having numerical domain (e.g. dimensional parameters), predefined class domain (e.g. facies type) or text domain (e.g. original naming of facies unit).

FAKTS is made of nine tables, each hierarchically related to others by one-to-many relationships in a way that approximately corresponds to a hierarchy of scales. In the following, a concise description of each entity type (table) and of some of their attributes (columns and associated domains) is provided (cf. figure 2.3).

Table *DATA SOURCE*. This table contains all the basic metadata that refers to whole datasets, describing the original source of the data and information for each case study. Among its attributes, this table includes the type of work from where the data have been derived (e.g. peer-reviewed literature, unpublished academic works, technical reports), the methods of acquisition employed (e.g. outcrop observations, GPR profiles, aerial photos), the chronostratigraphic stages corresponding to lower and upper age limits of the studied interval, the geographic location, the names of the basin and river or lithostratigraphic unit, and a dataset *data quality index (DQI)*, see below). In addition, all the associated literature that has been used to constrain the case study boundary conditions is included in this table in the form of bibliographic references.

Table *SUBSETS*. This table holds all the data about subsets. Some of its attributes contain metadata: original subset coding (figure, table or entry naming or numbering in the source work), descriptors of subset spatial, vertical and horizontal extension, type of spatial observation and sampling (1D vertical, 1D horizontal, 2D cross-section, 2D planform, pseudo-3D, full-3D), fields about the main scales of observation investigated by the authors (*original target scale*) and chosen for the database by the operators (*subset target scale* – whose importance for properly characterizing fluvial architecture is clarified later). The remainder of the attributes store all the constraints on external and internal controls and variables that contribute to define the subsets themselves (e.g. tectonic setting, subsidence rates, basin climate type, sediment load dominance type, river pattern). Some of these fields are only expressed as relative change across subsets in a given variable (e.g. relative regional base level change, relative distality between subsets showing proximal to distal relationships within the same time-span), and their domain comprises ‘increase’, ‘decrease’ and ‘no change’ classes, that refer to change either over time or space, depending on the relationships between the subsets. This table is made of a total of 61 attributes; new attributes can be added at any time depending on the external and internal controls recognized and being considered for investigation in order to accommodate all the available constraints. A note field

(with a text domain) is assigned to every subset for the inclusion of information that cannot be stored in the existing thematic attributes: this note field is used to store information on attributes that relate to single case studies to limit table size. Subsets can be reassigned at any time, as new constraints on the categorical or numerical variables used for distinguishing them in a dataset emerge.

Table *DEPOSITIONAL ELEMENTS*. This table contains attributes about depositional elements including original numbering and naming convention, element type (channel-complex or floodplain), the hierarchical order of the channel-complex lower bounding surface (according to Miall 1996), dimensional parameters (e.g. thickness, width), net-to-gross ratio, and descriptors of the planform morphology of the channels contained within channel-complex elements.

Table *ARCHITECTURAL ELEMENTS*. This table contains attributes about architectural elements including original numbering and naming convention, element type classifications, dimensional parameters, net-to-gross ratio and descriptors of reach morphology (depth and width) for *CH* architectural elements.

Table *FACIES*. This table contains attributes about facies units including original numbering and naming convention, lithofacies classifications, dimensional parameters and percentage proportions of textural classes.

Tables *DEPOSITIONAL ELEMENTS-*, *ARCHITECTURAL ELEMENTS-*, and *FACIES-TRANSITIONS*. These tables store the transitions between objects belonging to the same scale (depositional elements, architectural elements and facies units) in the right-lateral, up-dip and upwards vertical directions, expressed using object identifiers. The two tables for facies units and architectural elements transitions also permit specification of bounding surface order (according to Miall 1996) across which the transition occurs.

Table *SUBSET STATISTICS*. This table holds all the statistical data arising from statistical summaries that cannot be treated using attributes relating to individual objects. The statistics refer to the entire subset and the table allows for the storage of data about object dimensions and transitions only.

All the metadata attributes storing original coding allow the tracking of data from the original dataset. For example, original depositional element numberings are retained within the database, allowing cross-reference back to the original literature. In fact, this field is not strictly required since the unique identifiers that are assigned to each object at the time of data entry are also used to track them graphically. Attributes containing original types are fundamental because they communicate the original object classifications (e.g. original facies type): retaining original classifications ensures that it remains possible to reassign object types at a later

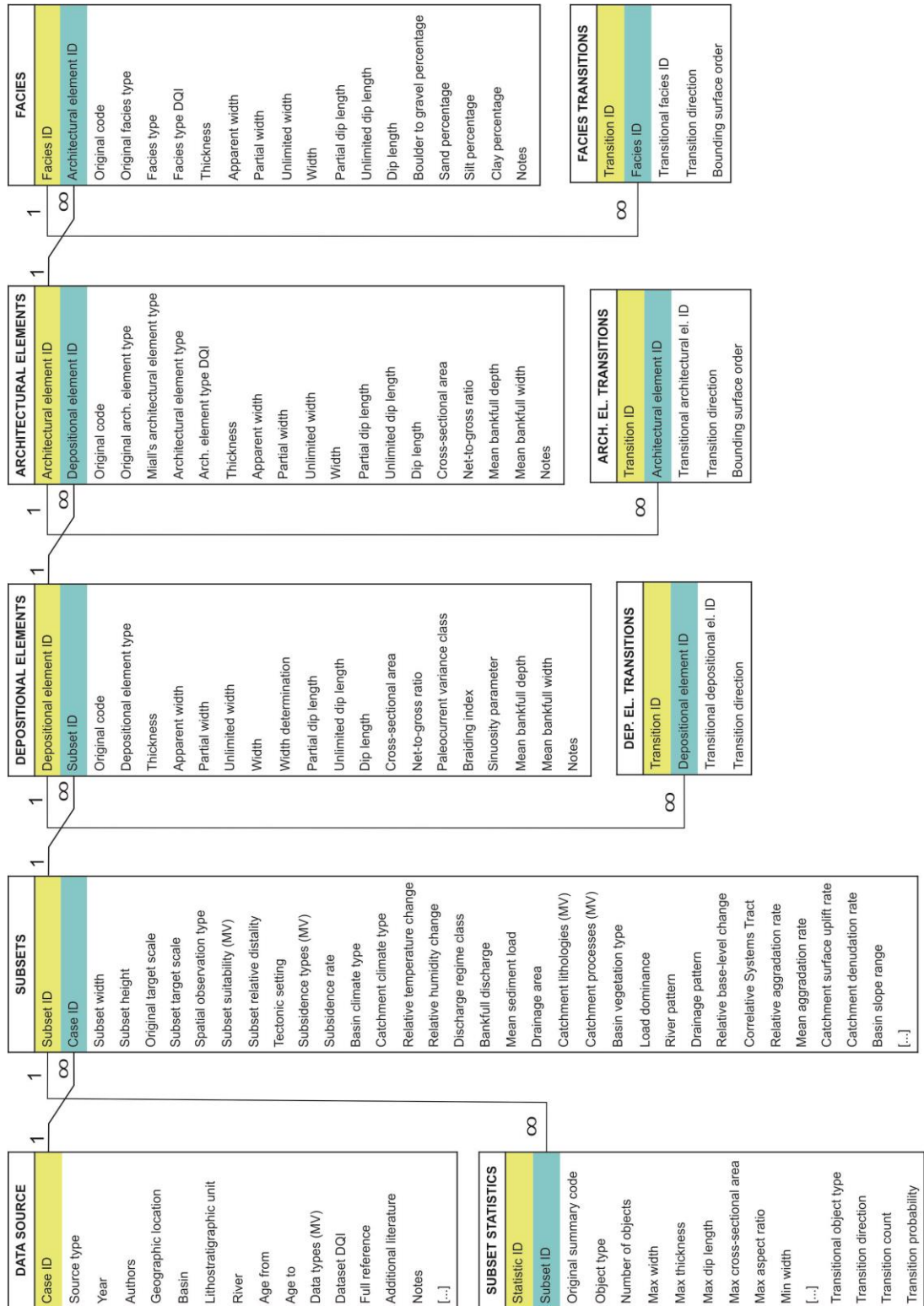
time, in the event of a change being made to the domain of the relative attribute (e.g. inclusion of a new class of facies).

A series of data quality indices (*DQI*'s) have been included as a threefold ranking system (rating datasets and attributes as *A*, *B* or *C* level, in order of decreasing quality). This provides a mechanism for the ranking of perceived data quality and reliability following established criteria (Baas et al. 2005), and to filter it accordingly when querying the database. Although *dataset DQI* is meant to rate the entire case study quality, other similar *DQI*'s are used for ranking class domain attribute assignment for each entry (e.g. ranking the reliability of attribution of architectural element type). For every table containing descriptive data, *notes* fields with text domain are provided for the inclusion of additional information.

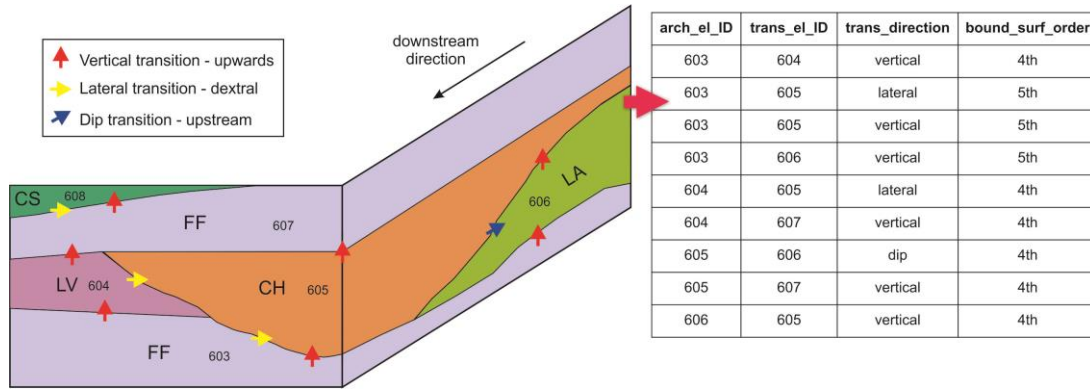
Every entry in a table is given a unique numerical identifier; these numerical indices are used to relate the tables (working as primary keys, used to unequivocally identify each record, and foreign keys, used to link the entries in the table to other tables through primary keys), so that not only is it possible to track relationships to a specific case study but also the nature of the containment (nesting) of each object within its higher-scale parent object can be reproduced in the database (depositional elements within subsets, architectural elements within depositional elements, facies units within architectural elements; figures 2.2 and 2.3).

Skipping scales is always possible by leaving object types undefined (e.g. facies belonging to an undefined architectural element, which in turn belongs to an undefined depositional element). The same numerical indices that are used for representing cross-scale containment relationships are also used in the three tables for transitions with the purpose of re-creating neighbouring relationships between objects contained at the same scale (figure 2.4).





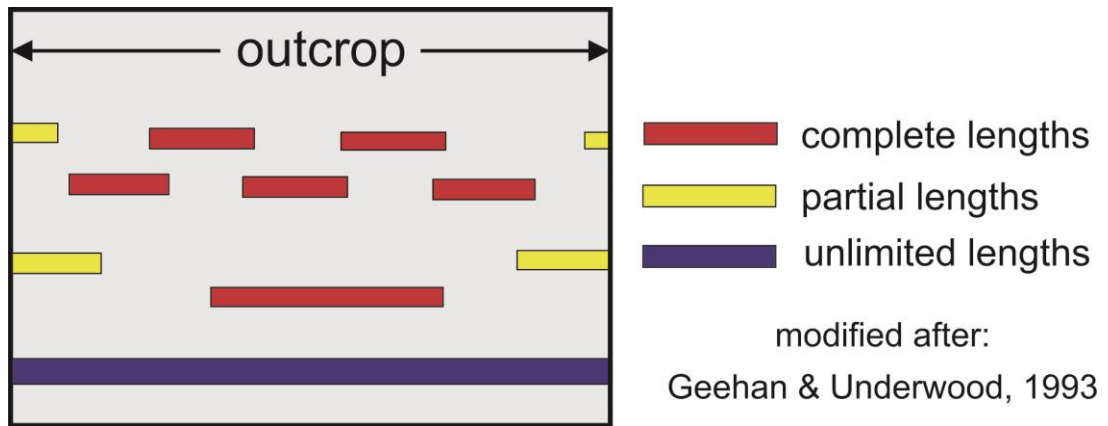
**Figure 2.3:** database structure, with constituent tables and selected attributes; yellow: primary keys, light blue: foreign keys. The (MV) abbreviation denotes attributes with multi-valued fields (e.g. different lithotypes included in the same entry for contributing basin lithologies attribute).



**Figure 2.4:** hypothetical example illustrating how transitions between neighbouring architectural elements are stored within the database; the same procedure applies to depositional elements and facies units. Transitions between subsets need not be stored as they are conventionally ordered from bottom to top (ancient systems) and in downstream direction (modern systems). Bounding surface orders follow the classification proposed by Miall (1996).

In the same way as for subsets, the implemented indexing allows depositional, architectural and facies elements to be deleted, edited or added at any time, making all the stored fluvial architectural data entirely editable, for example as new interpretations emerge after original data entry.

The dimensional parameters of each depositional element, architectural element and facies unit can be stored in their respective tables as representative thicknesses, cross-valley widths, downstream lengths, cross-sectional areas, and planform areas. Widths and lengths are classified according to the completeness of observations into *complete*, *partial* or *unlimited* categories (figure 2.5), as proposed by Geehan & Underwood (1993). *Apparent* widths are stored whenever only oblique observations with respect to palaeoflow are available. Where derived from borehole correlations, widths and lengths are always stored as 'unlimited'. Dimensions are obtained from graphical representations employing *ImageJ* image analysis software, which is used for measuring manually digitized vector geometries.



**Figure 2.5:** terminology of length types according to Geehan & Underwood (1993).

## 2.4 Applications

FAKTS can be interrogated through SQL queries (see appendix B) in order to generate quantitative information on fluvial architecture; this information can be exported to spreadsheets, analysed and represented in a variety of forms. In its fundamental form, the database is a means for the quantitative characterization of fluvial architecture. The internal organization of genetic packages can be characterized in terms of the objects belonging to lower-order scales (e.g. subsets corresponding to correlative systems tracts characterized in terms of depositional elements; depositional elements corresponding to channel-belts characterized in terms of architectural elements). Information on the relative proportion of the building blocks and on the trends in their spatial distribution in the investigated packages can be obtained. To characterize the internal composition of genetic bodies, proportions can be obtained from object occurrences only (e.g. number of facies units), or by combining occurrences and dimensions in several ways (e.g. relative proportion of facies unit thicknesses). Trends in spatial distributions are described by trends in object transitions: data on transition occurrences can be filtered so that only transitions observed within the type of element being investigated and across given bounding surface orders are taken into account. In effect, this means that transitions across erosional surfaces can be discarded (cf. Godin 1991) when searching for patterns.

In order to gain a fuller understanding of fluvial architecture in its broader context, information derived about the internal organization of any type of geological object can be coupled with information about its external geometry and dimensions.

Since subsets do not belong to a given scale, it must be born in mind that the types of object that are most suitable for characterizing a subset are only the ones stated

in the *subset target scale* attribute, whose choice depends on both data availability and subset spatial extension (for example, we can define subsets that are smaller than a channel-complex, in which case the depositional element type would be left undefined and only architectural elements and facies units would be properly defined. The subset target scale would then be set as: *// + ///*, where *//* denotes the architectural element scale and *///* the facies unit scale).

The most general application of FAKTS output is the quantitative comparison of fluvial depositional systems, which – assuming the collation of a statistically significant amount of data – can be conducted by applying data-filters. Subsets are the basic entities for this type of analysis, but even individual geological objects can be investigated (e.g. comparison of the internal and geometrical features of channels in different settings). Since a standard procedure has been devised for the digitization of fluvial architecture, more objective comparisons between case studies or subsets can be made. One of the far reaching objectives is to exploit this capability for determining the sensitivity of fluvial architecture to its controlling factors, ultimately enhancing understanding of the relative importance of intra- and extra-basinal controls in different settings and at different time-scales (given by subset temporal duration), and testing multiple cases of field data against existing models in order to understand the limits of a model's applicability. The exploitation of databases for assessing the role of controlling factors on particular features of sedimentary architecture has already proven to be useful (Baas et al. 2005; Gibling 2006).

In a manner similar to D-MAKS (DWAKB in Baas et al. 2005), the application of multiple filters to the data enables the generation – for every set of parameters – of synthetic models of fluvial depositional systems, which are represented by distinctive stacking patterns and lithosome geometries, modes of internal organization and reciprocal relationships. Synthetic models can be constructed by integrating data from modern and ancient fluvial systems; modern case histories are used as a primary source of data for the geometrical characterization of geological objects (especially for planform geometries; Tye 2004), although information on their internal organization can also be obtained (Brierley 1996). The value of inferences made regarding the long-term preserved stratigraphic architecture of fluvial systems based on the geomorphic organization of modern rivers is debatable (Shanley 2004; Miall 2006). Since the modern and ancient domains are kept distinct within FAKTS, the database output may offer information on the suitability of modern analogues to ancient systems and their applicability to subsurface studies, by making effective comparisons. These synthetic models may span all scales and object types or be focussed on a particular aspect of fluvial

architecture; for example, it is possible to derive a quantitative depositional model for braid bars by synthesizing information from: (a) studies on their internal organization in modern and ancient systems, (b) studies on their preserved geometry in the stratigraphic record, (c) studies on their relationships with other geomorphic elements and associated lithosomes.

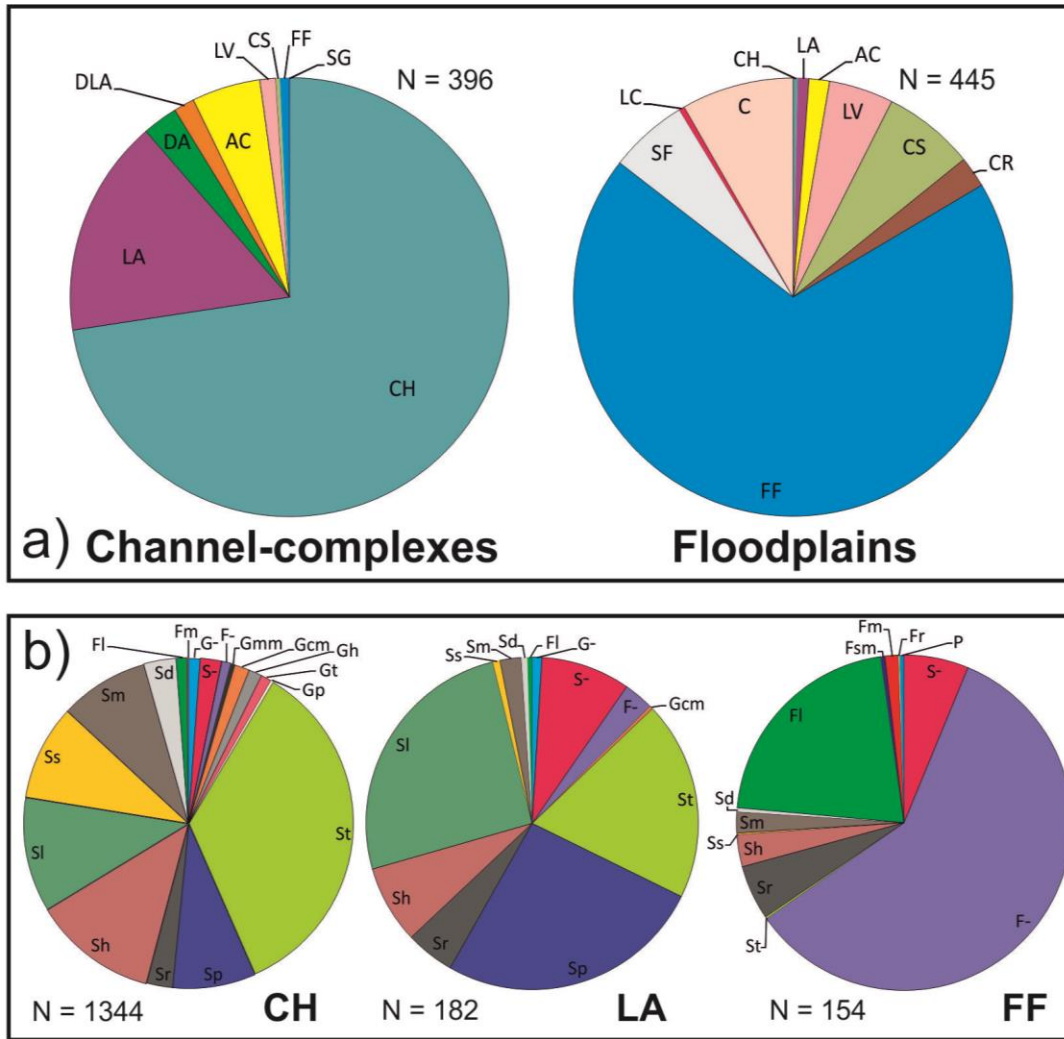
Other than its descriptive functions, the database also operates as a source of quantitative information that can be used for aiding predictions of subsurface fluvial architecture. As far as FAKTS applications to reservoir characterization are concerned, not only is it possible to determine the most suitable ancient and modern analogues to subsurface systems through quantitative analysis and statistical comparison of their architectural features, but additionally this approach also overcomes the limitations of the analogue approach by generating composite systems with particular internal and external properties (cf. Baas et al. 2005), which would represent case-study-defined conceptual frameworks for subsurface reconstructions. Furthermore, the database output can also provide input parameters to constrain geostatistical models of reservoir architecture.

Some example outputs are considered in the following discussion, with a more detailed explanation of certain applications.

#### **2.4.1 Example output 1: genetic-unit proportions**

It is possible to obtain information on the internal organization of genetic packages in terms of proportions of lower-order objects: architectural elements can be described in terms of proportions of facies units (figure 6a), channel-complexes or floodplains can be described in terms of proportions of architectural elements (figure 6b), and so on. Depending on the scale of interest, scales can be skipped (e.g. subsets can be characterized in terms of facies proportions).

Although net:gross data may sometimes be provided by the source datasets, becoming part of FAKTS input, the techniques for characterizing the internal organization of genetic packages leads automatically to the calculation of net:gross ratios for each object, with different levels of refinement depending on the completeness of volumetric data (e.g. ranging from only thicknesses being available, to full 3D dimensional data) and the type of objects employed (e.g. subsets with net:gross determined only as channel-complex/floodplain ratios, subsets with net:gross estimated from facies-based analysis of sand and shale ratios). For a full account of the internal organization of genetic packages, it is possible to combine object proportions with statistics about object spatial arrangement, described by transitions statistics.



**Figure 2.6:** a) Pie charts showing proportions of architectural elements in channel-complex and floodplain depositional elements computed as summed thicknesses. b) Pie charts showing proportions of facies units in CH (channel-fill), LA (laterally-accreted barform) and FF (overbank fines) architectural elements computed as summed thicknesses. Refer to table 2.1 and table 2.2 for architectural element and lithofacies coding.

### 2.4.2 Example output 2: transition statistics

Transitions derived from 1D, 2D and 3D datasets can be merged to obtain only 1D transition counts (and thereby probabilities) provided that they are filtered in a way that forces the transition data to be one-dimensional. Thus, a sorting of 2D and 3D data can be accomplished by running a query that performs a random selection through the objects so that only one transition per direction is chosen for each element. The output of this query can then be corrected to take into account typical object dimensions along any direction, in order to derive more realistic 1D transition statistics (even though – since every subset is classified according to the type of spatial observation – it is possible to obtain operable transition probabilities through

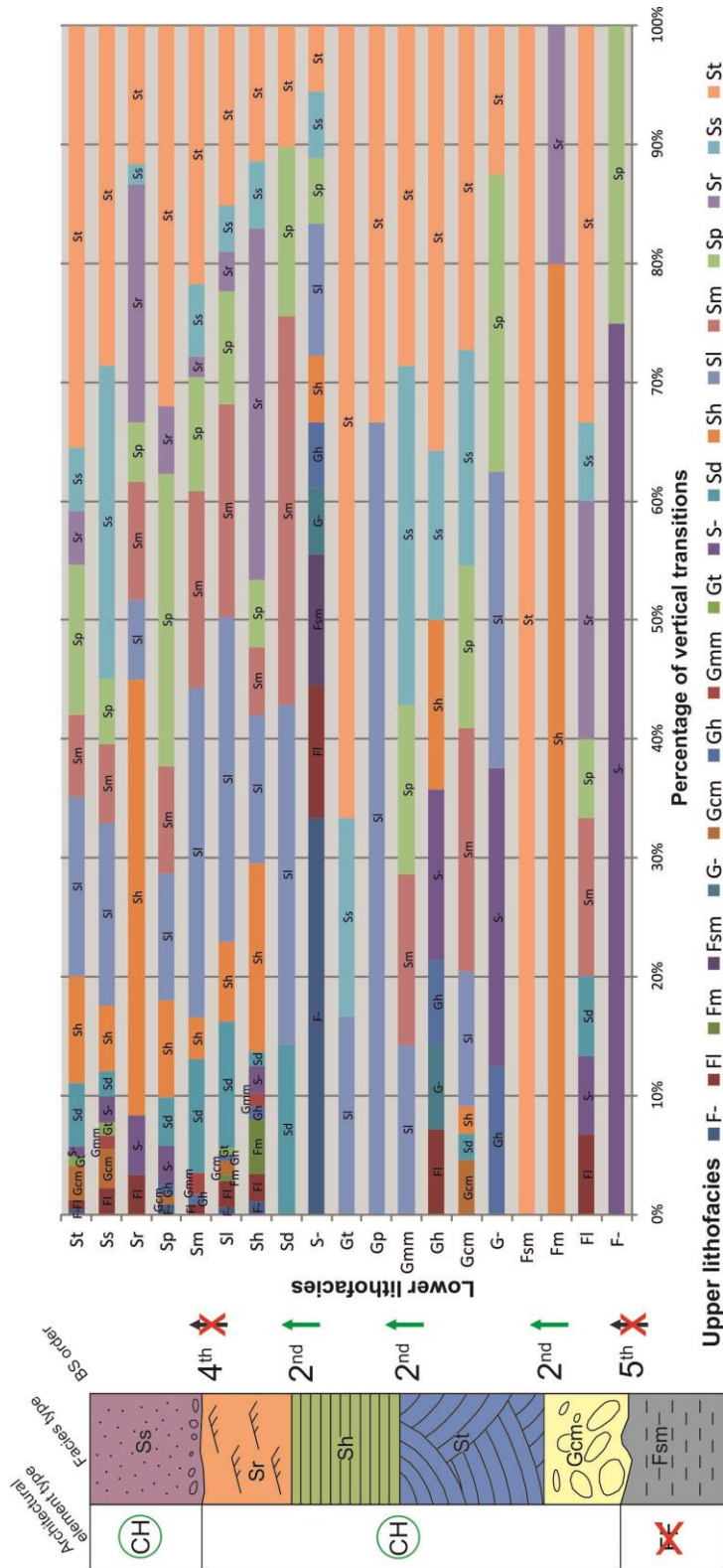
selection of originally-1D data only). Also, manipulating transition data using dimension statistics could make transition statistics applicable to a discretized space.

Especially during the 1970s, several authors working on the facies analysis of ancient and modern fluvial systems and their successions (e.g. Allen 1970; Miall 1973; Cant & Walker 1976; McDonnell 1978; Brierley 1989) used Markov Chain analysis as an instrument for detecting and describing significant relationships between geological objects, notably lithofacies, mainly working on single case study datasets. Although Miall (1996, pg. 325) states the inadequacy of such a technique to test cyclicity in fluvial contexts, FAKTS offers the opportunity to investigate the existence of spatial trends in the vertical, cross-valley and along-valley directions, by taking bounding surface information into account (cf. Godin 1991), allowing transitions between the same object type to be included (cf. Carr 1982), and working with multiple classified case histories (figure 2.7). Moreover, transition probability matrices to be used as input to transition probability-based techniques for the stochastic modelling of fluvial architecture (Carle & Fogg 1997; Elfeki & Dekking 2001) can be tailored to suit the subsurface case study by applying appropriate data-filters.

### **2.4.3 Example output 3: object dimensions**

Compilations of cross-plots of fluvial channel sand-body width:thickness aspect ratios have become increasingly popular (e.g. Fielding & Crane 1987; Cowan 1991; Robinson & McCabe 1997; Shanley 2004; Gibling 2006; Rittersbacher et al. 2013), since they are useful for subsurface sand-body width estimations when only thickness data are available, and in borehole correlation, especially for the definition of maximum correlation distances. Moreover, sand-body dimensions and geometries are intimately linked to a series of controls (cf. Reynolds 1999; Gibling 2006), whose relationships can be inferred by filtering FAKTS subsets appropriately and by analysing the results. Despite being unattached to any particular scale and not being classified qualitatively (their lower bounding surfaces are tentatively classified according to Miall's (1996) classes, but a genetic classification of channel-complexes – for example into channels, channel-belts and valley-fills – is not attempted), FAKTS channel-complexes are particularly suitable for these applications (figure 2.8).

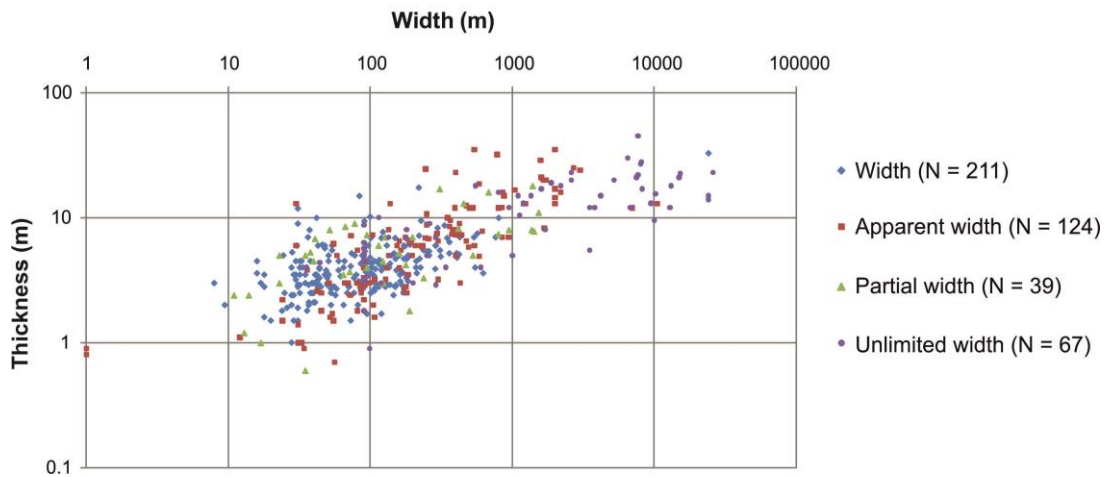




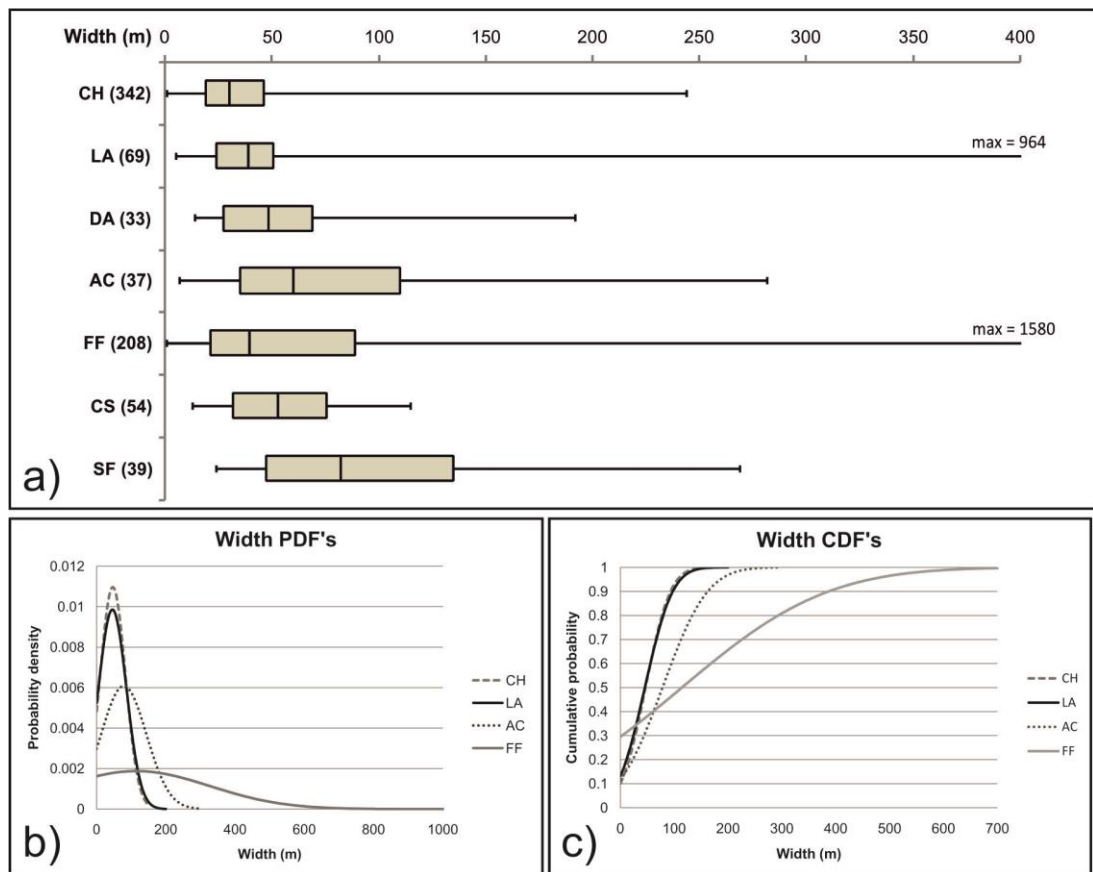
**Figure 2.7:** left: representation of facies transition filtering based on architectural element type (only CH – channel-fill element – included) and bounding surface order (4<sup>th</sup> and higher-order surfaces excluded). Right: bar-chart showing the result of this type of filtering as transition percentages in the vertical direction, computed performing a random selection of singular transition per facies unit in order to derive 1D information from 2D/3D datasets also. Refer to table 2.2 for lithofacies coding. The number of readings for each facies transition is reported in the bars (total N = 337).



### Channel-complexes width/thickness aspect ratios



**Figure 2.8:** scatter-plot of width:thickness aspect ratios for channel-complexes classified according to dimension completeness class (*sensu* Geehan & Underwood 1993); the number of observations for each class is reported in legend.



**Figure 2.9:** a) box-plots of cross-valley width distribution for a selection of architectural elements, constructed including total, apparent, partial and unlimited (*sensu* Geehan & Underwood 1993) widths. Refer to table 2.1 for architectural element coding. The number of readings is reported next to the element code. b,c) probability density function (b) and cumulative distribution function (c) of CH (channel-fill) architectural element width including total, apparent, partial and unlimited width classes, and assuming a normal distribution.

Frequency distribution of architectural dimensions of any type of lithosome/geomorphic-element (e.g. crevasse-splay width) can be obtained (figure 9a). Especially if filtered according to measurable classes (e.g. thickness), such results may result in useful subsurface prediction refinement, as a frame of reference for comparing the statistical distributions of dimensional parameters with the subsurface interpretation outcome, and as constraints for conditioning stochastic models (e.g. in form of probability density functions and cumulative distribution functions, figures 9b and 9c; cf. Hirst et al. 1993).

## 2.5 Future developments

The FAKTS database schema has been devised as a flexible structure that can be amended at any time, to optimize its potential in describing fluvial architecture and its boundary conditions. Future development will involve the addition of new attributes, relating to subsets or genetic units, and the refinement of the existing ones. For example, the implementation of descriptors of object shape for genetic bodies is practicable, either by linking these objects to 2D/3D vector graphics and making use of their unique identifiers, or by adding table attributes (columns) relating to cross-sectional, planform and/or 3D shape types. The inclusion of additional columns containing meta-attributes that relate to some specific subset attributes (e.g. subset time-scale specification or literature citation of the source for each constraint) could be also useful. The addition of non-fluvial genetic units (presently unclassified), within their attribute domains, might result valuable for encapsulation of interactions with other environments and evaluating the importance of local geomorphic controls on fluvial architecture, while the inclusion of particle-scale properties and/or diagenetic properties could widen the range of potential database applications, as both particle size and diagenetic properties play an important role in controlling reservoir quality, and are strongly influenced by controlling factors already included in the database (e.g. climate, basin type), whose importance could be examined quantitatively (cf. Duller et al. 2010), and by feedbacks between these properties and the associated fluvial architecture.

Furthermore, the database could be exploited for the objective evaluation of the influence of one-dimensional data (e.g. borehole) sampling density on observations (e.g. thickness distributions) and interpretations (e.g. correlated width distributions). This would be achieved by replicating the FAKTS structure, modifying it by implementing the specification of subset sampling spacing, and using that structure for accommodating several possible realizations for each case study. Working with outcrop and subsurface datasets, by comparing all the possible outcomes for each

sampling spacing interval, it will be possible, for example, to determine thresholds of sampling density over which the quantitative description of fluvial architecture properties (especially sand-body geometries and connectivity) remains substantially constant, in different settings. This implies that it might be possible to estimate the likelihood that, in a given fluvial depositional system, well sampling interval confidently captures major heterogeneities.

## 2.6 Conclusions

A relational database for the digitization of fluvial architecture has been devised, developed and populated with literature-derived data, from studies of both modern rivers and their ancient counterparts in the stratigraphic record. The database scheme has been structured in a manner capable of encapsulating all the major characteristics of fluvial architecture, including geometries, style of internal organization, spatial distribution of elements, and reciprocal relationships of genetic bodies. Further, the database allows for the integration of both quantitative (hard) and qualitative (soft) data, and it is also sufficiently flexible to allow the consideration of case studies either in whole or in part, according to which types of controlling factors and internal characteristics are being considered.

Database output allows the quantitative characterization of fluvial architecture associated with either single or multiple case studies, with results filtered according to a range of specified parameters, which permits objective comparisons to be carried out. Three main general fields of application for database output are: (i) the quantitative evaluation of the sensitivity of fluvial architecture to changes in its controlling factors; (ii) the compilation of synthetic fluvial depositional models; (iii) guidance for the prediction of subsurface fluvial architecture by providing relational data in a format suitable for input into deterministic and stochastic models.

Perhaps the major shortcoming of a database-approach to fluvial characterization is the reliance on literature-derived interpretations of fluvial successions; such qualitative interpretations are by their very nature subjective and biased by existing depositional (facies) models and the research trends in vogue at the time of original publication. Retaining original genetic unit classifications and extending or changing the classification schemes in common (tables 2.1 and 2.2), ensure that the database has the flexibility that is needed to follow scientific trends influencing interpretations. The option to keep objects undefined and to rank the quality of their interpretation/attribution (via the *DQI* rating) is valuable for determining which fluvial contexts require additional research.

The correspondence between the scales of observations considered and the main scales of heterogeneity which need to be recognized within subsurface fluvial successions for applied purposes makes the database a powerful source of information for the characterization, modelling and simulation of fluvial hydrocarbon reservoirs and for the quantitative determination of their most suitable modern or ancient analogues.

### **3 A quantitative approach to fluvial facies models: methods and example results**

#### **3.1 Summary**

Traditional facies models lack quantitative information concerning sedimentological features: this significantly limits their value as references for comparison and guides to interpretation and subsurface prediction. This chapter aims to demonstrate how a relational-database methodology can be used to generate quantitative facies models for fluvial depositional systems. This approach is employed to generate a range of models, comprising sets of quantitative information on proportions, geometries, spatial relationships and grain sizes of genetic units belonging to three different scales of observation (depositional elements, architectural elements and facies units). The method involves a sequential application of filters to the knowledge base that allows only database case studies that developed under appropriate boundary conditions to contribute to any particular model. Specific example facies models are presented for fluvial environmental types categorized on channel pattern, basin climatic regime and water-discharge regime; the common adoption of these environmental types allows a straightforward comparison with existing qualitative models. The models presented here relate to: (i) the large-scale architecture of single-thread and braided river systems; (ii) meandering sub-humid perennial systems; (iii) the intermediate- and small-scale architecture of dryland, braided ephemeral systems; (iv) the small-scale architecture of sandy meandering systems, and (v) individual architectural features of a specific sedimentary environment (a terminal fluvial system) and its sub-environments (architectural elements). Although the quantification of architectural properties represents the main advantage over qualitative facies models, other improvements include the capacity: (i) to model on different scales of interest; (ii) to categorize the model on a variety of environmental classes; (iii) to perform an objective synthesis of many real-world case studies; (iv) to include variability- and knowledge-related uncertainty in the model; (v) to assess the role of preservation potential by comparing ancient- and modern-system data input to the model.

## 3.2 Introduction

### 3.2.1 Background

The primary purpose of facies models is to provide a "general summary of a specific sedimentary environment" (Walker 1984), in terms of its characteristic sedimentary features. The descriptive characteristics of facies models are obtained by combining results from studies of both modern systems and ancient successions preserved in the rock record. The general validity of a facies model stems from the process of "distillation" by which the sedimentary features observed in many real-world examples are synthesized to develop the model; the expected generality of a facies model makes it suitable to be considered as a norm for comparison, a basis for interpretation, a guide for future observations and a predictor in new geological situations (Walker 1984).

The commonly applied approach to facies modelling involves representing the archetypal sedimentary architecture of classified systems representative of a particular depositional environment in the form of ideal logs, cross-sections or block-diagrams that exemplify the ideal geometry, internal organization, and spatial relationships of a hierarchy of sedimentary units. The sedimentary architecture of modelled systems is typically conceptually described in terms of lithofacies, defined as sedimentary units with descriptive and objective characters, such as sediment composition, texture, structure and geometry (Anderton 1985; Bates & Jackson 1987; Bridge 1993; Reading & Levell 1996). However, the preservation in the stratigraphic record of surfaces that bound sedimentary bodies and whose origins can be accounted for in terms of the evolution and behaviour of specific landforms within a depositional system has long been recognized as a justification on which to base the genetic categorization of sedimentary units according to their geomorphic significance (Potter 1967). Thus, sedimentary units are also commonly classified according to interpretations of facies associations interpretable as geomorphic sub-environments and such an approach is routinely used to constitute the building blocks of fluvial depositional and facies models (Walker & Cant 1984; Miall 1985; 1996; Collinson 1996; Bridge 2003; 2006; and references therein). Published fluvial facies models characterize systems at different scales of observation, ranging from the basin-fill scale to the lithofacies scale. Depositional facies models focussing on the architecture of single sedimentary sub-environments (e.g. point bars, crevasse splays) are commonly proposed (e.g. Allen 1970; Bridge 2003; Fisher et al. 2008) to provide reference for the interpretation of individual genetic packages. The classification of types of fluvial facies models can be based on several environmental categories based on parameters such as planform morphology, grain-size, discharge regime, climate type, dominant transport mechanism, or on a

combination of such parameters; some examples of facies models for a range of fluvial environments are presented in works by Cant (1982), Walker & Cant (1984), Miall (1985; 1996), Nadon (1994) Kelly & Olsen (1993), Bridge (2003; 2006), Nichols & Fisher (2007), Fielding et al. (2009), among others.

Given that most river systems evolve in a variable and complex manner downstream, facies models for fluvial systems are usually not set in any spatial framework, instead they describe the sedimentary architecture of a generic segment of a system, although the recognized regularity in the downstream change of some of the parameters on which fluvial facies models are classified allows for the derivation of a possible paradigmatic description of the downstream evolution of fluvial systems (cf. Orton & Reading 1993). Typically, information concerning the spatial evolution of a fluvial system type is included in a model only when it is considered one of its diagnostic characteristics, for example when a recurrent proximal-to-distal organization is recognized, as is the case for fan-like alluvial systems (e.g. Miall 1977; Kelly & Olsen 1993; Nichols & Fisher 2007). Although this study focuses discussion on the descriptive characters of “environmental facies models” (*sensu* Reading 2001), the idealized temporal evolution of the system under the effect of dynamic controls is also taken into account by some models such as those that encapsulate concepts in sequence stratigraphy, although the effects of such controls are not the primary subject of this study. It is commonly argued that the possible value of the facies modelling approach for the purposes claimed by Walker (1984) appears to be limited by a number of shortcomings (Hickin 1993; North 1996; Miall 1999; Reading 2001). Firstly, facies models are often based on data derived from very few or single case studies (cf. models of Miall 1996; Lunt et al. 2004; Fielding et al. 2009; Horn et al. 2012), and as such might be biased in the sense that they reflect the limited experience of individuals or research groups, whose work is often concentrated on particular geographical areas (Reading 2001). Furthermore, there exists a tendency to derive models for single field examples or for very specific categories of fluvial system such that the resultant model is excessively specialized to the extent that it is of little use as a predictive tool beyond the scope of the original study example; in such cases, the proposed model may obscure the underlying unity of the systems in order to preserve their uniqueness (Dott & Bourgeois 1983; Miall 1999). A major limitation of traditional facies models is that the degree of generality of such models in their current form is not adjustable to the particular needs of a geologist attempting to apply the model to a new situation or dataset. Another problem relates to how the process of distillation is actually carried out: given that the process of synthesis is expected to be subjective, how can it be possible to ensure that different authors equally and objectively include the fundamental patterns and exclude accessory

detail in developing their models? Also, the inclusion of some form of mechanism for the evaluation of the uncertainty (“any departure from the unachievable ideal of complete determinism” according to Walker et al. 2003) associated with developed models has not been attempted to date (Hickin 1993); it can be argued that the proliferation of categories on which facies models are classified is an endeavour to ensure that the variability between systems can be perceived. It is therefore important to devise a way to consider uncertainty (i) by measuring the variability between different systems that are classified on the basis of development under similar conditions and are therefore represented by the same model, and (ii) by assessing the limitations and deficiencies in our knowledge of those systems. However, the most notable drawback of traditional facies models lies in their qualitative nature, as the lack of quantitative information seriously limits their predictive value (North 1996). In subsurface prediction problems it is common to combine qualitative, conceptual information about the type of sedimentary heterogeneities and their distribution with quantitative geometrical information derived from supposed outcropping analogues.

Quantitative information on the geometry of sedimentary units is commonly stored in quantitative databases that serve to provide input to deterministic and stochastic subsurface models (e.g. Bryant & Flint 1993; Cuevas Gozalo & Martinius 1993; Dreyer et al. 1993; Robinson & McCabe 1997; Reynolds 1999; Eschard et al. 2002; Tye 2004); the collation of such geometrical data – as derived from a variety of case histories – combined with the classification of system parameters, permits the derivation of sets of quantitative information through a process of synthesis, as advocated by Walker (1984). One approach of this kind has been applied to fluvial systems for obtaining descriptions of channel geometries by Gibling (2006). However, facies models are not merely geometrical descriptions of a depositional system; thus, some databases have been designed to better describe spatial relationships between genetic units, for example by including summary transition statistics for deep-water genetic-unit types (Baas et al. 2005), by specifying patterns of spatial distribution for carbonate genetic-unit types (Jung & Aigner 2012), or by digitizing the spatial relationships between individual fluvial genetic units (Colombera et al. 2012a, chapter 2). Also, efforts have been made to implement such systems to variably investigate the internal organization of sedimentary units (Baas et al. 2005; Colombera et al. 2012a, chapter 2; Jung & Aigner 2012).



### 3.2.2 Aims

The aim of this study is to demonstrate how a database approach to the description and classification of fluvial sedimentary systems can be used to improve facies models as a benchmark for research purposes and as a tool for subsurface prediction. Whereas some techniques adopted in the study of sedimentary geology are inherently quantitative (e.g. numerical and physical modelling, sandbody-geometry quantification), facies modelling is still typically qualitative in nature. The aim is to show how the innovation in the approach lies essentially in the systematic quantification of observations and interpretations, which permits a more rigorous description and classification of architectural styles of fluvial systems. An important, broad-reaching implication for the understanding of the stratigraphic record is that the proposed approach, if used to carry out comparative studies, can be applied to deduce the relative influence of boundary conditions and potential overriding controls for given depositional contexts. Specific objectives of this chapter are as follows: (i) to discuss the process of synthesis by which partial information from individual case studies is merged into a model and how this process is implemented in practical terms for different types of information, which concern the geometry, internal organization and spatial relationships and distribution of genetic units; (ii) to illustrate, through a range of example database-derived quantitative depositional models for different fluvial systems, that this database-driven quantitative approach to the development of facies models can assist in overcoming the above-mentioned problems inherent in traditional qualitative approaches.

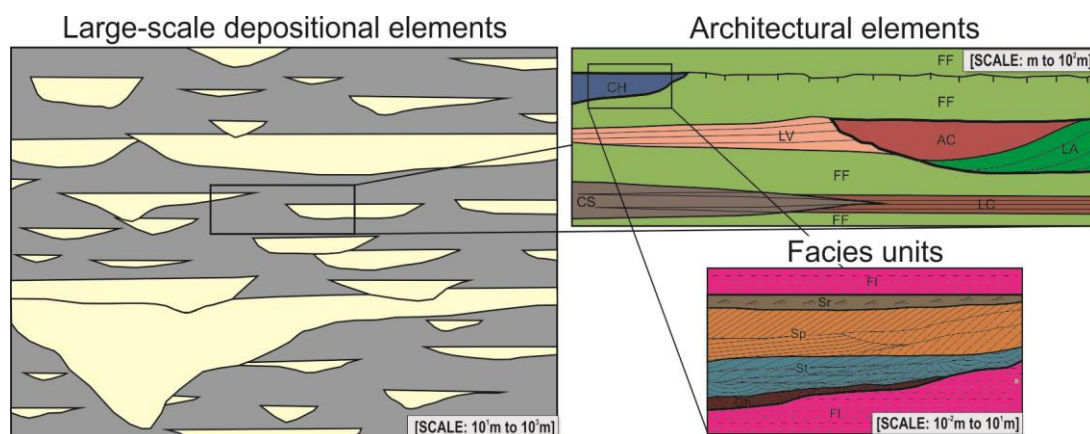
## 3.3 Database and method

### 3.3.1 Database structure and building blocks

#### 3.3.1.1 Overview of FAKTS database schema

The Fluvial Architecture Knowledge Transfer System (*FAKTS*) is a database comprising field- and literature-derived (see appendix C) quantitative and qualitative data relating to the architecture of both modern rivers and ancient successions (Colombera et al. 2012a, chapter 2). Genetic units included in the database are equally recognizable in both the stratigraphic and geomorphic realms and belong to three hierarchies of observation (figure 3.1): *depositional elements*, *architectural elements* and *facies units*, in order of descending scale. The geometry of the genetic units is characterized by dimensional parameters describing their extent in the vertical, strike-lateral and downstream directions, relative to the channel-belt-scale (palaeo-) flow direction (thickness, width and length). The relations between

genetic units are stored by recording and tracking (i) the containment of each unit within its higher-scale parent unit (e.g. facies unit within architectural elements) and (ii) the spatial relationships between genetic units at the same scale, recorded as transitions along the vertical, cross-gradient and downstream directions. Additional attributes are defined to improve the description of specific units (e.g. braiding index, sinuosity value, bank-full depth and width for channel complexes, grain-size curves for facies units), whereas accessory information (e.g. ichnological or pedological characters) can also be stored for every unit within open fields. The database also stores statistical parameters referring to genetic-unit types, as literature data are often presented in this form. Each genetic unit or set of statistical parameters belongs to a stratigraphic volume called a *subset*; each subset is a portion of the total dataset characterized by given attribute values, such as system controls (e.g. subsidence rate, basin type, climate type) and system-descriptive parameters (e.g. river pattern, distality relative to other subsets). For each case study of fluvial architecture, FAKTS also stores metadata describing, for example, the methods of data-acquisition employed, the chronostratigraphy of the studied interval and the geographical location. A threefold data-quality ranking system is also implemented with the purpose of rating datasets and genetic units (as *A*, *B* or *C* level, in order of decreasing quality). A more detailed description of the FAKTS database schema is given in Colombera et al. (2012a, Chapter 2); for the purposes of this work, the key focus is on the adopted classifications of geological entities, described in the following paragraphs, as they are the building blocks of the quantitative facies models being developed.



**Figure 3.1:** representation of the main scales of observation and types of sedimentary genetic units included in the FAKTS database. Refer to table 3.1 for architectural-element codes and to table 3.2 for facies-unit codes (modified from Colombera et al. 2012a, Chapter 2).

### 3.3.1.2 Classification of bounding surfaces

The subdivision of fluvial successions into genetic packages through recognition, classification and numbering of hierarchically-ordered sets of bounding surfaces is a common sedimentological practice (Allen 1983; Miall 1988a; 1996; Holbrook 2001). FAKTS permits specification of the order of bounding surfaces corresponding to the basal surface of depositional elements (highest order in case of composite surfaces) and the order of surfaces across which architectural-element or facies-unit transitions occur. FAKTS classifies bounding surfaces according to the popular hierarchical classification scheme proposed by Miall (1988a; 1996), whereby surface-orders are assigned on the basis of observable characters (e.g. lateral extension, erosional or accretionary character), but are also interpretative in nature. Attribution of order (i.e. rank) to bounding surfaces is difficult in many real-world situations (Bridge 1993) and therefore has uncertainty associated with it; however, it is worthwhile to tentatively rank bounding surfaces according to a series of hierarchical orders, so as to be able to capture architectural features and changes associated to surfaces with genetic significance and often temporal and spatial relevance. Whenever observable elements on which to base the attribution of a given bounding-surface order are lacking, corresponding database fields are left undefined.

### 3.3.1.3 Classification of depositional elements

The general approach to the segmentation of alluvial architecture at the largest scale involves picking and indexing channel bodies, then dividing the remaining non-channelized floodplain bodies into discrete objects that are juxtaposed to the channel bodies in a spatially coherent way. Large-scale depositional elements are then classified as *channel-complexes* or *floodplain* segments on the basis of the origin of their deposits, and are distinguished on the basis of geometrical rules (see appendix A). The application of these rules is generally flexible, as the criteria devised for the definition of these objects may sometimes be difficult to apply due to limitations brought about by the possible lack of data of either a geometrical or geological nature (e.g. 3D channel-body geometries, recognizable internal bounding surfaces): such difficulties are recorded by data-ranking, data-type and target-scale attributes. In addition, the geometrical criteria cannot be followed altogether for cases where data are derived from published works presenting only summary results (e.g. from works presenting plots of dimensional parameters of channelized bodies and no reproduction of the original 2D or 3D dataset from

where the data were originally derived); this form of uncertainty is recorded by a data-ranking attribute.

General criteria followed for depositional-element subdivision are presented below. The choice of interpretative units at this scale is justified by the fact that the recognition of channel and floodplain segments is possible for virtually any depositional system interpreted as being fluvial in origin (cf. Miall 1996; Bridge 2006; and references therein).

#### 3.3.1.3.1 Channel complex

Each stratigraphic volume that can be characterized at the depositional-element scale is firstly segmented into channel-complexes; the aforementioned set of geometrical criteria needs to be followed to distinguish individual units among channelized deposits that are complexly juxtaposed and/or interfingered with floodplain deposits. Such criteria consider geometrical change across the channel-cluster vertical extension, taking into account the interdigitation of floodplain deposits, mode and rate of change in the lateral extension of contiguous channel deposits along the vertical direction, and existence of lateral offsets where channel-bodies are vertically stacked (cf. Cuevas Gozalo & Martinius 1993). Whenever geological knowledge permits the lateral tracing of important erosional surfaces (possibly associated with high palaeo-relief), it is possible to adopt such surfaces as depositional-element bounding surfaces. When dealing with subsurface case studies, the approach is usually purely geometrical. Due to the way they are defined, channel complexes simply represent genetic bodies interpreted as having been deposited in a channelized context and encased by floodplain deposits: in geological terms they could still span a rather wide range of hierarchical orders (e.g. distributary channel-fills, channel-belts, valley-fills); definition in this way attempts to minimize interpretation, thereby still ensuring the possibility for the analysis of channel clustering in different depositional settings.

#### 3.3.1.3.2 Floodplain

The subdivision of floodplain segments takes place subsequent to channel-complex assignment, such that the remainder of the stratigraphic volume is broken down into floodplain packages that are referable as neighbouring bodies (either lateral or vertical) to each channel-complex. Thus, floodplain depositional elements simply represent geometrical genetic bodies interpreted as deposited by out-of-channel floods (cf. Miall 1996; Bridge 2006).

### 3.3.1.4 Classification of architectural elements

FAKTS' architectural elements are defined as components of a fluvial depositional system with characteristic facies associations that are interpretable as sub-environments. Also for these genetic units, it is not possible to separate descriptions from interpretations, as unit types are fundamentally interpretative. The attribution of a particular element type follows the criteria proposed by Miall (1985; 1996): the elements are interpreted on the basis of the character of their bounding surfaces, their geometry, scale, and internal organization. However, FAKTS' architectural element types differ significantly from the ones included in Miall's (1985; 1996) schemes: additions and deductions strive to provide a more interpretative classification scheme containing mutually-exclusive classes that are consistent in terms of geomorphological expression, in order to make it easier to include datasets from modern rivers; an analogous attempt to define the basic geomorphic building blocks of fluvial systems was proposed by Brierley (1996). Importantly, FAKTS' architectural-element types correspond to classes of sub-environments that are commonly recognized in both the stratigraphic record and in modern rivers alike (cf. Bridge 2006), and are conveniently chosen to represent variability in sedimentary architecture.

Architectural-element types may differ from each other on just geometrical/geomorphological characters (e.g. downstream-accreting barforms from laterally-accreting barforms, crevasse splays from levees) or interpreted dominant processes (e.g. sandy aggradational floodplain from floodplain fines, abandoned channel-fill from aggradational channel-fill). The essential diagnostic characteristics of each interpretative architectural-element type are included in table 3.1. In addition to the features summarized in table 3.1, other characteristics concerning the geometry, internal organization, and reciprocal spatial relationships may have also been considered by the authors whose studies were incorporated into FAKTS to reach their interpretations.

**Table 3.1:** Summary of the fundamental diagnostic characteristics and environmental significance of the 14 interpretative architectural-element types employed in the FAKTS database.

Code/Type	Key characteristics	Interpreted sub-environment
CH aggradational channel-fill	These elements are characterized by downstream-elongated incisional concave-upward bases, on which depositional increments – recorded in the database in the form of facies units – are overall vertically stacked, either concentrically ( <i>sensu</i> Hopkins	These elements generally represent the overall aggradational infill of active channel forms.

	<p>1985; Gibling 2006) or onlapping the channel margin, resulting in the dominantly horizontal orientation of planar, undulating or scour-like internal 2<sup>nd</sup>- and 3<sup>rd</sup>-order bounding surfaces (cf. Schumm 1960; Allen 1965a; Friend 1983; Miall 1985; 1996; Holbrook 2001; Bridge 2003; 2006; and references therein). Although CH elements may be locally composed of small-scale downstream-, oblique-, lateral- or upstream-accretion increments, they significantly lack the laterally-persistent bedding grown through inclined accretion that is typical of barform deposits.</p>	
<p>LA lateral- accretion barform</p>	<p>These elements are characterized by sharp, subhorizontal to slightly concave-upward, and often erosional bases, on which depositional increments are laterally stacked, with dip direction at high angle with respect to the palaeoflow direction, and dip angle up to 25° (cf. Miall 1979; 1996), generally showing offlapped upper terminations (cf. Allen 1965a; Miall 1985; 1996; Thomas et al. 1987; Willis 1993a; Collinson 1996; Bridge 2003; 2006; and references therein).</p>	<p>These elements represent the infill of active channel-belts by laterally-migrating bars, most commonly typified by meander point bars.</p>
<p>DA downstream- accretion barform</p>	<p>These elements are characterized by subhorizontal to slightly concave-upward and often erosional bases, on which depositional increments are stacked at low angle with respect to palaeoflow, determining a dominance of low-angle (generally &lt;10°; Miall 1996) downstream-dipping 2<sup>nd</sup>- and 3<sup>rd</sup>-order bounding surfaces (cf. Banks 1973; Haszeldine 1983; Miall 1985; 1996; Wizevich 1992; Bridge 2003; 2006; and references therein). DA elements may be locally composed of oblique-, lateral- or upstream-accretion increments, but the overall preponderance of downstream growth is their key character.</p>	<p>These elements represent the infill of active channel-belts by downstream-migrating bars.</p>
<p>DLA downstream- and lateral- accretion barform</p>	<p>These elements differ from pure LA and DA elements in that bedding geometries demonstrate dominantly oblique accretion, embodied by a combination of downstream accretion at their downstream ends and cross-bar accretion along their flanks (cf. Cant &amp; Walker 1978; Kirk 1983; Bristow 1987; 1993; Miall</p>	<p>These elements represent the infill of active channel-belts by the migration of compound bars that accrete both downstream and laterally in comparable proportions; barforms whose accretion direction is uncertain are classified as DLA, and the uncertainty in the attribution of the</p>

	1996; Bridge 2003; 2006; Best et al. 2003; Skelly et al. 2003; and references therein). Upstream- and vertical-accretion increments are often observed but are volumetrically minor (Cant 1978; 14% of upstream accretion in bar examined by Bristow 1987; Best et al. 2003; Skelly et al. 2003).	element type is recorded by a data-ranking attribute.
HO scour-hollow fill	This element type encompasses major scour-hollow fills, characterized by incisional concave-upward scoop-shaped bases, and by infill through accretion on inclined or horizontal surfaces or on a combination of both (cf. Cowan 1991; Bristow et al. 1993; Salter 1993; Miall 1996; Miall & Jones 2003).	These elements represent the infill of deeply-incised trough-shaped scours within channel-belts, for example by the migration of mouth-bars into deep confluence scours (Best 1988; Bristow et al. 1993) or by infilling of flood-related scours during waning-flood stage (Salter 1993).
SG sediment gravity-flow body	These elements are characterized by irregular and sharp – but often non-erosional – bases, and form lobes, ribbons or sheets (cf. Miall 1985; 1996; Blair & McPherson 1992; 1994; Bridge 2006). The associated facies assemblages testify to the activity of debris flows and related sediment gravity flows as formative mechanisms.	These elements may represent gravity-flow sheets/lobes, the genetically related levees, or possibly a complex association of them.
AC abandoned channel-fill	Similarly to aggradational channel-fills, abandoned-channel fills are channelized units dominated by vertical accretion; however, the associated facies assemblages demonstrate that deposition occurred in the lower-energy conditions of an abandoned reach, where the importance of suspension settling and organic accumulation in ponded waters increases relative to stream-flow processes, which tend to become intermittent (cf. Allen 1965a; Collinson 1996; Miall 1996; Hornung & Aigner 1999; Bridge 2003; 2006; Lewin et al. 2005). In modern case studies, the recognition of these elements can be based on purely geomorphological observations, as they typically form ponded water bodies with channelized planforms.	These elements represent the infill of ponded water bodies developed in abandoned reaches.
LV levee	Levee elements typically take the form of tapering wedges that thin away from channel-belt margins, demonstrating superelevation on the rest of the floodplain (cf. Allen 1965a; Coleman 1969; Collinson 1996; Miall 1996; Brierley et al.	Although levees may develop at smaller-scales (e.g. crevasse-channel levees), <i>LV</i> elements usually represent the sedimentary and geomorphic expression of the most proximal overbank deposition next to channel-belt

	<p>1997; Bridge 2003; 2006; North &amp; Davidson 2012; and references therein); their base may be poorly defined (cf. Brierley et al. 1997), and internal accretion surfaces may offlap and/or downlap (Fielding et al. 1993), showing dip angles up to 10° (Bown &amp; Kraus 1987), although 2° to 5° are more common (Miall 1996; Brierley et al. 1997), associated with the sloping topography bordering channels; (palaeo)flow direction is usually oriented at high-angle with the channel border (Miall 1996).</p>	<p>margins.</p>
<p>CR crevasse channel</p>	<p>Similarly to most aggradational and abandoned channel-fills, crevasse channels are channelized units with concave-upward bases and usually forming ribbon-like bodies; the intimate association with other floodplain deposits (e.g. levees, crevasse splays) is a key feature for their recognition (cf. Allen 1965a; Miall 1996; Bridge 2003; 2006; and references therein). No distinction is operated on the modes of channel-fill accretion.</p>	<p>These elements represent the infill of channels emanating from the river into the adjacent floodplain and active during floods.</p>
<p>CS crevasse splay or lacustrine delta</p>	<p>These elements are tongue-shaped bodies bordering channel-belt margins (cf. Allen 1965a; Brierley 1996; Collinson 1996; Miall 1996; Bristow et al. 1999; Bridge 2003; 2006; North &amp; Davidson 2012; and references therein). These bodies thin away from the channel margins, as they interfinger or grade laterally into other elements, and they tend to have flat, sharp and slightly erosive bases (Mjøs et al. 1993; Jones et al. 1995; Bristow et al. 1999); although tabular bedding is common, internal accretion surfaces usually downlap, dipping at low angle to angle-of-repose, as they record the progradation of the splay onto the floodplain or into standing bodies of water (Miall 1996; Bristow et al. 1999; Bridge 2006). They are distinguishable from levees when there is no amalgamation of thin coalescing splays (cf. Coleman 1969; Jordan &amp; Pryor 1992), but when they form instead recognizable fans or lobes, which tend to be coarser and thicker (Brierley 1996; Bridge 2006); as crevasse splays and lacustrine deltas are difficult to distinguish in the rock record (Miall 1996), they are classified under the</p>	<p>These elements represent the sedimentary and geomorphic product of splay progradation and aggradation through the periodic unconfined flow from crevasse channels tapping channel-belts during floods.</p>



	same type.	
SF sandy sheetflood- dominated aggradational floodplain	<p>These elements are characterized by having lower bounding surfaces that are sharp, planar to irregular, and ranging from non-erosive to slightly erosive in nature; they usually form tabular or lenticular sandstone bodies, in which depositional increments tend to be vertically stacked and bounded by subplanar surfaces, demonstrating an overall aggradational character (cf. Olsen 1989; Miall 1996; Sánchez-Moya et al. 1996; Miall &amp; Jones 2003; Nichols 2005; Hampton &amp; Horton 2007; Cain &amp; Mountney 2009; and references therein). As no agreement exists on the definition of sheetflood (Hogg 1982; North &amp; Davidson 2012), there is need to remark that here sheetfloods are referred to as unconfined subaerial flows (cf. Fisher et al. 2007). Since LV and CS elements represent also sand-dominated deposits produced by unconfined flows in floodplain settings, the geomorphic expression (in modern systems) and the internal geometrical organization of the lithosomes are fundamental to distinguish SF elements from LV and CS elements; instead, SF elements are differentiated from FF elements on grain-size because the proportion of sand-grade deposits demonstrates that traction-current deposition is dominant over suspension settling.</p>	<p>These elements represent vertically aggrading areas controlled by bedload deposition from unconfined flows; they could encompass the sedimentary sheets forming proximal terminal splays (Nichols &amp; Fisher 2007; Fisher et al. 2008).</p>
FF overbank fines	<p>These elements consist in usually tabular or prismatic fine-grained bodies in which laterally-persistent depositional increments tend to be vertically stacked and bounded by planar surfaces, demonstrating an overall aggradational character; pedogenic alteration is relatively common (cf. Miall 1985; 1996; Platt &amp; Keller 1992; Ghazi &amp; Mountney 2009; and references therein).</p>	<p>These elements are the sedimentary expression of vertically aggrading floodbasins, in which suspension settling from subaerial unconfined flows is the dominant process (Allen 1965a; Miall 1985; 1996; Bridge 2003; 2006; North &amp; Davidson 2012; and references therein); bedload deposition of mud aggregates on the floodplain can also produce fine-grained floodplain units (Müller et al. 2004, Wakelin-King &amp; Webb 2007; and references therein).</p>
LC floodplain lake	<p>These elements are typically characterized by having non-erosive bases, tabular shapes and laterally-persistent, vertically-stacked sheet-like depositional increments; they</p>	<p>These elements represent the infill of ephemeral or perennial floodplain lakes.</p>

	<p>may have a wide lithological variety, including clastic, organic and chemical deposits testifying to deposition in a lacustrine setting (cf. Gore 1989; Platt &amp; Keller 1992; Hornung &amp; Aigner 1999; Bridge 2006; Hampton &amp; Horton 2007; Ghazi &amp; Mountney 2009; and references therein). They are distinguishable from abandoned channels as they lack a channelized base; in the rock record they are distinguishable from overbank fines by the evidence of subaqueous conditions, either ephemeral or perennial.</p>	
C coalbody	<p>These elements consist in packages of coal/peat or carbonaceous mudstones, typically having irregular sheet-like geometry, possibly associated with thin clastic partings (cf. Fielding 1984; McCabe 1984; 1987; Kirschbaum &amp; McCabe 1992; Jorgensen &amp; Fielding 1996; Miall 1996; and references therein). Coal seams deposited in floodplain lakes (Cabrera &amp; Saez 1987) or abandoned channels (Horne et al. 1978) would rather be included as C facies units within LC or AC elements, wherever the distinctive facies associations and geometries of these elements are recognized.</p>	<p>These elements are the sedimentary expression of floodplain swamps/mires dominated by organic accumulation.</p>

### 3.3.1.5 Classification of facies units

According to the classification of bounding surfaces proposed by Miall (1985; 1996) and adopted in the FAKTS database, 2<sup>nd</sup>-order surfaces can be traced where a change in lithofacies or palaeocurrent are observed; on this basis, facies units represent genetic packages that are bounded by second- or higher-order bounding surfaces and are characterized by given textural and structural properties. Such genetic units are considered as corresponding to the 2<sup>nd</sup>-order units of Miall (1985; 1996) and to the microscale to mesoscale stratasets of Bridge (1993). These units are based on observable characteristics and are thus more objectively defined than depositional and architectural elements.

As each unit is primarily classified according to the codes provided in the original works, a detailed description of grain size is optionally stored for each unit in the database field containing the original coding. The grain-size characterization given by the FAKTS' facies-unit classes is instead very limited, as the FAKTS' facies

classification scheme largely follows the scheme proposed by Miall (1977; 1978; 1996), although with some additions. The adoption of this scheme has some advantages. Firstly, the use of few mutually exclusive classes simplifies database use, as a more detailed description of grain size in the code could generate a high number of classes to account for all possible grain-size modalities and tails, so that description of textures that are originally less detailed (e.g. following Miall's scheme) would not be easily translated. Secondly, as many authors have adopted the Miall scheme (1977; 1978; 1996), use of this scheme (albeit in a slightly modified form) negates the requirement to translate similar facies codes described in many case studies as they are incorporated into the database. So, although FAKTS' lithofacies coding – as well as the original facies codes of Miall (1978; 1996) – could be improved to better account for textural and structural variability, the use of a classification scheme that is well established in the scientific community is especially well-suited for database use, because for many published case examples, lithology classifications do not need to be re-coded. Nevertheless, caution must be exercised when translating original lithology data. For example, there is no consensus on the definition of matrix: the American Geological Institute defined the matrix as the "finer-grained, continuous material enclosing, or filling the interstices between the larger grains or particles of a sediment or sedimentary rock" (Gary et al. 1974). Thus, gravel-grade sediment acting as matrix could still be consistent with this definition. However, the inclusion of clean sand- or gravel-grade deposits (cf. Shultz 1984; Sohn et al. 1999; for alluvial examples) into the definition of matrix precludes the differentiation of lithofacies associated to fundamentally different formative processes: therefore, for data entry into the FAKTS database, matrix is defined as being dominantly fine grained (clay + silt), possibly partially sandy, roughly in agreement with Miall (1996). Thus, care must be taken as the same code could be used by different authors to designate deposits that would be classified differently in the FAKTS database system.

In contrast to the approach taken to the classification of architectural elements, properties concerning the geometry or the bounding surfaces of facies units are only occasionally important for their definition (e.g. facies type Ss): facies-unit types are usually only designated on the textural and structural characteristics of the deposits. There is no scope for provision of a rich and detailed description of each facies-unit type here, as their accessory sedimentological characteristics may vary widely among the different fluvial systems included in the database. Instead, only a summary of the essential features of each of the 25 types is given, in table 3.2.

Each facies-unit type may be associated with more than one genetic process, with more than one bedform type, and with variable flow regime: see Miall (1978; 1996)

and Bridge (1993) for explanations of the genetic significance of these lithofacies types. It should be noted that the FAKTS scheme is sufficiently flexible to allow implementation of alternative classification schemes in addition to those of the original authors' and FAKTS' facies codes, possibly separating textural and structural data in different fields.

**Table 3.2:** Summary of the fundamental textural and structural characteristics of the 25 facies-unit types employed in the FAKTS database.

Code	Characteristics
G-	Gravel deposits with undefined structure and undefined additional textural characteristics. Gravel-grade sediment (granule to boulder) usually constitutes the majority of the unit by volume, as the graded or massive structure of bi- or pluri-modal matrix-supported conglomerates/gravels is very likely to be recognized.
Gmm	Matrix-supported, massive or crudely-bedded gravel.
Gmg	Matrix-supported, graded gravel.
Gcm	Clast-supported, massive gravel.
Gci	Clast-supported, inversely-graded gravel.
Gh	Clast-supported, horizontally- or crudely-bedded gravel; possibly imbricated.
Gt	Trough cross-stratified gravel.
Gp	Planar cross-stratified gravel.
S-	Sand deposits with undefined structure. Sand-grade sediment must constitute the majority of the package by volume.
St	Trough cross-stratified sand.
Sp	Planar cross-stratified sand.
Sr	Current ripple cross-laminated sand.
Sh	Horizontally-bedded sand.
Sl	Low-angle (<15°) cross-bedded sand.
Ss	Faintly laminated/cross-bedded, massive or graded sandy fill of a shallow scour.
Sm	Massive sand; possibly locally graded or faintly laminated.
Sd	Soft-sediment deformed sand.
Sw	Symmetrical ripple cross-laminated sand.
F-	Fine-grained (silt/clay) deposits with undefined structure. Fine-grained sediment must constitute the majority of the package by volume.
Fl	Interlaminated very-fine sand, silt and clay; thin cross-laminated sandy lenses may be included into these heterolithic packages.
Fsm	Laminated to massive silt and clay.
Fm	Massive clay.
Fr	Fine-grained root bed.
P	Pedogenic carbonate.
C	Coal or highly carbonaceous mud.

### **3.3.2 An approach to building quantitative facies models: practical considerations**

As of September 2012, FAKTS comprised 111 case histories – defined as individual sedimentological studies on a particular river or succession, by specific authors – and included data referring to 4285 classified depositional elements, 3446 classified architectural elements, and 20101 classified facies units, as well as additional statistical summaries referring to architectural properties of groups of genetic units. Summaries of the case studies included in the database and of the published literature considered for derivation of primary data and for system classification are given in Appendix C and as a digital appendix (D2).

Through interrogation of the database, it is possible to obtain a multi-scale quantitative characterization of the sedimentary architecture of fluvial systems primarily consisting of three types of information (Colombera et al. 2012a, Chapter 2), respectively concerning: (i) the internal organization of genetic units and stratigraphic volumes; (ii) the geometry of genetic units; (iii) the spatial relationships between genetic units. This section discusses some issues on how to best incorporate such information within quantitative facies models by synthesizing different case studies; in particular, it is important to identify which (if any) data types might be biased, for example by under-sampling, and to specify how the integration of data from multiple scales can be achieved in practice.

At the outset, subsets should be filtered according to their suitability to given queries; this information is contained within metadata fields that specify: (i) what scales of observation (and relative orders of genetic units) each subset is focussed on; (ii) the type(s) of output that it is possible to derive from a subset (i.e. proportions and/or dimensional parameters and/or transition statistics and/or grain-size information).

