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

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ABSTRACT

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 paper 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; (v) to 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.

Keywords: facies models, fluvial architecture, quantitative sedimentology, channel pattern, discharge regime, basin climate.

INTRODUCTION

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 characters 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).

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 similar conditions and 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). 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; Jung & Aigner 2012).

Aims

The aim of this paper 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 paper 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.

DATABASE AND METHOD

Database structure and building blocks

Overview of FAKTS database schema

The Fluvial Architecture Knowledge Transfer System (*FAKTS*) is a database comprising field- and literature-derived quantitative and qualitative data relating to the architecture of both modern rivers and ancient successions (Colombera et al. 2012a). Genetic units included in the database are equally recognizable in both the stratigraphic and geomorphic realms and belong to three hierarchies of observation (Fig. 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 is 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); 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.

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 1988; 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 (1988; 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.

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. 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).

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.

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).

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 characters 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 1. In addition to the features summarized in Table 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.

Classification of facies units

According to the classification of bounding surfaces proposed by Miall (1985; 1996) and adopted in the FAKTS database, 2nd-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 2nd-order units of Miall (1985; 1996) and to the microscale to mesoscale stratasets of Bridge (1993). These units are based on observable characteristics and represent more objective units 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 is good for 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 requiredment 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 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: refer to Miall (1978; 1996) and Bridge (1993) for explanations of the genetic significance of these lithofacies types. Notably, several alternative classification schemes could be implemented into the database structure in addition to those of the original authors' and FAKTS' facies codes, possibly separating textural and structural data in different fields.

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. A summary of the case studies included in the database and of the published literature considered for derivation of primary data and for system classification is given in Table S1 (see supplementary material).

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), 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 this 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.

1) 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. Fig. 2); a drawback of this approach is that case studies that have been studied more extensively 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.
2) 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. Fig. 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.

3) 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. Fig. 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 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.

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 3rd-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 advancement 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) 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 (Fig. 3).

RESULTS: EXAMPLE MODELS

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 1965; 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 1965; Bridge 1993). Here, large-scale models based on channel pattern are presented for single-thread and braided systems (Fig. 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.

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 (Fig. 3 and 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 (Fig. 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.

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 (Fig. 5 and supplementary material S2). The results presented in Fig. 5 and 6 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. 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 1988; 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 in 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 1965; 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 Fig. 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.

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 Fig. S3 (see supplementary material): 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 (Fig. 7 to 10) 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 braiding, which requires recognition of contemporaneity in-channel activity, 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. 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 (Fig. 8), and of the sandy meandering-system model (Fig. S3, see supplementary material) 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 crevasses 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 Fig. 11 and S4 (see supplementary material). 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 (Fig. S4) – can be highlighted through quantification.

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 12 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.

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).
- 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.
- 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 character 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 non-mutually-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. Fig. S5, see supplementary material), 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).

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. Fig. 13), 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 we presented. 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). 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. Nevertheless, 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.

CONCLUSIONS

This paper 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. Yet, the example models presented herein demonstrate the value of the approach, especially in relation to its quantitative nature, its flexibility of application, and its capability 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.

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CAPTIONS

Table 1
Summary of the fundamental diagnostic characteristics and environmental significance of the 14 interpretative architectural-element types employed in the FAKTS database.

Table 2
Summary of the fundamental textural and structural characteristics of the 25 facies-unit types employed in the FAKTS database.

Figure 1
Representation of the main scales of observation and types of sedimentary genetic units included in the FAKTS database. Refer to Table 1 for architectural-element codes and to Table 2 for facies-unit codes (modified from Colombera et al., 2012a).

Figure 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.

Figure 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.

Figure 4
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.

Figure 5a
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 Fig. 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 5b
Continuation of Fig. 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 6a
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/semiarid ephemeral braided systems and systems associated with intermediate filtering steps.

Figure 6b
Continuation of Fig. 6. 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 7
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 8
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 Fig. 7, to render the models comparable.

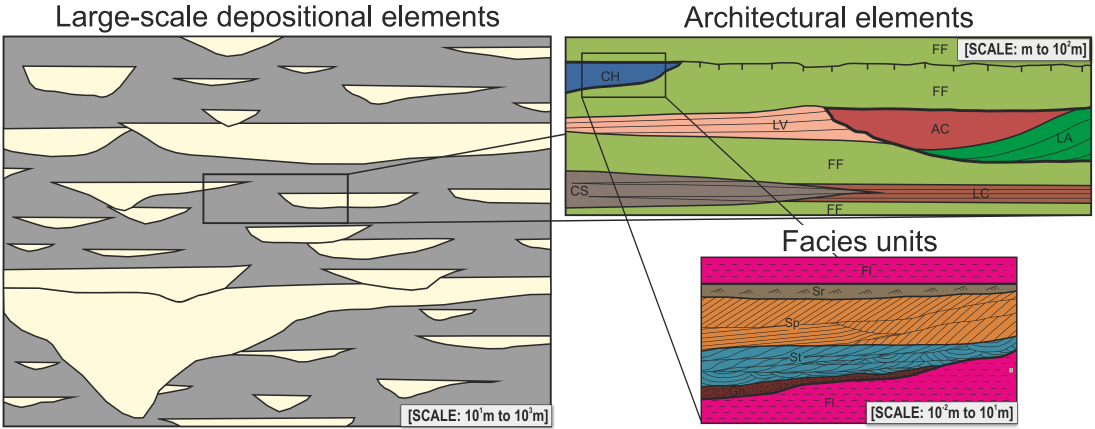
Figure 9
Example quantitative information that can be incorporated into a small-scale facies model referring to dryland braided systems, filtering braided systems on the basin climate type. Results are presented as in Fig. 7 and 8, to render the models comparable.

Figure 10
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 Fig. 7, 8 and 9, to render the models comparable.

Figure 11
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 Fig. 10.

Figure 12
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.

Figure 13
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 Fig. 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 with 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.



Large-scale depositional elements

Architectural elements

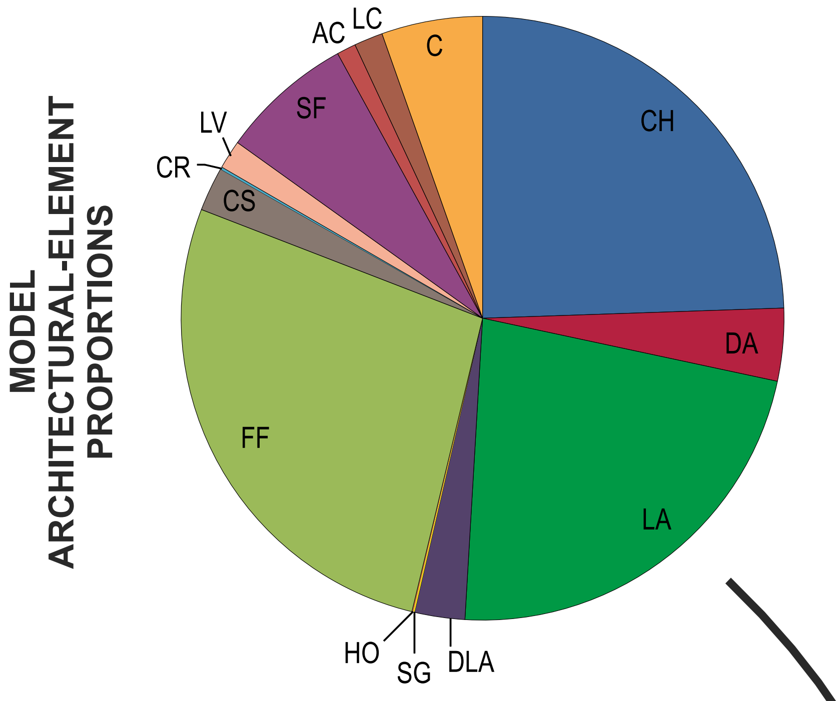
Facies units

ARCHITECTURAL-ELEMENT PROPORTIONS - NO FILTER APPLIED

representation of the relative abundance of architectural elements among all fluvial environments

Method 1

Computation of architectural-element proportions based on the product of their thickness and (I) lateral extent (2D/3D subsets) or (II) average lateral extent of element type (1D subsets)



Architectural-element type legend

CH	🟦	Aggradational channel-fill
DA	🟥	Downstream-accreting barform
LA	🟩	Laterally-accreting barfrom
DLA	🟪	Downstream/lateral-accreting barform
SG	🟨	Sediment gravity-flow body
HO	🟧	Scour-hollow fill
AC	🟥	Abandoned channel fill
LV	🟧	Levee
FF	🟩	Floodplain fines
SF	🟪	Sandy aggradational floodplain
CR	🟦	Crevasse channel
CS	🟫	Crevasse splay
LC	🟫	Floodplain lake
C	🟧	Coal-body

N = 2607

Number of architectural elements suitable for deriving proportions:

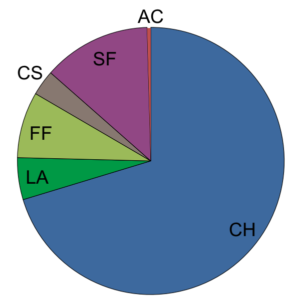
N = 2886

Method 2

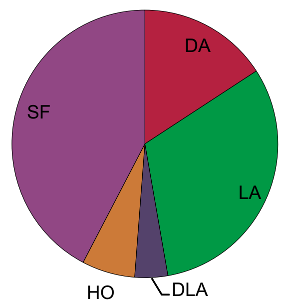
Computation of architectural-element proportions within individual subsets.

Examples:

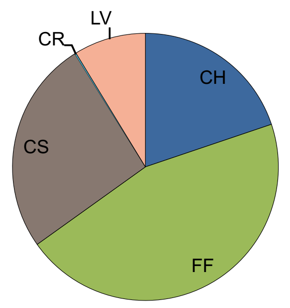
Subset 143



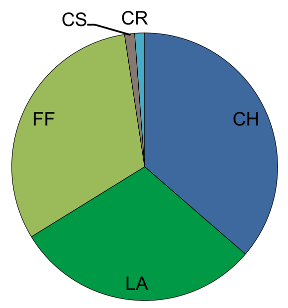
Subset 149



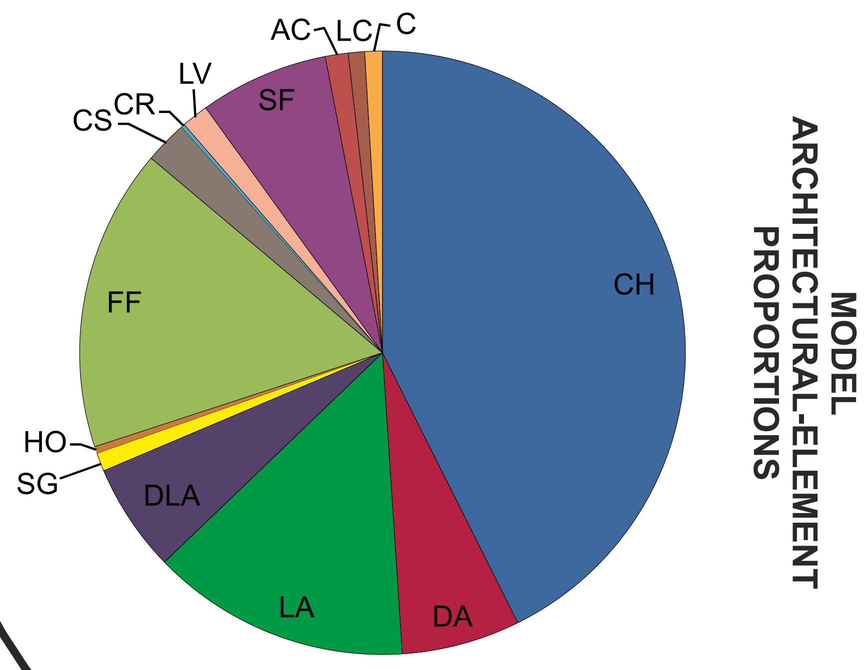
Subset 316



Subset 741

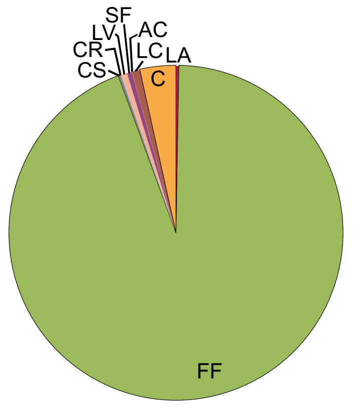


Averaging of architectural-element proportions from individual subsets

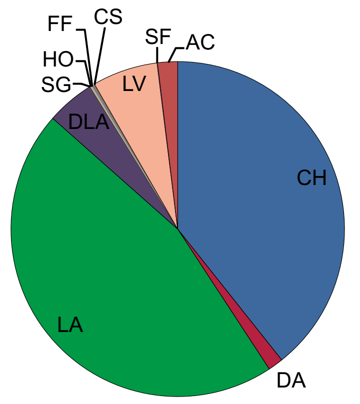


Method 3

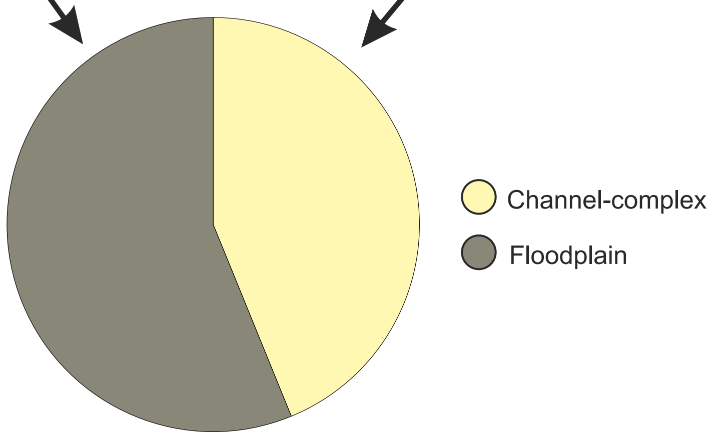
Computation of architectural-element proportions within floodplain and channel-complex depositional elements