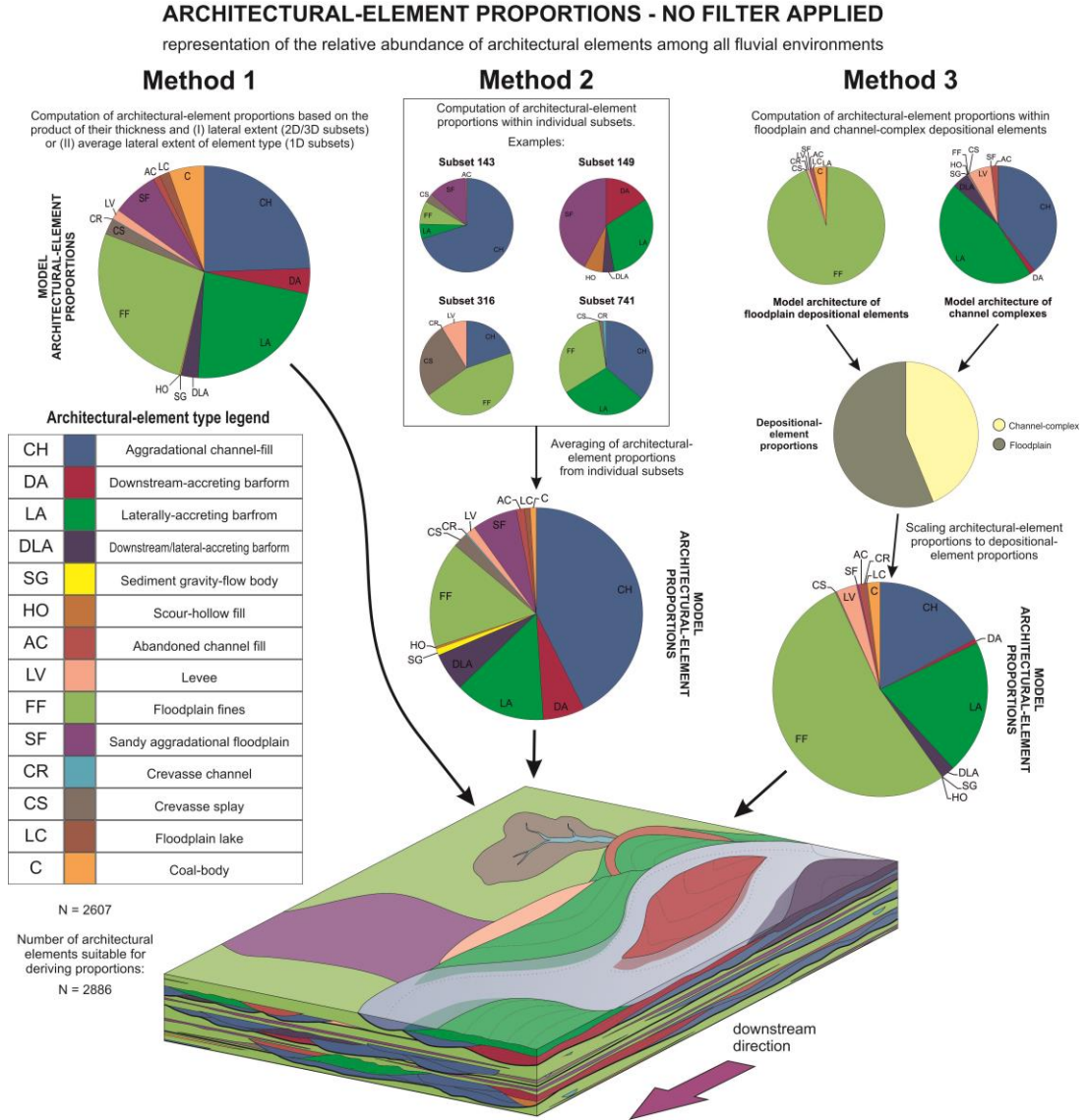
A first-order description of the internal organization of genetic units or stratigraphic volumes is given by the proportion of lower-order genetic units forming them. Here, three approaches to compute such proportions are outlined.

A first approach involves computing genetic-unit-type proportions as based on the sum of all occurrences, or thicknesses, or products of dimensional parameters (e.g. thickness times width) of genetic units (cf. figure 3.2); a drawback of this approach is that case studies that have been studied more extensively and for which more genetic units are recorded (e.g. datasets derived from the study of more extensive outcrops) are over-represented, resulting in a biased output that is unbalanced in favour of some case studies.

An alternative second approach is to compute genetic-unit-type proportions as based on the sum of genetic-unit percentage proportions (obtained as above) within each suitable subset, thereby obtaining corrected proportions that account for the fact that some case studies may have been studied less extensively than others (cf. figure 3.2); the principal drawback of this approach is that case studies that have been studied in only modest detail for which relatively few genetic units have been classified (e.g. datasets derived from the study of less extensive outcrops) are over-represented, resulting in a biased output in which some genetic-unit types are under-sampled.

Thirdly, in cases where the aim is to obtain unit-type proportions within genetic units that do not belong to the immediately higher scale (i.e. to derive proportions of facies-unit types composing depositional elements, or proportions of architectural-element or facies-unit types within stratigraphic volumes), it is possible to compute proportions that are weighted according to the proportions of the intermediate-scale units (cf. figure 3.2). For instance, an abundance of facies-unit types composing channel-complexes can be achieved based on a combination of facies-unit proportions forming each architectural element type with architectural-element proportions forming channel-complexes. As a specific example, if *CH* (aggradational channel-fill) architectural elements represent 50% of all channel-complexes and 20% of all *CH* elements are represented by facies unit *St*, it is straightforward to compute 10% as a contribution of *CH* to the model proportion of *St* within channel-complexes. Given that some case studies are focused on specific features of fluvial architecture, this approach would return more accurate proportions when scales are skipped. For example, if a case study is focussed on the facies architecture of *LA* (laterally-accreting barform) architectural elements, the relative facies-unit type proportions will not be an accurate description of the entire fluvial system, but of *LA* architecture only. Practically, constraining genetic-unit proportions to higher-scale genetic-unit proportions would result in a more effective integration of observations at different scales. However, when obtaining proportions according to such an approach, it must be borne in mind that the result may be biased by not incorporating genetic relationships between different unit types. For example, if the aim is to derive the overall *CS* (crevasse splay) proportion for a model by integrating architectural-element-scale information from a case study in which the proportion of floodplain depositional element is 25% and in which *CS* elements constitute 20% of the floodplain (and therefore 5% of total volume), with depositional-element-scale information from a case study in which the proportion of floodplain is 50%, we would derive a proportion of *CS* within the model stratigraphic volume equal to 10%. In practical terms, this may not be realistic as the proportion of crevasse-splay deposits may actually decrease with a decreasing proportion of

channel-belt deposits, with which they are genetically related, instead of simply scaling with the proportion of floodplain depositional elements within which they are contained.



**Figure 3.2:** example application of three different methods for computing model architectural-element proportions (see text); as no filter has been applied on either system parameters or sedimentological properties, the results refer to an ideal model of a “generic” fluvial environment derived from and constrained by the entire knowledge base.

The uncertainty associated with quantitative descriptions of dimensional parameters of genetic units is partially intrinsic to the way dimensional data and metadata are stored: the width and length of a genetic unit are classified using categories of completeness of observation (*complete*, *partial*, or *unlimited*), as proposed by Geehan & Underwood (1993), whereas widths are classified as *apparent* when derived from sections oriented oblique to palaeocurrent directions; in addition,

metadata qualifying the type of observations are included (e.g. outcrop extension, type of observations from which dimensional parameters are drawn). Inclusion of geometrical information in a model can lead to problems concerning over- or under-representation of specific case studies, which might also need to be confronted.

Database-informed quantitative facies models describe the spatial relationships between genetic units in each of the three directions (vertical, cross-stream, and upstream) by employing embedded transition statistics, with self-transitions (i.e. transitions between likewise-classified genetic units) considered admissible. When obtaining transition statistics, issues that are analogous to the ones related to the computation of proportions may be encountered, such as the integration of facies-unit transitions mapped from different architectural elements into a model of facies-unit transition statistics that refer to an ideal stratigraphic volume. Such problems could be tackled in a way that is entirely analogous to the approaches proposed for deriving proportions. It is also important to note that a system that allows filtering of transitions both on the bounding-surface order across which the transition occurs and on the genetic-unit type in which the transition occurs, permits the derivation of genetic-unit transitions referring to a variety of genetically-related stratigraphic packages (e.g. architectural-element transitions within channel-complexes, facies-unit transitions within 3<sup>rd</sup>-order packages contained in *LA* barforms), as envisioned by Godin (1991).

If Markov-chain analysis is attempted, two notable advantages are provided by the method the database employs to store the transition data. Firstly, because self-transitions are admissible they can be included in the Markov-chain analysis (cf. *multistory lithologies* of Carr et al. 1966), resulting in improved independent random matrices (cf. Selley 1970; Schwarzacher 1975); this is a methodological advance over many previously-published transition matrices containing predefined diagonal zeros (i.e. matrices that do not allow self-transitions; e.g. Gingerich 1969; Allen 1970; Miall 1973; Cant & Walker 1976), which cannot result from independent random processes (Goodman 1968; Schwarzacher 1975; Carr 1982). Secondly, the inclusion of bounding-surface information in Markov-chain analysis was advocated by Cant & Walker (1976) and Godin (1991): sorting on bounding-surface order it is possible to filter transitions on the likelihood of their genetic significance, for example by excluding erosional transitions between lithofacies (i.e. across bounding surfaces of a specified order).

The necessity to incorporate variability-related uncertainty in a model can be partially tackled by quantifying the variability of architectural properties in each facies model, possibly exemplifying extreme values within the range of each property (e.g. maximum channel-complex thickness, maximum *LA* proportion within



any systems) by referring to real-world case studies. In addition, the implementation of a ranking system (*Data Quality Index* or *DQI*; cf. Baas et al. 2005; Colombera et al. 2012a, Chapter 2) is employed to evaluate the quality and reliability of (i) datasets, for example by considering the type of data available; (ii) genetic-unit classification, by considering the type of observable attributes on which a class is attributed to a unit; (iii) system classification, for example by considering the reliability of proxies on which a class is attributed to a subset. Thus, uncertainty related to inadequate knowledge (rather than to the inherent variability of the system) can also be taken into account by associating to the model a measure of value that is proportional to the DQI's of the systems or units, and to the amount of data (number of systems and units) on which the model is based.

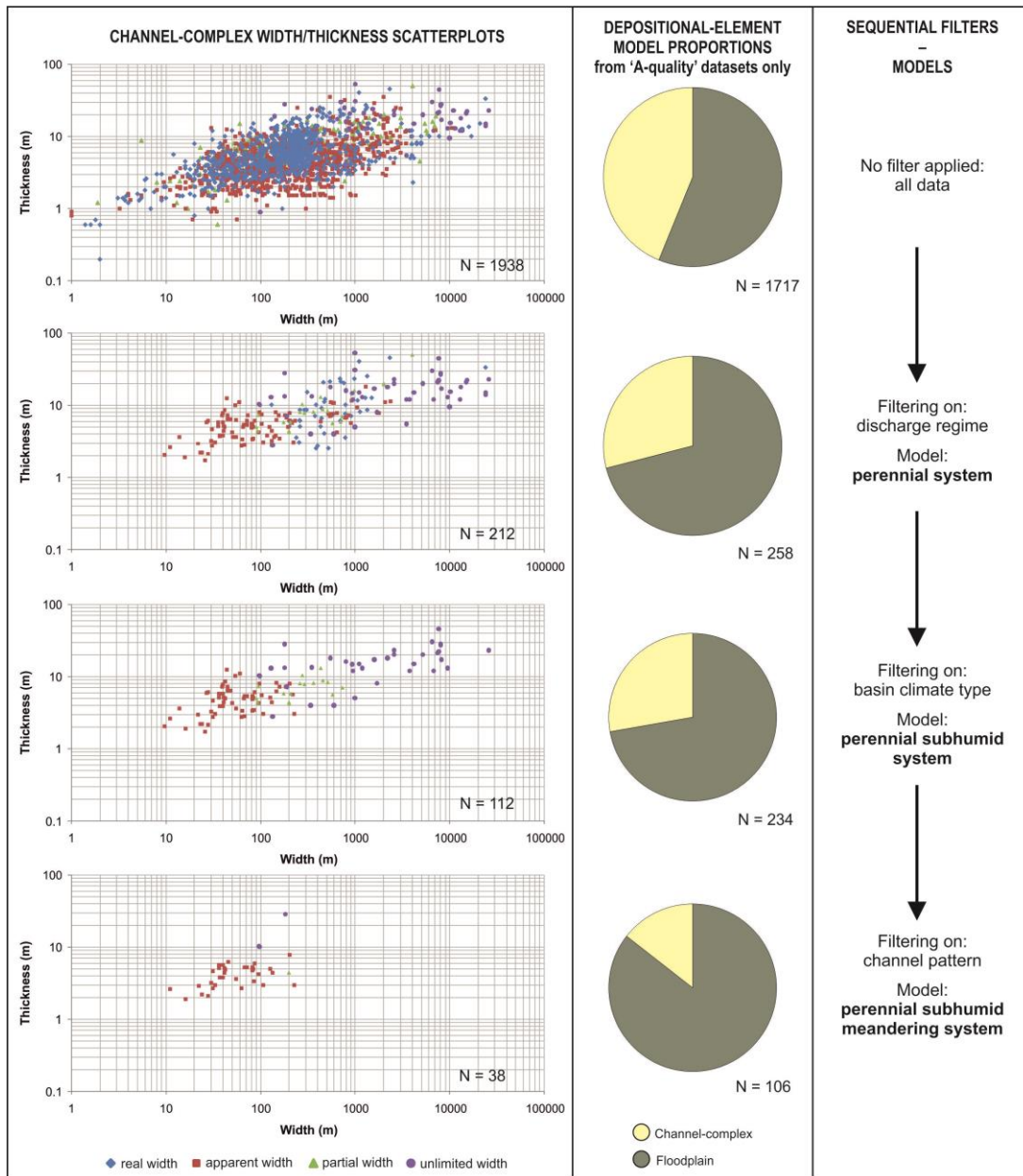
The process of synthesis (or distillation in the terminology of Walker 1984) of the model, to which the issues presented above relate, is actually implemented only after performing the selection of the case studies or individual subsets whose parameters match with the ones chosen for the classification of the quantitative depositional model. Such a process of filtering may be performed on architectural features (e.g. choice of systems in which the thickness of gravel deposits exceed 50% of all measured thickness), descriptive-parameters (e.g. choice of systems classified as meandering), boundary conditions (e.g. choice of dryland systems), or on a combination of each (figure 3.3).

## **3.4 Results: example models**

### **3.4.1 Large-scale architecture**

The importance of including large-scale information in conceptual models of fluvial architecture has long been recognized, and such information has been included in models summarizing the distribution of channel and floodplain deposits in stratigraphic volumes (e.g. Allen 1965a; Friend 1983). However, contrasting views have been expressed regarding the type of system parameters (external controls, frequency/velocity of autogenic processes, descriptive parameters) on which the categorization of the models should be based; for example, as to whether channel-pattern can actually be considered as a good predictor for large-scale organization (cf. Allen 1965a; Bridge 1993). Here, large-scale models based on channel pattern are presented for single-thread and braided systems (figure 3.4). It is not the purpose of this study to assess what type of controls or control-dependent system parameters are most suitable for the categorization of models of large-scale fluvial

architecture (cf. Miall 1980), but one aim is to explain how this approach can be potentially applied to solve this issue, as explained below.



**Figure 3.3:** quantitative information regarding the proportion and geometry (width and thickness) of channel-complexes, constituting large-scale facies models for perennial sub-humid meandering systems and systems associated with intermediate filtering steps. In this case, as in all models presented here, the term 'basin climate type' only refers to the observed/inferred humidity-based climate class at the locus of deposition; a catchment climate classification is also stored, but it applies mostly to modern systems and may refer to average conditions.

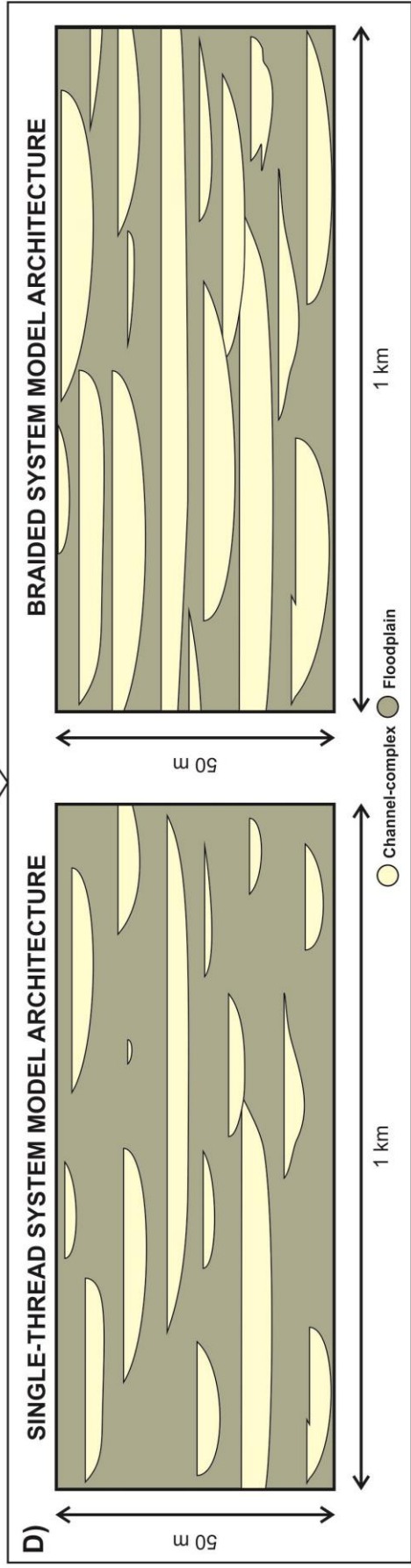
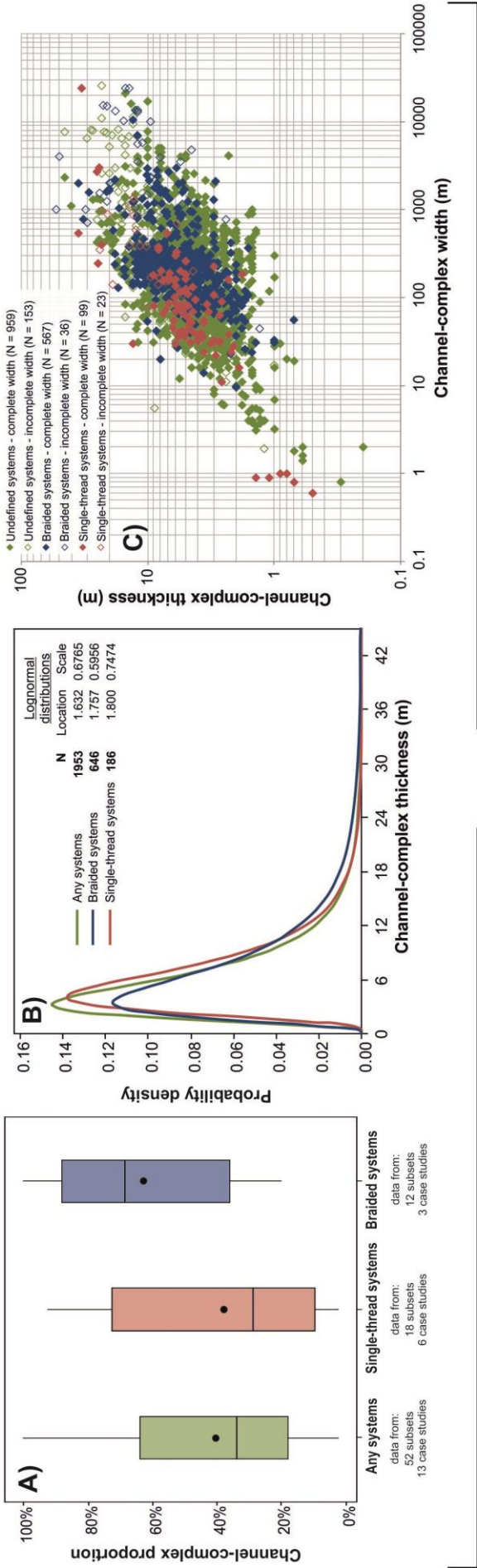
More generally, the main scope of this study is to show how the use of such database systems permit the generation of facies models through an objective

process of synthesis, even though this does not mean that such models will necessarily be unbiased, as they will still be associated with uncertainty related to the interpretations of the systems from which the data were originally derived. These database-derived facies models describe large-scale fluvial architecture in terms of the proportions and geometries of channel-complex and floodplain depositional elements (figure 3.3 and 3.4).

Separately computing genetic-unit type proportions for each stratigraphic volume (subset) is a sensible choice if the subset is large and few categories are included. As this is the case for subsets suitable for computing depositional-element proportions, it is then possible to quantify how proportions vary between volumes (figure 3.4a). Thus, it is possible, for example, to include information on the observed variability in channel density and geometry in the same end-member model: variability becomes part of the model, and there is no need to advocate alternative models to represent it. This also means that, ideally, the approach could be used for determining what classifications are most suitable for categorizing the models, by recognizing ensembles of categories that ensure maximum inter-type variability and minimum intra-type variability in quantities describing architectural styles.

### **3.4.2 Intermediate-scale architecture**

Many traditional fluvial facies models provide a relatively detailed characterization of sedimentary architecture in terms of building blocks interpretable as sub-environments, reflecting their recognition in modern systems and the interpretation of preserved ancient facies assemblages (e.g. Galloway & Hobday 1983; Walker & Cant 1984; Miall 1985; 1996; Nadon 1994). FAKTS' architectural elements broadly match this level of detail: by querying the database, it is possible to derive quantitative information to be included in facies models describing intermediate-scale fluvial architecture in terms of the proportions, geometries and 3D spatial relationships of architectural elements (figure 3.5 to 3.9). The results presented in figure 3.5 to 3.8 illustrate the generation of a facies model for dryland ephemeral braided systems by the application of multiple filters (based on categories of basin climate type, stream discharge regime and channel pattern type), as well as all the models resulting from intermediate filtering steps.



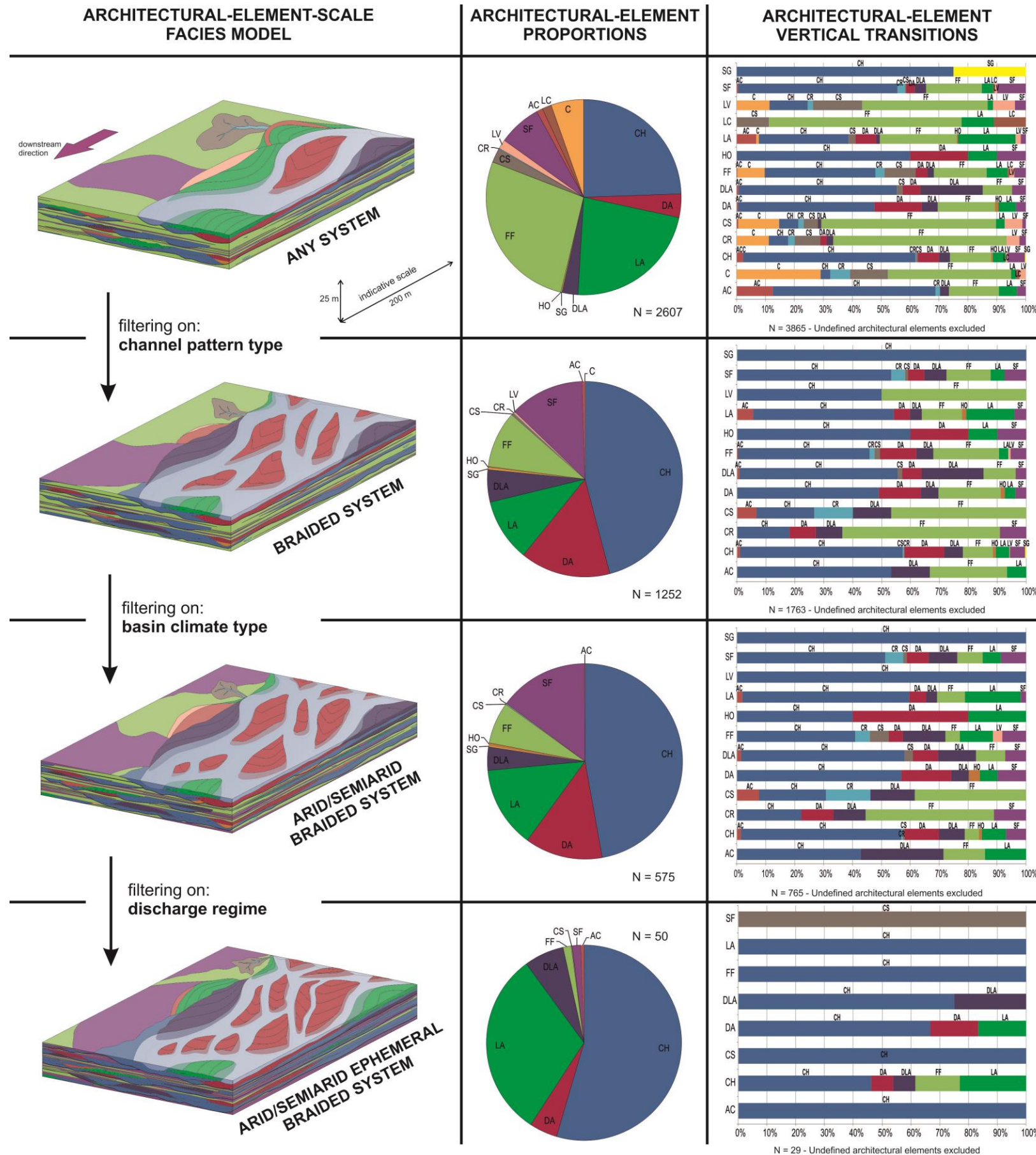
**Figure 3.4 (previous page):** quantitative information referring to large-scale facies models for single-thread and braided river systems: a) boxplots describing the distribution of channel-complex proportions within different stratigraphic volumes (subsets) used to include information about the variability in depositional-element proportions in the models; b) log-normal probability density functions describing the distribution of channel-complex thickness; c) cross-plots of channel-complex thickness and width, classified as complete (real or apparent widths) or incomplete (partial or unlimited widths). Idealized cross-sections comparable to traditional models and informed on such quantitative information are depicted in (d) to highlight architectural differences between the two models.

In this case, because of the level of detail in model categorization (i.e. the number of filters), the ephemeral-river model (step 4) is built upon a limited number of systems and genetic units, thereby resulting in scant general value. Instead, the “arid to semiarid braided system” model (step 3) proposed here incorporates a far larger knowledge base, lending itself better to a discussion of its intermediate-scale architectural features. Mainly, ancient sandy systems were considered for the database-assisted creation of this model, including data from the Jurassic Kayenta Formation, USA (authors’ field data; Miall 1988a; Bromley 1991; Luttrell 1993; Stephens 1994; Sanabria 2001), from the Jurassic Morrison Formation, USA (Miall & Turner-Peterson 1989; Robinson & McCabe 1997; Kjemperud et al. 2008), from the Triassic Moenave Formation, USA (Olsen 1989), from the Triassic Sherwood Sandstone Group, UK (Steel & Thompson 1983; Cowan 1993), from the Miocene Vinchina Formation, Argentina (Limarino et al. 2001), from the Triassic Omingonde Formation, Namibia (Holzförster et al. 1999), and from the Permo-Triassic Balfour Formation, South Africa (Catuneanu & Elango 2001).

In agreement with other existing braided-river models (e.g. Allen 1965a; Miall 1977; 1978; Cant 1982; Walker & Cant 1984; Nanson & Croke 1992), the resulting ideal braided dryland system is dominated by channel deposits because in-channel architectural elements represent over 75% by volume of the model, if only fluvial elements are considered (as in figure 3.5). As these architectural-element proportions are solely based on ancient-system data, it can be observed that the most frequently preserved product of in-channel deposition is represented by aggradational channel-fills, rather than horizontally-migrating barforms. It must be considered that this observation may not be indicative of the original geomorphic organization of channel-belts, as observed abundances may relate to channel-fills having a higher preservation potential than barforms, to channel-deposit accretion directions not being discernable in all cases (for example because of inappropriate outcrop exposure and orientation, especially if surfaces dip at very low angle, cf. Bristow 1987), or to accretion surfaces not always being preserved in barform deposits (cf. Jackson 1978; Kraus & Middleton 1987) potentially resulting in

deposits categorized as *CH* that include the product of the horizontal migration of barforms. Within the model, non-channelized deposits of high-energy sandy aggradational-floodplain elements (*SF*) appear to dominate over floodplain-fine elements (*FF*), with the former more often tending to stack on top of channel-fills and downstream-accreting barforms, and the latter more frequently developed on top of laterally-accreting barform elements. However, *FF* elements display the largest observed lateral extent among floodplain elements, some examples exceeding 1000 m in maximum observed width. Crevasse channels, splays, abandoned channels and levees represent only a volumetrically minor portion of the model floodplain, and the available transition statistics suggest a tendency for these elements to be associated with *FF*, rather than *SF*, floodplain elements. However, the model lacks features that are likely to be included in a qualitative model of a dryland braided system, such as dryland floodplain lakes, suggesting that the data employed to generate the model do not yet fully account for natural variability.

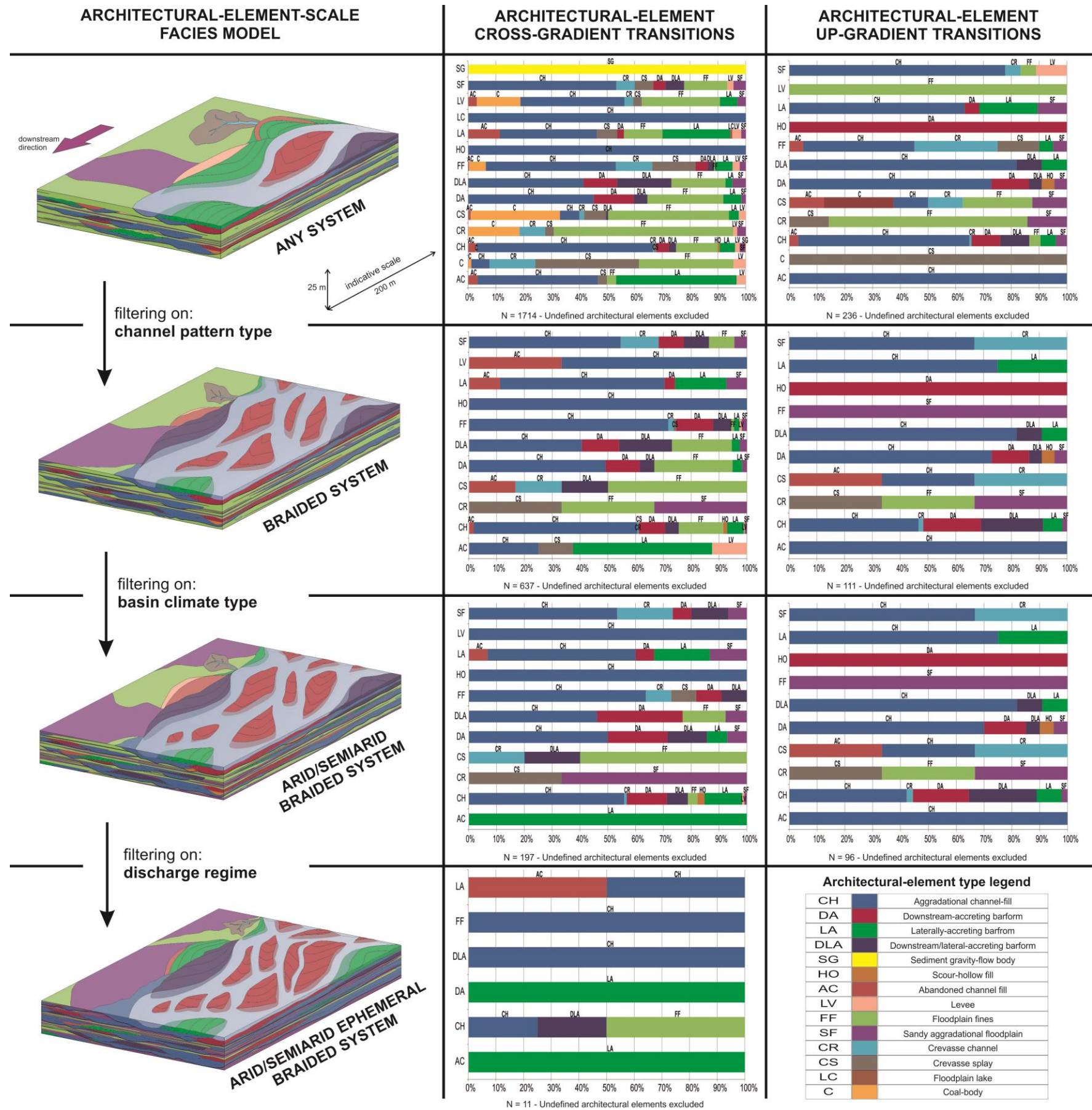




**Figure 3.5:** quantitative information regarding the proportion and vertical transition statistics of architectural elements, constituting intermediate-scale facies models for arid/semiarid ephemeral braided systems and systems associated with intermediate filtering steps. Idealized block-diagrams comparable to traditional models and informed on such quantitative information are depicted in the left-hand column; model architectural-element proportions, presented as pie-charts in the central column, are derived as the sum of the thickness of all elements from adequate subsets (method 1 in figure 3.2 and in the text); vertical transition statistics are presented in the right-hand column as bar charts quantifying the percentage of types of ‘upper’ elements (colour-coded and labelled in the bars) stacked on top of a given type of ‘lower’ element (labels on the vertical axis).

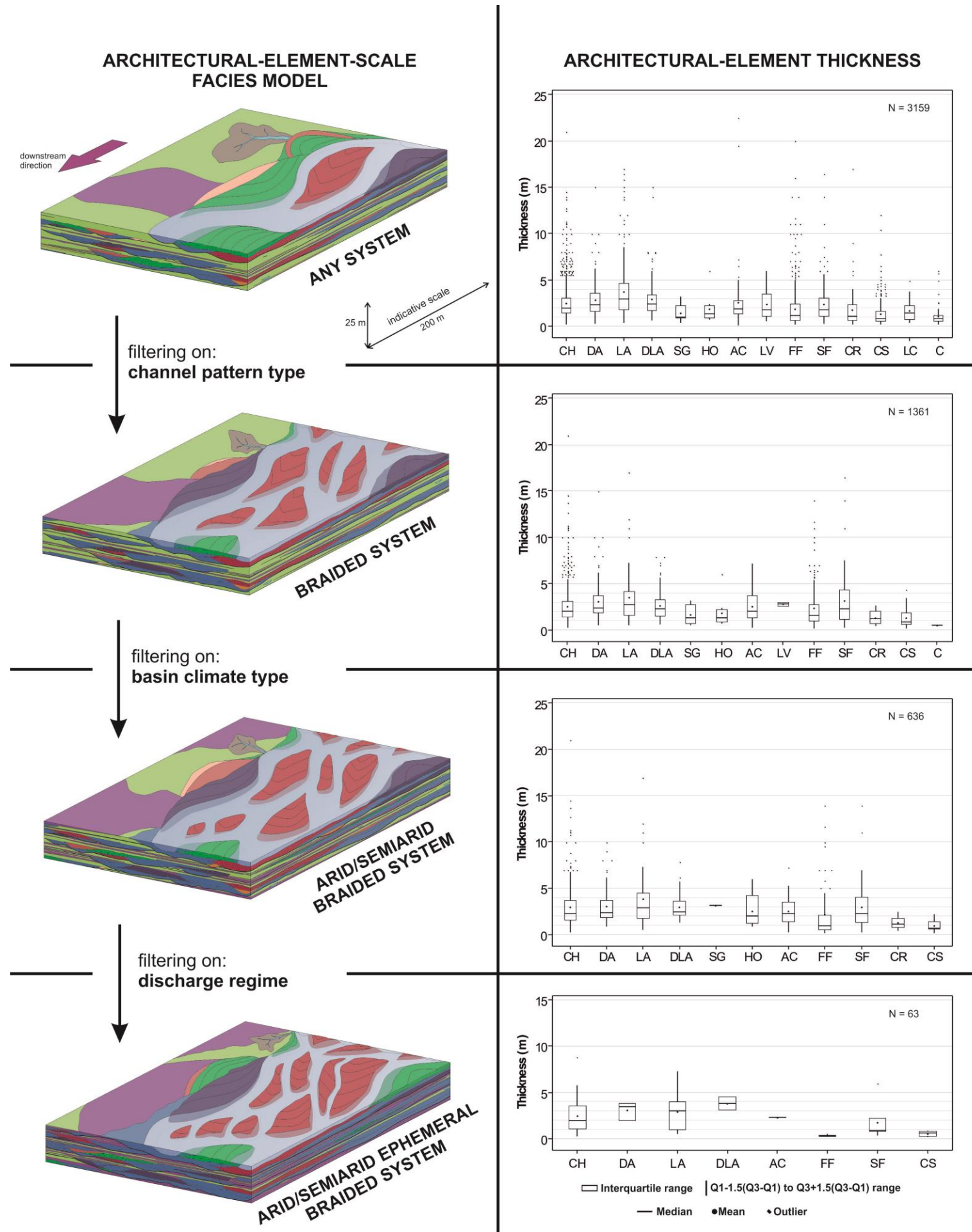






**Figure 3.6:** continuation of figure 3.5. Information on architectural-element horizontal spatial relationships, in the form of cross-gradient and up-gradient transition statistics. Results are presented in the central and right-hand column as bar charts quantifying the percentage of 'cross-gradient' or 'up-gradient' element types (colour-coded and labelled in the bars) juxtaposed to element types labelled on the vertical axis.

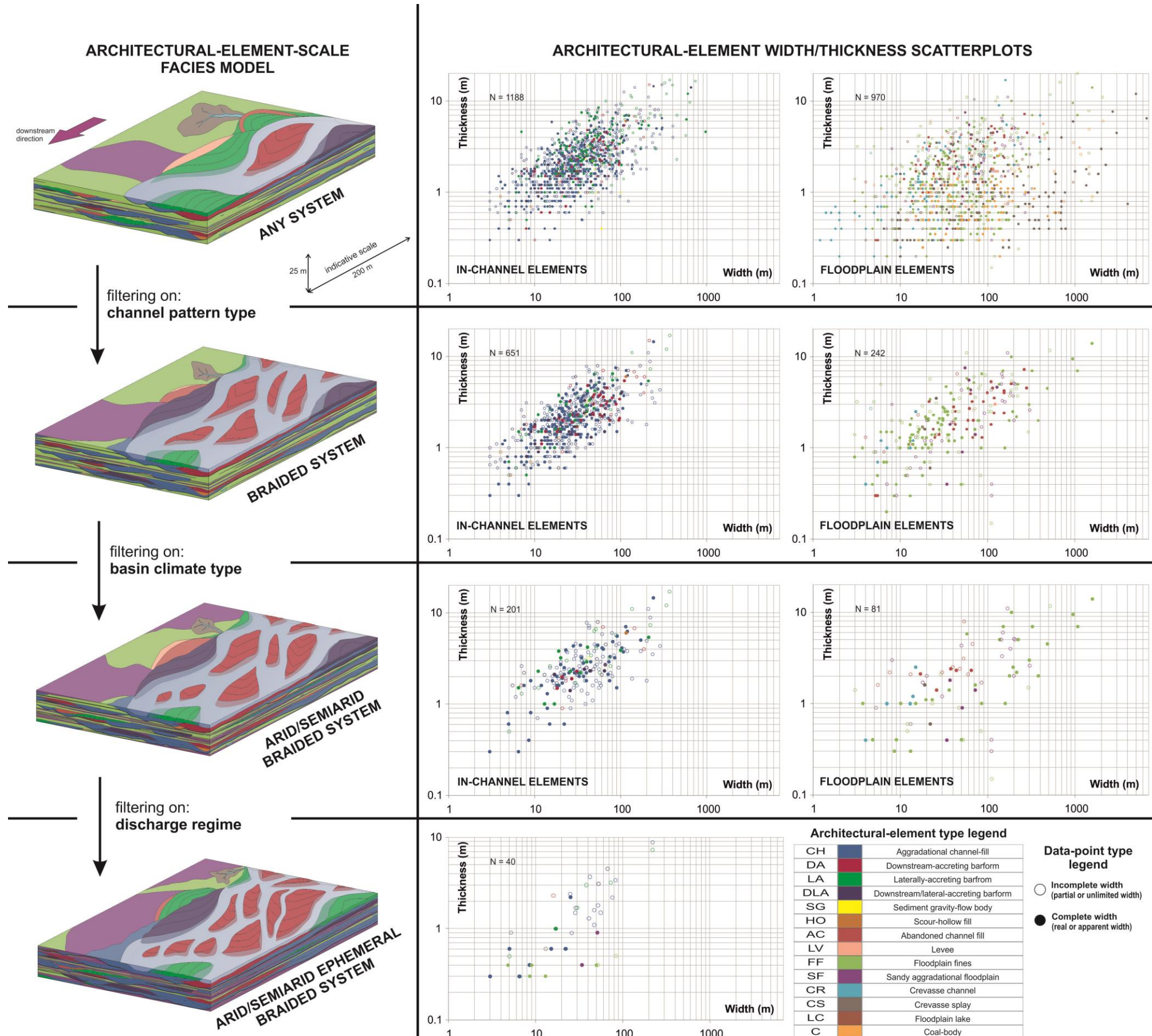




**Figure 3.7:** description of architectural-element geometries for different models. Box-plots in the right-hand column include information on the thickness of the different architectural-element types, for facies models of arid/semi-arid ephemeral braided systems and systems associated with intermediate filtering.

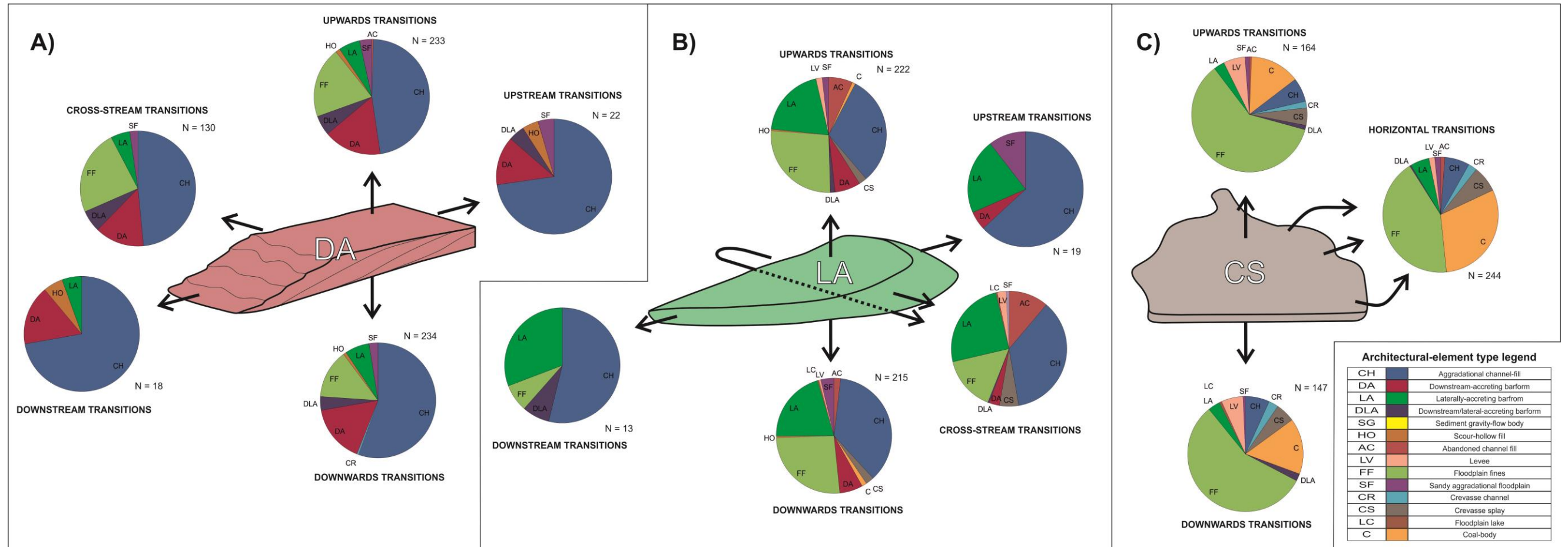






**Figure 3.8:** continuation of figure 3.7. Cross-plots in the right-hand column include information on the relationship between width and thickness of different architectural-element types for facies models of arid/semiarid ephemeral braided systems and systems associated with intermediate filtering steps.





**Figure 3.9:** Models of architectural-element spatial relationships, in the form of pie-charts depicting transition counts between architectural-element types in the upwards, downwards, up-gradient, cross-gradient and down-gradient directions. a) transition statistics referring to downstream-accreting barforms; b) transition statistics referring to lateral-accretion barforms; cross-stream transitions conventionally refer to the right-hand direction, regardless of the dip-direction of accretion surfaces or migration direction of the barform; c) transition statistics referring to crevasse splays; lateral, upstream and downstream transitions have been grouped into horizontal transitions for convenience.



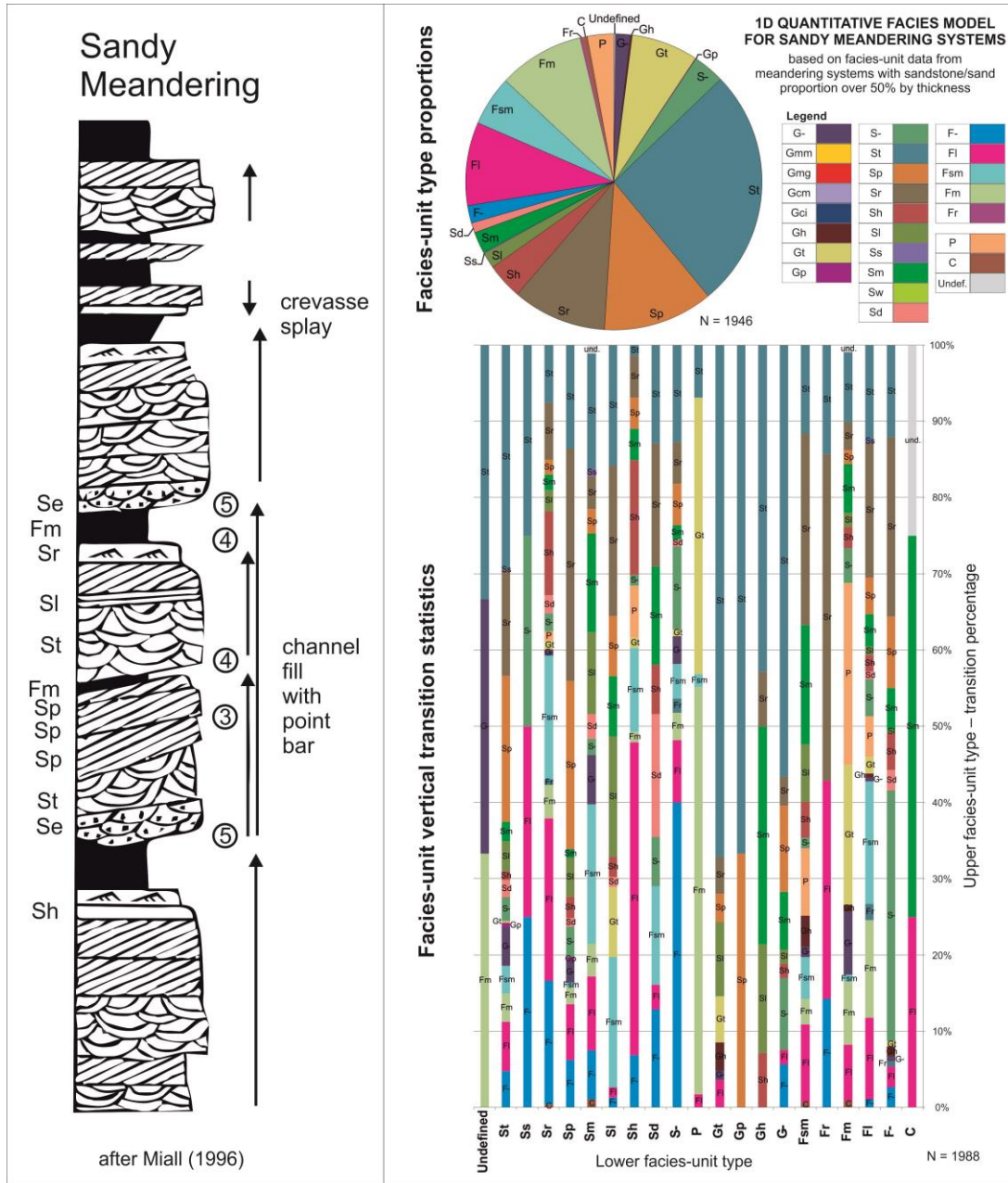


### 3.4.3 Small-scale architecture

Some facies models widely used for interpreting ancient systems are represented by vertical profiles summarizing fluvial styles – related to environmental categories – in terms of lithofacies occurrences, proportions, typical thicknesses and vertical stacking (cf. Miall 1977; 1978; 1996). FAKTS permits the derivation of similar one-dimensional models, represented by proportions, thickness and vertical juxtapositional trends of facies units within system types, by performing an objective distillation of different case studies, as illustrated in figure 3.10: the inclusion of quantitative information relating to facies units may aid the interpretation of 1D subsurface data by making model comparison more objective.

The approach can be generalized to include three-dimensional information: example results (figures 3.11 to 3.14) are again associated with the “dryland ephemeral braided system” model and with the models related to its intermediate filtering steps, to demonstrate the capability to generate multi-scale models.

As the “dryland ephemeral braided system” model currently comprises one fifth of all facies units included in the knowledge base (represented by the model at step 1), the model is richer in data than its intermediate-scale architectural-element-based counterpart, reflecting the fact that the database currently includes more data from lithofacies-scale-oriented studies than from architectural-element-scale studies, for this set of system boundary conditions. The proposed “braided dryland ephemeral” model is based on categories relying on concurrent interpretations of planform type, which requires recognition of contemporaneity of in-channel activity for the braided category, and of basin climate type and discharge regime, which require proxies and may refer to average conditions through time; although the quality of data and interpretations can be ranked, the possibility of including data from case studies whose environmental interpretations are incorrect increases with the number of filters applied and results must therefore be considered with care.



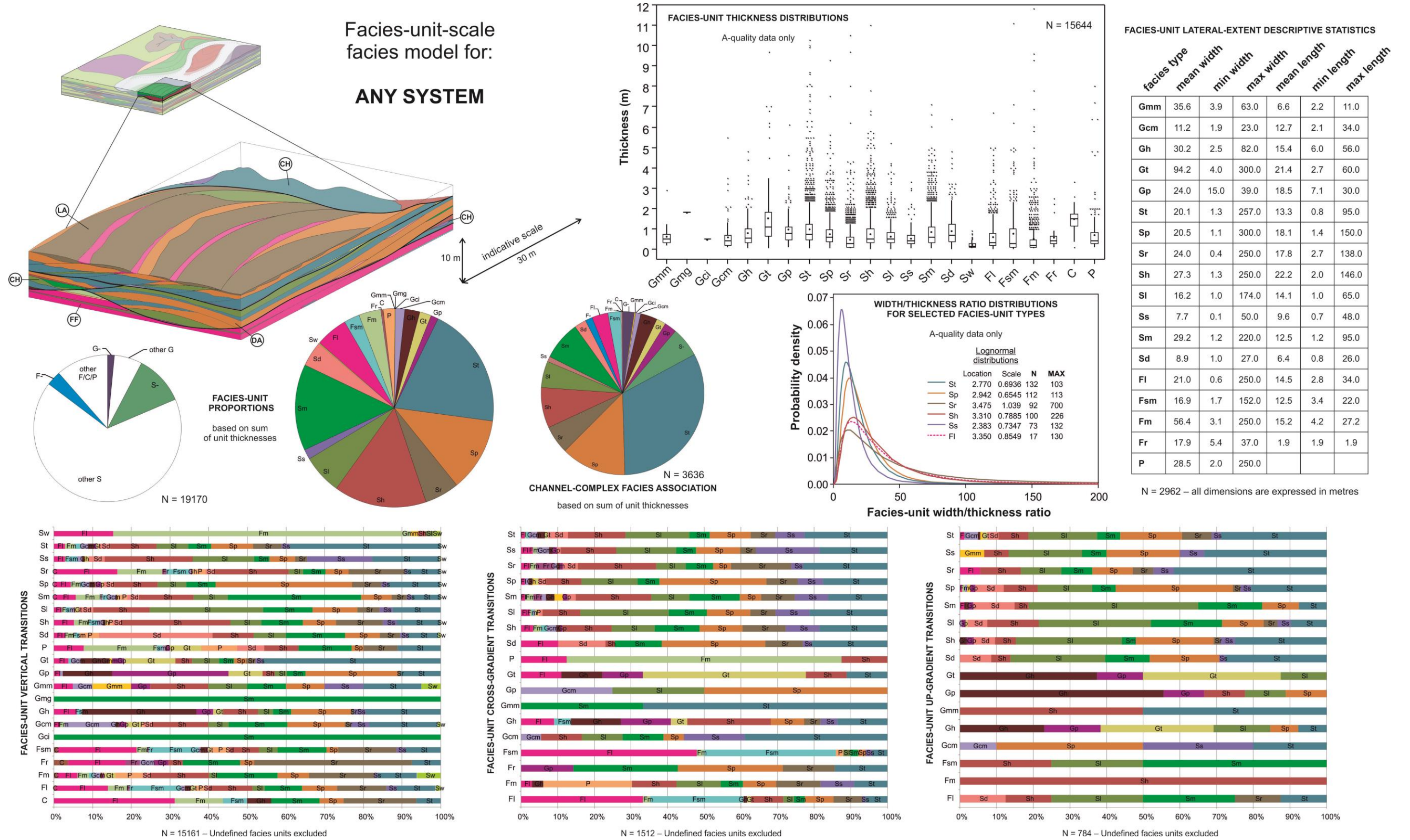
**Figure 3.10:** comparison between the Miall's (1996) facies model for sandy meandering systems presented in the form of a vertical profile, on the left, and a corresponding FAKTS model, on the right. The FAKTS model has been built filtering the database on both a system parameter (meandering channel pattern) and a sedimentological feature (proportion of sandy facies units within subsets higher than 50% by thickness); lithofacies-type proportions are represented as a pie-chart, and were derived as the sum of the thickness of all facies units from adequate subsets (method 1 in figure 3.2 and in the text); vertical transition statistics are presented in the bar chart, quantifying the percentage of types of 'upper' facies units (colour-coded and labelled in the bars) stacked on top of a given type of 'lower' lithofacies (labels on the horizontal axis). In this case, results include 'undefined' lithofacies types, i.e. facies units (e.g. non-fluvial aeolian facies) that cannot be classified according to the adopted classification scheme (table 3.2).

However, the possibility to contrast this model with the ones resulting from intermediate-stage filtering serves the aim of demonstrating the capabilities of the database system in highlighting the peculiarities of the different models, in quantitative terms. For example, the “dryland ephemeral braided system” model includes case studies that collectively show a high abundance of sand-grade deposits, making this model comparable to Miall’s (1985; 1996) sandy-river models 11 and 12. Compared to its intermediate-step models, the “dryland ephemeral braided system” model presented here does not show any significant increase in the proportion of *Sh* (horizontally bedded sandstone) and *Sl* (low-angle cross-bedded sandstone) lithofacies, which are often considered a diagnostic architectural feature of such systems, supposedly in relation to the influence of upper-flow regime processes associated with flash floods (Miall 1985; 1996). Instead, a comparison between the facies-unit proportions of the braided-system model (figure 3.12), and of the sandy meandering-system model (figure 3.10) reveals that the proportion of *Sh* and *Sl* facies-units among sandy deposits are significantly higher in the former compared to the latter.

Facies models often contain information on individual genetic packages: models of this sort represent a tool for guiding the interpretation of lithosomes with characteristic facies associations as sub-environments, such as point bars (e.g. Allen 1970) or crevasse splays (e.g. Bridge 2003), which can be variably arranged in the rock record, thereby representing a reference to interpretations that can be flexibly applied to different fluvial environmental types. The facies architecture of lithosomes corresponding to FAKTS’ depositional and architectural elements can be investigated to derive model proportions, geometries, grain-size and spatial relationships of facies units within them, as illustrated in figures 3.15 and 3.16. The examples shown demonstrate how basic features relating to the internal architecture of the lithosomes – such as the lack of conglomeratic beds, the dominance by flat-bedded sandstone, and the on average higher horizontal extent of the formative facies units characterizing sandy aggradational floodplain elements (figure 3.16) – can be highlighted through quantification.



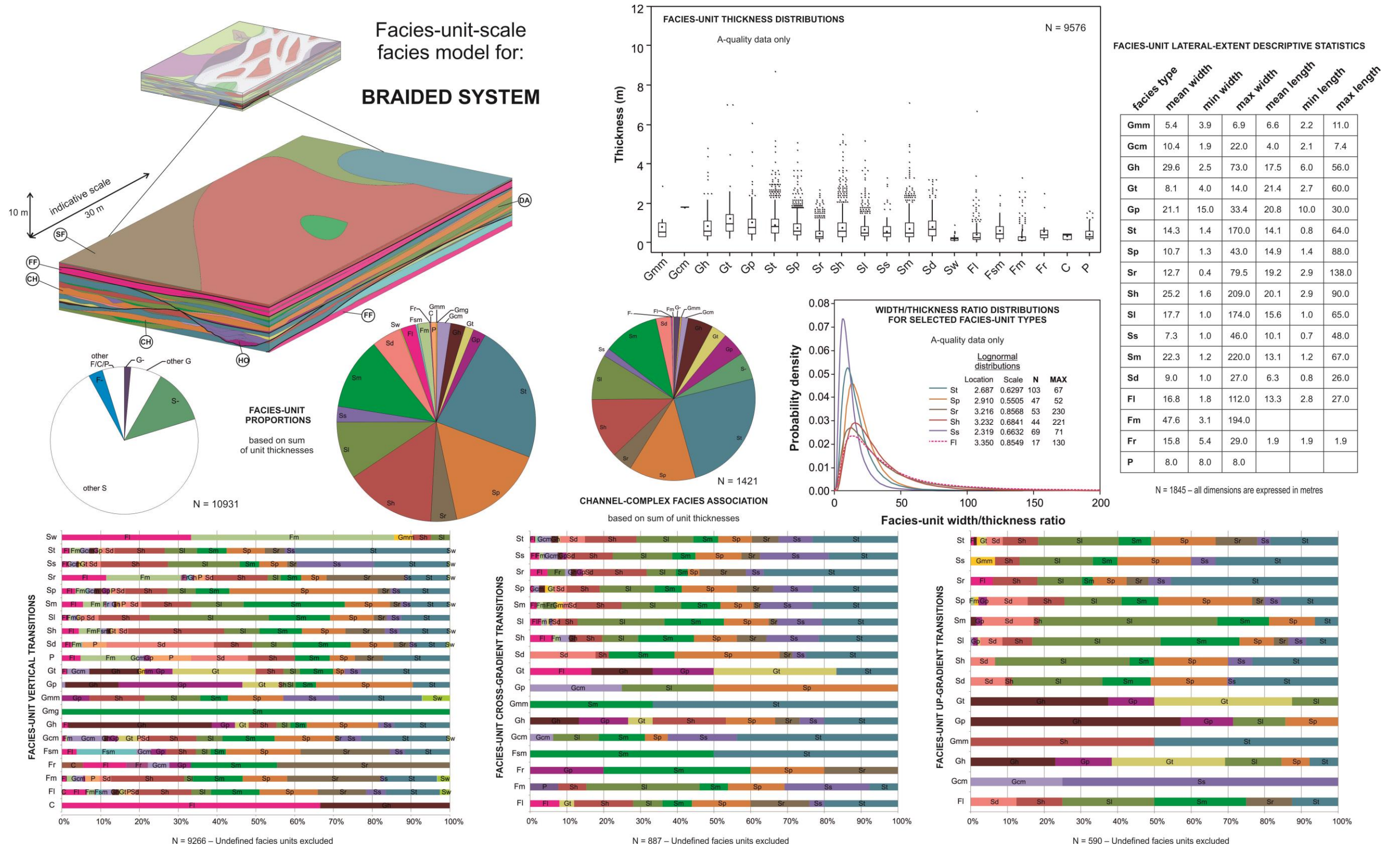




**Figure 3.11:** example quantitative information that can be incorporated into a small-scale facies model referring to the entire knowledge base (no filter applied). Overall facies-unit proportions are presented as pie-charts of textural classes and of ‘texture + structure’ facies-unit classes, and are compared with the facies organization of channel deposits, described by facies unit proportions within channel-complexes. The geometry of different facies-unit types is quantified by box-plots of their thickness distribution, summary descriptive statistics of their lateral extent, and probability density functions of the width/thickness aspect ratio of selected types. Upwards, cross-gradient and up-gradient transition statistics are presented as bar charts quantifying the percentage of types of facies units (colour-coded and labelled in the bars) juxtaposed to a given type of facies unit (labels on the vertical axis). In addition, the facies-unit-scale block diagram has been built based on database-derived information relating to the facies organization and geometry of individual architectural-element types.







**Figure 3.12:** example quantitative information that can be incorporated into a small-scale facies model referring to braided systems, filtering the knowledge-base on the channel-pattern type. Results are presented as in figure 3.11, to render the models comparable.





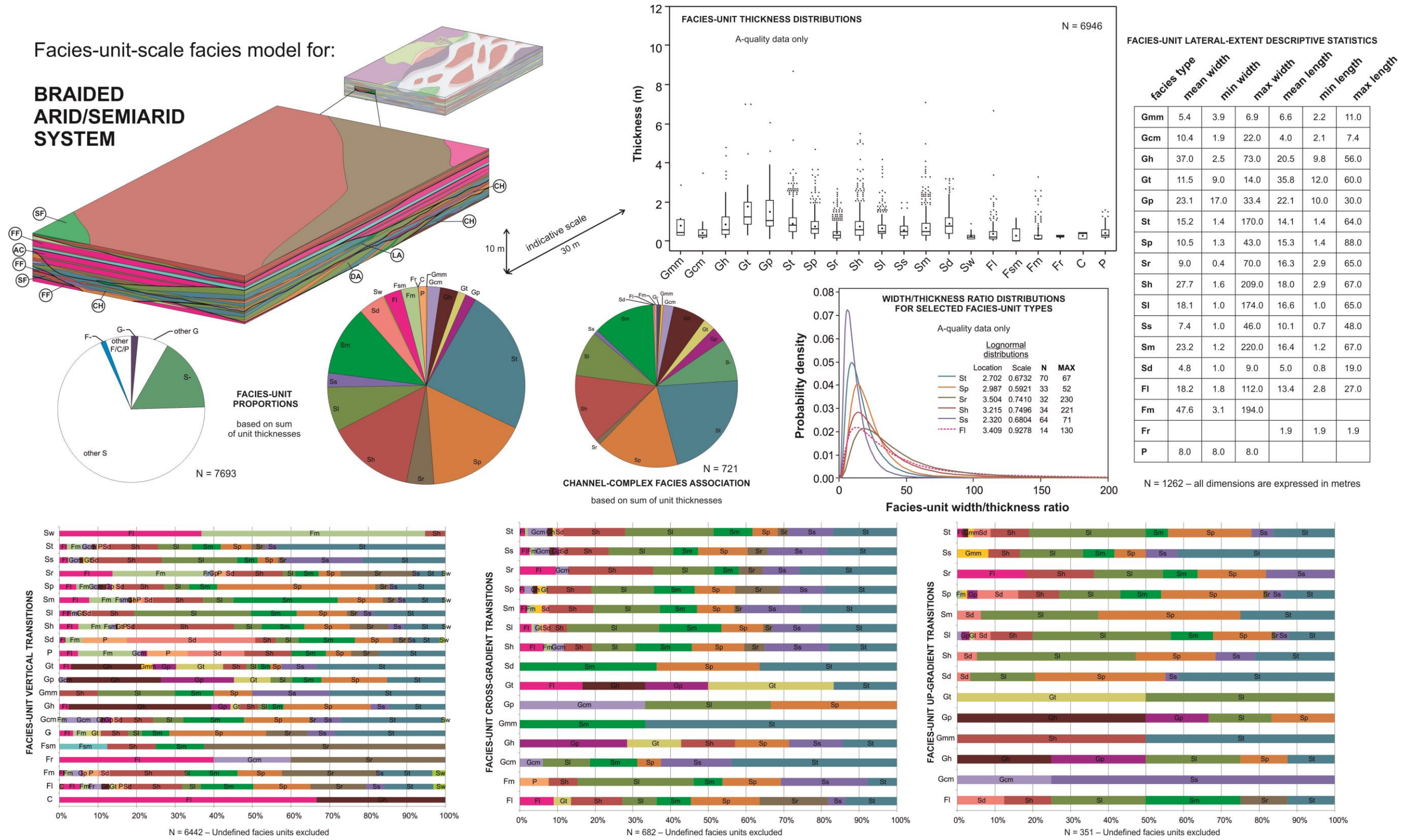


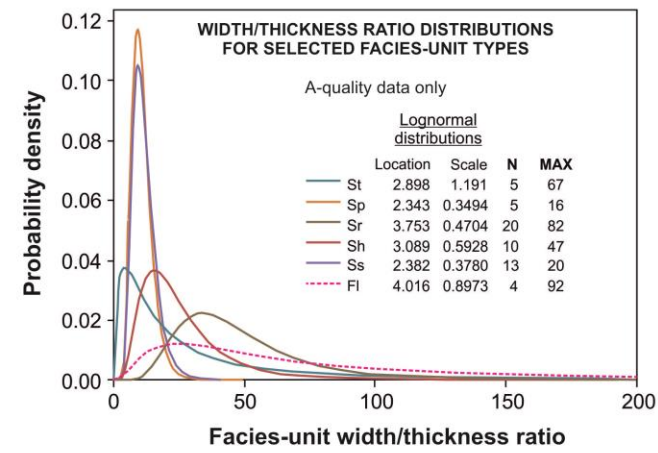
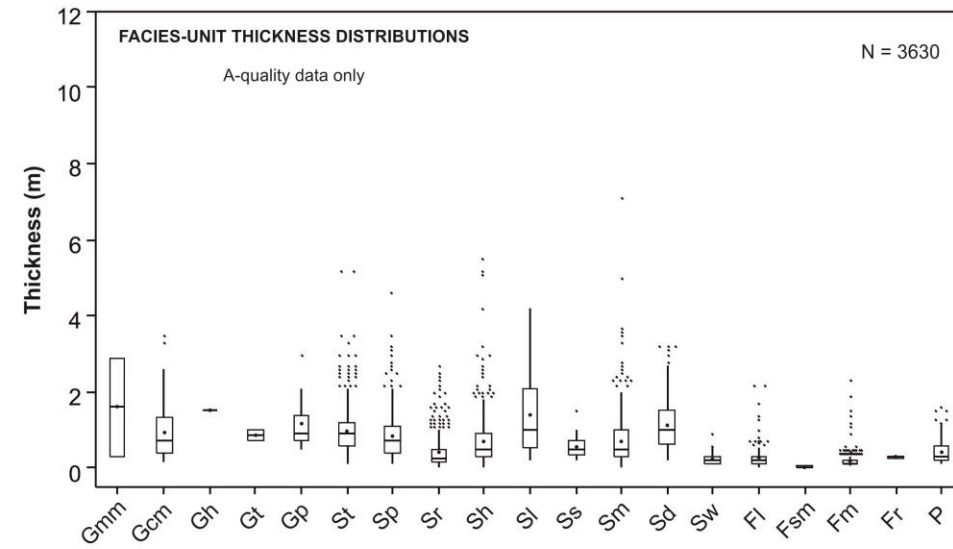
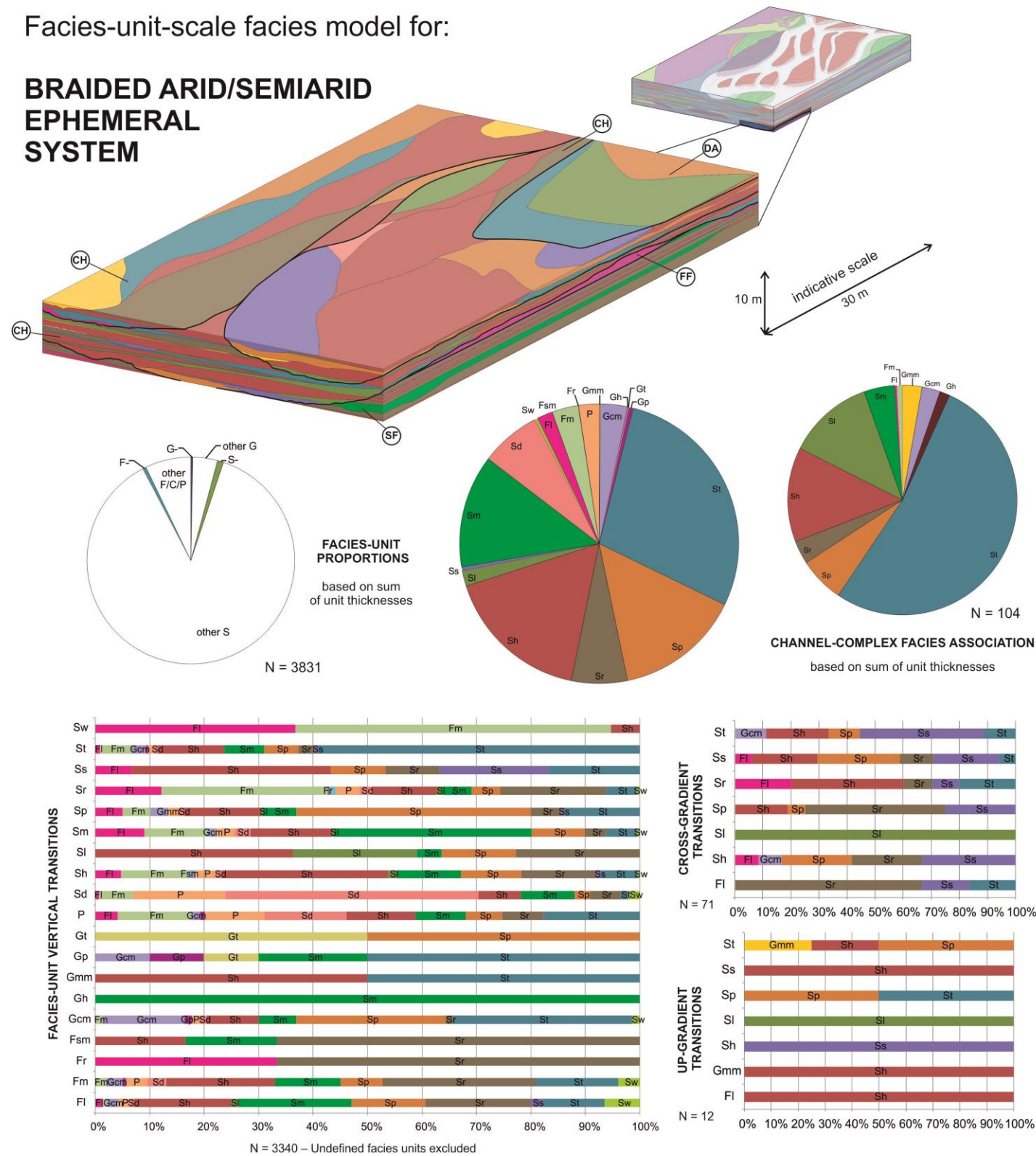
Figure 3.13: example quantitative information that can be incorporated into a small-scale facies model referring to dryland braided systems, filtering braided systems on the basin climate type. Results are presented as in figures 3.11 and 3.12, to render the models comparable.





Facies-unit-scale facies model for:

**BRAIDED ARID/SEMIARID EPHEMERAL SYSTEM**



G-	Gravel to boulders - undefined structure
Gmm	Matrix-supported massive gravel
Gmg	Matrix supported graded gravel
Gcm	Clast-supported massive gravel
Gci	Clast-supported inversely-graded gravel
Gh	Horizontally-bedded or imbricated gravel
Gt	Trough cross-stratified gravel
Gp	Planar cross-stratified gravel
S-	Sand - undefined structure
St	Trough cross-stratified sand
Sp	Planar cross-stratified sand
Sr	Asymmetric-ripple cross-laminated sand
Sh	Horizontally-laminated sand
Sl	Low-angle cross-bedded sand
Ss	Scour-fill sand
Sm	Massive or faintly laminated sand
Sw	Symmetric-ripple cross-laminated sand
Sd	Soft-sediment deformed sand
F-	Fines (silt, clay) - undefined structure
Fl	Laminated sand, silt and clay
Fsm	Laminated to massive silt and clay
Fm	Massive clay and silt
Fr	Fine-grained root bed
P	Paleosol carbonate
C	Coal or carbonaceous mud

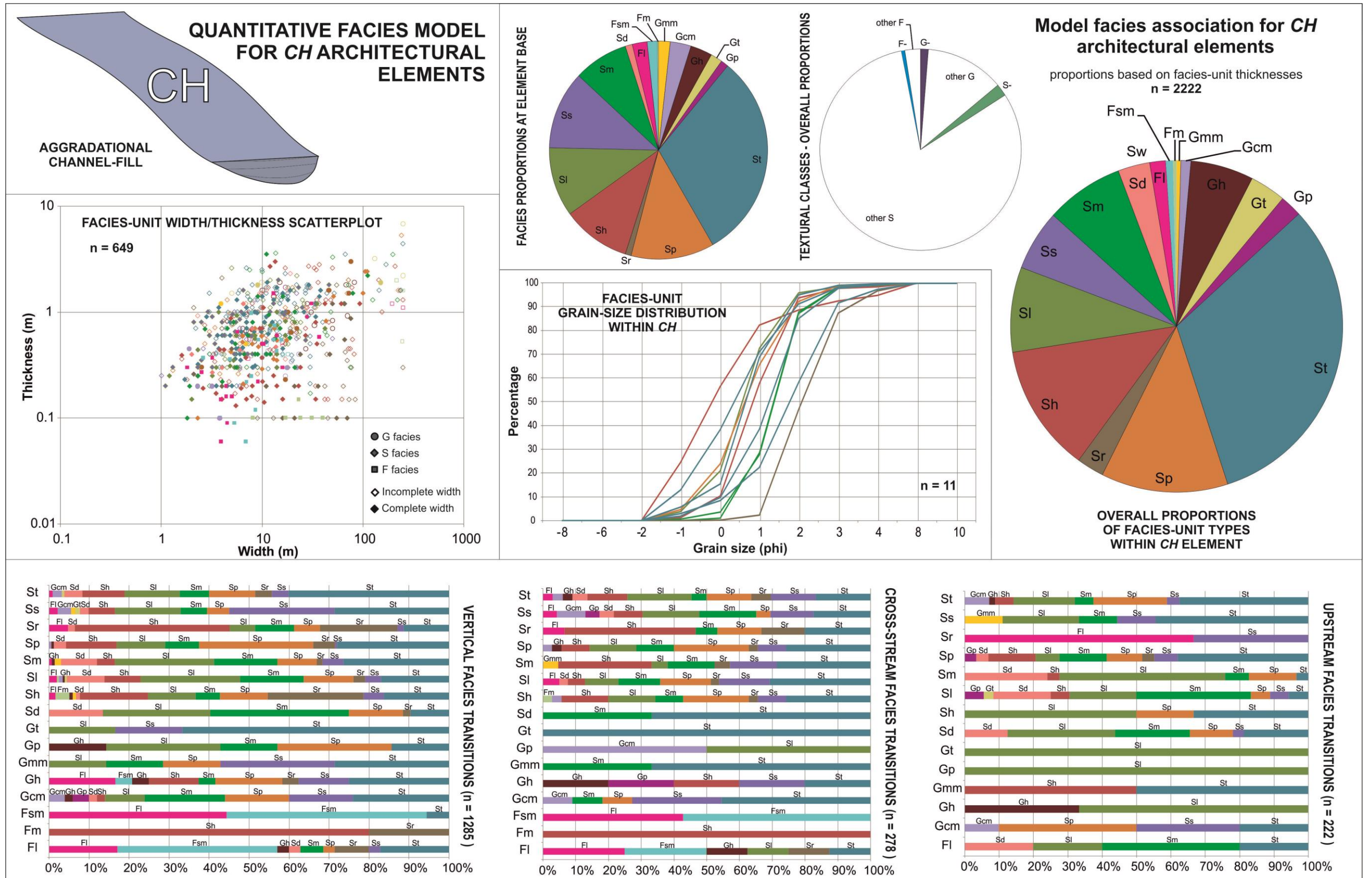
**Facies-thickness boxplot legend**

- Interquartile range
- ▭ Q1-1.5(Q3-Q1) to Q3+1.5(Q3-Q1) range
- Median
- Mean
- ◆ Outlier

**Figure 3.14:** example quantitative information that can be incorporated into a small-scale facies model referring to ephemeral dryland braided systems, filtering dryland braided systems on the water-discharge regime. Results are presented as in figures 3.11, 3.12 and 3.13, to render the models comparable.