Model architecture of floodplain depositional elements

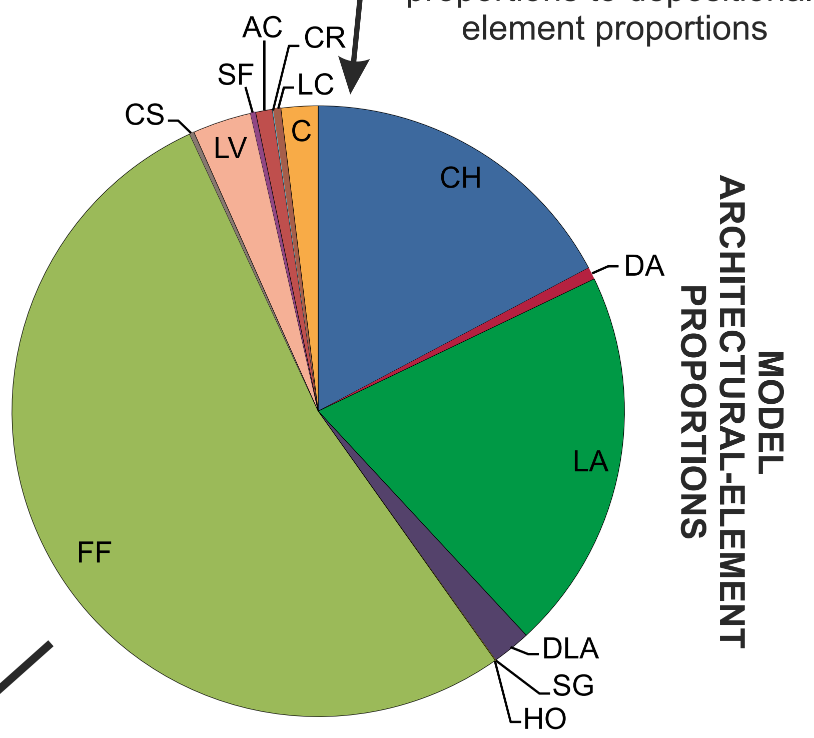


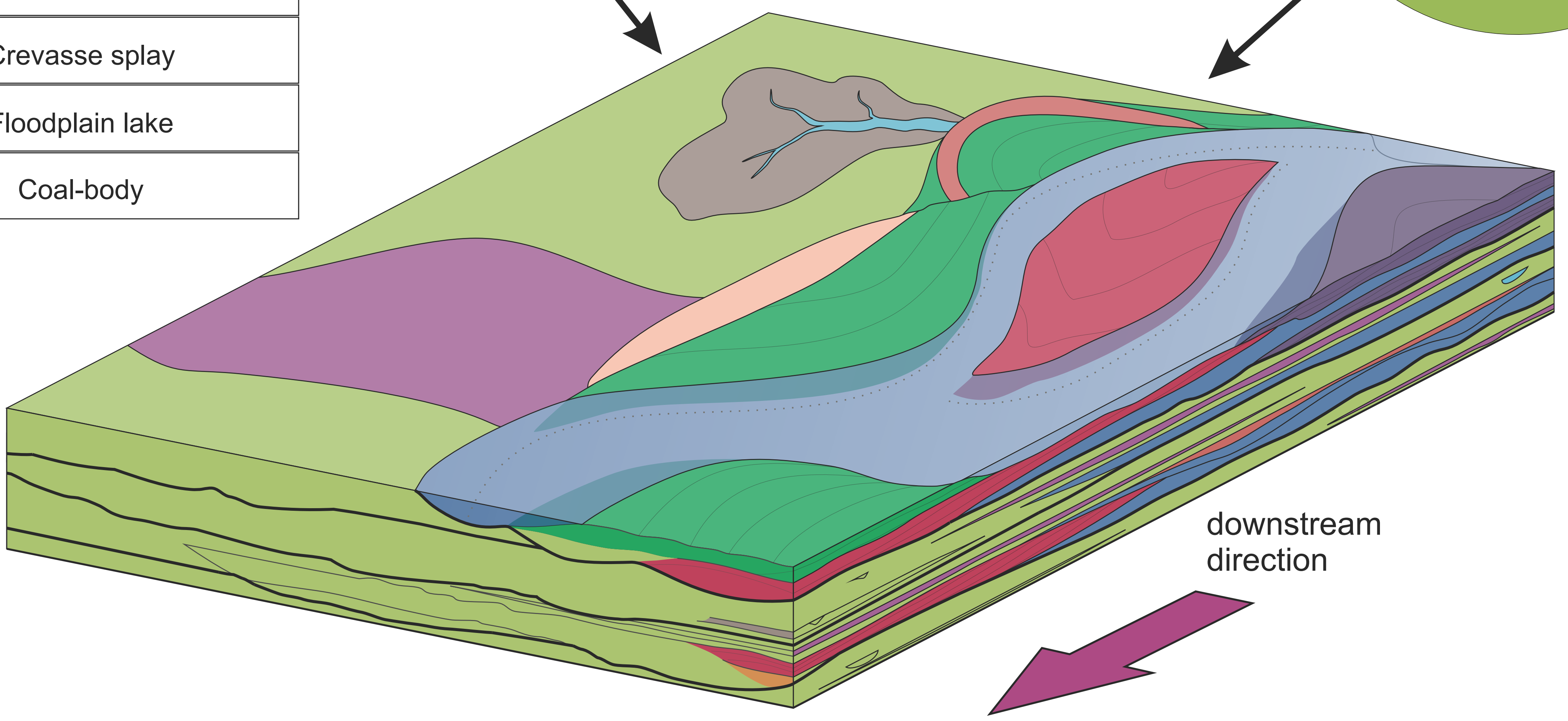
Model architecture of channel complexes

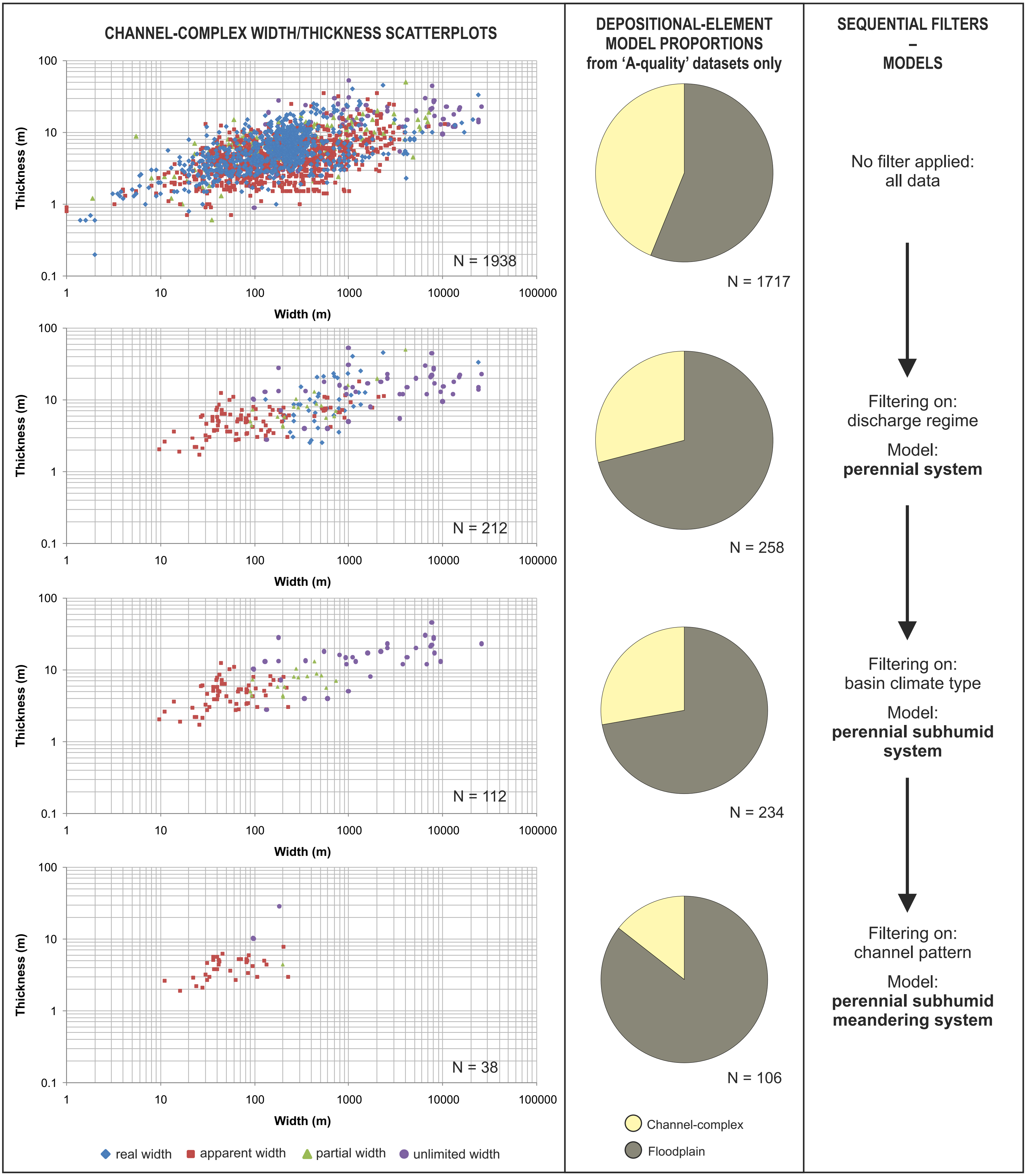


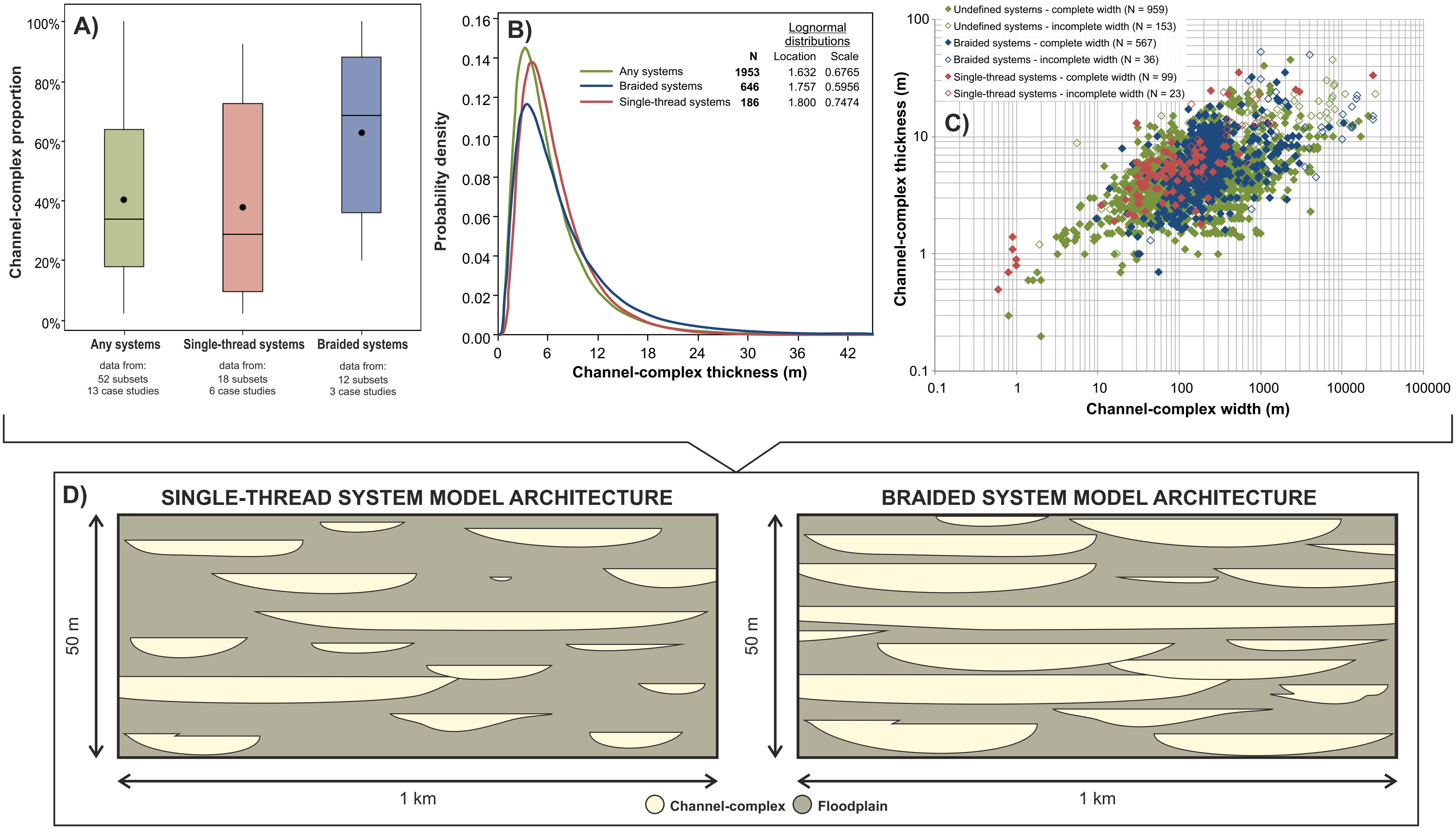
Depositional-element proportions

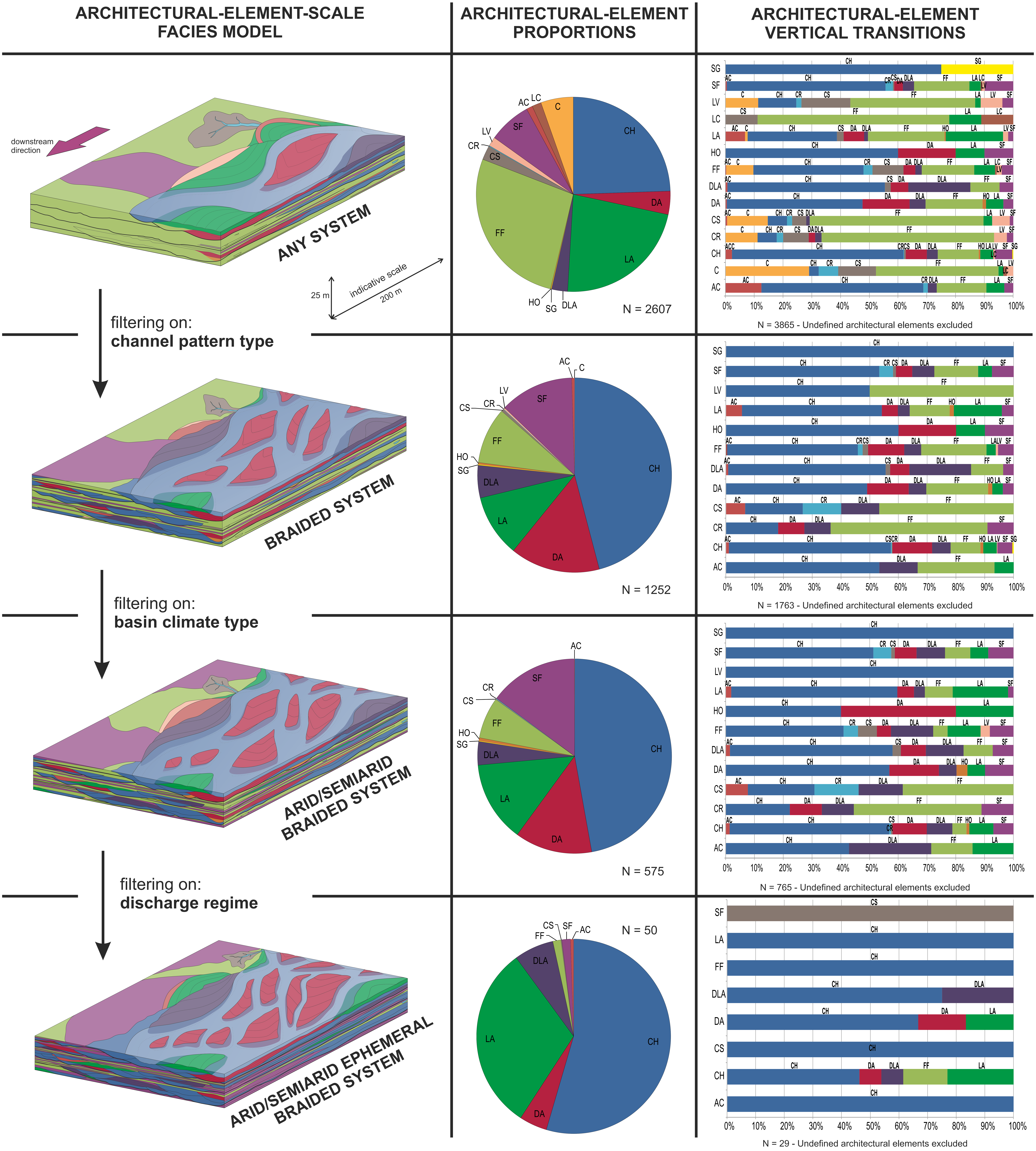
Scaling architectural-element proportions to depositional-element proportions

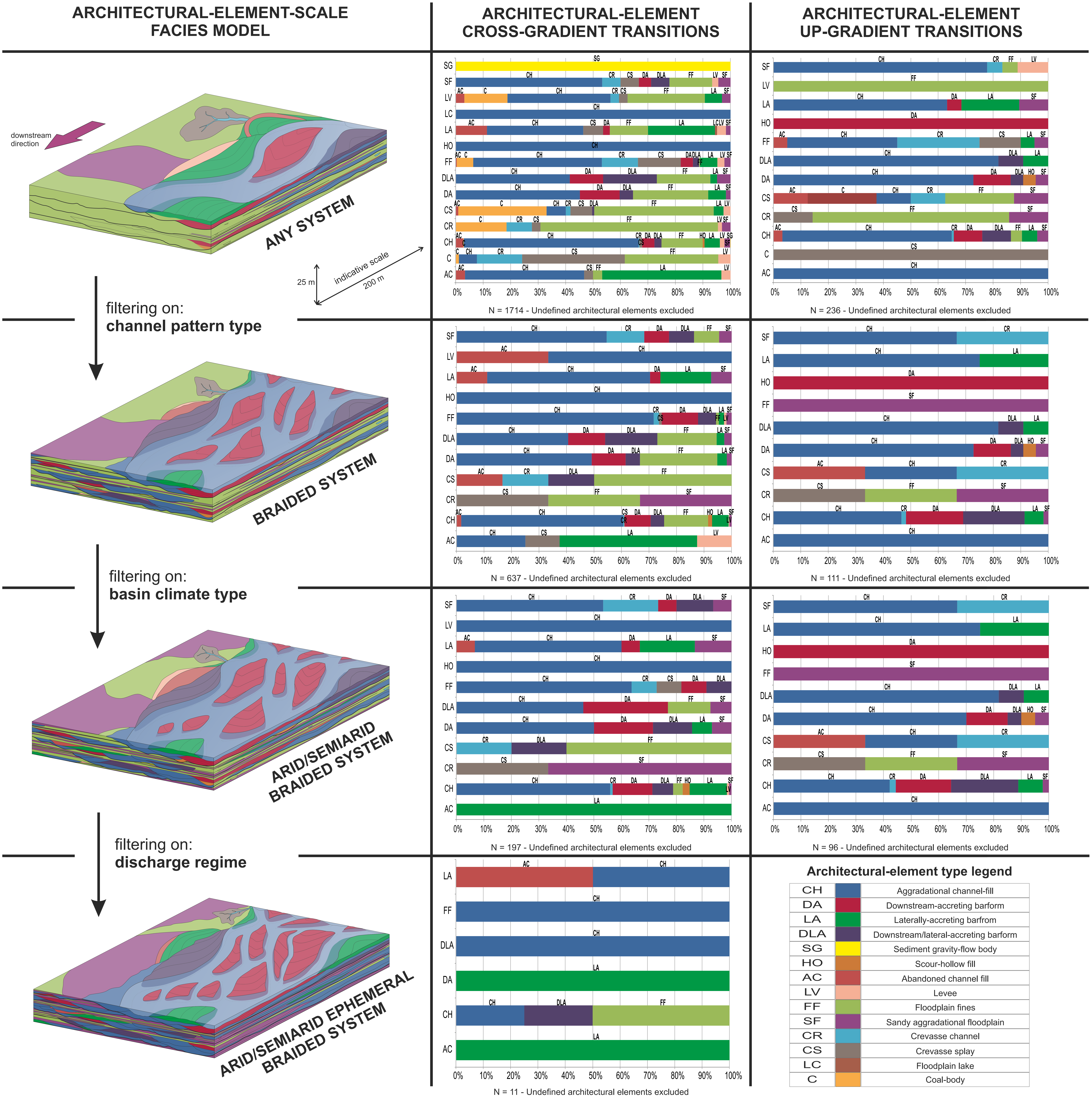


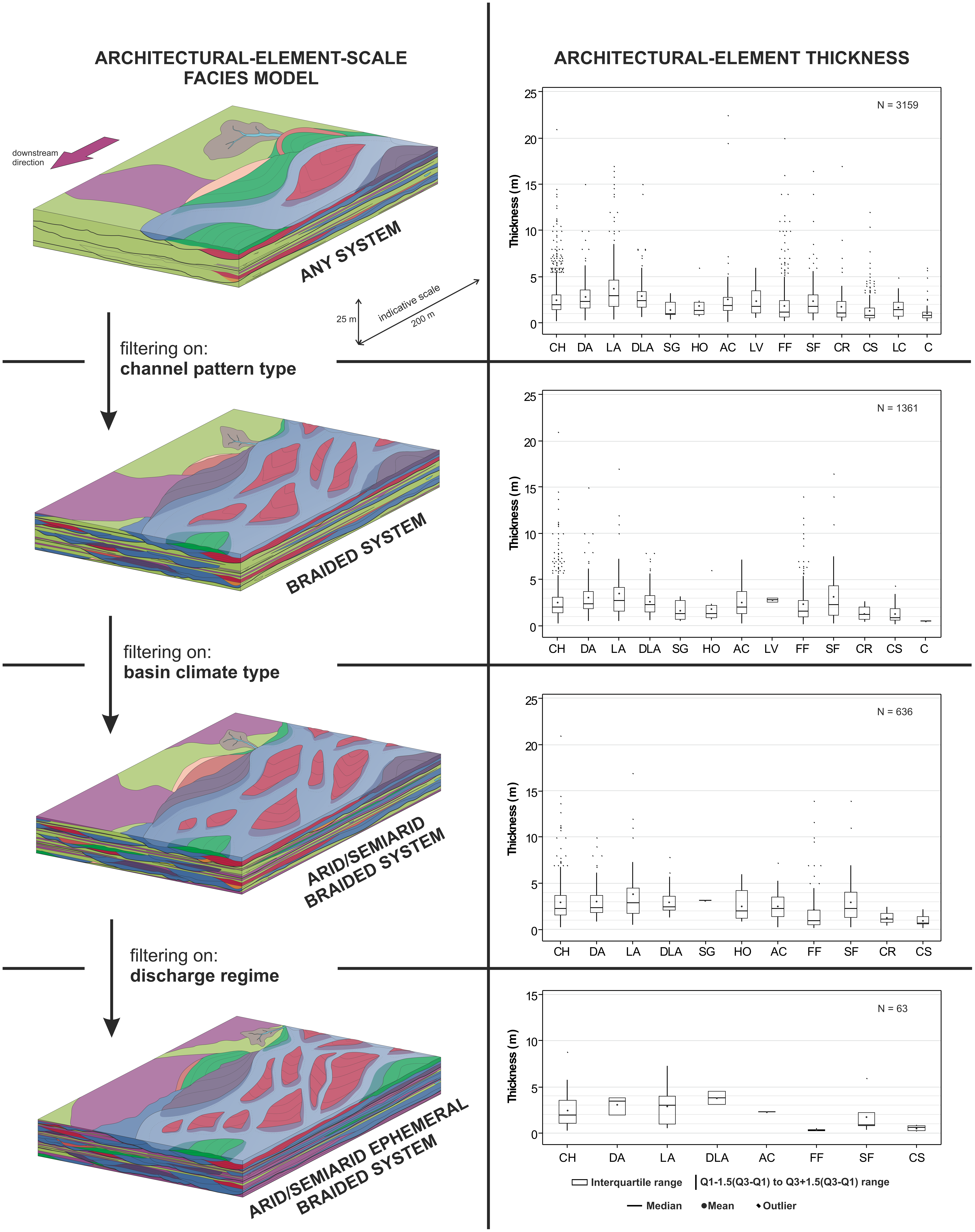


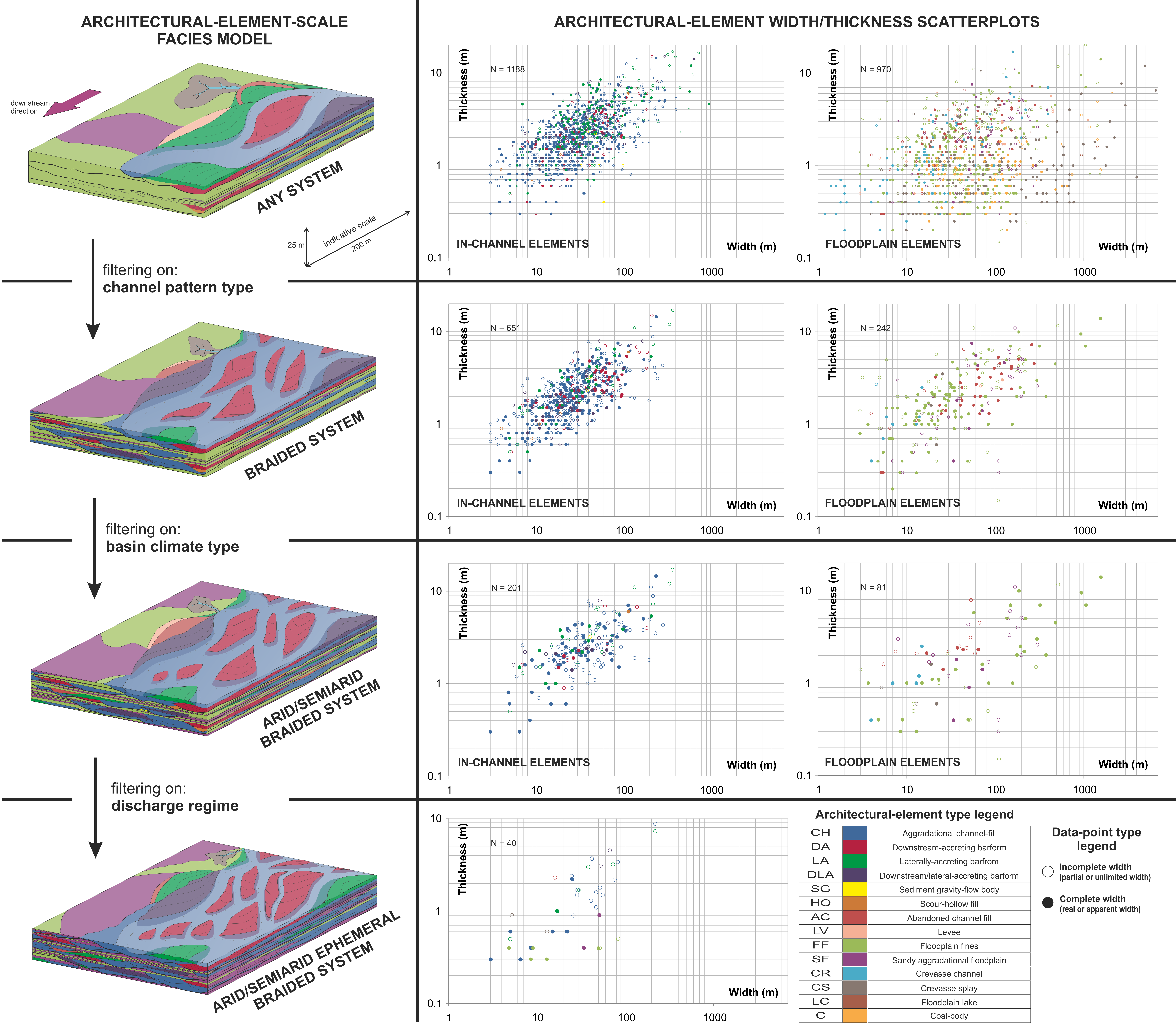

CHANNEL-COMPLEX WIDTH/THICKNESS SCATTERPLOTS
DEPOSITIONAL-ELEMENT MODEL PROPORTIONS from 'A-quality' datasets only
SEQUENTIAL FILTERS – MODELS
Thickness (m)
Width (m)
100
10
1
0.1
1
10
100
1000
10000
100000
N = 1938
N = 1717
No filter applied: all data
N = 212
N = 258
Filtering on: discharge regime
Model: **perennial system**
N = 112
N = 234
Filtering on: basin climate type
Model: **perennial subhumid system**
N = 38
N = 106
Filtering on: channel pattern
Model: **perennial subhumid meandering system**
◆ real width
■ apparent width
▲ partial width
● unlimited width
○ Channel-complex
● Floodplain


A)
Channel-complex proportion
100%
80%
60%
40%
20%
0%
Any systems
data from:
52 subsets
13 case studies
Single-thread systems
data from:
18 subsets
6 case studies
Braided systems
data from:
12 subsets
3 case studies
B)
Probability density
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
6
12
18
24
30
36
42
Channel-complex thickness (m)
Lognormal distributions
N
Location
Scale
Any systems 1953 1.632 0.6765
Braided systems 646 1.757 0.5956
Single-thread systems 186 1.800 0.7474
C)
◆ Undefined systems - complete width (N = 959)
◇ Undefined systems - incomplete width (N = 153)
◆ Braided systems - complete width (N = 567)
◇ Braided systems - incomplete width (N = 36)
◆ Single-thread systems - complete width (N = 99)
◇ Single-thread systems - incomplete width (N = 23)
Channel-complex thickness (m)
100
10
1
0.1
0.1
1
10
100
1000
10000
100000
Channel-complex width (m)
D)
SINGLE-THREAD SYSTEM MODEL ARCHITECTURE
BRAIDED SYSTEM MODEL ARCHITECTURE
50 m
50 m
1 km
1 km
Channel-complex
Floodplain

ARCHITECTURAL-ELEMENT-SCALE FACIES MODEL
ARCHITECTURAL-ELEMENT PROPORTIONS
ARCHITECTURAL-ELEMENT VERTICAL TRANSITIONS
downstream direction
ANY SYSTEM
25 m
indicative scale
200 m
filtering on: **channel pattern type**
BRAIDED SYSTEM
filtering on: **basin climate type**
ARID/SEMIARID BRAIDED SYSTEM
filtering on: **discharge regime**
ARID/SEMIARID EPHEMERAL BRAIDED SYSTEM
CH
DA
LA
DLA
SG
HO
FF
CS
CR
LV
SF
AC
LC
C
N = 2607
N = 1252
N = 575
N = 50
SG
SF
LV
LC
LA
HO
FF
DLA
DA
CS
CR
CH
C
AC
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
N = 3865 - Undefined architectural elements excluded
N = 1763 - Undefined architectural elements excluded
N = 765 - Undefined architectural elements excluded
N = 29 - Undefined architectural elements excluded