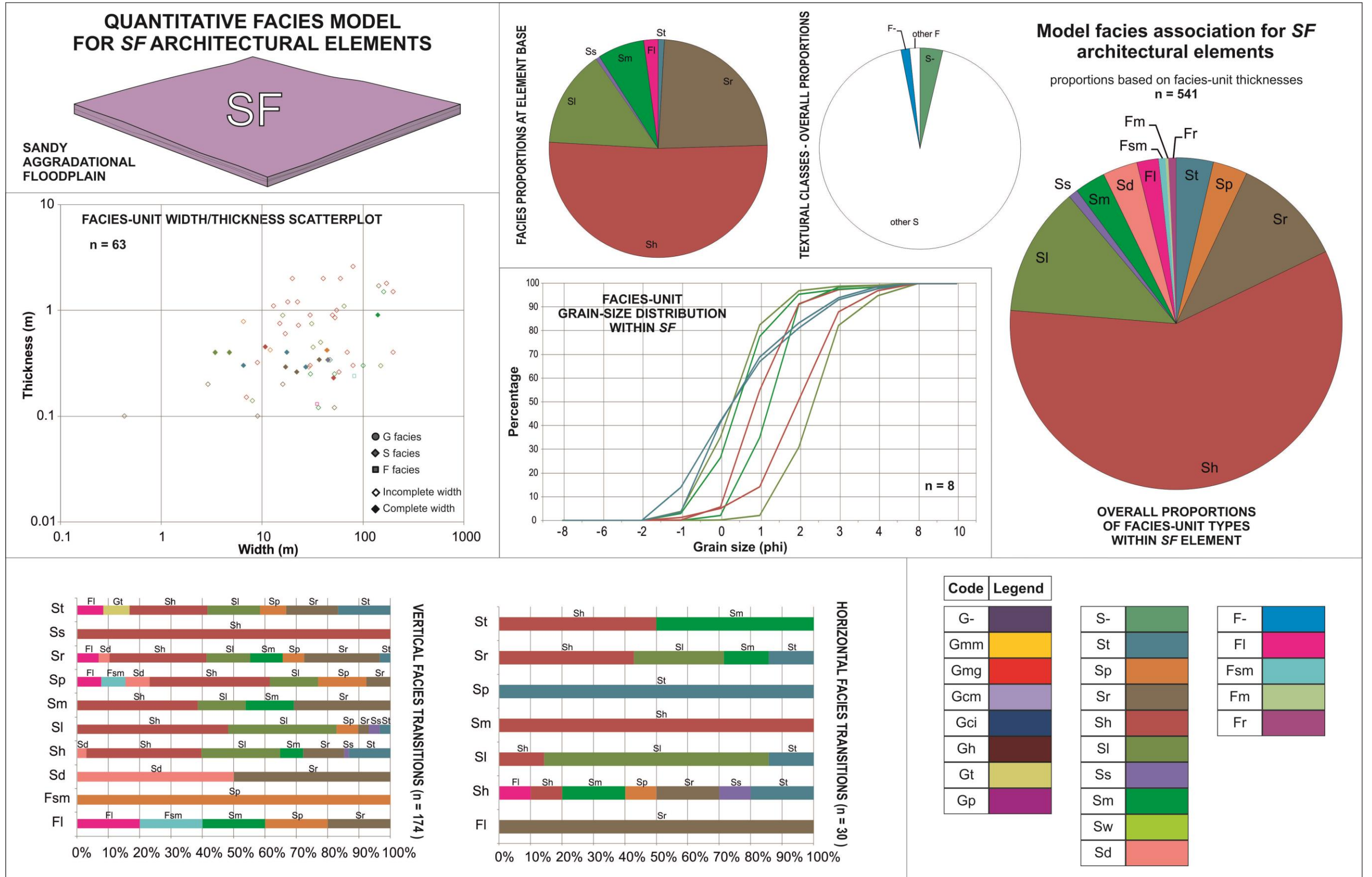




**Figure 3.15:** partial quantitative information constituting a small-scale facies model of aggradational channel fills (*CH* architectural elements). The model facies association of the element is described by overall lithofacies-type proportions, presented as pie-charts of textural classes and of 'texture + structure' facies-unit classes; proportions of facies types observed at the base of channel-fills are also given. Example cumulative grain-size distributions for facies units within *CH* elements are presented for different lithofacies types; the thickness and width of classified facies units within aggradational channel fills is represented in the cross-plot; upwards, cross-gradient and up-gradient transition statistics are presented as bar charts quantifying the percentage of types of facies units (colour-coded and labelled in the bars) juxtaposed to a given type of facies unit (labels on the vertical axis) within *CH* elements. Legend and colour code are given in figure 3.16.







**Figure 3.16:** partial quantitative information constituting a small-scale facies model of aggradational sheetflood-dominated sandy floodplain elements (*SF* architectural elements). As in figure 3.15, the model facies association of the element is described by overall lithofacies-type proportions, presented as pie-charts of textural classes and of 'texture + structure' facies-unit classes; proportions of facies types observed at the base of channel-fills are also given. Example cumulative grain-size distributions for facies units within *SF* elements are presented for different lithofacies types; the thickness and width of classified facies units within sandy aggradational floodplain elements is represented in the cross-plot; upwards and horizontal (cross-gradient + up-gradient) transition statistics are presented as bar charts quantifying the percentage of types of facies units (colour-coded and labelled in the bars) juxtaposed to a given type of facies unit (labels on the vertical axis) within *SF* elements.





#### **3.4.4 Spatial and temporal evolution**

Given that FAKTS stores architectural information relating to stratigraphic volumes that can be arranged in relative temporal and spatial frameworks, information on the temporal and spatial evolution of architectural features from individual case studies can be derived and included in quantitative facies models of fluvial systems. Quantitative comparative studies can be performed between different systems to investigate spatial and temporal trends with the aim being to derive models of architectural change, in terms of space and/or time. Figure 3.17 presents downstream changes in facies-unit proportions (cf. Miall 1977) for a modern system and an ancient system, both of which are believed to represent terminal fluvial fans, for which the identification of proximal, medial and distal fan zones is justifiable, although arbitrary rather than objective.

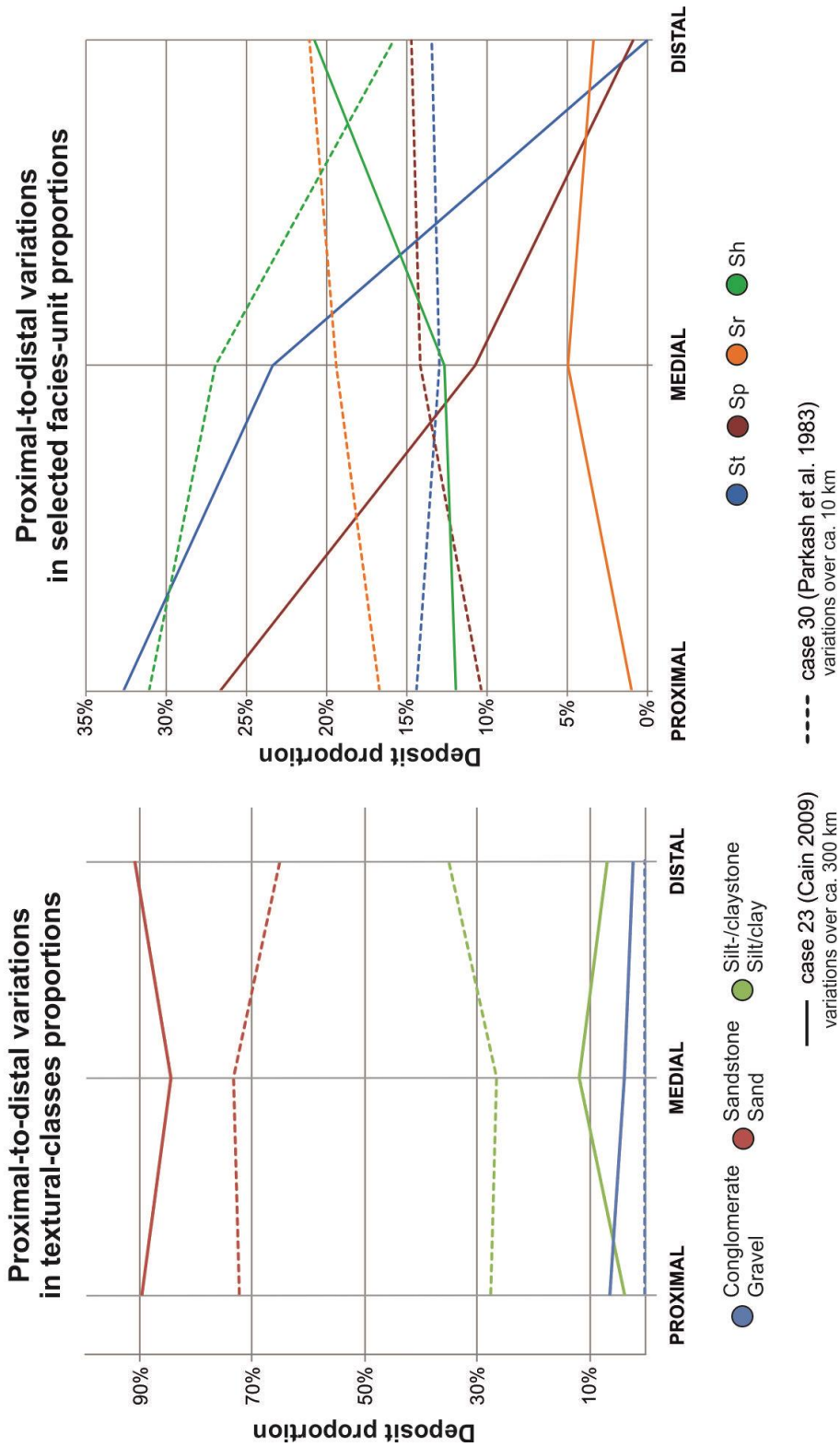
### **3.5 Discussion**

A database-driven method for the creation of quantitative fluvial facies models such as the one presented here has several advantages, as listed below.

Most importantly, this approach satisfies the long-recognized need for inclusion of quantitative information in facies models (North 1996; Anderson et al. 1999; Lunt et al. 2004), improving the value of facies models as a reference for comparison, interpretation and subsurface prediction. For example, database-derived models can be used as quantitative synthetic analogues to subsurface systems with which to better inform stochastic structure-imitating simulations of sedimentary architecture (Colombera et al. 2012b, Chapter 6).

Although several alternative procedures can be followed for obtaining the same type of information, the process of synthesis by which information from the individual case studies is distilled into the model can be carried out objectively, and permits the preservation of local detail through incorporation of features with limited occurrence. The number of case studies and genetic units included will justify and quantify the model generality.

**COMPARISON BETWEEN SYSTEMS CLASSIFIED AS TERMINAL FANS**



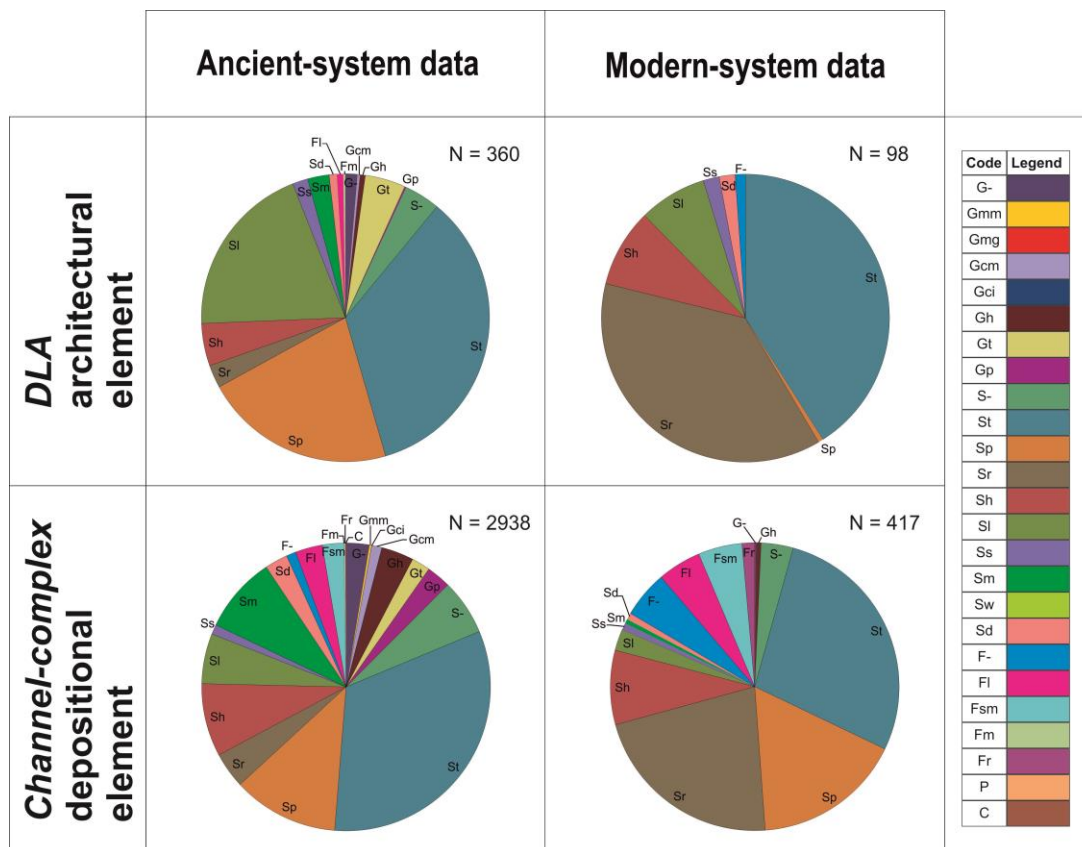
**Figure 3.17:** graphs quantifying the downstream variations in the proportion of textural classes (left-hand graph) and example facies-unit types (right-hand graphs), for two different depositional systems (Parkash et al. 1983; Cain 2009, cf. Cain & Mountney 2009; 2011) classified as “terminal fans”. Note that the length scales over which the variations are observed are different for the two systems, to make the results referable to a tripartite subdivision of the systems into ‘proximal’, ‘medial’ and ‘distal’ zones and comparable with existing models; similar results could be derived for absolute-distance scales.

Quantitative facies models generated by a database approach can be flexibly tailored on any system parameters and/or concurrent architectural properties (e.g. gravel-bed braided system), and any of the scales of observation considered can be included in the model (e.g. channel-complex distribution in an ideal alluvial basin, architectural-element distribution in a meandering-system model; lithofacies distribution in a model of a crevasse splay element), either individually or in the form of hierarchically-nested depositional products.

As metadata concerning the quality of observations and interpretations can be stored in such a database, it is possible to include information about the uncertainty related to variability in data quality and data deficiency in the model. If all – or at least all the most significant – studies on the sedimentology of fluvial systems were included, the database could help identify gaps in current knowledge, in a way similar to the original intention of facies models (cf. Walker 1984).

The use of a database system permits inclusion of architectural variability as a characteristic of the model, in contrast to traditional facies models. For example, Miall's models 11 and 12 (Miall 1985; 1996) are solely differentiated on the basis of architectural style, with the scope of including information on the variability of facies assemblages, despite the two model systems being categorized on mutually non-exclusive classes. Instead, this database approach allows inclusion of information on the variability in sedimentary architecture into models classified on mutually-exclusive categories. This has implications for the recognition of the environmental categories that, by maximizing architectural variability between types and minimizing variability within types, are most suitable for facies-model classification.

The inclusion of information that refers to interpretative system types and unit types (depositional elements, and, especially, architectural elements) permits comparison of facies associations from ancient and modern systems (cf. figure 3.18), thereby providing the possibility to validate interpretations of environments or sub-environments in ancient fluvial systems. For example, the principle of comparative sedimentology can be applied to test planform-based interpretations of the rock record against observations on the facies organization of modern rivers, for which planform types are known. Additionally, as information from ancient and modern systems can be derived separately, this method overcomes the limitation of assuming that modern systems are closely analogous to ancient systems and provides the opportunity to assess the role of differential preservation potential for various types of fluvial deposits (cf. Jackson 1978; Hickin 1993; Miall 2006).



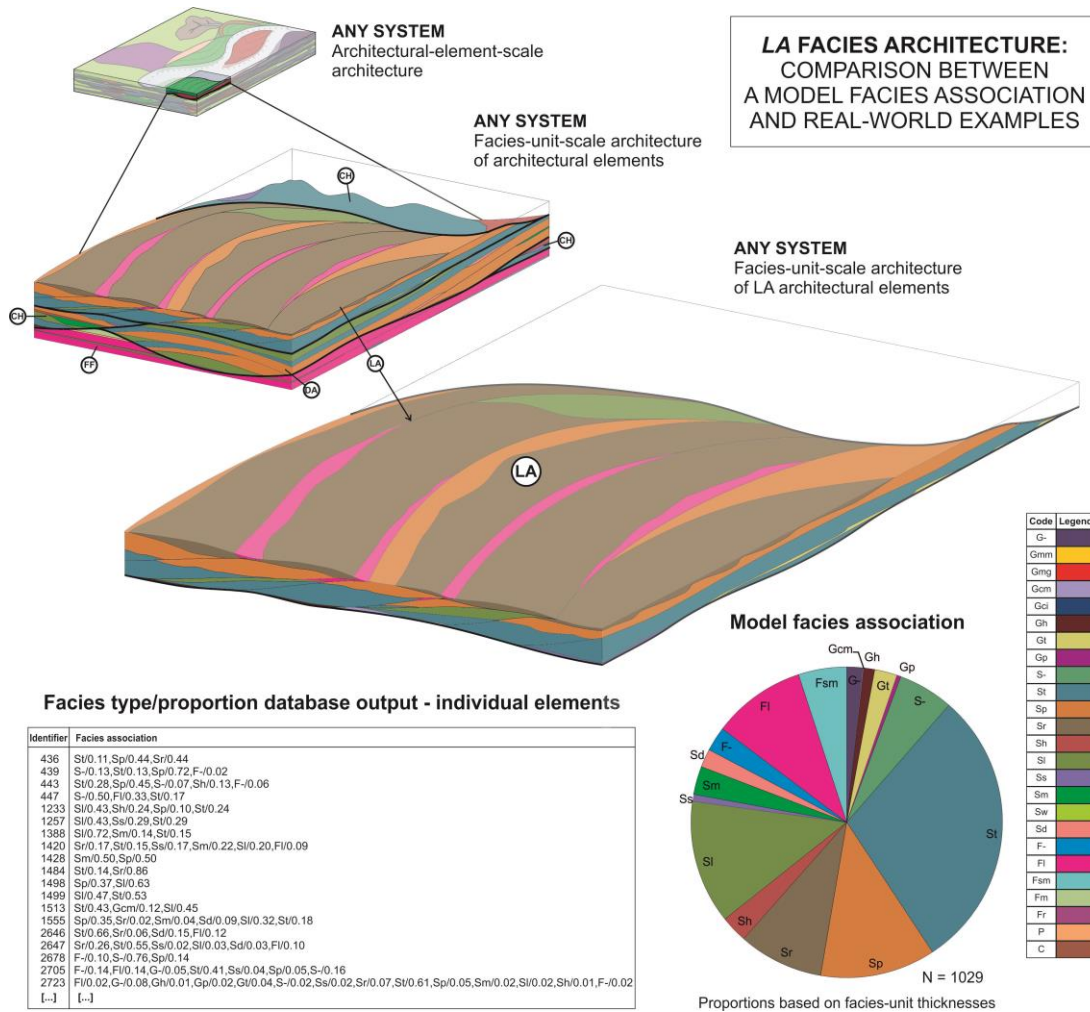
**Figure 3.18:** example facies associations for ‘downstream- and lateral-accretion barforms’ (DLA architectural elements) and ‘channel-complex’ depositional elements, as derived by separately considering data from ancient systems preserved in the rock record and modern river systems; results are presented as pie-charts quantifying facies-unit proportions derived as the sum of the thickness of all facies units from adequate subsets (method 1 in figure 3.2 and in the text).

Perhaps, the most important strength of this database approach is its capability to overcome the end-member classification mentality in general; for example, the tendency to classify fluvial systems as braided or meandering – embodied by some of the example models presented herein – may tend to ignore the range of natural variability and may convey the idea that sedimentary systems must obey the ideal conditions of the end-members. A database of this kind can effectively be used to highlight the uniqueness of depositional systems, since each one is stored individually in the database and can be individually retrieved for comparison (cf. figure 3.19), thereby providing a more flexible benchmark for reference. This system can therefore reconcile the “facies model” school-of-thought (as commonly taught, if not as originally conceived) in which there exists a discrete number of sedimentary environments, with the view that sedimentary environments tend to grade into each other (cf. Galloway & Hobday 1983; Anderton 1985; Miall 1985).

In addition, it should be apparent that, apart from generating quantitative fluvial facies models, whose scope is solely capturing patterns of sedimentary organization for environmental classes, a similar database provides the possibility to test the validity of theories concerning the genetic significance of architectural characteristics of fluvial systems and their occurrence within environmental types.

However, it must be borne in mind that the approach of utilizing a database for the generation of quantitative fluvial facies models suffers from several limitations, principally inherent in the source-to-database workflow (cf. Saunders et al. 1995) and with the adoption of closed classification schemes, some of which include classes of purely interpretative nature: systems or genetic units may simply not fit in the existing classes, and interpretations may not be correct, may be uncertain, or may be mistakenly translated into the database system. Therefore, some precautions were taken at the database-design stage to avoid uncritical use of the system presented here. For example, to ensure consistency with original classifications and flexibility in categorization, open classification fields and multiple editable classification schemes are adopted, while the quality of interpretations and the resulting reliability of system and genetic-unit classifications is quantified by data-quality ranking (cf. Baas et al. 2005; Colombera et al. 2012a, Chapter 2). Additionally, in cases where data do not fit in the existing classes, the relative attribute values are left undefined, signifying a lack of data or understanding on which to base the interpretation.

Notwithstanding such precautions, limitations in the approach must always be borne in mind and the application of such a system should never be conceived as a black-box technique. For example, creation of database-informed facies models requires that careful consideration be given to assessing uncertainty associated with the difficulty in constraining boundary conditions or system parameters for the rock record: this information could be integrated qualitatively in the model. Also, the specific database presented here could be significantly improved in the way it describes architectural styles. For example, this system currently lacks descriptors of genetic-unit shape (e.g. wedge, sheet), descriptors of geometrical style of transition (e.g. onlap, offlap), and genetic-unit porosity and permeability data.



**Figure 3.19:** comparison between the model facies association of ‘lateral accretion barforms’ (LA architectural elements) represented by the pie-chart, which quantifies facies-unit proportions derived as the sum of facies-unit thickness (method 1 in figure 3.2 and in the text), and the partial result of a query returning the proportion of facies-unit types within each individual LA architectural element, in tabulated form (e.g. ‘St/0.11’ means 11% of St facies unit within the given element). The possibility to individually store and retrieve each depositional system or genetic unit renders the FAKTS database system a reference for comparison that is richer and more flexible than traditional facies models.

### 3.6 Conclusions

This work demonstrates how a relational database created for the digitization of fluvial sedimentary architecture can be employed for the objective generation of facies models that are quantitative in nature and are customizable both in terms of system parameters on which they are categorized and type and scale of sedimentary units by which they are built. The type of information such models include is entirely analogous to what is traditionally presented in the form of idealized vertical logs or block diagrams, as they quantify genetic-unit abundances,

geometries, spatial relationships and grain size. Data-input into the system is on-going: it is therefore still not possible to provide an exhaustive range of models spanning all environmental types and including all studied systems, and even the models presented here are only partially characterized in that they still lack information available from numerous published case studies. Nevertheless, the example models presented herein demonstrate the value of the approach, especially in relation to its quantitative nature, its flexibility of application, and its capacity to incorporate information concerning model uncertainty and variability. The proposed models may also serve as reference, as they provide insight into the sedimentary architecture of specific environmental types by quantifying the signature of basin climate regime, discharge regime and channel pattern – or of conditions conducive to the development of a channel-pattern type – on the large- to small-scale architecture of fluvial systems. Although the systems are only partially characterized in terms of their boundary conditions, future analysis of multiple case studies can be applied to the investigation of the role of a range of autogenic and allogenic controls on fluvial architecture. The method could be potentially applied to other depositional systems.





## **4 Testing alluvial architecture models through a comparative study: implications for sequence stratigraphy**

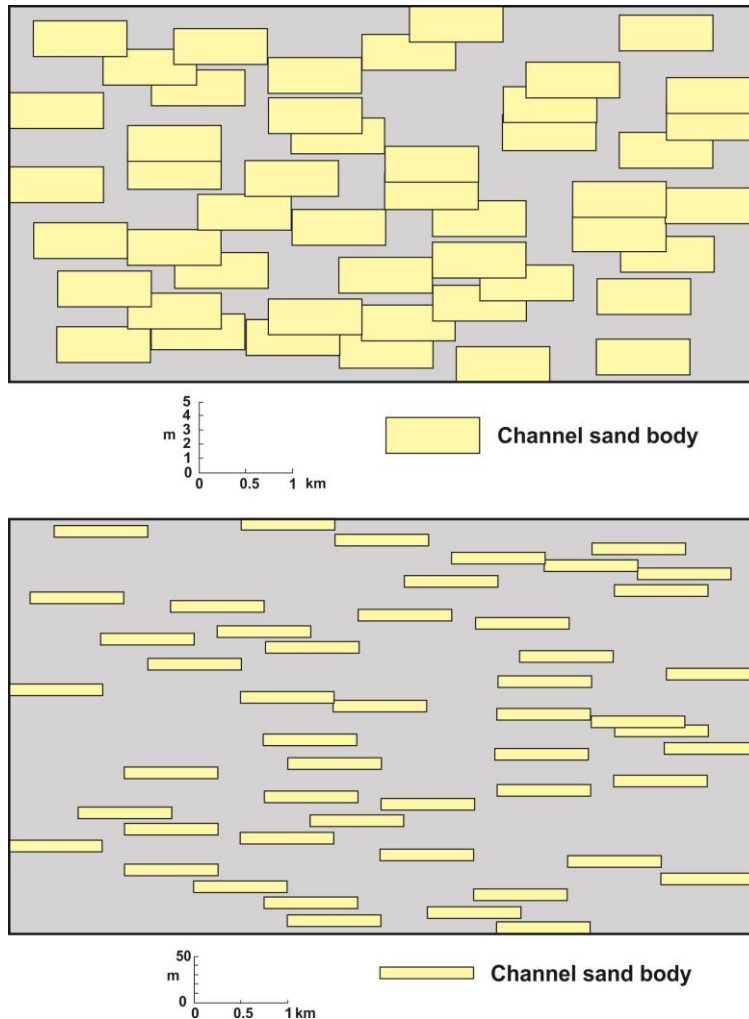
### **4.1 Summary**

A quantitative comparative investigation of literature-derived case studies of fluvial sedimentary systems has been undertaken to test the validity of assumptions made in previously published models of alluvial architecture concerning (i) inverse proportionality between channel-deposit density and basin-wide aggradation rates, and (ii) resulting characteristics of channel-body geometry and connectedness. This work makes use of architectural data from ancient fluvial successions to determine relationships between aggradation rate, or its relative variations, and quantities describing proportion, geometry and vertical connectivity of channel deposits in depositional systems or parts thereof. It has been observed that systems undergoing changes in aggradation rates are most often characterized by an increase in channel density with increasing sedimentation rates, whereas no relationship between aggradation rate and channel-body abundance is observed as evaluated across all stratigraphic volumes. In addition, positive trends have mostly been observed between changes in mean aggradation rates and variations in mean channel-complex thickness, width and vertical connectivity. Thus, results bear little correspondence with relationships predicted by earlier stratigraphy models: this highlights the necessity to reconsider fluvial sequence stratigraphy models and practice, which are partly based on concepts that still need to be better tested through incorporation of primary data from a wider range of outcrop successions.

### **4.2 Introduction**

The proportion, geometry and spatial distribution of sedimentary lithosomes interpreted as the product of deposition within channels in fluvial systems are commonly cited to be dependent on floodplain-wide aggradation rate, whereby a general assumption exists that slower rates of aggradation facilitate floodplain reworking by migrating and avulsing channels (Allen 1978; Bridge and Leeder 1979). Consequently, channel density is commonly expected to inversely correlate with aggradation rate, thereby also affecting the geometry and connectedness of

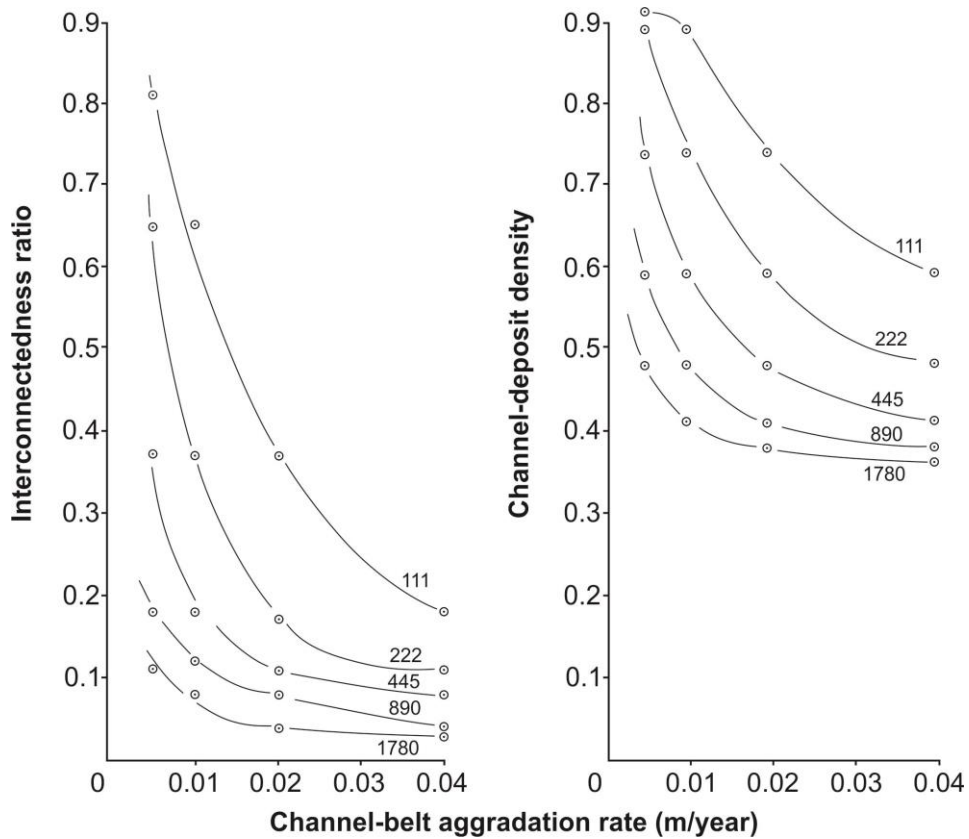
channel clusters; this result is predicted by a suite of numerical models collectively known as the Leeder-Allen-Bridge (LAB; Bryant et al. 1995) models of alluvial architecture (Leeder 1978; Allen 1978; Bridge and Leeder 1979 – figures 4.1 and 4.2, below).



**Figure 4.1:** alluvial architecture models from Allen (1978), representing the distribution of fluvial channel sand bodies within stratigraphic volumes developed under different aggradation rates keeping pace with subsidence rates (subsidence rate =  $4.43 \times 10^{-3}$  m/a for the lower model; subsidence rate =  $2.46 \times 10^{-4}$  m/a for the upper model). Whereas these models directly relate architectural style to the controlling factor of subsidence rate, other models show similar styles to be controlled simply by aggradation rate (e.g. Bridge & Leeder 1979). Figure modified after Allen (1978).

This tenet still dominates current thinking in fluvial sequence stratigraphy such that results from the largely conceptual LAB models have been incorporated into, and form an underpinning basis for, most continental sequence-stratigraphy models (e.g. Wright and Marriott 1993 – see figure 4.3, below; Shanley and McCabe 1994; Dalrymple et al. 1998; Martinsen et al. 1999). There exists a wide-held assumption

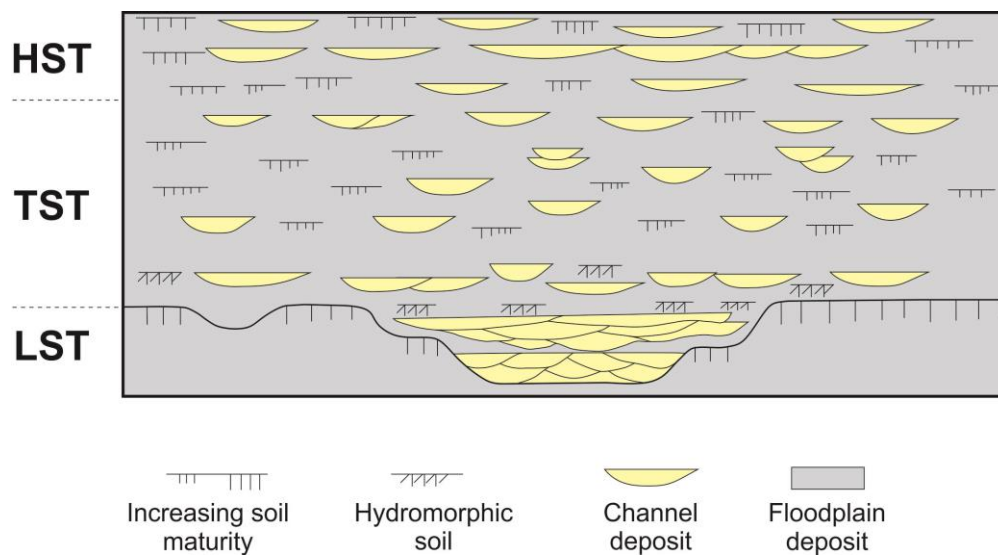
that changes in aggradation rates in alluvial coastal plain systems are indicative of variable rates of creation of accommodation space driven by relative-sea level changes. Also, on the basis of the same conceptual framework, the recognition of ‘low-accommodation’ versus ‘high-accommodation’ systems tracts in continental fluvial successions is now routinely undertaken on the sole basis of recognition of the degree of channel amalgamation (Catuneanu et al. 2009); this is now widely accepted practice.



**Figure 4.2:** measure of channel-body interconnectedness and density as a function of floodplain aggradation rate for a suite of alluvial architecture models by Bridge & Leeder (1979) with variable avulsion period (given in years by numbers on the curves). Figure modified after Bridge & Leeder (1979).

However, as pointed out by Bryant et al. (1995) and Heller and Paola (1996), the LAB models are limited, for example, by not accounting for the effect of the relationship between aggradation rates and avulsion frequency. As sedimentation rates are higher closer to the channel belt than further away from it in the floodplain (Pizzuto 1987), a gradient advantage for the establishment of avulsion pathways – quantifiable by the cross-system to down-system slope ratio – is generated by channel-belt aggradation. Avulsion frequency likely depends on the rate of generation of channel-belt super-elevation, which is driven by differential sedimentation between channel belts and the adjacent floodplain, which in turn

appears to be scaled to overall aggradation rate (Heller & Paola 1996). This ultimately means that avulsion frequency is likely to increase with increasing aggradation rate. Current understanding (Bryant et al. 1995; Heller & Paola 1996) suggests that if a change of avulsion rate in relation to aggradation rate follows a power-law relationship of the type  $f_{\text{avulsion}} \propto r^b$  (where  $r$  is aggradation rate and  $b > 1$ ; Bryant et al. 1995; Heller & Paola 1996; case 3 in figure 4.4 below), then an increase in channel density would be expected in response to an increase in aggradation rate, as opposed to the simple control by aggradation rate predicted by the LAB models.

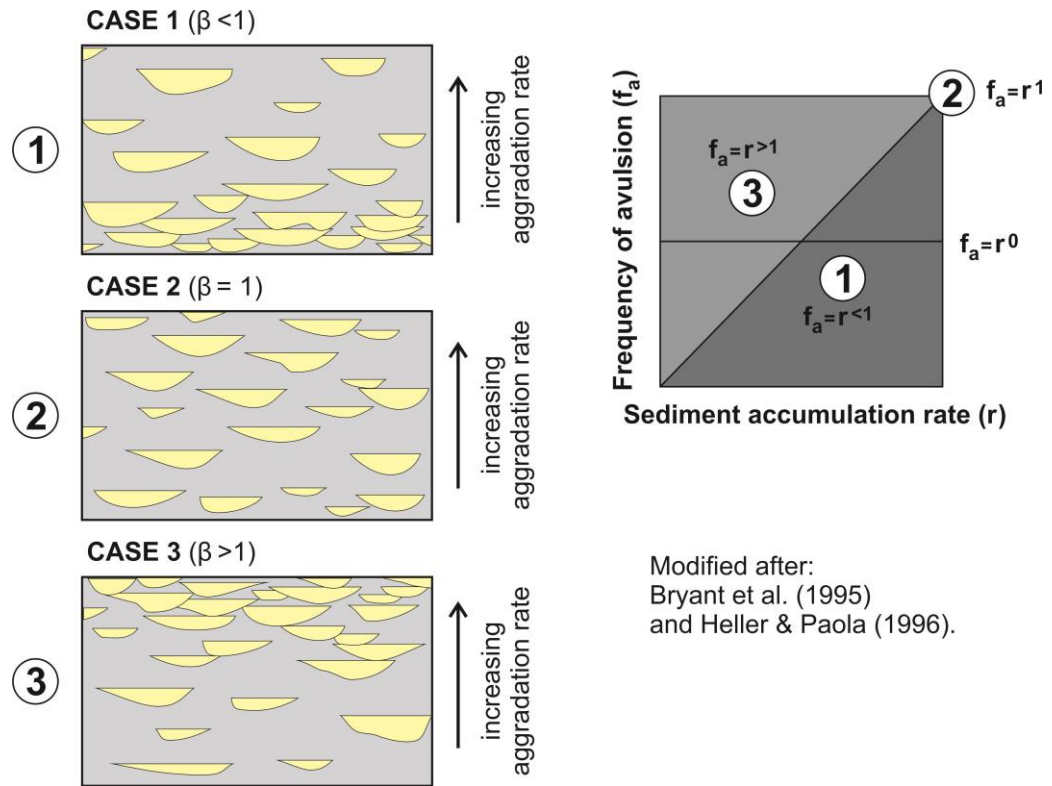


**Figure 4.3:** ideal fluvial sequence stratigraphic model proposed by Wright and Marriott (1993) for a third-order sea-level fall-rise cycle. This model incorporates the assumption that higher rates of floodplain aggradation determine lower channel density by reducing floodplain reworking, and vice versa; the rate of creation of accommodation is implied to be governed by sea level and to reach its maximum during the period represented by the Transgressive Systems Tract (TST). Figure modified after Wright and Marriott (1993).

Nevertheless, observations from the Holocene records of the Rhine-Meuse delta (Stouthamer and Berendsen 2007) – probably the highest-quality dataset documenting an avulsion history linked with aggradation rates – and of the Mississippi River (Aslan et al. 2005) point to more complex relationships between aggradation rates, gradient advantages and avulsion frequency, especially by demonstrating that differential aggradation between channel belt and floodplain may not scale to overall aggradation rates and that gradient advantages may be overridden by other controls that act to drive avulsion.

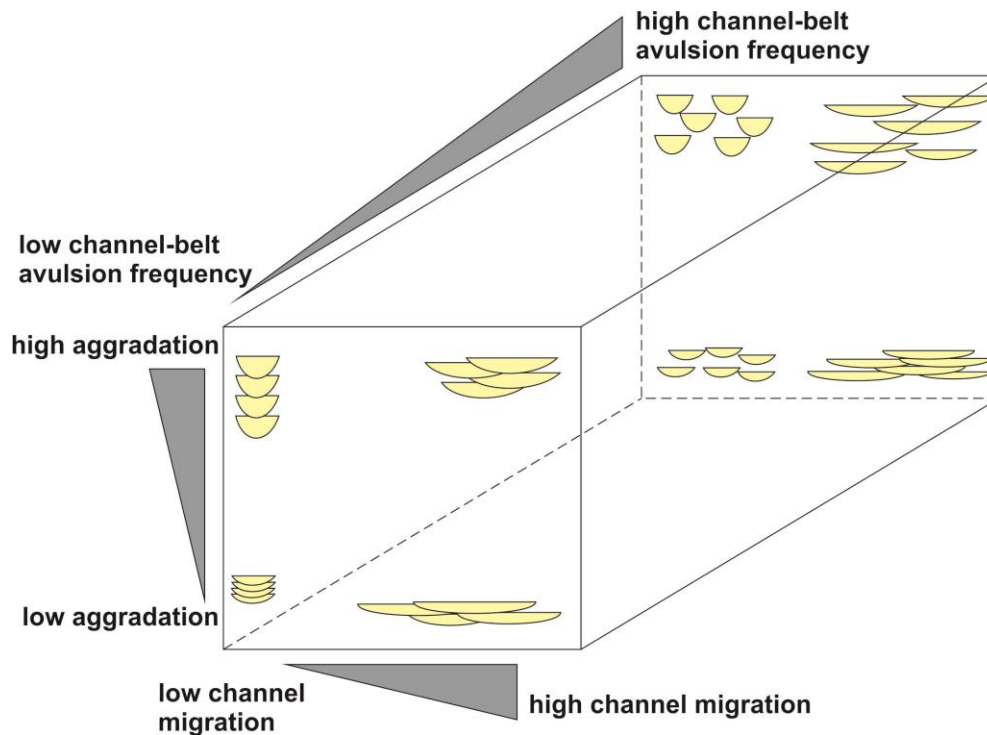
Furthermore, the relative proportion of channel and floodplain deposits in a given stratigraphic volume and the sheet- or ribbon-like geometry of channel bodies will

also depend on channel size and velocity of lateral migration (Bristow & Best 1993 – see figure 4.5, below).



**Figure 4.4:** idealized alluvial architecture models from Bryant et al. (1995), depicting variations in the distribution of fluvial channel bodies (in black) under different conditions defined by the exponent  $\beta$  in the power-law relationship between avulsion frequency and aggradation rate. For case 3 ( $\beta > 1$ ), an increase in channel-deposit proportions is observed for increasing floodplain aggradation rate. The right-hand diagram by Heller & Paola (1996) synthesizes the possible relationships between aggradation rate and avulsion frequency, with reference to the three scenarios represented on the left. Figure modified after Bryant et al. (1995) and Heller & Paola (1996).

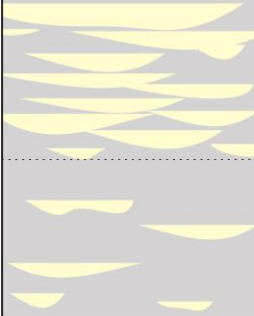

So, depending on the relative dominance of the different drivers for the generation of accommodation, different scenarios could be envisaged. For example, if increasing aggradation is driven by an increase in sediment supply and water discharge such that the ratio between the two is allowed to increase, it would be sensible to foresee a situation whereby channel hydraulic geometry (Leopold & Maddock 1953) increased together with avulsion frequency (cf. Stouthamer & Berendsen 2007) and channel mobility (cf. Church 2006), which could be enhanced by higher erosive power (cf. Nanson & Hickin 1986), faster in-channel deposition (cf. Howard 1992; Wickert et al. 2013) and decreased bank stability as coarser grain-size belts migrated downstream (i.e. a grain-size increase was seen at any given point due to reduced rates of downstream fining; cf. Paola et al. 1992; Robinson & Slingerland 1998).



**Figure 4.5:** schematic diagram that synthesizes the effects of channel-belt aggradation, lateral migration and avulsion on preserved channel-body morphology (modified after Bristow & Best 1993).

This could ultimately result in an increase in channel proportion concomitant with the increase in rate of aggradation (figure 4.6). If an analogous situation of a supply-driven increase in aggradation was observed in the context of a prograding deltaic plain, possibly even during an episode of slow relative sea-level rise, one outcome to be expected would be the observation, for a given point in space, of a temporal evolution of widening channel-bodies as the area is brought out of the river backwater length, i.e. the distal reach of a river where the streambed drops below sea level resulting in river-flow deceleration on approach to the static water body (cf. Lamb et al. 2012, and references therein). This example situation would be explained by distal backwater zones being characterized by avulsive, laterally-stable, and mostly incisional distributary channels (cf. Jerolmack 2009; Nittrouer et al. 2012). Considering the Mississippi system as an example, a ca. factor 2 reduction in channel-belt width-to-thickness aspect ratio could be observed with a shift in backwater length of ca. 40 km in some areas (Blum et al. 2013). These situations are merely illustrative of possible scenarios by which a given stratigraphic organization of fluvial deposits could be generated to incorporate patterns that could be mistakenly interpreted in terms of the mentioned LAB model prediction, but actually resulting from the interplay of factors that determine opposite relationships between channel-body density and rates of aggradation.

Example hypothetical scenario producing fluvial architecture characterized by increase in channel density with increasing mean aggradation rates.

	$Q_s$	Q	$Q_s/Q$	Aggradation rate	Channel migration and avulsion rates	Channel hydraulic geometry	Standard-defined systems tracts
	+	+	+	+	+	+	LAST
							HAST

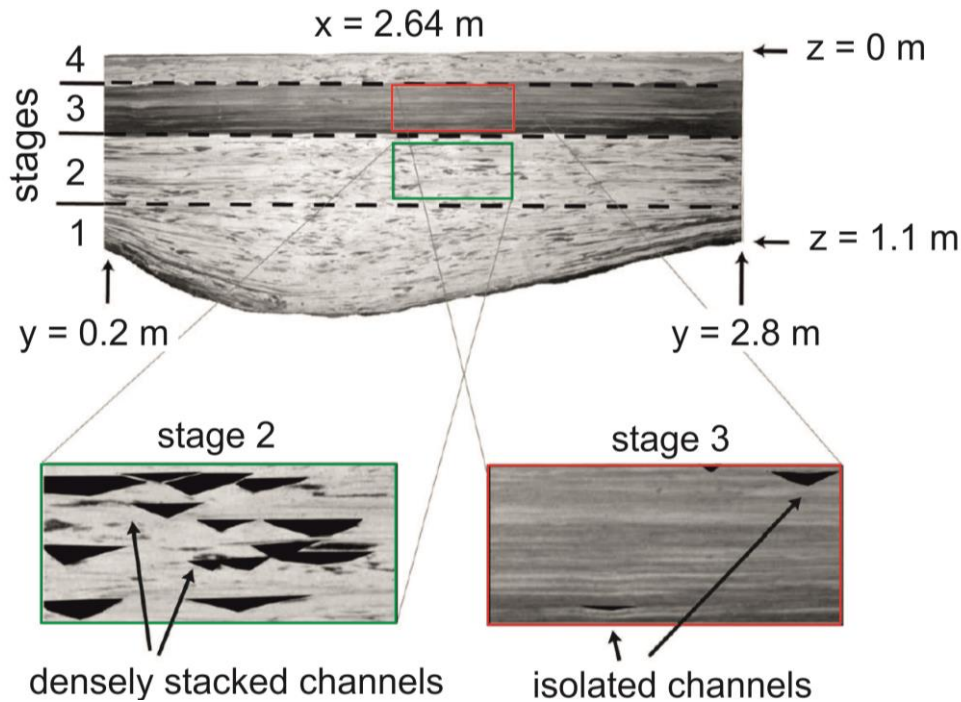
**Figure 4.6:** hypothetical scenario whereby a temporal evolution in fluvial architecture characterized by an increase in channel amalgamation is generated by a set of controls that determine a corresponding increase in aggradation rate (see text for explanation); channel deposits are represented in light yellow and floodplain deposits in grey, in the ideal cross-sectional sketch. The example shows how the attribution of standard terrestrial systems tracts as based on the recognition of increasing channel density following recommendations by Catunen et al. (2009) would be mistaken. ( $Q_s$  = rate of sediment supply; Q = water discharge; LAST = low-accommodation systems tract; HAST = high-accommodation systems tract).

These considerations illustrate the complexity of the problem arising – as it is widely recognized – from the fact that fluvial systems respond in a complex manner to changes in a number of key controlling parameters, most of which are not accounted for by the relatively simplistic LAB models.

Experimental investigations of the problem benefit from the possibility of isolating the effect of individual parameters. Under different experimental designs, contrasting results have been obtained from physical models aiming to test the validity of the LAB models, displaying evidence that either disproves (Bryant et al. 1995; Hickson et al. 2005/Strong et al. 2005, figure 4.7 below) or supports (Ashworth et al. 2004) the prediction of channel density as a function of aggradation rate. Yet, whereas numerical models, such as the LAB models, are limited by the choice of the boundary conditions that are thought to control system evolution, likely resulting in biased results, physical models aiming to simulate analogous situations are subject to scaling problems (Hickson et al. 2005; Strong et al. 2005; Paola et al. 2009). Thus, it is important to test the validity of the basic prediction of the LAB models as to how temporal variations in aggradation rate relate to changes in channel density, geometry and stacking pattern against real-world datasets of fluvial sedimentary architecture from the rock record. Suitable real-world datasets of fluvial sedimentary architecture are not straight-forward to collect since they demand both constraint of aggradation rates and the collation of large architectural datasets in a quantitative form. Hence, few individual tests of this kind have ever been attempted, and those that have been reveal examples that do (e.g. Shuster &



Steidtmann 1987) and do not (e.g. Willis 1993b) conform to the relationship predicted by the LAB models. So, there is scope to widen the range of field examples and to compare them under a unifying framework to be able to better assess whether LAB-model responses are effectively the norm in the stratigraphic record.



**Figure 4.7:** cross-gradient section through an experimental stratigraphy of a braided fluvial fan delta in which the interval with the slowest aggradation rates (stage 3) is characterized by the lowest density of channelized features (Strong 2006).

This analysis presents results from a meta-study of real-world architectural data obtained from several ancient fluvial successions and uses these to test LAB-model predictions regarding temporal evolution of fluvial systems. The aim of this study is to verify the existence of relationships between overall aggradation rates (and temporal variations thereof) and fluvial sedimentary architecture (and its change through a succession). Specific objectives are as follows:

- to compare the proportion of channel deposits for stratigraphic volumes from systems with different average aggradation rates, and to evaluate the change in channel-deposit proportions in systems undergoing temporal variations in aggradation rate;
- to compare channel-body dimensional parameters from different systems with different average aggradation rates, and to evaluate the change in channel-body geometry in systems undergoing temporal variations in aggradation rate;



- to compare vertical connectivity of channel deposits from systems with different average aggradation rates, and to evaluate the change in channel connectivity in systems undergoing temporal variations in aggradation rate.

Testing these fundamental relationships by comparing real-world case studies from various contexts is a step toward assessing the limits within which the LAB-model predictions are valid, which has important implications concerning sequence-stratigraphy practice and, more generally, the interpretation of fluvial sedimentary architecture.

### 4.3 Methods

This work involves a comparative study based on literature-derived architectural data collated from several ancient fluvial depositional systems into a relational database, named the Fluvial Architecture Knowledge Transfer System (FAKTS), which digitizes sedimentary units in a hierarchical scheme (Colombera et al. 2012a, Chapter 2). At the largest scale of observation, the system characterizes fluvial architecture in terms of units termed as ‘depositional elements’ and classified as ‘channel complex’ or ‘floodplain’ units, depending on the origin of their deposits. Geometrical attributes are used to characterize each individual depositional element, and the spatial relationships between each of them are stored in the form of transitions (e.g. unit 2 vertically stacked on unit 1; unit 3 laterally neighbouring unit 4 in the cross-gradient direction). The subdivision of stratigraphic volumes into these units follows in part the application of geometrical criteria (see appendix A), which aims to achieve an objective distinction of complexly clustered channel bodies. Such criteria consider the following: (i) the style of interdigitation of floodplain deposits; (ii) geometrical change across the channel-cluster lateral extension (e.g. two juxtaposed channel bodies with base or top in common are distinguished if sudden thickness changes occur across a geological surface and overcome a 0.5 threshold of relative thickness, defined as the ratio between smallest and largest thickness); (iii) geometrical change across the channel-cluster vertical extension (e.g. two non-offset stacked units are distinguished if sudden width changes overcome a 0.5 threshold of relative width, defined as the ratio between smallest and largest width); (iv) the existence of vertical superposition and lateral offsets where channel-bodies are vertically stacked (e.g. two offset stacked units are distinguished if the ratio between the vertical extent of their overlap and the thickness of the thinner unit is less than 0.5, or two offset stacked units are distinguished if the ratio between the cross-stream extent of their overlap and the width of the narrower unit is less than 0.5). One of the reasons why criteria for

channel-complex definition have been established lies in the necessity to include subsurface datasets of limited resolution and/or quality, as the same system is designed to be employed for other applications (e.g. Colombera et al. 2012b, Chapter 6) for which criteria have not been planned with a specific application in mind. These criteria – although partly based on clearly defined values – are meant to be applied flexibly and with consideration of limitations in the quality of observations. For example, whenever geological knowledge permits the lateral tracing of important erosional surfaces, such surfaces may be adopted as depositional-element bounding surfaces. The advantage of this geometrical approach lies in its objectivity: channel complexes as defined here are simple stratigraphic packages interpreted as being deposited in a fluvial-channel context: they are not attached to more specific genetic significance, so they cannot be regarded as, for example, the sedimentary expression of inter-avulsion channel belts. After the definition of channel complexes is carried out, the subdivision of the floodplain domain into geometrical packages is achieved by defining objects that are vertically and laterally adjacent to the recognized channel complexes. Then, in the database, stratigraphic volumes to which depositional elements belong are classified on a range of attributes, including their average aggradation rate or the relative change in aggradation rate as compared to vertically-neighbouring volumes; aggradation-rate attributes are again compiled from literature review. The database includes a variety of types of datasets, but the results presented here are derived mainly from outcrop and 3D seismic data types. Two-dimensional or pseudo-3D architectural panels depicting the cross-gradient sedimentary architecture of fluvial systems as composed of ‘channel’ versus ‘floodplain’ deposits are the most common type of dataset included; for these datasets depositional-element proportions are based on cross-sectional areas estimated as the product of the lateral and vertical extent of the depositional-elements. Thickness-based proportions are derived from 1D datasets.

This approach is subject to several limitations. Notably, unlike the procedure adopted for experimental methods, it lacks full control on spatial (down- and cross-stream) variability of architectural products and boundary conditions. For example, although we are aware of systems for which important lateral changes in subsidence are likely to control channel clustering (e.g. half-graben systems subject to syn-sedimentary tilting), some datasets may represent preserved portions of systems subject to subsidence patterns characterized by lateral variability in subsidence rates and possibly inversions in cross-stream gradients in subsidence rates. Also, it is impossible to establish a way to refer observations of a fragmentary record spatially in a way that enables full comparison of different case studies, as done for example in laboratory conditions by referring data to a mass-extraction

parameter (i.e. by considering proximity at any point as described by the fraction of all sediment fed to the system that is deposited upstream of that point; Strong et al. 2005). Only qualitative classifications (e.g. proximal vs. distal) or case-specific quantitative relationships (e.g. downstream distance between two volumes) can be considered. Another limitation is associated with the inclusion of geometrical data from published summary datasets in the form of channel-body width/thickness aspect-ratio cross-plots, as for these datasets the geometrical criteria cannot be checked, making comparisons with other systems less reliable. In addition, stored aggradation rates may just represent average values of rates changing at high frequency through time, and such values may have been averaged over different time scales for different stratigraphic volumes. As a general reference, however, stratigraphic volumes considered in this study appear to be the product of deposition at the  $10^{-1}$ - $10^1$  Ma timescale, and are typically tens of metres thick. The choice of this spatial/temporal scale makes our results directly comparable with volumes simulated by the LAB models. Further limitations are inherent as a function of variability in the dataset quality, relating for example to restricted continuity of exposure, 3D control, reliability of interpretations, and choice of a minimum cut-off size for mappable units by the original authors of the source work. Thus, applying this approach, care must be exercised in the choice of the systems included in the analysis as well as in the interpretation of the results. In this analysis, neither average aggradation rates nor channel-complex dimensional parameters have been corrected to account for the effects of sediment compaction.

#### **4.4 Results**

The method has been employed to compare the evolution of different depositional systems that underwent vertical changes in channel-deposit proportions combined with temporal changes in overall aggradation rates; variations within individual systems are also compared with variations between different systems (figure 4.8). On the basis of the assumption that aggradation rate provides an approximation of the rate of creation of accommodation space, this methodology can be of use to assess whether accommodation itself represents an overriding control with general predictive value that determines architectural differences observable between different systems and potentially also between different basins (cf. distinction between high- and low-accommodation 'settings'; Catuneanu 2006, p. 253, and references therein).

The systems that provide data of a type suitable for investigation of the temporal evolution (i.e. for which changes in aggradation rates through time are documented)

cover different tectonic and physiographic settings and typify different scenarios of accommodation generation and architectural evolution; these literature-derived datasets consist of architectural data mapped from the Blackhawk Formation (Hampson et al. 2012), from the Chinji Formation (McRae 1990), from the Omingonde Formation (Holzförster et al. 1999), and from the Price River and North Horn Formations (Olsen 1995).

From these case studies, only the Triassic Omingonde Fm. (Namibia) developed in an extensional tectonic setting, representing the infill of a half-graben (the Waterberg Basin). For the scope of this work, this is the lowest-quality dataset, being based on relatively sparse 1D data (Holzförster et al. 1999) and having poor constraints on aggradation rate; in particular, there exists no agreement regarding the duration of sedimentation recorded by the Upper Omingonde Formation and the duration of the hiatus associated with its upper limit in the Waterberg-Erongo area (cf. Wanke 2000; Smith & Swart 2002; Catuneanu et al. 2005; Zeffass et al. 2005; Abdala et al. 2013), thereby placing some uncertainty on inferences made on the evolution represented in figure 4.8 for the Middle to Upper Omingonde system. Depositional-element variations observed within the Omingonde Formation are not representative of basin-wide changes and are not suitable for examining the LAB prediction on temporal variations for systems with uniform subsidence distribution: the existence of spatial variations in subsidence impedes the evaluation of LAB predictions of temporal evolution made for settings in which accommodation is created uniformly. However, this case study does allow evaluation of another prediction based on LAB models (Bridge & Leeder 1979; Alexander & Leeder 1987), pertaining to the temporal evolution of fluvial infills of half-graben depocentres subject to variable subsidence through time. In accordance with the models, the observed positive relationship between changes in channel proportion and changes in aggradation rates (figure 4.8) in a portion of the basin bordering the Waterberg-Omaruru Fault is thought to represent local drainage reorganization – and therefore a change in channel-belt clustering – in response to temporal variations in cross-stream gradients of subsidence associated with variable rates of crustal extension, whereby the topography built by the lateral increase in subsidence rate “draws” channels toward the depocentre. Other controls on accommodation – notably climatic changes during deposition of the Omingonde Formation as demonstrated by indicators of a progressive temporal increase in aridity punctuated by short-lived intervals characterized by relatively more humid conditions, and tectonically-driven supply variations – were believed to be overridden by basin tectonics (cf. Holzförster et al. 1999; Smith & Swart 2002). This dataset is not used in the successive analysis on channel-complex geometries and

connectivity, as no information on channel-complex geometries and spatial relationships is available.

The Miocene Chinji Fm. (Siwalik Group, Pakistan) is a well-studied fluvial-megafan succession (McRae 1990; Willis 1993b; Willis & Behrensmeyer 1994; Zaleha 1997a; 1997b; Friend et al. 2001) that developed under the convergent tectonic regime of the Himalaya peripheral foreland basin, in an inland setting, several hundreds of kilometres upstream of the coast (Jain & Sinha 2003), and in which sediment aggradation rates are known to be directly related to thrust activity (Meigs et al. 1995). The dataset of McRae (1990) is based on an architectural panel that records a ca. 11 km-wide, 200 m-high part of the succession in which constraints on aggradation rates are provided by palaeomagnetic isochrons. Variations in thickness for packages bounded by the isochrons suggest non-uniform aggradation rates in space; yet, differently from what can be observed in the Omingonde Formation, thickness changes do not occur at fixed positions through time, indicating the absence of a stable depocentre across the considered section. Thus, this dataset appears to be suitable for evaluating the validity of LAB predictions on the temporal evolution of systems undergoing variations in aggradation rates. Overall, the relationships between aggradation rate and architectural data from this system do not match LAB model predictions. A progressive decrease in aggradation rates is recorded and the considered stratigraphic volumes evolved by exhibiting a decrease, followed by an increase, in channel-complex abundance and density (figure 4.8); in addition, the post-Chinji evolution of the succession is known to be characterized by an increase in channel-body proportions and sizes associated with an overall increase in aggradation rate (Nagri Formation – not documented in FAKTS database; cf. Zaleha et al. 1997b).

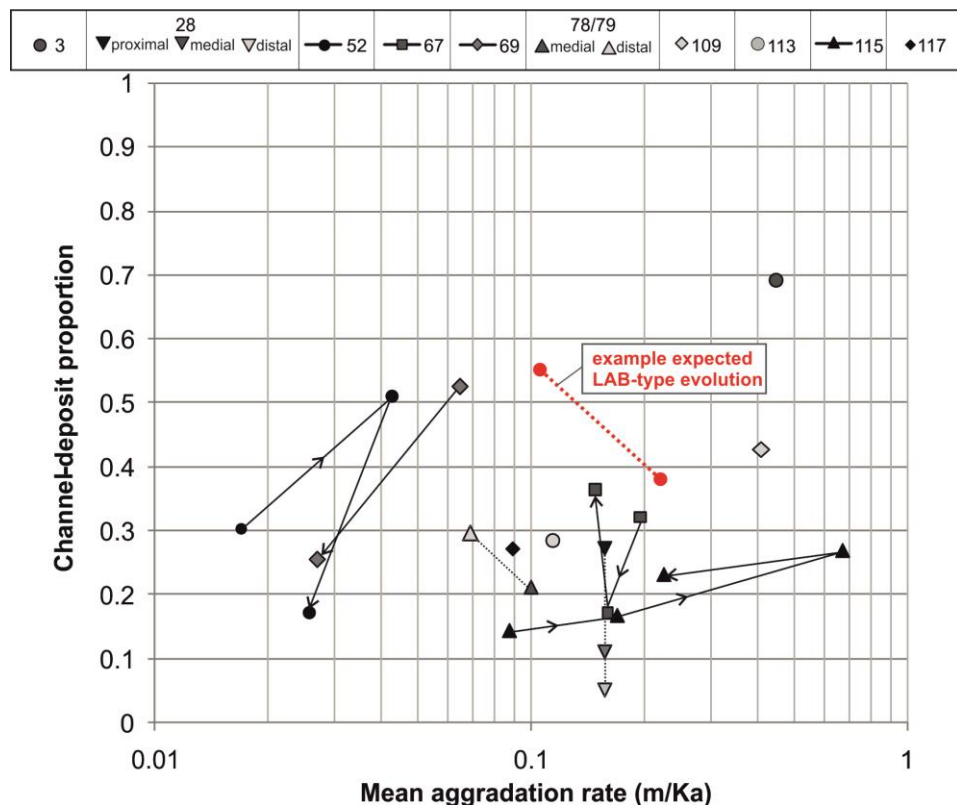
The Upper Cretaceous Blackhawk Formation (Mesaverde Group, USA) records deposition in an alluvial to coastal plain setting in the Western Interior Foreland Basin. The sedimentary architecture of this system has been studied extensively (e.g. Van Wagoner 1995; Yoshida 2000); the data we present were originally presented as part of a dataset collected by Hampson et al. (2012), which consists of a set of architectural panels covering the entire unit thickness over an horizontal extension of more than 70 km in the Wasatch Plateau (Utah); constraints on aggradation rates inferred on durations based on regional correlations permit the recognition of four stratigraphic volumes. In general, in marine-influenced paralic coastal plain contexts such as this, the contribution of eustatic changes in affecting accommodation would favour uniformity in the cross-gradient distribution of accommodation variations, making the associated architectural data very suitable for the scope of this study. However, even though two third-order eustatic cycles

partially cover the episode of time represented by the Blackhawk Formation (Haq et al. 1988), flexural subsidence is probably the dominant component in determining the variable accumulation rates observed for stratigraphic volumes of the duration of the ones discussed here (Hampson et al. 2012). Nevertheless, important cross-gradient variations in the rate of creation of accommodation are not documented. In spite of significant variations in average aggradation rates, temporal changes do not display dramatic variations in channel-deposit proportions (see also Hampson et al. 2013), but rather demonstrate a consistent positive relationship between aggradation rate and channel abundance.

Within the same basin, the Price River and North Horn Formations (Upper Cretaceous to Paleocene; Mesaverde Group, USA) record the transition towards a tectonic regime characterized by the uplift of basement-cored blocks (Laramide-style deformation; Cross 1986); notably, the upwarping of one of these domes – the San Rafael Swell – began during deposition of the Price River Fm. (Lawton 1983; Franczyk & Pitman 1991; Guiseppe & Heller 1998). The sedimentary architecture of these units has been studied by several authors (Olsen 1995; Olsen et al. 1995; Guiseppe & Heller 1998); the data presented here were originally depicted in the form of 2D architectural panels mapped along a 6 km-wide, several hundreds metres-high exposure at Price Canyon (Olsen 1995). Mean aggradation rates have been separately estimated for the two formations, but uncertainty in estimation is determined by an unconformity between the two units (whose importance at Price Canyon is debated; cf. Dickinson et al. 1986; Olsen et al. 1995; Guiseppe & Heller 1998; Horton et al. 2004). Furthermore, determination of the significance of these values is hampered because sedimentation appears to have been interrupted by a significant hiatus during accumulation of the North Horn Formation (Yi & Cross 1997). Basin tectonics represents the main control on accommodation: aggradation rates are considerably slower than the estimated uplift rates for the San Rafael Swell (0.07-0.36 m/Ka; Lawton 1983) and accommodation was not uniformly generated across the basin, resulting in topographically-driven channel clustering in the Price Canyon area (Guiseppe & Heller 1998), to which the data presented here refer. Thus, the overall decrease in channel-deposit proportions (figure 4.8) in the more slowly aggrading North Horn Formation may relate to either continued growth of the San Rafael Swell, which would have driven the position of the channel-belts further away from the upwarp (and from the sampled area to which the available data refer), or to a deceleration in uplift rates, which would permit channels to be more aerally distributed during episodes when the palaeo-relief was being buried under the onlapping floodplain deposits (cf. Franczyk & Pitman 1991; Sitaula & Aschoff 2012). Crucially, the inability to investigate shorter-time-scale changes, the

non-uniformity of subsidence patterns, and the relatively small observation window make this case study only partially suitable for the scope of this study.

Information from systems for which a temporal evolution constrained to accumulation rates could not be reconstructed was drawn from the Tortola fluvial system (Loranca Basin, Spain; Martinius & Nieuwenhuijs 1995; Martinius 2000), from the Sariñena Formation (Ebro Basin, Spain; Hirst 1991), from the Caspe Formation (Ebro Basin, Spain; Cuevas Martínez et al. 2010), from the Po Basin (Amorosi et al. 2008), from the Kaiparowits Formation (Western Interior Basin, USA; Roberts 2007), and from the Ferris Formation (Hanna Basin, USA; Hajek et al. 2010). Based on evaluation across stratigraphic volumes from all systems, a trend of increasing channel proportion with increasing aggradation rate is seen; although this relationship is not statistically significant, it nevertheless contradicts results that would be expected if the relative proportion of channel and floodplain deposits was actually diagnostic of low- or high-accommodation settings (cf. Catuneanu 2006).



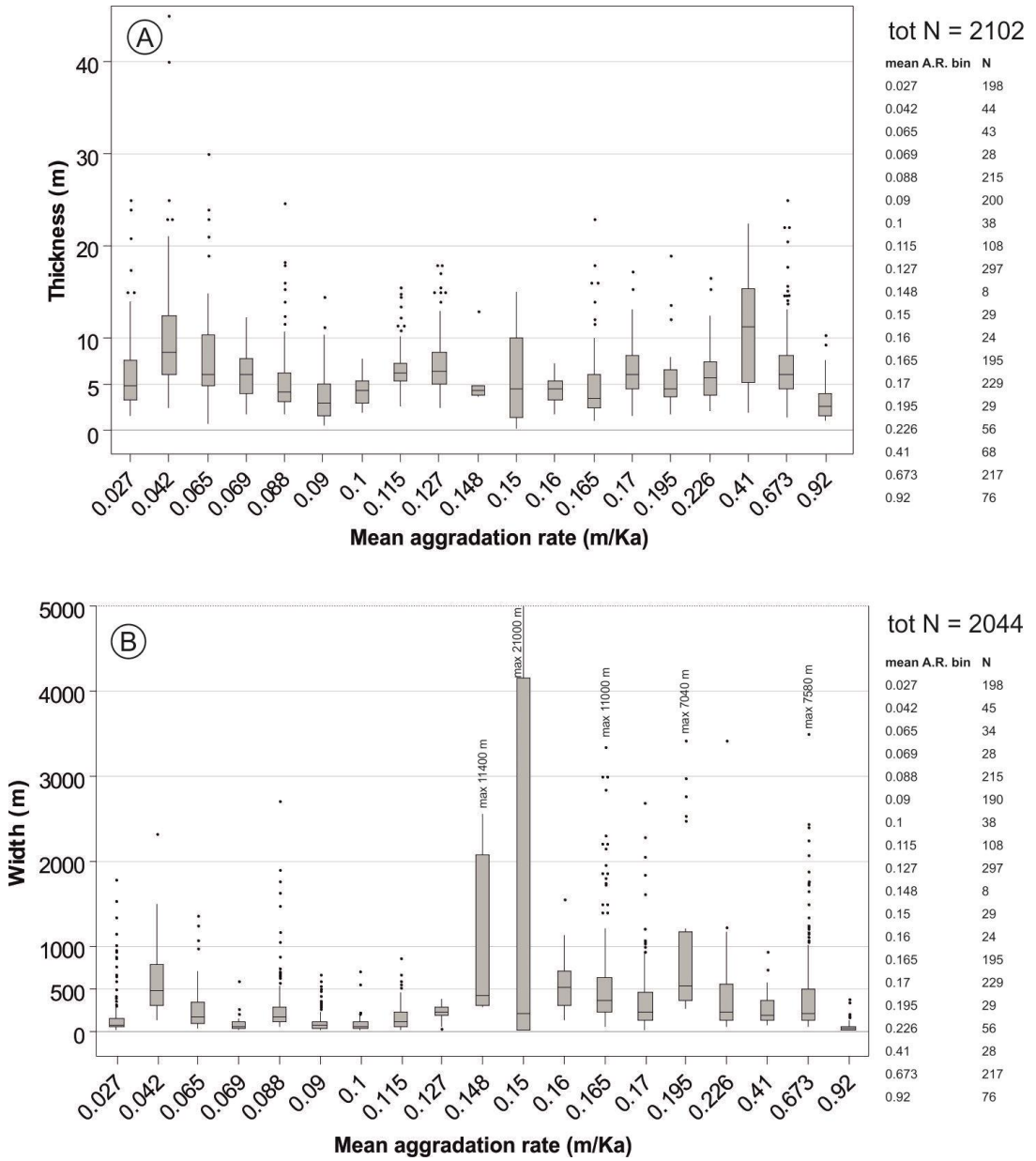
**Figure 4.8:** cross-plot of channel proportion and mean aggradation rate for different stratigraphic volumes. Data from the same system are joined by arrowed lines to indicate temporal evolution, and by dotted lines to indicate downstream evolution. Case studies are coded as follows: 3: Po Basin (Amorosi et al. 2008); 28: Caspe Fm. (Cuevas Martínez et al. 2010); 52: Omingonde Fm. (Holzförster et al. 1999); 67: Chinji Fm. (McRae 1990); 69: Price River Fm. and North Horn Fm. (Olsen 1995); 78/79: Tortola system (Martinius & Nieuwenhuijs 1995; Martinius 2000); 109: Kaiparowits Fm. (Roberts 2007); 113: Ferris Fm. (Hajek et al. 2010); 115: Blackhawk Fm. (Hampson et al. 2012); 117: Sariñena Fm. (Hirst 1991).

The distributions of channel-complex thicknesses and widths from 19 stratigraphic volumes for which mean aggradation rates could be constrained are presented in figure 4.9. In addition to most of the above-mentioned case studies, other systems that allowed evaluation of channel-complex geometries include the Muda Formation (West Natuna Basin, South China Sea; Darmadi et al. 2007), the Olson Member of the Escanilla Formation (Ainsa Basin, Spain; Labourdette 2011), the Durham Coal Measures (Pennine Basin, UK; Fielding 1986), and the Joggins Formation (Cumberland Basin, Canada; Rygel & Gibling 2006). The maximum thickness of the channel-complex across its exposure has been considered, whereas width distributions have been constructed from data that provide estimates of real cross-stream widths, uncorrected apparent widths and incompletely observed widths. No clear trend is observed between the central tendency or dispersion of channel-complex thickness and the mean aggradation rates of the volumes within which they are contained; although a positive trend between channel-complex median width and mean aggradation rate is indicated, this is not statistically significant.

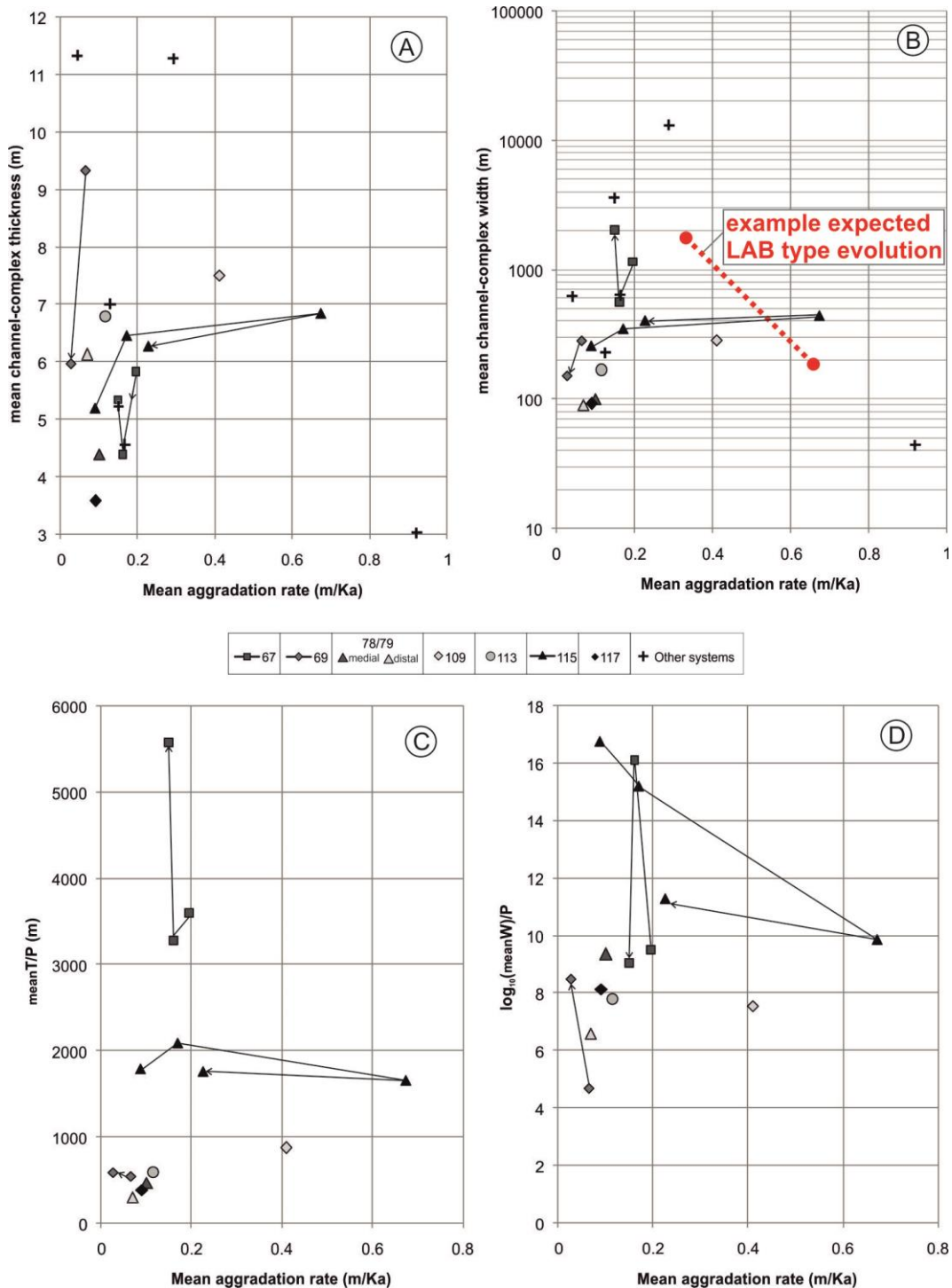
Values of mean channel-complex thickness and width from stratigraphic volumes within the systems for which temporal changes in aggradation rates are documented demonstrate a consistent positive relationship between changes in thickness and changes in width (figures 4.10a and 4.10b). More significantly, from the same systems, five out of six temporal changes show a positive relationship between changes in thickness and width, and changes in average aggradation rate. Comparison with figure 4.8 reveals that variations in channel-complex geometrical parameters have the same sign as variations in channel-complex proportion; it is therefore reasonable to consider that this trend in the evolution of channel-complex geometries may partly reflect the effect of variable channel clustering. Since the analysis of a larger number of case studies – also based on other systems included in the same database – has permitted the determination of relationships of linear proportionality between (i) the mean thickness of channel complexes and their overall proportion in a volume, and (ii) the logarithm in base 10 of the mean width of channel complexes and their overall proportion in a volume (cf. Chapter 5), an attempt has been made to normalize observations regarding geometrical parameters on the proportion of channel deposits of the same volumes. It must be noted that this normalization is entirely empirical and results must be treated with care. However, results presented in figures 4.10c and 4.10d show the lack of any significant relationship between aggradation rates and channel-complex normalized geometrical parameters, when these two parameters are considered together. A weak positive trend is observed between aggradation rates and normalized width as assessed between all volumes, but a negative correlation between changes in



aggradation rates and changes in normalized width appears to be dominant within systems subject to variable aggradation rates.