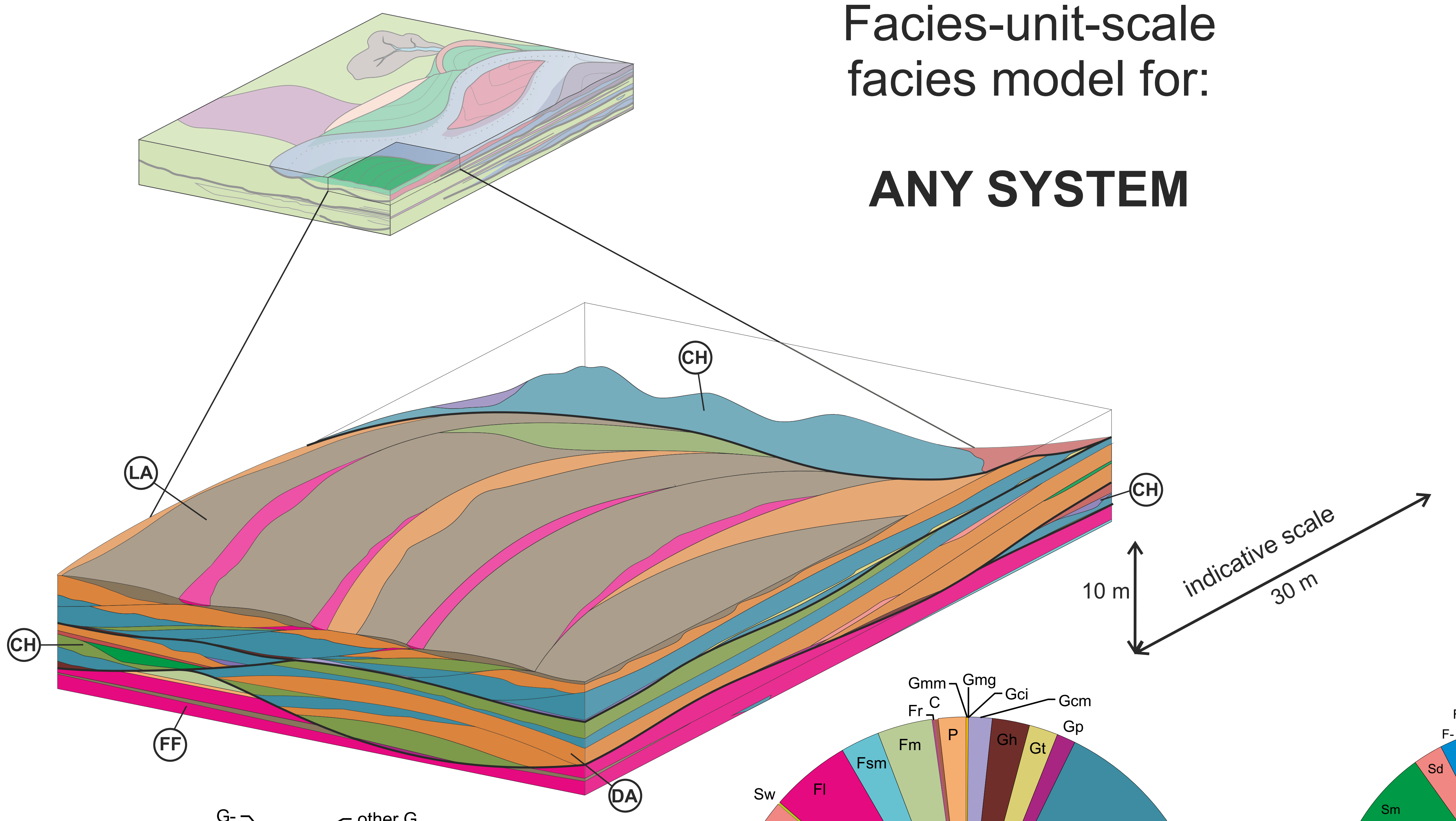

ARCHITECTURAL-ELEMENT-SCALE FACIES MODEL
ARCHITECTURAL-ELEMENT CROSS-GRADIENT TRANSITIONS
ARCHITECTURAL-ELEMENT UP-GRADIENT TRANSITIONS
downstream direction
ANY SYSTEM
indicative scale
25 m
200 m
filtering on: channel pattern type
BRAIDED SYSTEM
filtering on: basin climate type
ARID/SEMIARID BRAIDED SYSTEM
filtering on: discharge regime
ARID/SEMIARID EPHEMERAL BRAIDED SYSTEM
N = 1714 - Undefined architectural elements excluded
N = 236 - Undefined architectural elements excluded
N = 637 - Undefined architectural elements excluded
N = 111 - Undefined architectural elements excluded
N = 197 - Undefined architectural elements excluded
N = 96 - Undefined architectural elements excluded
N = 11 - Undefined architectural elements excluded
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
SG SF LV LC LA HO FF DLA DA CS CR CH C AC
Architectural-element type legend
CH Aggradational channel-fill
DA Downstream-accreting barform
LA Laterally-accreting barfrom
DLA Downstream/lateral-accreting barform
SG Sediment gravity-flow body
HO Scour-hollow fill
AC Abandoned channel fill
LV Levee
FF Floodplain fines
SF Sandy aggradational floodplain
CR Crevasse channel
CS Crevasse splay
LC Floodplain lake
C Coal-body

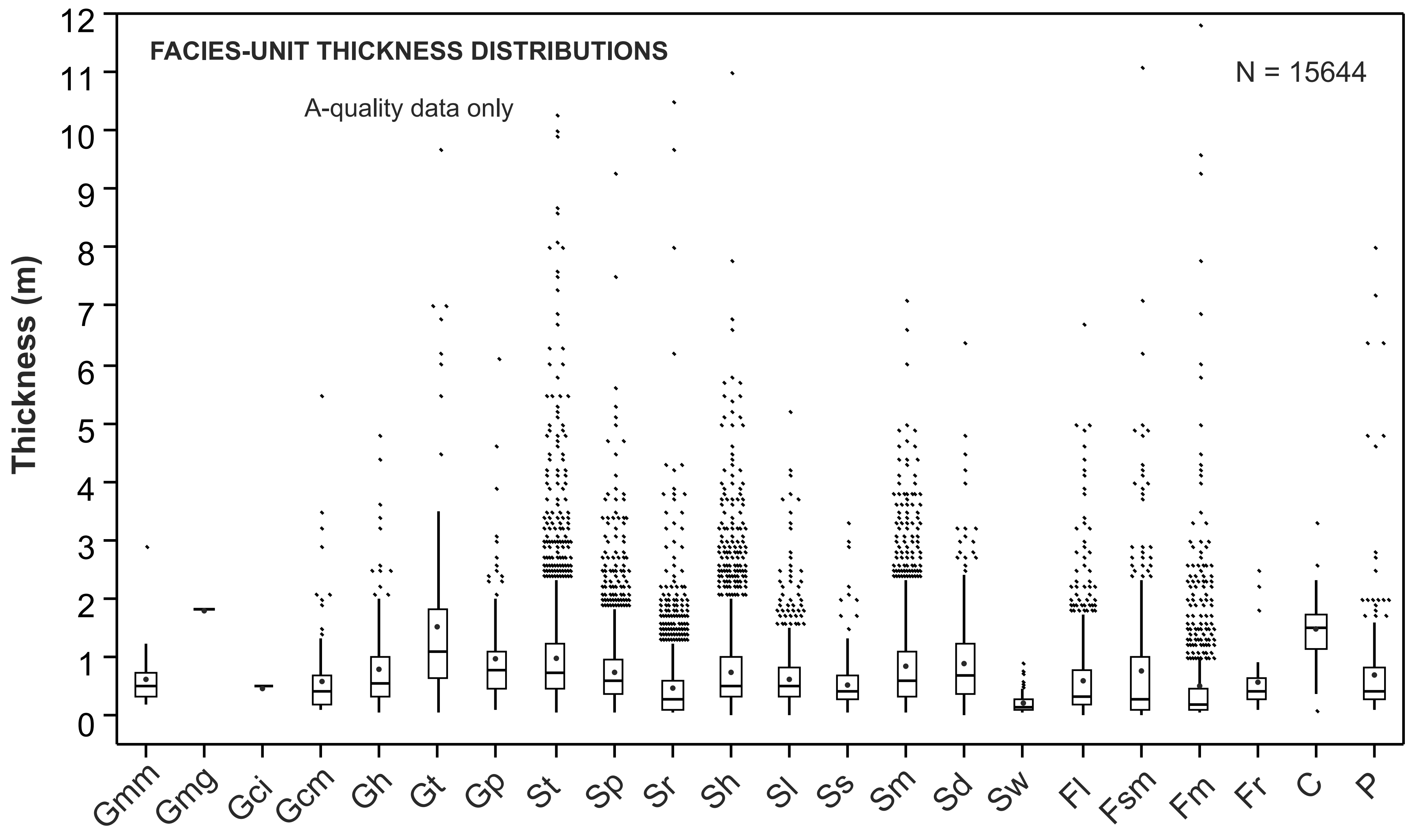

ARCHITECTURAL-ELEMENT-SCALE FACIES MODEL
ARCHITECTURAL-ELEMENT THICKNESS
downstream direction
ANY SYSTEM
25 m
indicative scale
200 m
filtering on: channel pattern type
BRAIDED SYSTEM
filtering on: basin climate type
ARID/SEMIARID BRAIDED SYSTEM
filtering on: discharge regime
ARID/SEMIARID EPHEMERAL BRAIDED SYSTEM
N = 3159
N = 1361
N = 636
N = 63
Thickness (m)
0
5
10
15
20
25
CH
DA
LA
DLA
SG
HO
AC
LV
FF
SF
CR
CS
LC
C
Interquartile range
Q1-1.5(Q3-Q1) to Q3+1.5(Q3-Q1) range
Median
Mean
Outlier


ARCHITECTURAL-ELEMENT-SCALE FACIES MODEL
ARCHITECTURAL-ELEMENT WIDTH/THICKNESS SCATTERPLOTS
downstream direction
ANY SYSTEM
25 m
indicative scale
200 m
filtering on:
channel pattern type
BRAIDED SYSTEM
filtering on:
basin climate type
ARID/SEMIARID BRAIDED SYSTEM
filtering on:
discharge regime
ARID/SEMIARID EPHEMERAL BRAIDED SYSTEM
Thickness (m)
Width (m)
N = 1188
IN-CHANNEL ELEMENTS
N = 970
FLOODPLAIN ELEMENTS
N = 651
IN-CHANNEL ELEMENTS
N = 242
FLOODPLAIN ELEMENTS
N = 201
IN-CHANNEL ELEMENTS
N = 81
FLOODPLAIN ELEMENTS
N = 40
0.1
1
10
100
1000
Architectural-element type legend
CH Aggradational channel-fill
DA Downstream-accreting barform
LA Laterally-accreting barfrom
DLA Downstream/lateral-accreting barform
SG Sediment gravity-flow body
HO Scour-hollow fill
AC Abandoned channel fill
LV Levee
FF Floodplain fines
SF Sandy aggradational floodplain
CR Crevasse channel
CS Crevasse splay
LC Floodplain lake
C Coal-body
Data-point type legend
○ Incomplete width (partial or unlimited width)
● Complete width (real or apparent width)

Facies-unit-scale facies model for:

ANY SYSTEM

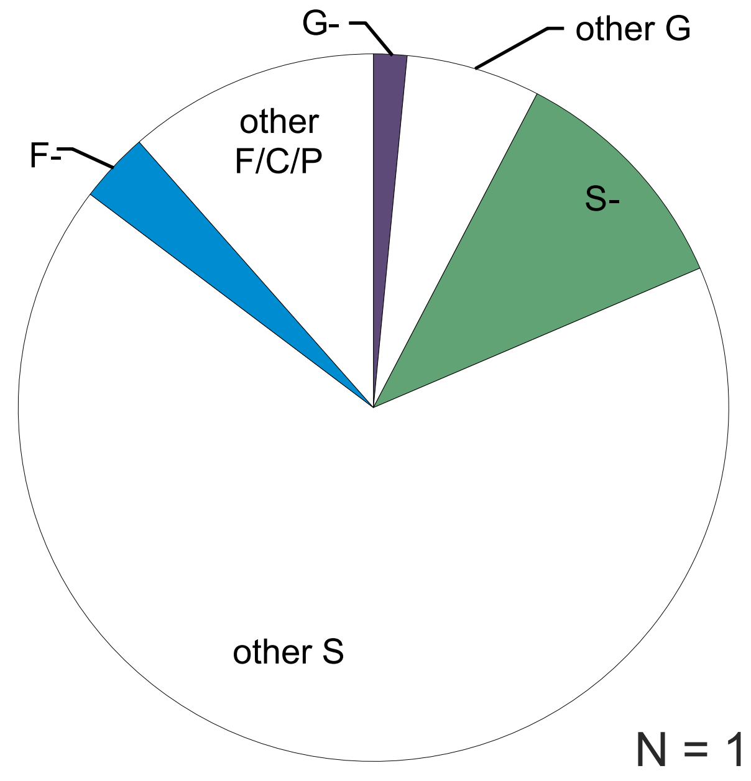




FACIES-UNIT LATERAL-EXTENT DESCRIPTIVE STATISTICS

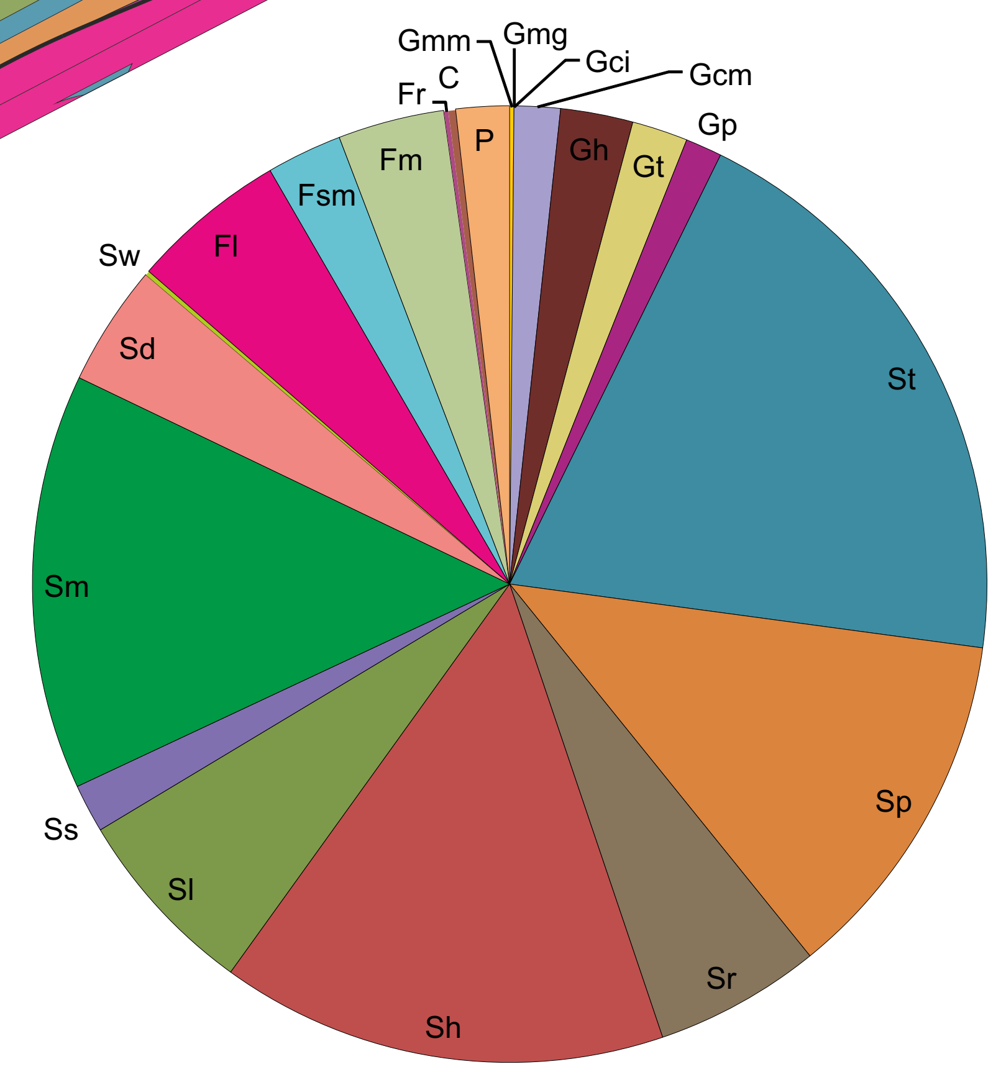
facies type	mean width	min width	max width	mean length	min length	max length
Gmm	35.6	3.9	63.0	6.6	2.2	11.0
Gcm	11.2	1.9	23.0	12.7	2.1	34.0
Gh	30.2	2.5	82.0	15.4	6.0	56.0
Gt	94.2	4.0	300.0	21.4	2.7	60.0
Gp	24.0	15.0	39.0	18.5	7.1	30.0
St	20.1	1.3	257.0	13.3	0.8	95.0
Sp	20.5	1.1	300.0	18.1	1.4	150.0
Sr	24.0	0.4	250.0	17.8	2.7	138.0
Sh	27.3	1.3	250.0	22.2	2.0	146.0
Sl	16.2	1.0	174.0	14.1	1.0	65.0
Ss	7.7	0.1	50.0	9.6	0.7	48.0
Sm	29.2	1.2	220.0	12.5	1.2	95.0
Sd	8.9	1.0	27.0	6.4	0.8	26.0
Fl	21.0	0.6	250.0	14.5	2.8	34.0
Fsm	16.9	1.7	152.0	12.5	3.4	22.0
Fm	56.4	3.1	250.0	15.2	4.2	27.2
Fr	17.9	5.4	37.0	1.9	1.9	1.9
P	28.5	2.0	250.0			

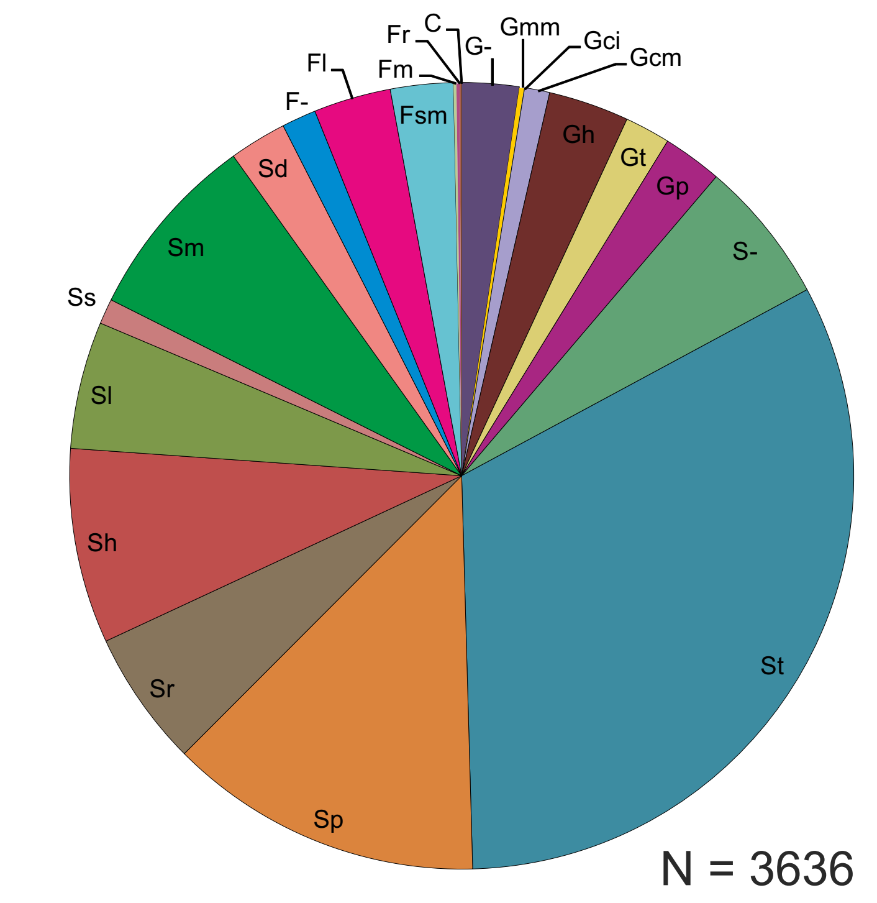
N = 2962 – all dimensions are expressed in metres