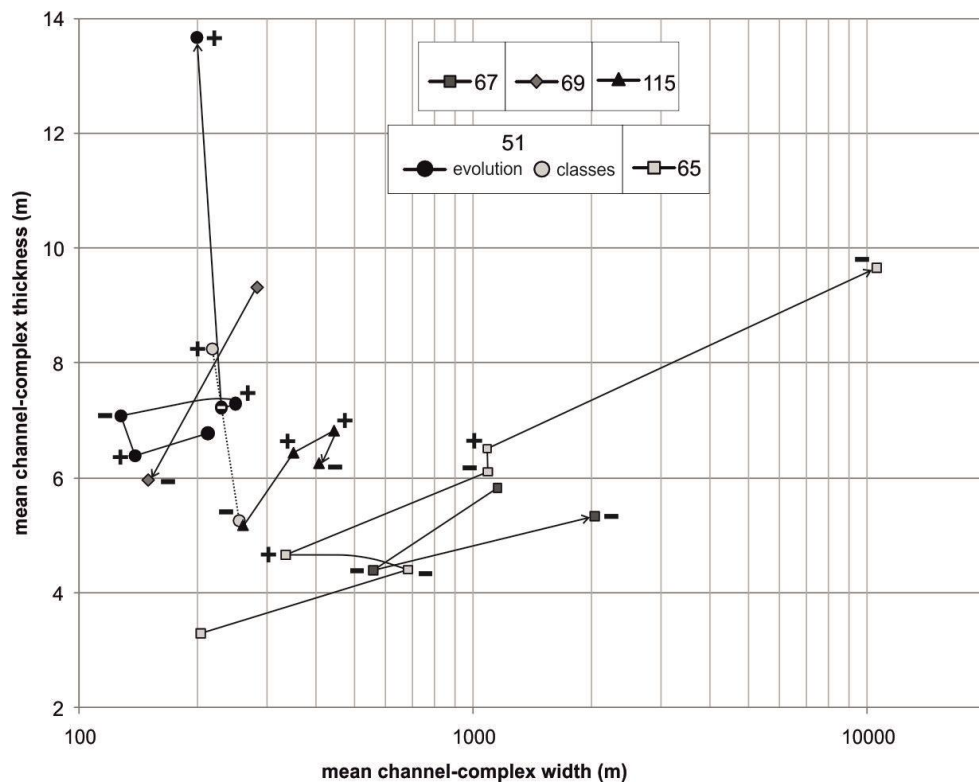


**Figure 4.9:** modified box plots representing channel-complex thickness (A) and width (B) distributions for 19 studied stratigraphic volumes, in ascending order of mean aggradation rate. Width distributions also incorporate uncorrected values of apparent (i.e. oblique with respect to palaeoflow) and incomplete observations.



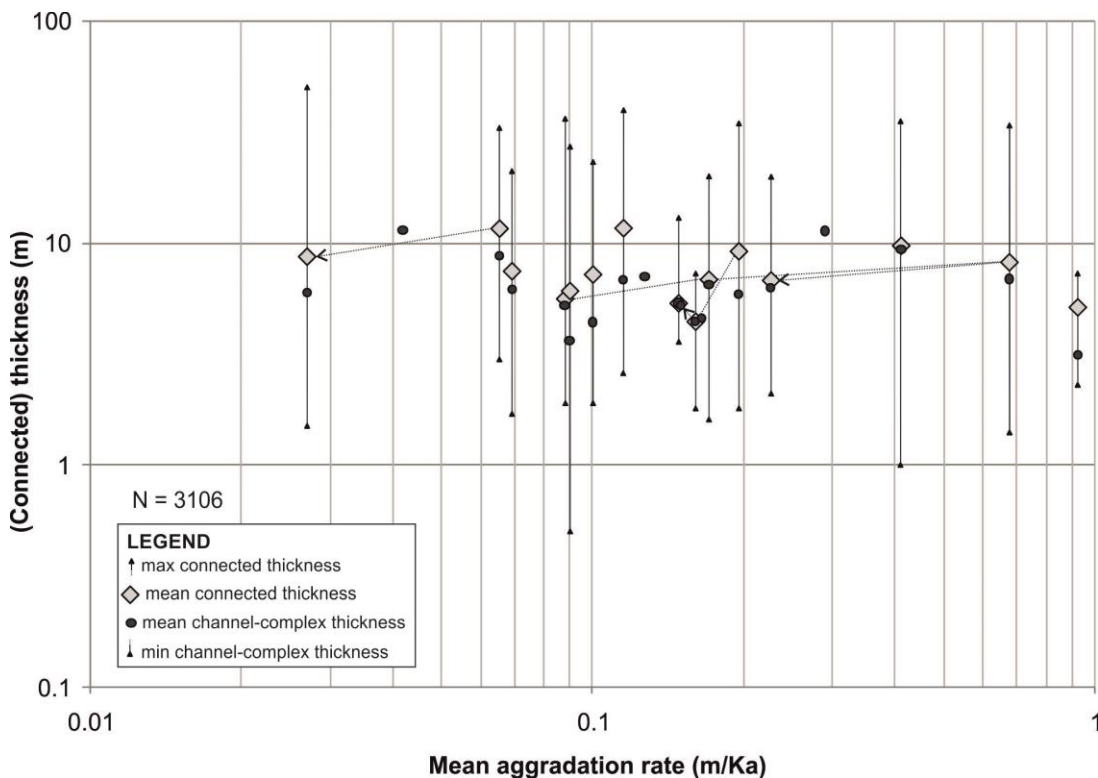
**Figure 4.10:** cross-plots of mean channel-complex thickness (A) and width (B) against mean aggradation rate for different stratigraphic volumes. The same results are also presented for normalized values of thickness and width, expressed as the ratio between channel-complex mean thickness and proportion (C) and between the base-ten logarithm of channel-complex width and channel proportion (D); see text for explanation. Data from the same system are joined by arrowed lines to indicate temporal evolution of channel-complex geometry. Mean widths have been computed including apparent (i.e. oblique with respect to palaeoflow) and incomplete observations. Case studies are coded as follows: 67: Chinji Fm. (McRae 1990); 69: Price River Fm. and North Horn Fm. (Olsen 1995); 78/79: Tortola system (Martinius & Nieuwenhuijs 1995; Martinius 2000); 109: Kaiparowits Fm. (Roberts 2007); 113: Ferris Fm. (Hajek et al. 2010); 115: Blackhawk Fm. (Hampson et al. 2012); 117: Sariñena Fm. (Hirst 1991).

The analysis of channel-complex geometrical variations observed within evolving systems has then been extended by comparing the same results with high-quality datasets from two more systems for which sequence stratigraphic frameworks were established by identifying low- and high-accommodation systems tracts on the basis of the proportion and geometries of channel bodies (figure 4.11). This has been attempted for the Olson Member of the Escanilla Formation (primary data from Labourdette 2011) and the Morrison Formation (USA; primary data from Kjemperud et al. 2008). Increase in width/thickness aspect ratios of channel bodies concurrent with increase in channel density is often advocated as an architectural indicator of reducing accommodation; however, trends of decrease in channel-complex width/thickness aspect ratios with decrease in aggradation rate have been observed in datasets for which aggradation rate was constrained.



**Figure 4.11:** cross-plots of mean channel-complex thickness against width for different stratigraphic volumes within three systems characterized by temporal changes in aggradation rate, and within two systems interpreted as being characterized by temporal changes in aggradation rate. Relative changes in aggradation rate are represented by the plus (increase) or minus (decrease) signs; data from the same system are joined by arrowed lines to indicate temporal evolution of channel-complex geometry. Case studies are coded as follows: 51: Escanilla Fm. (Labourdette 2011); 65: Morrison Fm. (Kjemperud et al. 2008); 67: Chinji Fm. (McRae 1990); 69: Price River Fm. and North Horn Fm. (Olsen 1995); 115: Blackhawk Fm. (Hampson et al. 2012).

Finally, data relating to the spatial arrangement of the channel complexes within the stratigraphic volumes have been used to derive information concerning the degree of channel clustering and its influence on vertical channel connectivity. This information is provided by values of channel-complex 'connected thickness' – defined as the sum of the thicknesses of vertically-stacked channel complexes, with the admissible condition of channel complexes being included in more than one stack. No particular relationship is seen between the mean or maximum connected thickness and the mean aggradation rate, when evaluated across different systems (figure 4.12). Instead, a positive relationship between variations in mean connected thickness and mean aggradation rate are observed within systems for which evolution is tracked, although this is not matched by a similar relationship between the increase in vertical connectivity (quantified by the difference between mean connected thickness and channel-complex thickness) and the mean aggradation rate.



**Figure 4.12:** cross-plots of minimum and mean channel-complex thickness and mean and maximum channel-complex 'connected' thickness against mean aggradation rate for different stratigraphic volumes. Values of mean connected thickness from the same system are joined by dotted arrowed lines to indicate temporal evolution of channel vertical connectivity. See text for explanation.

## 4.5 Discussion

Terminology problems persist in continental sequence stratigraphy; a particularly important issue relates to the lack of agreement on a standardized definition of the concept of “subaerial accommodation” (cf. Jervey 1988; Posamentier & Vail 1988; Catuneanu 2006). Since the term has become part of a common geological vocabulary, the lack of rigour in the definition of “accommodation” presents some problems with its use, such as the recognition of its three-dimensional character, or the consideration of it as a pure control on stratal organization (Muto & Steel 2000; Blum & Törnqvist 2000). The following discussion refers to accommodation as the volume within the elevation difference between the long-term river equilibrium profile and the topography, largely in agreement with Posamentier & Vail (1988), so that, consistently with respect to the geomorphological perspective, the equilibrium profile is controlled by sediment supply. However, in agreement with most authors, we practically quantify accommodation as a vertical distance, and we infer rates of creation of accommodation on the basis of aggradation rates, in agreement with the definition of accommodation by Muto & Steel (2000; cf. ‘realized accommodation’, Cross 1988).

With this in mind, the main implications drawn from the results presented above are as follows.

- Within the considered fluvial systems, temporal variations in aggradation rates do not serve as good predictors of changes in channel-deposit proportions through an inverse relationship, as implied by the LAB models: on the contrary, positive relationships emerge, even in conditions of uniformly-distributed accommodation. Furthermore, increases in channel-complex thickness and widths are observed with concurrent increases in channel proportion, and *vice versa*. Accordingly, positive relationships between mean aggradation rate and average values of estimates of channel-complex vertical connectivity also contradict those predicted by the LAB models. These considerations suggest that sequence stratigraphic models interpreting temporal changes in channel proportions and geometry in terms of changes in the rate of creation of accommodation need to be re-evaluated.
- The data presented here refer to volumes for which mean aggradation rates collectively span almost two orders of magnitude. When variations in channel proportions as a function of aggradation rates are considered for stratigraphic volumes from nine different systems, a weak positive correlation is observed. Moreover, no particular trend is observed in the

distributions of channel-complex thickness and width, on the basis of analysis of data from eleven different systems (19 stratigraphic volumes) subject to variable aggradation rates. This provides evidence against the practicability of inferring low- or high-accommodation settings from channel-deposit proportions and geometries.

The use of terms such as 'high-' or 'low-accommodation systems tracts' (Olsen et al. 1995; Catuneanu 2006; Catuneanu et al. 2009; Labourdette 2011) was previously criticized because of the intrinsic difficulty posed by the model in tracing a bounding surface within portions of depositional systems undergoing progressive increase in accommodation (Embry et al. 2007). Here we demonstrate that the recognition of such systems tracts as solely based on channel-body amalgamation may also be misleading for interpretations of basin evolution, as floodplain cannibalization by slowly aggrading systems does not seem to be the norm in determining high channel density and channel-body sheet-like geometries, at least when evaluated at the spatial and temporal scales to which the LAB models refer. Equally, the possibility to infer the ratio between accommodation and sediment supply ( $A/S$ ) on the basis of channel proportions (Ramón & Cross 1997; Martinsen et al. 1999; Kjemperud et al. 2008; Nádor & Sztanó 2011) requires discussion, especially in view of the fact that terrestrial accommodation rate depends on sediment supply rate, in contrast to contexts where the concept of sea-level-based accommodation is applicable. This discussion is complicated further because the terms 'accommodation' and ' $A/S$ ' (accommodation/sediment supply ratio) have been used interchangeably in the same works (Martinsen et al. 1999; Kjemperud et al. 2008). Overall, results support the claim made by Gibling et al. (2011) that it is dangerous to infer accommodation conditions from degree of channel amalgamation, and provide evidence to recommend against the use of terms such as high- or low-accommodation systems tracts based exclusively on observed channel density. Instead, the use of non-genetic terms (e.g. channel-dominated interval, low channel-amalgamation tract) in absence of temporal constraints or evidence of specific controls should be favoured. While acknowledging the difficulty in constraining the controls on fluvial-system evolution, it appears evident that the interpretation of continental stratigraphy requires careful consideration of the full suite of system boundary conditions, as obtained from independent constraints on palaeoenvironment and basin evolution. Results presented here highlight the necessity to include more case studies so that (i) results can be better substantiated, and (ii) it becomes possible to concentrate on the direct investigations of architectural response to the controls that determine variations in aggradation rate. It is important to understand how fluvial systems respond to the different drivers of changes in aggradation and the relative importance of each

factor. Thus, future work involving similar quantitative comparative studies should focus on the analysis of how sedimentary architecture and its temporal evolution are controlled by various factors, possibly combining information from different scales of observations by including genetic units that are diagnostic of fluvial processes and subenvironments.

## **4.6 Conclusions**

Real-world data from ancient fluvial sedimentary successions suggest that the evolution of systems subject to variable aggradation rates may not regularly follow the path expected by the LAB models of alluvial architecture, whereby a negative relationship between aggradation rate and channel-deposit density is expected; therefore, rates of aggradation cannot be employed as reliable predictors of architectural evolution. This exposes limitations in popular fluvial sequence stratigraphy models that draw heavily upon the LAB-model principles and it demonstrates the inadequacy of the established practice in continental sequence stratigraphy of defining accommodation-based stratigraphic packages exclusively on the basis of variations in channel-body density and geometry. More generally, results presented herein may give an insight into the fact that different architectural effects stem from different factors controlling accommodation: sedimentological works should focus on assessing which of such control-response situations may be dominant in fluvial systems developed in various settings, rather than fitting observations into models based on predictors of supposed general validity.





## **5 Models for guiding and ranking well-to-well correlations: example applications to fluvial reservoirs**

### **5.1 Summary**

A method based on a set of probabilistic tools has been devised to assess the geological realism of subsurface well-to-well correlations that entail the lateral tracing of geological bodies across a well array with constant spacing. Models quantifying the likelihood of well correlation of geobodies (here termed 'correlability' models and based on the ratio between correlatable and penetrated geobodies) are obtained from total probabilities of penetration and correlation, which are themselves dependent on the distribution of lateral extent of the geobody type. Employing outcrop-analogue data to constrain the width distribution of the geobodies, it is possible to generate a model that describes realistic well-to-well correlation patterns for given types of depositional systems. The correlability models can be applied for checking the quality of correlation-based subsurface interpretations, by assessing their geological realism as compared with one or more suitable outcrop analogues. The flexibility of the approach in terms of analogue selection is illustrated by generating total-probability curves that refer to fluvial channel complexes and that are categorized on the basis of outcrop-analogue classification (e.g. a model braided river system, or a model system with 20% channel deposits), making use of information from a database for the quantification of fluvial sedimentary architecture. From these total-probability functions, values can be drawn to adapt the correlability models to any well-array spacing. The method has been specifically applied to rank three published alternative interpretations of a stratigraphic interval of the Travis Peak Formation (Texas, USA) that was previously interpreted as a braided fluvial deposystem; the ranking is based on quantified geological realism of correlation patterns as compared to (i) all analogues recorded in the FAKTS fluvial architecture database and considered suitable for large-scale architectural characterization, and (ii) a subset of them including only systems interpreted as braided.

## 5.2 Introduction

For hydrocarbon reservoirs or aquifers that are composed principally of fluvial channel lithosomes, it is desirable to be able to realistically forecast the lateral continuity of sedimentary architectural elements when attempting well-to-well correlations. For this reason several predictive techniques have been proposed in past decades to improve the realism of models of subsurface fluvial sedimentary heterogeneity based on well-to-well correlation panels. Commonly, empirical quantitative relationships are used for this purpose. For example, a popular approach is the one proposed by Collinson (1978), who used previously published empirical relationships obtained from modern systems linking meander-belt width, mean annual discharge, formative-channel bankfull depth and bankfull width (equations by Leopold & Wolman 1960; Carlston 1965; Leeder 1973), to derive a relationship to permit estimation of the likely cross-gradient extent of channel sandbodies produced by meandering rivers as a function of channel depth. Similarly, Lorenz et al. (1985) inferred a range of likely meandering-channel sandstone-body widths on the basis of estimated formative-channel bankfull width, which is in turn estimated from point-bar cross-stream width, employing empirical relationships by Leopold & Wolman (1960) and Allen (1965b), respectively. Additional constraints to facilitate the application of approaches based on palaeo-hydrological interpretations have been adopted, specifically in the form of relations linking thickness of cross-stratified sets, dune height and flow depth (Bridge & Tye 2000), or bar-scale macroform thickness and channel depth (e.g. Bhattacharya & Tye 2004). Extending Collinson's (1978) results, Fielding & Crane (1987) produced a set of similar relationships for a wider range of fluvial planform types, as well as relationships expressing likely formative-channel depths as a function of channel sandbody thickness, which would ideally permit the application of those relationships to datasets that record channel sandstone thickness only. These relationships were then combined by Fielding & Crane (1987) to derive a relationship for the most likely width of a channel sandbody of known thickness, which could be applied without requiring knowledge of palaeo-hydrological parameters. Analogous curves have also been directly derived from geometrical data obtained from the systematic measurement of fluvial channel sandstone thickness and width from various ancient successions (e.g. Dreyer 1993; Robinson & McCabe 1997). More generally, a large amount of rock-record data has been included in cross-plots of channel sandstone thickness and width, with the aim of establishing general guides for achieving realistic well correlations (e.g. Mjøs & Prestholm 1993; Reynolds 1999); in a similar fashion and for the same scope, information about the cross-gradient extent of channel belts in modern fluvial

environments has been distilled into width distributions, by taking advantage of the full lateral control and knowledge about flow direction and environmental conditions that are ensured only by study of modern systems (e.g. Tye 2004).

One of the underlying themes of all these approaches is a desire to inform deterministic models by variably making use of architectural data drawn from outcrop or modern analogues, i.e. ancient or modern sedimentary systems displaying sedimentary architecture that is thought to be comparable with the interpreted subsurface system. Another fundamental characteristic shared by these methods is that the information they provide is useful for assessing whether correlation of an individual channel lithosome results in a realistic reconstruction of likely lateral extension: likelihood is independently considered for each single channel unit, but no information is provided to guide correlations by quantifying the realism of heterogeneity patterns of the sedimentary succession as a whole. In other words, whereas these approaches inform the lateral tracing of a channel body so that it results in a plausible lateral extent, they do not tell us whether the correlations carried out for all channel bodies in a succession result in a realistic distribution of channel-body lateral extent.

In view of the limitations associated with such past approaches, the aim of this study is to illustrate a new method for guiding well-to-well correlations of fluvial channel bodies. Specific objectives are as follows:

- to employ a large outcrop-analogue database to further evaluate the usefulness and limitations of previously-proposed approaches to the deterministic modelling of fluvial hydrocarbon reservoirs or aquifers;
- to present a new probabilistic method to guide the development of well-to-well correlation panels and to appraise their quality, using descriptors of sedimentary architecture derived from analysis of whole depositional systems or stratigraphic volumes rather than individual channel bodies;
- to demonstrate the utility of the approach by ranking the geological realism of three different interpretations of the same system based on the employment of different techniques for the correlation of the same well array.

In terms of the generic application of this type of approach to elucidate subsurface architecture, it is worth noting that, although the approach proposed here specifically refers to well correlation of fluvial channel complexes, the method can be generalized to any genetic-unit type (e.g. deep-water sand sheets) provided that an appropriate database of their lateral extent, as measured from reservoir analogues, is available.

### **5.3 Database**

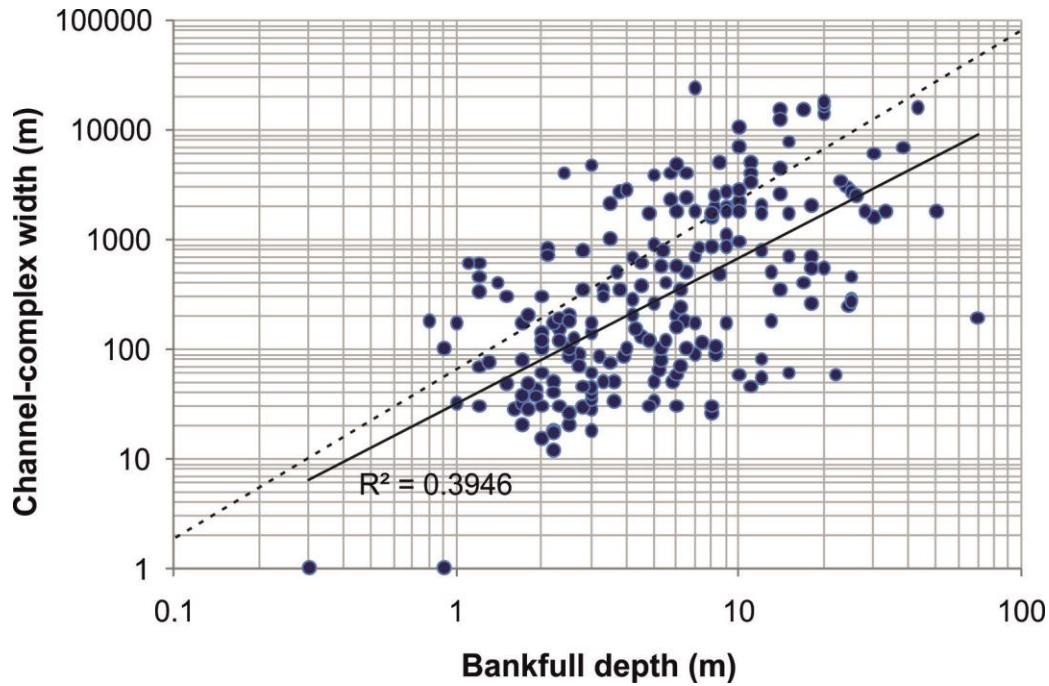
Given that established approaches to guiding subsurface correlations of fluvial channel bodies are based on the derivation of an expected value of width for each individual channel element by using relationships based on either geometry (channel-body thickness) or palaeo-hydrology (the inferred depth or width of associated formative channels), this study intends to further test the applicability of such methods using a large architectural knowledge base: the Fluvial Architecture Knowledge Transfer System (FAKTS; Colombera et al. 2012a, Chapter 2). Among other things FAKTS includes geometrical and (palaeo-) hydrological data of depositional elements that are defined on geometrical rules and classified as channel complexes or floodplain units. As of February 2013, the database includes 3345 channel complexes to which geometrical information is associated, obtained from 40 different case histories, representing mostly studies from the published literature. FAKTS channel complexes are objects whose geometry is effectively described by thickness and width. Therefore, it is appropriate to use data derived from these geo-bodies to construct numerical instruments to guide well-to-well correlations. Such instruments are employed in this study to implement a new assessment of likelihood of correlation (here termed correlability) by making use of data that collectively refer to entire successions or parts thereof, rather than to single channel bodies.

### **5.4 Assessing past approaches to channel-body width prediction and introducing a new probabilistic method**

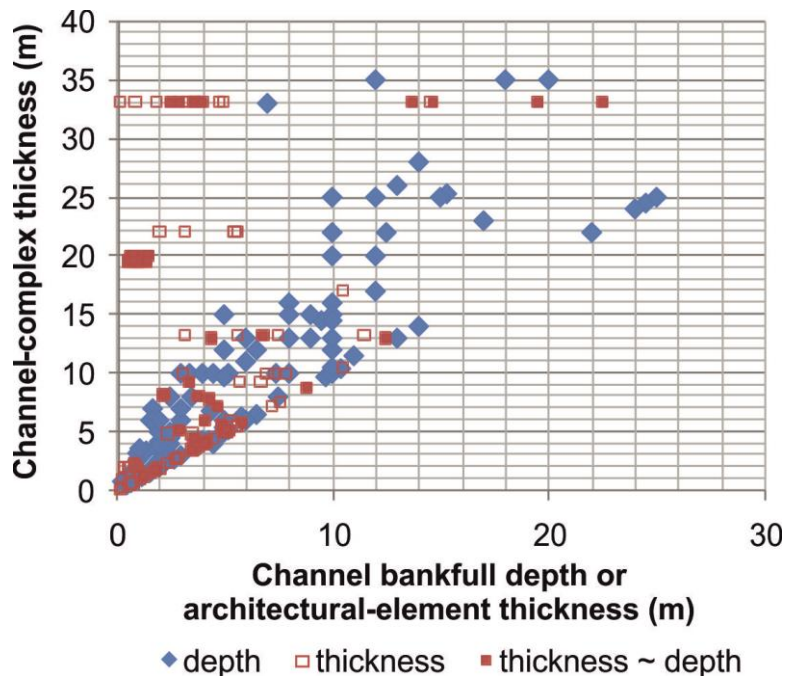
Firstly, this study re-considers past approaches to inform correlation panels by guiding the lateral tracing of each individual channel element, in the light of information derived from the large architectural knowledge base (FAKTS) that is now available. It is not within the scope of this work to provide a full account of the drawbacks of analogue-based or palaeohydrology-based approaches, and neither is this necessary since these pitfalls have already been discussed in detail by Bridge & Mackey (1993), Bridge & Tye (2000) and Miall (2006). Instead, this work further highlights the inadequacy of approaches based on the correlation of each single channel body by focusing once more on the wide architectural variability that might stem from adopting such methods without checking for the geological realism of the modelled succession. This problem is emphasized by the considerable

scatter observed in the architectural data presented here, which highlights the difficulty of reliably inferring channel-body width from the formative-channel bankfull depth, of inferring formative-channel bankfull depth from the thickness of a channel sandstone body, or of inferring channel-body width directly from its thickness. For example, considering bankfull depths observed in the 7 to 23 m range, FAKTS channel-complex widths cover as much as four orders of magnitude (figure 5.1); overall the two variables yield a Pearson correlation coefficient of 0.341. The architectural database stores both the inferred/measured bankfull depth of channels and the geometry of lower-scale units (architectural elements) contained within the channel complexes; since architectural-element thickness, in some cases, may relate to formative channel bankfull depth, some architectural elements whose thickness was interpretable as the entirely preserved thickness of the associated in-channel geomorphic element (barform) were therefore considered to estimate bankfull depth (cf. Bhattacharya & Tye 2004). With regard to the relationship between measured or inferred bankfull depths and channel-complex thickness (figure 5.2), FAKTS data do not fit well with the relationship given by Fielding & Crane (1987) in the form of *channel depth = 0.55 sandstone thickness*, or with a linear relationship altogether (application of a linear best fit to the FAKTS dataset returns  $R^2 = 0.0656$ ). The FAKTS channel-complex width-to-thickness scatterplot (figure 5.3) displays substantial scatter, even if only real widths are considered, with three to four order of magnitudes in width are possibly associated with any given value of thickness; importantly, the power-regression best fit of all FAKTS channel-complex real-width data shows a significant discrepancy with the *most-likely case* predicted by Fielding & Crane (1987), especially for channel complexes that are thicker than 8 m.

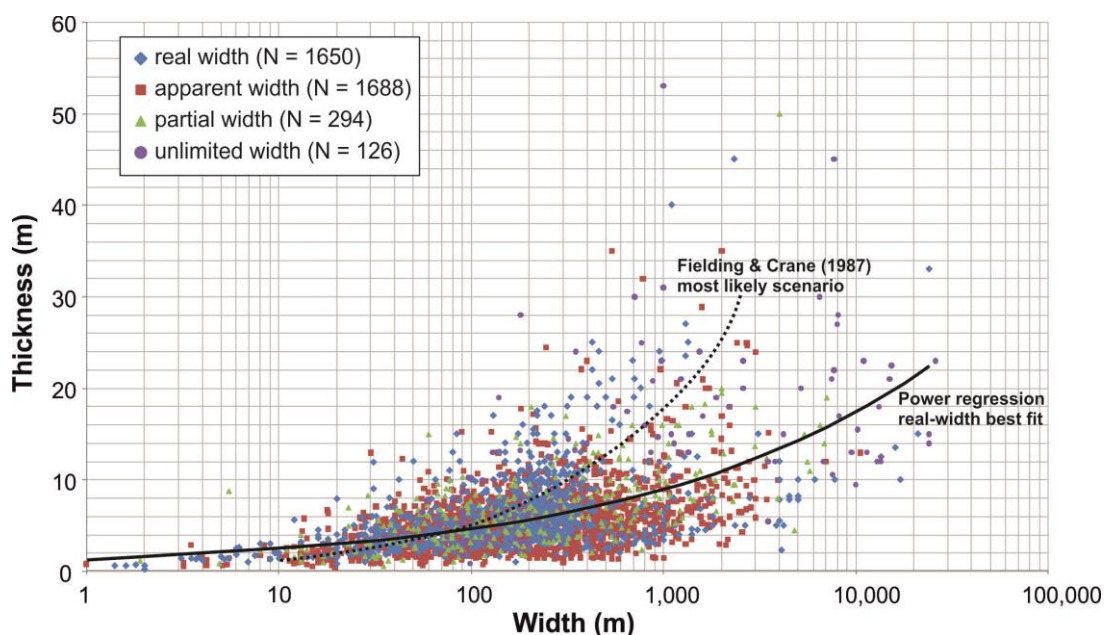
Consequently, the strict application of quantitative relationships clearly entails significant risk; even a flexible application of analogue information, based on the range of natural variability in architectural characteristics would still potentially lead to many correlation panels that are architecturally very different but equally acceptable, given that they would honour geometrical constraints. Although it is important to recognize that there is value in basing such models on geometrical information, and that it is useful to synthesize such information into empirical relationships, in this study a different set of constraints are used – again derived by outcrop or modern analogues – to better inform or rank well-to-well correlation frameworks of subsurface fluvial architecture.



**Figure 5.1:** scatterplot of channel-complex width against formative-channel bankfull depth based on all suitable data contained in the FAKTS database, including data published by Fielding & Crane (1987), Jordan & Pryor (1992), Fielding et al. (1993), Friend & Sinha (1993), and Tye (2004). The power-regression curve is plotted as a continuous line, whereas the equation given by Collinson (1978) – included for comparison – is represented as a dashed line.



**Figure 5.2:** scatterplot of channel-complex thickness against formative-channel bankfull depth or architectural-element thickness based on all suitable data contained in the database. Architectural elements represent lower-scale units contained within channel complexes and that are interpretable as the preserved product of geomorphic units, such as barforms; geomorphic elements whose thickness appears to be completely preserved and which are considered reasonable and useful indicators of channel bankfull depth are depicted as filled data-point markers.



**Figure 5.3:** scatterplot of channel-complex width against channel-complex thickness; apparent widths refer to measurements made from exposures that are oblique with respect to the channel-belt-scale flow axis or from situations where palaeoflow was uncertain; real widths refer to the entire body lateral extent along a direction normal to the flow axis; following the terminology by Geehan & Underwood (1993), partial widths refer to measurements of channel complexes for which one lateral termination is not exposed, whereas unlimited widths refer to bodies for which both lateral terminations are not exposed. The curve expressing the “most-likely scenario” of Fielding & Crane (1987) is also plotted, for comparison with a power-regression curve obtained from all FAKTS channel-complexes for which real-width data are available.

Specifically, in the approach taken in this study we do not consider relationships that refer to individual elements that need to be correlated over several wells; instead we consider relationships that refer to either the sedimentary succession as a whole, or to specific portions thereof. In particular, we provide probabilistic tools that can be employed to check the realism of a given fluvial reservoir/aquifer model, so that the interpretation can be iteratively adjusted to match with a target quantity describing the correlability of channel bodies over a given inter-well distance for an ideal synthetic analogue made of architectural data obtained from several real-world case studies (cf. Colombera et al. in press, Chapter 3). Analogue data on which estimates of target system correlability are based can be customized to fit interpreted palaeo-environmental or system-descriptive parameters (e.g. bankfull discharge, channel pattern), but the use of this approach does not require palaeo-environmental or palaeo-hydrological interpretation, as it potentially only involves the use of relationships describing associated architectural properties of the preserved record (e.g. geometry and proportions as shown in a specific model later). Clearly, the method can be used in conjunction with expressions for estimating the lateral extent of individual bodies; for example, relationships linking

channel body thickness with range in width can be flexibly used to inform the lateral extent of any given sandstone body, provided that the width distributions are such that they match the target correlability given by the model presented below. The approach can be used either to guide or validate/evaluate a model in cases where well spacing is fixed; later in this work a set of previously-interpreted correlation panels are used to perform an example quality check.

## 5.5 Correlability models

### 5.5.1 Total probability of penetration of a randomly selected channel-complex

The procedure employed herein to guide or rank a correlation framework is based on knowledge of the following: (1) the proportion of channel complexes that are likely to be penetrated (or equivalently the total probability of penetration of a randomly-chosen channel complex) by a well array with given spacing  $S$ , for any channel-complex width distribution; (2) the proportion of channel complexes that are correlatable (or equivalently the total probability of correlation of a random channel complex) over variable inter-well distance (i.e.  $S$ ,  $2S$ ,  $3S\dots$ ), for any channel-complex width distribution. Thus, the adopted approach first obtains the expression for the total probability of channel-complex penetration for a known channel-complex width distribution. Width distributions represent the analogue data with which correlation panels need to be compared.

The conditional probability of penetration of a channel-complex of width  $W$  for penetration angle  $\theta$  and well spacing  $S$  (figure 5.4) can be described by the relation given by McCammon (1977) for parallel-line search of a dike by geophysical surveys; for  $W \leq S$ :

$$P(p/\theta) = \left(\frac{W}{S}\right) \sin \theta$$

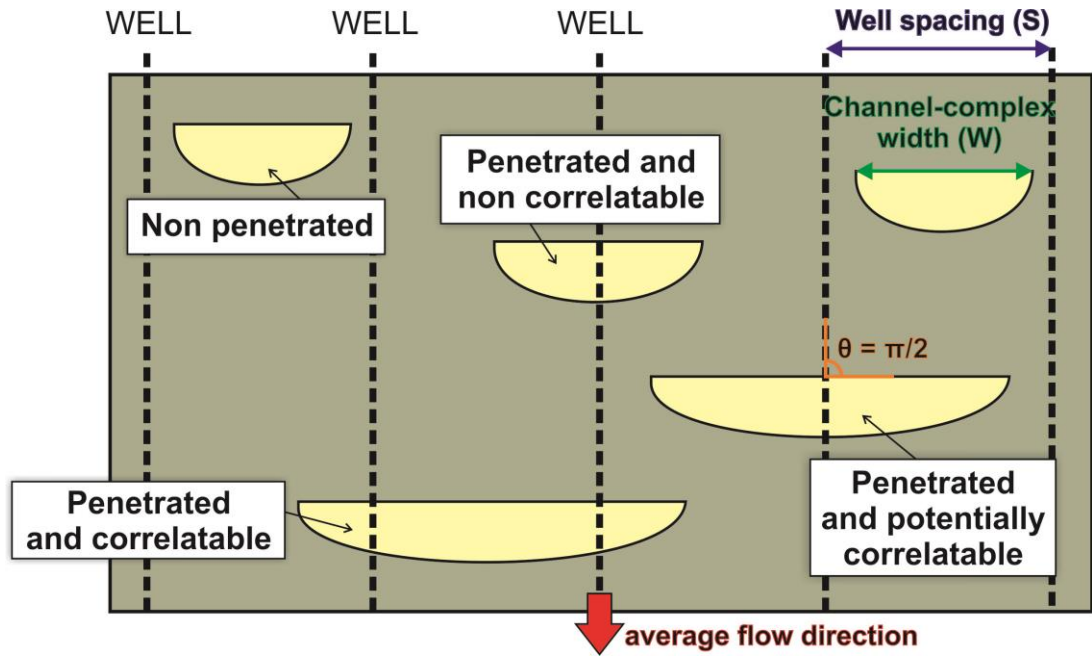
the unconditional probability can be written as:

$$P(p) = (2/\pi)(W/S) \int_0^{\pi/2} \sin \theta \, d\theta$$

For the sake of simplicity this study only considers penetration in an orientation that is orthogonal to floodplain palaeo-surfaces, in which case  $\theta = \pi/2$ :

$$P(p) = \left(\frac{W}{S}\right)$$





**Figure 5.4:** sketch representing the problem treated in this work and the terminology adopted; the approach employed refers to a situation in which a well array penetrates orthogonally through a fluvial succession composed of channel complexes in a floodplain background; for the method to be applicable, well-spacing  $S$  needs to be constant; different basin portions with different inter-well spacings need to be considered separately. The method introduced in this study is based on analysis of analogue-derived knowledge of channel-complex width distribution; if the correlation panel runs at an angle to the cross-gradient direction, a distribution of channel-complex apparent widths can be considered. Channel complexes whose width is smaller than the inter-well spacing are non correlatable between two wells; channel complexes whose width is larger than the inter-well spacing are potentially correlatable or actually correlatable: the method illustrated here is based on the recognition of the probability of a channel complex with width narrower than twice the inter-well spacing being both penetrated and correlatable.

So, the conditional probability of channel-complex penetration for width  $W$  can be expressed as follows (cf. figure 5.5):

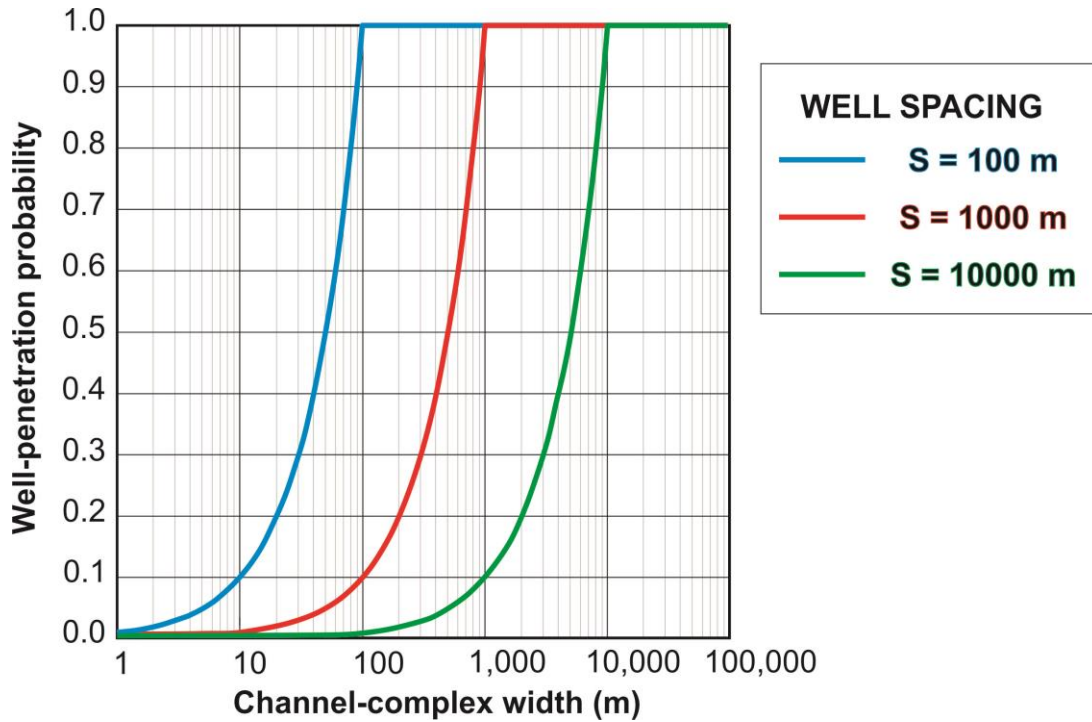
$$P(p/w) = \begin{cases} \left(\frac{W}{S}\right) & \forall W \leq S \\ 1 & \forall W > S \end{cases}$$

Now, the method requires determination of a value of total probability of penetration by a well array of spacing  $S$  of a fluvial reservoir with channel-complexes that follow a width distribution with a probability density function  $P(w)$ ; the total probability theorem is then applied:

$$P(p) = \int_{\bar{w}} P(p/w)P(w) dw$$

So, the total probability of penetration of a randomly chosen channel-complex (equivalent to the non-volumetric proportion of channel-complexes penetrated) is given by (cf. figure 5.6):

$$P(p) = \int_0^S \left(\frac{w}{S}\right) P(w) dw + \int_S^{W_{max}} P(w) dw$$

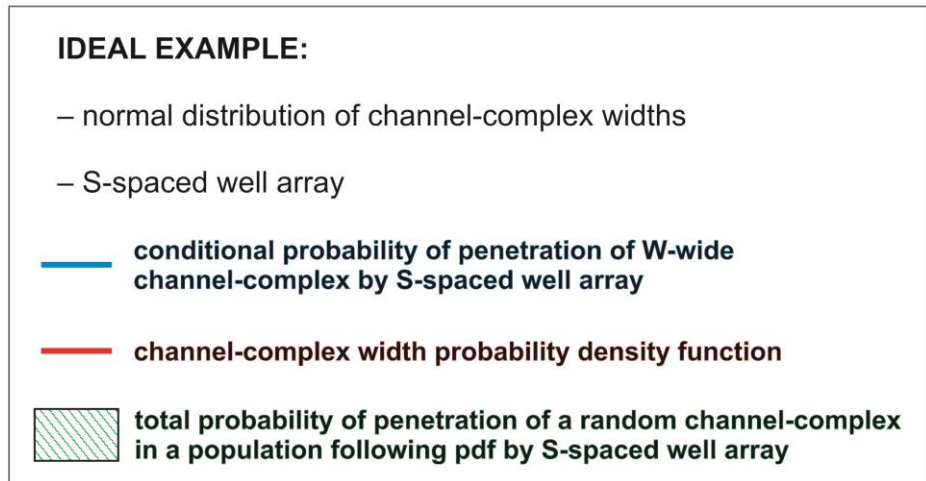
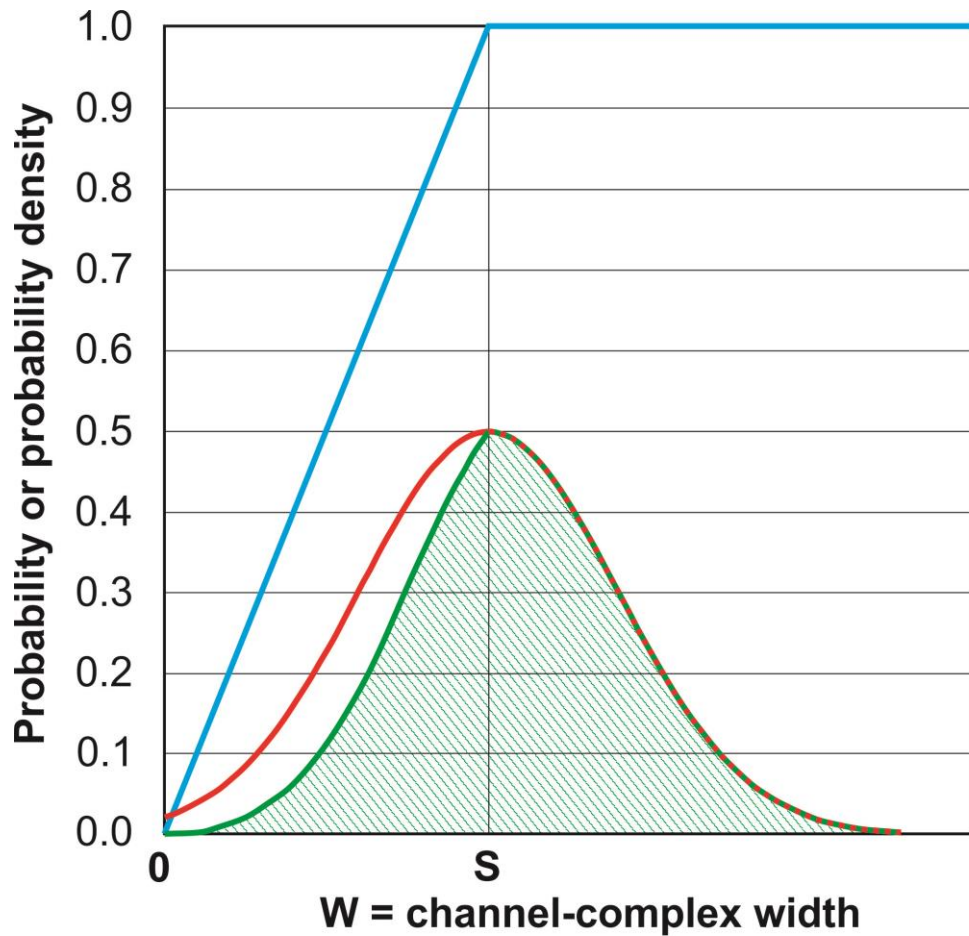


**Figure 5.5:** probability of a random channel complex to be penetrated by a well-array with spacing  $S$  as a function of channel-complex width; these functions are employed to describe conditional probability of penetration given channel-complex width.

Database analysis (e.g. figure 5.7) reveals that for channel-complexes  $P(w)$  is typically adequately described by log-normal probability density functions, which take the form:

$$P(w) = \left(\frac{1}{w\sigma\sqrt{2\pi}}\right)e^{-\frac{(\ln w - \mu)^2}{2\sigma^2}}$$

where  $\mu$  is the location parameter and  $\sigma$  is the scale parameter of the channel-complex width distribution (parameters  $\mu$  and  $\sigma$  represent the mean and standard deviation of the natural logarithm of the width, respectively).

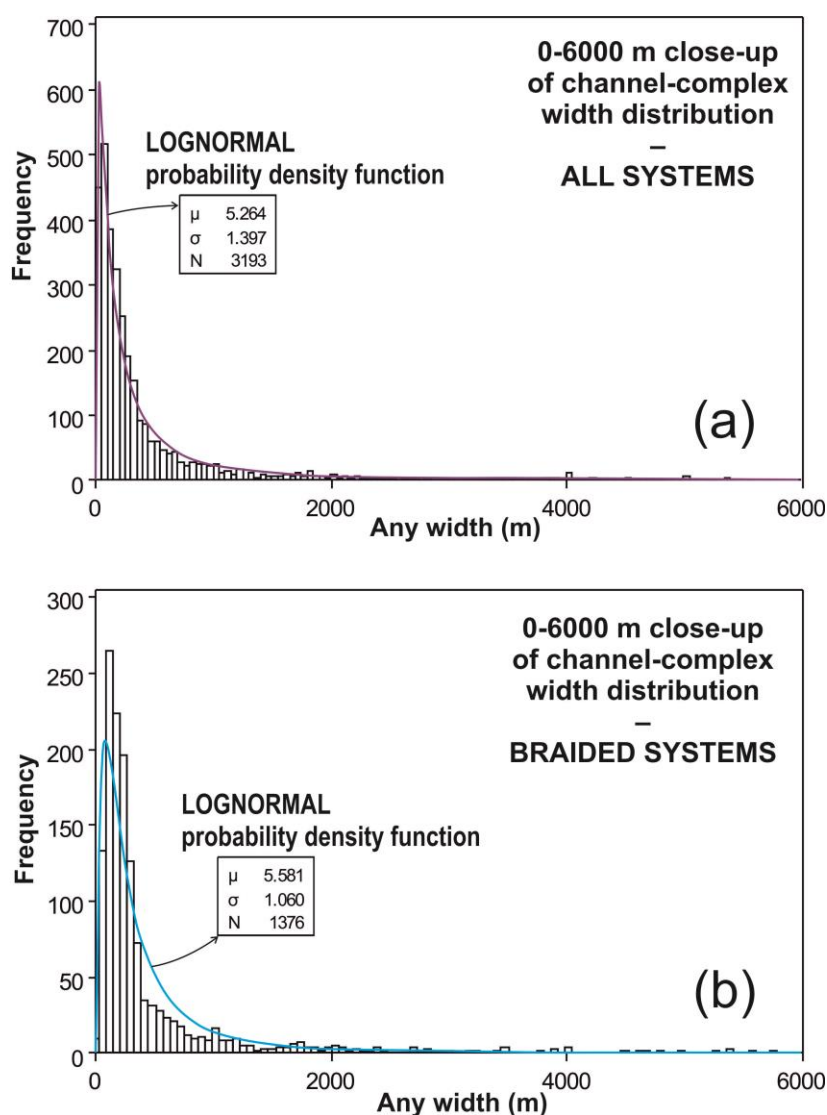


**Figure 5.6:** ideal example in which a total probability of channel-complex penetration is derived by assuming that the well-array has spacing  $S$  and the channel-complex width distribution follows a normal probability density function with mode/mean at channel-complex width equal to  $S$ ; the total probability of channel-complex penetration (i.e. the proportion of penetrated channel-complexes) is given by the area underlying the product between the width probability density function and the conditional probability of penetration as a function of channel-complex width.

For such width distributions the total probability of channel-complex penetration  $P(p)$  is given by:

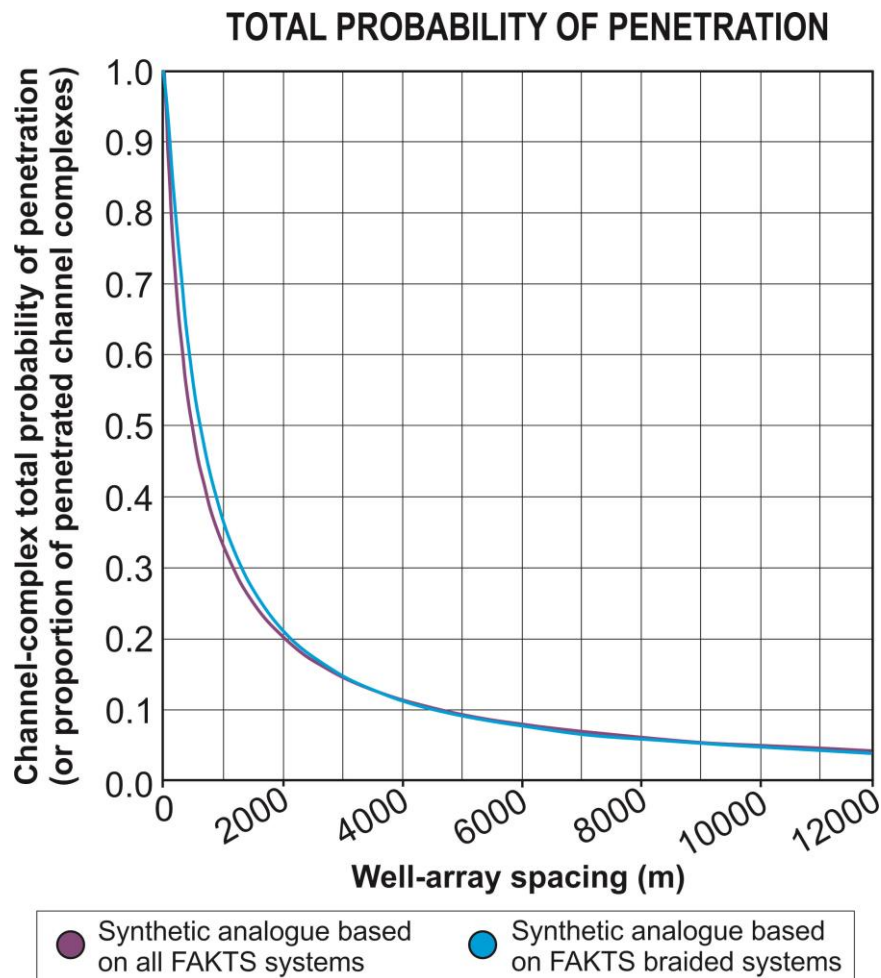
$$P(p) = \int_0^S \left(\frac{w}{S}\right) \left(\frac{1}{w\sigma\sqrt{2\pi}}\right) e^{-\frac{(\ln w - \mu)^2}{2\sigma^2}} dw + \int_S^{W_{max}} \left(\frac{1}{w\sigma\sqrt{2\pi}}\right) e^{-\frac{(\ln w - \mu)^2}{2\sigma^2}} dw$$

By operating the definite integral, it is then possible to obtain relationships describing the total probability of penetration for channel complexes belonging to specific fluvial types (i.e. characterized by specific probability density functions) as a function of well spacing  $S$ .



**Figure 5.7:** channel-complex width distributions obtained from the FAKTS database: (a) for all suitable case studies; (b) for systems classified on an interpretation of braided river pattern. Results include all types of width observation (real, apparent, partial, and unlimited; cf. figure 5.3). Only the 0 to 6000 m width range is shown although some maximum widths do exceed 6000 m. Best-fit log-normal probability density functions are derived from MINITAB software.  $N$  refers to the number of readings;  $\mu$  and  $\sigma$  respectively refer to the location and scale parameters of the log-normal distributions).

From the example given in figures 5.7 and 5.8, it is apparent how the choice of the type of synthetic analogue (in this particular case, a generic non-categorized fluvial system that includes all FAKTS data, figure 5.7a, or an ideal fluvial facies model based on FAKTS systems classified as braided, figure 5.7b) will eventually affect the model describing the total probability of penetration as a function of well spacing (figure 5.8). It is important to note that the total probability is not representative of a volumetric proportion, but only of the ratio between the number of geometrically defined fluvial channel bodies that are penetrated and the total number of bodies along the section.



**Figure 5.8:** curves that quantify the total probability of channel-complex penetration as a function of well-array spacing for two different channel-complex width probability density functions; the different width distributions are respectively based on synthetic analogues made of all FAKTS case studies (figure 5.7a) and systems classified on an interpreted braided river pattern (figure 5.7b). Total probability corresponds to the proportion of channel-complexes that are penetrated for a given well spacing; proportions are not volumetric, but instead represent the fractional number of channel-complexes.

### 5.5.2 Total probability of correlation of a randomly selected channel-complex

Just as the expected proportion of channel complexes penetrated by the well array can be quantified by the total probability of penetration, the proportion of channel complexes that are correlatable between two wells is also quantified by a measure of total probability. To obtain the total probability of *correlation* of a randomly selected channel complex, a method is first employed to obtain the expression for the conditional probability of channel-complex correlation between two adjacent wells for channel-complex width  $W$ . Relations by McCammon (1977) are used to obtain the following:

for  $\theta = \frac{\pi}{2}$  and  $W \leq S$ :  $P(c) = 0$ ;

for  $\theta = \frac{\pi}{2}$  and  $W \geq 2S$ :  $P(c) = 1$ ;

for  $\theta = \frac{\pi}{2}$  and  $S \geq W \leq 2S$ :  $P(c) = \left(\frac{W}{S}\right) - 1$

where  $\theta$  remains the penetration angle and  $S$  the distance between two wells.

So, the conditional probability of channel-complex correlation for width  $W$  can be expressed as follows (orange curve in figure 5.9):

$$P(c/w) = \begin{cases} 0 & \forall W \leq S \\ \left(\frac{W-S}{S}\right) & \forall S < W < 2S \\ 1 & \forall W \geq 2S \end{cases}$$

Again, to obtain a value of total probability of channel-complex correlation (i.e. proportion of correlatable channel complexes) between two wells of spacing  $S$  in a fluvial reservoir with channel-complexes following a width distribution with probability density function  $P(w)$ , the total probability theorem is applied:

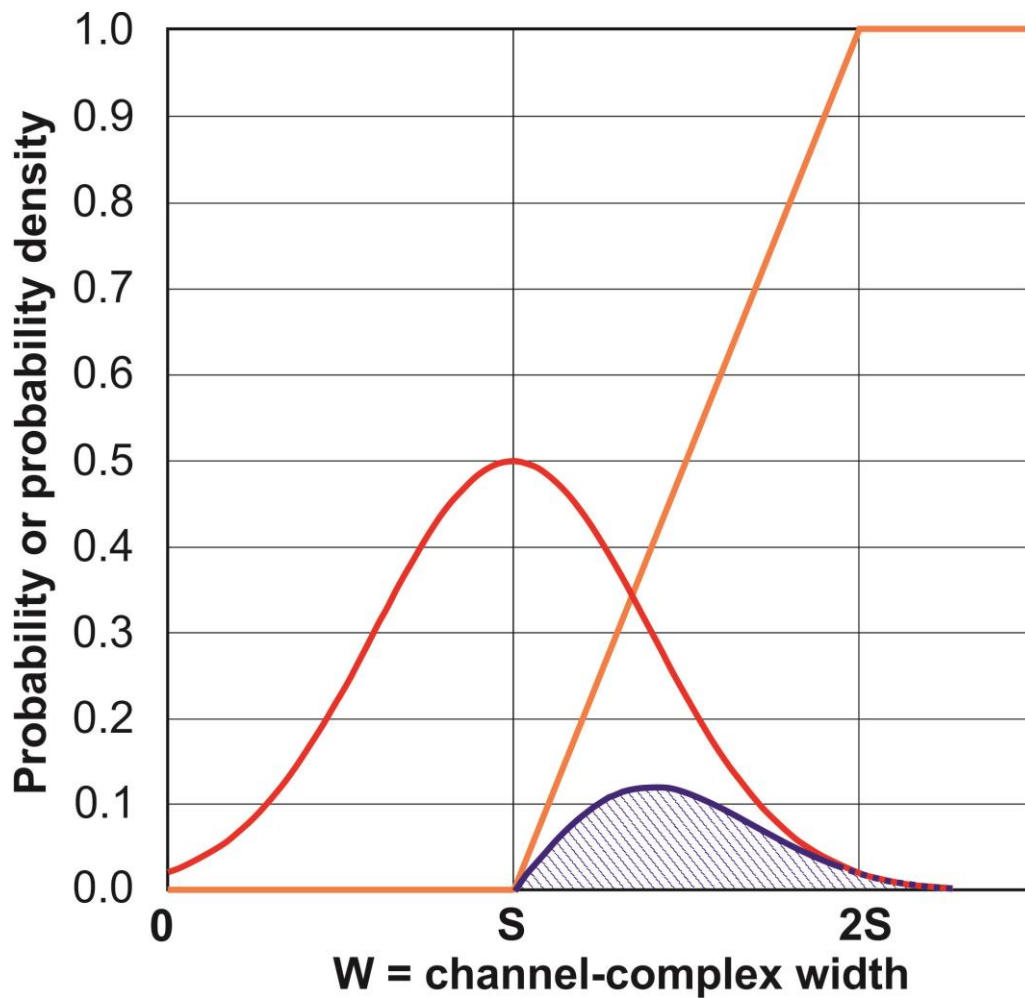
$$P(c) = \int_{\bar{w}} P(c/w)P(w) dw$$

So, the total probability of correlation between a pair of wells spacing  $S$  of a randomly chosen channel-complex (i.e. the non-volumetric proportion of channel-complexes correlatable) is given by (hatched area in figure 5.9):

$$P(c) = \int_0^S 0 \cdot P(w)dw + \int_S^{2S} \left(\frac{w-S}{S}\right)P(w)dw + \int_{2S}^{W_{max}} P(w) dw$$

Then:

$$P(c) = \int_S^{2S} \left(\frac{w-S}{S}\right)P(w)dw + \int_{2S}^{W_{max}} P(w) dw$$

**IDEAL EXAMPLE:**

- normal distribution of channel-complex widths
- S-spaced well array

conditional probability of correlation of W-wide channel-complex between two S-spaced wells

channel-complex width probability density function

total probability of correlation of a random channel-complex in a population following pdf between two S-spaced wells

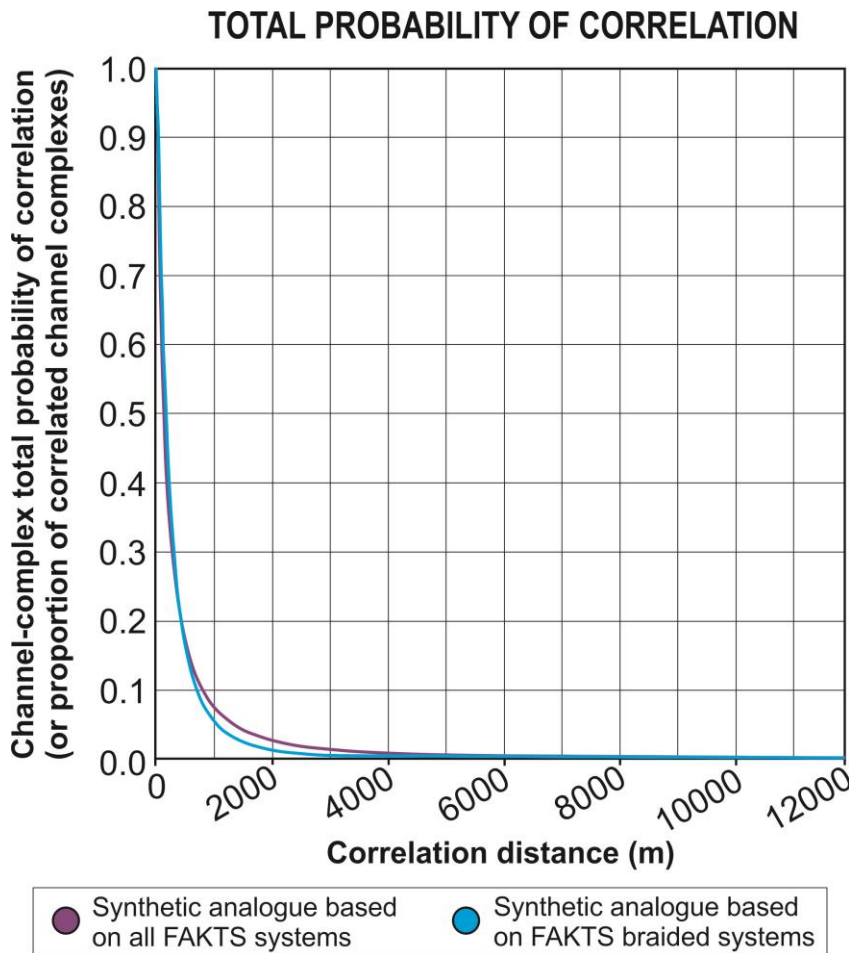
**Figure 5.9:** ideal example in which a total probability of channel-complex correlation between two-wells is derived by assuming that the well-array has spacing  $S$  and the channel-complex width distribution follows a normal probability density function with mode/mean at channel-complex width equal to  $S$ ; the total probability of channel-complex correlation (i.e. the proportion of channel-complexes correlatable between two wells) is given by the area underlying the product between the width probability density function and the conditional probability of correlation as a function of channel-complex width.



For a fluvial reservoir with channel-complex widths following a log-normal distribution the total probability of channel-complex correlation between two wells of spacing  $S$  is given by:

$$P(c) = \int_S^{2S} \left(\frac{W-S}{S}\right) \left(\frac{1}{w\sigma\sqrt{2\pi}}\right) e^{-\frac{(\ln w - \mu)^2}{2\sigma^2}} dw + \int_{2S}^{W_{max}} \left(\frac{1}{w\sigma\sqrt{2\pi}}\right) e^{-\frac{(\ln w - \mu)^2}{2\sigma^2}} dw$$

By operating the definite integral, it is then possible to obtain relationships describing the total probability of correlation for channel complexes belonging to specific fluvial types (i.e. characterized by specific probability density functions) as a function of correlation distance  $S$ .



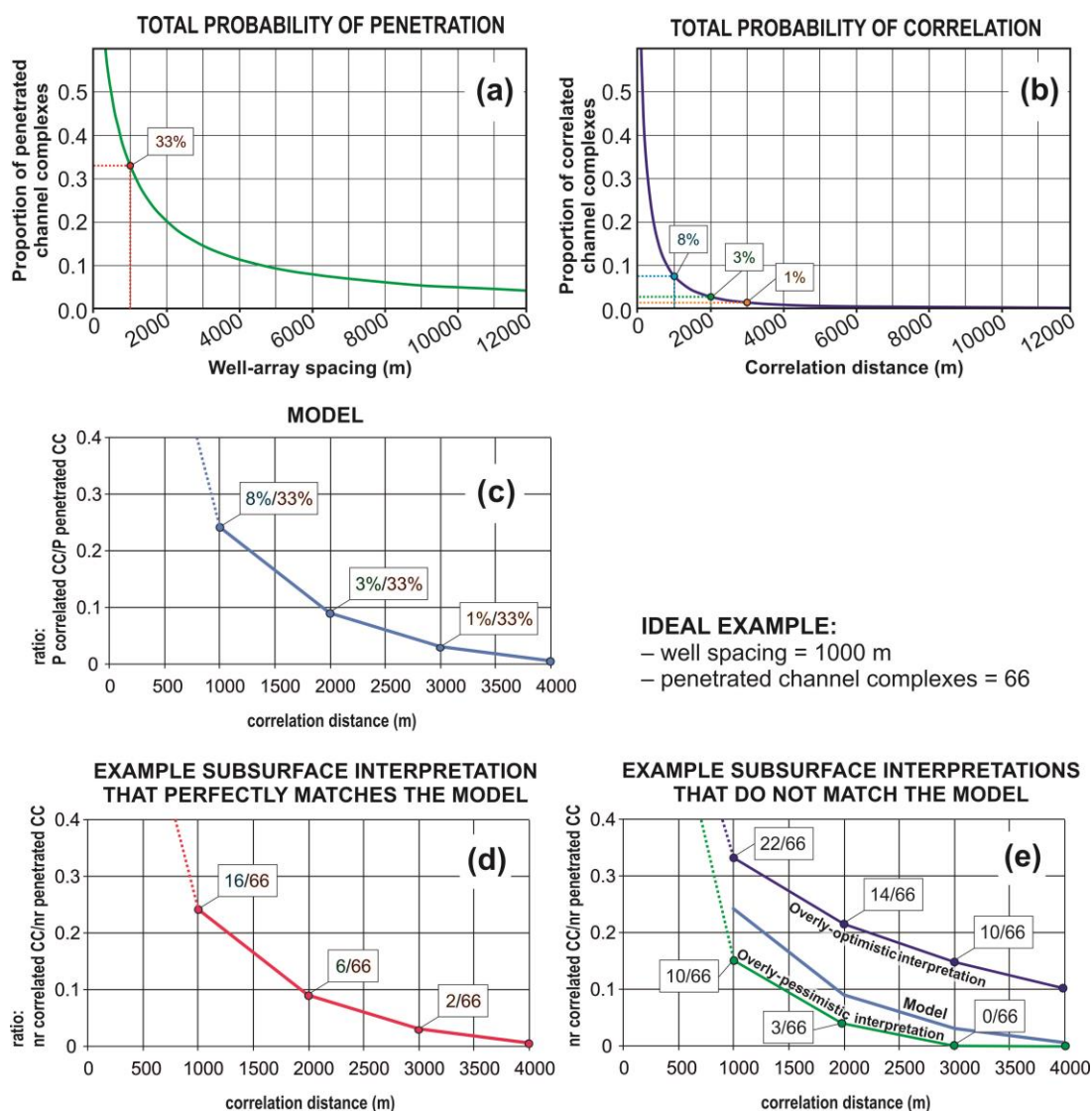
**Figure 5.10:** curves that quantify the total probability of channel-complex correlation between two wells as a function of correlation distance for two different channel-complex width probability density functions; the different width distributions are respectively based on synthetic analogues made of all FAKTS case studies (figure 5.7a) and systems classified on an interpreted braided river pattern (figure 5.7b). Total probability corresponds to the proportion of channel-complexes that are correlated over a given distance; proportions are not volumetric, but instead represent the fractional number of channel-complexes.



Again, it is evident how differing width distributions, associated with different types of synthetic analogues, will determine the models that describe the total probability of correlation as a function of inter-well correlation distance (figure 5.10).

### **5.5.3 Comparison between probability-based models and subsurface interpretations: a quality check**

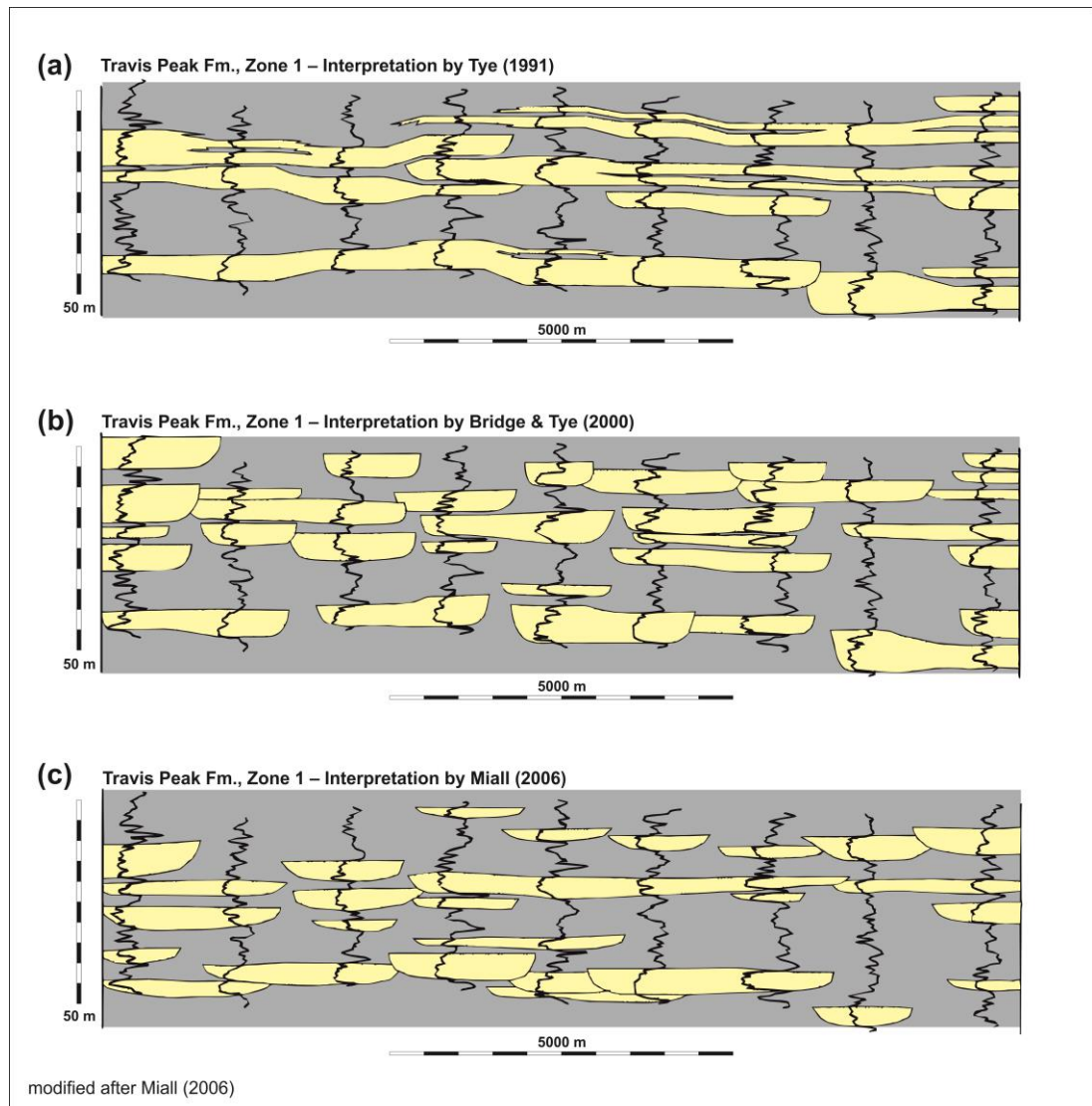
Once knowledge of total probability of penetration and correlation is obtained for a suitable field analogue or database-informed synthetic analogue, it is possible to draw from the curves (i) values of total probability of penetration for the given well spacing and (ii) total probability of correlation for each integer multiple of the well-spacing (figure 5.11a, b). Then, operating the ratio between the values of total probability of correlation and the total probability of penetration (figure 5.11c) it is possible to obtain values that quantify the proportion of penetrated channel complexes that are correlatable over a given distance. If these values are plotted as a function of inter-well distance (figure 5.11c) a curve describing the proportion of penetrated channel bodies that are likely to be correlatable as a function of correlation distance is obtained: this curve is here termed 'correlability' model and represents the model against which to test interpretations. The actual process of comparison between the correlability model and the subsurface interpretation can be carried out graphically, allowing for recognition of the degree of approximation of the interpretation to the model and whether the interpretation is too conservative or excessively confident (figure 5.11d, e).



**Figure 5.11:** ideal example in which several subsurface interpretations based on well-to-well correlation are compared with a correlability model. This example assumes well spacing  $S = 1000$  m. Thus, a value of total probability of channel-complex penetration for  $S$  is drawn from the curve of total probability of penetration based on all FAKTS analogues (a); then, also values of total probability of correlation are drawn from the relative curve (b) for  $S$  and values that are whole multiples of  $S$ . The ratio between values of total probability of correlation and penetration are then plotted against the correlation distance (c), to obtain the correlability model used to test interpretations. Afterwards, values of the ratio between the number of correlated channel complexes (dependent on the correlation distance) and the total number of penetrated channel complexes (66 in this idealized example) are plotted for each interpretation on the same graph, to reveal whether interpretations resulting from well-to-well correlations display correlation patterns that do (d) or do not (e) match with what is expected from the synthetic analogue.

### 5.5.4 Case study example application: ranking alternative correlation panels for the subsurface Travis Peak Formation (Texas, USA)

To illustrate an application of this method, it is here used to rank the likelihood of three alternative architectural interpretations proposed by Tye (1991), Bridge & Tye (2000) and Miall (2006) for the same well array, through a stratigraphic interval (Zone 1) of the Lower Cretaceous Travis Peak Formation, East Texas (figure 5.12).



**Figure 5.12:** three alternative interpretations of the same subsurface fluvial succession in the Lower Cretaceous Travis Peak Formation (east Texas, USA). Correlation panels by (a) Tye (1991), (b) Bridge & Tye (2000), and (c) Miall (2006). Although well spacing is actually variable, an equal inter-well distance as represented in these panels is assumed for ranking the geological realism of the interpretations. In similar cases of variable well spacing, the quality-check method presented here could either be separately applied for adjacent stratigraphic portions with comparable spacing or replicated for maximum and minimum well spacing in order to identify a confidence interval – rather than a correlability curve – against which discrepancies could be evaluated.

In this area, the Travis Peak Formation comprises fluvial and paralic depositional systems (Tye et al. 1989; Dutton et al. 1991; Davies et al. 1993); variable architectural styles of the fluvial systems have been recognized and related to planform evolution; both high-sinuosity and braided planform types have been interpreted. The interval to which the three correlation panels refer has been interpreted as a dominantly braided fluvial deposystem (cf. Tye 1991; Davies et al. 1993). This dataset was chosen because it is a good published example of different models of fluvial subsurface architecture based on the adoption of different sets of assumptions. However, it is not necessarily the most suitable dataset for the method because the channel/floodplain interpretation of the logs differs slightly for the different panels. In addition, it is necessary to assume that the wells were equally spaced (spacing = 1.54 km) as depicted in figure 5.12 even though they are not in reality (the actual spacing varies between 0.8 and 2.2 km); this shortcoming has been ignored in the following discussion as this dataset is used merely to illustrate a potential application of the method.

The correlability technique described above is applied to this dataset in order to rank the deterministic models by identifying which of these panels represents the most realistic subsurface fluvial architecture by comparison with an ideal channel-complex width distribution obtained by (1) all FAKTS analogues or (2) a synthetic analogue based on many systems matching the dataset in terms of interpreted planform type (i.e. braided river), so that discrepancies between the results obtained from assuming each of the two types of analogy can also be assessed. Thus, probability density functions describing channel-complex width have been obtained as follows:

- extracted from all analogues contained in the FAKTS database and considered suitable for deriving geometrical output (figure 5.7a);
- extracted from all FAKTS analogues interpreted as representing braided fluvial systems and considered suitable for derivation of required geometrical output (figure 5.7b).