FACIES-UNIT PROPORTIONS

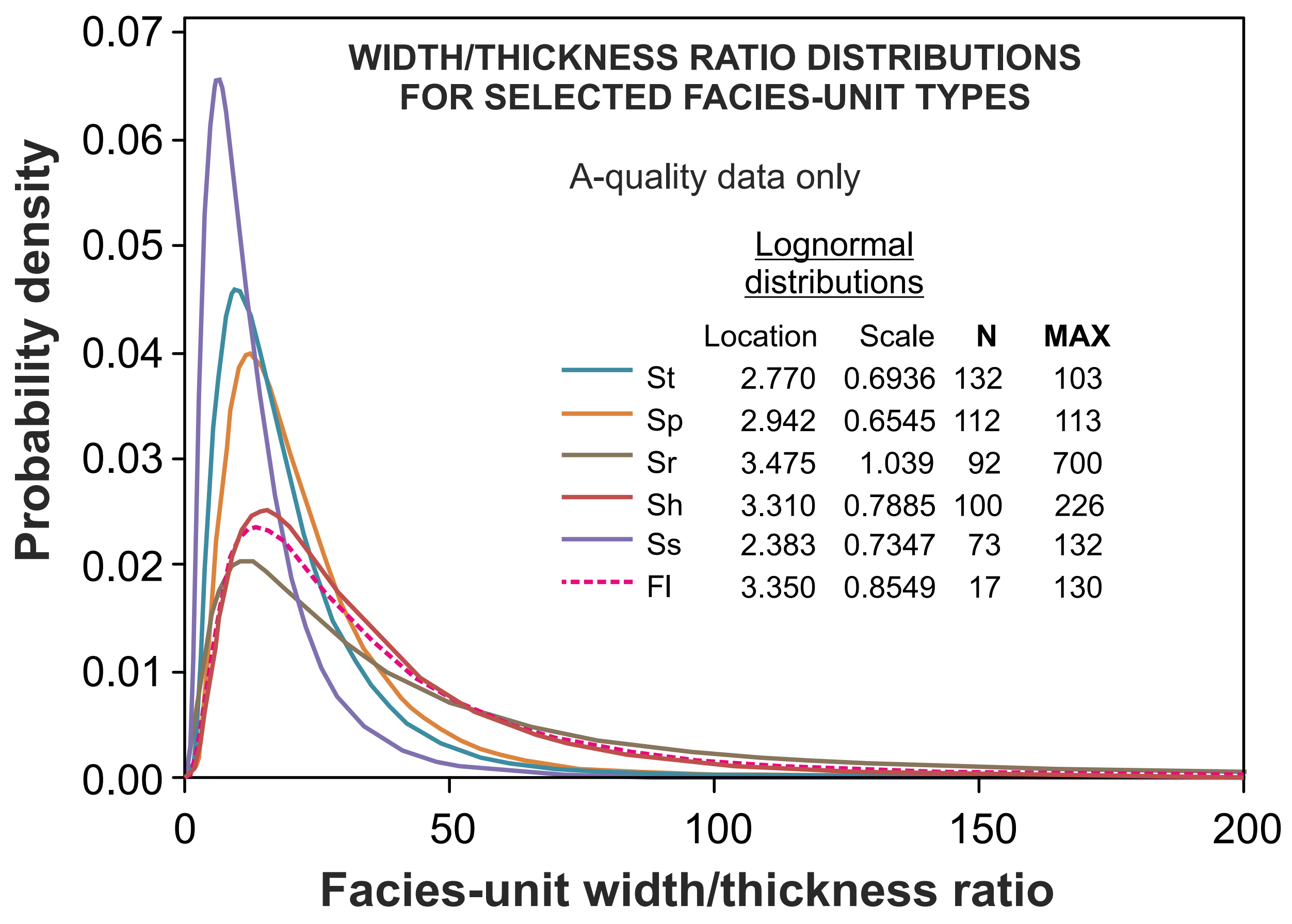
based on sum of unit thicknesses



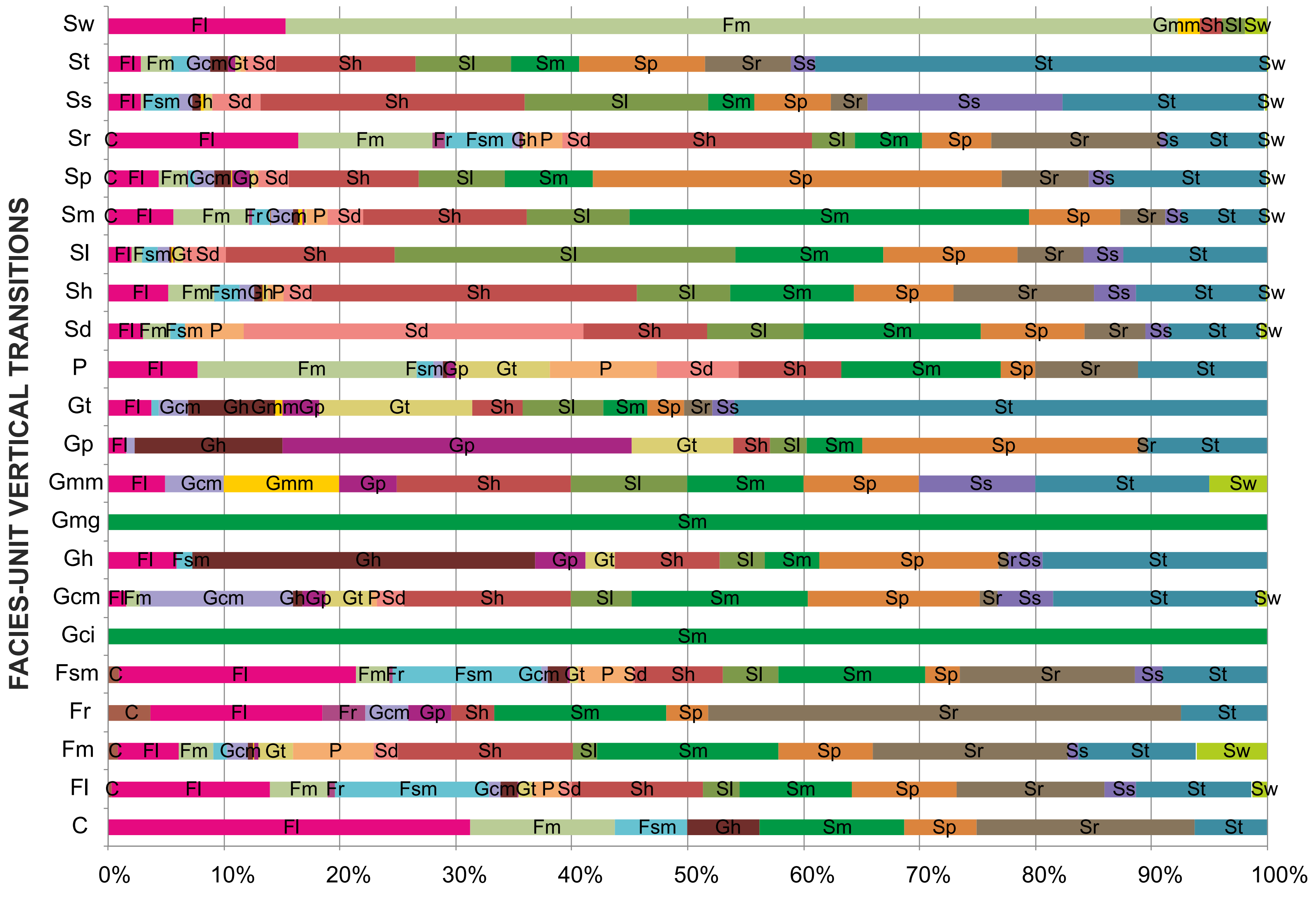


CHANNEL-COMPLEX FACIES ASSOCIATION

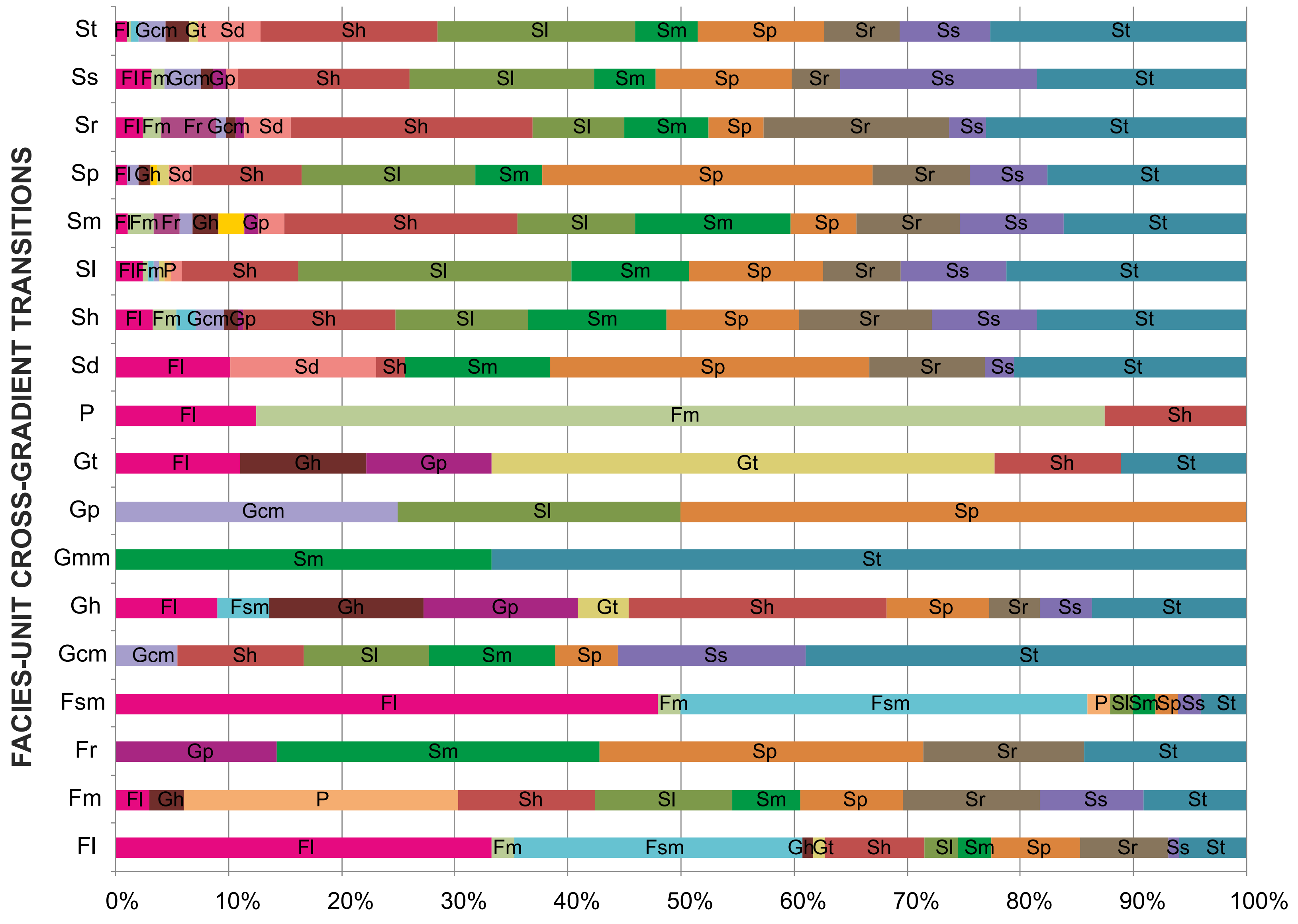
based on sum of unit thicknesses



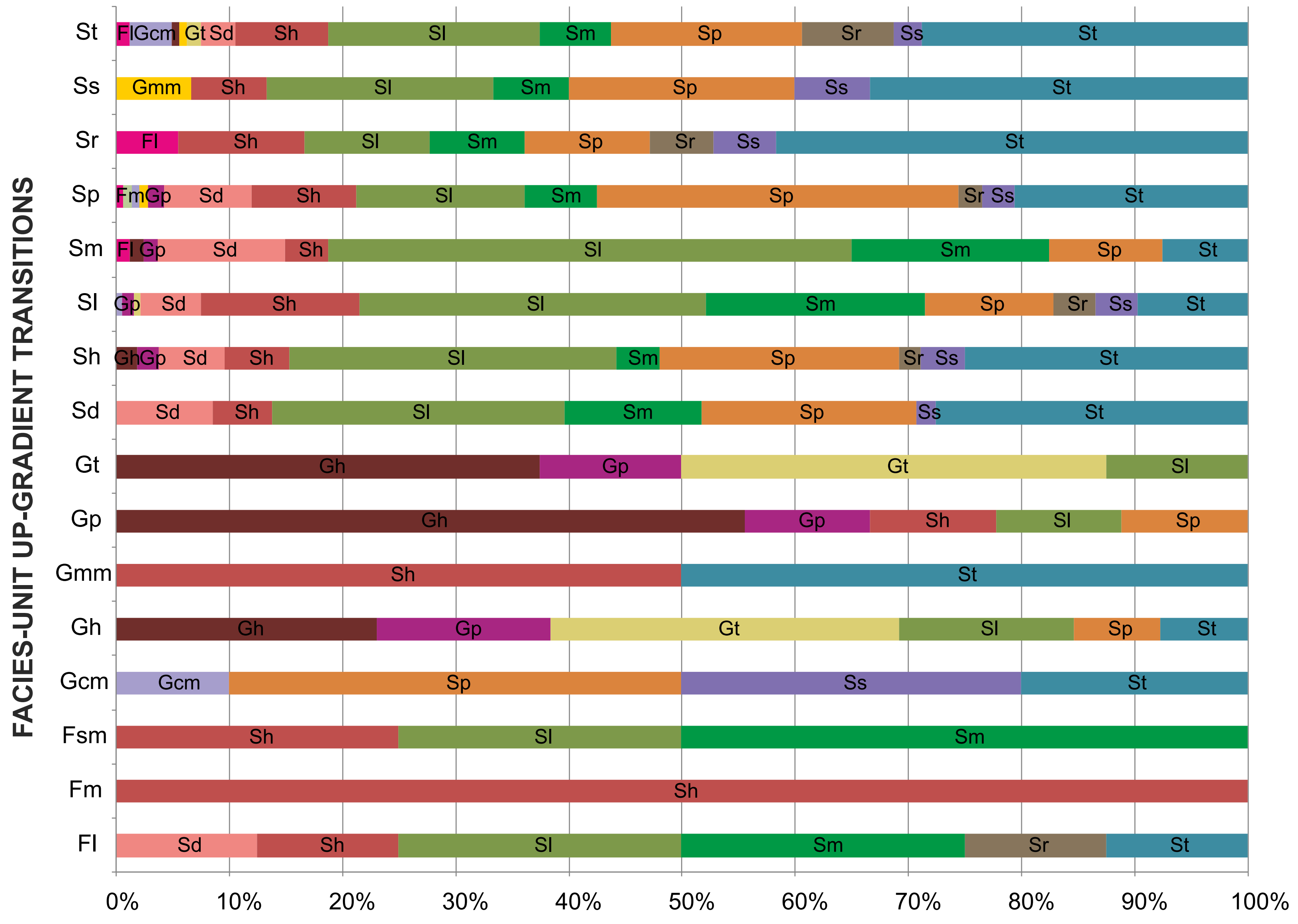
	Location	Scale	N	MAX
St	2.770	0.6936	132	103
Sp	2.942	0.6545	112	113
Sr	3.475	1.039	92	700
Sh	3.310	0.7885	100	226
Ss	2.383	0.7347	73	132
Fl	3.350	0.8549	17	130



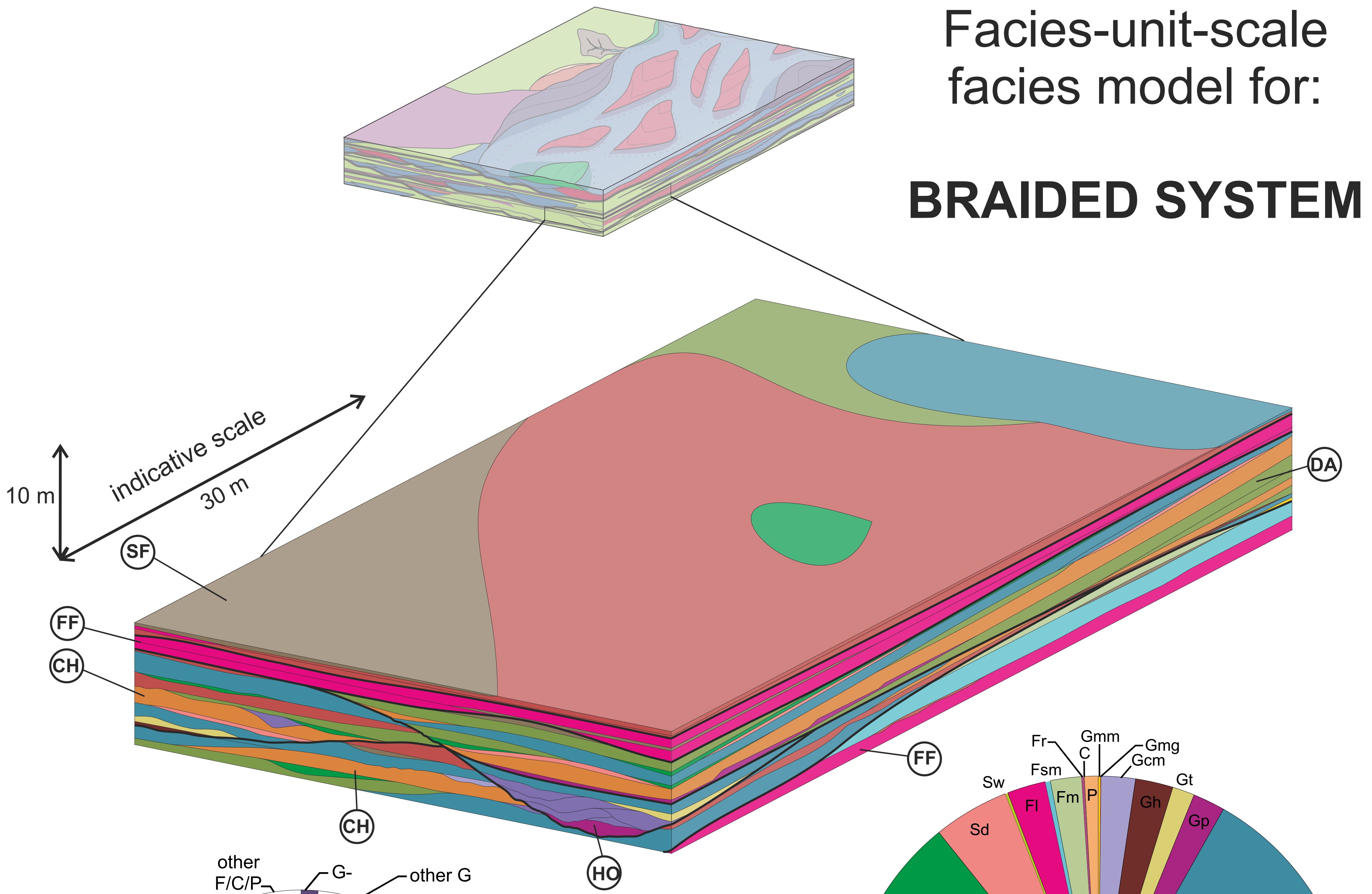
N = 15161 – Undefined facies units excluded



N = 1512 – Undefined facies units excluded

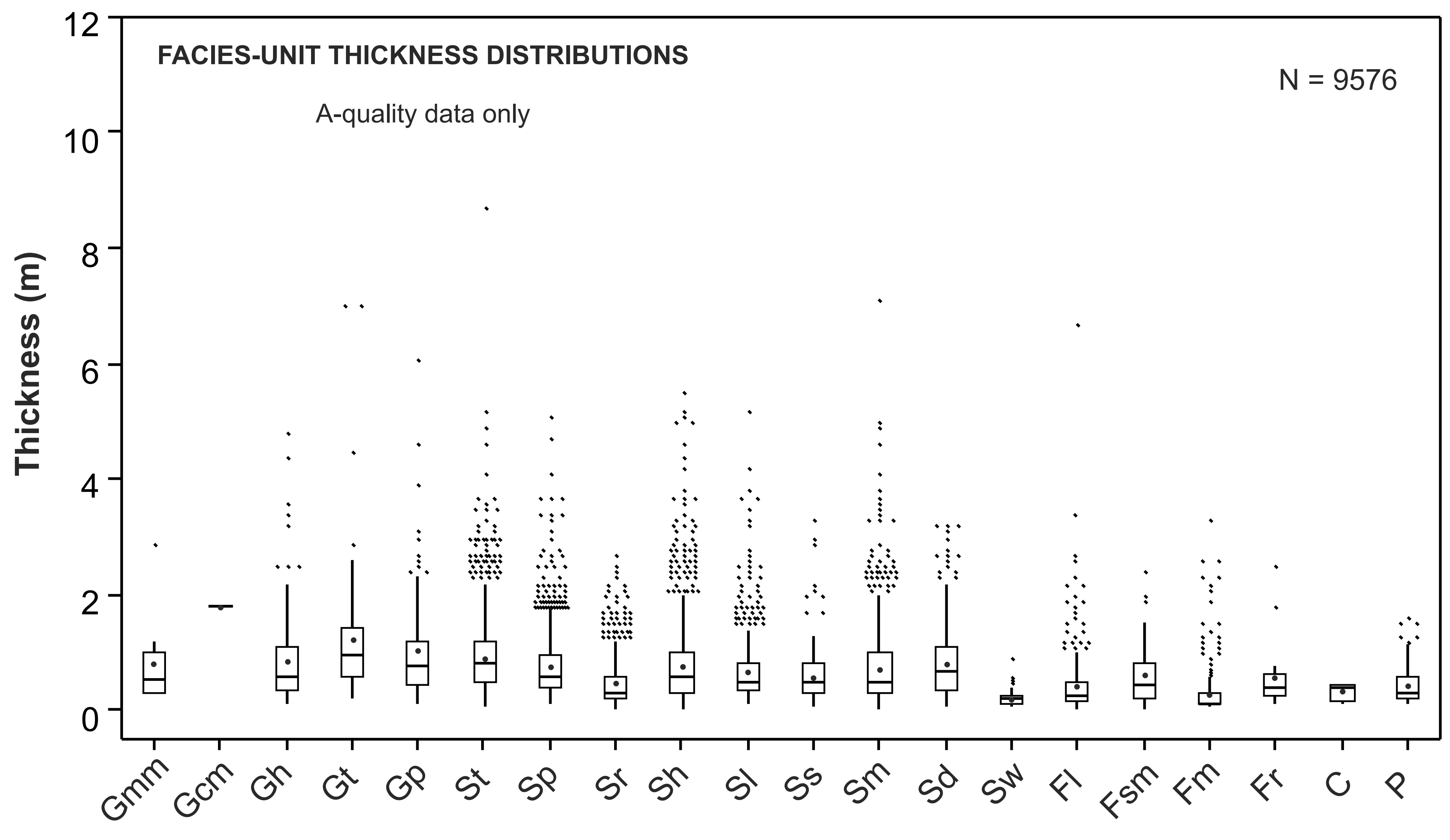


N = 784 – Undefined facies units excluded



Facies-unit-scale facies model for:

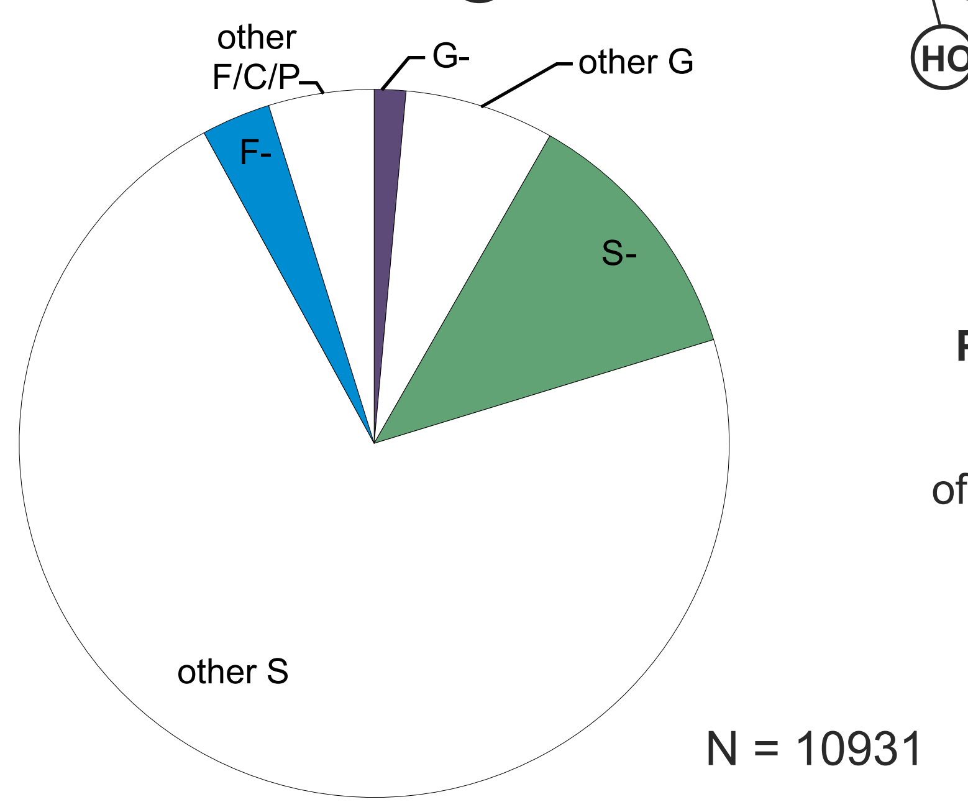
BRAIDED SYSTEM



FACIES-UNIT LATERAL-EXTENT DESCRIPTIVE STATISTICS

facies type	mean width	min width	max width	mean length	min length	max length
Gmm	5.4	3.9	6.9	6.6	2.2	11.0
Gcm	10.4	1.9	22.0	4.0	2.1	7.4
Gh	29.6	2.5	73.0	17.5	6.0	56.0
Gt	8.1	4.0	14.0	21.4	2.7	60.0
Gp	21.1	15.0	33.4	20.8	10.0	30.0
St	14.3	1.4	170.0	14.1	0.8	64.0
Sp	10.7	1.3	43.0	14.9	1.4	88.0
Sr	12.7	0.4	79.5	19.2	2.9	138.0
Sh	25.2	1.6	209.0	20.1	2.9	90.0
Sl	17.7	1.0	174.0	15.6	1.0	65.0
Ss	7.3	1.0	46.0	10.1	0.7	48.0
Sm	22.3	1.2	220.0	13.1	1.2	67.0
Sd	9.0	1.0	27.0	6.3	0.8	26.0
Fl	16.8	1.8	112.0	13.3	2.8	27.0
Fm	47.6	3.1	194.0			
Fr	15.8	5.4	29.0	1.9	1.9	1.9
P	8.0	8.0	8.0			

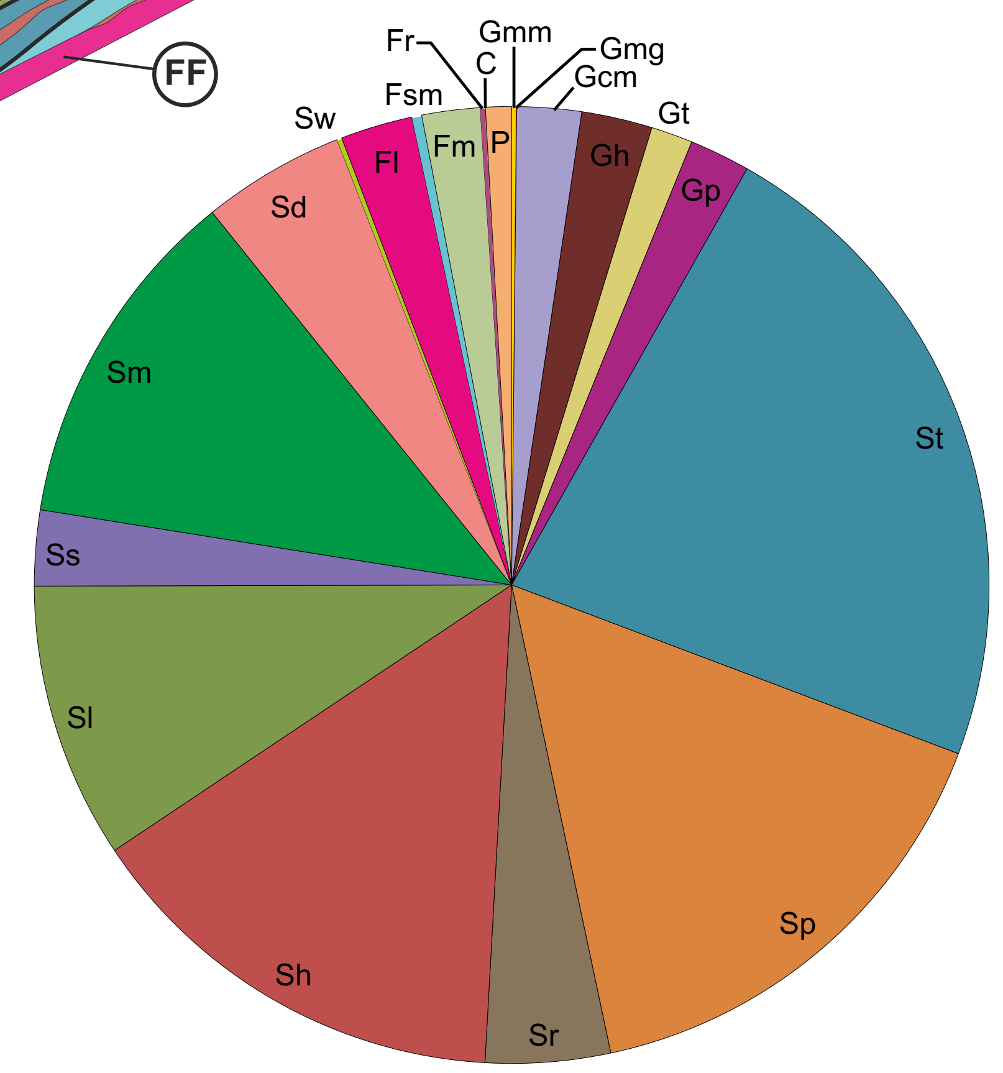
N = 1845 – all dimensions are expressed in metres

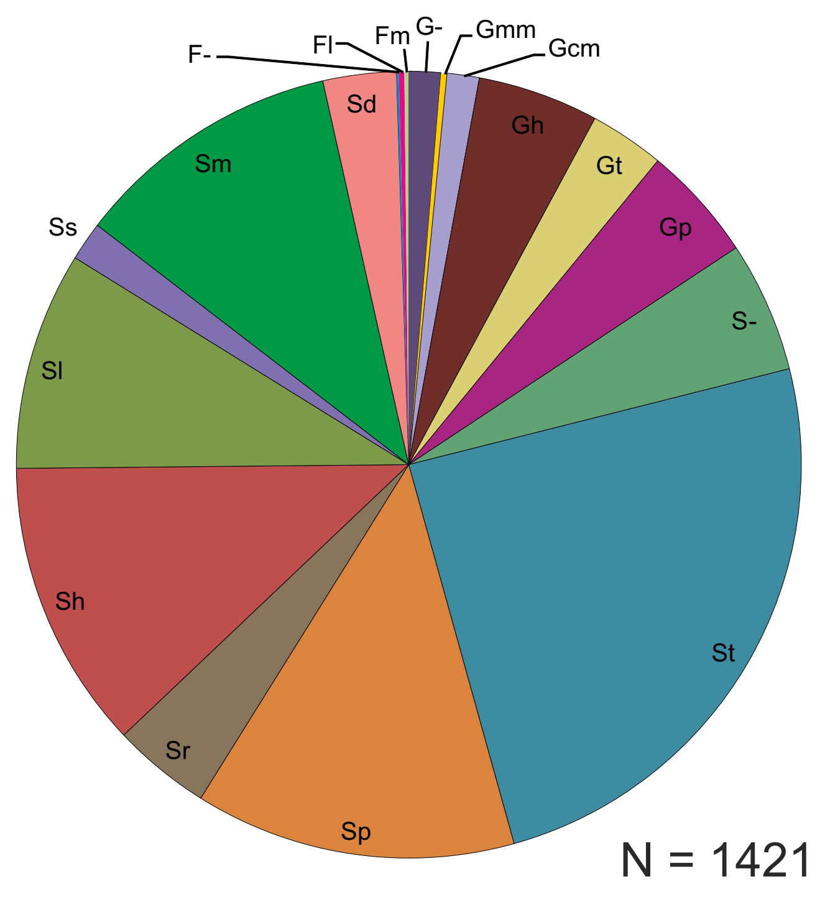


FACIES-UNIT PROPORTIONS

based on sum of unit thicknesses

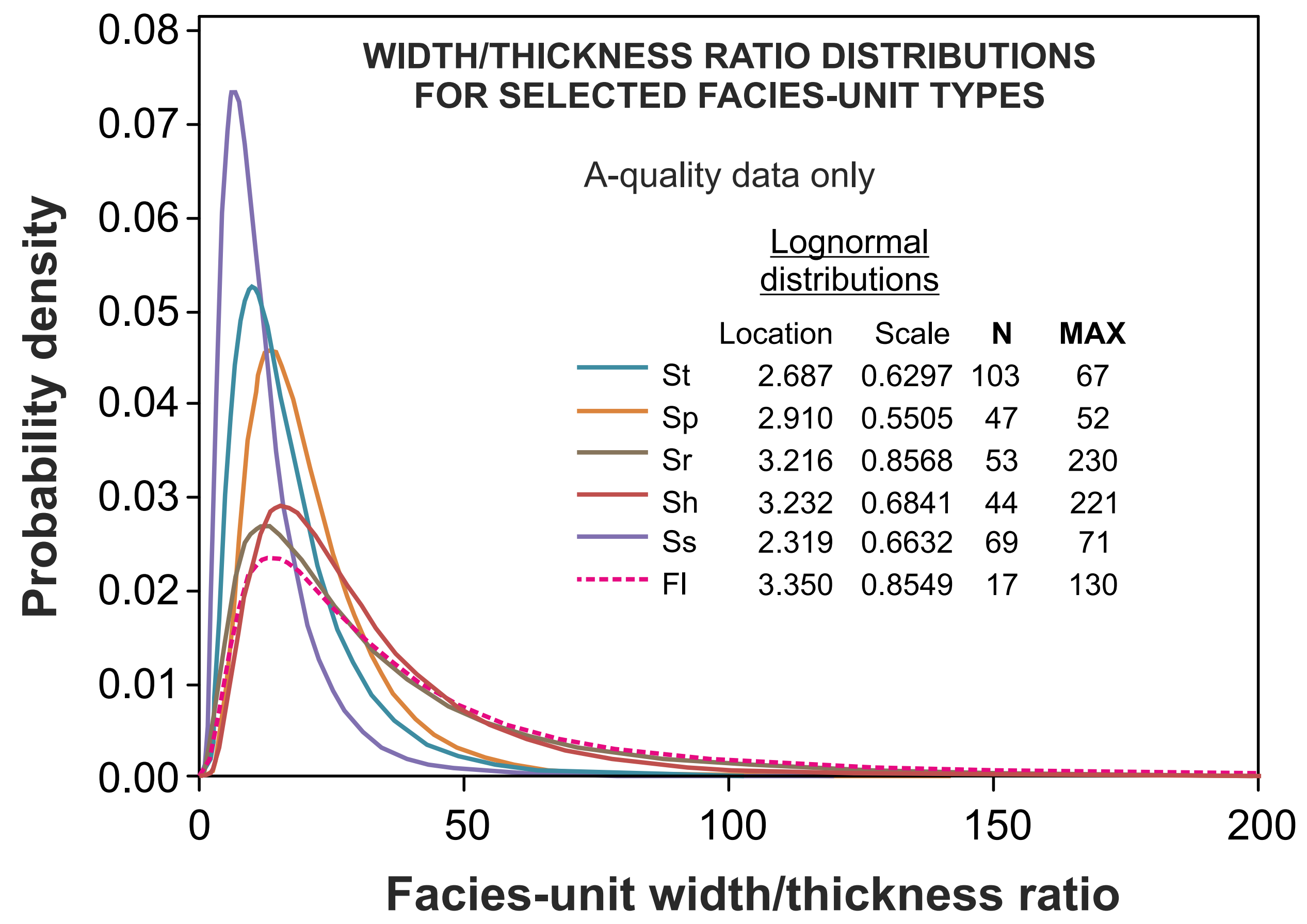
N = 10931

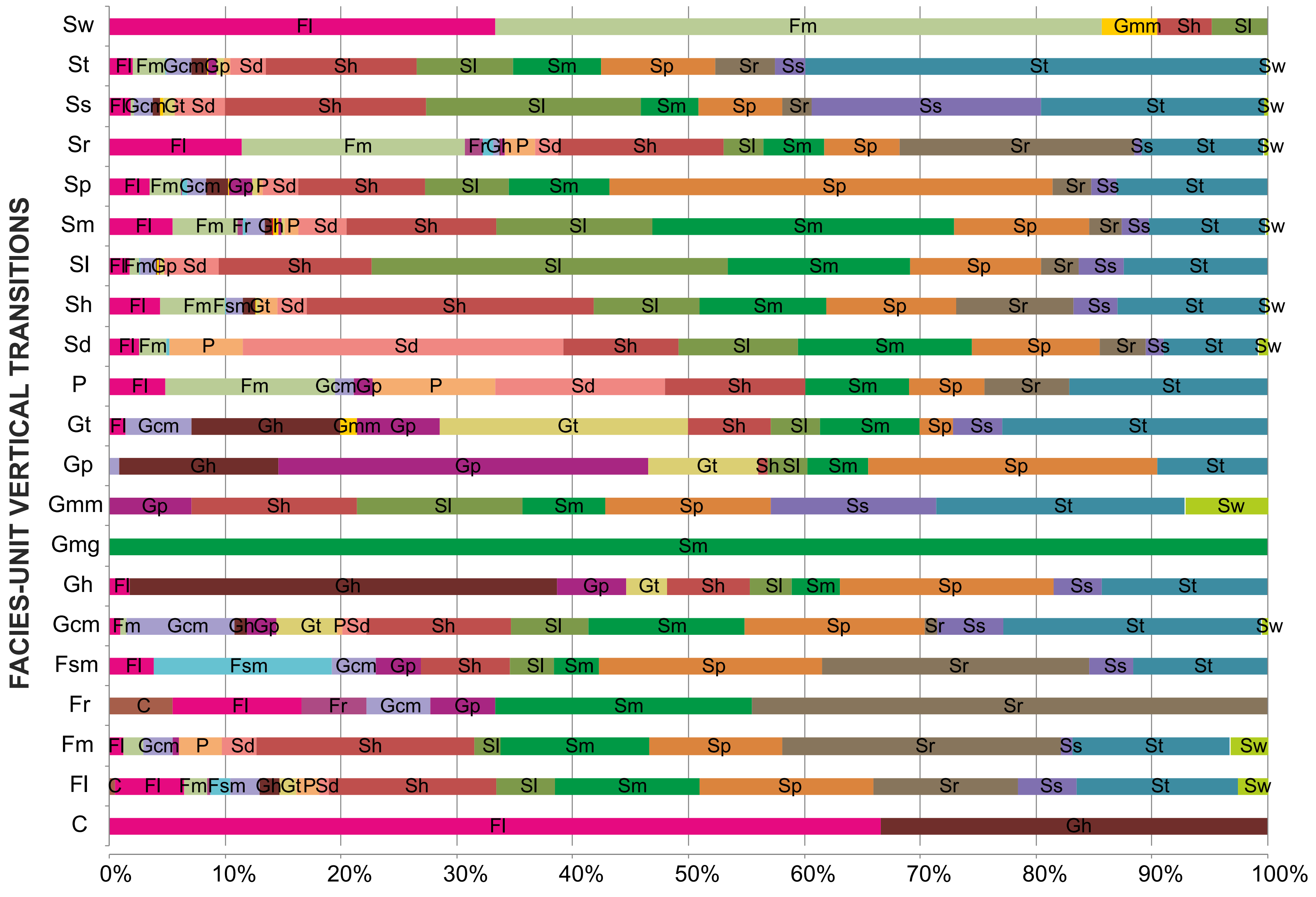




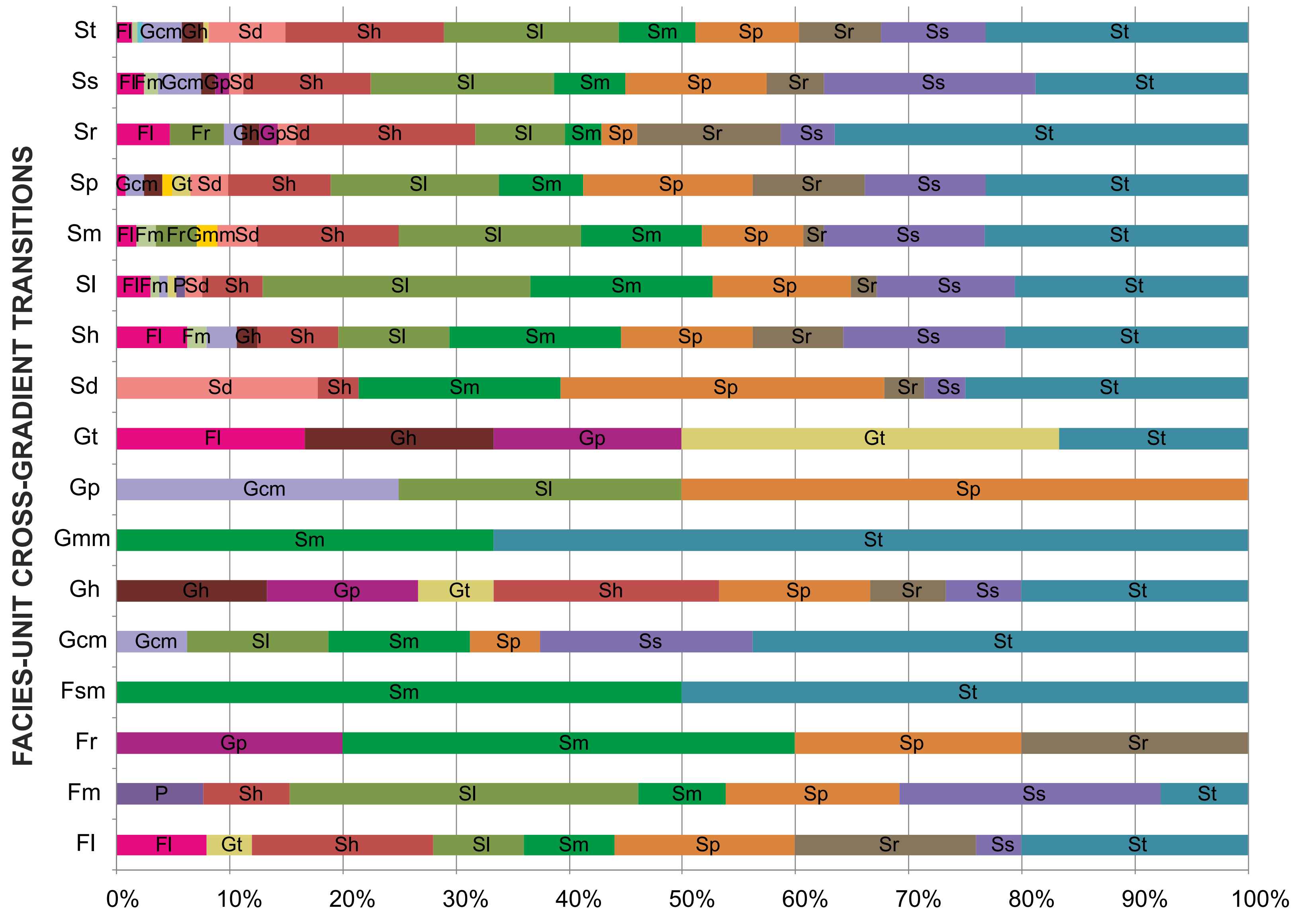
CHANNEL-COMPLEX FACIES ASSOCIATION

based on sum of unit thicknesses

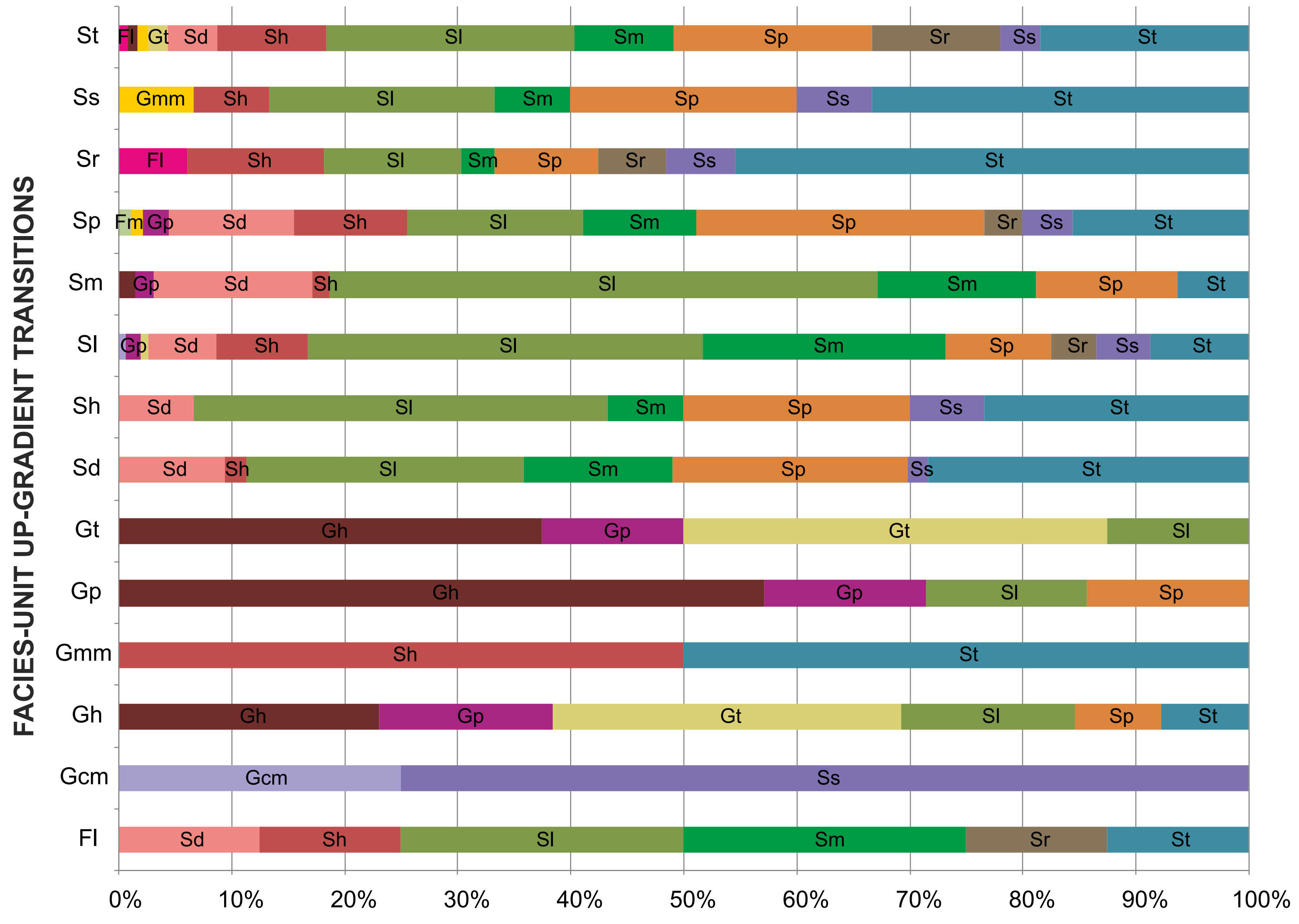




N = 9266 – Undefined facies units excluded



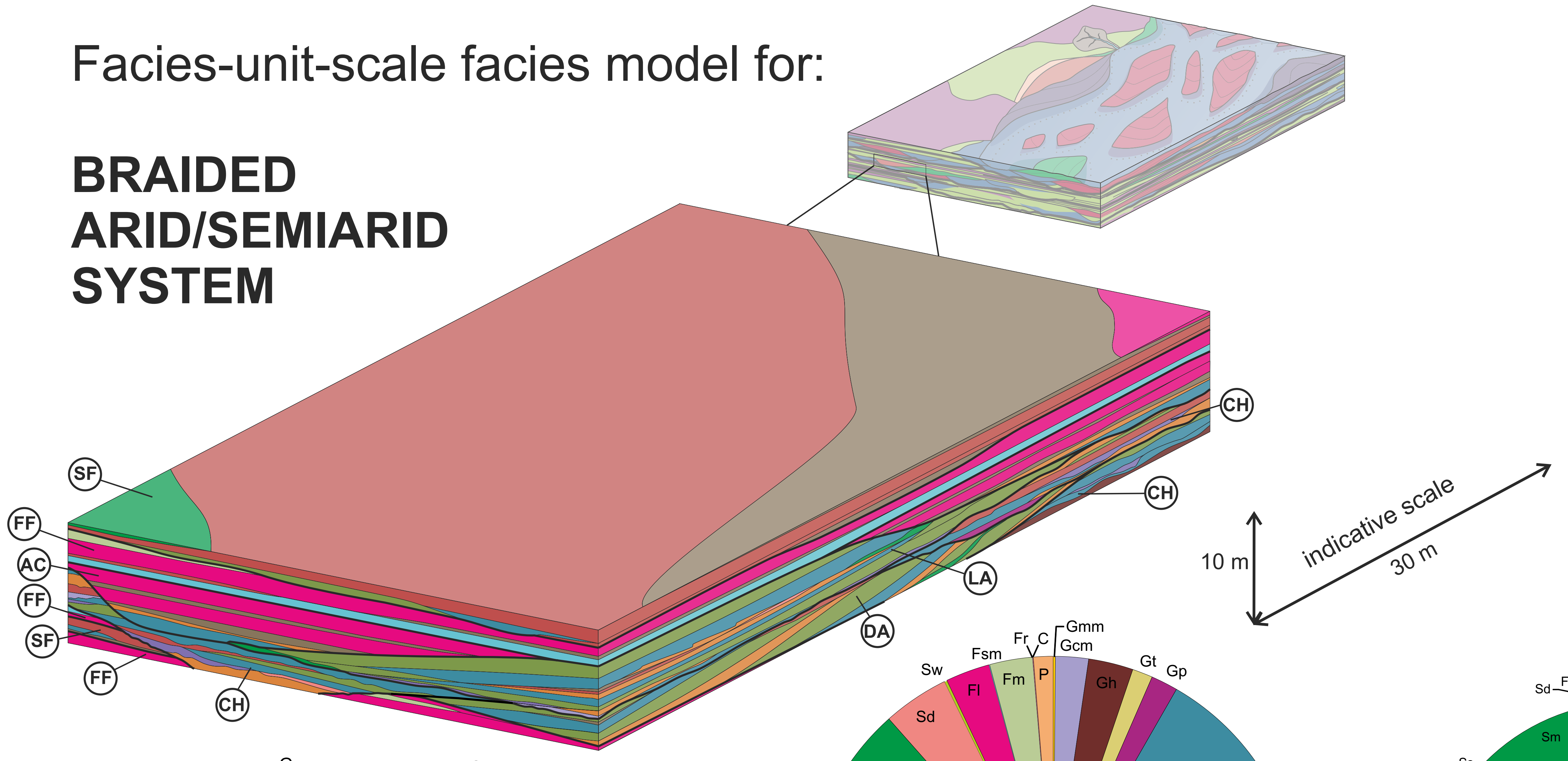
N = 887 – Undefined facies units excluded