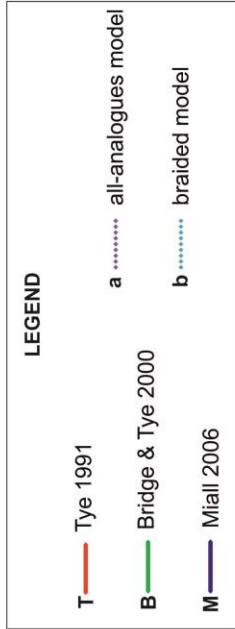
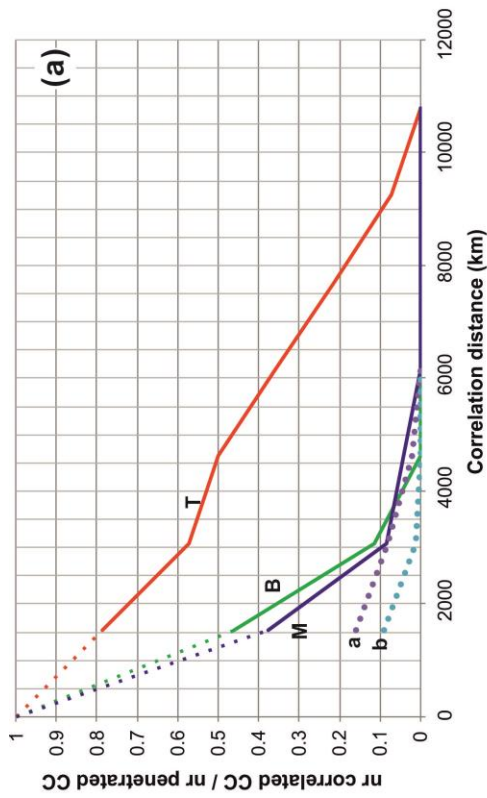
Curves describing the total probability of penetration (figure 5.8) and correlation (figure 5.10) have been obtained for the two types of synthetic analogues, and from these values of total probability of penetration for  $S = 1540$  m and total probability of correlation for  $S$  and multiples of  $S$  were derived. This enables a correlability model based on total probabilities to be plotted as the ratio between total probability of correlation and total probability of penetration for  $S$  and its multiples.

The definition of subsurface units must match with the definition of outcrop-analogue units. So, the channel bodies depicted in the panels (figure 5.12) have

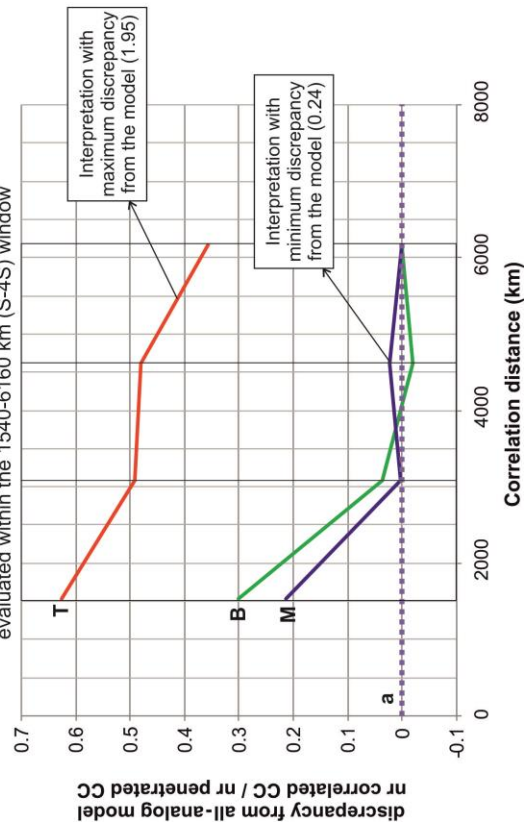
been subdivided geometrically in agreement with the definition of a channel-complex adopted for the FAKTS database (cf. Colombera et al. 2012a, Chapter 2), to ensure that results are comparable with correlability models based on width probability density functions derived from the database. Next, the ratio between the number of correlated channel-complexes and the number of channel-complexes in each panel was computed for multiples of  $S$  (up to  $7S = 10780$  m, for which no channel-complex is correlatable in any of the three panels). Resulting ratios relating to the subsurface interpretations were plotted together with the total-probability-based correlability model based on FAKTS analogues for graphical comparison against correlation distance (figure 5.13a). It is immediately evident how, compared to either of the other two models, the interpretation by Tye (1991) consisted of lateral correlations that were considerably too optimistic. To facilitate comparison and quantification of the discrepancy between the subsurface interpretations and each of the two correlability models (i.e. all analogues vs. braided systems), the difference between the ratio of correlated and penetrated channel complexes for the interpretation and for the model was also plotted independently for the two models (figure 5.13b, c). The total discrepancy can then be measured as the sum of the absolute values of the discrepancy at each correlation distance ( $S$  to  $7S$ , in this example) to rank the subsurface interpretations in terms of geological realism. The interpretation panels by Bridge & Tye (2000) and Miall (2006) show comparable results: they both appear to be overly optimistic with well correlations, especially over a single well spacing (i.e. between adjacent wells), and have similar values of discrepancy; the interpretation panel by Miall (2006) has the lowest total discrepancy value and ranks highest when compared with both correlability models.

The same results that have been used here to illustrate the method of quality-checking could be used to inform the deterministic model through iterative adjustment of the interpretation panel until it matches realistic correlation patterns.

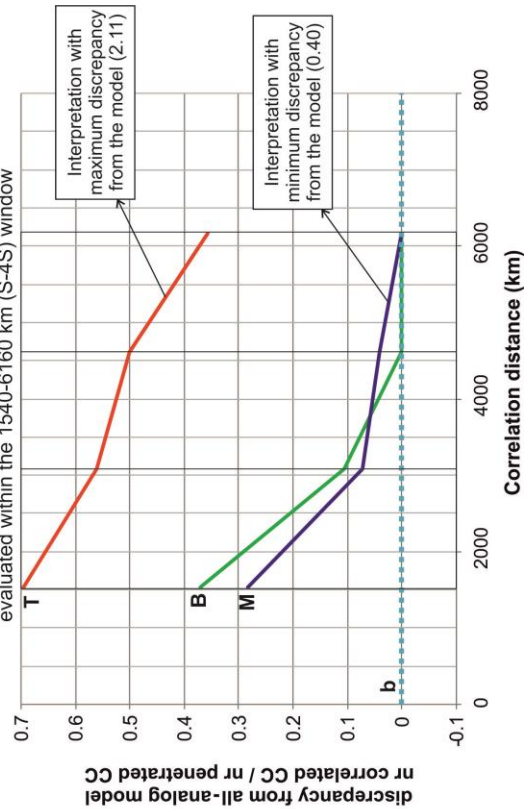
Further insight into the realism of the subsurface reconstructions is offered by channel-complex width-to-thickness scatterplots (figure 5.14), which permit comparison of the dimensions of subsurface channel bodies with the geometry of FAKTS' outcrop analogues. However, because the thickness values associated with well data are obtained from one-dimensional sampling the significance of the comparison is limited, chiefly because channel-complex thicknesses recorded in the FAKTS database refer to maximum thickness, and the thickness of these bodies can be highly variable laterally. Nevertheless, these plots can be useful for qualitatively adjusting the likely position of pinch-out of channel bodies between two wells.



(a) RANKING INTERPRETATIONS ON DISCREPANCY FROM SYNTHETIC ANALOGUE MODEL INCLUDING ALL SUITABLE FAKTS CASE STUDIES evaluated within the 1540-6160 km (S-4S) window



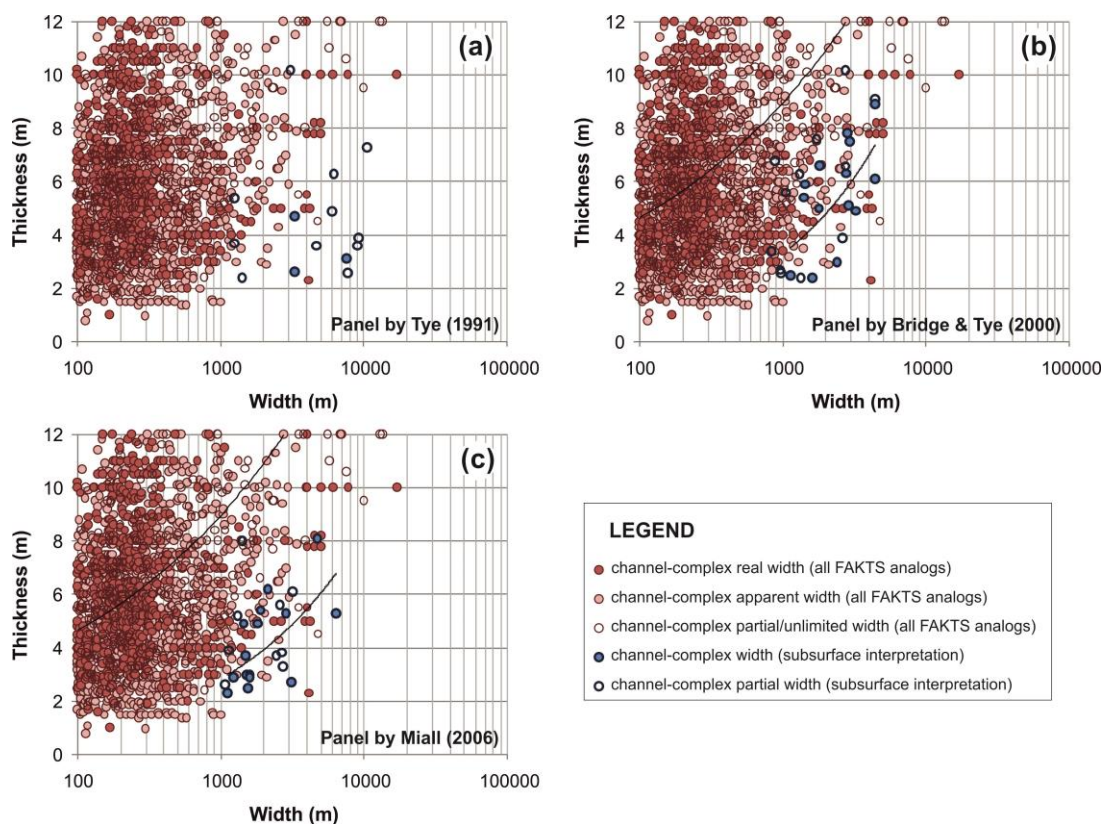
(b) RANKING INTERPRETATIONS ON DISCREPANCY FROM SYNTHETIC ANALOGUE MODEL INCLUDING ALL SUITABLE FAKTS CASE STUDIES evaluated within the 1540-6160 km (S-4S) window



(c) RANKING INTERPRETATIONS ON DISCREPANCY FROM SYNTHETIC ANALOGUE MODEL INCLUDING FAKTS BRAIDED FLUVIAL SYSTEMS evaluated within the 1540-6160 km (S-4S) window



**Figure 5.13 (previous page):** comparison between the three subsurface interpretations of the Travis Peak Formation and the correlability models based on all FAKTS outcrop analogues and on interpreted braided river systems only. The ratios between the number of correlated channel complexes and the number of penetrated channel complexes are plotted (a) together with the ratio between total probabilities of correlation and penetration for multiple of well spacing (1540 m); this demonstrates that the interpretation by Tye (1991) is the least realistic. The difference between ratios obtained from the interpretations and the models are plotted separately for the two models, in (b) and (c), for well spacing between S and 4S (as no channel-complex is correlated for a distance larger than 3S); summing the absolute values of all discrepancies observed between subsurface interpretations and correlability models for all correlation distances, the interpretation by Miall (2006) returns the lowest total discrepancy for both models.



**Figure 5.14:** comparison between the geometry of channel complexes represented in the three panels depicting proposed channel-complex architectures for the Travis Peak Formation for (a) Tye (1991), (b) Bridge & Tye (2000), and (c) Miall (2006), and the geometry of channel complexes included in the FAKTS database, in the form of width-to-thickness scatterplots. The widths in the graphs consider the positions of lateral channel-body pinch-out as represented in the panels. See figure 5.3 for width nomenclature in legend.

If the approach is followed to guide interpretations, additional attributes that can be inferred in subsurface correlation-based reconstructions are:

- the percentage (as fractional number) of channel-complexes that are not yet penetrated by the array of wells, which coincides with '1 - total probability of penetration';
- the expected width distribution of those channel complexes, given by the difference between the analogue channel-complex width probability density function and the curve obtained as the product between the same probability density function and the conditional probability of penetration.

From this information volumetric proportions of non-penetrated channel complexes can then be estimated by relating widths to likely thickness, for example by following previously documented empirical relationships (e.g. Collinson 1978; Fielding & Crane 1987).

Well configurations characterized by constant inter-well distance are common (e.g. He et al. 2013), making this approach of direct use for such situations. Whenever the condition of constant well spacing is not applicable, if there exist adjacent stratigraphic portions within which inter-well distance is roughly constant, the quality-check method presented here could be applied separately for different segments. Instead, if the well spacing is randomly distributed, correlability models could be obtained for the maximum and minimum values of well spacing, in order to identify a confidence interval – rather than a single correlability curve – with which subsurface interpretations could be compared, for example in terms of discrepancy between the underlying area and the curve given by the ratio between correlated and penetrated units plotted for the average spacing, or even just graphically.

### **5.5.5 A general probabilistic model based on channel-deposit proportions**

Total-probability-based models of channel-complex correlability such as the ones presented for braided systems (figure 5.13a, c) can be customized on any fluvial environmental type (e.g. fluvial coastal plain meandering system developed under the influence of a sub-humid climatic regime; cf. Colombera et al. in press, Chapter 3), provided that a channel-complex width distribution is available. Furthermore, these models can be constructed on architectural properties that are distinctively associated with a given distribution of channel-complex width; it is thus useful to be able to generate models categorized on properties that can directly be derived from interpreted well data, such as the relative proportion of channel and floodplain deposits.

In the FAKTS database, stratigraphic volumes within a succession are distinguished whenever different classifications of system descriptive parameters or



boundary conditions can be assigned (Colombera et al. 2012a, Chapter 2). These volumes do not refer to a standard spatial or temporal scale, but they are typically tens of metres thick for case studies that are considered suitable for investigation at the channel-complex scale. So, for each volume for which at least two-dimensional information is available, both descriptive statistics (figure 5.15) of channel-complex width and the proportion of channel complexes, as based on the product of their thickness and lateral extent have been computed. Such information is useful *per se* as a general constraint to inform well-to-well correlations for adjacent stratigraphic zones with variable channel proportions, but has greater predictive potential if it is incorporated into a correlability model.

By considering only the highest-quality datasets (well exposed outcrop analogues for which comprehensive datasets captured as a product of direct observation are available), empirical relationships linking the mean and standard deviation of channel-complex width with the proportion of channel deposits within each volume can be obtained (figure 5.15b, c). As would be expected, the average lateral extent of the channel complexes shows a positive relationship with channel-complex proportion, since FAKTS channel complexes are geometrically defined channel clusters, and clustering increases with channel-deposit proportion. It is important to note that some high-quality datasets derived from studies of outcrop analogues with great lateral extent and continuity of exposure (of which channel-complex mean widths are included in figure 5.15a) are not accounted for by the equations in figure 5.15b-c, and that the inclusion of all suitable analogues would return a relationship that would predict higher mean widths, especially for low channel-deposit proportions, ultimately suggesting overly optimistic well-penetration and correlation total probabilities.

The empirical relationships derived from exponential regression of the highest-quality datasets are given by:

$$meanW = 42.4e^{3.9P}$$

$$stdevW = 40.7e^{3.8P}$$

where P refers to the proportion of channel deposits and W to the channel-complex width.

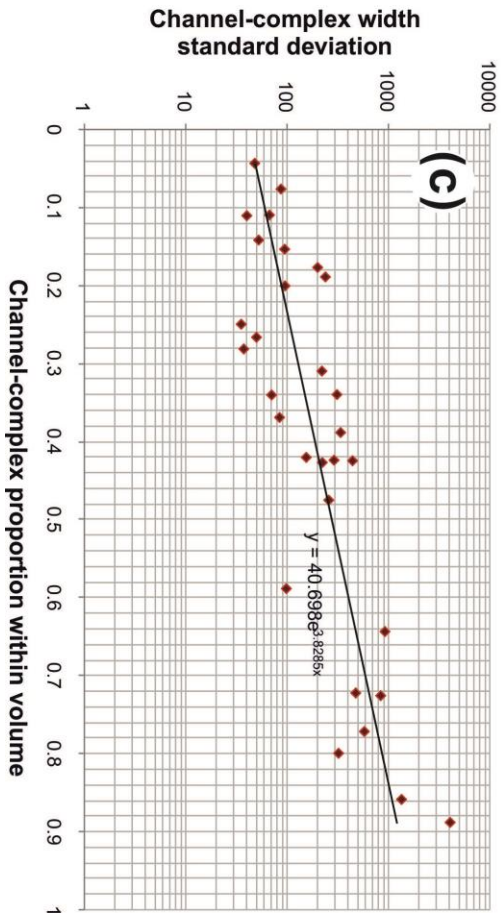
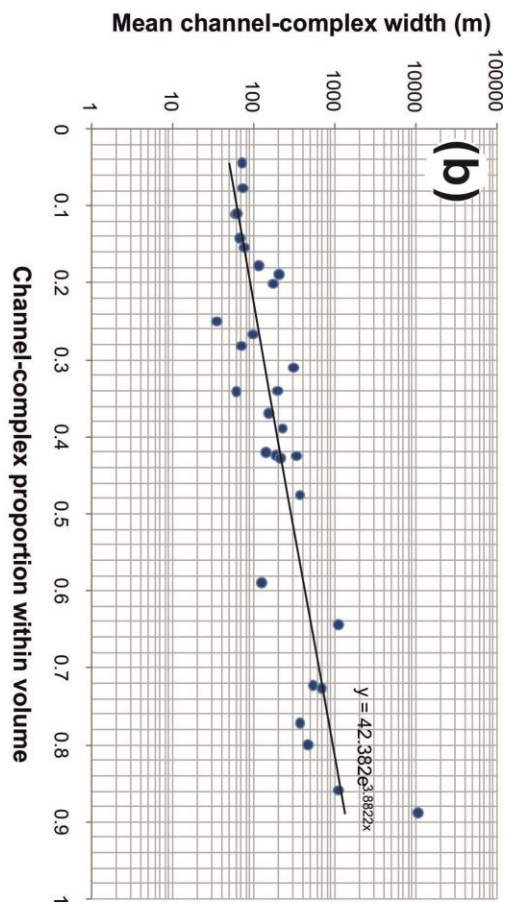
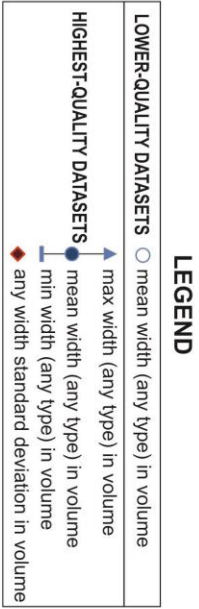
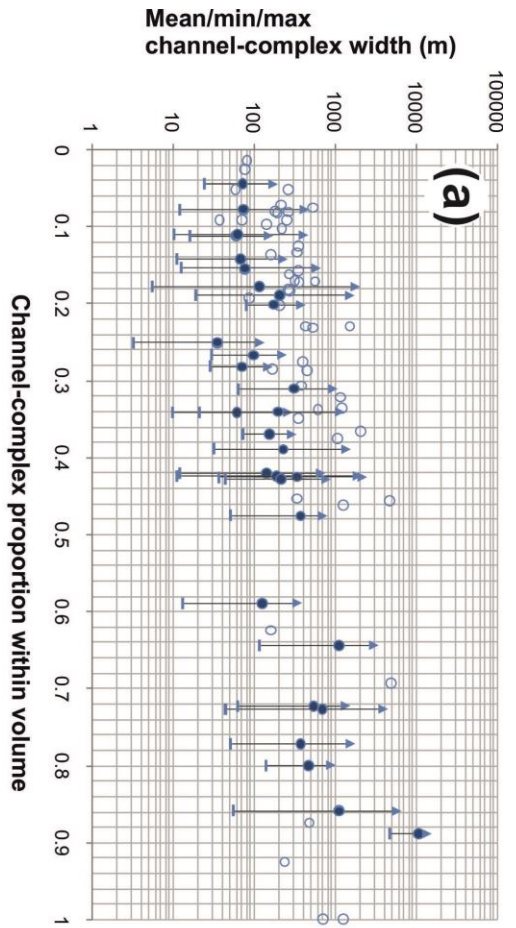
Assuming that a log-normal distribution adequately describes channel-complex width distribution for any proportion in the range 10/90%, it is possible to express location and scale parameters as a function of proportions, since these parameters are related to width mean and standard deviation:

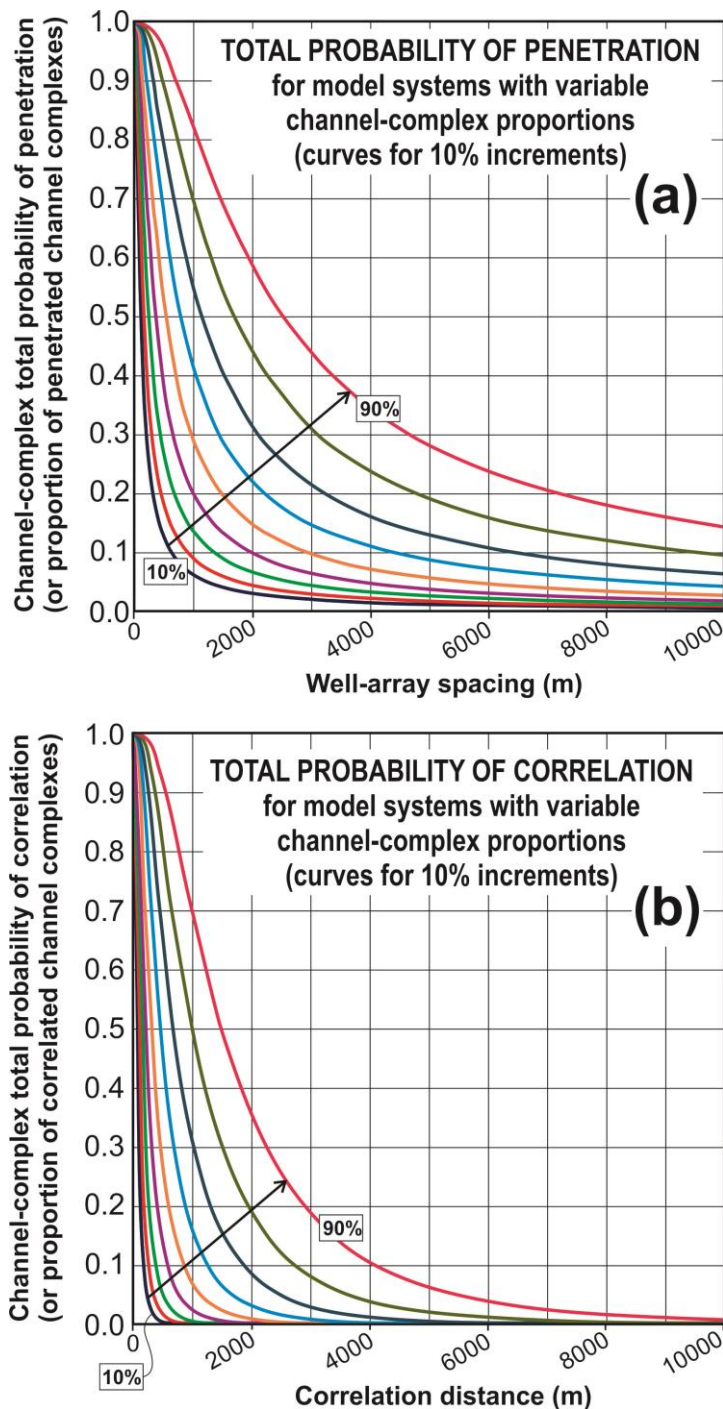
$$\mu = 2 \ln(42.4e^{3.9P}) - \left( \frac{\ln((42.4e^{3.9P})^2 + (40.7e^{3.8P})^2)}{2} \right)$$

$$\sigma = \sqrt{\ln((42.4e^{3.9P})^2 + (40.7e^{3.8P})^2) - 2 \ln(42.4e^{3.9P})}$$

These values have been used to obtain probability density functions that are employed for calculating total probabilities of channel-complex penetration (figure 5.16a) and correlation (figure 5.16b) by a well array in stratigraphic volumes with channel-deposit proportions variable between 10% and 90%. The resulting models are limited by the assumption of width distributions being log-normal for any value of proportions; however, groups of stratigraphic volumes with variable channel-deposit proportions can be separately analysed to gain insight into the type of distributions that best describe channel-complex widths in any range of proportions, thereby allowing for a refinement of the total probability curves. Nonetheless, a FAKTS stratigraphic volume containing 32 channel complexes composing 86% of its volume returned a channel-complex width distribution satisfactorily described by a log-normal curve, suggesting that the assumption is reasonable even for high net-to-gross successions. These curves can then be used to generate, for a given well-spacing, a correlability model similar to the ones presented above (i.e. by operating ratios of proportions of correlated and penetrated channel-complexes, as drawn from the curves). The resultant correlability model can then be used as a target correlation pattern for cases in which only channel-deposit proportion and well-array spacing are known.

**Figure 5.15 (following page):** (a) descriptive statistics including mean, minimum and maximum channel-complex width, in ordinate values, from stratigraphic volumes with variable proportions of channel deposits, in abscissa values; (b) mean channel-complex width from highest-quality datasets, plotted against the proportion of channel deposits in the relative stratigraphic volumes; an exponential regression curve is fitted to the data; (c) standard deviation in channel-complex width from highest-quality datasets, plotted against the proportion of channel deposits in the relative stratigraphic volumes; an exponential regression curve is fitted to the data.





**Figure 5.16:** curves that quantify the total probability of channel-complex penetration by a well array (a) and of correlation between two wells (b) as a function of well spacing/correlation distance, for different channel-complex width probability density functions (all log-normal) associated with variable proportions of channel deposits (10% to 90%, in 10% increments).

It is important to reiterate, once again, that the values in figure 5.16b refer to channel-complexes defined on a set of geometrical rules and can be variably stacked; for example vertically-juxtaposed channel complexes may be solely

distinguished on the recognition of discontinuously-interfingered floodplain deposits: the curve of total probability of correlation as a function of distance cannot therefore be simply considered in terms of lateral connectivity. In practice, it may be deemed useful to consider dimensional attributes that describe the geometry of interconnected reservoir-quality rocks; using the same database this could be done by quantifying the effect of the juxtaposition of units of the same type on the dimension of the composite bodies (cf. material units of Colombera et al. 2012b, Chapter 6). Also, in this specific example, a more easily applicable – and arguably more useful – quality check for subsurface interpretations of systems characterized by a very high proportion of channel deposits would be given by correlability models for fine-grained floodplain units.

## 5.6 Conclusions

The difficulty in developing readily applicable methods to realistically capture the lateral extent of sedimentary bodies when applying deterministic well correlations is still perceived as a major limiting factor for better constraining models of reservoir characterization (cf. Borgomano et al. 2008). The method presented here makes use of total probabilities of well penetration and correlation for guiding and quality-checking subsurface interpretations based on well-to-well correlations of fluvial channel lithosomes, given *a priori* knowledge of a realistic distribution of their lateral extent and a well array with constant spacing. The likelihood of the subsurface interpretation is assessed by comparison with dimensional parameters obtained by outcrop analogues not just by considering the most likely width of individual geological units, but by ensuring geological realism for the whole succession. Thus, the approach is not necessarily alternative to, but rather integrative with previous methods based on the use of empirical relationships for deriving channel sandstone body widths from palaeo-hydrological interpretations or measured thicknesses.

The approach illustrated here for channel complexes has general value: it can be applied to the correlation of any geological units (e.g. deep-water channels, sand sheets, carbonate shoals), provided that a realistic description of their lateral extent can be obtained in the form of a probability density function. This consideration has implications concerning the need for extensive and good-quality outcrop-analogue data that are essential for the practical application of this sort of correlability model to subsurface reservoir prediction.

Ranking interpretations by comparing geological-body correlations with reference patterns expressed as ‘correlability’ models can be especially useful if different

correlation frameworks equally reproduce geologically-sensible scenarios in terms of depositional features (e.g. distribution of interpreted sub-environments, palaeo-surface gradients); in addition, the method can be used to independently rank stochastic well correlations that involve the lateral tracing of geological bodies (cf. Lallier et al. 2012), and computer-assisted correlations in general.

The usefulness of the method can be enhanced by generalizing it through reformulation of the expressions of total probabilities of penetration and correlation to account for different angles of well penetration, and by implementing the method as a software-based predictive tool.

## **6 A database approach for constraining stochastic simulations of the sedimentary heterogeneity of fluvial reservoirs**

### **6.1 Summary**

Quantitative databases storing analogue data describing the geometry of sedimentological features are often used to derive input for geostatistical simulations of reservoir sedimentary architecture; however, geometrical information alone is inadequate for the detailed characterization of sedimentary heterogeneity.

A relational database storing fluvial architecture data has been developed and populated with literature- and field-derived data from modern rivers and ancient successions. The database scheme characterizes fluvial architecture at three different scales of observation, recording style of internal organization, geometries and spatial relationships of genetic units, classifying datasets according to controlling factors (e.g. climate type) and context-descriptive characteristics (e.g. river pattern). The database can therefore be filtered on both architectural features and boundary conditions to yield outputs tailored on the system being modelled, in order to generate input to object- and pixel-based stochastic simulations of reservoir architecture.

When modelling heterogeneity with stochastic simulations, the choice of input parameters quantifying spatial variation is problematic because of the paucity of primary data and the partial characterization of supposed analogues. This database-driven approach permits the definition of various constraints referring to either genetic units (e.g. architectural elements) or material units (i.e. contiguous volumes of sediment characterized by the same value of a given categorical or discretized variable; e.g. same lithofacies type, clay + silt content, etc.), which permit realistic description of fluvial architecture heterogeneity. Applications of this database approach include the computation of relative dimensional parameters and the generation of auto- and cross-variograms and transition probability matrices, which are necessary to effectively model spatial complexity.

## 6.2 Introduction

Fluvial architecture refers to the geometries, internal organization, spatial distribution and reciprocal relationships of genetic bodies within fluvial sedimentary successions (Allen 1978; Miall 1996). Different types of fluvial genetic bodies are commonly recognizable over a wide range of scales, often in a hierarchically-nested fashion (Miall 1988b; 1996; Robinson & McCabe 1997; Bridge 2003; 2006), and the arrangement of these genetic bodies gives rise to a broad range of scales of sedimentary heterogeneity from basin-fill scale, to channel-belt scale, to channel scale, to bed-set scale, and to pore framework scale. As fluvial genetic bodies typically have distinctive petrophysical properties, sedimentary heterogeneity is closely correlated with petrophysical heterogeneity at all the above-mentioned scales (cf. Weber 1982; 1986; Koltermann & Gorelick 1996; Heinz & Aigner 2003; Ringrose et al. 2008). Knowledge of the spatial distribution of fluvial genetic bodies enables constraints to be placed on the spatial distribution of ranges of variability in porosity and permeability. Thus, it is imperative to properly characterize and predict those heterogeneities that are inherent in the subsurface architecture of fluvial hydrocarbon reservoirs, in order to determine the interconnectedness of reservoir-quality rocks, which itself serves as a major control on hydrocarbon production.

In industry scenarios, the typical paucity of data relating to sedimentary heterogeneity at a resolution finer than the seismic and interwell-spacing scales, together with the need to undertake uncertainty analysis for the assessment of risk, has resulted in the need for the development and implementation of stochastic methods for modelling reservoir sedimentary architecture by simulating a number of different equiprobable architectural realizations. Structure-imitating stochastic reservoir modelling aims at simulating sedimentary architecture without considering depositional/erosional processes; two types of fundamentally different approaches are commonly adopted: object-based and pixel-based techniques (for reviews of these approaches see: Haldorsen & Damsleth 1990; Bryant & Flint 1993; Srivastava 1994; North 1996; Koltermann & Gorelick 1996; Galli & Beucher 1997; Dubrule 1998; Deutsch 2002).

Object-based techniques, otherwise known as Boolean models, simulate the distribution in the reservoir space of geological features that are discrete in nature (i.e. form geo-bodies with pre-defined geometrical properties). Simulations generated by object-based algorithms are conditioned to parameters that describe the geometry of the building blocks (dimensions, shapes, orientations – typically in form of probability distributions) and their density in the space (proportions). In fluvial depositional contexts, admissible discrete objects could be channel, point bar or crevasse splay elements. Several examples of the application of object-based



techniques to the modelling of fluvial reservoirs are cited in Haldorsen & Damsleth (1990) and Keogh et al. (2007).

By contrast, pixel-based techniques employ a 3D discretization of the reservoir volume, with each node of the resulting grid being assigned a single value of the categorical variable that describes the sedimentary architecture (e.g. a facies class). The variable value at any grid point depends on the values at the neighbouring sites and on input descriptors of spatial correlation. These techniques are well suited to modelling either continuous (e.g. porosity) or categorical (e.g. lithofacies type) variables; categorical variables are generally represented by indicators:

$$I_a(x) = 1$$

if the categorical variable takes value  $a$  at position  $x$ , otherwise the indicator takes value

$$I_a(x) = 0$$

(Goovaerts 1994; after concepts from: Journel 1983). There exist a variety of pixel-based algorithms applicable to stochastic reservoir modelling; their typical input includes the marginal probability of each category to be modelled and descriptors of their spatial (cross-)correlation such as indicator (cross-)variograms (e.g. used in Sequential Indicator Simulation – Journel & Alabert 1990, in Truncated Gaussian simulation – Matheron et al. 1987 – and in Truncated Plurigaussian Simulation – Le Loc'h & Galli 1997) and transition probabilities (e.g. used in different forms in algorithms by Carle & Fogg 1997, and Elfeki & Dekking 2001). Instead of working with two-point statistic variograms, other pixel-based methods work with multiple-point statistics borrowed from 3D training images that describe the typical geometrical characteristics and the spatial relationships of the geological building blocks (Guardiano & Srivastava 1993; Caers 2001; Strebelle & Journel 2001; Strebelle 2002; Liu 2006); these methods generally permit the reproduction of geological features with well-defined shapes, as captured from the training image. However, training images for Multiple-Point Statistics simulation (MPS) are usually obtained from simulation realizations generated by object- or process-based methods and conditioned on analogue data (e.g. Pyrcz et al. 2008; Strebelle & Levy 2008; Maharaja 2008) or directly from 2D or pseudo-3D representations of supposed analogues (Caers & Zhang 2004).

Although object-based techniques may be deemed as better suited to model fluvial contexts because of their ability to easily model channel-belts, individual channels or other genetic units as discrete objects with sharp boundaries and well-defined shapes (Deutsch 2002; Keogh et al. 2007), pixel-based techniques may be more

flexible, allowing a better representation of irregular and variable features (cf. Seifert & Jensen 1999), and still being able to reproduce curvilinear shapes when capturing multiple-point statistics from a training image (cf. Liu et al. 2004). Each of these methods has its own relative merits and pitfalls when applied to the simulation of the architecture of fluvial reservoirs (cf. comparative studies in: Journel et al. 1998; Seifert & Jensen 2000), and in some circumstances the integration of both object- and pixel-based techniques (e.g. Seifert & Jensen 2000) may be advisable.

Crucially, a valid and appropriate application of these modelling methods depends on input data that describe sedimentological features in a quantitative way: it is common to derive such data from other better-documented depositional systems with comparable boundary conditions, i.e. from *analogues* (cf. Alexander 1993). The derived quantitative parameters and geological information is often compiled into databases, including data derived either from outcrop successions or modern depositional systems (e.g. Bryant & Flint 1993; Cuevas Gozalo & Martinius 1993; Dreyer et al. 1993; Robinson & McCabe 1997; Dalrymple 2001; Eschard et al. 2002; Tye 2004), and many oil and gas companies now have their own quantitative databases of geometrical data (Dubrule & Damsleth 2001). The possibility to selectively use quantitative data (i.e. better focusing on the type of genetic units and the type of depositional context being modelled) is an important requirement for generating improved reservoir modelling results (Bryant & Flint 1993). For this reason, a large amount of geometry data relating to the sedimentological features present in fluvial systems that have become available through publications in the past decades have been incorporated into compilations that classify depositional systems on some of their boundary conditions (e.g. Gibling 2006; Kelly 2006). However, these approaches do not typically provide a full characterization of fluvial architecture, as only geometrical features and relationships are characterized. Other features of fluvial architecture (e.g. styles of internal organization, spatial distribution and reciprocal relationships of genetic units) are typically summarized as facies models but the usefulness of such models for reservoir modelling is restricted by their qualitative nature (North 1996). Thus, there exists a clear need for the generation of versatile quantitative facies models, the development of which should be based on a new method for constructing a catalog that encapsulates worldwide examples of facies geometry and properties, classified according to the boundary conditions of the sedimentary systems, and based on the assumption that similar sets of controls will generate similar deposits (de Marsily et al. 2005). A significant advance in this direction was given by the method proposed by Baas et al. (2005) for deepwater clastic systems, which involved the development of a relational database for the quantitative description of sedimentary architecture

(architectural element dimensions and transition statistics, and lithofacies proportions) from several published case histories classified according to their controls and environmental parameters. However, despite utilizing an architectural database of considerable size, not even this method has been capable of fully capturing *all* significant architectural features and it has not been possible to obtain certain types of quantitative information required to appropriately constrain stochastic simulations of sedimentary architecture. For example, a major problem that is commonly encountered when working with pixel-based methods is how to define the indicator variogram parameters and the transition probability matrices for lateral directions (Bridge 2006). Dubrule & Damsleth (2001) argue that a common mistake is to identify the indicator variogram range with the size of the heterogeneity (cf. Journel et al. 1998), although the range of the indicator variogram model should additionally take into account dimension variance and category proportions (Ritzi 2000). When working with object-based methods, users routinely need to choose dimensional parameters expressed as relative dimensions (e.g. channel-fill thickness/levee thickness), but data are ordinarily drawn from databases from which relative dimensional parameters cannot be derived, as they simply store dimension distributions of individual objects.

The aim of this study is to demonstrate how a new and novel database approach has the potential to provide sufficient quantitative data, derived from several classified case studies of fluvial sedimentary architecture, to fully constrain stochastic fluvial reservoir models, thereby overcoming the main problems encountered when relying on traditional databases. Specific objectives of this study are: (i) to illustrate an ideal outcrop-to-database-to-simulation workflow; (ii) to demonstrate database versatility in terms of system filtering and choice of appropriate modelling-category; (iii) to demonstrate how to derive input parameters to both object- and pixel-based simulations, including relative dimensional parameters, indicator auto- and cross-variograms, and transition probability/rate matrices. This last point is particularly important in a practical perspective, as the inference of parameters quantifying lateral variation is always very difficult (Dubrule & Damsleth 2001). This database approach attempts to bridge the gap between sedimentology and geostatistics.

### **6.3 Database architecture and use**

The Fluvial Architecture Knowledge Transfer System (FAKTS) is a relational database that has been designed as a tool for translating numeric and descriptive data relating to fluvial architecture derived from both modern rivers and their ancient

counterparts in the stratigraphic record and is populated with field- and literature-derived examples (Colombera et al. 2012a, Chapter 2). The FAKTS database currently includes 64 case studies from 38 lithostratigraphic units and 14 rivers, and currently stores more than 20,000 classified genetic units (as of March 2012). Population of the database with additional data is ongoing. The stratigraphy of preserved ancient fluvial successions and the geomorphology of modern rivers are translated into the database schema by subdividing them into genetic units that are in common between the stratigraphic and geomorphic realms and which belong to different scales of observation, nested in a hierarchical fashion (figure 6.1). Each order of genetic unit is assigned a different table and each unit within a table is given a unique numeric identifier that is used to track relationships between the different objects, both at the same scale (transitions between units) and across different scales (containment of units within larger-scale units). To allow for the classification not only of each depositional system but also of parts thereof, each single dataset is split into a series of stratigraphic windows or geomorphic segments called *subsets*: each subset is characterized by homogeneous attributes, such as system controls (e.g. subsidence rate) and system-descriptive parameters (e.g. river pattern). The subsets are broken down at the largest scale into *depositional elements* defined as channel-complexes and floodplain segments on the basis of flexible but unambiguous geometrical criteria (see appendix A), so that they are not related to any particular genetic significance or spatial or temporal scale (cf. Dalrymple 2001; Gibling 2006). Each depositional element can be subdivided into a suite of *architectural elements*, defined, following Miall's (1985; 1996) concepts, as components of a fluvial depositional system with characteristic facies associations that are interpretable in terms of sub-environments; architectural elements are classified according to a scheme derived from the modification of some of Miall's (1985; 1996) classes (table 6.1). Architectural elements can be in turn further subdivided into the *facies units* from which they are constructed; facies units are here defined as genetic bodies characterized by homogeneous lithofacies type and bounded by second- or higher-order bounding surfaces (*sensu* Miall 1985; 1996); such facies units are classified on textural and structural characters according to a classification that is largely based on Miall's (1977; 1996) scheme (table 6.2).

**Table 6.1:** Architectural element type classification adopted in FAKTS; modified after Miall (1996).

<b>Code</b>	<b>Architectural element type – geomorphic significance</b>
CH	Vertically accreting (aggradational) channel (fill)
DA	Downstream accreting macroform
LA	Laterally accreting macroform
DLA	Downstream + laterally accreting macroform and 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

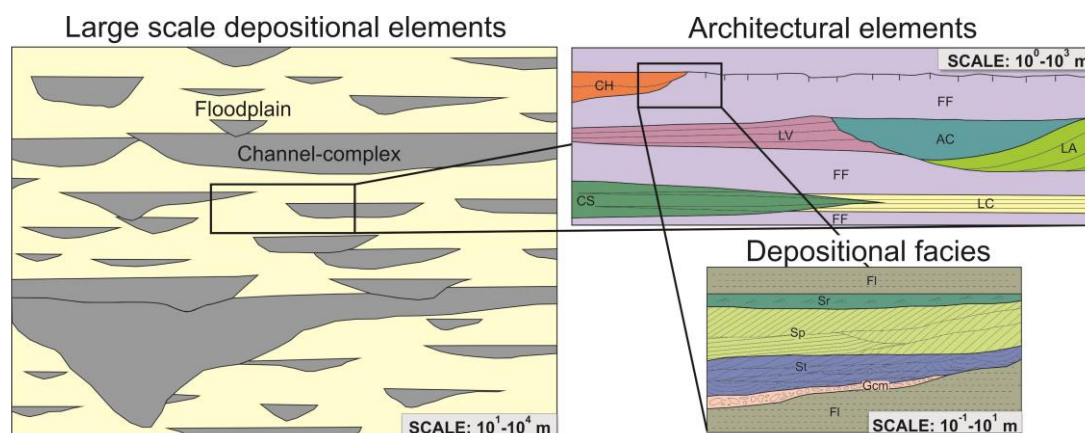
A description of the implementation of the database conceptual model and a full account of the numeric and categorical attributes of genetic units and subsets are provided in Colombera et al. (2012a; Chapter 2).

The database is intended for use as an instrument for the quantitative description of the geometry and internal organization of geological objects and of their reciprocal relationships. Each genetic unit, at any given scale, can be geometrically characterized in terms of dimensional parameters describing their extent in the vertical, strike-lateral, and downstream directions, relative to overall flow direction of the system recorded at the channel-belt-scale. Unit widths and lengths are classified according to the completeness of observations into *complete*, *partial* or *unlimited* categories, as proposed by Geehan & Underwood (1993), whereas *apparent* widths are stored in cases where observations were made only from sections oriented oblique to palaeoflow. The internal organization of genetic units can be characterized in terms of the proportions and spatial distribution of objects belonging to lower-order scales. The spatial relationships between the units are

described by the transition statistics relating juxtapositional trends along the vertical, cross-stream and along-stream directions.

**Table 6.2:** Lithofacies classification adopted in FAKTS; modified after Miall (1996).

Code	Characteristics
G-	Gravel deposits with undefined structure and undefined additional textural characteristics. Gravel-grade sediment (granule to boulder) usually constitutes the majority of the unit by volume, as the graded or massive structure of bi- or pluri-modal matrix-supported conglomerates/gravels is very likely to be recognized.
Gmm	Matrix-supported, massive or crudely-bedded gravel.
Gmg	Matrix-supported, graded gravel.
Gcm	Clast-supported, massive gravel.
Gci	Clast-supported, inversely-graded gravel.
Gh	Clast-supported, horizontally- or crudely-bedded gravel; possibly imbricated.
Gt	Trough cross-stratified gravel.
Gp	Planar cross-stratified gravel.
S-	Sand deposits with undefined structure. Sand-grade sediment must constitute the majority of the package by volume.
St	Trough cross-stratified sand.
Sp	Planar cross-stratified sand.
Sr	Current ripple cross-laminated sand.
Sh	Horizontally-bedded sand.
Sl	Low-angle (<15°) cross-bedded sand.
Ss	Faintly laminated/cross-bedded, massive or graded sandy fill of a shallow scour.
Sm	Massive sand; possibly locally graded or faintly laminated.
Sd	Soft-sediment deformed sand.
Sw	Symmetrical ripple cross-laminated sand.
F-	Fine-grained (silt/clay) deposits with undefined structure. Fine-grained sediment must constitute the majority of the package by volume.
Fl	Interlaminated very-fine sand, silt and clay; thin cross-laminated sandy lenses may be included into these heterolithic packages.
Fsm	Laminated to massive silt and clay.
Fm	Massive clay.
Fr	Fine-grained root bed.
P	Pedogenic carbonate.



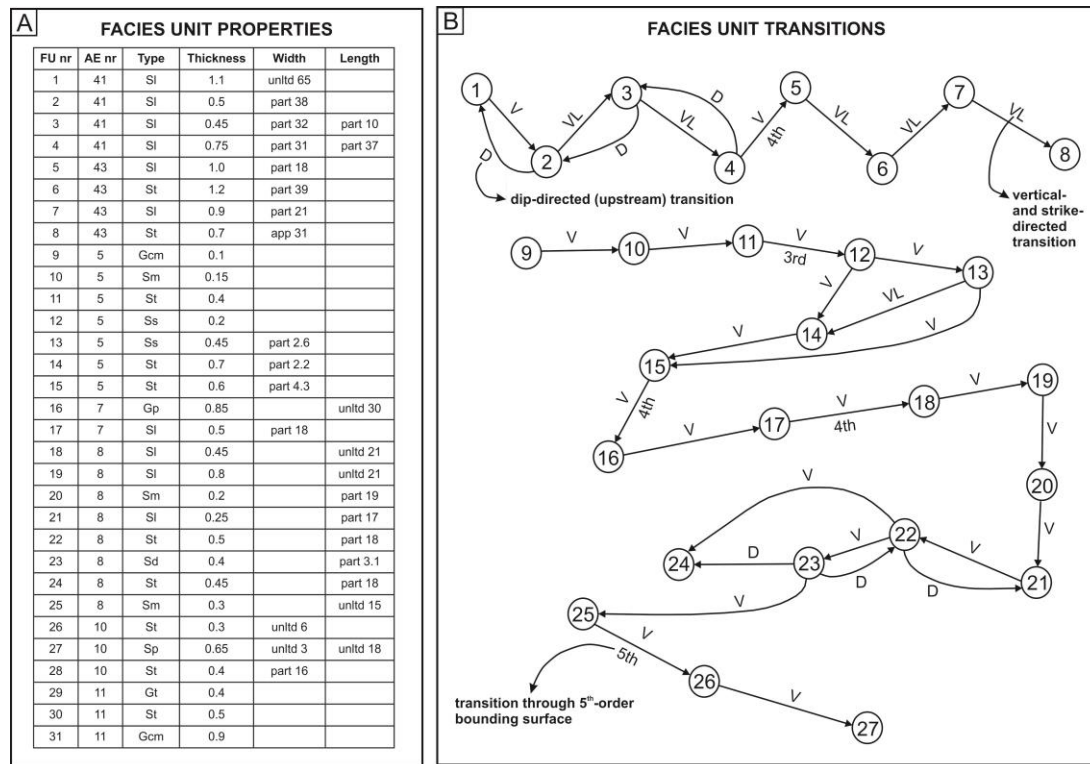
**Figure 6.1:** representation of the main scales of observation and types of geological genetic units translated into the database in the form of tables (genetic unit types) and entries (genetic units). Refer to table 6.1 for architectural-element codes and to table 6.2 for facies-unit codes.

## 6.4 Field to database

Although a large part of the database content is derived from published literature studies, it is important to present a best-practice field technique to be employed in an ideal ‘field-to-database-to-simulation’ workflow, to establish an efficient method by which to derive data from a supposed ancient analogue in a format that best suits the database design.

This database-oriented field technique was developed and tested during field data collection in SE Utah (USA – Sevenmile Canyon, Dewey Bridge, Newspaper Rock and Potash Road areas), mapping the sedimentary architecture of the Lower Jurassic Kayenta Formation, a continental succession dominantly consisting of coarse- to fine-grained fluvial sandstone elements, with minor occurrences of associated argillaceous fluvial and aeolian elements, developed in the overall arid/semiarid climatic context of the Glen Canyon Group (Miall 1988a; Bromley 1991; Luttrell 1993). Interpreted architectural elements were indexed by numeric identifiers, some of their properties (element type and dimensional parameters) were tabulated, and their spatial arrangement was sketched – in form of cross-sectional and planform sketches – including bounding surface order (scheme by Miall 1996) and palaeocurrent information. Facies units were also indexed and their properties (facies type, dimensional parameters and identifier of the parent architectural element within which they occur) tabulated (figure 6.2a). As the number of facies units per outcrop is far larger than the number of architectural elements, the reciprocal relationships between facies units were not drawn as sketches but were instead depicted in transition diagrams, storing strike-, dip-, and

vertical-directed transitions between facies units, including bounding surface order information (figure 6.2b).



**Figure 6.2:** (A) field-work table reporting the properties of facies units, including: facies unit unique numeric identifier (FU nr), unique identifier of the architectural element each facies unit belongs to (AE nr), dimensional parameters (thickness, cross-stream width, downstream length) classified according to a scheme of completeness (app = apparent, part = partial, unltd = unlimited) partly based on Geehan & Underwood (1993); (B) transition diagram representing spatial relationships between facies units (circles coded according to facies unit code) by storing strike- (L), dip- (D), and vertical-directed (V) transitions (arrows), including information about the order of the bounding surface (scheme by Miall 1996) across which the transition occurs: for example, facies unit 25 passes vertically into facies unit 26 across a 5th-order bounding surface. No scale, directionality, temporal or spatial significance is attached to the spatial distribution of the circles on the diagram.

Any additional information associated with each genetic unit (e.g. occurrence of bioturbation) can be stored in a table column for general notes, as done in the database itself. No scale or spatial significance is attached to the spatial distribution of the units – represented by circles coded according to the facies unit numeric identifiers – on the transition diagram in figure 6.2b; the spatial relationships are exclusively expressed by means of arrows representing transitions along the indicated direction. So, similarly to what is done in the database itself, the unique numeric identifiers were used to keep track of the transitions between facies units and of the containment of facies units in architectural elements. The same type of



transition diagram is applicable to the architectural element scale, and the 'table-and-diagram' approach is also applicable at the depositional element scale. In contrast to sedimentary logging or the construction of drawn architectural panels, this field technique does not generate standalone representations, such as those commonly expressed as drawn architectural panels. Rather, all the data required for database use are acquired in a more time-efficient manner in comparison to such traditional methods, with data recorded in a format that is well suited for coding into the database structure.

## **6.5 Database to simulation**

The FAKTS database can be interrogated by means of SQL scripting language queries, in order to generate quantitative output (dimensional parameters, proportions and transition statistics of genetic units) that represents the basic source of information for constraining stochastic simulations of fluvial architecture. The following database-to-simulation workflow demonstrates how an extensive dataset can be filtered to yield a refined dataset that is relevant to the subsurface case study that needs to be simulated, and how to tailor the output on the simulation input requirements.

### **6.5.1 Data filtering**

The analogue approach is still widely used for constraining stochastic models of sedimentary architecture. With FAKTS, it is possible to generate 'synthetic analogues', which are ideally based on all the case studies that can be considered closely comparable, in terms of environmental characteristics and controlling factors, to the subsurface depositional system to be modelled. This is achieved by exclusively selecting genetic units belonging to subsets having appropriate attribute values.

Additionally, subsets are filtered according to their suitability for the scope of the query. This is achieved firstly by selecting only subsets that are characterized at the same scale chosen for the simulation (e.g. through inclusion of only those subsets that are properly characterized at the depositional-element scale if this type of unit is chosen for the simulation). These subsets should be additionally filtered by selecting only the ones that permit computation of genetic unit proportions and/or dimensions and/or transitions depending on the aim of the query (e.g. through exclusion of subsets derived from scatter-plots of depositional-element dimensional

parameters when computing depositional-element proportions, since such subsets would return results suitable for computing dimension statistics only).

### 6.5.2 Conditioning object-based models

To demonstrate the potential value of FAKTS as a tool for constraining object-based techniques, example work has been carried out with FLUVSIM v. 2.900 (Deutsch & Tran 2002), a public-domain object-based algorithm that was purposely developed for simulating the sedimentary architecture of fluvial systems. FLUVSIM generates stochastic channel centerlines and fits stochastic channel, levee and crevasse splay geometries to these centerlines in a floodplain background (Deutsch & Tran 2002; Deutsch & Wang 1996). FLUVSIM simulations are run by a FORTRAN program that is conditioned by parameters stored in GSLIB (Geostatistical Software Library) parameter files (Deutsch & Tran 2002).

Although the Boolean objects that are simulated by the FLUVSIM program are designated as *facies types* (Deutsch & Tran 2002) or *architectural elements* (Pyrzcz et al. 2008), FAKTS' depositional elements and architectural elements would both be suitable genetic-unit types for providing input to FLUVSIM simulations (cf. Deutsch & Tran 2002). At the FAKTS' depositional-element scale, channel-complex and floodplain-segment data can be used to generate FLUVSIM simulations that would simply model the distribution of channel-complexes (possibly filtered in order to correspond with 5<sup>th</sup> and/or 6<sup>th</sup> order channel-belts) in a floodplain matrix. Alternatively, to include in the simulations all the FLUVSIM *facies types* comprising levee and crevasse splay objects, object constraints can be derived by either of the following methods:

- 1) working at the FAKTS' architectural-element scale whereby it would be appropriate to consider FLUVSIM channels as properly described by either FAKTS *CH* elements or by material units (see below) themselves composed of neighbouring FAKTS' in-channel elements (*CH*, *DA*, *LA*, *DLA*, *HO*; see table 6.1 for code explanation) and to identify FLUVSIM levees with FAKTS' *LV* elements and FLUVSIM crevasse splays with either FAKTS' *CS* elements or combinations of stacked *CS* and *CR* elements; FLUVSIM floodplain proportions would be derived by either FAKTS' *FF* element proportions or cumulative *FF+SF* proportions;
- 2) combining depositional-element information, which is used to constrain the dimensional and geometrical properties of the FLUVSIM channel *facies type*, with architectural-element information, which is used to constrain all FLUVSIM *facies type* proportions as well as the dimensional parameters of the levee and crevasse splay FLUVSIM *facies types*.

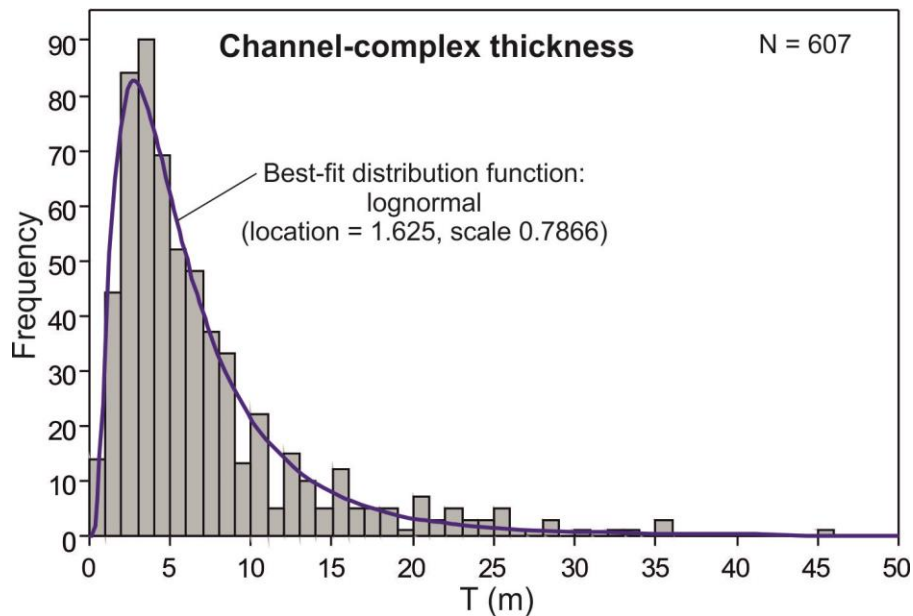
In the first instance, database-derived architectural-element proportions results are useful for determining what type of fluvial depositional contexts can be properly modelled by using all the *facies types* available for the FLUVSIM code (i.e. employing FAKTS' information derived at the architectural-element scale or combined architectural- and depositional-element scale). Secondly, both depositional- and architectural-element proportions can be used to condition FLUVSIM *facies type* proportions, working at the depositional- or architectural-element scale respectively.

Thus, working at the depositional-element scale, modelling the distribution of channel-complexes in a floodplain background, the simulation would be satisfactorily conditioned by specifying proportions of channel and floodplain deposits and channel-complex geometrical parameters, as derived from FAKTS.

Ideally, it would be desirable to obtain volumetric proportions of genetic units, but in practice, only very rarely are data recording 3D geometries available, as most of FAKTS' data originates from 2D architectural panels, 2D/pseudo-3D borehole- or log-correlation diagrams, and 1D logs. Using an architectural panel dataset purposely acquired from a 300-m-wide section of the Kayenta Formation and characterized at the facies-unit scale, it has been possible to test the sensitivity of FAKTS' genetic-unit proportions to the method of estimation, whose choice depends on available data types and dataset completeness. Where there exists high palaeocurrent variability, proportions based on cross-sectional areal extents can be considered as good estimators of volumetric proportions, as the sizes of the genetic bodies intersected by the cross-section (e.g. lateral extent of architectural element cropping out along an architectural panel) are expected to be representative of their anisotropy. By comparison with cross-sectional areal proportions, we have observed that, the sum of unit thicknesses corrected according to average lateral dimensions (product of individual-unit thickness, mean unit-type width and mean unit-type length) also return accurate estimations of volumetric proportions, when working with 2D or pseudo-3D datasets. Proportions computed as summed thicknesses would be used when working with datasets based on 1D logs. The FAKTS-derived proportion of channel deposits would then be entered in the FLUVSIM parameter file at line 22 (Deutsch & Tran 2002).

Dimensional parameters of FLUVSIM channels are specified in the form of triangular distributions – defined by minimum, mode, and maximum values – of channel thickness and width/thickness ratios, with along-channel variability in thickness and width optionally expressed by undulation parameters and by the correlation length of such undulation (Deutsch & Tran 2002). FAKTS provides channel-complex thickness (figure 6.3) and width/thickness ratio (figure 6.4a)

information that can be straightforwardly input in FLUVSIM parameter file (lines 33 and 36). When values are assigned for the undulation-parameter, FAKTS-derived minimum and maximum values for triangular distributions of dimensional parameters should be corrected in order to account for the maximum undulation; in such cases at least maximum thickness input values should always be corrected to account for channel-complex thicknesses being generally entered in the FAKTS database with values representative of their maximum thickness.

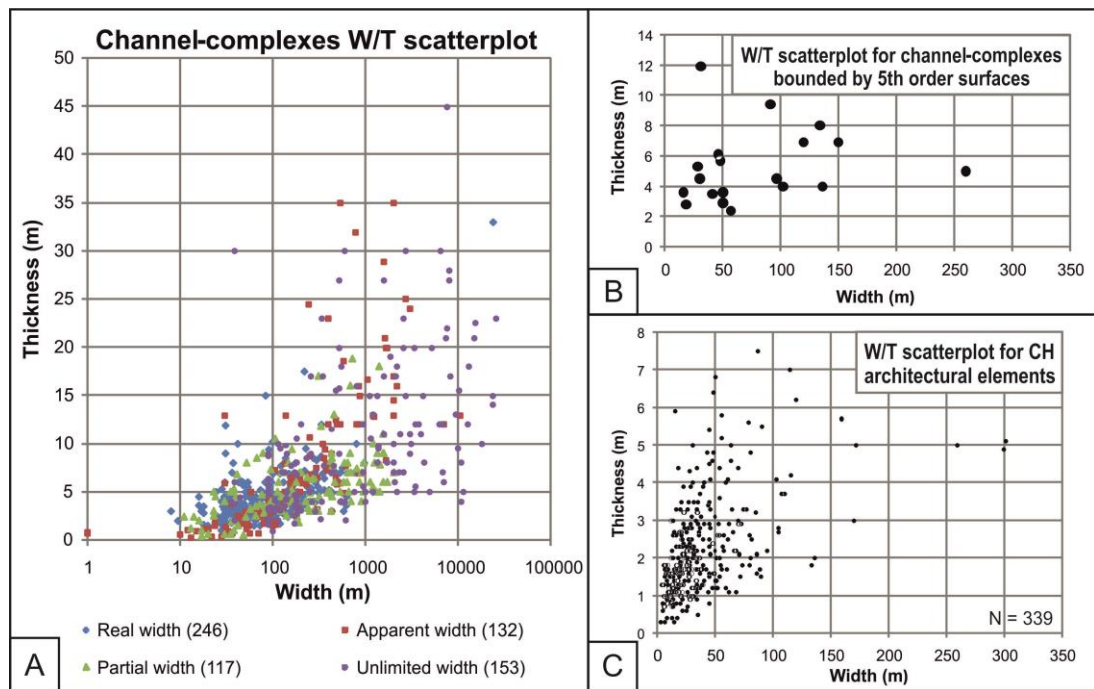


**Figure 6.3:** frequency distribution of all FAKTS channel-complex thicknesses and best-fit probability density function.

Channel sinuosity is not a direct input to FLUVSIM simulations; however geometrical input parameters related to channel sinuosity are the channel deviation from its axis (departure) and the correlation length of the sinusoidal departure. Thus, FAKTS-derived channel-complex sinuosity values can be used to obtain departure and length scale values, for example by referring to the relation depicted in Pycrz et al. (2008, their figure 7). Additionally, the triangular distribution function that describes the orientation of FLUVSIM channels (line 30 of parameter file) can be informed by FAKTS channel-complex palaeocurrent variability within subsets, qualitatively assigned as ‘High’, ‘Intermediate’, or ‘Low’.

As FAKTS channel-complexes represent channel-clusters defined on the basis of clearly defined geometrical rules, FLUVSIM channels – which can stack on each other themselves generating channel-clusters – would more appropriately embody 5<sup>th</sup> and/or 6<sup>th</sup> order (*sensu* Miall 1996) channel-belts. Since FAKTS allows storing information on the order of the lower bounding surface of depositional elements, it

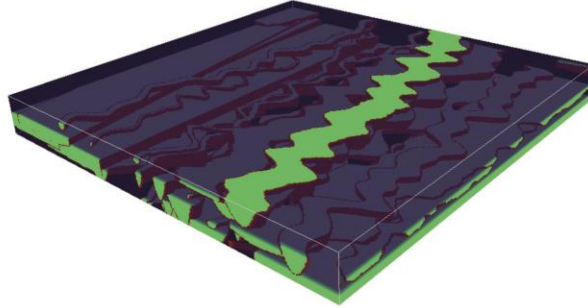
is possible, for example, to filter the database in order to obtain parameters relating to the geometry of 5<sup>th</sup>-order surface bounded channel-clusters (figure 6.4b) with which to constrain the object-based simulation. A visual depiction of the sensitivity of FLUVSIM realizations to the choice of the type of channelized genetic units is offered in figure 6.5.



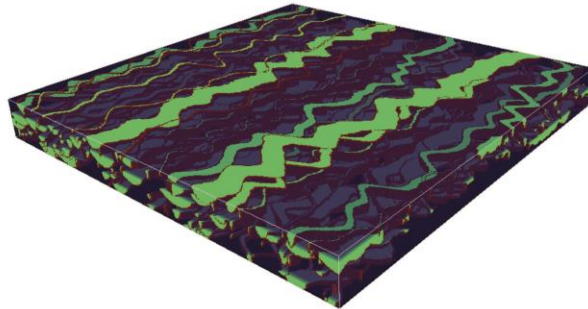
**Figure 6.4:** (A) scatter-plot of all FAKTS channel-complex width vs. thickness (W/T), classified according to observation completeness classes by Geehan & Underwood (1993); (B) scatter-plot of 5<sup>th</sup> order-bounded FAKTS channel-belt width vs. thickness; (C) scatter-plot of 4<sup>th</sup> order FAKTS channel-fill (CH) architectural elements.

Working at the architectural-element scale (i.e. including levee and crevasse splay objects in the FLUVSIM simulations), FLUVSIM channels can be described by FAKTS 5<sup>th</sup>-order channel-complexes, FAKTS 4<sup>th</sup> order *CH* architectural elements (cf. figure 6.4b for width/thickness ratios), or by material units (see below) composed of neighbouring FAKTS in-channel elements (*CH*, *DA*, *LA*, *DLA*, *HO*). Levee and crevasse splay proportions can be constrained by FAKTS-derived proportions as outlined above. The FLUVSIM levee and crevasse splay dimensional parameters are partly specified as triangular distribution functions (levee width and splay planform area), which can be readily derived from FAKTS output, and partly entered as a relative dimension (levee height and depth and splay thickness), expressed as a fraction relative to the thickness of the adjacent channel (Deutsch & Tran 2002).

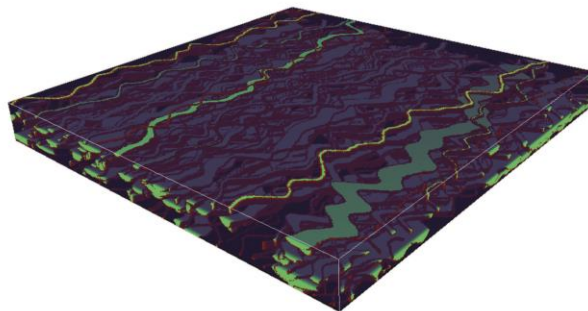
### Channel-complexes



### 5<sup>th</sup>-order channel-clusters



### 4<sup>th</sup>-order channel fills



volume:  $5000 \times 5000 \times 50 \text{ m}^3$   
VERTICAL EXAGGERATION: 10X

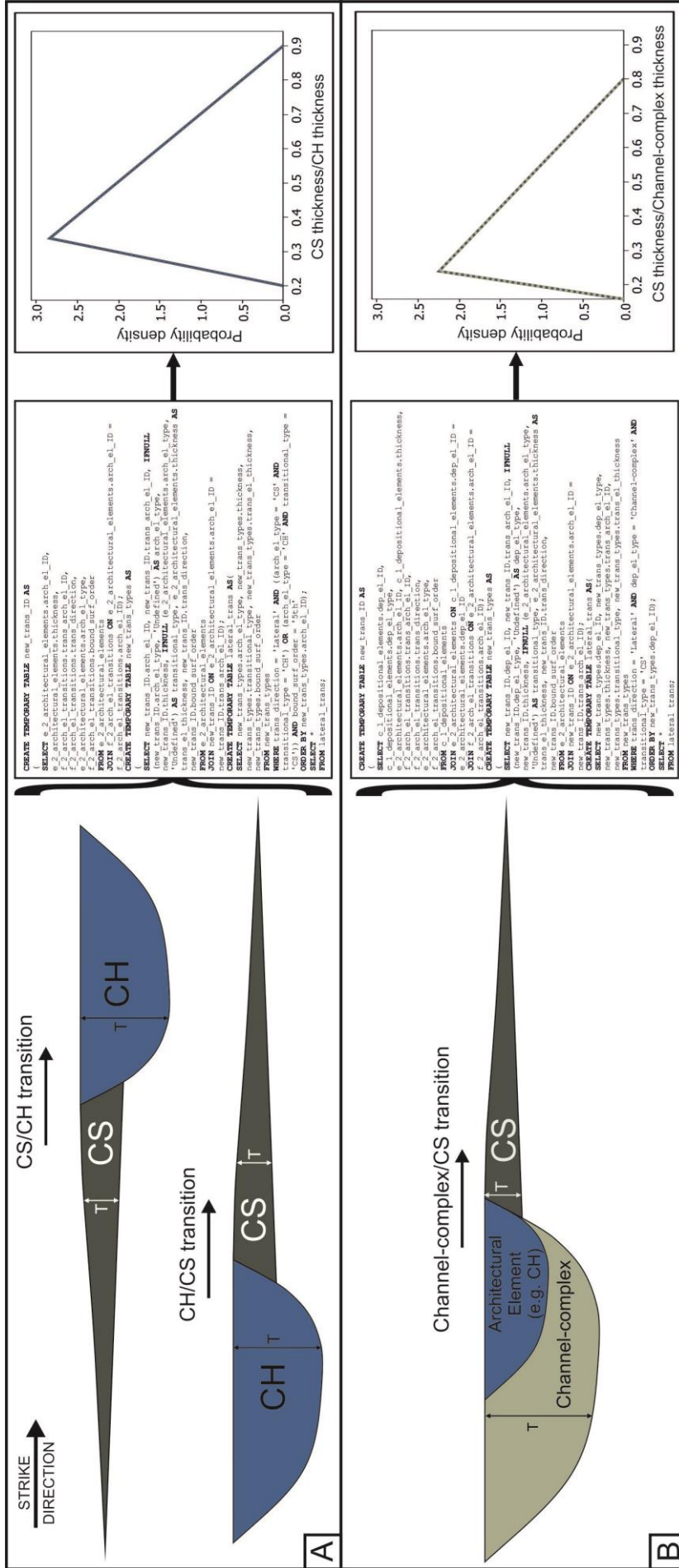
**Figure 6.5:** example FLUVSIM realizations modelling the distribution of channelized bodies in a floodplain background; the simulations were conditioned on geometrical data from (left to right): FAKTS channel-complexes, channel-complexes bounded by 5th-order lower bounding surfaces (5th-order channels), and CH architectural elements (channel-fills).

As the FAKTS database allows a full storage of the relationships of spatial adjacency between genetic units belonging to the same scale (Colombera et al. 2012a; Chapter 2), it is possible to query the database to derive dimensional parameters of laterally juxtaposed units, thereby yielding the relative dimensional parameters required by FLUVSIM (but also employed by widely used commercial software with programs for object-based simulations of fluvial depositional systems; e.g. PETREL by Schlumberger). An example of this type of query is presented in figure 6.6a, where the interrogation that returns the thicknesses of juxtaposed 4<sup>th</sup> order *CH* and *CS* architectural elements is shown. Since the containment of genetic units within larger-scale genetic units is also properly represented in FAKTS, it is also possible to derive relative dimensional parameters associated to genetic units belonging to different scales (figure 6.6b); for example it is possible to submit a query to return the thickness of all the crevasse splay architectural elements (*CS*) neighbouring 5<sup>th</sup>-order channel-cluster depositional elements (channel-complexes bounded by 5<sup>th</sup>-order lower bounding surfaces) and the thickness of the channel-clusters themselves in order to derive their relative thicknesses, in cases where FLUVSIM channels are described by FAKTS' 5<sup>th</sup>-order channel-complexes.

In a similar fashion, the same type of FAKTS output (proportions, absolute and relative dimensional parameters) can be used to constrain mixed object/process-based simulation methods of fluvial architecture, like ALLUVSIM (Pyrzc et al. 2008).

### **6.5.3 Conditioning pixel-based models**

Although any database that quantifies sedimentary architecture is potentially a valuable instrument for conditioning object-based simulations, FAKTS also has utility for constraining pixel-based simulations of fluvial architecture, though, in comparison to when working with object-based techniques, its use is less direct and requires additional data processing to obtain simulation inputs for variogram-based algorithms. However, whenever the traditional empirical curve-fitting approach is not practicable, auto-variogram parameters can be derived from database knowledge of sedimentological attributes (Ritzi 2000). The discussion below demonstrates how FAKTS can inform simulation techniques that are based either on variograms (e.g. sequential indicator simulations and plurigaussian simulations) or transition probabilities.





**Figure 6.6 (previous page):** (A) representation of example query returning relative dimensional parameters: the thicknesses of all juxtaposed 4th order CH and CS architectural elements are obtained and a frequency distribution of the thickness ratio derived, ready to be input in the simulation. As FAKTS transitions are directional (left-to-right, upstream-to-downstream), FAKTS space needs to be sampled in both directions to ensure a successful query;(B) representation of example query returning relative thicknesses of all laterally neighbouring juxtaposed channel-complex depositional elements and CS architectural elements and derived thickness ratio triangular distribution.

### 6.5.3.1 Derivation and use of indicator auto-variograms: Sequential Indicator Simulation

FAKTS' three-dimensional space is not discretized into cells, but only into embedded genetic units that are vertically and laterally (in both strike- and dip-direction) juxtaposed. Moreover, a genetic unit belonging to a given type may be neighbouring a genetic unit that is likewise classified (e.g. two vertically-stacked *CH* architectural elements). Therefore, to derive indicator variogram parameters for a given genetic-unit type from their relationships with genetic-unit proportion and extension, as formulated in Ritzi (2000), it is necessary to take into account the occurrence of genetic-unit self-transitions and their effect on the lateral and vertical extent of a continuous volume belonging to the same genetic-unit type. This volume is hereafter called the *material unit*, as it is formed by multiple likewise-classified genetic units (figure 6.7): in effect, the indicator auto-variograms derived via this process would measure the spatial continuity of these material units, instead of the original FAKTS' genetic units. Generating material units from genetic units is always possible since vertical and lateral juxtapositional relationships are stored in FAKTS in the form of genetic unit transitions. Therefore, FAKTS must be interrogated by means of a series of  $N$  queries in order to obtain dimensional parameters describing the extent of a certain material unit type in a given direction, where  $N$  is the largest number of consecutively juxtaposed genetic units in that direction (figure 6.8). Performing  $N + 1$  queries ensures the determination of  $N$ , as the  $(N + 1)^{\text{th}}$  query would return no result. For every direction, descriptive statistics (mean and coefficient of variation) of the dimensional parameters of material units can then be used in conjunction with their proportions to derive the ranges ( $a$ ) of their indicator variograms according to:

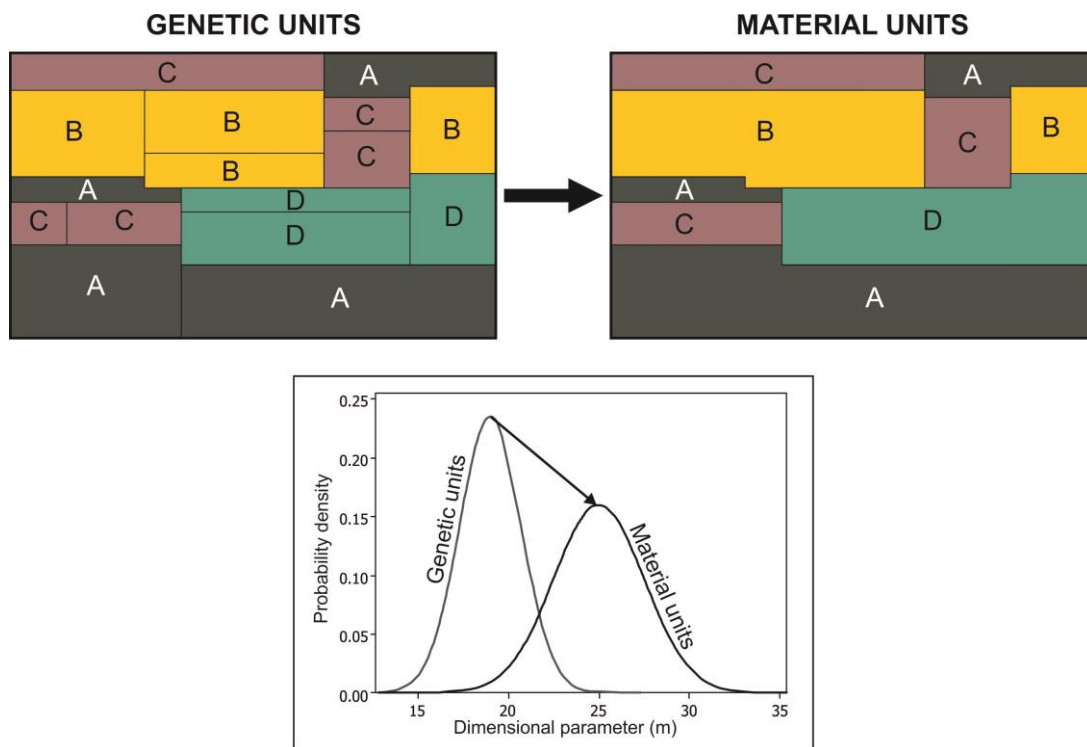
$$a_{k,x} = \Phi(1 - p_k) \bar{l}_{k,x} \quad (\text{Ritzi 2000}),$$

where, referring to a material unit  $k$ ,  $p_k$  is its proportion and  $\bar{l}_{k,x}$  is its mean size along direction  $x$ , whereas  $\Phi = 1.5$  or  $3$  for spherical or exponential models, respectively (Ritzi 2000).