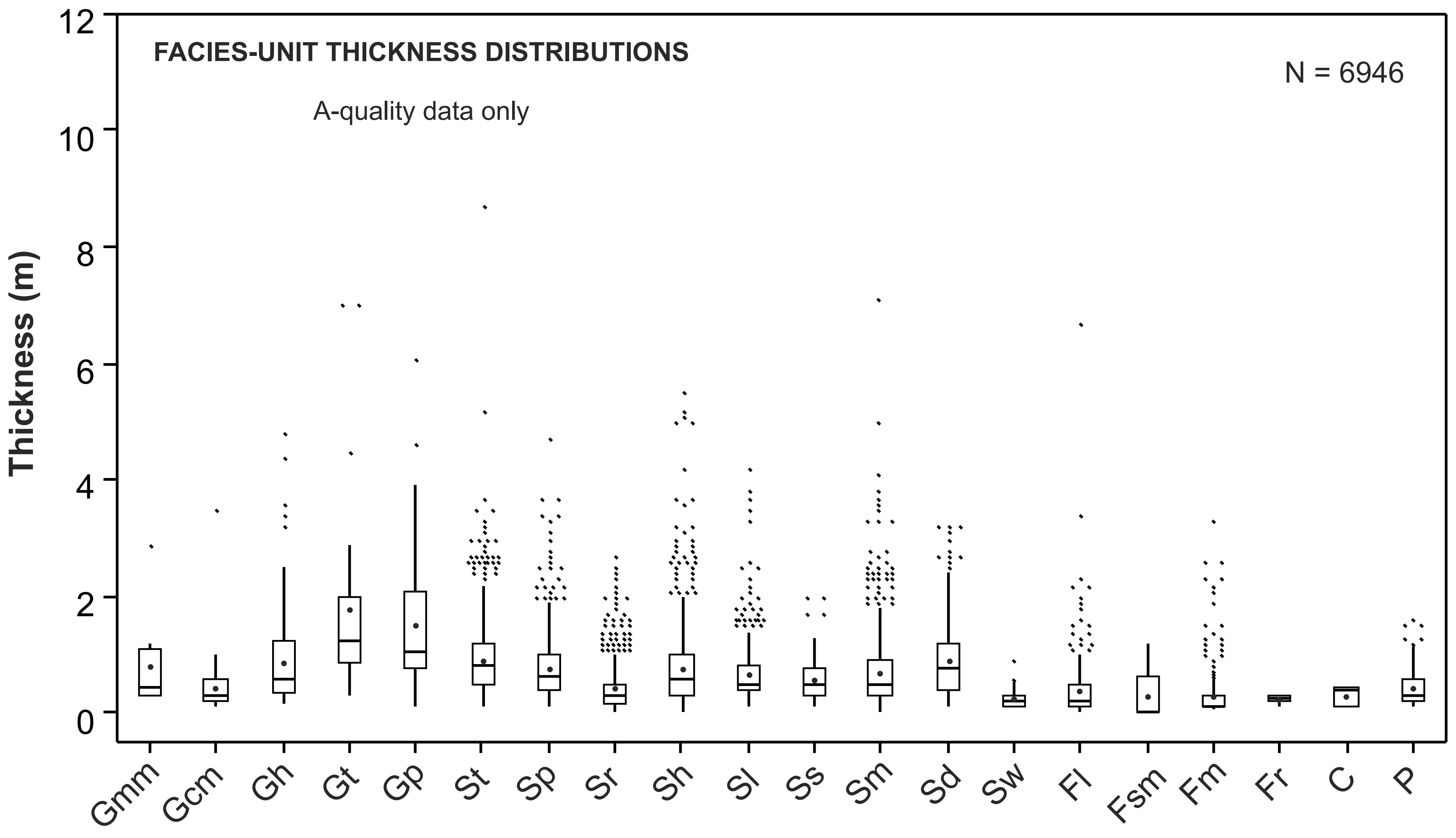


N = 590 – Undefined facies units excluded

Facies-unit-scale facies model for:

BRAIDED ARID/SEMIARID SYSTEM

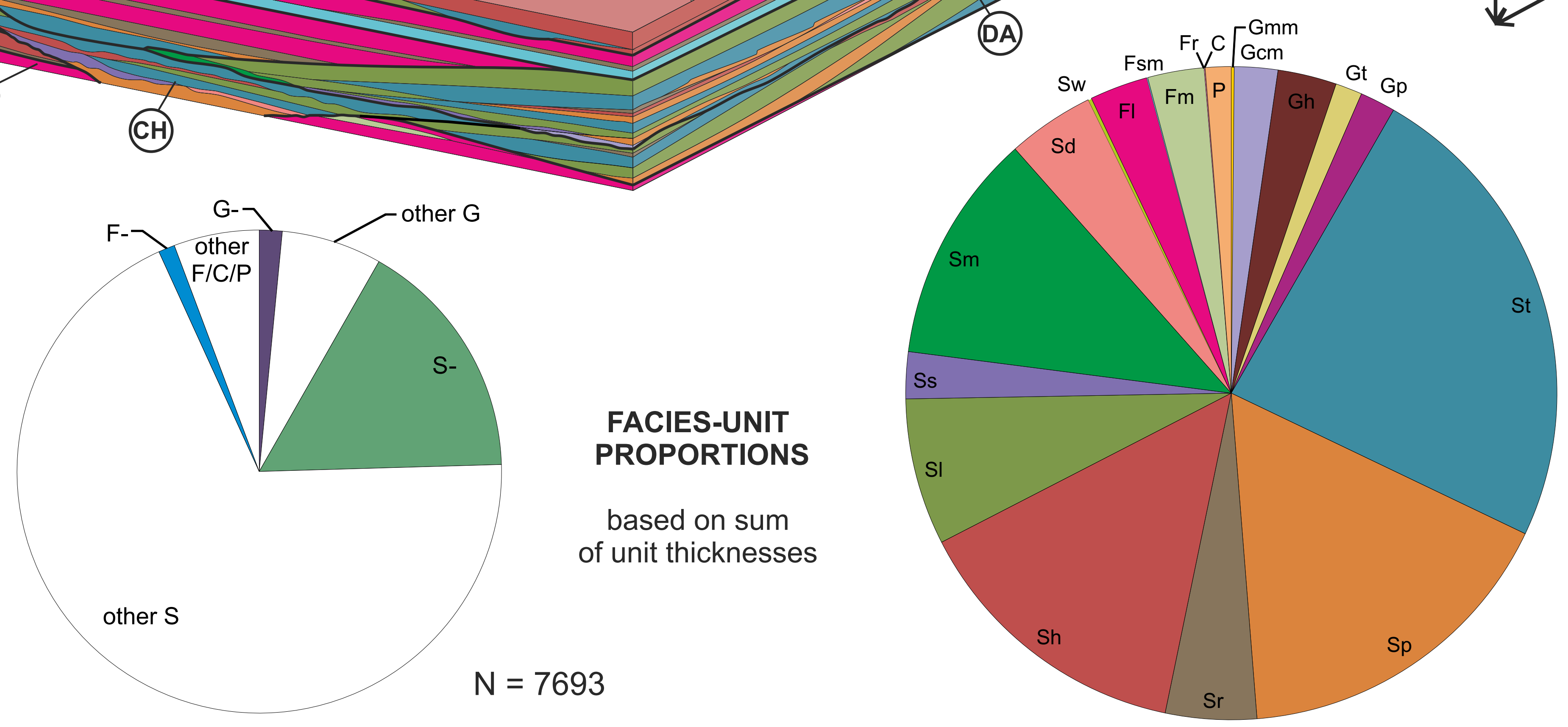




FACIES-UNIT LATERAL-EXTENT DESCRIPTIVE STATISTICS

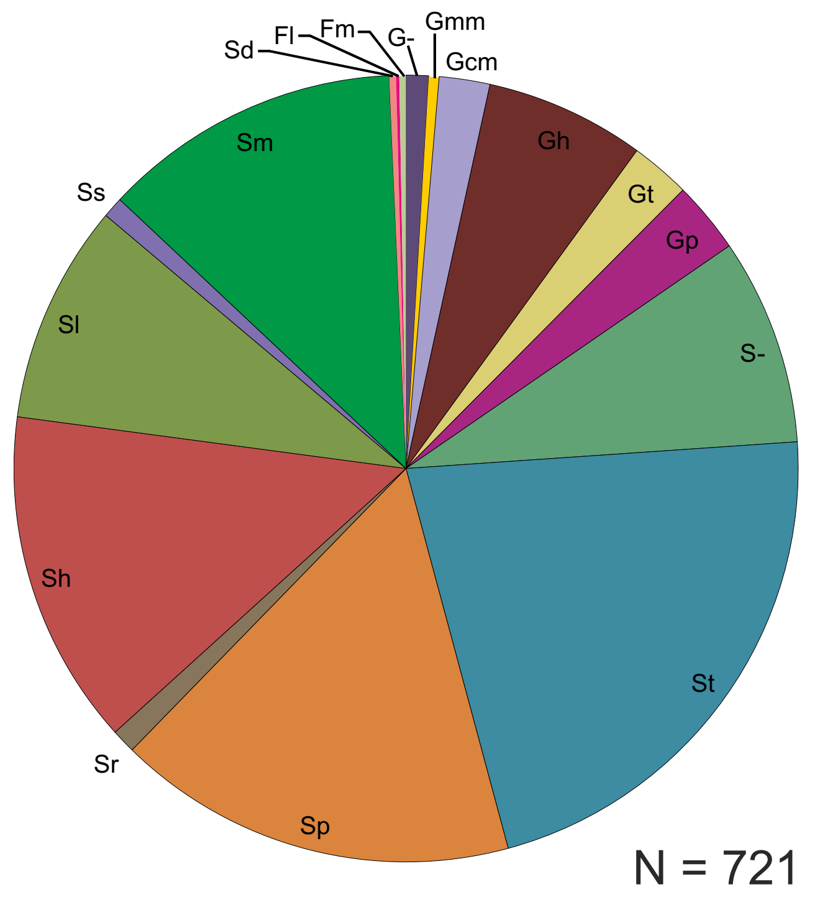
facies type	mean width	min width	max width	mean length	min length	max length
Gmm	5.4	3.9	6.9	6.6	2.2	11.0
Gcm	10.4	1.9	22.0	4.0	2.1	7.4
Gh	37.0	2.5	73.0	20.5	9.8	56.0
Gt	11.5	9.0	14.0	35.8	12.0	60.0
Gp	23.1	17.0	33.4	22.1	10.0	30.0
St	15.2	1.4	170.0	14.1	1.4	64.0
Sp	10.5	1.3	43.0	15.3	1.4	88.0
Sr	9.0	0.4	70.0	16.3	2.9	65.0
Sh	27.7	1.6	209.0	18.0	2.9	67.0
Sl	18.1	1.0	174.0	16.6	1.0	65.0
Ss	7.4	1.0	46.0	10.1	0.7	48.0
Sm	23.2	1.2	220.0	16.4	1.2	67.0
Sd	4.8	1.0	9.0	5.0	0.8	19.0
Fl	18.2	1.8	112.0	13.4	2.8	27.0
Fm	47.6	3.1	194.0			
Fr				1.9	1.9	1.9
P	8.0	8.0	8.0			