Indicator variogram sills can be calculated from material-unit proportions as:

$$p_k(1 - p_k) \text{ (Ritzi 2000),}$$

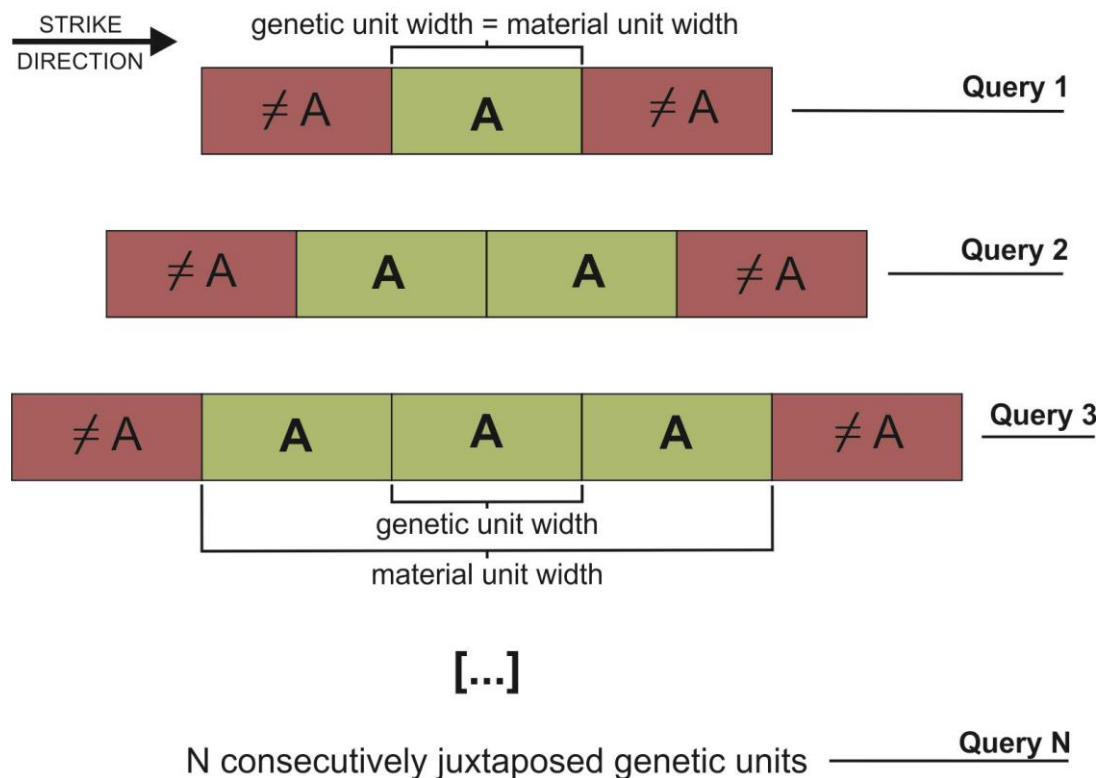
whereas the variogram model can be inferred from the coefficient of variation of the dimensional parameters, as illustrated by Ritzi (2000). This means that FAKTS provides a wealth of data with which to constrain indicator variogram model parameters, whenever the scarcity of directly-derived primary data precludes employment of the typical curve-fitting procedure; for hydrocarbon reservoirs this is routinely the case in the horizontal directions as the majority of boreholes are vertically oriented.



**Figure 6.7:** conceptual depiction of the translation of genetic units into material units according to a given categorical variable (or discretized continuous variable); letters indicate categorical types (e.g. genetic unit type): through this process we are able to obtain the lateral and vertical extent of a continuous volume belonging to the same categorical type.

Some example FAKTS-derived anisotropic indicator variogram parameters are presented here for material units consisting of floodplain and channel depositional elements (table 6.3) and for a selection of 15 facies unit types (table 6.4). In the computation of the variogram model parameters, FAKTS' partial and unlimited (*sensu* Geehan & Underwood 1993) dimensional parameters should be also included; their exact values should be used to estimate volumetric proportions whereas an excess correction of their values should be used to determine

dimension distributions, as their values provide minimum figures on the maximum lateral extension of genetic units. Since subset lateral extension is also stored in FAKTS, the correction of partial dimensions could be carried out according to the method proposed by Visser & Chessa (2000a; 2000b). It is important to note that material units do not necessarily have to be defined on the basis of genetic-unit classes: material units can be defined on any categorical variable, on any discretized continuous variable, or on a combination thereof; for example FAKTS could be used to derive variogram parameters referring to all the facies units classified as sand facies, yet having a fine (clay and silt) content higher than a given percent threshold. This allows for flexibility through the definition of several possible reservoir and non-reservoir categories with which to populate variogram-based simulations.



**Figure 6.8:** representation of an ideal example of sequential queries performed in order to obtain width data of a given type of material unit (characterized by category value 'A') from the widths of genetic units; if N is the largest number of consecutively laterally-juxtaposed genetic units in the strike direction, N queries are required. This example illustrates an approach that is equally applicable in all directions (strike-lateral for material unit widths, downstream for dip lengths, vertical for thicknesses).

The indicator variograms of categorical variables whose distribution needs to be simulated represent, together with their proportions, the basic input to the Sequential Indicator Simulation (SIS) method (Journel & Alabert 1990). SIS is a

simulation algorithm that describes each category through an indicator variable (which takes the value 1 if the category is encountered at a given location, 0 if it is not) and that builds a categorical image within a 3D grid by simulating individual voxels by drawing from the local probability distributions of the categories, updating probability distributions to account for categories that have already been simulated at neighbouring voxels (Alabert 1987; Journel & Alabert 1990; Deutsch & Journel 1998). To test the ideas presented in this chapter, the GSLIB code SISIM (Deutsch & Journel 1998) has been used, with the source code being run through the open-source software SGeMS (Remy et al. 2009; see Bianchi & Zheng 2008, for review).

Given that SISIM does not account for cross-correlation between categories (e.g. by including indicator cross-variograms), working with more than two categorical variables is not recommended as category interactions corresponding to juxtapositional tendencies would not be simulated. Thus, FAKTS' depositional element classes, being binary in nature (channel-complex or floodplain), represent a material description of fluvial architecture that is entirely appropriate to be used as SIS indicator categories. Moreover, working with depositional elements requires little database querying for obtaining cumulative widths or dip lengths of material units corresponding to depositional-element types, as floodplain depositional elements may be vertically stacked but not laterally juxtaposed. This means that SIS' input marginal probabilities for the indicators would consist of in-channel-deposit and floodplain-deposit proportions as obtained from FAKTS, whereas indicator variograms would be computed for material units corresponding to FAKTS channel-complex and floodplain depositional element classes (see table 6.3 for variogram parameters associated with channel and floodplain material units derived from (i) the entire FAKTS knowledgebase, (ii) from arid/semiarid-climate basins and (iii) from subhumid/humid-climate basins).

However SIS, like other pixel-based techniques in general, fails to represent some topological features of the objects it seeks to model: if channel-complexes comprise sinuous channels or channel-belts, it would not be possible to model their sinuosity. In addition, because depositional elements are the largest-scale genetic units in FAKTS, the size distribution of some of the dimensional parameters associated to their material units could be unrealistic due to size underestimation (e.g. including partial and unlimited measurements) when working with data assigned a low-quality ranking (Colombera et al. 2012a, Chapter 2), and this could affect the resulting indicator variogram. For instance, if the observation windows of several case studies are too narrow to include a significant number of complete measurements of channel-complex dip lengths, the resulting dip-directed range could be significantly underestimated (see table 6.3, arid/semiarid channel-complex ranges);

**Table 6.3:** FAKTS-derived indicator auto-variogram parameters for channel-complex and floodplain depositional elements, classified according to the interpreted basin climate regime.

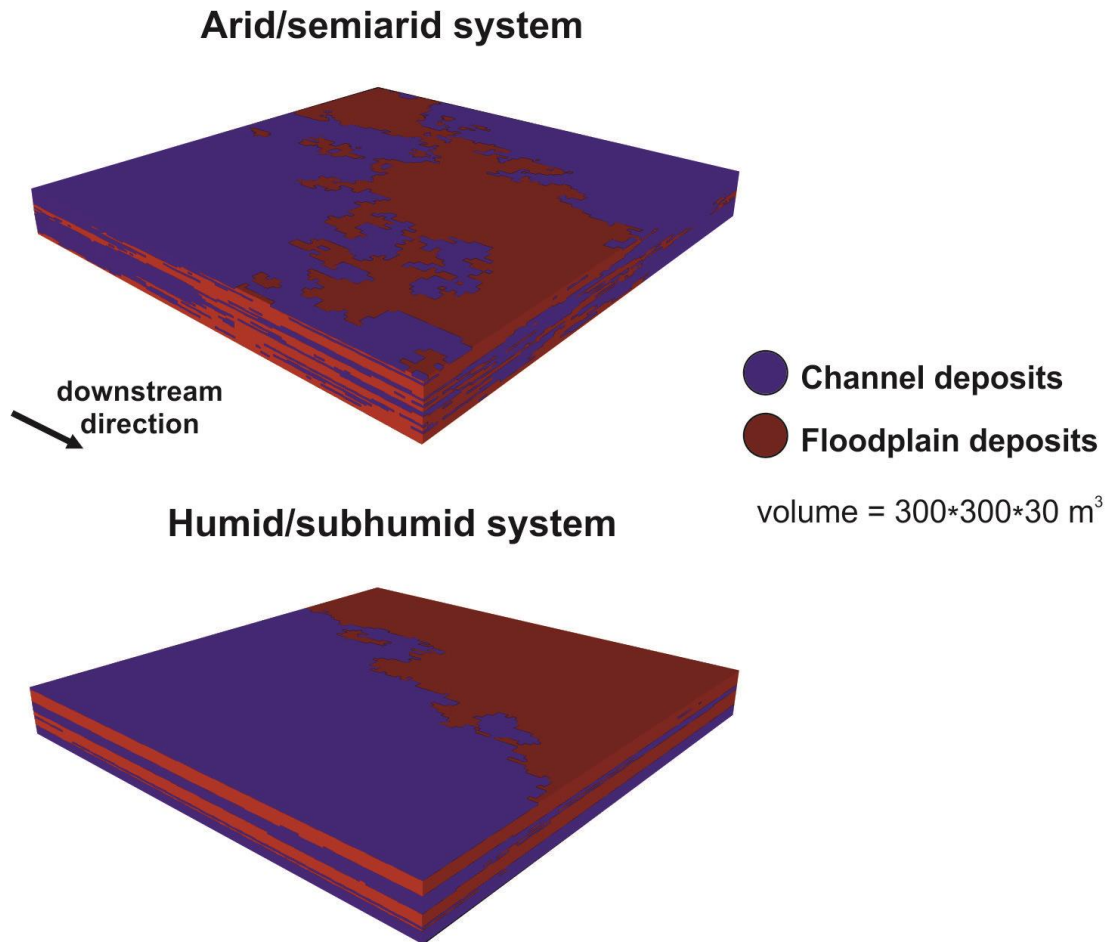
		INDICATOR VARIOGRAM PARAMETERS				
BASIN CLIMATE TYPE	DEPOSITIONAL ELEMENT TYPE	MODEL	RANGE (m)			SILL
			X	Y	Z	
Any climate	Channel-complex	Exponential	815	1358	5.3	0.177
	Floodplain	Exponential	2641	1290	21.5	0.177
Arid/semiarid	Channel-complex	Exponential	619	562	1.9	0.171
	Floodplain	Exponential	414	166	21.3	0.171
Subhumid/humid	Channel-complex	Exponential	2469	5990	11.0	0.193
	Floodplain	Exponential	7169	3819	23.1	0.193

**Table 6.4:** FAKTS-derived indicator auto-variogram parameters for material units corresponding to 15 selected facies unit types (see table 6.2 for classification) that account for almost the entire facies unit types in the database. The rest of the lithofacies types have been excluded due to the little amount of data on their lateral extension (mean and coefficient of variation) on the basis of which to confidently derive a model and a range; however, as the overall proportion of the remainder of lithofacies types is small, their inclusion would have little effect on the variogram sills of the units presented here.

INDICATOR VARIOGRAM PARAMETERS					
FACIES UNIT TYPE	MODEL	RANGE (m)			SILL
		X	Y	Z	
Gmm	Exponential	8.1	19.8	2.5	0.0009
Gcm	Exponential	21.9	40.0	2.3	0.0047
Gh	Spherical	12.5	27.4	1.2	0.0042
Gt	Spherical	13.5	82.4	1.5	0.0017
St	Exponential	35.7	34.6	3.7	0.1460
Sp	Exponential	34.6	50.2	3.0	0.0272
Sr	Exponential	49.9	52.6	1.3	0.0797
Sh	Exponential	91.6	43.8	2.0	0.2394
Sm	Exponential	66.8	39.6	3.6	0.1005
Sl	Exponential	42.5	43.3	3.3	0.0959
Sd	Spherical	7.4	9.9	1.7	0.0032
Ss	Exponential	22.0	30.5	1.9	0.0480
Fl	Spherical	24.5	22.9	0.9	0.0181
Fm	Spherical	34.1	23.9	0.41	0.0053
P	Exponential	24.0	24.0	1.8	0.0003

in such cases the range value should be corrected, for example by filtering high-quality-ranked FAKTS' studies in order to either re-compute the length distribution or use preserved-width/length ratios to derive a more realistic range.

Example SIS realizations constraining unconditional simulations on FAKTS' depositional-element data classified according to basin climate regimes are presented in figure 6.9.



**Figure 6.9:** example SISIM realizations derived by constraining unconditional (no direct data) simulations based on FAKTS' depositional-element data, filtered according to basin climate type (variograms in table 6.3). At this scale (hundred-meter lateral extent), the effect of different univariate statistics describing lateral dimensional parameters on indicator variogram ranges translates into more complexly interbedded channel and floodplain deposits for dryland fluvial systems in comparison to more humid systems, which show more laterally continuous depositional elements.

### 6.5.3.2 Determination and use of indicator cross-variograms and transition rates: Plurigaussian simulations and T-PROGS

FAKTS-derived indicator variograms can also find application for the conditioning of another popular pixel-based method: plurigaussian simulations. The principle

behind the method involves the generation of two or more Gaussian fields and their truncation at a specified number of thresholds in order to attribute discrete values representing the categories (Le Loc'h & Galli 1997; Dowd et al. 2003; Xu et al. 2006; Armstrong et al. 2011). Unlike the SIS method, the plurigaussian method permits consideration of the juxtapositional tendencies of the modelled categories: contact relations among the categories, which describe juxtapositional trends, can be specified by using pre-defined contact templates (*lithotype rules* in: Armstrong et al. 2011; Dowd et al. 2003) or user-defined contact matrices (*dynamic contact matrix* in Xu et al. 2006). The inputs to this method consist of the proportions of the chosen categorical variables, their experimental indicator auto- and cross-variograms, a model of their spatial relations and the Gaussian correlation coefficients. FAKTS can be used to obtain proportions as explained above, in case of sparse or no data (e.g unconditional simulations of fluvial architecture). In addition, instead of inputting experimental (cross-)variogram values, it is possible to derive indicator (cross-)variogram values from sampling at a given lag-spacing (cross-)variogram models generated using FAKTS data for each categorical variable (or each pair of categorical variables) (figure 6.10). FAKTS can be used to generate models of indicator auto-variograms for material units as explained above. Also, since FAKTS stores data about the spatial relationships between genetic units, the database can be used to derive models of indicator cross-variograms for each pair of indicators. This would be done by exploiting the relationship between indicator-cross variograms of a pair of categories and their continuous-lag transition probability (Carle & Fogg 1996). The sill of the indicator cross-variogram model can be computed from category proportions, as it approaches  $-p_j p_k$  (Carle & Fogg 1996), where the  $j$  and  $k$  subscripts denote the two categories and  $p$  their proportion. As an approximation (downward) of the range of the model indicator cross-variogram for two categories, it is possible to assume the lag value at the intersection between the sill ( $p_k$ ) of the continuous-lag transition probability for the same categories and the tangent ( $s$ ) to the same transition probability at lag zero. The lag value at this intersection is given by:

$$h(s = p_k) = \frac{P_{k,x}}{r_{jk,x}}$$

The slope of the transition probability approaching lag zero corresponds to the transition rate  $r_{jk,x}$  (Carle & Fogg 1997), which can be estimated from mean dimensions ( $\bar{L}$ ) and embedded transition frequencies ( $f$ ) or probabilities ( $\pi$ ) (Carle 1997a; 1999) as:

$$r_{jk,x} = \frac{f_{jk,x}}{f_{j,x} \bar{L}_{j,x}} \quad \text{and} \quad r_{jk,x} = \frac{\pi_{jk,x}}{\bar{L}_{j,x}}$$

Notably, working with embedded categories means considering self-transitions as unobservable: this is consistent with switching from genetic units to material units (see above). A problem arises because  $t_{jk,x}(h)$  may be significantly different from  $t_{kj,x}(h)$ , as transition probability, unlike cross-variograms, considers asymmetry, i.e. transition probability takes into account direction-specific patterns (Carle & Fogg 1996). Therefore, it could be possible to derive a reference value of range for the cross-variograms from transition rates computed from bidirectionally-averaged transition probabilities, obtained by sampling FAKTS' space in both directions for each axis (e.g. upwards and downwards along the vertical axis); this would be simply done by obtaining corrected transition count values as:

$$c_{jk,x}^* = c_{kj,x}^* = c_{jk,x} + c_{kj,x}.$$

From  $c_{jk,x}^*$  we can derive  $\pi_{jk,x}^*$ , then  $r_{jk,x}^*$  with which to estimate a single value of range. Assuming the coincidence in transition counts in both directions, given by

$$c_{jk,x}^* = c_{kj,x}^*$$

means deriving coincident transition probabilities:

$$t_{jk}(h) = t_{kj}(h)$$

$$\text{then: } t_{jk}(h) = t_{jk}(-h).$$

Assuming this, the relationship between indicator cross-variogram and transition probability given by:

$$\gamma_{jk}(h) = p_j \{t_{jk}(0) - [t_{jk}(h) + t_{jk}(-h)]/2\} \quad (\text{Carle \& Fogg 1996})$$

can be reduced to:  $\gamma_{jk}(h) = -p_j t_{jk}(h)$ .

Thus, the tangent of the cross-variogram at lag zero is equal to:  $-p_j r_{jk} h$

This means that the lag value at the intersection between the sill of the indicator cross-variogram for the same categories and the tangent ( $q$ ) to the same cross-

variogram at lag zero is:  $h(q = -p_j p_k) = \frac{p_{k,x}}{r_{jk,x}}$  (figure 6.10a).

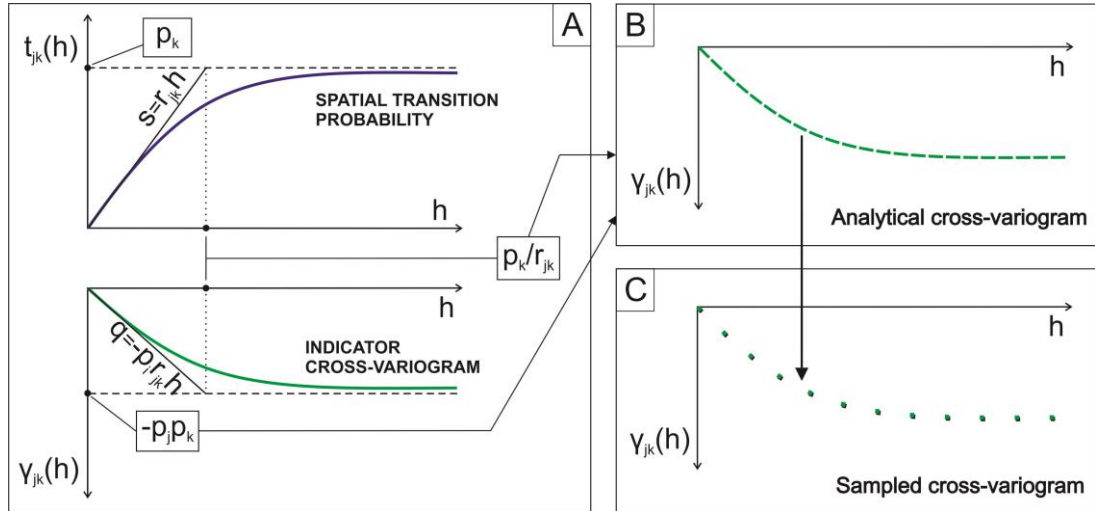
The cross-variogram range can be estimated by correcting in excess this value, since:

$$\text{range}(\gamma_{jk,x}) > \frac{p_{k,x}}{r_{jk,x}}.$$

This approach only generates approximate models of cross-variograms, but it would only be used whenever lack of direct data precludes the calculation of cross-variograms (e.g. actual lack of data or need to generate a training image). An example application whereby FAKTS is used to derive indicator cross-variogram



parameters for material units defined on facies unit types, referring to horizontal directions, is presented in tables 6.5 and 6.6.



**Figure 6.10:** (A) example spatial transition probability between categories  $j$  and  $k$  as a function of lag  $h$  ( $t_{jk}(h)$ ) in a given direction, and corresponding cross-variogram ( $\gamma_{jk}(h)$ ): the tangents to the curves at lag zero, the sills and their intersections are represented; the lag value at the sill-tangent intersection constrains the minimum value of cross variogram range; (B) analytical cross-variogram obtained from the sill and estimated range values derived from category proportions and transition rates; (C) the sampling of the analytical cross-variogram at given lag spacing yields cross-variogram values that can be used as input in plurigaussian simulations.

**Table 6.5:** FAKTS-derived indicator cross-variogram parameters for material units corresponding to five selected facies unit types, referring to the cross-valley direction; range corrected in excess of 10% of calculated tangent/sill intersection lag value.

INDICATOR CROSS-VARIOGRAM parameters – direction X (cross-valley/ strike)								
St		Sp		Sr		Sh		
Range	Sill	Range	Sill	Range	Sill	Range	Sill	
<b>St</b>	Tab. 6.4							
<b>Sp</b>	33	-0.0050	Tab. 6.4					
<b>Sr</b>	18	-0.0155	15	-0.0024	Tab. 6.4			
<b>Sh</b>	17	-0.0705	1.5	-0.011	3.5	-0.0347	Tab. 6.4	
<b>FI</b>	138	-0.0033	4.1	-0.0005	22	-0.0016	66	-0.0073

**Table 6.6:** FAKTS-derived indicator cross-variogram parameters for material units corresponding to five selected facies unit types, referring to the along-valley direction; range corrected in excess of 10% of calculated tangent/sill intersection lag value.

INDICATOR CROSS-VARIOGRAM parameters – direction Y (along-valley/dip)								
St		Sp		Sr		Sh		
Range	Sill	Range	Sill	Range	Sill	Range	Sill	
<b>St</b>	Tab. 6.4							
<b>Sp</b>	12	-0.0050	Tab. 6.4					
<b>Sr</b>	18	-0.0155	7.8	-0.0024	Tab. 6.4			
<b>Sh</b>	24	-0.0705	3.0	-0.011	7.8	-0.0347	Tab. 6.4	
<b>FI</b>	169	-0.0033	-	-0.0005	10	-0.0016	74	-0.0073

To fully constrain a plurigaussian simulation, it is necessary to choose a model that describes the spatial relationships between the categories. Given that FAKTS describes the spatial relationships between genetic units in terms of transitions, transition frequency matrices can be derived from the database for every type of genetic unit (and can be related to material units by setting diagonal values as zero) in order to obtain a quantitative description of spatial relationships (e.g. transition patterns from Markov analysis) with which to inform the choice of an appropriate model of contact relations.

Other pixel-based methods that consider the spatial cross-correlation between the categories that need to be modelled describe the spatial structure by using Markov chains, quantifying spatial relationships using transition probabilities (Carle 1997a; 1999; Elfeki & Dekking 2001). A popular transition-probability/Markov-chain geostatistical simulation method is implemented in the software T-PROGS (Carle 1999). The T-PROGS package allows the calculation of three-dimensional Markov-chain models of spatial variability that can be used in sequential indicator simulations (SIS) that are iteratively adjusted – in terms of matching simulated and modelled transition probabilities – by applying a simulated quenching (zero-temperature annealing) algorithm (Carle 1996; 1997b) to generate a geostatistical realization of categorical variables. In comparison to variogram-based geostatistical methods, this transition-probability approach simplifies the link between observable attributes and model parameters. T-PROGS simulations are easily constrained by

proportions, mean dimensions and juxtapositional tendencies; the creation of variograms through either curve-fitting or modelling on FAKTS-derived data (as above) is not needed. In this method, spatial variability is incorporated in form of transition probability instead of indicator cross-variogram, thereby permitting the representation of asymmetrical correlation structures (e.g., fining-upward trends) (Carle & Fogg 1996). T-PROGS allows the generation of each 1D Markov chain following five different possible approaches, each of them leading to a transition rate matrix that defines the matrix exponential form of the Markov chain model (Carle 1999). After querying FAKTS in order to obtain mean dimensional parameters and transition counts (and then converting output into embedded transition frequencies or probabilities) for a given direction, the entries of the transition rate matrix for that direction can be derived by prescribing off-diagonal (cross-) transition rates by dividing embedded transition probability/frequency values by mean dimension and diagonal (auto-) transition rates by mean dimension (since:  $r_{jj,x} = -\frac{1}{L_{j,x}}$ ). Further constraint is given by the proportions of all the

categories, which can again be derived from FAKTS. Due to transition rate matrix properties, there is no need to specify row and column entries for one of the categories in the rate matrix: it is convenient to consider this “background” category as the material that “fills in the space” not occupied by other categories (e.g. low-energy fine-grained floodplain sediments).

Given (i) that direct data from which spatial transition probabilities can be computed are often lacking in the horizontal (strike and dip) directions, and (ii) that the advocacy of Walther’s law (cf. Carle & Fogg 1997) is not advisable in fluvial depositional contexts (e.g. discrepancies in vertical and lateral transition probabilities testify to a tendency of vertical stacking of abandoned channel-fills on aggradational channel-fills that has no counterpart in the lateral directions), FAKTS can provide important quantitative information with which to condition the Markov models of lateral spatial variability. Examples of FAKTS-derived transition probability matrices for material units defined on facies unit types, referring to vertical and horizontal directions are presented in tables 6.7, 6.8 and 6.9.

In contrast to the SIS approach, plurigaussian simulations and T-PROGS take into account spatial relationships: this means that it is possible to reliably simulate more than two indicators, making it possible to work more confidently with material units defined on the basis of FAKTS’ architectural elements and facies units.

**Table 6.7:** FAKTS-derived transition-probability matrix for material units (no embedded self-transitions) based on 15 selected facies unit types, referring to the vertical (upwards) direction; lower units in rows and upper units in columns; values based on 6562 embedded transitions.

Z	Fl	Fm	Gcm	Gh	Gmm	Gt	P	Sd	Sh	Sl	Sm	Sp	Sr	Ss	St
Fl	-	0.02	0.03	0.00	0.00	0.00	0.03	0.01	0.19	0.06	0.15	0.13	0.17	0.07	0.14
Fm	0.00	-	0.03	0.00	0.00	0.00	0.04	0.03	0.23	0.02	0.20	0.07	0.24	0.01	0.13
Gcm	0.02	0.02	-	0.01	0.00	0.05	0.01	0.03	0.18	0.07	0.18	0.17	0.02	0.06	0.22
Gh	0.04	0.00	0.00	-	0.00	0.00	0.00	0.00	0.20	0.20	0.08	0.00	0.00	0.16	0.32
Gmm	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.18	0.18	0.09	0.09	0.00	0.18	0.27
Gt	0.00	0.00	0.12	0.00	0.04	-	0.00	0.00	0.15	0.12	0.23	0.08	0.00	0.08	0.19
P	0.04	0.14	0.01	0.00	0.00	0.00	-	0.13	0.14	0.00	0.25	0.06	0.07	0.00	0.17
Sd	0.02	0.05	0.00	0.00	0.00	0.00	0.10	-	0.17	0.15	0.25	0.13	0.05	0.02	0.08
Sh	0.05	0.08	0.02	0.01	0.00	0.00	0.02	0.04	-	0.10	0.18	0.12	0.18	0.05	0.14
Sl	0.03	0.01	0.02	0.00	0.00	0.00	0.00	0.07	0.19	-	0.24	0.14	0.04	0.05	0.19
Sm	0.06	0.11	0.03	0.00	0.00	0.00	0.03	0.05	0.23	0.15	-	0.13	0.05	0.03	0.11
Sp	0.05	0.04	0.04	0.00	0.00	0.00	0.01	0.05	0.20	0.12	0.15	-	0.08	0.03	0.22
Sr	0.14	0.21	0.01	0.00	0.00	0.00	0.02	0.02	0.27	0.03	0.09	0.07	-	0.01	0.14
Ss	0.03	0.00	0.02	0.00	0.00	0.01	0.00	0.04	0.27	0.22	0.06	0.08	0.03	-	0.23
St	0.02	0.05	0.05	0.01	0.00	0.00	0.01	0.04	0.22	0.16	0.13	0.15	0.11	0.05	-

**Table 6.8:** FAKTS-derived transition-probability matrix for material units (no embedded self-transitions) based on 15 selected facies unit types, referring to the lateral (right) direction; left-hand units in rows and right-hand units in columns; values based on 629 embedded transitions.

X	Fl	Fm	Gcm	Gh	Gmm	Gt	P	Sd	Sh	Sl	Sm	Sp	Sr	Ss	St
<b>Fl</b>	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.14	0.10	0.19	0.19	0.05	0.14
<b>Fm</b>	0.00	-	0.00	0.00	0.00	0.00	0.06	0.00	0.19	0.19	0.06	0.13	0.13	0.19	0.06
<b>Gcm</b>	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.13	0.13	0.13	0.00	0.00	0.19	0.44
<b>Gh</b>	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.20	0.40
<b>Gmm</b>	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.67
<b>Gt</b>	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
<b>P</b>	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<b>Sd</b>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.40	0.20	0.00	0.00	0.40
<b>Sh</b>	0.05	0.05	0.06	0.00	0.00	0.00	0.00	0.00	-	0.08	0.19	0.06	0.20	0.15	0.17
<b>Sl</b>	0.06	0.01	0.01	0.00	0.00	0.01	0.01	0.02	0.06	-	0.23	0.10	0.03	0.18	0.28
<b>Sm</b>	0.02	0.02	0.02	0.00	0.02	0.00	0.00	0.02	0.21	0.14	-	0.07	0.13	0.14	0.21
<b>Sp</b>	0.02	0.00	0.02	0.02	0.02	0.00	0.00	0.02	0.13	0.16	0.10	-	0.15	0.18	0.20
<b>Sr</b>	0.05	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.36	0.08	0.09	0.02	-	0.05	0.33
<b>Ss</b>	0.03	0.02	0.05	0.02	0.00	0.00	0.00	0.02	0.15	0.20	0.08	0.14	0.07	-	0.22
<b>St</b>	0.02	0.01	0.06	0.02	0.00	0.00	0.00	0.03	0.19	0.23	0.10	0.07	0.14	0.14	-

**Table 6.9:** FAKTS-derived transition-probability matrix for material units (no embedded self-transitions) based on 15 selected facies unit types, referring to the dip (upstream) direction; downstream units in rows and upstream units in columns; values based on 436 embedded transitions.

Y	Fl	Fm	Gcm	Gh	Gmm	Gt	P	Sd	Sh	Sl	Sm	Sp	Sr	Ss	St
Fl	-	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.13	0.25	0.25	0.00	0.13	0.00	0.13
Fm	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Gcm	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.33	0.22
Gh	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.33
Gmm	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.50
Gt	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
P	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.02	0.31	0.17	0.17	0.00	0.02	0.31
Sh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	-	0.34	0.00	0.22	0.00	0.06	0.31
Sl	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.11	0.12	-	0.38	0.15	0.04	0.04	0.15
Sm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.02	0.57	-	0.15	0.00	0.00	0.09
Sp	0.00	0.02	0.02	0.00	0.02	0.00	0.00	0.11	0.10	0.18	0.15	-	0.05	0.03	0.34
Sr	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.07	0.04	0.04	-	0.07	0.56
Ss	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.09	0.18	0.09	0.09	0.00	-	0.45
St	0.02	0.00	0.06	0.01	0.01	0.00	0.00	0.03	0.11	0.27	0.08	0.23	0.13	0.04	-

## **6.6 Case study example application: generating training images for MPS modelling of the Walloon Subgroup (Surat Basin, Australia)**

### **6.6.1 Overview**

The application of database output to the production of training images for multiple-point statistics (MPS) simulation of sedimentary architecture is here exemplified by work carried out with the purpose of generating training images suitable for modelling the subsurface architecture of the Walloon Coal Measures (Walloon Subgroup, WSG), a Middle Jurassic lithostratigraphic unit of the Surat Basin (eastern Australia).

The WSG, which attains a thickness of up to ca. 450 m, is a heterogeneous succession of sandstones, siltstones, claystones, carbonaceous mudstones and coals, sporadically interbedded with ashfall tuffs, all interpreted to have accumulated in an alluvial plain setting (Clark & Cooper 1982; Fielding 1993; Martin et al. 2013) in the thermal-subsidence-controlled Surat Basin (Totterdell al. 2009). Different formations are distinguished within the Subgroup, and these tend to be characterized by variable proportions of the same types of sedimentary units (cf. Scott et al. 2007); however, the training images presented in this work consider the WSG as a whole, as stratigraphic variations (including the occurrence of major composite coal seams) are meant to be implemented in the MPS simulation by using so-called facies proportions curves rather than alternative training images for each interval.

The drive to develop database-informed training images specifically for modelling this succession stems from the necessity to predict the subsurface sedimentary heterogeneity that determines the distribution and connectivity of aquifer units that are hosted in the WSG and which are locally connected with superficial alluvium forming an unconfined aquifer. A model describing subsurface stratigraphic architecture is needed in order to inform plans for sustainable groundwater management in the region to best reconcile the competing needs of (i) the coal-seam gas industry who need to pump water as a by-product of gas production, and (ii) farmers of the Great Artesian Basin, who require groundwater for irrigation.

In the following paragraphs, a description is given of the approach taken for the creation of candidate training images based on the application of FAKTS analogue knowledge. This piece of work serves as an example practice of database-informed MPS training-image generation.

Since MPS modelling algorithms capture patterns of heterogeneity from training images, it is crucial to incorporate realistic sedimentary architecture into such

training images. The approach adopted to ensure that the training images represent geologically realistic fluvial facies models makes use of object-based modelling techniques constrained by geometrical information referring to fluvial sedimentary units derived from a suite of ancient and modern fluvial systems that can be, to various degrees, considered as potential analogues to the Walloon Subgroup.

### **6.6.2 Fluvial sedimentary units**

The building blocks composing the training images are sedimentary units categorized on fluvial sub-environments recognized in the WSG on the basis of original well (geophysical logs and cores or cuttings) interpretations and work done by other authors (Clark & Cooper 1982; Fielding 1993; Martin et al. 2013). The chosen categories include:

- fluvial channel-belt deposits
- proximal sandy floodplain deposits
- distal fine-grained floodplain/lake deposits
- coal bodies.

The choice of a limited number of modelling categories ensures that (i) only the sedimentary units that are most significant in the WSG hydrostratigraphic context are included, and that (ii) it is possible to limit the uncertainty associated with the interpretation of wells used for model conditioning for which core data are not available, i.e. for which discriminating levee deposits from crevasse splay deposits would carry uncertainty, for example.

### **6.6.3 Obtaining quantitative constraints from the sedimentary architecture of analogue fluvial systems**

Modern-system and outcrop information on the sedimentary architecture of potential analogues has been derived from FAKTS on the assumption that, by filtering the database on any user-defined combination of system parameters or architectural properties, it is possible to obtain information that effectively represents a quantitative fluvial facies model (cf. Chapter 3) that can be employed as a synthetic analogue to inform training images that will be representative of that fluvial system type. An obvious limitation of the method is brought about by the progressively smaller amount of data – and number of analogues – that are included in the model as filters are successively added: if only a modest amount of architectural data are available for a set of filters, the resulting model will fail to



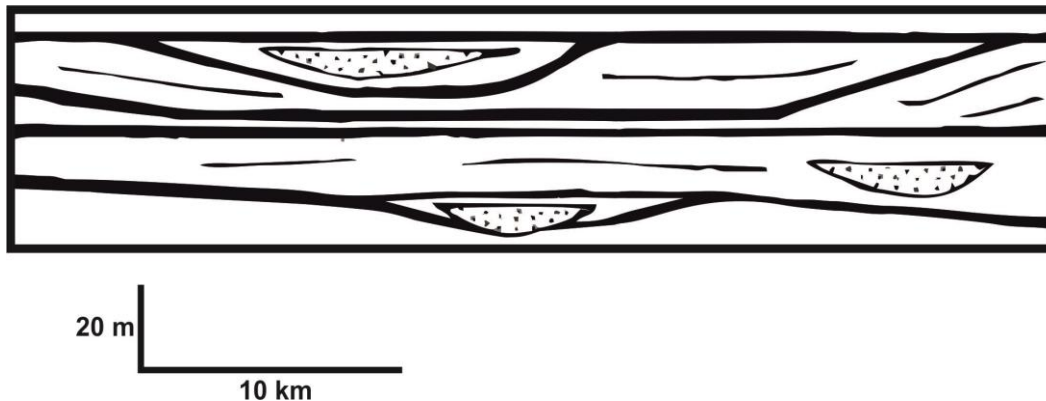
embody the natural variability associated with that system type. It was not possible to contemporaneously guarantee the incorporation of many data-rich systems and the choice of a single synthetic analogue that would match all available WSG environmental interpretations; instead the approach taken was to derive alternative sets of architectural information representing different fluvial classes that at least partially match with interpretations proposed by several authors concerning planform type (dominantly meandering; cf. Clark & Cooper 1982) and basin climate regime (humid; cf. Turner et al. 2009).

A total of five alternative synthetic facies models have been derived from FAKTS (April 2013) to variably inform the training images and these models are defined as follows:

- 1) a generic model fluvial system including information from the entire FAKTS analogue knowledge base concerning channel complexes, levees and crevasse splays;
- 2) a model based on channel-complex data from FAKTS for meandering systems, and proximal floodplain (levee and crevasse splay) data from all FAKTS systems;
- 3) a model based on FAKTS analogue information relating to systems placed in humid/sub-humid settings;
- 4) a model based on channel-complex data from FAKTS systems in humid/sub-humid settings in the 45°-75° palaeo-latitude range, integrated with proximal floodplain (levee and crevasse splay) data from systems placed in humid/sub-humid settings at any latitude;
- 5) a model based on parameters drawn from empirical relationships derived from all FAKTS systems and relating descriptive statistics (mean and standard deviation) of channel-complex geometries (thickness and width) to proportions (cf. Chapter 5), with reference to corehole-derived WSG channel-complex proportions, integrated with proximal floodplain (levee and crevasse splay) data from all FAKTS systems.

This information has been independently combined with two alternative sets of information concerning the geometry of coal bodies, as respectively derived from the entire FAKTS knowledge base on coal-bearing systems or from the correlation of densely-spaced wells in the WSG by Morris & Martin (2012). Thus, a total of ten alternative sets of quantitative parameters have been considered for conditioning training images associated with different models of fluvial systems. Each set of information – and related training image – is identified by a letter (F if FAKTS coal-body data is included; W if WSG coal-body data by Morris & Martin 2012 is

included) followed by a number (1 to 5, referring to one of the five FAKTS facies models, as numbered above). Notably, the training images incorporate analogue information referring to individual coal bodies, rather than composite heterogeneous coal seams; convergent coal-seam split geometries associated with interburden pinch-out, as recognized in the WSG (Fielding 1987; figure 6.11), are not reproduced by the training images.



**Figure 6.11:** schematic WSG cross-section depicting the persistent nature of coal-seam and seam-split geometries (bold lines); stippled units represent large channelized features (modified after Fielding 1987). The proposed training images do not include composite heterogeneous coal seams as discrete unit types, and do not include seam-split geometries.

#### 6.6.4 Constructing training images through object-based modelling

Object-based methods for stochastic structure-imitating modelling of geological media have been employed for generating training images based on the combined use of corehole-derived genetic-unit proportions and database-derived genetic-unit geometrical constraints. Ultimately, the training images are representative models of fluvial successions composed of fluvial channel-complexes, frequently transitional to proximal floodplain sandy units, dispersed in a fine-grained floodplain background in which several coal-bodies are distributed.

Two alternative approaches have been attempted to generate candidate training images, which differ in the way they allow for honouring different types of available constraints.

A first set of candidate training images was obtained through a combination of the use of the FLUVSIM algorithm (Deutsch & Tran 2002), which permits modelling of the distribution of channel complexes, levees and crevasse splays in a distal floodplain background, with another object-based software called TiGenerator

(Maharaja 2008), which has instead been used for simulating coal bodies in the distal floodplain region, by modelling the bodies as lenses with circular planform shapes. Both steps are conditioned by assigning triangular distributions describing the geometry of the genetic units; the main advantage of employing FLUVSIM to model channel complexes lies in the possibility to prescribe width-to-thickness aspect ratios for constraining channel-complex geometries. The choice of a suitable FLUVSIM model required visual inspection of the resulting realization, as no rules can be assigned to ensure that the stacking of the channel units are consistent with the geometrical definition of FAKTS channel complexes.

A second trial set of training images was generated by using a different object-based program for training-image generation called TETRIS (Boucher et al. 2010). TETRIS permits the assignment of lognormal distributions to the geometrical parameters of the genetic units, thereby allowing for the reproduction of more realistic distributions of channel-complex and coal-bodies widths and thicknesses (cf. Chapter 5). In addition, rules describing the style of stacking of channel-complexes can also be specified, facilitating the generation of realizations including channel-complexes that honour FAKTS geometry-based definitions; spatial relationships between different types of objects can also be established, so that levee and crevasse-splay objects can be attached to channel-complexes. The major drawback to the scope of this work is that it is not possible to condition the model on genetic-unit width-to-thickness aspect ratios.

Overall, the first set of training images is characterized by a perceived higher realism in the reproduction of geological features, mainly due to the inclusion of constraints on object shape aspect ratios. In consideration of this fact, the first set of training images (figure 6.12 and 6.13) has only been considered for MPS simulation use, taking into account both groups based on alternative coal-body geometries (figure 6.14).

These training images can find application to the MPS modelling of other fluvial coal-bearing successions, although a major limitation to their applicability is given by the choice of a limited number of unit types, which is related to their project-specific nature.



# Candidate training images for MPS modeling of the Jurassic Walloon Coal Measures (Surat Basin, E Australia)

as based on analog information derived from:

Coal-body geometries based on FAKTS output

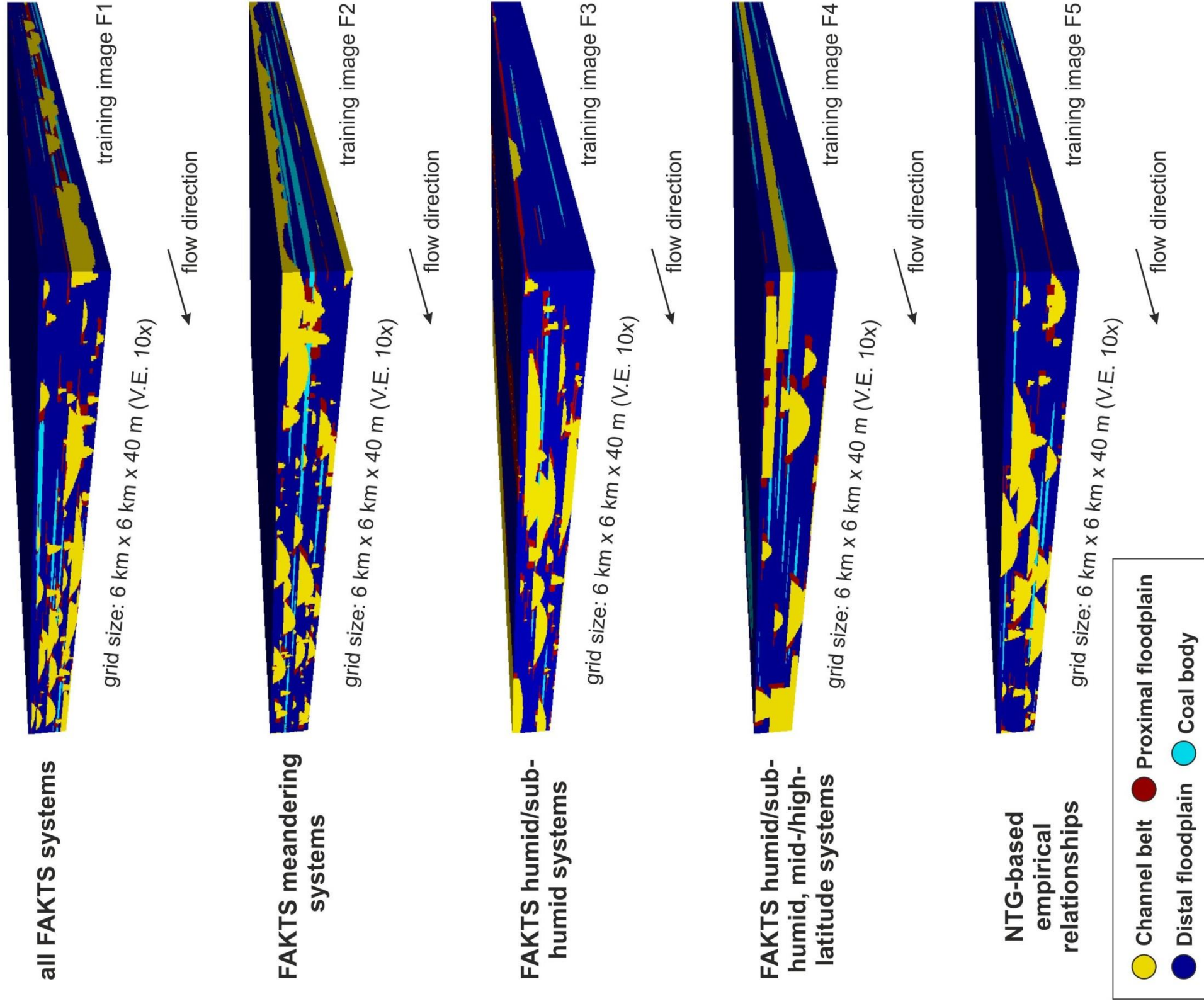


Figure 6.12: training images F1 to F5, including analogue knowledge from classified FAKTS systems. See main text for further explanation.





# Candidate training images for MPS modeling of the Jurassic Walloon Coal Measures (Surat Basin, E Australia)

as based on analog information derived from:

Coal-body geometries based on Morris & Martin (2012)

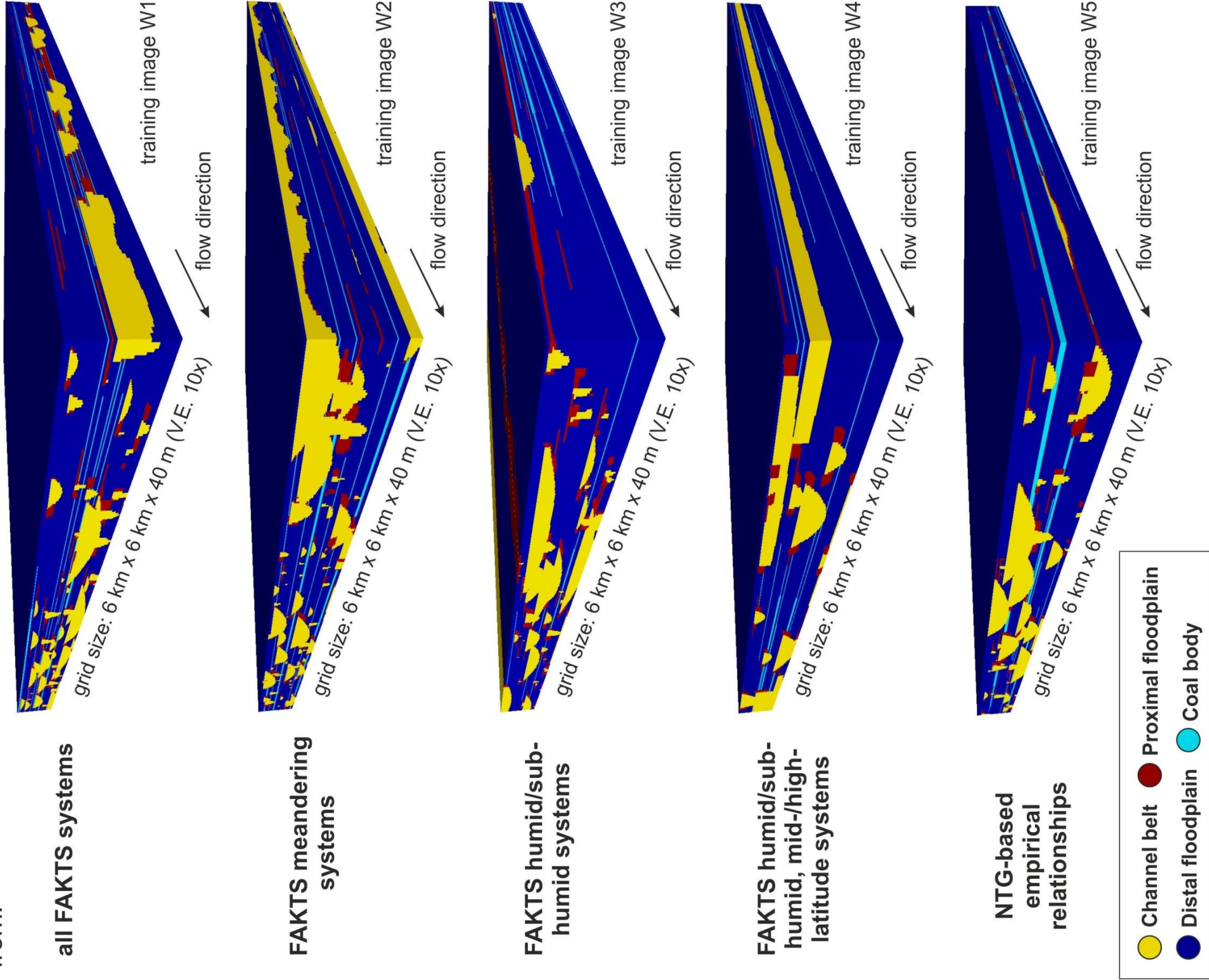
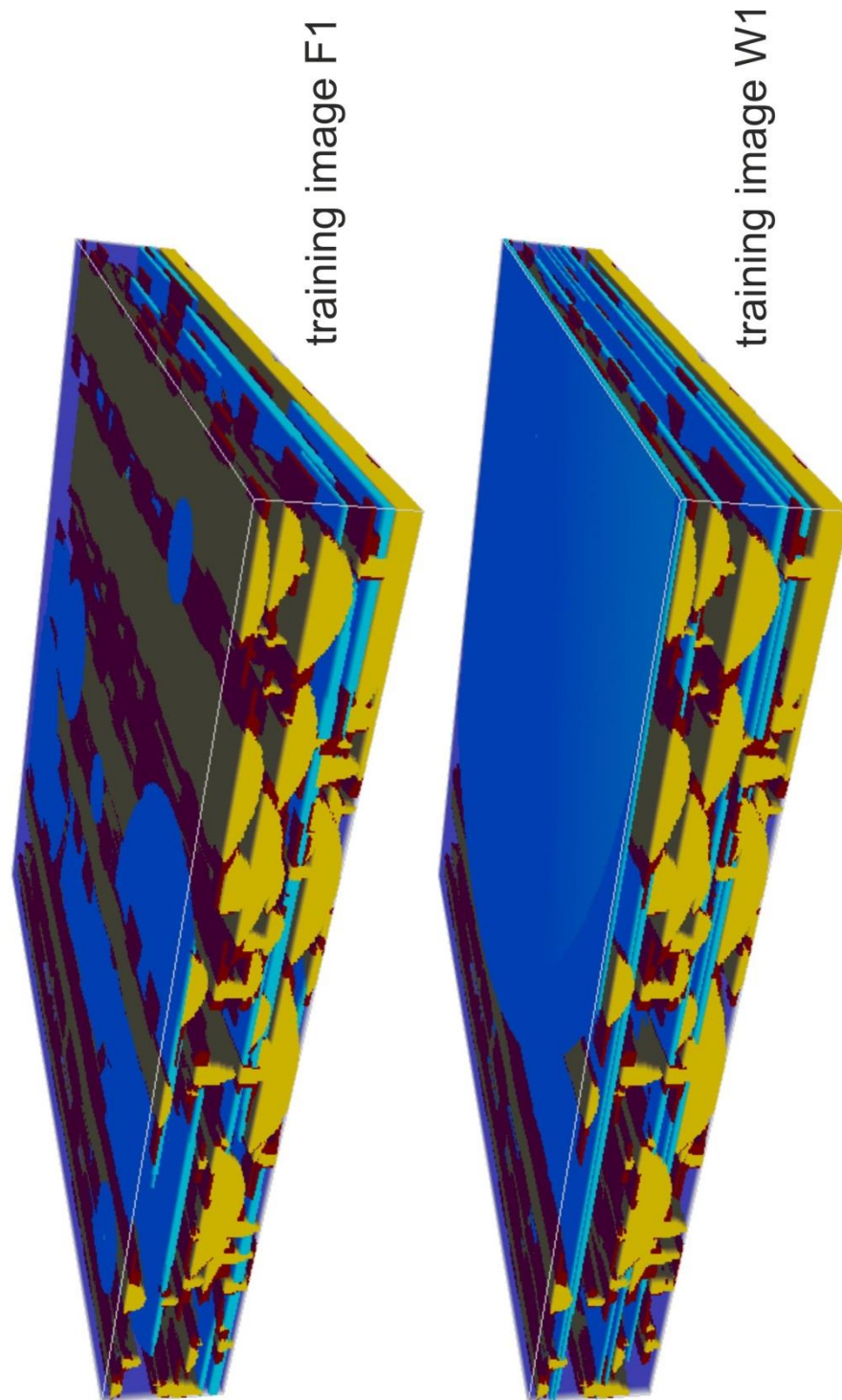


Figure 6.13: training images W1 to W5, including analogue knowledge from classified FAKTS systems combined with geometrical information about WSG coal bodies by Morris & Martin (2012). See main text for further explanation.



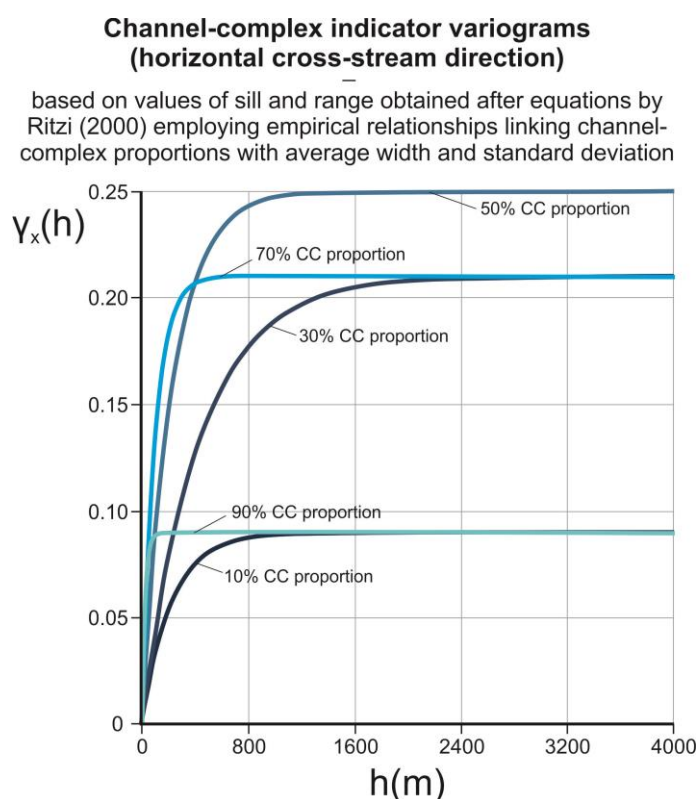




**Figure 6.14:** comparison between training images F1 and W1; legend, volume size and vertical exaggeration are as in figure 6.12 and figure 6.13, floodplain fines are transparent. Above: training image F1, including analogue knowledge from all FAKTS systems. Below: training image W1, including analogue knowledge from all FAKTS systems combined with coal-body geometries as given by Morris & Martin (2012) for the WSG. The larger average horizontal extent of the coal-bodies (light-blue units) as compared to training image F1 is evident.

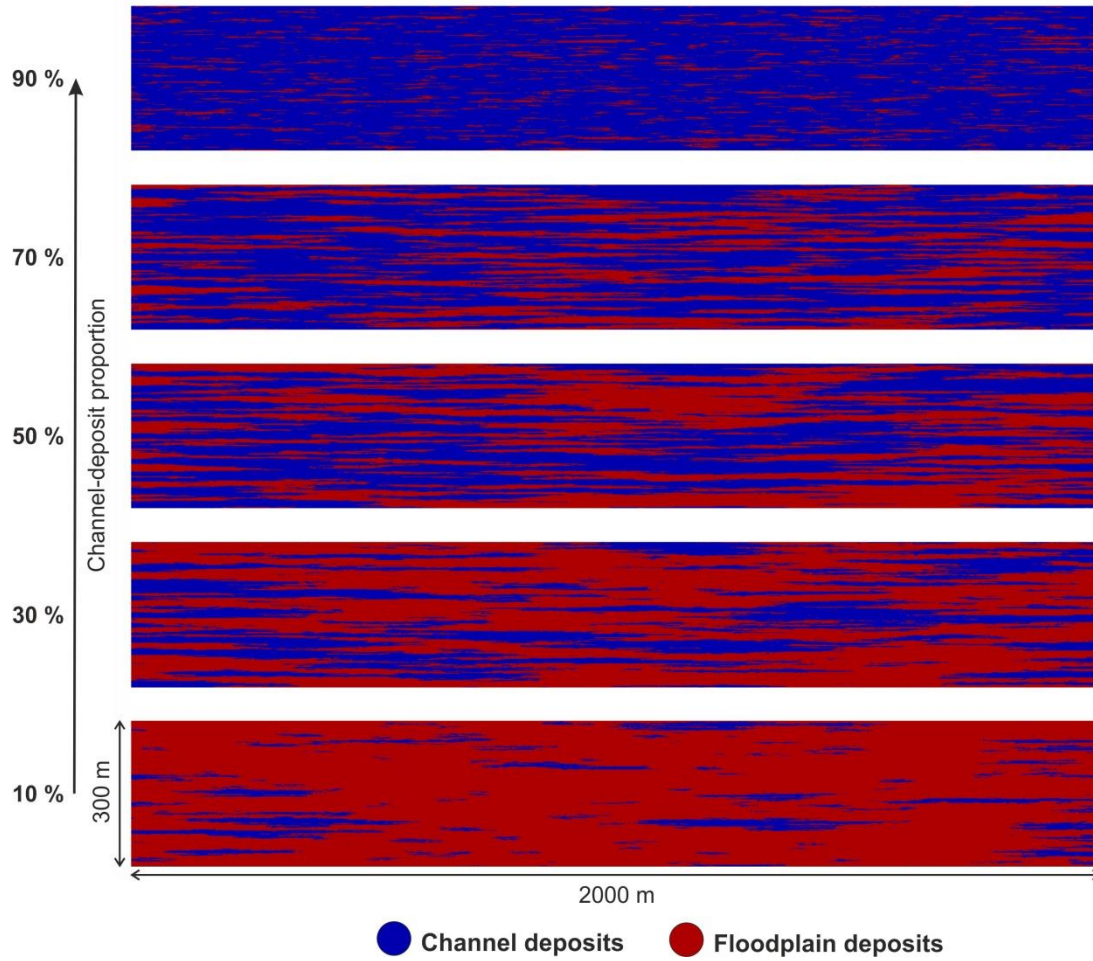
## 6.7 Informing variogram-based simulations of fluvial architecture through empirical relationships linking channel-complex geometries and proportions

In Chapter 5, empirical relationships linking channel-complex depositional-element width descriptive statistics (mean, and standard deviation) with proportions were presented as means to guide the prediction of the lateral extent of channel sandstones as a function of net-to-gross within stratigraphic volumes. The same relationships have been employed here to derive range, sill and model for indicator auto-variograms for the horizontal cross-stream direction for channel-complexes (figure 6.15), whereas corresponding relationships (cf. digital appendix D4) have been used to derive the same indicator-variogram parameters for floodplain depositional elements, following the methodology based on the work by Ritzi (2000). These horizontal indicator variogram models could be employed in real-world situations by coupling them with indicator variograms for the vertical direction, which could be readily derived through the common curve-fitting approach applied to well data.

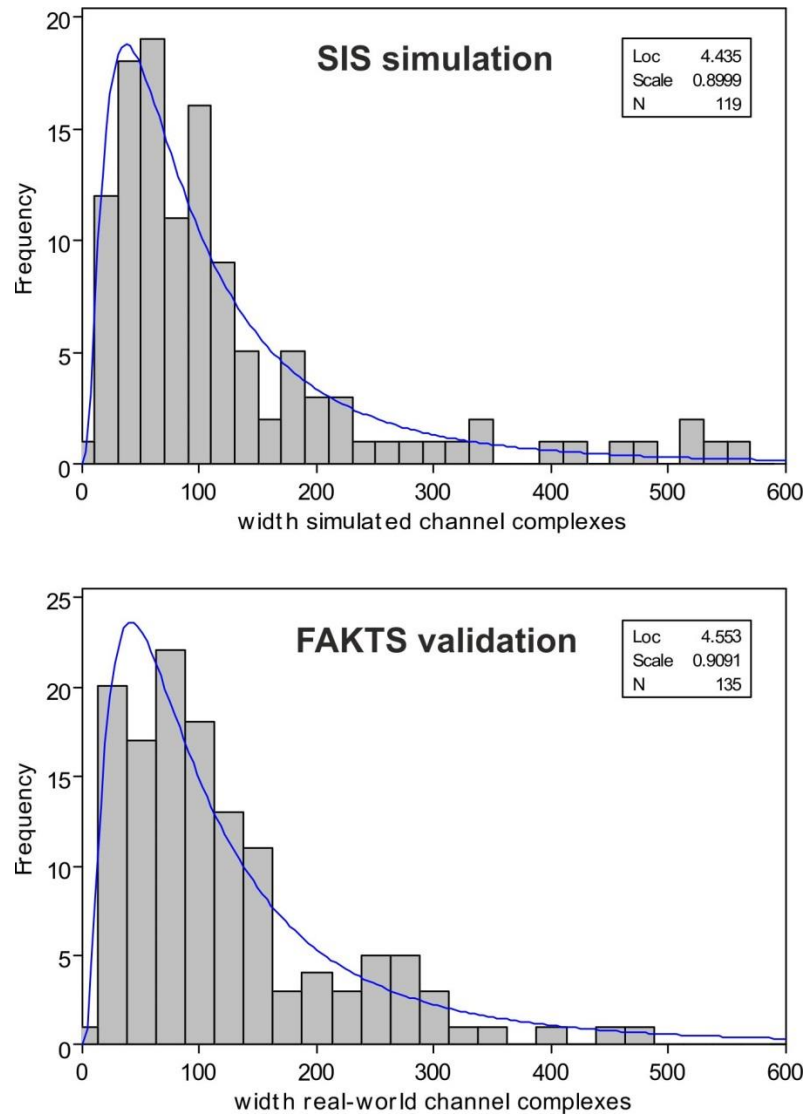


**Figure 6.15:** indicator auto-variograms for channel-complex units referring to volumes with variable proportions of channel deposits ('CC proportion' in labels); the variograms are based on model types, sill values and range values derived from channel-complex proportions and empirical relationships describing channel-complex descriptive statistics (mean, standard deviation and coefficient of variation) as functions of channel proportion.

Here, this approach has been used to simulate the sedimentary architecture of ideal fluvial systems with variable proportion of channel deposits with a SIS algorithm (SISIM; Deutsch & Journel 1998). The same work undertaken to obtain horizontal variograms has been performed for the vertical direction for material units built from channel complexes, by employing relationships linking channel-complex connected thickness with proportion (cf. digital appendix D4), and the same vertical range value has been applied to floodplain depositional elements for sake of simplicity. Results are presented in the form of simulated (2 km wide x 0.3 km high) cross sections for 20% channel-proportion increments in the 10/90% range of channel abundance (figure 6.16). This approach to guiding SIS modelling of fluvial architecture could be applied to cases of aquifer/reservoir modelling for which only well-derived information about thickness and proportion is available. For the cases of high channel-deposit proportion, the same approach to the generation of unconditional SIS simulations would be more appropriately informed by making use of indicator variograms based on empirical relationships linking the connected thickness of floodplain depositional elements to their proportion. The validity of the approach has been tested for the modelled stratigraphic section with 10% channel deposits: the simulated section has been segmented into channel complexes, following the definition given by the FAKTS standard, and the distribution in cross-stream width of the modelled channel complexes has been compared with the distribution in channel-complex width derived from all FAKTS stratigraphic volumes characterized by channel-deposit proportion in the 8.5/11.5% range. Results of the validation (figure 6.17) demonstrate that there is a good match between the best-fit lognormal distributions of channel-complex width from the model and the real-world data, suggesting the value of this empirical method for uncertainty quantification of poorly-characterized subsurface fluvial successions.



**Figure 6.16:** ideal cross-gradient-oriented cross-sections representing large-scale fluvial sedimentary architecture for variable proportions of channel deposits; these geostatistical simulations have been obtained by SIS conditioned by indicator variograms informed by empirical relationships linking channel-complex lateral extent to their proportion within stratigraphic volumes.



**Figure 6.17:** comparison between the distribution of channel-complex width (expressed in metres) derived from the cross-section obtained by SIS simulation of an ideal system with 10% channel deposits and the distribution of channel-complex width derived from all stratigraphic volumes included in FAKTS and displaying a proportion of channel deposits of  $10\% \pm 1.5\%$ . Best-fit lognormal distribution functions have been also included, and their location and scale parameters have been reported in the upper-right box.

## 6.8 Conclusions

A new approach is proposed for conditioning stochastic simulations of the sedimentary heterogeneity of fluvial reservoirs: it makes use of a relational database that includes literature- and field-derived fluvial architectural data from studies of both modern rivers and ancient successions, recording every fundamental architectural feature (style of internal organization, geometry, spatial distribution and reciprocal relationships of genetic units), and classifying datasets – or parts thereof – according to both controls and context-descriptive characteristics.

The novel features embedded in the database conceptual model and design give rise to important advantages over traditional databases describing sedimentary architecture, making it a valuable tool for providing tightly constrained input parameters for use in the development of fluvial reservoir models. The major advantages are as follows:

- it is possible to apply a variety of filters with which to sort the fluvial data into synthetic analogues having boundary conditions corresponding with the depositional system to be modelled;
- sedimentary architecture is represented by means of genetic units corresponding to different scales nested in a hierarchical fashion. This permits (i) the choice of different modelling categories corresponding to different scales of heterogeneity, and (ii) the adoption of a hierarchical approach to simulation according to which smaller-scale features are sequentially simulated within larger-scale features (e.g. lithofacies within channel-fills distributed within channel-complexes; cf. Deutsch 2002);
- it is possible to build any type of material unit (defined as contiguous volumes of sediment characterized by given values of any categorical and/or continuous variable) to be used as modelling categories and to derive associated proportion, dimension and transition statistics;
- it is possible to derive relative dimensional parameters (i.e. dimensions of a given object expressed as a fraction relative to the dimension of an adjacent object) with which to condition object-based simulations; this is done by querying the database for dimensions of genetic units whose juxtaposition is tracked in the form of transitions in the vertical, dip and strike directions;
- it is possible to generate models of indicator auto- and cross-variograms – from data on material unit dimensions, proportions and transitions – with which to constrain variogram-based simulations whenever empirical curve-fitting is not applicable (this is most useful in horizontal directions);
- it is possible to obtain embedded transition frequency/probability matrices for material/genetic units (vertical, strike and dip directions) with which to constrain Markov chain-based simulations or with which to derive transition patterns that can be used to establish lithotype rules or contact matrices for plurigaussian simulations;
- it is possible to employ database-derived output with which to fully constrain unconditional simulations (i.e. simulations that are not conditioned to direct

data) of fluvial architecture and to use the resulting realizations as 3D training images for multiple-point statistics simulations;

- database-derived empirical relationships relating descriptive statistics of the geometry of material units to their proportion in a stratigraphic volume can be used to inform indicator auto-variograms, which can then be used to condition pixel-based simulations of fluvial architecture in poorly-characterized subsurface contexts.





## 7 Conclusions

This Thesis has provided an account of a research initiative that has an overarching aim to demonstrate how a relational database can practically be employed as a means for the digital storage of fluvial sedimentary architectural data, and how such a database can be useful for addressing topical issues in both pure and applied sedimentological research by employing database-derived information in a series of applications. Specifically, as shown throughout Chapters 3-6, different database-oriented lines of research have been undertaken with regard to (i) fluvial facies models, (ii) fluvial physical stratigraphy models, (iii) well-to-well correlation of fluvial geobodies, and (iv) stochastic structure-imitating simulations of fluvial sedimentary architecture. The applications presented all make use of database output and often share part of a common work-flow, but results are necessarily independent and are therefore summarized separately in the following paragraphs.

### 7.1 Summary

**Chapter 2** described the database methodology for the digitization of fluvial sedimentary architecture. The focus was on how the database design permits the reproduction of the natural complexity of fluvial depositional architecture through a series of related tables, and on the range of information that can be obtained from this type of database through interrogation. Thus, the database design was presented as a potential reference for the development of similar systems (cf. Naumann 2012) – even for other depositional contexts – and was explained by presenting the way features in the conceptual scheme of the database (e.g. hierarchical relationships between geological units) were implemented in the logical scheme (e.g. relationships between tables reproducing geological hierarchical relationships). The FAKTS database, has built on data obtained by studies consisting of both original fieldwork carried out by the author (or colleagues working in the Fluvial Research Group) and published peer-reviewed articles of both modern rivers and ancient successions. The database has been designed to capture geometries, bounding-surface information, style of internal organization, spatial distribution and reciprocal relationships of genetic units. In order of descending scale, the three orders of reciprocally-nested database building blocks that are recorded consist of (i) ‘depositional elements’ and (ii) ‘architectural

elements', which are both interpretative in nature, and (iii) 'facies units', which form more objective lithology-based entities. The database design allows for the inclusion of both quantitative and qualitative data, and permits the classification of case studies or of any part thereof on the basis of context-descriptive parameters (e.g. channel-pattern type) or boundary conditions (e.g. subsidence rate). A major strength of the database lies in its flexibility to deal with both system and genetic-unit classifications: assignment of units to classified stratigraphic volumes can be edited to reflect improved understanding and multiple classifications can be adopted contemporaneously, although the segmentation of the architecture into interpretative units (especially architectural elements) still relies on the recognition of bounding surfaces marking a transition in interpreted preserved sub-environment, which may not be trivial. The adoption of a practical geometrical approach for the distinction of depositional elements in the FAKTS database serves as an example of how architecture definition can be considered to facilitate the inclusion of subsurface case studies (well and seismic data). The chapter finally provided an overview of the most general output that can be obtained through database queries and that can be employed in several applications, as discussed in the subsequent chapters.

**Chapter 3** focussed on how to employ the database to generate quantitative multi-scale fluvial facies models, consisting of sets of information concerning proportions, geometries, hierarchical organization, spatial relations and grain sizes of FAKTS' genetic units. Information is synthesized into the models from a range of suitable FAKTS case studies, selected by filtering the database on the parameters on which the models need to be categorized. The approach was demonstrated by presenting example models classified on dominant grain size, channel pattern, basin humidity and water-discharge regime, as well as facies models relating to individual sub-environments. Collectively, these examples showed the main improvements over traditional qualitative facies models. Such advantages and improvements include: (i) the quantification of architectural characteristics, (ii) the more objective nature of the process of distillation of sedimentological information into the model, (iii) the possibility to include variability- and knowledge-related uncertainty in the model, (iv) the capacity to discriminate modern- and ancient-system input to each model, and (v) the possibility to retrieve original model-forming information associated with each individual system or genetic unit. The models presented can act as references for comparison, interpretation and subsurface prediction for those particular environmental types, similar to any other facies model. However, the chapter mainly used the example models to stress the significance of the approach for related research purposes. For example, the system can be employed to define the types of models with the highest predictive power. In the published literature it is common

to encounter a tendency to force interpretations of fluvial successions in terms of dominant channel/river pattern, even though objective elements on which to base interpretations may be scarce, especially in subsurface datasets. This widespread practice stems from the implicit assumption that channel-pattern categories are associated with the most distinctive suites of architectural styles; in other words, it is commonly implied that channel pattern-based facies models incorporate the largest architectural variability between different types and the minimum architectural variability within types, making them the most suitable models to be used as predictive tools. As shown in the chapter through a comparison between 'single-thread' and 'braided' models, database-derived facies models permit the inclusion of quantified architectural variability within the model itself, therefore potentially enabling the recognition of environmental classes that are most suitable for model classification, as well as allowing uncertainty quantification. Furthermore, this has implications concerning the need to overcome the excessive proliferation of facies models, as resulting models do not require advocating equally-classified alternative models to account for architectural variability. The system is evidently also applicable to other problems, such as the identification of gaps in the characterization of specific system types or the assessment of the possible role played by preservation potential in the facies organization of specific fluvial sedimentary units.

**Chapter 4** described the use made of FAKTS in a comparative study of the architectural organization of various systems with the aim to investigate the value of system-wide aggradation rate as a predictor of fluvial architecture. In effect, the work is a test of commonly considered physical stratigraphy models predicting an inverse relationship between the rate of basin-wide aggradation and the density of channel bodies in a fluvial succession, on the basis of the recognition of floodplain reworking by mobile and avulsive channels as the main process controlling channel amalgamation. In a broader context, this served as an example of a way in which the database could be employed to study relationships between architectural products and controls (in-as-much-as aggradation rate can be considered as indicative of the rate of generation of subaerial accommodation, and subaerial accommodation can be considered as a pure control – which is debatable). The analysis included architectural data consisting of depositional-element proportions, geometries and vertical connectivity as obtained from stratigraphic volumes deposited over a  $10^{-1}$ - $10^1$  Ma timescale, drawn from a series of large-scale architecture studies for which temporal constraints were available. Results showed that for the depositional systems considered, temporal variations in aggradation rates and channel-deposit proportions do not regularly follow inverse proportionality; instead, increases in aggradation rate are dominantly associated

with increases in channel density – and *vice versa*. Quantities describing changes in channel-complex geometries and vertical connectivity within systems undergoing temporal variations in aggradation rates also contradict predictions expected by common fluvial architecture models. These results only relate to relatively few case studies from a limited number of depositional settings, and therefore clearly need to be substantiated by incorporation of additional primary data. However, on the basis of these findings it is possible to claim that existing fluvial architecture models may be the exception rather than the rule, and that there is thus need for reconsideration of sequence stratigraphy models and practice (such as the definition of accommodation-based stratigraphic packages based on variations in channel-body density or geometry) that currently rely heavily upon unproven assumptions.

In **Chapter 5** the focus shifted to subsurface applications of the FAKTS database. The use of outcrop analogues as natural templates for informing subsurface predictions is a well established practice, and so is the creation of outcrop analogue databases, typically storing geometrical information; thus, in this chapter and in the subsequent Chapter 6, the main scope was to propose new ways in which the FAKTS architectural database could be employed in workflows for forecasting fluvial reservoir or aquifer sedimentary architecture. Chapter 5 specifically dealt with the use of analogue data as a means to guide well-to-well correlations of fluvial channel bodies, therefore restricting its scope to large-scale sedimentary architecture. First, database output concerning channel complexes was used to test the predictive value of previously-published empirical relationships meant to be used to predict the likely lateral extent of individual fluvial channel bodies, on the basis of inferred palaeo-hydrological information or observed geometrical data. Results showed the considerable uncertainty associated with the use of such relationships as a guide to well correlation, therefore highlighting the need for a way to quantify the realism of the resulting correlation panels, rather than the likely size of each of the individual sandstone bodies. To fulfil this necessity, in the rest of this chapter a novel probabilistic method was introduced to assess the geological realism of subsurface deterministic models constructed on correlations across well arrays with constant spacing, demonstrating from first principles how outcrop analogue data are incorporated into models that quantify the correlability of fluvial channel complexes. Such ‘correlability models’ are expressed as the ratio between expected correlatable and penetrated bodies as a function of correlation distance, and are obtained from total probabilities of penetration and correlation, which are themselves dependent on the distribution of lateral extent of the channel complexes. Thus, employing outcrop-analogue data to constrain the width distribution of the bodies, it is possible to generate a model that describes realistic well-to-well correlation patterns for a given type of depositional system and well-

array spacing. Correlability models can be used for checking the quality of correlation-based subsurface interpretations, by assessing their geological realism as compared with one or more suitable outcrop analogues. The flexibility of the approach was illustrated by generating total-probability curves that refer to channel complexes and that are categorized on different classifications (e.g. braided river system, system with 20% channel deposits). The method was specifically applied to rank three published alternative interpretations of a stratigraphic interval of the Cretaceous Travis Peak Formation (Texas, USA), in terms of realism of correlation outcomes as compared to (i) all analogues recorded in the database and considered suitable for large-scale architectural characterization, and (ii) analogues interpreted exclusively as the sedimentary expression of braided systems.

**Chapter 6** focussed on the application of the database to inform stochastic structure-imitating simulations of subsurface fluvial sedimentary architecture at different scales. Database output was employed to define a range of different parameters that collectively demonstrated how the system is able to provide more sophisticated constraints than solely descriptive statistics of genetic-unit geometries, which is the typical information offered by outcrop-analogue databases. This capability is related to database design: an important implication is that the system can be used for conditioning both object- and pixel-based modelling methods, again making use of filtered information to define synthetic analogues that match the subsurface in terms of boundary conditions, context-descriptive parameters and/or architectural properties. Object-based simulations can be constrained by database-derived absolute dimensional parameters, exemplified in the chapter by information referring to the thickness and width-to-thickness aspect ratio of different orders of channelized units, and relative dimensional parameters, expressed as the fractional dimension of a given genetic unit relative to the dimension of another adjacent and genetically-related genetic unit, even belonging to a different scale, as shown in the chapter by the relative thickness of crevasse-splay elements and channel-fill elements or complexes. FAKTS' capability of keeping track of unit spatial relationships was used to derive information regarding 'material units', defined as rock volumes characterized by given values of any categorical and/or continuous variable. Such information was then employed to the generation of indicator auto- and cross-variograms (model, range and sill) for the vertical, strike and dip directions, referring to material units based on depositional-element and facies-unit types; variogram-based geostatistical methods can thereby be conditioned without requiring the empirical curve fitting of well data. Furthermore, database output referring to transition statistics of facies units was presented as information with which to directly inform Markov chain-based simulations or with which to define spatial patterns to be used to generate lithotype

rules or contact matrices for plurigaussian simulations. To illustrate the use of FAKTS as a tool for informing multi-point statistical (MPS) simulations, database-derived information from variably defined synthetic analogues was used to generate a set of stochastic realizations representing alternative training images that – together with facies-proportion curves – are meant to be utilized for MPS modelling of the large-scale subsurface architecture of the Jurassic Walloon Coal Measures (Surat Basin, Australia). Finally, a set of empirical relationships (presented previously in Chapter 5) relating descriptive statistics of the geometry of depositional elements to their proportion in a stratigraphic volume were used to inform indicator auto-variograms, which were then used to condition sequential indicator simulations of ideal fluvial architecture, to exemplify the application of such relationships to the simulation of the large-scale architecture of subsurface fluvial systems for which only well-derived channel-deposit proportion is known.

## 7.2 Future research

The work presented in this Thesis has set the stage for further progress in the application of a database-approach to the characterization of fluvial sedimentary architecture and in its use to pursue both pure and applied forms of research.

The value of a relational database as a means for the digitization of sedimentary architecture would certainly benefit from several improvements in the database design, and several such modifications could be easily implemented in the FAKTS database itself. Some possible improvements are listed below, and how the approach would benefit from their inclusion is also elucidated.

- The inclusion of descriptors of the 2D/3D shape of genetic units, relating to cross-sectional, planform and/or 3D types, would permit a fuller characterization of architectural styles and would therefore enhance database-derived facies models and provide additional information for stochastic models that attempt to simulate subsurface complexity.
- The addition of non-fluvial genetic-unit types (e.g. aeolian architectural-element types) to the FAKTS classification schemes would allow for quantitative investigations of the relationships of interaction between such units and fluvial/alluvial units.
- The inclusion of attributes describing petrophysical (essentially porosity and permeability) and diagenetic properties could find several applications; importantly, it would be possible to further improve the quantitative characterization of aquifer or reservoir analogues, to tentatively assess the

role of external and architectural controls on small-scale reservoir quality, and to employ the information in dynamic modelling of fluid flow in fluvial porous media that could serve various purposes (e.g. assess architectural controls on water-flood performance, generate models of dynamic connectivity for classified fluvial system types).

- The inclusion of additional metadata that could be used for improving the way the database links additional bibliography to depositional-system classifications would be useful to inform choices about possible system reclassification once additional evidence becomes available.
- A significant improvement would be given by the redefinition of stratigraphic volumes into several orders of volume types, so that each type would embody a different time scale, in a way that would permit the same genetic unit to be contained within different volumes. This would effectively allow users to be able to investigate architecture at different timescales, so that database output could potentially be used to identify the effects of timescale-dependent controls. Attributes referring to each order of stratigraphic volume could then be considered as averaged over that given timescale. Although this modification would ideally broaden the database capabilities, the common lack of temporal constraints on sedimentary succession at different scales would currently make this functionality of only limited use.

Even with the database in its current form, most of FAKTS applications explored in this Thesis demonstrate the need for more architectural data, as well as additional soft data with which to further constrain the classification of included depositional systems. In particular, the progressive inclusion of additional primary data to the database is required to permit the generation (or update) of deliverables of the type presented here (e.g. facies models, relationships and models for subsurface application). Additionally, in the current state, depositional systems are only partially characterized in terms of boundary conditions controlling their architecture and relevant information has variable quality: this considerably hinders database applications, especially with regard to comparative studies aiming to determine the sensitivity of sedimentary architecture to its controls or to assess the value of possible architectural predictors.

As the database grows, some future results will consist in the refinement and further development of several of the outcomes presented in this work. For example, it will be possible to obtain facies models referring to other types of depositional systems or sub-environments than the ones presented in this Thesis. It ought to be possible to develop more sophisticated correlability models associated

with different deposystem classes or relating to different genetic/material units (e.g. channel-levee-splay sandstones). However, additionally the database approach to architectural characterization could also find several applications that have not been treated in this Thesis.

The assessment of architectural sensitivity to given controls – only marginally treated in this work – could be a far-reaching objective if the project was taken further; this is the type of application that crucially requires more of both the hard and soft data mentioned above. Future work in this direction could possibly make use of multivariate analysis that simultaneously involves several dependent and independent variables as a means to test the effect of different controls. Yet, to attempt this, it is first imperative to overcome the current deficiency of knowledge on the characteristics on which depositional systems are classified.

From a more applied perspective, the sets of quantitative information associated with database-derived facies models could be employed to constrain unconditional stochastic simulations of the sedimentary architecture of fluvial system types at several scales, so that the resulting realizations could be investigated in terms of the static connectivity of their formative genetic units that are deemed as being of appropriate reservoir or aquifer quality. It would thereby be possible to derive a suite of scenarios that quantify static connectivity for various types of fluvial depositional systems, possibly offering the opportunity to assess the sensitivity of static connectivity to system boundary conditions, to architectural characteristics and to the inclusion of several scales of heterogeneity (cf. Larue & Hovadik 2006). The same stochastic architectural realizations could be subjected to dynamic flow modelling, involving mono- and multi-phase fluids, provided that information about typical genetic-unit porosity and permeability is available. Results could be used to generate models characterizing dynamic reservoir behaviour during hydrocarbon production for different types of fluvial depositional systems, thereby providing likely scenarios of reservoir performance to be used as predictive templates. Database-informed water-flood simulations could find application to general research questions concerning enhanced oil recovery (cf. Larue & Friedmann 2005): by varying architectural and petrophysical properties within realistic ranges dictated by database output, it ought to be possible to assess the role played by these properties in controlling reservoir behaviour (cf. Howell et al. 2008; Enge & Howell 2010; for non-fluvial outcrop-informed examples). For example, it is imperative to understand what types of fluvial sedimentary features consisting of genetic units or associations of genetic units generate “thief zones” (highly permeable zones through which the injection water is preferentially channelled) that cause early water breakthrough in high net-to-gross contexts with significant permeability



heterogeneity. Such an approach will enable assessment of the types of depositional systems in which such features and processes are likely to occur.

Furthermore, an important part of future research could be represented by the generalization of the database approach presented in this work through its application to other clastic (and possibly non-clastic) depositional contexts. The same types of applications presented here could then be extended, for instance, to the deep- and shallow-marine realms. However, the FAKTS database design may not necessarily be directly transferable (portable) to other sedimentary environments, and the development of different conceptual and logical schemes is likely to be required. For example, if a similar database system was created for the digitization of the sedimentary architecture of deep-water depositional systems, it would be necessary to take into account issues such as the lack of consensus as to how to assign genetic units to a hierarchical scheme, or as to whether sedimentary units are organized in a fractal rather than hierarchical manner (cf. Straub & Pyles 2012). Thus, although it is clear that the system would equally need to reproduce geometries, bounding-surface information, internal organization, spatial and reciprocal relationships of genetic units, and spatial and temporal relationships of stratigraphic volumes, it would still be necessary to devise new ways to best implement such features for the different sedimentary environments.



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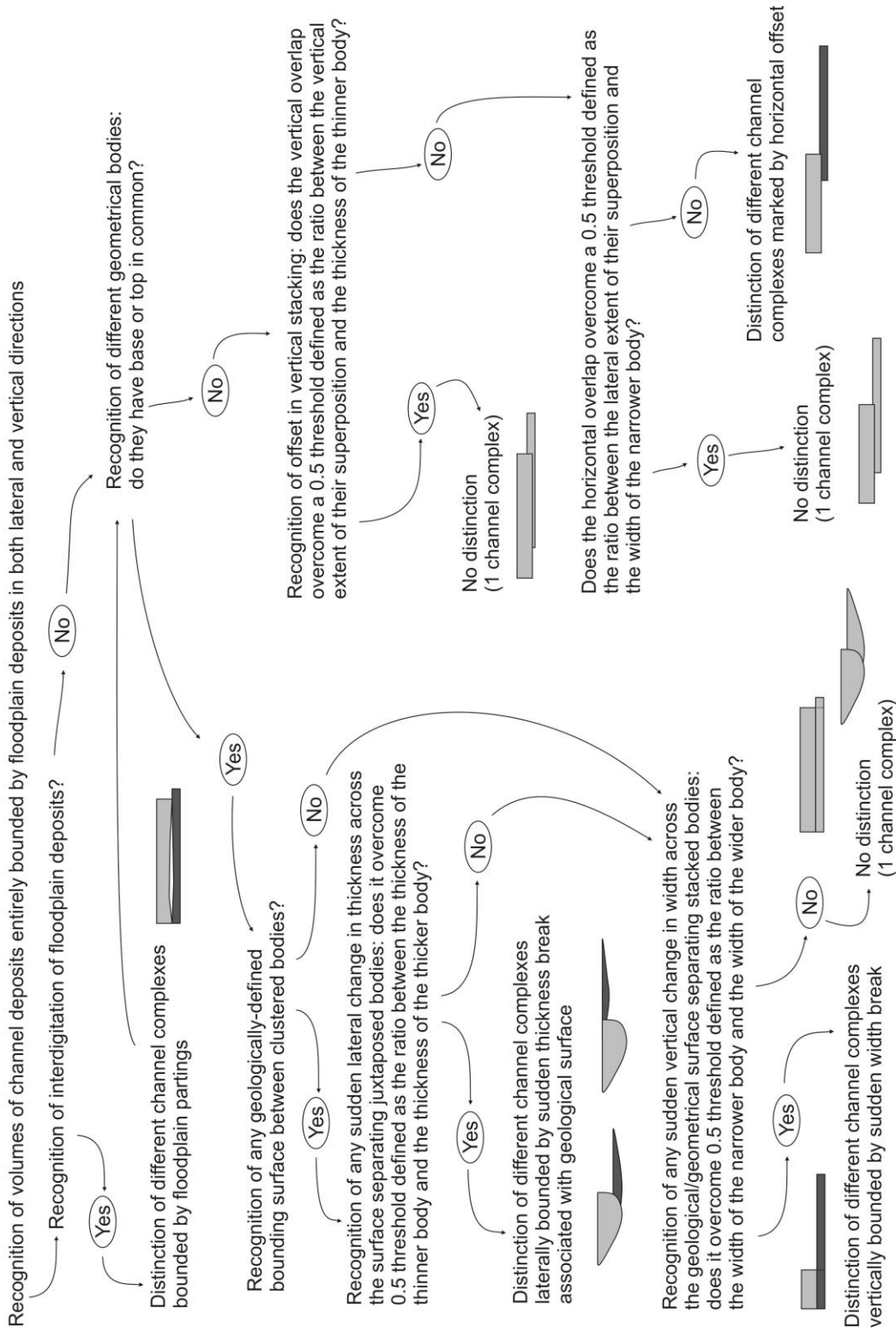
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## **Appendix A: schematic guidelines to the definition of channel complexes**

To guide the segmentation of fluvial stratigraphy into FAKTS' large-scale depositional elements, a set of geometrical rules have been established. The diagram presented in the following page summarizes the criteria that are used for subdivision of fluvial-channel deposits into different channel complexes. Rules based on cut-off values are meant to be applied to 2D cross-sectional datasets ideally oriented orthogonally to the gradient direction. The rules are presented in the order they need to be followed.

**GUIDELINES FOR THE GEOMETRICAL DEFINITION OF CHANNEL COMPLEXES (geological criteria may also apply independently)**



## **Appendix B: example SQL queries for database interrogation**

This appendix contains a series of example SQL queries that can be adopted as templates for database interrogation. The queries themselves and brief explanations of the output returned by each query are given. The same set of queries is also included as a digital appendix (D3), consisting in a compilation of SQL files, each of them named as *tg\_n*, where *n* follows the numbering given in the following list. The queries are listed according to the type of output they generate, grouped into 'metadata', 'unit dimensions', 'unit proportions', and 'unit transitions'.

## Metadata

### tq\_31 – General metadata: reference, case history, number of genetic units

```

create temporary table case_IDs as select distinct
a_source_data.case_ID, a_source_data.authors, a_source_data.year,
a_source_data.lithostratigraphic_unit as 'lithostratigraphic_unit', a_source_data.river
from a_source_data join b_subsets on a_source_data.case_ID = b_subsets.case_ID;
create temporary table dep_el_nr select a_source_data.case_ID,
COUNT(c_1_depositional_elements.dep_el_type) as 'nr_of_depositional_elements'
from a_source_data join b_subsets on a_source_data.case_ID = b_subsets.case_ID
join c_1_depositional_elements on b_subsets.subset_ID =
c_1_depositional_elements.subset_ID
group by a_source_data.case_ID;
create temporary table arch_el_nr as select a_source_data.case_ID,
COUNT(e_2_architectural_elements.arch_el_type) as 'nr_of_architectural_elements'
from a_source_data join b_subsets on a_source_data.case_ID = b_subsets.case_ID
join c_1_depositional_elements on b_subsets.subset_ID =
c_1_depositional_elements.subset_ID join e_2_architectural_elements on
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID
group by a_source_data.case_ID;
create temporary table facies_nr as select a_source_data.case_ID,
COUNT(g_3_facies.facies_ID) as 'nr_of_facies_units'
from a_source_data join b_subsets on a_source_data.case_ID = b_subsets.case_ID
join c_1_depositional_elements on b_subsets.subset_ID =
c_1_depositional_elements.subset_ID join e_2_architectural_elements on
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID
join g_3_facies on e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID
group by a_source_data.case_ID;
create temporary table statistics_nr as select a_source_data.case_ID,
COUNT(i_subset_statistics.statistic_ID) as 'nr_of_statistical_parameters'
from a_source_data join b_subsets on a_source_data.case_ID = b_subsets.case_ID
join i_subset_statistics on b_subsets.subset_ID = i_subset_statistics.subset_ID
group by a_source_data.case_ID;
select case_IDs.case_ID, case_IDs.authors, case_IDs.year,
case_IDs.lithostratigraphic_unit, case_IDs.river,
dep_el_nr.nr_of_depositional_elements, arch_el_nr.nr_of_architectural_elements,
facies_nr.nr_of_facies_units, statistics_nr.nr_of_statistical_parameters
from case_IDs left join dep_el_nr on case_IDs.case_ID = dep_el_nr.case_ID
left join arch_el_nr on case_IDs.case_ID = arch_el_nr.case_ID
left join facies_nr on case_IDs.case_ID = facies_nr.case_ID
left join statistics_nr on case_IDs.case_ID = statistics_nr.case_ID;

```

For each case study, it returns: authors, year of publication/data-acquisition, the lithostratigraphic units or the river where the data come from, the number of not-undefined depositional element, the number of not-undefined architectural elements, the number of all the facies units, and the number of entries as statistical parameters.

### tq\_33 – Identifiers of gravel dominated case studies

```

create temporary table facies_t as select case_ID, g_3_facies.facies_type,
g_3_facies.thickness from b_subsets join c_1_depositional_elements on
b_subsets.subset_ID = c_1_depositional_elements.subset_ID
join e_2_architectural_elements on c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID join g_3_facies on
e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID;
create temporary table facies_t2 as select facies_t.case_ID, facies_t.facies_type,
sum(thickness) sum from facies_t group by facies_type, case_ID;
create temporary table facies_t3 as select facies_t2.case_ID, sum(sum) total from
facies_t2 group by case_ID;
create temporary table chosen_cases as select facies_t2.case_ID, sum(sum) partial
from facies_t2 where facies_type like '%G%' group by case_ID;
select distinct chosen_cases.case_ID from chosen_cases join facies_t3 on
chosen_cases.case_ID = facies_t3.case_ID where partial/total > 0.5;

```

It returns the identifiers of the case studies dominated by gravel-size deposits (more than 50% by thickness).

## Unit dimensions

### tq\_05 – Channel-complex thickness and aggradation rates

```
SELECT `dep_el_type`, `thickness`, b_subsets.mean_aggradation_rate
FROM b_subsets JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID WHERE b_subsets.mean_aggradation_rate IS NOT
NULL AND thickness IS NOT NULL AND dep_el_type = 'Channel-complex'
ORDER BY mean_aggradation_rate;
```

It returns channel-complex thicknesses and subset aggradation rates, ordered by aggradation rates.

### tq\_11 – Channel-complex thickness, width, DQI

```
SELECT `dataset_DQI`, `dep_el_type`, `thickness`, `width`
FROM a_source_data JOIN b_subsets ON a_source_data.case_ID = b_subsets.case_ID
JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID WHERE thickness IS NOT NULL AND width IS NOT
NULL AND dep_el_type = 'Channel-complex' ORDER BY dataset_DQI;
```

It returns channel-complex thicknesses and widths (where not null) ordered according to DQI ranking.

### tq\_07 – Channel-complex geometries from individual case study

```
SELECT `dep_el_type`, `thickness`, `width`, `unlimited_width`, `partial_width`,
`apparent_width` FROM a_source_data JOIN b_subsets ON a_source_data.case_ID =
b_subsets.case_ID JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID WHERE thickness IS NOT NULL AND dep_el_type =
'Channel-complex' AND a_source_data.case_ID = 23 AND (width IS NOT NULL OR
apparent_width IS NOT NULL OR partial_width IS NOT NULL OR unlimited_width IS NOT
NULL);
```

It returns dimensional parameters (all classes of width + thickness, where not null) for channel-complexes belonging to a given case study (here: case\_ID = 23).

### tq\_10 – SF architectural-element geometries from individual case

```
SELECT arch_el_type, e_2_architectural_elements.thickness,
e_2_architectural_elements.width, e_2_architectural_elements.apparent_width,
e_2_architectural_elements.partial_width, e_2_architectural_elements.unlimited_width
FROM a_source_data JOIN b_subsets ON a_source_data.case_ID = b_subsets.case_ID
JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID
WHERE a_source_data.case_ID = 23 and arch_el_type = 'SF';
```

It returns dimensional parameters of a given type of architectural element (here: SF), filtered according to the case study (here: case\_ID = 23).

### tq\_01 – Architectural-element thicknesses classified on relative distality

```
SELECT a_source_data.case_ID, a_source_data.authors, b_subsets.subset_ID,
b_subsets.relative_distality, arch_el_type, e_2_architectural_elements.thickness
FROM a_source_data JOIN b_subsets ON a_source_data.case_ID = b_subsets.case_ID
JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID
WHERE a_source_data.case_ID = 9;
```

It returns types and thicknesses of architectural elements, classified according to the relative distality of the subset they belong to, filtered according to the case study (here: case\_ID = 9).

### tq\_08 – Facies-unit original classes, FAKTS classes and thicknesses

```
SELECT b_subsets.subset_ID, b_subsets.relative_distality, original_facies_type,
facies_type, g_3_facies.thickness FROM a_source_data JOIN b_subsets ON
a_source_data.case_ID = b_subsets.case_ID JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID JOIN g_3_facies ON
e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID
WHERE a_source_data.case_ID = 23;
```

It returns thicknesses for facies units belonging to a given case study (here: case\_ID = 23), classified according to both the FAKTS classification scheme and the classification scheme adopted in the original source work; subset relative distality is also shown.

### tq\_21 – Widths of laterally-adjacent CH and LV architectural elements

```
CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
e_2_architectural_elements.arch_el_ID, e_2_architectural_elements.width,
f_2_arch_el_transitions.trans_arch_el_ID, f_2_arch_el_transitions.trans_direction,
e_2_architectural_elements.arch_el_type, f_2_arch_el_transitions.bound_surf_order
FROM e_2_architectural_elements JOIN f_2_arch_el_transitions ON
e_2_architectural_elements.arch_el_ID = f_2_arch_el_transitions.arch_el_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.arch_el_ID,
new_trans_ID.trans_arch_el_ID, IFNULL(new_trans_ID.arch_el_type, 'Undefined') AS
arch_el_type, new_trans_ID.width, IFNULL(e_2_architectural_elements.arch_el_type,
'Undefined') AS transitional_type, e_2_architectural_elements.width AS
trans_el_width, new_trans_ID.trans_direction, new_trans_ID.bound_surf_order
FROM e_2_architectural_elements JOIN new_trans_ID ON
e_2_architectural_elements.arch_el_ID = new_trans_ID.trans_arch_el_ID);
CREATE TEMPORARY TABLE lateral_trans AS( SELECT new_trans_types.arch_el_type,
new_trans_types.width, new_trans_types.transitional_type,
new_trans_types.trans_el_width FROM new_trans_types WHERE trans_direction =
'Lateral' AND ((arch_el_type = 'LV' AND transitional_type = 'CH') OR (arch_el_type =
'CH' AND transitional_type = 'LV')) ORDER BY new_trans_types.arch_el_ID);
SELECT * FROM lateral_trans;
```

It returns widths of strike-laterally neighbouring architectural elements, selected on their element type (here: LV laterally adjacent to CH).

### tq\_30 – Thicknesses of laterally-adjacent channel-complexes and SF architectural elements

```
CREATE TEMPORARY TABLE new_trans_ID AS (SELECT c_1_depositional_elements.dep_el_ID,
c_1_depositional_elements.dep_el_type, e_2_architectural_elements.arch_el_ID,
c_1_depositional_elements.thickness, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, e_2_architectural_elements.arch_el_type,
f_2_arch_el_transitions.bound_surf_order FROM c_1_depositional_elements
JOIN e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID JOIN f_2_arch_el_transitions ON
e_2_architectural_elements.arch_el_ID = f_2_arch_el_transitions.arch_el_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.dep_el_ID,
new_trans_ID.trans_arch_el_ID, IFNULL(new_trans_ID.dep_el_type, 'Undefined') AS
dep_el_type, new_trans_ID.thickness, IFNULL(e_2_architectural_elements.arch_el_type,
'Undefined') AS transitional_type, e_2_architectural_elements.thickness AS
trans_el_thickness, new_trans_ID.trans_direction, new_trans_ID.bound_surf_order
FROM e_2_architectural_elements JOIN new_trans_ID ON
e_2_architectural_elements.arch_el_ID = new_trans_ID.trans_arch_el_ID);
CREATE TEMPORARY TABLE lateral_trans AS(SELECT new_trans_types.dep_el_ID,
new_trans_types.dep_el_type, new_trans_types.thickness,
new_trans_types.trans_arch_el_ID, new_trans_types.transitional_type,
new_trans_types.trans_el_thickness FROM new_trans_types WHERE trans_direction =
'Lateral' AND dep_el_type = 'Channel-complex' AND transitional_type = 'CS'
ORDER BY new_trans_types.dep_el_ID);
SELECT * FROM lateral_trans;
```

It returns thicknesses of strike-laterally neighbouring depositional and architectural elements, selected on their element type (here: Channel-complex laterally adjacent to CS).



**tq\_25 – Widths of 3 laterally-adjacent CH architectural elements**

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
e_2_architectural_elements.arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, e_2_architectural_elements.arch_el_type
FROM e_2_architectural_elements JOIN f_2_arch_el_transitions ON
e_2_architectural_elements.arch_el_ID = f_2_arch_el_transitions.arch_el_ID
WHERE arch_el_type <> 'CH');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.arch_el_ID,
new_trans_ID.trans_arch_el_ID, IFNULL (new_trans_ID.arch_el_type, 'Undefined') AS
arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, e_2_architectural_elements.unlimited_width,
e_2_architectural_elements.partial_width, e_2_architectural_elements.width,
e_2_architectural_elements.apparent_width, new_trans_ID.trans_direction
FROM e_2_architectural_elements JOIN new_trans_ID ON
e_2_architectural_elements.arch_el_ID = new_trans_ID.trans_arch_el_ID
WHERE trans_direction = 'Lateral' AND (e_2_architectural_elements.width IS NOT NULL
OR e_2_architectural_elements.apparent_width IS NOT NULL OR
e_2_architectural_elements.partial_width IS NOT NULL OR
e_2_architectural_elements.unlimited_width IS NOT NULL));
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_types.trans_arch_el_ID AS
arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types.transitional_type AS
arch_el_type FROM new_trans_types JOIN f_2_arch_el_transitions ON
new_trans_types.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID
WHERE f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.arch_el_ID,
new_trans_ID_2.trans_arch_el_ID, IFNULL (new_trans_ID_2.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, e_2_architectural_elements.width,
e_2_architectural_elements.apparent_width, new_trans_ID_2.trans_direction
FROM e_2_architectural_elements JOIN new_trans_ID_2 ON
e_2_architectural_elements.arch_el_ID = new_trans_ID_2.trans_arch_el_ID
WHERE e_2_architectural_elements.width IS NOT NULL OR
e_2_architectural_elements.apparent_width IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_types_2.trans_arch_el_ID
AS arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types_2.transitional_type AS
arch_el_type FROM new_trans_types_2 JOIN f_2_arch_el_transitions ON
new_trans_types_2.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID
WHERE f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types_2.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.arch_el_ID,
new_trans_ID_3.trans_arch_el_ID, IFNULL (new_trans_ID_3.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, e_2_architectural_elements.unlimited_width,
e_2_architectural_elements.partial_width, e_2_architectural_elements.width,
e_2_architectural_elements.apparent_width, new_trans_ID_3.trans_direction
FROM e_2_architectural_elements JOIN new_trans_ID_3 ON
e_2_architectural_elements.arch_el_ID = new_trans_ID_3.trans_arch_el_ID
WHERE e_2_architectural_elements.width IS NOT NULL OR
e_2_architectural_elements.apparent_width IS NOT NULL OR
e_2_architectural_elements.partial_width IS NOT NULL OR
e_2_architectural_elements.unlimited_width IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT new_trans_types_3.trans_arch_el_ID
AS arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types_3.transitional_type AS
arch_el_type FROM new_trans_types_3 JOIN f_2_arch_el_transitions ON
new_trans_types_3.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID
WHERE f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types_3.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_4 AS (SELECT new_trans_ID_4.arch_el_ID,
new_trans_ID_4.trans_arch_el_ID, IFNULL (new_trans_ID_4.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_4.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_4 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_4.trans_arch_el_ID WHERE e_2_architectural_elements.arch_el_type <>
'CH');
SELECT DISTINCT new_trans_types.trans_arch_el_ID, new_trans_types.transitional_type,
new_trans_types.unlimited_width, new_trans_types.partial_width,
new_trans_types.width, new_trans_types.apparent_width,
new_trans_types_2.trans_arch_el_ID, new_trans_types_2.transitional_type,
new_trans_types_2.width, new_trans_types_2.apparent_width,
new_trans_types_3.trans_arch_el_ID, new_trans_types_3.transitional_type,

```

```

new_trans_types_3.unlimited_width, new_trans_types_3.partial_width,
new_trans_types_3.width, new_trans_types_3.apparent_width
FROM new_trans_ID JOIN new_trans_types ON new_trans_ID.arch_el_ID =
new_trans_types.arch_el_ID JOIN new_trans_types_2 ON
new_trans_types.trans_arch_el_ID = new_trans_types_2.arch_el_ID
JOIN new_trans_types_3 ON new_trans_types_2.trans_arch_el_ID =
new_trans_types_3.arch_el_ID JOIN new_trans_types_4 ON
new_trans_types_3.trans_arch_el_ID = new_trans_types_4.arch_el_ID
WHERE new_trans_ID.arch_el_ID <> new_trans_types_2.trans_arch_el_ID AND
new_trans_types.trans_arch_el_ID <> new_trans_types_3.trans_arch_el_ID AND
new_trans_types_2.trans_arch_el_ID <> new_trans_types_4.trans_arch_el_ID;

```

It returns the widths (any type) of a group of a given number (here strictly 3) of architectural elements that are laterally juxtaposed and belong to the same element type (here: CH), excluding erosive mutual transitions. This type of query is required for obtaining the cumulative width of material units from the widths of genetic units.

### tq\_26 – Thicknesses of 3 vertically-stacked channel-complexes

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT c_1_depositional_elements.dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
c_1_depositional_elements.dep_el_type FROM c_1_depositional_elements
JOIN d_1_dep_el_transitions ON c_1_depositional_elements.dep_el_ID =
d_1_dep_el_transitions.dep_el_ID WHERE dep_el_type <> 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.dep_el_ID,
new_trans_ID.trans_dep_el_ID, IFNULL (new_trans_ID.dep_el_type, 'Undefined') AS
dep_el_type, IFNULL (c_1_depositional_elements.dep_el_type, 'Undefined') AS
transitional_type, c_1_depositional_elements.thickness, new_trans_ID.trans_direction
FROM c_1_depositional_elements JOIN new_trans_ID ON
c_1_depositional_elements.dep_el_ID = new_trans_ID.trans_dep_el_ID
WHERE trans_direction = 'Vertical' AND c_1_depositional_elements.thickness IS NOT
NULL);
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_types.trans_dep_el_ID AS
dep_el_ID, d_1_dep_el_transitions.trans_dep_el_ID,
d_1_dep_el_transitions.trans_direction, new_trans_types.transitional_type AS
dep_el_type FROM new_trans_types JOIN d_1_dep_el_transitions ON
new_trans_types.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.dep_el_ID,
new_trans_ID_2.trans_dep_el_ID, IFNULL (new_trans_ID_2.dep_el_type, 'Undefined') AS
dep_el_type, IFNULL (c_1_depositional_elements.dep_el_type, 'Undefined') AS
transitional_type, c_1_depositional_elements.thickness,
new_trans_ID_2.trans_direction FROM c_1_depositional_elements JOIN new_trans_ID_2 ON
c_1_depositional_elements.dep_el_ID = new_trans_ID_2.trans_dep_el_ID WHERE
c_1_depositional_elements.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_types_2.trans_dep_el_ID
AS dep_el_ID, d_1_dep_el_transitions.trans_dep_el_ID,
d_1_dep_el_transitions.trans_direction, new_trans_types_2.transitional_type AS
dep_el_type FROM new_trans_types_2 JOIN d_1_dep_el_transitions ON
new_trans_types_2.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types_2.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.dep_el_ID,
new_trans_ID_3.trans_dep_el_ID, IFNULL (new_trans_ID_3.dep_el_type, 'Undefined') AS
dep_el_type, IFNULL (c_1_depositional_elements.dep_el_type, 'Undefined') AS
transitional_type, c_1_depositional_elements.thickness,
new_trans_ID_3.trans_direction FROM c_1_depositional_elements
JOIN new_trans_ID_3 ON c_1_depositional_elements.dep_el_ID =
new_trans_ID_3.trans_dep_el_ID WHERE c_1_depositional_elements.thickness IS NOT
NULL);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT new_trans_types_3.trans_dep_el_ID
AS dep_el_ID, d_1_dep_el_transitions.trans_dep_el_ID,
d_1_dep_el_transitions.trans_direction, new_trans_types_3.transitional_type AS
dep_el_type FROM new_trans_types_3 JOIN d_1_dep_el_transitions ON
new_trans_types_3.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types_3.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_4 AS (SELECT new_trans_ID_4.dep_el_ID,
new_trans_ID_4.trans_dep_el_ID, IFNULL (new_trans_ID_4.dep_el_type, 'Undefined') AS
dep_el_type, IFNULL (c_1_depositional_elements.dep_el_type, 'Undefined') AS
transitional_type, new_trans_ID_4.trans_direction
FROM c_1_depositional_elements JOIN new_trans_ID_4 ON
c_1_depositional_elements.dep_el_ID = new_trans_ID_4.trans_dep_el_ID
WHERE c_1_depositional_elements.dep_el_type <> 'Channel-complex');

```

```

SELECT DISTINCT new_trans_types.trans_dep_el_ID, new_trans_types.transitional_type,
new_trans_types.thickness, new_trans_types_2.trans_dep_el_ID,
new_trans_types_2.transitional_type, new_trans_types_2.thickness,
new_trans_types_3.trans_dep_el_ID, new_trans_types_3.transitional_type,
new_trans_types_3.thickness
FROM new_trans_ID JOIN new_trans_types ON new_trans_ID.dep_el_ID =
new_trans_types.dep_el_ID JOIN new_trans_types_2 ON new_trans_types.trans_dep_el_ID
= new_trans_types_2.dep_el_ID JOIN new_trans_types_3 ON
new_trans_types_2.trans_dep_el_ID = new_trans_types_3.dep_el_ID
JOIN new_trans_types_4 ON new_trans_types_3.trans_dep_el_ID =
new_trans_types_4.dep_el_ID WHERE new_trans_ID.dep_el_ID <>
new_trans_types_2.trans_dep_el_ID AND new_trans_types.trans_dep_el_ID <>
new_trans_types_3.trans_dep_el_ID AND new_trans_types_2.trans_dep_el_ID <>
new_trans_types_4.trans_dep_el_ID;

```

It returns the thicknesses of a group of a given number (here strictly 3) of channel-complex depositional elements that are vertically stacked, excluding duplicate values due to multiple transitions occurring in case of complex interfingering. This type of query is required for obtaining the cumulative thickness of material units from the thickness of genetic units.

### tq\_28 – Widths of 5 laterally-adjacent Sr facies units

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT g_3_facies.facies_ID,
h_3_facies_transitions.trans_facies_ID, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type, g_3_facies.width, g_3_facies.apparent_width,
g_3_facies.partial_width, g_3_facies.unlimited_width
FROM g_3_facies JOIN h_3_facies_transitions ON g_3_facies.facies_ID =
h_3_facies_transitions.facies_ID WHERE facies_type = 'Sh');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.facies_ID,
new_trans_ID.trans_facies_ID, IFNULL (new_trans_ID.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
g_3_facies.width, g_3_facies.apparent_width, new_trans_ID.trans_direction
FROM g_3_facies JOIN new_trans_ID ON g_3_facies.facies_ID =
new_trans_ID.trans_facies_ID WHERE trans_direction = 'Lateral' AND (g_3_facies.width
IS NOT NULL OR g_3_facies.apparent_width IS NOT NULL));
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_types.trans_facies_ID AS
facies_ID, h_3_facies_transitions.trans_facies_ID,
h_3_facies_transitions.trans_direction, new_trans_types.transitional_type AS
facies_type FROM new_trans_types JOIN h_3_facies_transitions ON
new_trans_types.trans_facies_ID = h_3_facies_transitions.facies_ID
WHERE h_3_facies_transitions.trans_direction = 'Lateral' AND
new_trans_types.transitional_type = 'Sh');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.facies_ID,
new_trans_ID_2.trans_facies_ID, IFNULL (new_trans_ID_2.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
g_3_facies.width, g_3_facies.apparent_width, new_trans_ID_2.trans_direction
FROM g_3_facies JOIN new_trans_ID_2 ON g_3_facies.facies_ID =
new_trans_ID_2.trans_facies_ID WHERE g_3_facies.width IS NOT NULL OR
g_3_facies.apparent_width IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_types_2.trans_facies_ID
AS facies_ID, h_3_facies_transitions.trans_facies_ID,
h_3_facies_transitions.trans_direction, new_trans_types_2.transitional_type AS
facies_type FROM new_trans_types_2 JOIN h_3_facies_transitions ON
new_trans_types_2.trans_facies_ID = h_3_facies_transitions.facies_ID
WHERE h_3_facies_transitions.trans_direction = 'Lateral' AND
new_trans_types_2.transitional_type = 'Sh');
CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.facies_ID,
new_trans_ID_3.trans_facies_ID, IFNULL (new_trans_ID_3.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
g_3_facies.width, g_3_facies.apparent_width, new_trans_ID_3.trans_direction
FROM g_3_facies JOIN new_trans_ID_3 ON g_3_facies.facies_ID =
new_trans_ID_3.trans_facies_ID WHERE g_3_facies.width IS NOT NULL OR
g_3_facies.apparent_width IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT new_trans_types_3.trans_facies_ID
AS facies_ID, h_3_facies_transitions.trans_facies_ID,
h_3_facies_transitions.trans_direction, new_trans_types_3.transitional_type AS
facies_type FROM new_trans_types_3 JOIN h_3_facies_transitions ON
new_trans_types_3.trans_facies_ID = h_3_facies_transitions.facies_ID
WHERE h_3_facies_transitions.trans_direction = 'Lateral' AND
new_trans_types_3.transitional_type = 'Sh');
CREATE TEMPORARY TABLE new_trans_types_4 AS (SELECT new_trans_ID_4.facies_ID,
new_trans_ID_4.trans_facies_ID, IFNULL (new_trans_ID_4.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
new_trans_ID_4.trans_direction, g_3_facies.width, g_3_facies.apparent_width,
g_3_facies.partial_width, g_3_facies.unlimited_width

```

```

FROM g_3_facies JOIN new_trans_ID_4 ON g_3_facies.facies_ID =
new_trans_ID_4.trans_facies_ID WHERE g_3_facies.facies_type = 'Sh');
SELECT DISTINCT new_trans_ID.facies_ID, new_trans_ID.facies_type,
new_trans_ID.width, new_trans_ID.apparent_width, new_trans_ID.partial_width,
new_trans_ID.unlimited_width, new_trans_types.trans_facies_ID,
new_trans_types.transitional_type, new_trans_types.width,
new_trans_types.apparent_width, new_trans_types_2.trans_facies_ID,
new_trans_types_2.transitional_type, new_trans_types_2.width,
new_trans_types_2.apparent_width, new_trans_types_3.trans_facies_ID,
new_trans_types_3.transitional_type, new_trans_types_3.width,
new_trans_types_3.apparent_width, new_trans_types_4.trans_facies_ID,
new_trans_types_4.transitional_type, new_trans_types_4.width,
new_trans_types_4.apparent_width, new_trans_types_4.partial_width,
new_trans_types_4.unlimited_width FROM new_trans_ID JOIN new_trans_types ON
new_trans_ID.facies_ID = new_trans_types.facies_ID JOIN new_trans_types_2 ON
new_trans_types.trans_facies_ID = new_trans_types_2.facies_ID JOIN new_trans_types_3
ON new_trans_types_2.trans_facies_ID = new_trans_types_3.facies_ID JOIN
new_trans_types_4 ON new_trans_types_3.trans_facies_ID = new_trans_types_4.facies_ID
WHERE new_trans_ID.facies_ID <> new_trans_types_2.trans_facies_ID AND
new_trans_types.trans_facies_ID <> new_trans_types_3.trans_facies_ID AND
new_trans_types_2.trans_facies_ID <> new_trans_types_4.trans_facies_ID;

```

It returns the widths (any type) of a group of a given number (here 5) of facies units that are laterally juxtaposed and belong to the same facies type (here: Sr), excluding erosive mutual transitions. This type of query is required for obtaining the cumulative width of material units from the widths of genetic units.

### tq\_29 – Thicknesses of 10 vertically-stacked Sr facies units

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT g_3_facies.facies_ID,
h_3_facies_transitions.trans_facies_ID, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type FROM g_3_facies JOIN h_3_facies_transitions ON
g_3_facies.facies_ID = h_3_facies_transitions.facies_ID
WHERE facies_type <> 'St');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.facies_ID,
new_trans_ID.trans_facies_ID, IFNULL (new_trans_ID.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
g_3_facies.thickness, new_trans_ID.trans_direction FROM g_3_facies
JOIN new_trans_ID ON g_3_facies.facies_ID = new_trans_ID.trans_facies_ID
WHERE trans_direction = 'Vertical' AND g_3_facies.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_types.trans_facies_ID AS
facies_ID, h_3_facies_transitions.trans_facies_ID,
h_3_facies_transitions.trans_direction, new_trans_types.transitional_type AS
facies_type FROM new_trans_types JOIN h_3_facies_transitions ON
new_trans_types.trans_facies_ID = h_3_facies_transitions.facies_ID
WHERE h_3_facies_transitions.trans_direction = 'Vertical' AND
new_trans_types.transitional_type = 'St');
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_ID_2.facies_ID,
new_trans_ID_2.trans_facies_ID, IFNULL (new_trans_ID_2.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
g_3_facies.thickness, new_trans_ID_2.trans_direction FROM g_3_facies
JOIN new_trans_ID_2 ON g_3_facies.facies_ID = new_trans_ID_2.trans_facies_ID
WHERE g_3_facies.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_types_2.trans_facies_ID
AS facies_ID, h_3_facies_transitions.trans_facies_ID,
h_3_facies_transitions.trans_direction, new_trans_types_2.transitional_type AS
facies_type FROM new_trans_types_2 JOIN h_3_facies_transitions ON
new_trans_types_2.trans_facies_ID = h_3_facies_transitions.facies_ID
WHERE h_3_facies_transitions.trans_direction = 'Vertical' AND
new_trans_types_2.transitional_type = 'St');
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_ID_3.facies_ID,
new_trans_ID_3.trans_facies_ID, IFNULL (new_trans_ID_3.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
g_3_facies.thickness, new_trans_ID_3.trans_direction FROM g_3_facies
JOIN new_trans_ID_3 ON g_3_facies.facies_ID = new_trans_ID_3.trans_facies_ID
WHERE g_3_facies.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT new_trans_types_3.trans_facies_ID
AS facies_ID, h_3_facies_transitions.trans_facies_ID,
h_3_facies_transitions.trans_direction, new_trans_types_3.transitional_type AS
facies_type FROM new_trans_types_3 JOIN h_3_facies_transitions ON
new_trans_types_3.trans_facies_ID = h_3_facies_transitions.facies_ID
WHERE h_3_facies_transitions.trans_direction = 'Vertical' AND
new_trans_types_3.transitional_type = 'St');
CREATE TEMPORARY TABLE new_trans_types_4 AS
(

```





```

WHERE h_3_facies_transitions.trans_direction = 'Vertical' AND
new_trans_types_9.transitional_type = 'St');
CREATE TEMPORARY TABLE new_trans_types_10 AS (SELECT new_trans_ID_10.facies_ID,
new_trans_ID_10.trans_facies_ID, IFNULL (new_trans_ID_10.facies_type, 'Undefined')
AS facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
g_3_facies.thickness, new_trans_ID_10.trans_direction FROM g_3_facies
JOIN new_trans_ID_10 ON g_3_facies.facies_ID = new_trans_ID_10.trans_facies_ID
WHERE g_3_facies.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_11 AS (SELECT new_trans_types_10.trans_facies_ID
AS facies_ID, h_3_facies_transitions.trans_facies_ID,
h_3_facies_transitions.trans_direction, new_trans_types_10.transitional_type AS
facies_type FROM new_trans_types_10 JOIN h_3_facies_transitions ON
new_trans_types_10.trans_facies_ID = h_3_facies_transitions.facies_ID
WHERE h_3_facies_transitions.trans_direction = 'Vertical' AND
new_trans_types_10.transitional_type = 'St');
CREATE TEMPORARY TABLE new_trans_types_11 AS (SELECT new_trans_ID_11.facies_ID,
new_trans_ID_11.trans_facies_ID, IFNULL (new_trans_ID_11.facies_type, 'Undefined')
AS facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
new_trans_ID_11.trans_direction FROM g_3_facies JOIN new_trans_ID_11 ON
g_3_facies.facies_ID = new_trans_ID_11.trans_facies_ID
WHERE g_3_facies.facies_type <> 'St');
SELECT DISTINCT new_trans_types.trans_facies_ID, new_trans_types.thickness,
new_trans_types_2.trans_facies_ID, new_trans_types_2.thickness,
new_trans_types_3.trans_facies_ID, new_trans_types_3.thickness,
new_trans_types_4.trans_facies_ID, new_trans_types_4.thickness,
new_trans_types_5.trans_facies_ID, new_trans_types_5.thickness,
new_trans_types_6.trans_facies_ID, new_trans_types_6.thickness,
new_trans_types_7.trans_facies_ID, new_trans_types_7.thickness,
new_trans_types_8.trans_facies_ID, new_trans_types_8.thickness,
new_trans_types_9.trans_facies_ID, new_trans_types_9.thickness,
new_trans_types_10.trans_facies_ID, new_trans_types_10.thickness
FROM new_trans_ID JOIN new_trans_types ON new_trans_ID.facies_ID =
new_trans_types.facies_ID JOIN new_trans_types_2 ON new_trans_types.trans_facies_ID
= new_trans_types_2.facies_ID JOIN new_trans_types_3 ON
new_trans_types_2.trans_facies_ID = new_trans_types_3.facies_ID
JOIN new_trans_types_4 ON new_trans_types_3.trans_facies_ID =
new_trans_types_4.facies_ID JOIN new_trans_types_5 ON
new_trans_types_4.trans_facies_ID = new_trans_types_5.facies_ID
JOIN new_trans_types_6 ON new_trans_types_5.trans_facies_ID =
new_trans_types_6.facies_ID JOIN new_trans_types_7 ON
new_trans_types_6.trans_facies_ID = new_trans_types_7.facies_ID
JOIN new_trans_types_8 ON new_trans_types_7.trans_facies_ID =
new_trans_types_8.facies_ID JOIN new_trans_types_9 ON
new_trans_types_8.trans_facies_ID = new_trans_types_9.facies_ID
JOIN new_trans_types_10 ON new_trans_types_9.trans_facies_ID =
new_trans_types_10.facies_ID JOIN new_trans_types_11 ON
new_trans_types_10.trans_facies_ID = new_trans_types_11.facies_ID
WHERE new_trans_ID.facies_ID <> new_trans_types_2.trans_facies_ID AND
new_trans_types.trans_facies_ID <> new_trans_types_3.trans_facies_ID AND
new_trans_types_2.trans_facies_ID <> new_trans_types_4.trans_facies_ID AND
new_trans_types_3.trans_facies_ID <> new_trans_types_5.trans_facies_ID AND
new_trans_types_4.trans_facies_ID <> new_trans_types_6.trans_facies_ID AND
new_trans_types_5.trans_facies_ID <> new_trans_types_7.trans_facies_ID AND
new_trans_types_6.trans_facies_ID <> new_trans_types_8.trans_facies_ID AND
new_trans_types_7.trans_facies_ID <> new_trans_types_9.trans_facies_ID AND
new_trans_types_8.trans_facies_ID <> new_trans_types_10.trans_facies_ID AND
new_trans_types_9.trans_facies_ID <> new_trans_types_11.trans_facies_ID;

```

It returns the thicknesses of a group of a given number (here 10) of facies units that are vertically stacked and belong to the same facies type (here: Sr), excluding duplicate values due to multiple transitions occurring in case of complex interfingering. This type of query is required for obtaining the cumulative thickness of material packages from the thicknesses of facies units. N.B.: as this query may require a long time to return results when dealing with large datasets, it is advisable to make it work with tables instead of temporary tables.

### tq\_37 – Thickness statistics for all facies types from a case study

```

CREATE TEMPORARY TABLE facies_thickness AS SELECT facies_type, g_3_facies.thickness
FROM b_subsets JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID
JOIN g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID
WHERE case_ID = 23;
SELECT facies_type, AVG(thickness), MIN(thickness), MAX(thickness), STD(thickness)

```

```
FROM facies_thickness GROUP BY facies_type;
```

It returns basic descriptive statistics (mean, maximum, minimum, standard deviation) relating to the thickness of all facies types for a given case study.

### tq\_38 – Average channel-complex thickness and width for aggradation rate value

```
SELECT mean_aggradation_rate, AVG(thickness), AVG(IF(width IS NOT NULL, width,
apparent_width)) AS avg_width FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID AND dep_el_type= 'Channel-
complex' AND thickness IS NOT NULL AND (width IS NOT NULL OR partial_width IS NOT
NULL OR unlimited_width IS NOT NULL OR apparent_width IS NOT NULL) AND
mean_aggradation_rate IS NOT NULL GROUP BY mean_aggradation_rate ORDER BY
mean_aggradation_rate;
```

It returns the mean thickness and complete width (real or apparent) of channel-complexes for each given value of mean aggradation rate.

### tq\_43 – Average channel-complex thickness and width, and proportion within subset

```
CREATE TEMPORARY TABLE dep_el_xsarea AS SELECT b_subsets.subset_ID, dep_el_type,
IFNULL((thickness* IF(width IS NOT NULL, width, apparent_width)),0) AS xsarea,
IFNULL((thickness* IF(partial_width IS NOT NULL, partial_width, unlimited_width)),0)
AS partial_xsarea FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID
WHERE 1_suitability LIKE '%proportion%' AND 1_suitability LIKE '%dimension%'
ORDER BY subset_ID;
CREATE TEMPORARY TABLE channel_complex_total_area AS SELECT subset_ID, SUM(xsarea)+
SUM(partial_xsarea) AS channel_complex_area FROM dep_el_xsarea
WHERE dep_el_type = 'Channel-complex' GROUP BY subset_ID;
CREATE TEMPORARY TABLE total_area AS SELECT subset_ID, SUM(xsarea)+
SUM(partial_xsarea) AS total_area FROM dep_el_xsarea GROUP BY subset_ID;
CREATE TEMPORARY TABLE channel_complex_proportions SELECT
channel_complex_total_area.subset_ID,
(channel_complex_total_area.channel_complex_area/total_area.total_area) AS
channel_complex_prop FROM channel_complex_total_area JOIN total_area ON
channel_complex_total_area.subset_ID = total_area.subset_ID WHERE
(channel_complex_total_area.channel_complex_area/total_area.total_area) IS NOT NULL;
CREATE TEMPORARY TABLE channel_complex_dimension_statistics SELECT subset_ID,
AVG(thickness) AS avg_thickness, AVG(IF(width IS NOT NULL, width, (IF(apparent_width
IS NOT NULL, apparent_width, IF(partial_width IS NOT NULL, partial_width,
unlimited_width)))) AS avg_any_width FROM c_1_depositional_elements WHERE
dep_el_type = 'Channel-complex' GROUP BY subset_ID;
SELECT channel_complex_proportions.subset_ID, channel_complex_prop, avg_thickness,
avg_any_width FROM channel_complex_proportions JOIN
channel_complex_dimension_statistics ON channel_complex_proportions.subset_ID =
channel_complex_dimension_statistics.subset_ID;
```

It returns the average thickness and width (any type) of channel-complexes – together with their proportion expressed as fraction of 1 – for any subset suitable for the computation of proportions and dimensional parameters of depositional elements.

### tq\_44 – Thicknesses of 3 vertically-stacked Channel-complexes and aggradation rate

```
CREATE TEMPORARY TABLE dep_el_clim AS (SELECT mean_aggradation_rate, dep_el_ID,
dep_el_type, thickness FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID
WHERE mean_aggradation_rate IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID AS (SELECT dep_el_clim.dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
dep_el_clim.dep_el_type FROM dep_el_clim JOIN d_1_dep_el_transitions ON
dep_el_clim.dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE dep_el_type <> 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.dep_el_ID,
new_trans_ID.trans_dep_el_ID, IFNULL (new_trans_ID.dep_el_type, 'Undefined') AS
```

```

dep_el_type, IFNULL (dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
dep_el_clim.thickness, new_trans_ID.trans_direction FROM dep_el_clim
JOIN new_trans_ID ON dep_el_clim.dep_el_ID = new_trans_ID.trans_dep_el_ID
WHERE trans_direction = 'Vertical' AND dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_types.trans_dep_el_ID AS
dep_el_ID, d_1_dep_el_transitions.trans_dep_el_ID,
d_1_dep_el_transitions.trans_direction, new_trans_types.transitional_type AS
dep_el_type FROM new_trans_types JOIN d_1_dep_el_transitions ON
new_trans_types.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.dep_el_ID,
new_trans_ID_2.trans_dep_el_ID, IFNULL (new_trans_ID_2.dep_el_type, 'Undefined') AS
dep_el_type, IFNULL (dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
dep_el_clim.thickness, new_trans_ID_2.trans_direction FROM dep_el_clim
JOIN new_trans_ID_2 ON dep_el_clim.dep_el_ID = new_trans_ID_2.trans_dep_el_ID
WHERE dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_types_2.trans_dep_el_ID
AS dep_el_ID, d_1_dep_el_transitions.trans_dep_el_ID,
d_1_dep_el_transitions.trans_direction, new_trans_types_2.transitional_type AS
dep_el_type
FROM new_trans_types_2 JOIN d_1_dep_el_transitions ON
new_trans_types_2.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types_2.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.dep_el_ID,
new_trans_ID_3.trans_dep_el_ID, IFNULL (new_trans_ID_3.dep_el_type, 'Undefined') AS
dep_el_type, IFNULL (dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
dep_el_clim.thickness, new_trans_ID_3.trans_direction FROM dep_el_clim
JOIN new_trans_ID_3 ON dep_el_clim.dep_el_ID = new_trans_ID_3.trans_dep_el_ID
WHERE dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT new_trans_types_3.trans_dep_el_ID
AS dep_el_ID, d_1_dep_el_transitions.trans_dep_el_ID,
d_1_dep_el_transitions.trans_direction, new_trans_types_3.transitional_type AS
dep_el_type FROM new_trans_types_3 JOIN d_1_dep_el_transitions ON
new_trans_types_3.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types_3.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_4 AS (SELECT new_trans_ID_4.dep_el_ID,
new_trans_ID_4.trans_dep_el_ID, IFNULL (new_trans_ID_4.dep_el_type, 'Undefined') AS
dep_el_type, IFNULL (dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
new_trans_ID_4.trans_direction FROM dep_el_clim JOIN new_trans_ID_4 ON
dep_el_clim.dep_el_ID = new_trans_ID_4.trans_dep_el_ID WHERE dep_el_clim.dep_el_type
<> 'Channel-complex');
CREATE TEMPORARY TABLE stacked_thickness AS SELECT DISTINCT
new_trans_types.trans_dep_el_ID AS ID_1, new_trans_types.thickness AS T_1,
new_trans_types_2.trans_dep_el_ID AS ID_2, new_trans_types_2.thickness AS T_2,
new_trans_types_3.trans_dep_el_ID AS ID_3, new_trans_types_3.thickness AS T_3
FROM new_trans_ID JOIN new_trans_types ON new_trans_ID.dep_el_ID =
new_trans_types.dep_el_ID JOIN new_trans_types_2 ON new_trans_types.trans_dep_el_ID
= new_trans_types_2.dep_el_ID JOIN new_trans_types_3 ON
new_trans_types_2.trans_dep_el_ID = new_trans_types_3.dep_el_ID JOIN
new_trans_types_4 ON new_trans_types_3.trans_dep_el_ID = new_trans_types_4.dep_el_ID
WHERE new_trans_ID.dep_el_ID <> new_trans_types_2.trans_dep_el_ID AND
new_trans_types.trans_dep_el_ID <> new_trans_types_3.trans_dep_el_ID AND
new_trans_types_2.trans_dep_el_ID <> new_trans_types_4.trans_dep_el_ID;
SELECT mean_aggradation_rate, T_1+T_2+T_3 AS 3de_stacked_T FROM b_subsets
JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN stacked_thickness ON
c_1_depositional_elements.dep_el_ID = stacked_thickness.ID_1;

```

It returns the thicknesses of a group of a given number (here strictly 3) of channel-complex depositional elements that are vertically stacked, excluding duplicate values due to multiple transitions occurring in case of complex interfingering, and the value of mean aggradation rate of the subset.

#### tq\_51 – Thicknesses of 2 vertically-stacked Channel-complexes in the same subset

```

CREATE TEMPORARY TABLE z_dep_el_clim AS (SELECT b_subsets.subset_ID,
mean_aggradation_rate, dep_el_ID, dep_el_type, thickness FROM b_subsets JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID);
CREATE TEMPORARY TABLE new_trans_ID AS (SELECT subset_ID, z_dep_el_clim.dep_el_ID,

```



```

d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
z_dep_el_clim.dep_el_type FROM z_dep_el_clim JOIN d_1_dep_el_transitions ON
z_dep_el_clim.dep_el_ID = d_1_dep_el_transitions.dep_el_ID WHERE dep_el_type <>
'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.subset_ID,
new_trans_ID.dep_el_ID, new_trans_ID.trans_dep_el_ID, IFNULL
(new_trans_ID.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID ON z_dep_el_clim.dep_el_ID = new_trans_ID.trans_dep_el_ID
WHERE trans_direction = 'Vertical' AND z_dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types.transitional_type AS dep_el_type FROM z_dep_el_clim
JOIN new_trans_types ON z_dep_el_clim.dep_el_ID = new_trans_types.trans_dep_el_ID
JOIN d_1_dep_el_transitions ON new_trans_types.trans_dep_el_ID =
d_1_dep_el_transitions.dep_el_ID WHERE d_1_dep_el_transitions.trans_direction =
'Vertical' AND new_trans_types.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.subset_ID,
new_trans_ID_2.dep_el_ID, new_trans_ID_2.trans_dep_el_ID, IFNULL
(new_trans_ID_2.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID_2.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID_2 ON z_dep_el_clim.dep_el_ID = new_trans_ID_2.trans_dep_el_ID
WHERE z_dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types_2.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types_2.transitional_type AS dep_el_type FROM z_dep_el_clim
JOIN new_trans_types_2 ON z_dep_el_clim.dep_el_ID =
new_trans_types_2.trans_dep_el_ID JOIN d_1_dep_el_transitions ON
new_trans_types_2.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types_2.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.subset_ID,
new_trans_ID_3.dep_el_ID, new_trans_ID_3.trans_dep_el_ID, IFNULL
(new_trans_ID_3.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID_3.trans_direction
FROM z_dep_el_clim JOIN new_trans_ID_3 ON z_dep_el_clim.dep_el_ID =
new_trans_ID_3.trans_dep_el_ID WHERE z_dep_el_clim.dep_el_type <> 'Channel-
complex');
SELECT DISTINCT new_trans_ID_2.subset_ID, new_trans_types.trans_dep_el_ID AS
channel_complex_ID_1, new_trans_types.thickness AS t_1,
new_trans_types_2.trans_dep_el_ID AS channel_complex_ID_2,
new_trans_types_2.thickness AS t_2, (new_trans_types.thickness +
new_trans_types_2.thickness) AS t_2cc_stack FROM new_trans_types
JOIN new_trans_ID_2 ON new_trans_types.trans_dep_el_ID = new_trans_ID_2.dep_el_ID
JOIN new_trans_types_2 ON new_trans_types.trans_dep_el_ID =
new_trans_types_2.dep_el_ID WHERE new_trans_types.subset_ID =
new_trans_types_2.subset_ID;

```

It returns the thicknesses of a group of a given number (here strictly 2) of channel-complex depositional elements that are vertically stacked and are strictly contained within the same subset.

## tg\_52 – Thicknesses of 6 vertically-stacked Channel-complexes and subset channel proportion

```

CREATE TEMPORARY TABLE z_dep_el_clim AS (SELECT b_subsets.subset_ID, dep_el_ID,
dep_el_type, thickness FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID);
CREATE TEMPORARY TABLE new_trans_ID AS (SELECT subset_ID, z_dep_el_clim.dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
z_dep_el_clim.dep_el_type FROM z_dep_el_clim JOIN d_1_dep_el_transitions ON
z_dep_el_clim.dep_el_ID = d_1_dep_el_transitions.dep_el_ID WHERE dep_el_type <>
'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.subset_ID,
new_trans_ID.dep_el_ID, new_trans_ID.trans_dep_el_ID, IFNULL
(new_trans_ID.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID ON z_dep_el_clim.dep_el_ID = new_trans_ID.trans_dep_el_ID

```

```

WHERE trans_direction = 'Vertical' AND z_dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types.transitional_type AS dep_el_type FROM z_dep_el_clim JOIN
new_trans_types ON z_dep_el_clim.dep_el_ID = new_trans_types.trans_dep_el_ID
JOIN d_1_dep_el_transitions ON new_trans_types.trans_dep_el_ID =
d_1_dep_el_transitions.dep_el_ID WHERE d_1_dep_el_transitions.trans_direction =
'Vertical' AND new_trans_types.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.subset_ID,
new_trans_ID_2.dep_el_ID, new_trans_ID_2.trans_dep_el_ID, IFNULL
(new_trans_ID_2.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID_2.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID_2 ON z_dep_el_clim.dep_el_ID = new_trans_ID_2.trans_dep_el_ID
WHERE z_dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types_2.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types_2.transitional_type AS dep_el_type FROM z_dep_el_clim
JOIN new_trans_types_2 ON z_dep_el_clim.dep_el_ID =
new_trans_types_2.trans_dep_el_ID JOIN d_1_dep_el_transitions ON
new_trans_types_2.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types_2.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.subset_ID,
new_trans_ID_3.dep_el_ID, new_trans_ID_3.trans_dep_el_ID, IFNULL
(new_trans_ID_3.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID_3.trans_direction
FROM z_dep_el_clim JOIN new_trans_ID_3 ON z_dep_el_clim.dep_el_ID =
new_trans_ID_3.trans_dep_el_ID WHERE z_dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types_3.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types_3.transitional_type AS dep_el_type FROM z_dep_el_clim
JOIN new_trans_types_3 ON z_dep_el_clim.dep_el_ID =
new_trans_types_3.trans_dep_el_ID JOIN d_1_dep_el_transitions ON
new_trans_types_3.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID
WHERE d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types_3.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_4 AS (SELECT new_trans_ID_4.subset_ID,
new_trans_ID_4.dep_el_ID, new_trans_ID_4.trans_dep_el_ID, IFNULL
(new_trans_ID_4.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID_4.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID_4 ON z_dep_el_clim.dep_el_ID = new_trans_ID_4.trans_dep_el_ID
WHERE z_dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_5 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types_4.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types_4.transitional_type AS dep_el_type FROM z_dep_el_clim JOIN
new_trans_types_4 ON z_dep_el_clim.dep_el_ID = new_trans_types_4.trans_dep_el_ID
JOIN d_1_dep_el_transitions ON new_trans_types_4.trans_dep_el_ID =
d_1_dep_el_transitions.dep_el_ID WHERE d_1_dep_el_transitions.trans_direction =
'Vertical' AND new_trans_types_4.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_5 AS (SELECT new_trans_ID_5.subset_ID,
new_trans_ID_5.dep_el_ID, new_trans_ID_5.trans_dep_el_ID, IFNULL
(new_trans_ID_5.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID_5.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID_5 ON z_dep_el_clim.dep_el_ID = new_trans_ID_5.trans_dep_el_ID
WHERE z_dep_el_clim.thickness IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_6 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types_5.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types_5.transitional_type AS dep_el_type FROM z_dep_el_clim JOIN
new_trans_types_5 ON z_dep_el_clim.dep_el_ID = new_trans_types_5.trans_dep_el_ID
JOIN d_1_dep_el_transitions ON new_trans_types_5.trans_dep_el_ID =
d_1_dep_el_transitions.dep_el_ID WHERE d_1_dep_el_transitions.trans_direction =
'Vertical' AND new_trans_types_5.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_6 AS (SELECT new_trans_ID_6.subset_ID,
new_trans_ID_6.dep_el_ID, new_trans_ID_6.trans_dep_el_ID, IFNULL
(new_trans_ID_6.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID_6.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID_6 ON z_dep_el_clim.dep_el_ID = new_trans_ID_6.trans_dep_el_ID
WHERE z_dep_el_clim.thickness IS NOT NULL);

```

```

CREATE TEMPORARY TABLE new_trans_ID_7 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types_6.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types_6.transitional_type AS dep_el_type FROM z_dep_el_clim
JOIN new_trans_types_6 ON z_dep_el_clim.dep_el_ID =
new_trans_types_6.trans_dep_el_ID JOIN d_1_dep_el_transitions ON
new_trans_types_6.trans_dep_el_ID = d_1_dep_el_transitions.dep_el_ID WHERE
d_1_dep_el_transitions.trans_direction = 'Vertical' AND
new_trans_types_6.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types_7 AS (SELECT new_trans_ID_7.subset_ID,
new_trans_ID_7.dep_el_ID, new_trans_ID_7.trans_dep_el_ID, IFNULL
(new_trans_ID_7.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.thickness, new_trans_ID_7.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID_7 ON z_dep_el_clim.dep_el_ID = new_trans_ID_7.trans_dep_el_ID
WHERE z_dep_el_clim.dep_el_type <> 'Channel-complex');
CREATE TEMPORARY TABLE synt_new_trans_types AS SELECT trans_dep_el_ID, thickness
FROM new_trans_types;
CREATE TEMPORARY TABLE synt_new_trans_types_2 AS SELECT subset_ID, trans_dep_el_ID,
dep_el_ID, thickness FROM new_trans_types_2;
CREATE TEMPORARY TABLE synt_new_trans_types_3 AS SELECT trans_dep_el_ID, dep_el_ID,
thickness FROM new_trans_types_3;
CREATE TEMPORARY TABLE synt_new_trans_types_4 AS SELECT trans_dep_el_ID, dep_el_ID,
thickness FROM new_trans_types_4;
CREATE TEMPORARY TABLE synt_new_trans_types_5 AS SELECT trans_dep_el_ID, dep_el_ID,
thickness FROM new_trans_types_5;
CREATE TEMPORARY TABLE synt_new_trans_types_6 AS SELECT subset_ID, trans_dep_el_ID,
dep_el_ID, thickness FROM new_trans_types_6;
CREATE TEMPORARY TABLE 6cc_part_1 AS SELECT DISTINCT
synt_new_trans_types_2.subset_ID, synt_new_trans_types.trans_dep_el_ID AS
channel_complex_ID_1, synt_new_trans_types.thickness AS t_1,
synt_new_trans_types_2.trans_dep_el_ID AS channel_complex_ID_2,
synt_new_trans_types_2.thickness AS t_2, synt_new_trans_types_3.trans_dep_el_ID AS
channel_complex_ID_3 FROM synt_new_trans_types JOIN synt_new_trans_types_2 ON
synt_new_trans_types.trans_dep_el_ID = synt_new_trans_types_2.dep_el_ID JOIN
synt_new_trans_types_3 ON synt_new_trans_types_2.trans_dep_el_ID =
synt_new_trans_types_3.dep_el_ID;
CREATE TEMPORARY TABLE 6cc_part_2 AS SELECT DISTINCT
synt_new_trans_types_3.trans_dep_el_ID AS channel_complex_ID_3,
synt_new_trans_types_3.thickness AS t_3, synt_new_trans_types_4.trans_dep_el_ID AS
channel_complex_ID_4, synt_new_trans_types_4.thickness AS t_4,
synt_new_trans_types_5.trans_dep_el_ID AS channel_complex_ID_5 FROM
synt_new_trans_types_3 JOIN synt_new_trans_types_4 ON
synt_new_trans_types_3.trans_dep_el_ID = synt_new_trans_types_4.dep_el_ID JOIN
synt_new_trans_types_5 ON synt_new_trans_types_4.trans_dep_el_ID =
synt_new_trans_types_5.dep_el_ID;
CREATE TEMPORARY TABLE 6cc_part_3 AS SELECT DISTINCT
synt_new_trans_types_6.subset_ID, synt_new_trans_types_5.trans_dep_el_ID AS
channel_complex_ID_5, synt_new_trans_types_5.thickness AS t_5,
synt_new_trans_types_6.trans_dep_el_ID AS channel_complex_ID_6,
synt_new_trans_types_6.thickness AS t_6 FROM synt_new_trans_types_5 JOIN
synt_new_trans_types_6 ON synt_new_trans_types_5.trans_dep_el_ID =
synt_new_trans_types_6.dep_el_ID;
CREATE TEMPORARY TABLE 6cc_stack AS SELECT 6cc_part_1.subset_ID, (6cc_part_1.t_1 +
6cc_part_1.t_2 + 6cc_part_2.t_3 + 6cc_part_2.t_4 + 6cc_part_3.t_5 + 6cc_part_3.t_6)
AS sum_t FROM 6cc_part_1 JOIN 6cc_part_2 ON 6cc_part_1.channel_complex_ID_3 =
6cc_part_2.channel_complex_ID_3 JOIN 6cc_part_3 ON 6cc_part_2.channel_complex_ID_5 =
6cc_part_3.channel_complex_ID_5 WHERE 6cc_part_1.subset_ID = 6cc_part_3.subset_ID;
CREATE TEMPORARY TABLE dep_el_xsarea AS SELECT b_subsets.subset_ID, dep_el_type,
IFNULL((thickness* IF(width IS NOT NULL, width, apparent_width)),0) AS xsarea,
IFNULL((thickness* IF(partial_width IS NOT NULL, partial_width, unlimited_width)),0)
AS partial_xsarea FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID WHERE 1_suitability LIKE
'%proportion%' AND 1_suitability LIKE '%dimension%' ORDER BY subset_ID;
CREATE TEMPORARY TABLE channel_complex_total_area AS SELECT subset_ID, SUM(xsarea)+
SUM(partial_xsarea) AS channel_complex_area FROM dep_el_xsarea WHERE dep_el_type =
'Channel-complex' GROUP BY subset_ID;
CREATE TEMPORARY TABLE total_area AS SELECT subset_ID, SUM(xsarea)+
SUM(partial_xsarea) AS total_area FROM dep_el_xsarea GROUP BY subset_ID;
CREATE TEMPORARY TABLE channel_complex_proportions SELECT
channel_complex_total_area.subset_ID,
channel_complex_total_area.channel_complex_area/total_area.total_area) AS
channel_complex_prop FROM channel_complex_total_area JOIN total_area ON
channel_complex_total_area.subset_ID = total_area.subset_ID WHERE
(channel_complex_total_area.channel_complex_area/total_area.total_area) IS NOT NULL;
CREATE TEMPORARY TABLE channel_complex_dimension_statistics SELECT subset_ID,
AVG(thickness) AS avg_thickness, AVG(IF(width IS NOT NULL, width, (IF(apparent_width

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```
IS NOT NULL, apparent_width, IF(partial_width IS NOT NULL, partial_width,
unlimited_width)))) AS avg_any_width FROM c_1_depositional_elements
WHERE dep_el_type = 'Channel-complex' GROUP BY subset_ID;
SELECT channel_complex_proportions.subset_ID, channel_complex_prop, sum_t FROM
channel_complex_proportions JOIN 6cc_stack ON channel_complex_proportions.subset_ID
= 6cc_stack.subset_ID;
```

It returns the thicknesses of a group of a given number (here strictly 6) of channel-complex depositional elements that are vertically stacked and are contained within the same subset, and the proportion of channel deposits within the subset.

### tq\_53 – Channel-complex lateral spacing and proportion within volume

```
CREATE TEMPORARY TABLE z_dep_el_clim AS (SELECT b_subsets.subset_ID,
mean_aggradation_rate, dep_el_ID, dep_el_type, IF(width IS NOT NULL, width,
apparent_width) AS complete_width FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID);
CREATE TEMPORARY TABLE new_trans_ID AS (SELECT subset_ID, z_dep_el_clim.dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
z_dep_el_clim.dep_el_type FROM z_dep_el_clim JOIN d_1_dep_el_transitions ON
z_dep_el_clim.dep_el_ID = d_1_dep_el_transitions.dep_el_ID WHERE dep_el_type =
'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.subset_ID,
new_trans_ID.dep_el_ID, new_trans_ID.trans_dep_el_ID, IFNULL
(new_trans_ID.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.complete_width, new_trans_ID.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID ON z_dep_el_clim.dep_el_ID = new_trans_ID.trans_dep_el_ID
WHERE trans_direction = 'Lateral' AND z_dep_el_clim.complete_width IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT z_dep_el_clim.subset_ID,
new_trans_types.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types.transitional_type AS dep_el_type FROM z_dep_el_clim JOIN
new_trans_types ON z_dep_el_clim.dep_el_ID = new_trans_types.trans_dep_el_ID
JOIN d_1_dep_el_transitions ON new_trans_types.trans_dep_el_ID =
d_1_dep_el_transitions.dep_el_ID WHERE d_1_dep_el_transitions.trans_direction =
'Lateral' AND new_trans_types.transitional_type = 'Floodplain');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.subset_ID,
new_trans_ID_2.dep_el_ID, new_trans_ID_2.trans_dep_el_ID, IFNULL
(new_trans_ID_2.dep_el_type, 'Undefined') AS dep_el_type, IFNULL
(z_dep_el_clim.dep_el_type, 'Undefined') AS transitional_type,
z_dep_el_clim.complete_width, new_trans_ID_2.trans_direction FROM z_dep_el_clim
JOIN new_trans_ID_2 ON z_dep_el_clim.dep_el_ID = new_trans_ID_2.trans_dep_el_ID
WHERE z_dep_el_clim.complete_width IS NOT NULL);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT subset_ID,
new_trans_types_2.trans_dep_el_ID AS dep_el_ID,
d_1_dep_el_transitions.trans_dep_el_ID, d_1_dep_el_transitions.trans_direction,
new_trans_types_2.transitional_type AS dep_el_type FROM new_trans_types_2 JOIN
d_1_dep_el_transitions ON new_trans_types_2.trans_dep_el_ID =
d_1_dep_el_transitions.dep_el_ID WHERE d_1_dep_el_transitions.trans_direction =
'Lateral' AND new_trans_types_2.transitional_type = 'Channel-complex');
CREATE TEMPORARY TABLE lcc AS SELECT DISTINCT new_trans_ID_2.subset_ID,
new_trans_types.trans_dep_el_ID AS floodplain_ID, new_trans_types.complete_width
FROM new_trans_types JOIN new_trans_ID_2 ON new_trans_types.trans_dep_el_ID =
new_trans_ID_2.dep_el_ID;
CREATE TEMPORARY TABLE dep_el_xsarea AS SELECT b_subsets.subset_ID, dep_el_type,
IFNULL((thickness* IF(width IS NOT NULL, width, apparent_width)),0) AS xsarea,
IFNULL((thickness* IF(partial_width IS NOT NULL, partial_width, unlimited_width)),0)
AS partial_xsarea FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID WHERE l_suitability LIKE
'%proportion%' AND l_suitability LIKE '%dimension%' ORDER BY subset_ID;
CREATE TEMPORARY TABLE channel_complex_total_area AS SELECT subset_ID, SUM(xsarea)+
SUM(partial_xsarea) AS channel_complex_area FROM dep_el_xsarea
WHERE dep_el_type = 'Channel-complex' GROUP BY subset_ID;
CREATE TEMPORARY TABLE total_area AS SELECT subset_ID, SUM(xsarea)+
SUM(partial_xsarea) AS total_area FROM dep_el_xsarea GROUP BY subset_ID;
CREATE TEMPORARY TABLE channel_complex_proportions SELECT
channel_complex_total_area.subset_ID,
(channel_complex_total_area.channel_complex_area/total_area.total_area) AS
channel_complex_prop FROM channel_complex_total_area JOIN total_area ON
channel_complex_total_area.subset_ID = total_area.subset_ID WHERE
(channel_complex_total_area.channel_complex_area/total_area.total_area) IS NOT NULL;
CREATE TEMPORARY TABLE channel_complex_dimension_statistics
```

```

SELECT subset_ID, AVG(thickness) AS avg_thickness, AVG(IF(width IS NOT NULL, width,
(IF(apparent_width IS NOT NULL, apparent_width, IF(partial_width IS NOT NULL,
partial_width, unlimited_width)))))) AS avg_any_width FROM c_1_depositional_elements
WHERE dep_el_type = 'Channel-complex' GROUP BY subset_ID;
SELECT channel_complex_proportions.subset_ID, channel_complex_prop,
lcc.complete_width AS CC_spacing FROM lcc JOIN channel_complex_proportions ON
lcc.subset_ID = channel_complex_proportions.subset_ID;

```

It returns the lateral cross-gradient spacing of two channel complexes (i.e. width of floodplain element laterally transitional to two channel complexes) in a stratigraphic volume and channel-complex proportion within the volume.

### Unit proportions

#### tq\_12 – All architectural-element entries and parent depositional elements

```

SELECT c_1_depositional_elements.dep_el_type,
e_2_architectural_elements.arch_el_type FROM c_1_depositional_elements JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID ORDER BY dep_el_type;

```

It returns all architectural element type entries and the depositional elements they belong to.

#### tq\_17 – Architectural-element entries from floodplain depositional elements wider than 100 m

```

SELECT c_1_depositional_elements.dep_el_type, e_2_architectural_elements.arch_el_type
FROM c_1_depositional_elements JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID WHERE
dep_el_type = 'Floodplain' AND (c_1_depositional_elements.apparent_width > 100 OR
c_1_depositional_elements.partial_width > 100 OR
c_1_depositional_elements.unlimited_width > 100 OR c_1_depositional_elements.width >
100);

```

It returns all architectural element type entries belonging to 'Floodplain' depositional element whose width is larger than 100 m.

#### tq\_03 – Facies-unit entries and architectural-element type they belong to from, semiarid basins

```

SELECT e_2_architectural_elements.arch_el_type, g_3_facies.facies_type FROM
((b_subsets JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID) JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID) JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID WHERE
`basin_synthetic_climate_type` = 'Semiarid' ORDER BY arch_el_type;

```

It returns all the facies units types and all the architectural element types of the elements they belong to, filtered according to their basin synthetic climate type (here: Semiarid).

#### tq\_18 – Bounding-surface orders and overlying facies-unit types

```

SELECT g_3_facies.facies_ID, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type, h_3_facies_transitions.bound_surf_order FROM g_3_facies JOIN
h_3_facies_transitions ON g_3_facies.facies_ID =
h_3_facies_transitions.trans_facies_ID WHERE trans_direction = 'Vertical';

```

It returns all the bounding surface orders underlying facies units and their facies types.

#### tq\_27 – Depositional-element type, thickness and width from subsets suitable for proportions

```
SELECT dep_el_type, thickness, width FROM b_subsets JOIN c_1_depositional_elements
ON b_subsets.subset_ID = c_1_depositional_elements.subset_ID WHERE 1_suitability
LIKE '%Unit proportions%';
```

It returns element types, widths and thickness of all the depositional elements belonging to datasets that are suitable for computations of depositional-element type proportions.

### tq\_32 – Types and thickness of facies-units overlying 4<sup>th</sup>-order channel-fill bases

```
CREATE TEMPORARY TABLE facies_bso AS SELECT g_3_facies.arch_el_ID,
g_3_facies.facies_ID, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type, h_3_facies_transitions.bound_surf_order,
g_3_facies.thickness FROM g_3_facies JOIN h_3_facies_transitions ON
g_3_facies.facies_ID = h_3_facies_transitions.trans_facies_ID WHERE trans_direction
= 'Vertical' AND bound_surf_order <> '2nd' AND bound_surf_order <> '3rd' AND
bound_surf_order IS NOT NULL;
SELECT facies_type, facies_bso.thickness FROM e_2_architectural_elements JOIN
facies_bso ON e_2_architectural_elements.arch_el_ID = facies_bso.arch_el_ID WHERE
facies_type IS NOT NULL AND facies_bso.thickness IS NOT NULL AND arch_el_type =
'CH';
```

It returns the thickness of all the facies units belonging to a 'CH' architectural element type and overlying 4<sup>th</sup>- or higher-order bounding surfaces.

### tq\_34 – Architectural-element information from case studies with min 20% fine-grained facies

```
create temporary table facies_t as select case_ID, g_3_facies.facies_type,
g_3_facies.thickness from b_subsets join c_1_depositional_elements on
b_subsets.subset_ID = c_1_depositional_elements.subset_ID join
e_2_architectural_elements on c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID join g_3_facies on
e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID;
create temporary table facies_t2 as select facies_t.case_ID, facies_t.facies_type,
sum(thickness) sum from facies_t group by facies_type, case_ID;
create temporary table facies_t3 as select facies_t2.case_ID, sum(sum) total from
facies_t2 group by case_ID;
create temporary table chosen_cases as select facies_t2.case_ID, sum(sum) partial
from facies_t2 where facies_type like '%F%' group by case_ID;
create temporary table suitable_cases as select distinct chosen_cases.case_ID from
chosen_cases join facies_t3 on chosen_cases.case_ID = facies_t3.case_ID
where partial/total > 0.2;
select e_2_architectural_elements.arch_el_type, e_2_architectural_elements.thickness
from suitable_cases join b_subsets on suitable_cases.case_ID = b_subsets.case_ID
join c_1_depositional_elements on b_subsets.subset_ID =
c_1_depositional_elements.subset_ID join e_2_architectural_elements on
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID where
e_2_architectural_elements.thickness is not null;
```

It returns the thickness of all the architectural elements belonging to case studies characterized by having at least 20% by thickness of fine-grained lithofacies.

### tq\_35 – Sum of thicknesses for each facies type from a case study

```
CREATE TEMPORARY TABLE facies_thickness AS SELECT facies_type, g_3_facies.thickness
FROM b_subsets JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID
WHERE case_ID = 23;
SELECT facies_type, SUM(thickness) FROM facies_thickness GROUP BY facies_type;
```

It returns the sum of the thicknesses of all facies types for a given case study.

### tq\_36 – Proportions of facies types in a case study



```

CREATE TEMPORARY TABLE facies_thickness AS SELECT facies_type, g_3_facies.thickness
FROM b_subsets JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID
WHERE case_ID = 23;
CREATE TEMPORARY TABLE individual_facies_t AS SELECT facies_type, SUM(thickness) AS
individual_sum FROM facies_thickness GROUP BY facies_type;
CREATE TEMPORARY TABLE total_facies_t AS SELECT SUM(thickness) AS total_sum
FROM facies_thickness;
SELECT facies_type, individual_sum/total_sum FROM individual_facies_t JOIN
total_facies_t GROUP BY facies_type;

```

It returns the proportion – expressed as fraction of 1 – of all facies types for a given case study.

### tq\_39 – Proportions of facies types in modern and ancient DLA architectural elements

```

CREATE TEMPORARY TABLE DLA_ancient_thickness AS SELECT a_source_data.case_ID,
g_3_facies.facies_type, SUM(g_3_facies.thickness) AS sum_thickness_ancient FROM
a_source_data JOIN b_subsets ON a_source_data.case_ID = b_subsets.case_ID JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID WHERE
arch_el_type = 'DLA' AND g_3_facies.thickness IS NOT NULL AND lithostrat_unit IS NOT
NULL GROUP BY g_3_facies.facies_type;
CREATE TEMPORARY TABLE DLA_ancient_total AS SELECT SUM(sum_thickness_ancient) AS
total_thickness_ancient FROM DLA_ancient_thickness;
CREATE TEMPORARY TABLE DLA_ancient_proportions AS SELECT facies_type,
sum_thickness_ancient/total_thickness_ancient AS proportion_ancient FROM
DLA_ancient_thickness JOIN DLA_ancient_total;
CREATE TEMPORARY TABLE DLA_modern_thickness AS SELECT a_source_data.case_ID,
g_3_facies.facies_type, SUM(g_3_facies.thickness) AS sum_thickness_modern FROM
a_source_data JOIN b_subsets ON a_source_data.case_ID = b_subsets.case_ID JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID WHERE
arch_el_type = 'DLA' AND g_3_facies.thickness IS NOT NULL AND river IS NOT NULL AND
age_from = 'Holocene' GROUP BY g_3_facies.facies_type;
CREATE TEMPORARY TABLE DLA_modern_total AS SELECT SUM(sum_thickness_modern) AS
total_thickness_modern FROM DLA_modern_thickness;
CREATE TEMPORARY TABLE DLA_modern_proportions AS SELECT facies_type,
sum_thickness_modern/total_thickness_modern AS proportion_modern FROM
DLA_modern_thickness JOIN DLA_modern_total;
CREATE TEMPORARY TABLE DLA_left_join SELECT DLA_ancient_proportions.facies_type,
DLA_ancient_proportions.proportion_ancient, DLA_modern_proportions.proportion_modern
FROM DLA_ancient_proportions LEFT JOIN DLA_modern_proportions ON
DLA_ancient_proportions.facies_type = DLA_modern_proportions.facies_type;
CREATE TEMPORARY TABLE DLA_right_join SELECT DLA_modern_proportions.facies_type,
DLA_ancient_proportions.proportion_ancient, DLA_modern_proportions.proportion_modern
FROM DLA_ancient_proportions RIGHT JOIN DLA_modern_proportions ON
DLA_ancient_proportions.facies_type = DLA_modern_proportions.facies_type;
SELECT * FROM DLA_left_join UNION SELECT * FROM DLA_right_join;

```

It returns two sets of proportions – expressed as fraction of 1 – of all facies types belonging to a 'DLA' architectural element type, classified into modern and ancient systems.

### tq\_40 – Proportions of facies types in individual LA architectural elements

```

CREATE TEMPORARY TABLE sum_el_thickness_incnnull AS SELECT g_3_facies.arch_el_ID,
SUM(g_3_facies.thickness) sum_el_thickness FROM b_subsets JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID WHERE
arch_el_type = 'LA' GROUP BY g_3_facies.arch_el_ID;
CREATE TEMPORARY TABLE sum_el_thickness AS SELECT *
FROM sum_el_thickness_incnnull WHERE sum_el_thickness IS NOT NULL;
CREATE TEMPORARY TABLE facies_thickness AS SELECT g_3_facies.arch_el_ID,
facies_type, g_3_facies.thickness FROM b_subsets JOIN c_1_depositional_elements ON

```

```

b_subsets.subset_ID = c_1_depositional_elements.subset_ID JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID JOIN g_3_facies ON
e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID WHERE arch_el_type =
'LA';
CREATE TEMPORARY TABLE individual_facies_t AS SELECT arch_el_ID, facies_type,
CONCAT(arch_el_ID,'_',facies_type), SUM(thickness) AS individual_sum FROM
facies_thickness GROUP BY CONCAT(arch_el_ID,'_',facies_type);
SELECT sum_el_thickness.arch_el_ID, facies_type, individual_sum/sum_el_thickness
FROM sum_el_thickness JOIN individual_facies_t ON sum_el_thickness.arch_el_ID =
individual_facies_t.arch_el_ID;

```

It returns the proportion – expressed as fraction of 1 – of all facies types belonging to each individual 'LA' architectural element (designated by its numerical identifier).

#### tq\_41 – Facies associations with proportions in individual LA architectural elements

```

CREATE TEMPORARY TABLE sum_el_thickness_incnnull AS SELECT g_3_facies.arch_el_ID,
SUM(g_3_facies.thickness) sum_el_thickness FROM b_subsets JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID
WHERE arch_el_type = 'LA' GROUP BY g_3_facies.arch_el_ID;
CREATE TEMPORARY TABLE sum_el_thickness AS SELECT * FROM sum_el_thickness_incnnull
WHERE sum_el_thickness IS NOT NULL;
CREATE TEMPORARY TABLE facies_thickness AS SELECT g_3_facies.arch_el_ID,
facies_type, g_3_facies.thickness FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID JOIN g_3_facies ON
e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID WHERE arch_el_type =
'LA';
CREATE TEMPORARY TABLE individual_facies_t AS SELECT arch_el_ID, facies_type,
CONCAT(arch_el_ID,'_',facies_type), SUM(thickness) AS individual_sum FROM
facies_thickness GROUP BY CONCAT(arch_el_ID,'_',facies_type);
CREATE TEMPORARY TABLE individual_facies_prop AS SELECT sum_el_thickness.arch_el_ID,
facies_type, ROUND(individual_sum/sum_el_thickness,2) AS proportion FROM
sum_el_thickness JOIN individual_facies_t ON sum_el_thickness.arch_el_ID =
individual_facies_t.arch_el_ID;
SELECT individual_facies_prop.arch_el_ID, GROUP_CONCAT(facies_type, '/',proportion)
AS facies_association FROM individual_facies_prop GROUP BY
individual_facies_prop.arch_el_ID;

```

It returns the facies association – expressed as a list of facies types and relative proportions expressed as fraction of 1 – composing each individual 'LA' architectural element (designated by its numerical identifier).

#### tq\_42 – Proportions of channel-complexes from subsets suitable for deriving dimensions

```

CREATE TEMPORARY TABLE dep_el_xsarea AS SELECT b_subsets.subset_ID, dep_el_type,
IFNULL((thickness* IF(width IS NOT NULL, width, apparent_width)),0) AS xsarea,
IFNULL((thickness* IF(partial_width IS NOT NULL, partial_width, unlimited_width)),0)
AS partial_xsarea FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID WHERE l_suitability LIKE
'%proportion%' AND l_suitability LIKE '%dimension%' ORDER BY subset_ID;
CREATE TEMPORARY TABLE channel_complex_total_area AS SELECT subset_ID, SUM(xsarea)+
SUM(partial_xsarea) AS channel_complex_area FROM dep_el_xsarea WHERE dep_el_type =
'Channel-complex' GROUP BY subset_ID;
CREATE TEMPORARY TABLE total_area AS SELECT subset_ID, SUM(xsarea)+
SUM(partial_xsarea) AS total_area FROM dep_el_xsarea GROUP BY subset_ID;
SELECT channel_complex_total_area.subset_ID,
(channel_complex_total_area.channel_complex_area/total_area.total_area) AS
channel_complex_prop FROM channel_complex_total_area JOIN total_area ON
channel_complex_total_area.subset_ID = total_area.subset_ID WHERE
(channel_complex_total_area.channel_complex_area/total_area.total_area) IS NOT NULL;

```



It returns the proportions – expressed as fraction of 1, and based on width and thickness – of channel-complexes within subsets that are suitable for deriving proportions and dimensional parameters.

#### tq\_45 – Architectural element proportions within individual 1D subsets

```
CREATE TEMPORARY TABLE arch_el_sum_t AS SELECT b_subsets.subset_ID, arch_el_ID,
arch_el_type, SUM(e_2_architectural_elements.thickness) AS sum_t FROM b_subsets JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID WHERE
2_suitability LIKE '%roport%' AND spatial_type = '1D vertical' AND arch_el_type IS
NOT NULL AND e_2_architectural_elements.thickness IS NOT NULL GROUP BY
arch_el_type,subset_ID;
CREATE TEMPORARY TABLE arch_el_total_t AS SELECT b_subsets.subset_ID,
SUM(e_2_architectural_elements.thickness) AS total_t FROM b_subsets JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID WHERE
2_suitability LIKE '%roport%' AND spatial_type = '1D vertical' AND arch_el_type IS
NOT NULL AND e_2_architectural_elements.thickness IS NOT NULL GROUP BY subset_ID;
SELECT arch_el_sum_t.subset_ID, arch_el_type, sum_t/total_t AS arch_el_proportion
FROM arch_el_sum_t JOIN arch_el_total_t ON arch_el_sum_t.subset_ID =
arch_el_total_t.subset_ID GROUP BY arch_el_sum_t.subset_ID,
arch_el_sum_t.arch_el_type;
```

It returns the proportion – expressed as fraction of 1 – of all architectural-element types within each individual subset, including only '1D vertical' subsets (e.g. logs, cores) suitable for computing architectural-element proportions.

#### tq\_46 – Architectural element proportions within individual 2D/3D subsets

```
CREATE TEMPORARY TABLE arch_el_sum_a AS SELECT b_subsets.subset_ID, arch_el_ID,
arch_el_type, SUM(e_2_architectural_elements.thickness*
IFNULL(IF(e_2_architectural_elements.width IS NOT
NULL,e_2_architectural_elements.width, IF(e_2_architectural_elements.apparent_width
IS NOT NULL,e_2_architectural_elements.apparent_width,
IF(e_2_architectural_elements.partial_width IS NOT NULL,
e_2_architectural_elements.partial_width,
IF(e_2_architectural_elements.unlimited_width IS NOT
NULL,e_2_architectural_elements.unlimited_width, IF(
e_2_architectural_elements.dip_length IS NOT
NULL,e_2_architectural_elements.dip_length,
IF(e_2_architectural_elements.partial_dip_length IS NOT NULL,
e_2_architectural_elements.partial_dip_length,e_2_architectural_elements.unlimited_d
ip_length))))),0)) AS sum_a FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID WHERE 2_suitability LIKE '%roport%' AND
(spatial_type = '2D section' OR spatial_type = 'Pseudo3D') AND arch_el_type IS NOT
NULL AND e_2_architectural_elements.thickness IS NOT NULL AND
(e_2_architectural_elements.width IS NOT NULL OR
e_2_architectural_elements.apparent_width IS NOT NULL OR
e_2_architectural_elements.partial_width IS NOT NULL OR
e_2_architectural_elements.unlimited_width IS NOT NULL OR
e_2_architectural_elements.dip_length IS NOT NULL OR
e_2_architectural_elements.partial_dip_length IS NOT NULL OR
e_2_architectural_elements.unlimited_dip_length IS NOT NULL)
GROUP BY arch_el_type,subset_ID;
CREATE TEMPORARY TABLE arch_el_total_a AS SELECT b_subsets.subset_ID,
SUM(e_2_architectural_elements.thickness* IFNULL(IF(e_2_architectural_elements.width
IS NOT NULL,e_2_architectural_elements.width,
IF(e_2_architectural_elements.apparent_width IS NOT
NULL,e_2_architectural_elements.apparent_width,
IF(e_2_architectural_elements.partial_width IS NOT NULL,
e_2_architectural_elements.partial_width,
IF(e_2_architectural_elements.unlimited_width IS NOT
NULL,e_2_architectural_elements.unlimited_width, IF(
e_2_architectural_elements.dip_length IS NOT
NULL,e_2_architectural_elements.dip_length,
IF(e_2_architectural_elements.partial_dip_length IS NOT NULL,
e_2_architectural_elements.partial_dip_length,e_2_architectural_elements.unlimited_d
ip_length))))),0)) AS total_a FROM b_subsets JOIN c_1_depositional_elements ON
```

```

b_subsets.subset_ID = c_1_depositional_elements.subset_ID JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID WHERE 2_suitability LIKE '%roport%' AND
(spatial_type = '2D section' OR spatial_type = 'Pseudo3D') AND arch_el_type IS NOT
NULL AND e_2_architectural_elements.thickness IS NOT NULL AND
(e_2_architectural_elements.width IS NOT NULL OR
e_2_architectural_elements.apparent_width IS NOT NULL OR
e_2_architectural_elements.partial_width IS NOT NULL OR
e_2_architectural_elements.unlimited_width IS NOT NULL OR
e_2_architectural_elements.dip_length IS NOT NULL OR
e_2_architectural_elements.partial_dip_length IS NOT NULL OR
e_2_architectural_elements.unlimited_dip_length IS NOT NULL) GROUP BY subset_ID;
SELECT arch_el_sum_a.subset_ID, arch_el_type, sum_a/total_a AS arch_el_proportion
FROM arch_el_sum_a JOIN arch_el_total_a ON arch_el_sum_a.subset_ID =
arch_el_total_a.subset_ID GROUP BY arch_el_sum_a.subset_ID,
arch_el_sum_a.arch_el_type;

```

It returns the proportion – expressed as fraction of 1 – of all architectural-element types within each individual subset, including only ‘2D section’ and ‘Pseudo 3D’ subsets (e.g. panels) suitable for computing architectural-element proportions.

### tq\_50 – User-defined facies-unit-based net-to-gross ratio for CH architectural elements

```

CREATE TEMPORARY TABLE non_net_T AS SELECT e_2_architectural_elements.arch_el_ID,
SUM(g_3_facies.thickness) AS non_net_thickness FROM a_source_data JOIN b_subsets ON
a_source_data.case_ID = b_subsets.case_ID JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID JOIN g_3_facies ON
e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID WHERE 3_suitability
LIKE '%proportion%' AND arch_el_type = 'CH' AND (facies_type LIKE '%F%' OR
facies_type='Gmm' OR facies_type = 'Gmg') GROUP BY
e_2_architectural_elements.arch_el_ID;
CREATE TEMPORARY TABLE all_T AS SELECT e_2_architectural_elements.arch_el_ID,
SUM(g_3_facies.thickness) AS all_thickness, COUNT(facies_ID) AS nr_facies FROM
a_source_data JOIN b_subsets ON a_source_data.case_ID = b_subsets.case_ID JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID
JOIN g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID
WHERE 3_suitability LIKE '%proportion%' AND arch_el_type = 'CH' GROUP BY
e_2_architectural_elements.arch_el_ID;
CREATE TEMPORARY TABLE arch_el_ntg AS SELECT all_T.arch_el_ID, (all_thickness-
non_net_thickness)/all_thickness AS NTG, nr_facies FROM all_T JOIN non_net_T ON
all_T.arch_el_ID = non_net_T.arch_el_ID WHERE all_thickness IS NOT NULL;
SELECT * FROM arch_el_ntg;

```

It returns a net-to-gross ratio for each individual ‘CH’ architectural element (designated by its numerical identifier), based on a set of non-net facies types, and the number of facies units on which the figures are based.

### Unit transitions

#### tq\_06\_transition\_filtering – Filter for deriving one transition per direction for each genetic unit

```

CREATE TABLE facies_trans_filter_vertical SELECT CONCAT
(`facies_ID`, `trans_direction`) AS facies_trans_string, `facies_ID`,
`trans_facies_ID`, `trans_direction`, `bound_surf_order` FROM h_3_facies_transitions
WHERE `trans_direction`='Vertical';
ALTER IGNORE TABLE facies_trans_filter_vertical ADD UNIQUE INDEX
(facies_trans_string);

```

It returns only one transition per direction (here: vertical) for each facies unit.

**tq\_49 – Show all architectural-element types and transitions**

```
SELECT b_subsets.subset_ID, e_2_architectural_elements.arch_el_ID,
e_2_architectural_elements.arch_el_type,
e_2_architectural_elements_1.arch_el_ID, e_2_architectural_elements_1.arch_el_type,
f_2_arch_el_transitions.trans_direction FROM (e_2_architectural_elements AS
e_2_architectural_elements_1 JOIN (f_2_arch_el_transitions JOIN
e_2_architectural_elements ON
f_2_arch_el_transitions.arch_el_ID = e_2_architectural_elements.arch_el_ID) ON
e_2_architectural_elements_1.arch_el_ID = f_2_arch_el_transitions.trans_arch_el_ID)
JOIN (b_subsets JOIN c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID) ON e_2_architectural_elements.dep_el_ID =
c_1_depositional_elements.dep_el_ID;
```

It returns architectural-element types from ID's, and transition direction.

**tq\_13 – Count facies-unit transitions for any direction**

```
CREATE TEMPORARY TABLE facies_trans_ID AS (SELECT g_3_facies.facies_ID,
h_3_facies_transitions.trans_facies_ID, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type, h_3_facies_transitions.bound_surf_order FROM g_3_facies JOIN
h_3_facies_transitions ON g_3_facies.facies_ID = h_3_facies_transitions.facies_ID);
CREATE TEMPORARY TABLE facies_trans_types AS (SELECT facies_trans_ID.facies_ID,
facies_trans_ID.trans_facies_ID, IFNULL (facies_trans_ID.facies_type, 'Undefined')
AS facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
facies_trans_ID.trans_direction, facies_trans_ID.bound_surf_order FROM g_3_facies
JOIN facies_trans_ID ON g_3_facies.facies_ID = facies_trans_ID.trans_facies_ID);
CREATE TEMPORARY TABLE facies_vertical_trans_strings AS (SELECT
facies_trans_types.facies_type, facies_trans_types.transitional_type, CONCAT
(facies_trans_types.facies_type, '_', facies_trans_types.transitional_type) AS
trans_string FROM facies_trans_types);
CREATE TEMPORARY TABLE facies_vertical_trans_counts SELECT facies_type,
transitional_type, COUNT(trans_string) FROM facies_vertical_trans_strings
GROUP BY trans_string;
SELECT * FROM facies_vertical_trans_counts;
```

It returns the count of every transition between facies units, regardless of the transition direction; undefined (NULL-valued) facies types are included in the query as 'Undefined'.

**tq\_48 – Count facies-unit transitions for vertical direction from braided systems**

```
CREATE TEMPORARY TABLE facies_trans_ID AS SELECT g_3_facies.facies_ID,
h_3_facies_transitions.trans_facies_ID, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type, h_3_facies_transitions.bound_surf_order FROM b_subsets JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID JOIN
h_3_facies_transitions ON g_3_facies.facies_ID = h_3_facies_transitions.facies_ID
WHERE river_pattern_type = 'Braided';
CREATE TEMPORARY TABLE facies_trans_types AS SELECT facies_trans_ID.facies_ID,
facies_trans_ID.trans_facies_ID, IFNULL (facies_trans_ID.facies_type, 'Undefined')
AS facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
facies_trans_ID.trans_direction, facies_trans_ID.bound_surf_order FROM g_3_facies
JOIN facies_trans_ID ON g_3_facies.facies_ID = facies_trans_ID.trans_facies_ID WHERE
trans_direction='Vertical';
CREATE TEMPORARY TABLE facies_vertical_trans_strings AS (SELECT
facies_trans_types.facies_type, facies_trans_types.transitional_type, CONCAT
(facies_trans_types.facies_type, '_', facies_trans_types.transitional_type) AS
trans_string FROM facies_trans_types);
CREATE TEMPORARY TABLE facies_vertical_trans_counts SELECT facies_type,
transitional_type, COUNT(trans_string) FROM facies_vertical_trans_strings
GROUP BY trans_string;
SELECT * FROM facies_vertical_trans_counts;
```

It returns the count of vertical transition between facies units from braided systems; undefined (NULL-valued) facies types are included in the query as 'Undefined'.

## tq\_47 – Count facies-unit transitions for vertical direction from sandy meandering systems

```

CREATE TEMPORARY TEMPORARY TABLE facies_t AS SELECT case_ID, g_3_facies.facies_type,
g_3_facies.thickness FROM b_subsets JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID JOIN g_3_facies ON
e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID;
CREATE TEMPORARY TABLE facies_t2 AS SELECT facies_t.case_ID, facies_t.facies_type,
SUM(thickness) SUM FROM facies_t GROUP BY facies_type, case_ID;
CREATE TEMPORARY TABLE facies_t3 AS SELECT facies_t2.case_ID, SUM(SUM) total FROM
facies_t2 GROUP BY case_ID;
CREATE TEMPORARY TABLE chosen_cases AS SELECT facies_t2.case_ID, SUM(SUM) PARTIAL
FROM facies_t2 WHERE facies_type LIKE '%S%' GROUP BY case_ID;
CREATE TEMPORARY TABLE suitable_cases AS SELECT DISTINCT chosen_cases.case_ID FROM
chosen_cases JOIN facies_t3 ON chosen_cases.case_ID = facies_t3.case_ID WHERE
PARTIAL/total > 0.5;
CREATE TEMPORARY TABLE selected_facies AS SELECT b_subsets.case_ID,
g_3_facies.facies_ID, g_3_facies.facies_type FROM suitable_cases JOIN b_subsets ON
suitable_cases.case_ID = b_subsets.case_ID JOIN c_1_depositional_elements ON
b_subsets.subset_ID = c_1_depositional_elements.subset_ID JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID JOIN g_3_facies ON
e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID WHERE
g_3_facies.thickness IS NOT NULL AND river_pattern_type = 'Meandering';
CREATE TEMPORARY TABLE facies_trans_ID AS (SELECT selected_facies.facies_ID,
h_3_facies_transitions.trans_facies_ID, h_3_facies_transitions.trans_direction,
selected_facies.facies_type, h_3_facies_transitions.bound_surf_order FROM
selected_facies JOIN h_3_facies_transitions ON selected_facies.facies_ID =
h_3_facies_transitions.facies_ID);
CREATE TEMPORARY TABLE facies_trans_types AS (SELECT facies_trans_ID.facies_ID,
facies_trans_ID.trans_facies_ID, IFNULL (facies_trans_ID.facies_type, 'Undefined')
AS facies_type, IFNULL (selected_facies.facies_type, 'Undefined') AS
transitional_type, facies_trans_ID.trans_direction, facies_trans_ID.bound_surf_order
FROM selected_facies JOIN facies_trans_ID ON selected_facies.facies_ID =
facies_trans_ID.trans_facies_ID WHERE facies_trans_ID.trans_direction = 'Vertical');
CREATE TEMPORARY TABLE facies_vertical_trans_strings AS (SELECT
facies_trans_types.facies_type, facies_trans_types.transitional_type, CONCAT
(facies_trans_types.facies_type, '_', facies_trans_types.transitional_type) AS
trans_string FROM facies_trans_types);
CREATE TEMPORARY TABLE facies_vertical_trans_counts SELECT facies_type,
transitional_type, COUNT(trans_string) FROM facies_vertical_trans_strings
GROUP BY trans_string;
SELECT * FROM facies_vertical_trans_counts;

```

It returns the count of vertical transition between facies units from meandering systems with sandy facies representing over 50% of total measured thickness; undefined (NULL-valued) facies types are included in the query as 'Undefined'.

## tq\_02 – Vertical architectural-element transitions within 6<sup>th</sup>-order channel-belts

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
c_1_depositional_elements.dep_el_type, e_2_architectural_elements.arch_el_ID,
f_2_arch_el_transitions.trans_arch_el_ID, f_2_arch_el_transitions.trans_direction,
e_2_architectural_elements.arch_el_type, f_2_arch_el_transitions.bound_surf_order
FROM (c_1_depositional_elements JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID) JOIN
f_2_arch_el_transitions ON e_2_architectural_elements.arch_el_ID =
f_2_arch_el_transitions.arch_el_ID WHERE c_1_depositional_elements.dep_el_type =
'Channel-complex');
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.dep_el_type,
new_trans_ID.arch_el_ID, new_trans_ID.trans_arch_el_ID, IFNULL
(new_trans_ID.arch_el_type, 'Undefined') AS arch_el_type, IFNULL
(e_2_architectural_elements.arch_el_type, 'Undefined') AS transitional_type,
new_trans_ID.trans_direction, new_trans_ID.bound_surf_order FROM
e_2_architectural_elements JOIN new_trans_ID ON
e_2_architectural_elements.arch_el_ID = new_trans_ID.trans_arch_el_ID)
ORDER BY dep_el_type;
CREATE TEMPORARY TABLE vertical_trans_under5 AS (SELECT new_trans_types.dep_el_type,
new_trans_types.arch_el_type, new_trans_types.transitional_type, CONCAT
(new_trans_types.arch_el_type, '_', new_trans_types.transitional_type) AS
trans_string FROM new_trans_types WHERE trans_direction = 'Vertical' AND

```

```
(new_trans_types.bound_surf_order = '4th' OR new_trans_types.bound_surf_order = '5th') ORDER BY new_trans_types.arch_el_ID);
CREATE TEMPORARY TABLE vertical_trans_under5_counts SELECT dep_el_type,
arch_el_type, transitional_type, COUNT(trans_string) FROM vertical_trans_under5
GROUP BY trans_string;
SELECT * FROM vertical_trans_under5_counts;
```

It returns the count of all the architectural elements transitions occurring in a given direction (here: Vertical) across determined bounding surface orders (here: 4<sup>th</sup> and 5<sup>th</sup>), with lower elements belonging to channel-complexes; undefined (NULL-valued) facies types are included in the query as 'Undefined'.

#### tq\_04 – Vertical facies-unit transitions within 4<sup>th</sup>-order channel-fills

```
CREATE TEMPORARY TABLE facies_trans_ID AS (SELECT g_3_facies.facies_ID,
h_3_facies_transitions.trans_facies_ID, e_2_architectural_elements.arch_el_type,
h_3_facies_transitions.trans_direction, g_3_facies.facies_type,
h_3_facies_transitions.bound_surf_order FROM (e_2_architectural_elements JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID) JOIN
h_3_facies_transitions ON g_3_facies.facies_ID = h_3_facies_transitions.facies_ID);
CREATE TEMPORARY TABLE facies_trans_types AS (SELECT facies_trans_ID.facies_ID,
facies_trans_ID.trans_facies_ID, IFNULL (facies_trans_ID.facies_type, 'Undefined')
AS facies_type, facies_trans_ID.arch_el_type, IFNULL (g_3_facies.facies_type,
'Undefined') AS transitional_type, facies_trans_ID.trans_direction,
facies_trans_ID.bound_surf_order FROM g_3_facies JOIN facies_trans_ID ON
g_3_facies.facies_ID = facies_trans_ID.trans_facies_ID WHERE (arch_el_type='CH' AND
trans_direction='Vertical' AND (bound_surf_order='2nd' OR bound_surf_order='3rd')));
CREATE TEMPORARY TABLE facies_vertical_trans_strings AS (SELECT
facies_trans_types.arch_el_type, facies_trans_types.facies_type,
facies_trans_types.transitional_type, CONCAT (facies_trans_types.facies_type, '_',
facies_trans_types.transitional_type) AS trans_string FROM facies_trans_types);
CREATE TEMPORARY TABLE facies_vertical_trans_counts SELECT arch_el_type,
facies_type, transitional_type, COUNT(trans_string) FROM
facies_vertical_trans_strings GROUP BY trans_string;
SELECT * FROM facies_vertical_trans_counts;
```

It returns the count of all the facies transitions occurring in a given direction (here: Vertical) within a given architectural element type (here: CH) across determined bounding surface orders (here: 2<sup>nd</sup> and 3<sup>rd</sup>); undefined (NULL-valued) facies types are included in the query as 'Undefined'.

#### tq\_09 – Vertical facies-unit transitions from 1D subsets from individual case study

```
CREATE TEMPORARY TABLE facies_trans_ID AS (SELECT a_source_data.case_ID,
b_subsets.subset_ID, g_3_facies.facies_ID, h_3_facies_transitions.trans_facies_ID,
e_2_architectural_elements.arch_el_type, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type, h_3_facies_transitions.bound_surf_order FROM
(((a_source_data JOIN b_subsets ON a_source_data.case_ID = b_subsets.case_ID) JOIN
c_1_depositional_elements ON b_subsets.subset_ID =
c_1_depositional_elements.subset_ID) JOIN e_2_architectural_elements ON
c_1_depositional_elements.dep_el_ID = e_2_architectural_elements.dep_el_ID) JOIN
g_3_facies ON e_2_architectural_elements.arch_el_ID = g_3_facies.arch_el_ID) JOIN
h_3_facies_transitions ON g_3_facies.facies_ID = h_3_facies_transitions.facies_ID
WHERE b_subsets.case_ID = 23 AND spatial_type = '1D vertical');
CREATE TEMPORARY TABLE facies_trans_types AS (SELECT facies_trans_ID.facies_ID,
facies_trans_ID.trans_facies_ID, IFNULL (facies_trans_ID.facies_type, 'Undefined')
AS facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
facies_trans_ID.trans_direction, facies_trans_ID.bound_surf_order FROM g_3_facies
JOIN facies_trans_ID ON g_3_facies.facies_ID = facies_trans_ID.facies_ID WHERE
facies_trans_ID.facies_ID IS NOT NULL AND facies_trans_ID.trans_facies_ID IS NOT
NULL AND trans_direction='Vertical');
CREATE TEMPORARY TABLE facies_vertical_trans_strings AS (SELECT
facies_trans_types.facies_type, facies_trans_types.transitional_type, CONCAT
(facies_trans_types.facies_type, '_', facies_trans_types.transitional_type) AS
trans_string FROM facies_trans_types);
CREATE TEMPORARY TABLE facies_vertical_trans_counts SELECT facies_type,
transitional_type, COUNT(trans_string) FROM facies_vertical_trans_strings
GROUP BY trans_string;
SELECT * FROM facies_vertical_trans_counts;
```

It returns the count of all the facies transitions occurring in a given direction (here: Vertical) for a given case study (here: 23, i.e. Cain, 2009) for 1D vertical datasets (logs) only; undefined (NULL-valued) facies types are included in the query as 'Undefined'.

#### tq\_14 – Count of architectural elements laterally-adjacent a CH element, classified on type

```
CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
c_1_depositional_elements.dep_el_type, e_2_architectural_elements.arch_el_ID,
e_2_architectural_elements.width, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, e_2_architectural_elements.arch_el_type,
f_2_arch_el_transitions.bound_surf_order FROM (c_1_depositional_elements JOIN
e_2_architectural_elements ON c_1_depositional_elements.dep_el_ID =
e_2_architectural_elements.dep_el_ID) JOIN f_2_arch_el_transitions ON
e_2_architectural_elements.arch_el_ID = f_2_arch_el_transitions.arch_el_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.dep_el_type,
new_trans_ID.arch_el_ID, new_trans_ID.trans_arch_el_ID, IFNULL
(new_trans_ID.arch_el_type, 'Undefined') AS arch_el_type, new_trans_ID.width, IFNULL
(e_2_architectural_elements.arch_el_type, 'Undefined') AS transitional_type,
new_trans_ID.trans_direction, new_trans_ID.bound_surf_order FROM
e_2_architectural_elements JOIN new_trans_ID ON
e_2_architectural_elements.arch_el_ID = new_trans_ID.trans_arch_el_ID) ORDER BY
dep_el_type;
CREATE TEMPORARY TABLE lateral_trans AS (SELECT new_trans_types.dep_el_type,
new_trans_types.arch_el_type, new_trans_types.width,
new_trans_types.transitional_type, CONCAT (new_trans_types.arch_el_type, '_',
new_trans_types.transitional_type) AS trans_string FROM new_trans_types WHERE
trans_direction = 'Lateral' AND arch_el_type = 'CH' AND width > 10 ORDER BY
new_trans_types.arch_el_ID);
CREATE TEMPORARY TABLE lateral_trans_counts SELECT dep_el_type, arch_el_type,
transitional_type, COUNT(trans_string) FROM lateral_trans GROUP BY trans_string;
SELECT * FROM lateral_trans_counts ORDER BY dep_el_type;
```

It returns the count of all the architectural elements laterally transitional to a given type (here: CH) of element, when the width of the latter is larger than a cut-off value (here: 10 m); the transitions are classified according to the type of depositional element the CH architectural element belongs to; undefined (NULL-valued) facies types are included in the query as 'Undefined'.

#### tq\_15 – Lateral transitions involving 3 architectural elements, conditioned on left-element type

```
CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
e_2_architectural_elements.arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, e_2_architectural_elements.arch_el_type,
f_2_arch_el_transitions.bound_surf_order FROM e_2_architectural_elements JOIN
f_2_arch_el_transitions ON e_2_architectural_elements.arch_el_ID =
f_2_arch_el_transitions.arch_el_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.arch_el_ID,
new_trans_ID.trans_arch_el_ID, IFNULL (new_trans_ID.arch_el_type, 'Undefined') AS
arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID.trans_direction, new_trans_ID.bound_surf_order FROM
e_2_architectural_elements JOIN new_trans_ID ON
e_2_architectural_elements.arch_el_ID = new_trans_ID.trans_arch_el_ID WHERE
trans_direction = 'Lateral' AND new_trans_ID.arch_el_type = 'CH');
CREATE TEMPORARY TABLE new_trans_ID_from_CH AS (SELECT
new_trans_types.trans_arch_el_ID AS arch_el_ID,
f_2_arch_el_transitions.trans_arch_el_ID, f_2_arch_el_transitions.trans_direction,
new_trans_types.transitional_type AS arch_el_type,
f_2_arch_el_transitions.bound_surf_order FROM new_trans_types JOIN
f_2_arch_el_transitions ON new_trans_types.trans_arch_el_ID =
f_2_arch_el_transitions.arch_el_ID WHERE f_2_arch_el_transitions.trans_direction =
'Lateral');
CREATE TEMPORARY TABLE new_trans_types_from_CH AS (SELECT
new_trans_ID_from_CH.arch_el_ID, new_trans_ID_from_CH.trans_arch_el_ID,
new_trans_ID_from_CH.arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type,
'Undefined') AS transitional_type, new_trans_ID_from_CH.trans_direction,
new_trans_ID_from_CH.bound_surf_order FROM e_2_architectural_elements JOIN
new_trans_ID_from_CH ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_from_CH.trans_arch_el_ID);
```



```

CREATE TEMPORARY TABLE unique_trans_types_from_CH SELECT CONCAT (`arch_el_ID`,
`_`,`trans_arch_el_ID`) AS trans_string, `arch_el_ID`, `trans_arch_el_ID`,
`arch_el_type`, `transitional_type`, `trans_direction`, `bound_surf_order` FROM
new_trans_types_from_CH; ALTER IGNORE TABLE unique_trans_types_from_CH ADD UNIQUE
INDEX (trans_string);
CREATE TEMPORARY TABLE lateral_trans AS(SELECT unique_trans_types_from_CH
.arch_el_type, unique_trans_types_from_CH.transitional_type, CONCAT
(unique_trans_types_from_CH.arch_el_type, `_`, unique_trans_types_from_CH
.transitional_type) AS trans_string FROM unique_trans_types_from_CH
ORDER BY unique_trans_types_from_CH.arch_el_ID);
CREATE TEMPORARY TABLE lateral_trans_counts SELECT arch_el_type, transitional_type,
COUNT(trans_string) FROM lateral_trans GROUP BY trans_string;
SELECT * FROM lateral_trans_counts;

```

It returns the count of all right-lateral architectural element transitions involving elements that are neighbouring, in the left-lateral direction, a given type (here: CH) of element: (CH →) XX → XX. Undefined (NULL-valued) facies types are included in the query as 'Undefined'.

### tg\_16 – Lateral transitions involving 3 architectural elements, conditioned on right-element type

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
e_2_architectural_elements.arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, e_2_architectural_elements.arch_el_type,
f_2_arch_el_transitions.bound_surf_order FROM e_2_architectural_elements JOIN
f_2_arch_el_transitions ON e_2_architectural_elements.arch_el_ID =
f_2_arch_el_transitions.arch_el_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.arch_el_ID,
new_trans_ID.trans_arch_el_ID, IFNULL (new_trans_ID.arch_el_type, 'Undefined') AS
arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID.trans_direction, new_trans_ID.bound_surf_order FROM
e_2_architectural_elements JOIN new_trans_ID ON
e_2_architectural_elements.arch_el_ID = new_trans_ID.trans_arch_el_ID WHERE
trans_direction = 'Lateral' AND e_2_architectural_elements.arch_el_type = 'CH');
CREATE TEMPORARY TABLE new_trans_ID_from_CH AS (SELECT new_trans_types.arch_el_ID,
f_2_arch_el_transitions.arch_el_ID AS trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types.arch_el_type,
f_2_arch_el_transitions.bound_surf_order FROM new_trans_types JOIN
f_2_arch_el_transitions ON new_trans_types.arch_el_ID =
f_2_arch_el_transitions.trans_arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral');
CREATE TEMPORARY TABLE new_trans_types_from_CH AS (SELECT
new_trans_ID_from_CH.arch_el_ID, new_trans_ID_from_CH.trans_arch_el_ID,
new_trans_ID_from_CH.arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type,
'Undefined') AS transitional_type, new_trans_ID_from_CH.trans_direction,
new_trans_ID_from_CH.bound_surf_order FROM e_2_architectural_elements JOIN
new_trans_ID_from_CH ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_from_CH.trans_arch_el_ID);
CREATE TEMPORARY TABLE unique_trans_types_from_CH SELECT CONCAT (`arch_el_ID`,
`_`,`trans_arch_el_ID`) AS trans_string, `arch_el_ID`, `trans_arch_el_ID`,
`arch_el_type`, `transitional_type`, `trans_direction`, `bound_surf_order` FROM
new_trans_types_from_CH; ALTER IGNORE TABLE unique_trans_types_from_CH ADD UNIQUE
INDEX (trans_string);
CREATE TEMPORARY TABLE lateral_trans AS(SELECT unique_trans_types_from_CH
.arch_el_type, unique_trans_types_from_CH.transitional_type, CONCAT
(unique_trans_types_from_CH.arch_el_type, `_`, unique_trans_types_from_CH
.transitional_type) AS trans_string FROM unique_trans_types_from_CH ORDER BY
unique_trans_types_from_CH.arch_el_ID);
CREATE TEMPORARY TABLE lateral_trans_counts SELECT arch_el_type, transitional_type,
COUNT(trans_string) FROM lateral_trans GROUP BY trans_string;
SELECT * FROM lateral_trans_counts;

```

It returns the count of all left-lateral architectural element transitions involving elements that are neighbouring, in the right-lateral direction, a given type (here: CH) of element: XX ← XX (← CH). Undefined (NULL-valued) facies types are included in the query as 'Undefined'.

### tg\_20 – Count of facies units overlying a given facies types

```

CREATE TEMPORARY TABLE new_trans_ID AS ( SELECT g_3_facies.facies_ID,

```

```

h_3_facies_transitions.trans_facies_ID, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type, h_3_facies_transitions.bound_surf_order FROM g_3_facies JOIN
h_3_facies_transitions ON g_3_facies.facies_ID = h_3_facies_transitions.facies_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.facies_ID,
new_trans_ID.trans_facies_ID, IFNULL (new_trans_ID.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
new_trans_ID.trans_direction, new_trans_ID.bound_surf_order FROM g_3_facies JOIN
new_trans_ID ON g_3_facies.facies_ID = new_trans_ID.trans_facies_ID);
CREATE TEMPORARY TABLE vertical_trans AS (SELECT new_trans_types.facies_type,
new_trans_types.transitional_type, CONCAT (new_trans_types.facies_type, '-',
new_trans_types.transitional_type) AS trans_string FROM new_trans_types WHERE
trans_direction = 'Vertical' AND facies_type = 'Sd' ORDER BY
new_trans_types.facies_ID);
CREATE TEMPORARY TABLE vertical_trans_counts SELECT facies_type, transitional_type,
COUNT(trans_string) FROM vertical_trans GROUP BY trans_string;
SELECT * FROM vertical_trans_counts;

```

It returns the count of all the facies units overlying a given type (here: Sd) of lithofacies; undefined (NULL-valued) facies types are included in the query as 'Undefined'.

### tq\_19 – Count of facies units underlying a given facies types

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT g_3_facies.facies_ID,
h_3_facies_transitions.trans_facies_ID, h_3_facies_transitions.trans_direction,
g_3_facies.facies_type, h_3_facies_transitions.bound_surf_order FROM g_3_facies JOIN
h_3_facies_transitions ON g_3_facies.facies_ID =
h_3_facies_transitions.facies_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.facies_ID,
new_trans_ID.trans_facies_ID, IFNULL (new_trans_ID.facies_type, 'Undefined') AS
facies_type, IFNULL (g_3_facies.facies_type, 'Undefined') AS transitional_type,
new_trans_ID.trans_direction, new_trans_ID.bound_surf_order FROM g_3_facies JOIN
new_trans_ID ON g_3_facies.facies_ID = new_trans_ID.trans_facies_ID);
CREATE TEMPORARY TABLE vertical_trans AS (SELECT new_trans_types.facies_type,
new_trans_types.transitional_type, CONCAT (new_trans_types.facies_type, '-',
new_trans_types.transitional_type) AS trans_string FROM new_trans_types WHERE
trans_direction = 'Vertical' AND transitional_type = 'Sd' ORDER BY
new_trans_types.facies_ID);
CREATE TEMPORARY TABLE vertical_trans_counts SELECT facies_type, transitional_type,
COUNT(trans_string) FROM vertical_trans GROUP BY trans_string;
SELECT * FROM vertical_trans_counts;

```

It returns the count of all the facies units underlying a given type (here: Sd) of lithofacies; undefined (NULL-valued) facies types are included in the query as 'Undefined'.

### tq\_22 – Derivation of groups of 5 laterally-adjacent CH architectural elements

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
e_2_architectural_elements.arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, e_2_architectural_elements.arch_el_type
FROM e_2_architectural_elements JOIN f_2_arch_el_transitions ON
e_2_architectural_elements.arch_el_ID = f_2_arch_el_transitions.arch_el_ID); CREATE
TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.arch_el_ID,
new_trans_ID.trans_arch_el_ID, IFNULL (new_trans_ID.arch_el_type, 'Undefined') AS
arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID.trans_direction FROM e_2_architectural_elements JOIN
new_trans_ID ON e_2_architectural_elements.arch_el_ID =
new_trans_ID.trans_arch_el_ID WHERE trans_direction = 'Lateral' AND
new_trans_ID.arch_el_type = 'CH');
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_types.trans_arch_el_ID AS
arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types.transitional_type AS
arch_el_type FROM new_trans_types JOIN f_2_arch_el_transitions ON
new_trans_types.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.arch_el_ID,
new_trans_ID_2.trans_arch_el_ID, IFNULL (new_trans_ID_2.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_2.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_2 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_2.trans_arch_el_ID);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_types_2.trans_arch_el_ID
AS arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,

```



```

f_2_arch_el_transitions.trans_direction, new_trans_types_2.transitional_type AS
arch_el_type FROM new_trans_types_2 JOIN f_2_arch_el_transitions ON
new_trans_types_2.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types_2.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.arch_el_ID,
new_trans_ID_3.trans_arch_el_ID, IFNULL (new_trans_ID_3.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_3.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_3 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_3.trans_arch_el_ID);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT new_trans_types_3.trans_arch_el_ID
AS arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types_3.transitional_type AS
arch_el_type FROM new_trans_types_3 JOIN f_2_arch_el_transitions ON
new_trans_types_3.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types_3.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_4 AS (SELECT new_trans_ID_4.arch_el_ID,
new_trans_ID_4.trans_arch_el_ID, IFNULL (new_trans_ID_4.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_4.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_4 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_4.trans_arch_el_ID WHERE e_2_architectural_elements.arch_el_type =
'CH');
SELECT DISTINCT new_trans_ID.arch_el_ID, new_trans_ID.arch_el_type,
new_trans_types.trans_arch_el_ID, new_trans_types.transitional_type,
new_trans_types_2.trans_arch_el_ID, new_trans_types_2.transitional_type,
new_trans_types_3.trans_arch_el_ID, new_trans_types_3.transitional_type,
new_trans_types_4.trans_arch_el_ID, new_trans_types_4.transitional_type FROM
new_trans_ID JOIN new_trans_types ON new_trans_ID.arch_el_ID =
new_trans_types.arch_el_ID JOIN new_trans_types_2 ON
new_trans_types.trans_arch_el_ID = new_trans_types_2.arch_el_ID JOIN
new_trans_types_3 ON new_trans_types_2.trans_arch_el_ID =
new_trans_types_3.arch_el_ID JOIN new_trans_types_4 ON
new_trans_types_3.trans_arch_el_ID = new_trans_types_4.arch_el_ID;

```

It returns a group of a given number (here 5 out of groups of at least 5) of architectural elements that are laterally transitional and belong to the same element type (here: CH).

### tq\_23 – Derivation of groups of 5 laterally-adjacent CH architectural elements excluding mutual erosional transitions

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
e_2_architectural_elements.arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, e_2_architectural_elements.arch_el_type
FROM e_2_architectural_elements JOIN f_2_arch_el_transitions ON
e_2_architectural_elements.arch_el_ID = f_2_arch_el_transitions.arch_el_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.arch_el_ID,
new_trans_ID.trans_arch_el_ID, IFNULL (new_trans_ID.arch_el_type, 'Undefined') AS
arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID.trans_direction FROM e_2_architectural_elements JOIN
new_trans_ID ON e_2_architectural_elements.arch_el_ID =
new_trans_ID.trans_arch_el_ID WHERE trans_direction = 'Lateral' AND
new_trans_ID.arch_el_type = 'CH');
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_types.trans_arch_el_ID AS
arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types.transitional_type AS
arch_el_type FROM new_trans_types JOIN f_2_arch_el_transitions ON
new_trans_types.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.arch_el_ID,
new_trans_ID_2.trans_arch_el_ID, IFNULL (new_trans_ID_2.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_2.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_2 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_2.trans_arch_el_ID);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_types_2.trans_arch_el_ID
AS arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types_2.transitional_type AS
arch_el_type FROM new_trans_types_2 JOIN f_2_arch_el_transitions ON
new_trans_types_2.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types_2.transitional_type = 'CH');

```

```

CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.arch_el_ID,
new_trans_ID_3.trans_arch_el_ID, IFNULL (new_trans_ID_3.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_3.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_3 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_3.trans_arch_el_ID);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT new_trans_types_3.trans_arch_el_ID
AS arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types_3.transitional_type AS
arch_el_type FROM new_trans_types_3 JOIN f_2_arch_el_transitions ON
new_trans_types_3.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types_3.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_4 AS (SELECT new_trans_ID_4.arch_el_ID,
new_trans_ID_4.trans_arch_el_ID, IFNULL (new_trans_ID_4.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_4.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_4 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_4.trans_arch_el_ID WHERE e_2_architectural_elements.arch_el_type =
'CH');
SELECT DISTINCT new_trans_ID.arch_el_ID, new_trans_ID.arch_el_type,
new_trans_types.trans_arch_el_ID, new_trans_types.transitional_type,
new_trans_types_2.trans_arch_el_ID, new_trans_types_2.transitional_type,
new_trans_types_3.trans_arch_el_ID, new_trans_types_3.transitional_type,
new_trans_types_4.trans_arch_el_ID, new_trans_types_4.transitional_type
FROM new_trans_ID JOIN new_trans_types ON new_trans_ID.arch_el_ID =
new_trans_types.arch_el_ID JOIN new_trans_types_2 ON
new_trans_types.trans_arch_el_ID = new_trans_types_2.arch_el_ID JOIN
new_trans_types_3 ON new_trans_types_2.trans_arch_el_ID =
new_trans_types_3.arch_el_ID JOIN new_trans_types_4 ON
new_trans_types_3.trans_arch_el_ID = new_trans_types_4.arch_el_ID WHERE
(new_trans_ID.arch_el_ID <> new_trans_types_2.trans_arch_el_ID AND
new_trans_types.trans_arch_el_ID <> new_trans_types_3.trans_arch_el_ID AND
new_trans_types_2.trans_arch_el_ID <> new_trans_types_4.trans_arch_el_ID);

```

It returns a group of a given number (here 5 out of groups of at least 5) of architectural elements that are laterally transitional and belong to the same element type (here: CH), excluding erosive mutual transitions. This type of query is required for obtaining material units from genetic units.

#### **tq\_24 – Derivation of groups of 3 laterally-adjacent CH architectural elements, excluding mutual erosional transitions, ensuring that the group is bounded by non-CH elements**

```

CREATE TEMPORARY TABLE new_trans_ID AS (SELECT
e_2_architectural_elements.arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, e_2_architectural_elements.arch_el_type
FROM e_2_architectural_elements JOIN f_2_arch_el_transitions ON
e_2_architectural_elements.arch_el_ID = f_2_arch_el_transitions.arch_el_ID);
CREATE TEMPORARY TABLE new_trans_types AS (SELECT new_trans_ID.arch_el_ID,
new_trans_ID.trans_arch_el_ID, IFNULL (new_trans_ID.arch_el_type, 'Undefined') AS
arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID.trans_direction FROM e_2_architectural_elements JOIN
new_trans_ID ON e_2_architectural_elements.arch_el_ID =
new_trans_ID.trans_arch_el_ID WHERE trans_direction = 'Lateral' AND
new_trans_ID.arch_el_type <> 'CH');
CREATE TEMPORARY TABLE new_trans_ID_2 AS (SELECT new_trans_types.trans_arch_el_ID AS
arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types.transitional_type AS
arch_el_type FROM new_trans_types JOIN f_2_arch_el_transitions ON
new_trans_types.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_2 AS (SELECT new_trans_ID_2.arch_el_ID,
new_trans_ID_2.trans_arch_el_ID, IFNULL (new_trans_ID_2.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_2.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_2 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_2.trans_arch_el_ID);
CREATE TEMPORARY TABLE new_trans_ID_3 AS (SELECT new_trans_types_2.trans_arch_el_ID
AS arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types_2.transitional_type AS
arch_el_type FROM new_trans_types_2 JOIN f_2_arch_el_transitions ON
new_trans_types_2.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE

```

```

f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types_2.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_3 AS (SELECT new_trans_ID_3.arch_el_ID,
new_trans_ID_3.trans_arch_el_ID, IFNULL (new_trans_ID_3.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_3.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_3 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_3.trans_arch_el_ID);
CREATE TEMPORARY TABLE new_trans_ID_4 AS (SELECT new_trans_types_3.trans_arch_el_ID
AS arch_el_ID, f_2_arch_el_transitions.trans_arch_el_ID,
f_2_arch_el_transitions.trans_direction, new_trans_types_3.transitional_type AS
arch_el_type FROM new_trans_types_3 JOIN f_2_arch_el_transitions ON
new_trans_types_3.trans_arch_el_ID = f_2_arch_el_transitions.arch_el_ID WHERE
f_2_arch_el_transitions.trans_direction = 'Lateral' AND
new_trans_types_3.transitional_type = 'CH');
CREATE TEMPORARY TABLE new_trans_types_4 AS (SELECT new_trans_ID_4.arch_el_ID,
new_trans_ID_4.trans_arch_el_ID, IFNULL (new_trans_ID_4.arch_el_type, 'Undefined')
AS arch_el_type, IFNULL (e_2_architectural_elements.arch_el_type, 'Undefined') AS
transitional_type, new_trans_ID_4.trans_direction FROM e_2_architectural_elements
JOIN new_trans_ID_4 ON e_2_architectural_elements.arch_el_ID =
new_trans_ID_4.trans_arch_el_ID WHERE e_2_architectural_elements.arch_el_type <>
'CH');
SELECT DISTINCT new_trans_ID.arch_el_ID, new_trans_ID.arch_el_type,
new_trans_types.trans_arch_el_ID, new_trans_types.transitional_type,
new_trans_types_2.trans_arch_el_ID, new_trans_types_2.transitional_type,
new_trans_types_3.trans_arch_el_ID, new_trans_types_3.transitional_type,
new_trans_types_4.trans_arch_el_ID, new_trans_types_4.transitional_type
FROM new_trans_ID JOIN new_trans_types ON new_trans_ID.arch_el_ID =
new_trans_types.arch_el_ID JOIN new_trans_types_2 ON
new_trans_types.trans_arch_el_ID = new_trans_types_2.arch_el_ID JOIN
new_trans_types_3 ON new_trans_types_2.trans_arch_el_ID =
new_trans_types_3.arch_el_ID JOIN new_trans_types_4 ON
new_trans_types_3.trans_arch_el_ID = new_trans_types_4.arch_el_ID WHERE
(new_trans_ID.arch_el_ID <> new_trans_types_2.trans_arch_el_ID AND
new_trans_types.trans_arch_el_ID <> new_trans_types_3.trans_arch_el_ID AND
new_trans_types_2.trans_arch_el_ID <> new_trans_types_4.trans_arch_el_ID);

```

It returns a group of a given number (here strictly 3) of architectural elements that are laterally transitional and belong to the same element type (here: CH) and the element types bounding the group, excluding erosive mutual transitions. This type of query is required for obtaining material units from genetic units.



## **Appendix C: summary of FAKTS case studies**

This appendix contains an account of the case studies included in the FAKTS database. The table in the following pages lists the studies in chronological order of database inclusion. Further, it identifies the sedimentary basin and lithostratigraphic unit or river from which the data originate, and includes reference to the data source. A fuller account including additional metadata (e.g. data quality indices, location) is given in the form of a digital appendix (D2).

<b>Case ID</b>	<b>Basin</b>	<b>Case study</b>	<b>Source</b>
1	-	Kayenta Fm.	Miall A. D. (1988) Sed. Geol. 55, 233-262.
2	Keuper Basin	Middle-Upper Stubensandstein	Hornung J., Aigner T. (1999) Sed. Geol. 129, 215-280.
3	Po Basin	Quaternary Po Basin	Amorosi A., Pavesi M., Ricci Lucchi M., Sarti G., Piccin A. (2008) Sed. Geol. 209, 58-68.
4	Kaiparowits Basin	Straight Cliffs Fm.	Dalrymple M. (2001) Petrol. Geosci., 7, 115-122.
5	Asri Basin	Talang Akar Fm.	Carter D. C. (2003) AAPG Bull. 87, 909-934.
6	East Irish Sea Basin	Ormskirk Sandstone Fm., Sherwood Sandstone Gp.	Meadows N. S. (2006) Geol. J. 41, 93-122.
7	Piceance Basin	Lower Williams Fork Fm.	Pranter M. J., Cole R. D., Panjaitan H., Sommer N. K. (2009) AAPG Bull. 93, 1379-1401.
8	Chuckanut Basin	Bellingham Bay Mb., Chuckanut Fm.	Johnson S. Y. (1984) Sed. Geol. 38, 361-391.
9	Ebro Basin	Rio Vero Fm.	Jones S. J., Frostick L. E., Astin T. R. (2001) Sed. Geol. 139, 229-260.
10	Barents Sea Basin	Segloddan Mb., Båsnæring Fm.	Hjellbakk A. (1997) Sed. Geol. 114, 131-161.
11	Bengal Basin	Brahmaputra (Jamuna)	Bristow C. S. (1993) Geol. Soc. London Spec Publ. 75, 277-289.
12	Henry Mountains Basin	Salt Wash Mb., Morrison Fm.	Robinson J. W., McCabe P. J. (1997) AAPG Bull. 81, 1267-1291.
13	-	Colville	Tye R. S. (2004) AAPG Bull. 88, 1123-1147.
14	-	Kuparuk	Tye R. S. (2004) AAPG Bull. 88, 1123-1147.
15	-	Sagavanirktok	Tye R. S. (2004) AAPG Bull. 88, 1123-1147.
16	San Jorge Basin	Bajo Barreal Fm.	Bridge J. S., Jalfin G. A., Georgieff S. M. (2000) J. Sed. Res. 70, 341-359.
17	Mississippi Embayment	Mississippi	Jordan D. W., Pryor W. A. (1992) AAPG Bull. 76, 1601-1624.
18	-	Kayenta Fm.	Bromley M. H. (1991) Sed. Geol. 73, 77-99.
19	-	Kayenta Fm.	Luttrell P. R. (1993) Sed. Geol. 85, 411-434.
20	Kyongsang	Sindong Gp.	Jo H. R. (2003) Sed. Geol. 161, 269-

	Basin		294.
21	Loranca Basin	Upper Unit, Tortola fluvial system	Cuevas Gozalo M. C., Martinius A. W. (1993) Geol. Soc. London Spec. Publ. 73, 79-94.
22	-	Kayenta Fm.	North C. P., Taylor K. S. (1996) AAPG Bull. 80, 811-830.
23	Paradox Basin	Organ Rock Fm.	Cain S. A. (2009) Unpublished PhD Thesis, Keele University, Keele (UK).
24	-	Kayenta Fm.	Sanabria D. I. (2001) Unpublished PhD Thesis, Rice University, Houston (USA).
25	-	Kayenta Fm.	Stephens M. (1994) Sed. Geol. 90, 179-211.
26	-	Kayenta Fm.	FRG in-house fieldwork.
27	River Atbara Rift	Gash	Abdullatif O. M. (1989) Sed. Geol. 63, 171-184.
28	Ebro Basin	Caspe Fm.	Cuevas Martínez J. L., Cabrera Perez L., Marcuello A., Arbues Cazo P., Marzo Carpio M., Bellmunt F. (2010) Sedimentology 57, 162-189.
29	-	Oukaimeden Fm.	Fabuel-Perez I., Redfern J., Hodgetts D. (2009) Sed. Geol. 218, 103-140.
30	-	Markanda	Parkash B., Awasthi A. K., Gohain K. (1983) Int. Assoc. Sedimentol. Spec. Publ. 6, 337-344.
31	-	Oukaimeden Fm.	Fabuel-Perez I., Hodgetts D., Redfern J. (2009) AAPG Bull. 93, 795-827.
32	North Devon Basin	Trentishoe Fm., Hangman Sandstone Gp.	Tunbridge I. (1984) Sedimentology 31, 697-715.
33	Bowen Basin	Rangal Coal Measures	Fielding C. R., Falkner A. J., Scott S. G. (1993) Sed. Geol. 85, 475-497.
34	Bengal Basin	Brahmaputra (Jamuna)	Best J. L., Ashworth P. J., Bristow C. S., Roden J. (2003) J. Sed. Res. 73, 516-530.
35	-	Composite database	Fielding C. R., Crane R. C. (1987) SEPM Spec. Publ. 39, 321-327.
36	Ganges Foreland Basin	Gandak	Friend P. F., Sinha R. (1993) Geol. Soc. London Spec Publ. 75, 105-111.
37	Ganges Foreland Basin	Burhi Gandak	Friend P. F., Sinha R. (1993) Geol. Soc. London Spec Publ. 75, 105-111.
38	Ganges Foreland Basin	Baghmati	Friend P. F., Sinha R. (1993) Geol. Soc. London Spec Publ. 75, 105-111.
39	Lake Eyre Basin	Thomson (Cooper Creek)	FRG in-house sat image analysis.
40	Roer Valley	Rhine-Meuse delta	Weerts H. J. T., Bierkens M. F. P.

	Graben		(1993) Sed. Geol. 85, 221-232.
41	Camaquã Basin	Guarda Velha Fm.	FRG in-house fieldwork.
42	Needwood and Stafford, Eccleshall Basins	Bunter Pebble Beds (Chester Pebble Beds Fm. and Cannock Chase Fm.)	Steel R. J., Thompson D. B. (1983) Sedimentology 30, 341-367.
43	Tugtutoq-Illimaussaq zone	Majût Mb., Eriksfjord Fm.	Tirsgaard H., Øxnevad I. E. I. (1998) Sed. Geol. 120, 295-317.
44	Piceance Basin	Lower Williams Fork Fm.	Pranter M. J., Ellison A. I., Cole R. D., Patterson P. E. (2007) AAPG Bull. 91, 1025-1051.
45	Ebro Basin	Sariñena Fm.	Donselaar M. E., Overeem I. (2008) AAPG Bull. 92, 1109-1129.
46	Western Interior Basin	Ferron Sandstone Mb., Mancos Shale	Corbeau R. M., Wizevich M. C., Bhattacharya J. P., Zeng X., McMechan G. A. (2004) AAPG Stud. Geol. 50, 427-449.
47	Upper Awash Basin	Melka Kunture Fm.	Raynal J.-P., Kieffer G., Bardin G. (2004) Studies on the Early Paleolithic site of Melka Kunture, Ethiopia. 137-166.
48	-	Plenty	Tooth S., Nanson G. C. (2004) Geol. Soc. Am. Bull. 116, 802-816.
49	-	Marshall	Tooth S., Nanson G. C. (2004) Geol. Soc. Am. Bull. 116, 802-816.
50	Altiplano Basin	Potoco Fm.	Hampton B. A., Horton B. K. (2007) Sedimentology 54, 1121-1147.
51	Ainsa Basin	Olson Mb., Escanilla Fm.	Labourdette R. (2011) AAPG Bull. 95, 585-617.
52	Waterberg Basin	Omingonde Fm.	Holzförster F., Stollhofen H., Stanistreet I. G. (1999) J. Afr. Earth. Sci. 29, 105-123.
53	Anthracite Coal Basin	Mauch Chunk Fm.	Fillmore D. L., Lucas S. G., Simpson E. L. (2010) Palaeogeogr., Palaeoclim., Palaeoecol. 292, 222-244.
54	Needwood Basin	Hawksmoor Fm. and Hollington Fm.	FRG in-house fieldwork.
55	Cheshire Basin	Wilmslow Sandstone Fm. and Helsby Sandstone Fm., Sherwood Sandstone Gp.	FRG in-house fieldwork.
56	Solway Basin	Annan Sandstone Fm., Sherwood Sandstone Gp.	Brookfield M. E. (2008) Sed. Geol. 210, 27-47.
57	East Irish Sea Basin	Sherwood Sandstone Gp.	Cowan G. (1993) Geol. Soc. London Spec. Publ. 73, 231-245.
58	-	Dinosaur Canyon Mb., Moenave Fm.	Olsen H. (1989) Sed. Geol. 61, 207-221.



59	Karoo Basin	Balfour Fm., Beaufort Gp.	Catuneanu O., Elango H. N. (2001) Sed. Geol. 140, 291-313.
60	Karoo Basin	Middleton Fm. and Koonap Fm., Beaufort Gp.	Catuneanu O., Bowker D. (2001) J. Afr. Earth. Sci. 33, 579-595.
61	San Juan Basin	Westwater Canyon Mb. and Brushy Basin Mb., Morrison Fm.	Miall A. D., Turner-Peterson C. E. (1989) Sed. Geol. 63, 21-60.
62	Unegt Basin	Sainshand Fm.	FRG in-house fieldwork.
63	Unegt Basin	Bayanshiree Fm.	FRG in-house fieldwork.
64	-	South Saskatchewan	FRG in-house sat image analysis.
65	-	Morrison Fm.	Kjemperud A. V., Schomacker E. R., Cross T. A. (2008) AAPG Bull. 92, 1055-1076.
66	West Natuna Basin	Muda Fm.	Darmadi Y., Willis B. J., Dorobek S. L. (2007) J. Sed. Res. 77, 225-238.
67	Himalayan Foredeep Basin	Chinji Fm.	McRae L. E. (1990) J. Geol. 98, 433-456.
68	Himalayan Foredeep Basin	Chinji Fm.	Friend P. F., Raza S. M., Geehan G., Sheikh K. A. (2001) J. Geol. Soc. 158, 163-177.
69	Western Interior Basin	Price River Fm. and North Horn Fm.	Olsen T. (1995) NPF Spec. Publ. 5, 75-96.
70	Pennine Basin	Durham Coal Measures	Fielding C. R. (1986) Sedimentology 33, 119-140.
71	Pilsen and Kladno-Rakovník Basins	Kladno Fm. and Týnec Fm.	Opluštil S., Martínek K., Tasáryová Z. (2005) Bull. Geosci. 80, 45-66.
72	-	Composite database	Reynolds A. D. (1999) AAPG Bull. 83, 211-229.
73	Wessex Basin	Wessex Fm., Wealden Gp.	Stewart D. J. (1983) Int. Assoc. Sedimentol. Spec. Publ. 6, 369-384.
74	Weald Basin	Fairlight Clay and Ashdown Beds Fm., Hastings Beds Gp.	Stewart D. J. (1983) Int. Assoc. Sedimentol. Spec. Publ. 6, 369-384.
75	Paradox Basin	Undifferentiated Cutler Fm.	FRG in-house fieldwork.
76	Hamilton Basin	Hinuera Fm.	Hume T. M., Sherwood A. M., Campbell S. N. (1975) J. Royal Soc. New Zeal. 5, 421-462.
77	Po Basin	Reno	Ori G. G. (1982) Sed. Geol. 31, 231-248.
78	Loranca Basin	Upper Unit, Tortola fluvial system	Martinius A. W., Nieuwenhuijs R. A. (1995) Petrol. Geosci. 1, 237-252.

79	Loranca Basin	Upper Unit, Tortola fluvial system	Martinius A. W. (2000) J. Sed. Res. 70, 850-867.
80	Cumberland Basin	Joggins Fm.	Rygel M. C., Gibling M. R. (2006) J. Sed. Res. 76, 1230-1251.
81	Ganges Foreland Basin	Ganges	Singh A., Bhardwaj B. D. (1991) Sed. Geol. 72, 135-146.
82	Midland Valley Basin	Lower Coal Measures	Kirk M. (1983) Sedimentology 30, 727-742.
83	Ganges Foreland Basin	Ganges	Shukla U. K., Singh I. B., Sharma M., Sharma S. (2001) Sed. Geol. 144, 243-262.
84	Munster Basin	Templetown Fm. (Brownstown Head Mb. and Beenlea Head Mb.) and Harrylock Fm., Old Red Sandstone	Ori G. G., Penney S. R. (1982) J. Earth Sci. R. Dubl. Soc. 5, 43-59.
85	Gulf of Mexico Basin	Pliocene/Miocene Northern Gulf of Mexico	Wood L. J. (2007) J. Sed. Res. 77, 713-730.
86	Munster Basin	Gun Point Fm., Old Red Sandstone	Sadler S. P., Kelly S. B. (1993) Sed. Geol. 85, 375-386.
87	North Devon Basin	Trentishoe Fm., Hangman Sandstone Gp.	Tunbridge I. (1981) Sed. Geol. 28, 79-95.
88	North German Basin	Upper Bunter Sand, Bunter Sandstone Fm., Bacton Gp.	Olsen H. (1987) Geol. Soc. London Spec. Publ. 35, 69-86.
89	-	Bijou Creek	McKee E. D., Crosby E. J., Berryhill H. L. Jr. (1967) J. Sed. Petrol. 37, 829-851.
90	Lake Eyre Basin	Paralana Creek	Williams G. E. (1971) Sedimentology 17, 1-40.
91	Lake Eyre Basin	The Wooldridge	Williams G. E. (1971) Sedimentology 17, 1-40.
92	Lake Eyre Basin	Goyder Creek	Williams G. E. (1971) Sedimentology 17, 1-40.
93	Lake Eyre Basin	Palmer Creek	Williams G. E. (1971) Sedimentology 17, 1-40.
94	Lake Eyre Basin	The Finke	Williams G. E. (1971) Sedimentology 17, 1-40.
95	Vindhyan Basin	Dhandraul Sandstone Fm., Kaimur Gp.	Bhattacharyya A., Morad S. (1993) Sed. Geol. 84, 101-114.
96	Ganges Foreland Basin	Ganges	Singh I. B. (1977) J. Sed. Petrol. 47, 747-752.
97	Roraima Basin	Uairén Fm.	Long D. G. F. (2002) Int. Assoc. Sedimentol. Spec. Publ. 33, 323-338.
98	Hekla Sund Basin	Rivieradal Sandstones, Rivieradal Gp.	Sønderholm M., Tirsgaard H. (1998) Sed. Geol. 120, 257-274.

99	-	Holmestrand Fm., Ringerike Gp.	Dam G., Andreasen F. (1990) Sed. Geol. 66, 197-225.
101	Datong Basin	Yungang Fm.	Yu X., Ma X., Qing H. (2002) Bull. Can. Petrol. Geol. 50, 105-117.
102	Iberian Trough	Buntsandstein	Sánchez-Moya Y., Sopeña A., Ramos A. (1996) J. Sed. Res. 66, 1122-1136.
100	Guadix Basin	Late Pliocene Guadix Basin	Viseras C., Soria J. M., Durán J. J., Pla S., Garrido G., García-García F., Arribas A. (2006) Palaeogeogr. Palaeoclim. Palaeoecol. 242, 139-168.
103	Vinchina Basin	Vinchina Fm.	Limarino C., Tripaldi A., Marensi S., Net L., Re G., Caselli A. (2001) J. South Am. Earth Sci. 14, 751-762.
104	-	Tuross	Ferguson R. J., Brierley G. J. (1999) Sedimentology 46, 627-648.
105	-	Warchha Sandstone Fm., Nilawahana Gp.	Ghazi S., Moutney N. P. (2009) Sed. Geol. 221, 99-126.
106	Orogrande Basin	Abo Fm.	Mack G. H., Leeder M., Perez-Arlucea M., Bailey B. D. J. (2003) Sed. Geol. 160, 159-178.
107	-	Columbia	Adams P. N., Slingerland R. L., Smith N. D. (2004) Geomorphology 61, 127-142.
108	-	Saskatchewan	Adams P. N., Slingerland R. L., Smith N. D. (2004) Geomorphology 61, 127-142.
109	Kaiparowits Basin	Kaiparowits Fm.	Roberts E. M. (2007) Sed. Geol. 197, 207-233.
110	Bighorn Basin	Willwood Fm.	Kraus M. J., Middleton L. T. (1987) SEPM Spec. Publ. 39, 253-262.
111	Snake River Plain	Glenns Ferry Fm.	Kraus M. J., Middleton L. T. (1987) SEPM Spec. Publ. 39, 253-262.
112	Stonehaven Basin	Cowie Fm., Stonehaven Gp.	FRG in-house fieldwork.
113	Hanna Basin	Ferris Fm.	Hajek E. A., Heller P. L., Sheets B. A. (2010) Geology 38, 535-538.
114	Strathmore Basin	Scone Sandstone Fm., Arbuthnott-Garvock Gp.	FRG in-house fieldwork.
115	Western Interior Basin	Blackhawk Fm.	Hampson G. J., Gani M. R., Sahoo H., Rittersbacher A., Irfan N., Ranson A., Jewell T. O., Gani N. D. S., Howell J. A., Buckley S. J., Bracken B. (2012) Sedimentology 59, 2226-2258.
116	Western Canada Basin	McMurray Fm.	Jablonski B. V. J. (2012) Unpublished PhD Thesis, Queen's University, Kingston (Canada).

117	Ebro Basin	Sariñena Fm.	Hirst J. P. P. (1991) SEPM Conc. Sed. Paleo. 3, 111-121.
118	-	Composite database	Constantine J. A., Dunne T. (2008) Geology 36, 23-26.

## List of digital appendices

In the attached CD, additional material is included and organized in folders named as follows:

- **Digital appendix D1:** it contains a MySQL dump file of the FAKTS database structure; the file includes all the tables but does not include any data.
- **Digital appendix D2:** it contains a Microsoft Excel spreadsheet that details the content of the FAKTS database; it reports the source of primary data, the lithostratigraphic unit or river to which each case study refers, the number of genetic units (depositional elements, architectural elements, facies units) or groups of genetic units (associated with statistical parameters) for which data is available for each case study, the geographic location of each dataset, and a three-fold data quality index ranking the dataset quality.
- **Digital appendix D3:** it contains a series of SQL files corresponding to the queries included in appendix B; each file can be loaded to run or edit the query.
- **Digital appendix D4:** it contains seven posters presented at national and international conferences; the posters include material that is relevant to the FAKTS research project, but that was not included in paper form in the Thesis; some of the material is part of work in progress.
- **Digital appendix D5:** it contains five Microsoft Powerpoint presentations presented at national and international conferences; the slides include material that is relevant to the FAKTS research project, but that was not included in paper form in the Thesis.