N = 1262 – all dimensions are expressed in metres



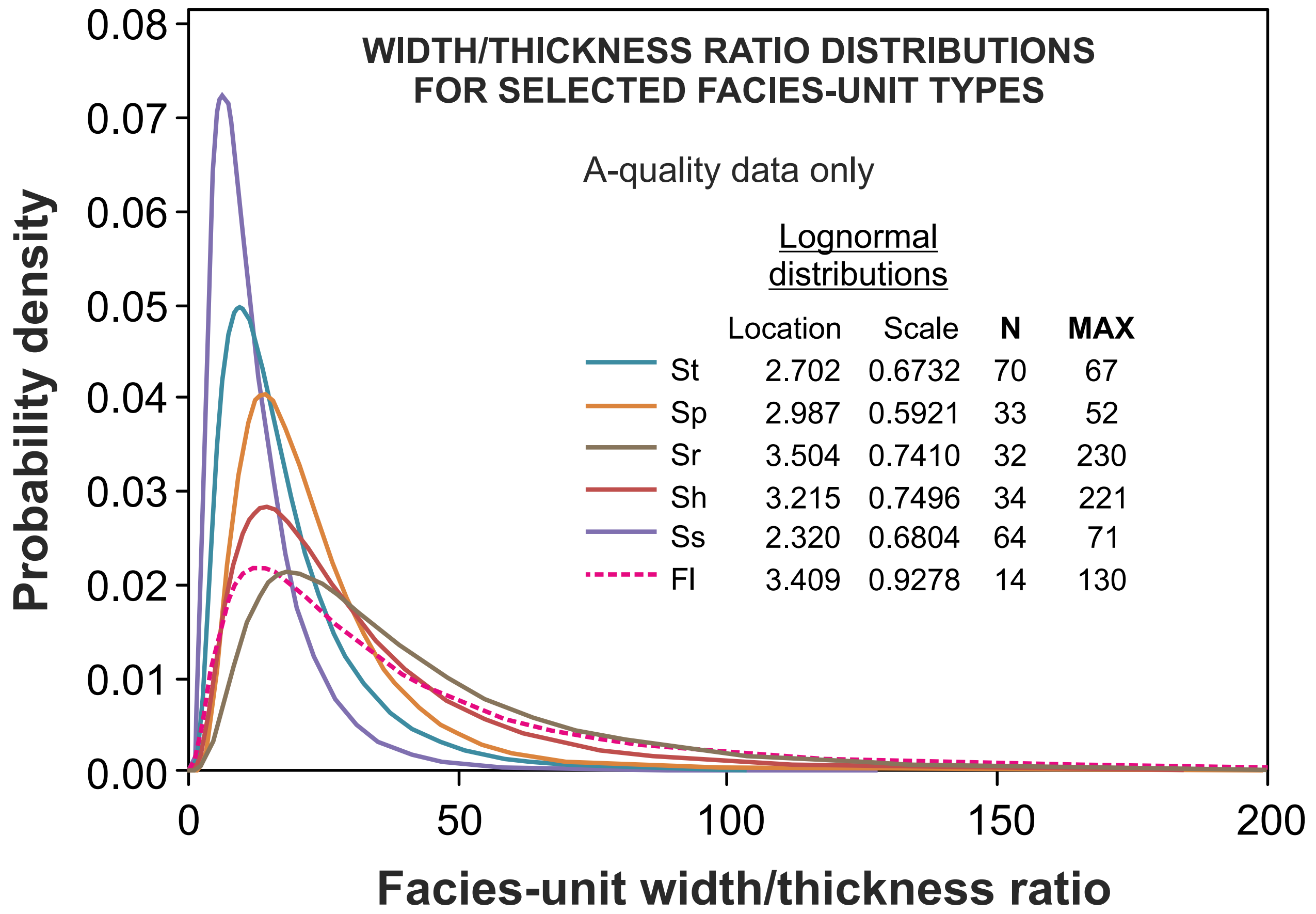
FACIES-UNIT PROPORTIONS

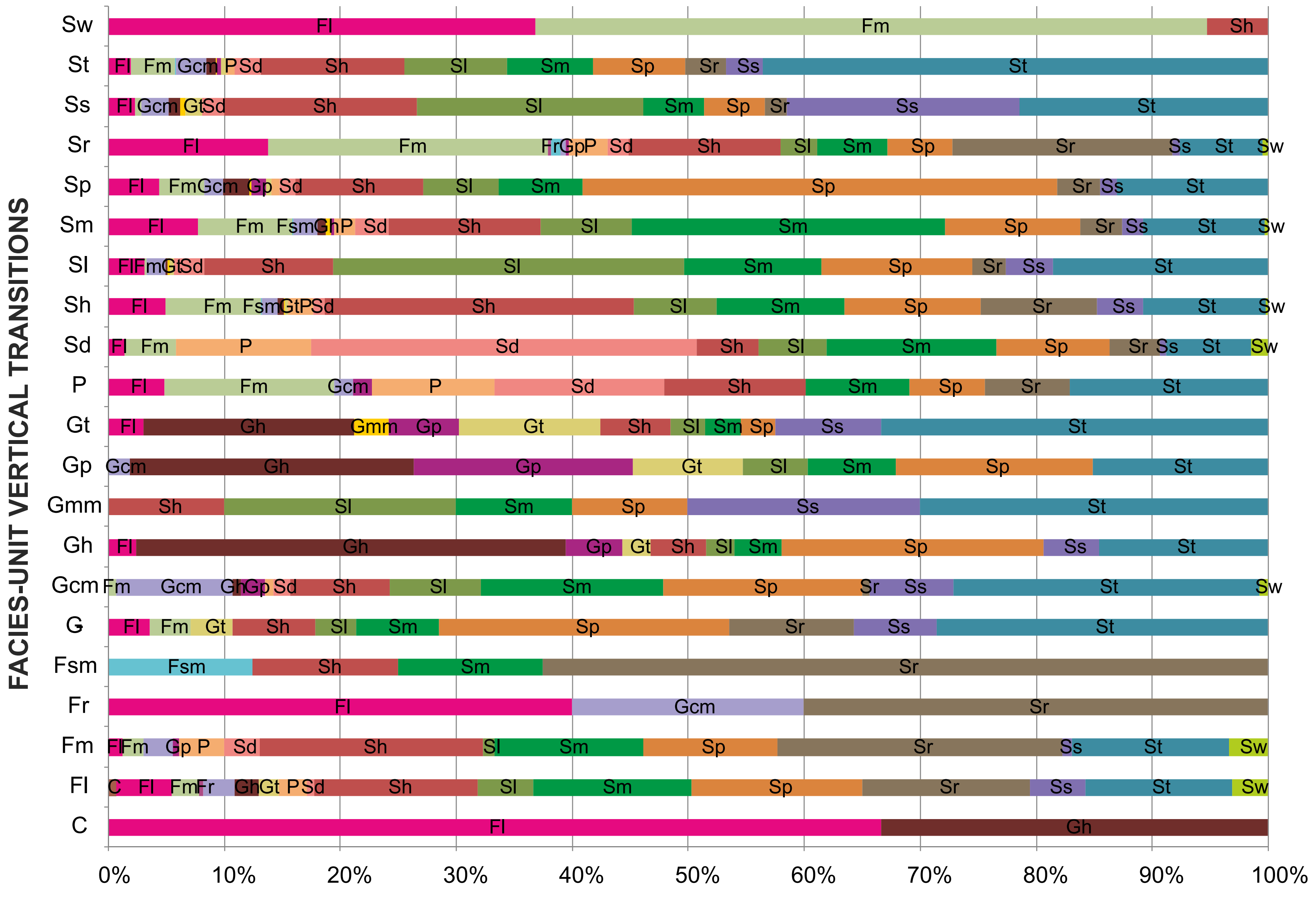
based on sum of unit thicknesses



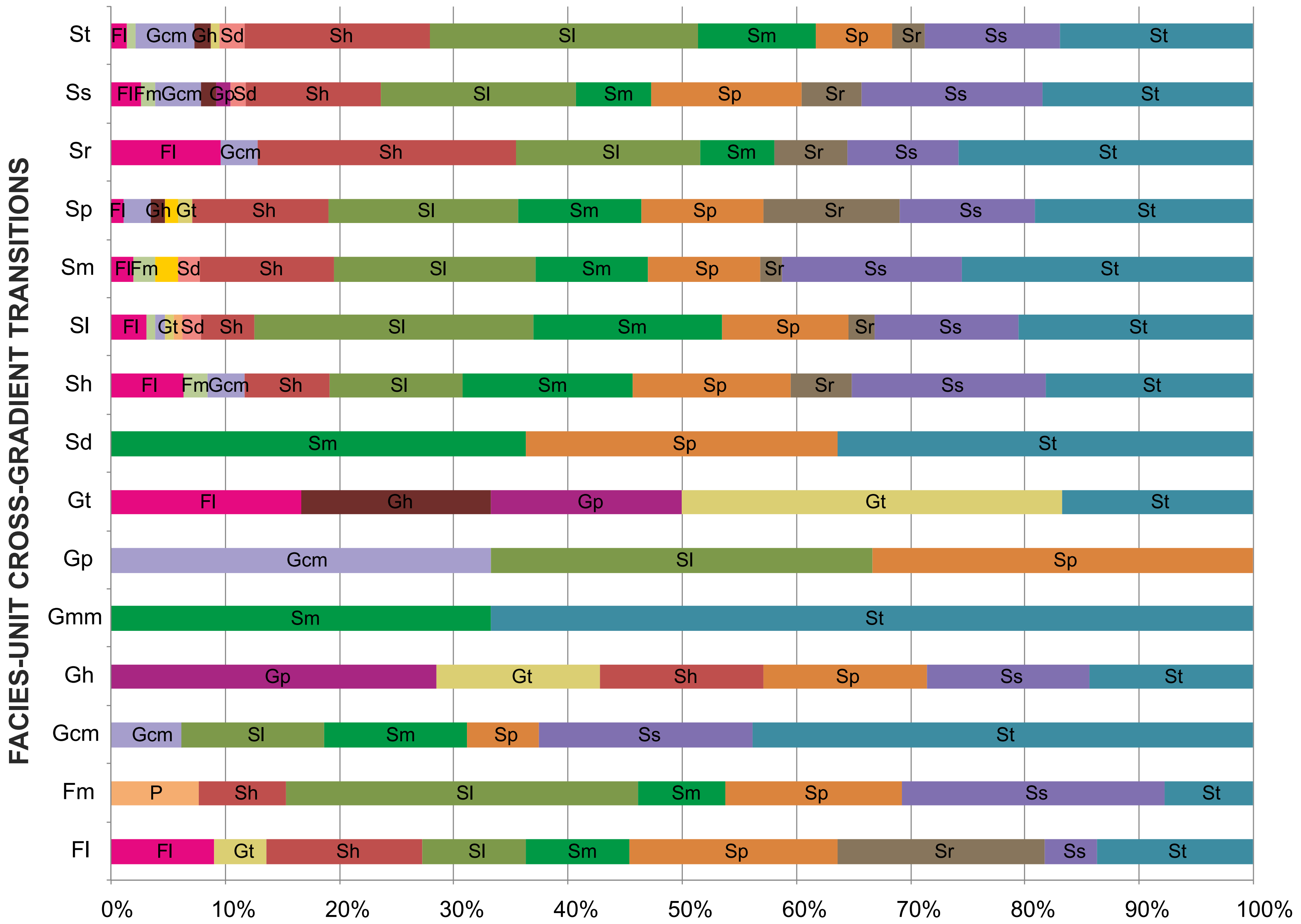
CHANNEL-COMPLEX FACIES ASSOCIATION

based on sum of unit thicknesses

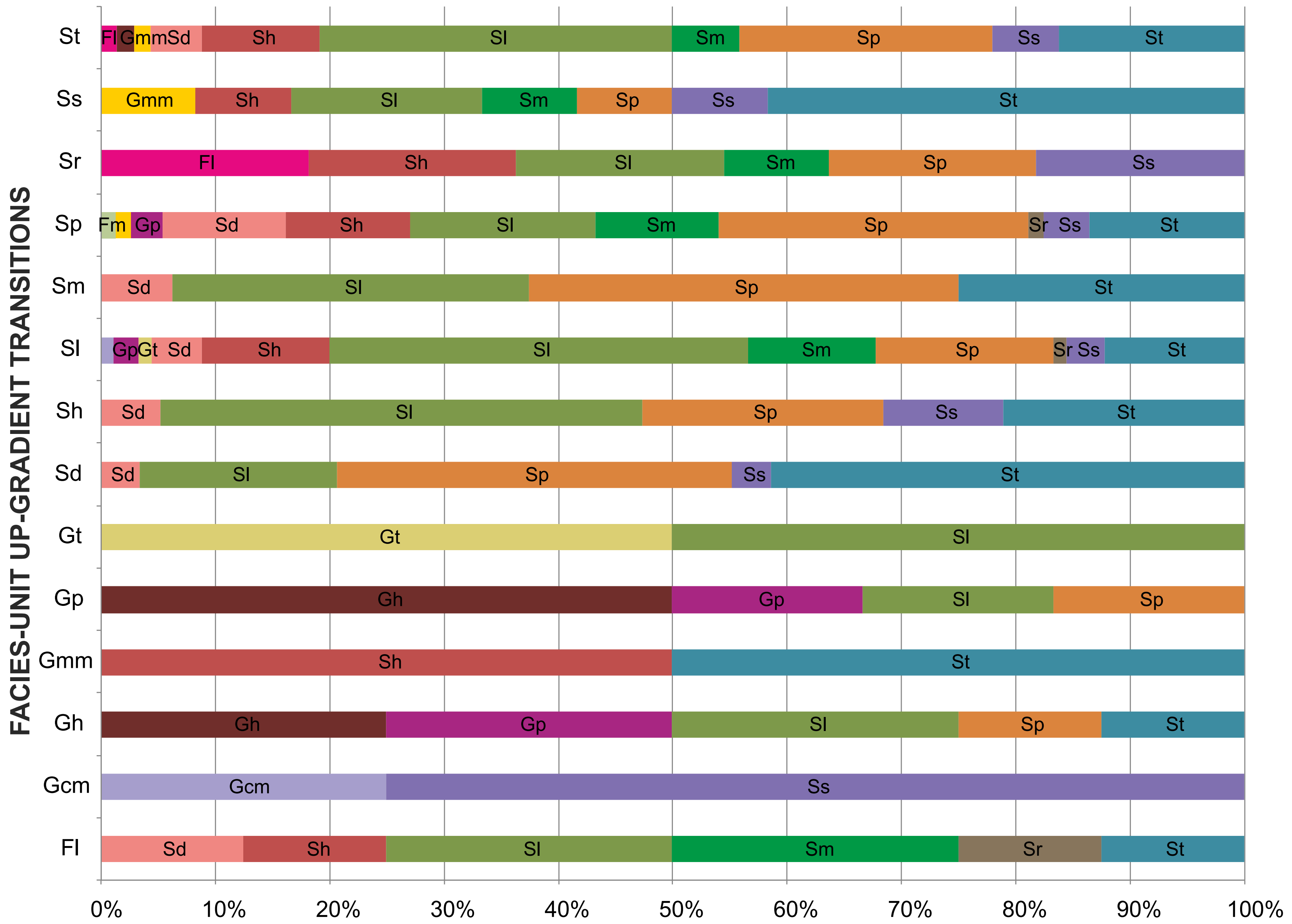




N = 6442 – Undefined facies units excluded



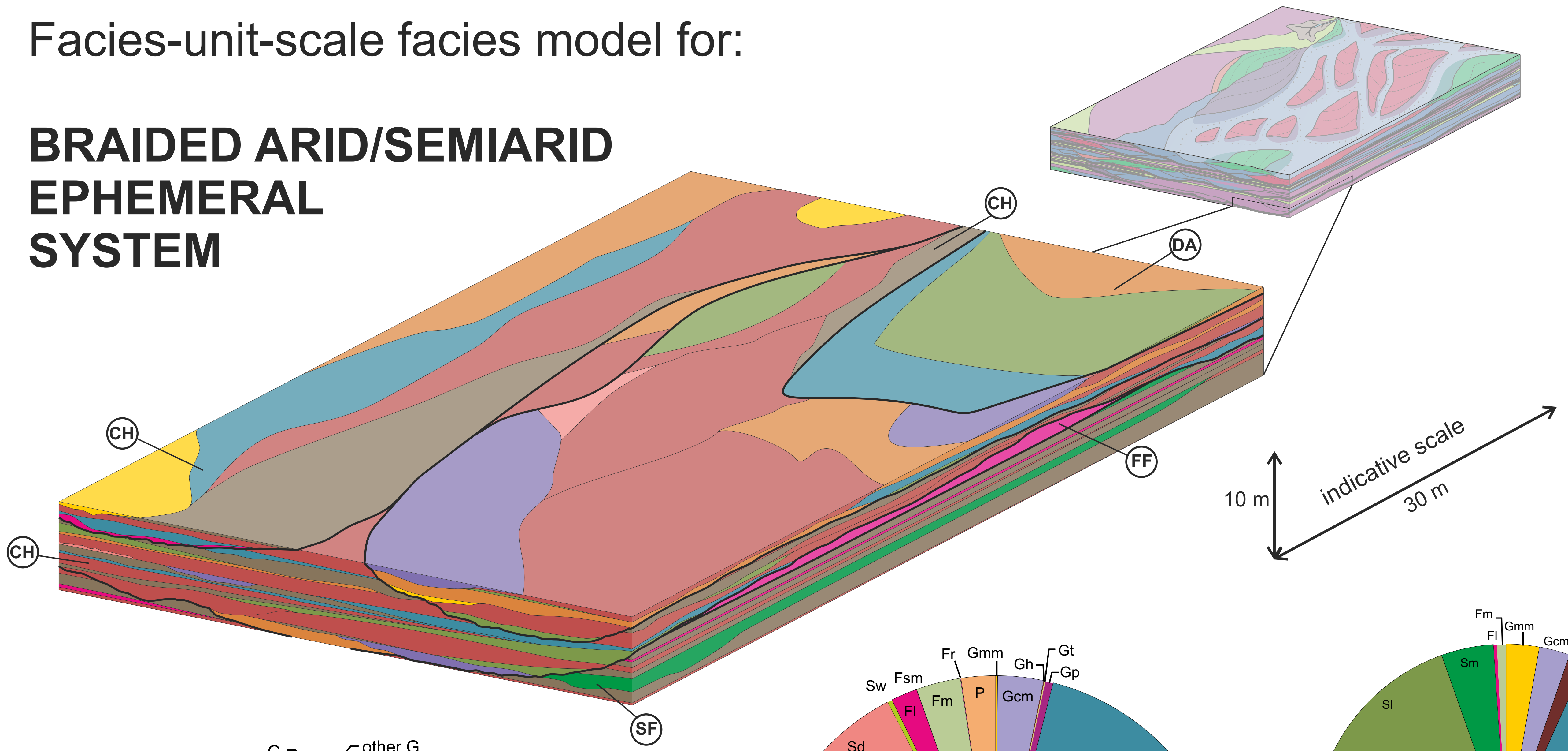
N = 682 – Undefined facies units excluded

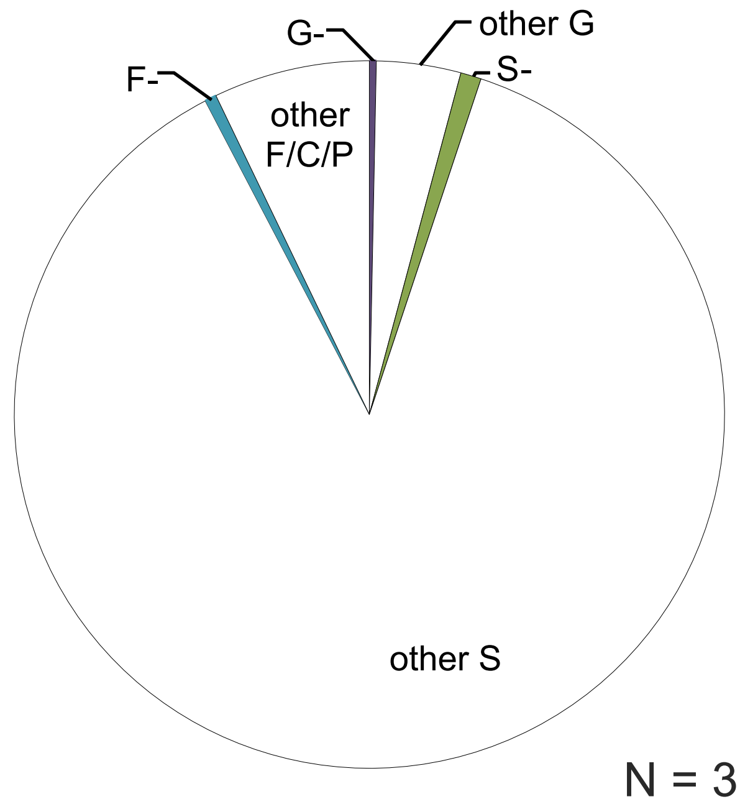


N = 351 – Undefined facies units excluded

Facies-unit-scale facies model for:

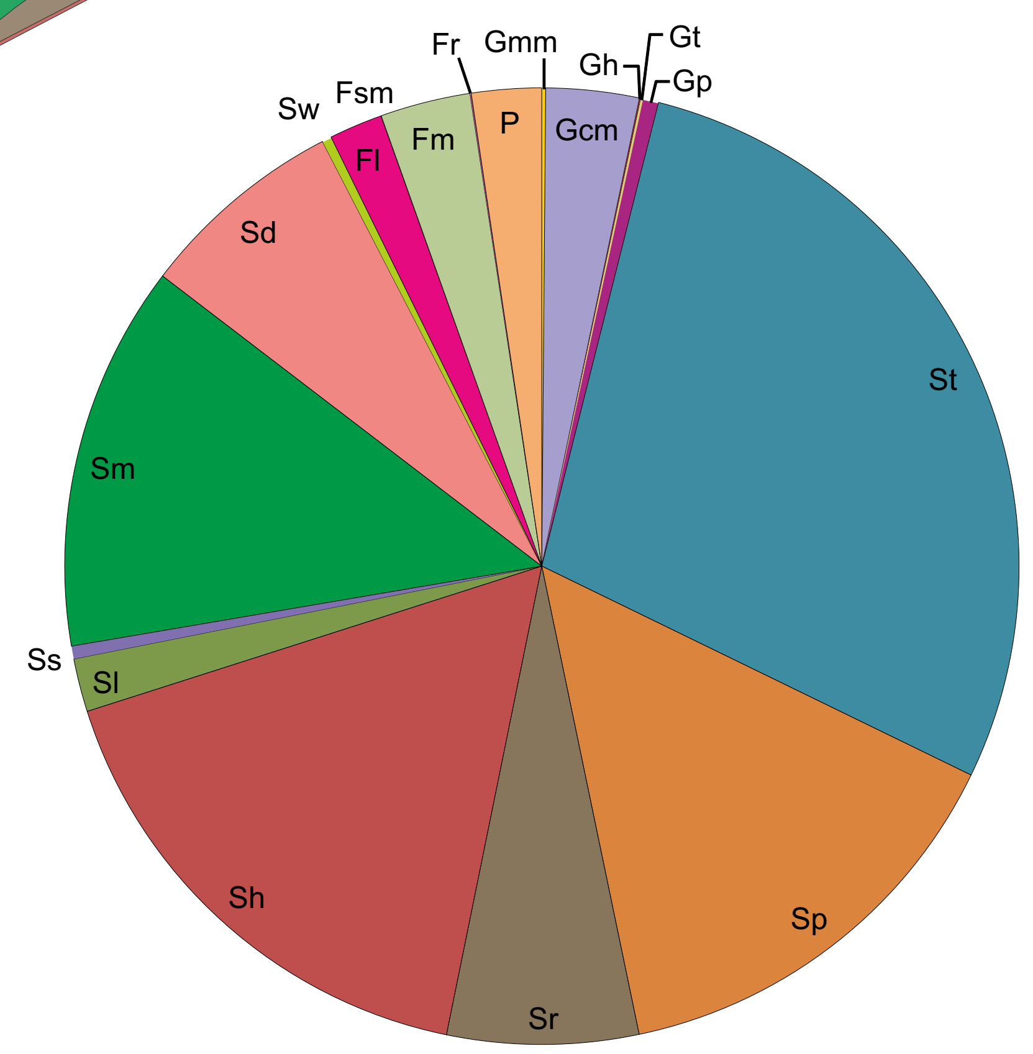
BRAIDED ARID/SEMIARID EPHEMERAL SYSTEM

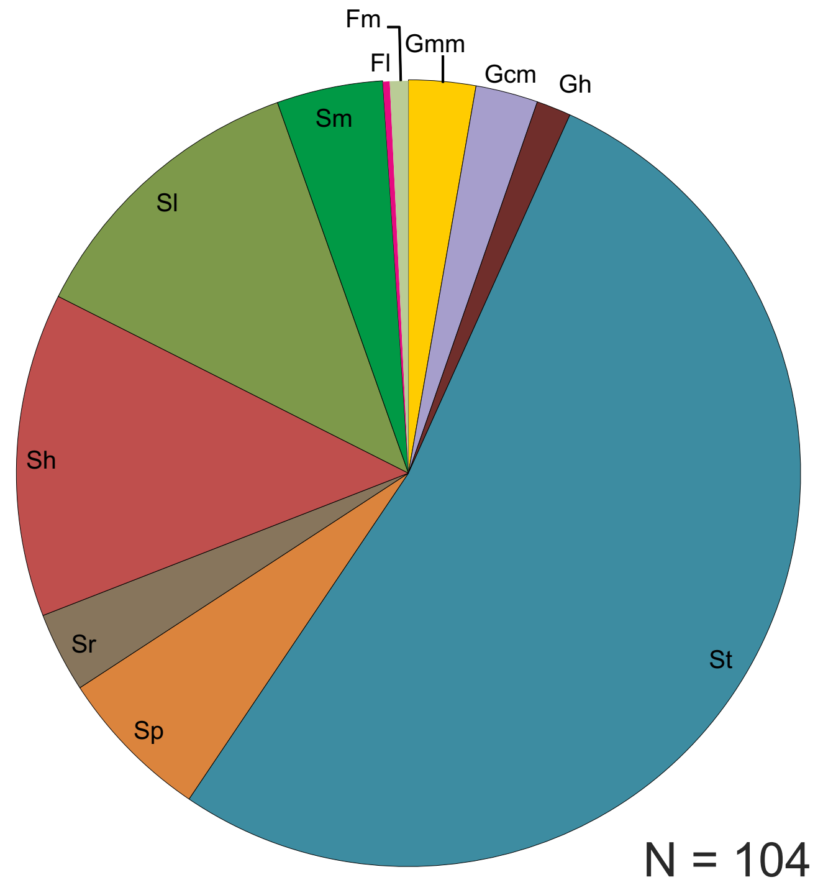




FACIES-UNIT PROPORTIONS

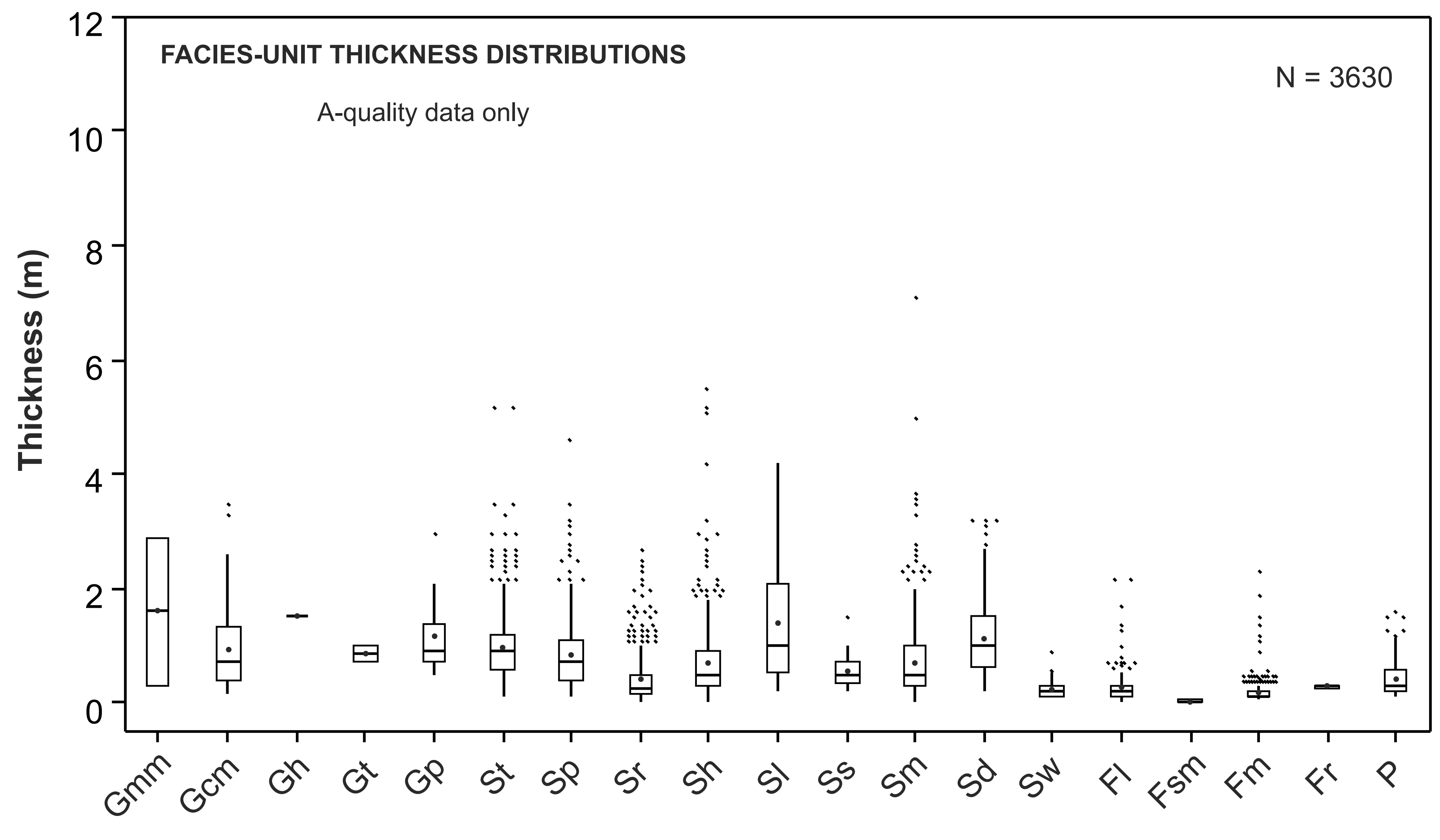
based on sum of unit thicknesses

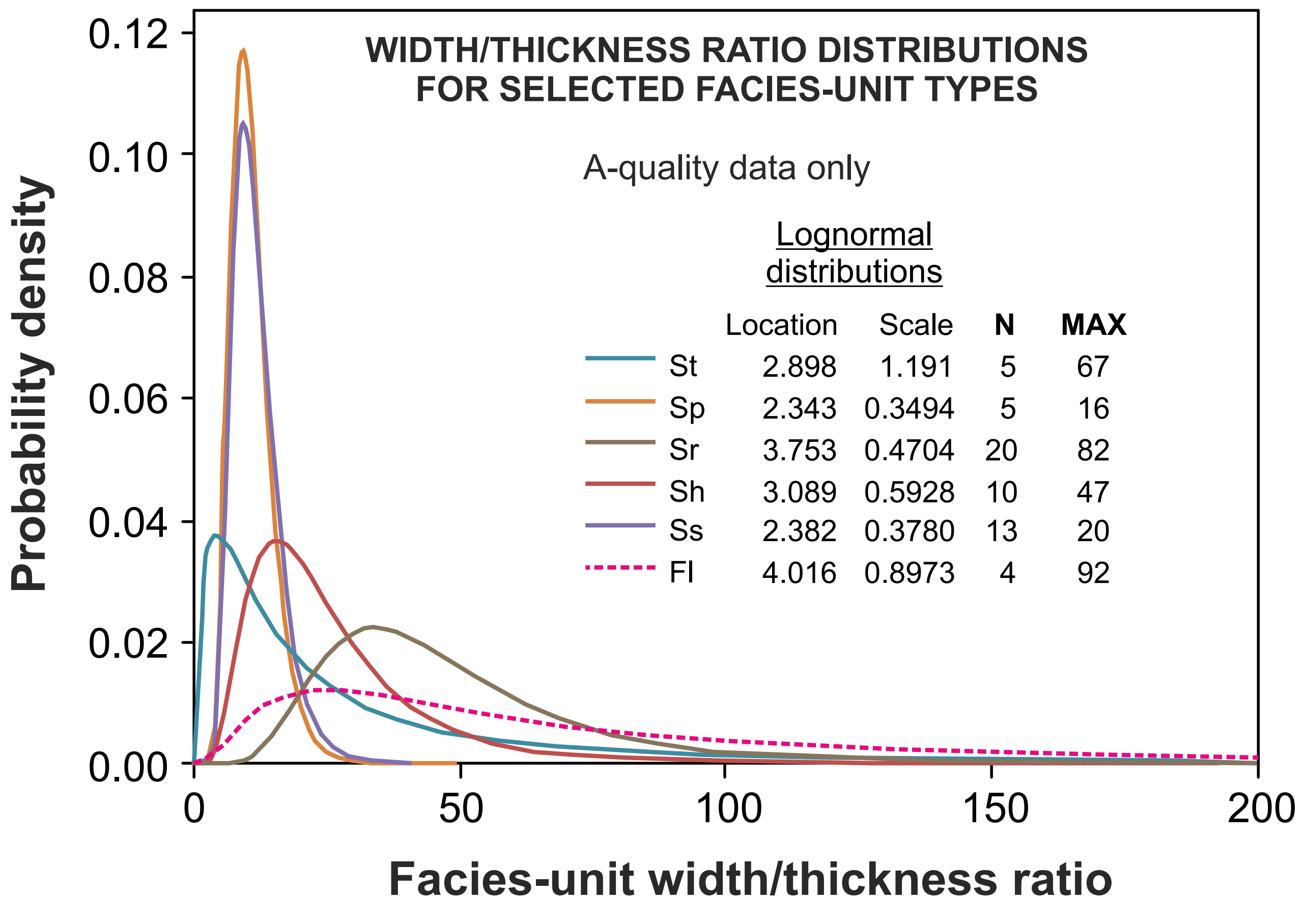




CHANNEL-COMPLEX FACIES ASSOCIATION

based on sum of unit thicknesses

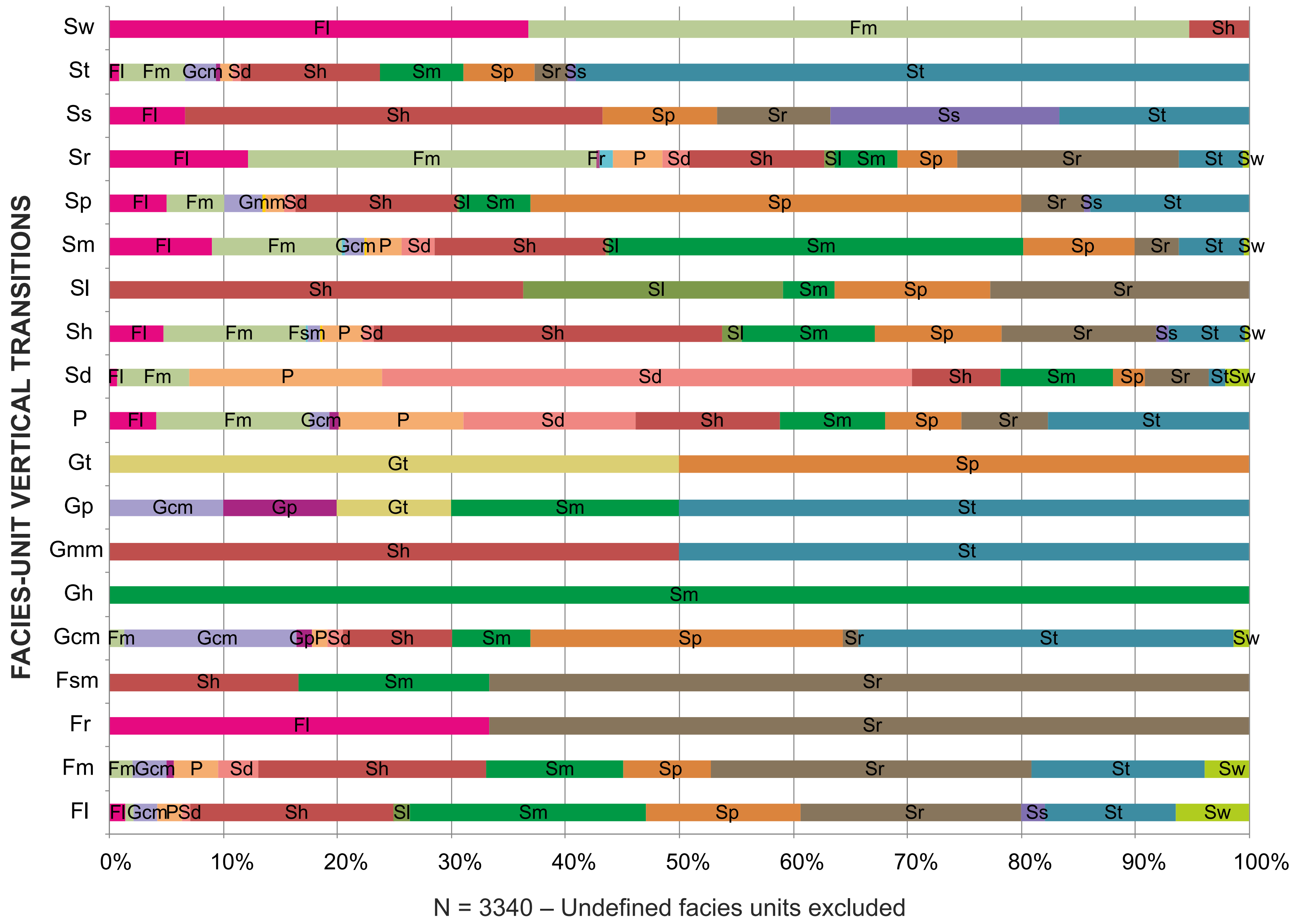




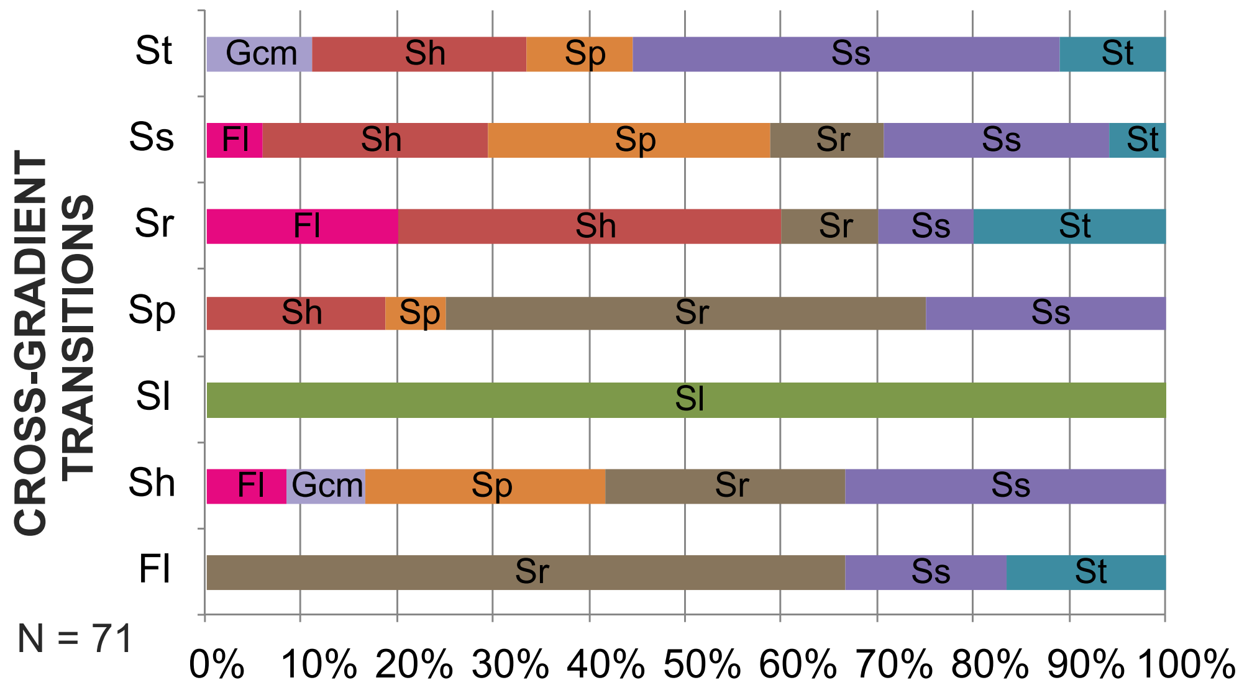
Lognormal distributions

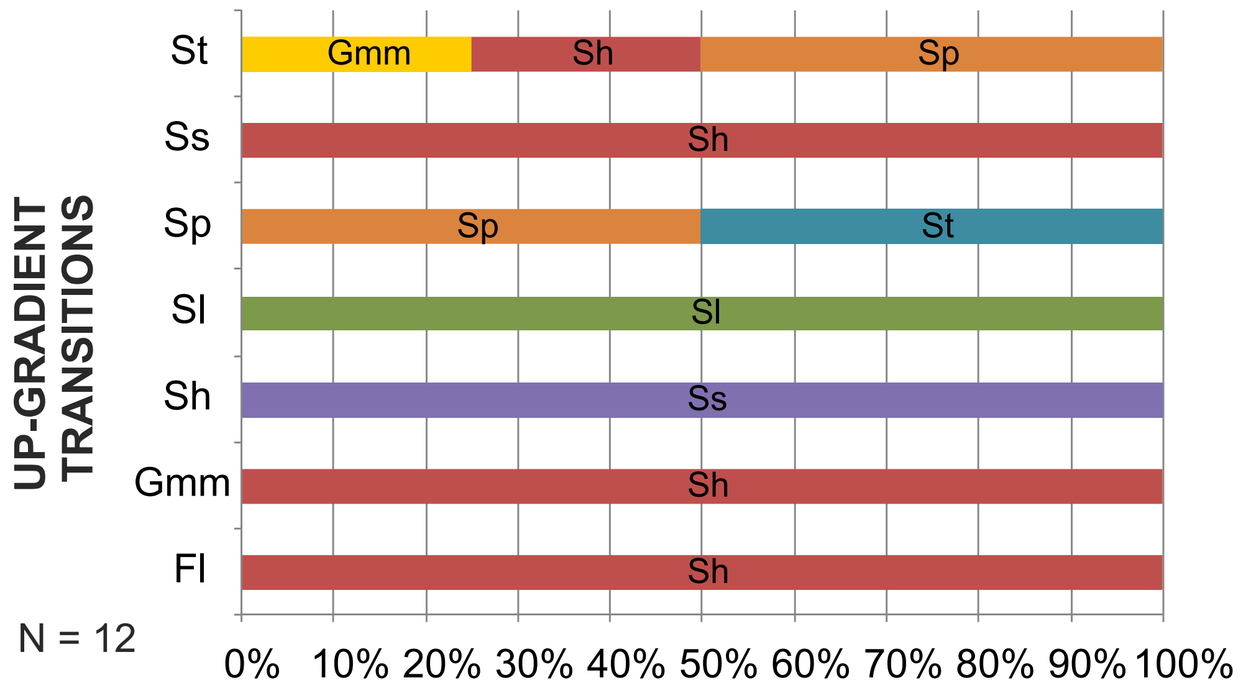
	Location	Scale	N	MAX
St	2.898	1.191	5	67
Sp	2.343	0.3494	5	16
Sr	3.753	0.4704	20	82
Sh	3.089	0.5928	10	47
Ss	2.382	0.3780	13	20
Fl	4.016	0.8973	4	92

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



N = 3340 – Undefined facies units excluded





FACIES-UNIT LATERAL-EXTENT DESCRIPTIVE STATISTICS

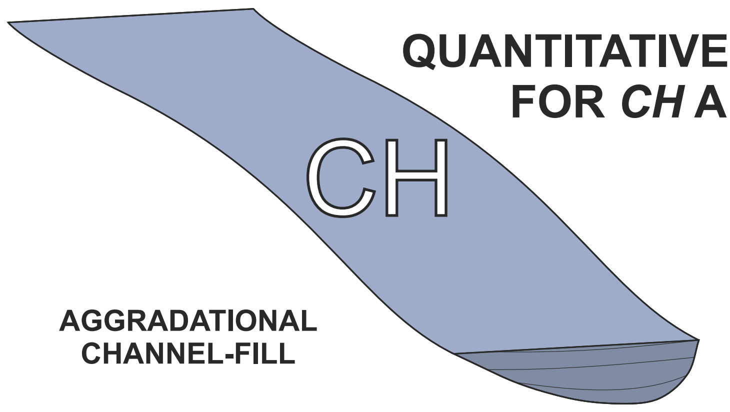
facies type	mean width	min width	max width	mean length	min length	max length
Gh	73.0	73.0	73.0			
St	12.2	2.0	22.1	13.6	1.4	38.3
Sp	7.6	1.9	25.0	14.9	10.0	33.3
Sr	6.7	1.5	22.0	15.0	10.0	20.0
Sh	21.6	2.3	209.0	15.5	10.0	33.4
Sl	125.5	77.0	174.0	20.7	14.0	29.0
Ss	5.9	1.8	13.5	10.7	4.3	17.0
Sm	146.0	94.0	198.0			
Fl	13.4	2.9	25.0	16.7	10.0	20.0

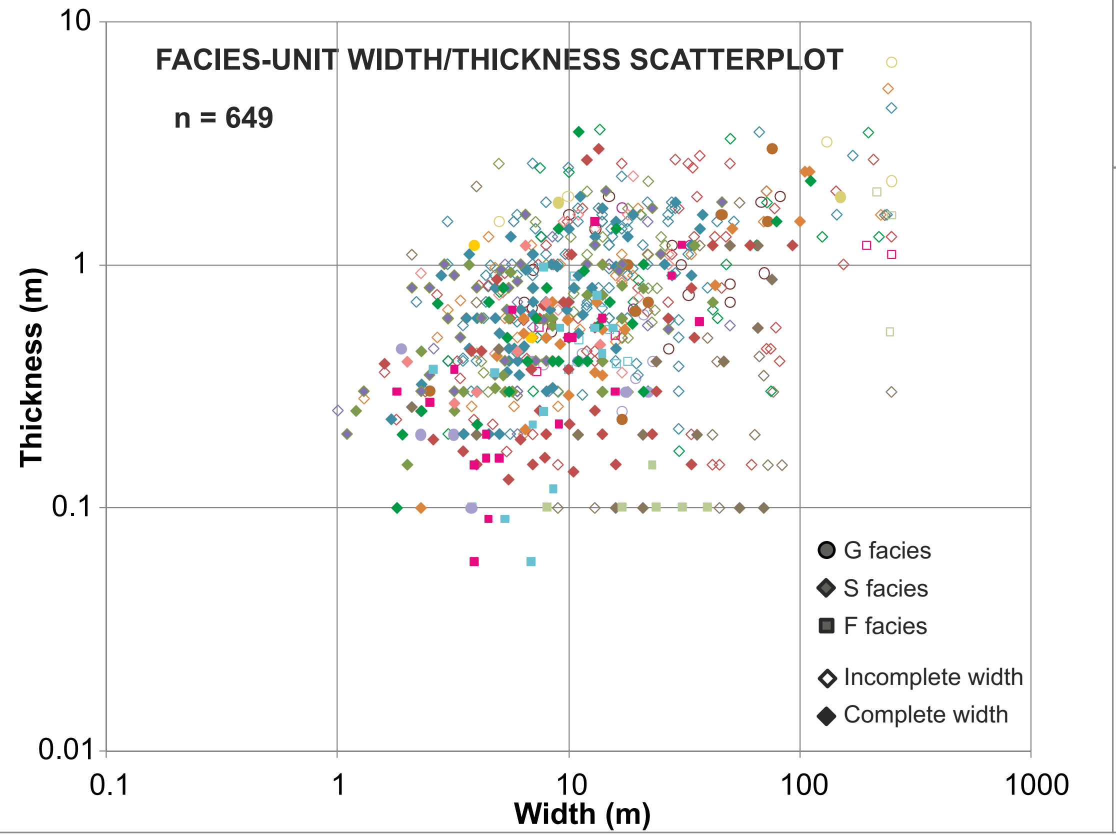
N = 128 – all dimensions are expressed in metres

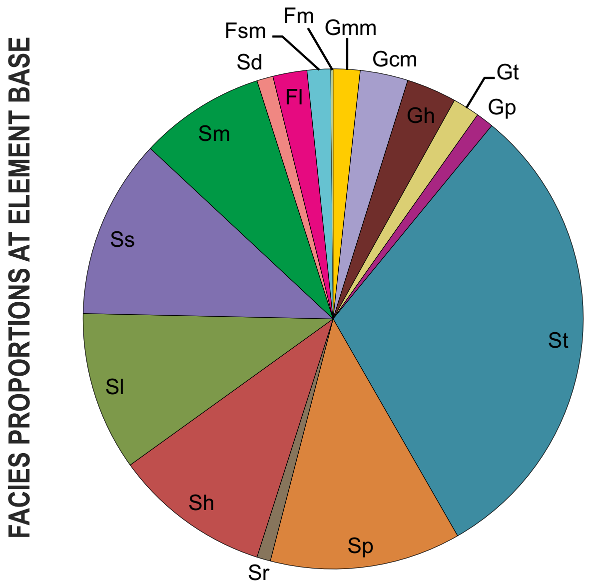
Facies-thickness boxplot legend

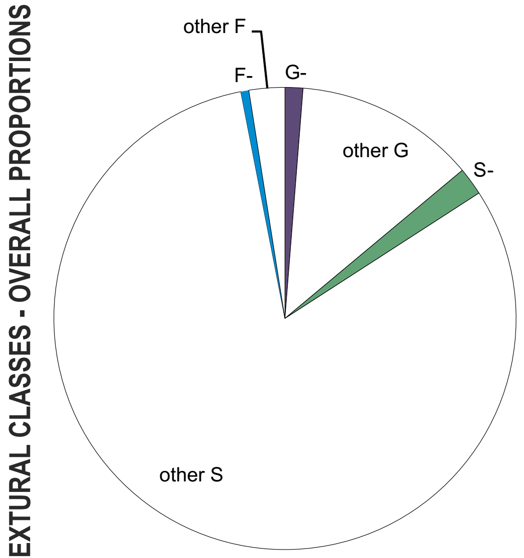
- ▭ Interquartile range
- | Q1-1.5(Q3-Q1) to Q3+1.5(Q3-Q1) range
- — Median
- ● Mean
- ◆ Outlier

QUANTITATIVE FACIES MODEL FOR *CH* ARCHITECTURAL ELEMENTS



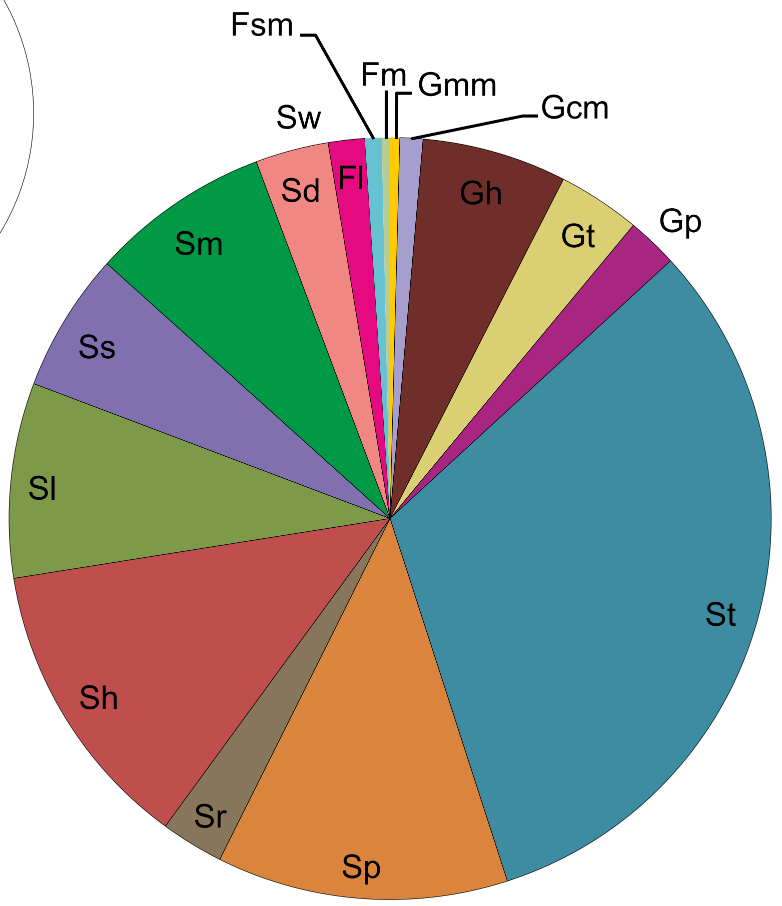

FACIES-UNIT WIDTH/THICKNESS SCATTERPLOT


FACIES PROPORTIONS AT ELEMENT BASE

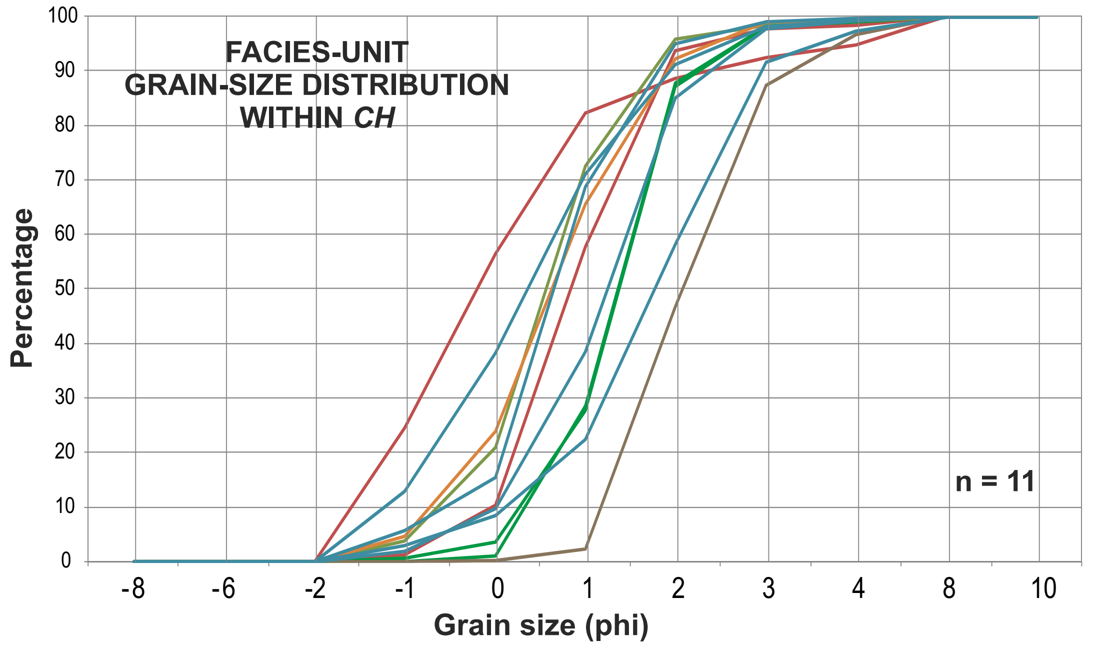

TEXTURAL CLASSES - OVERALL PROPORTIONS

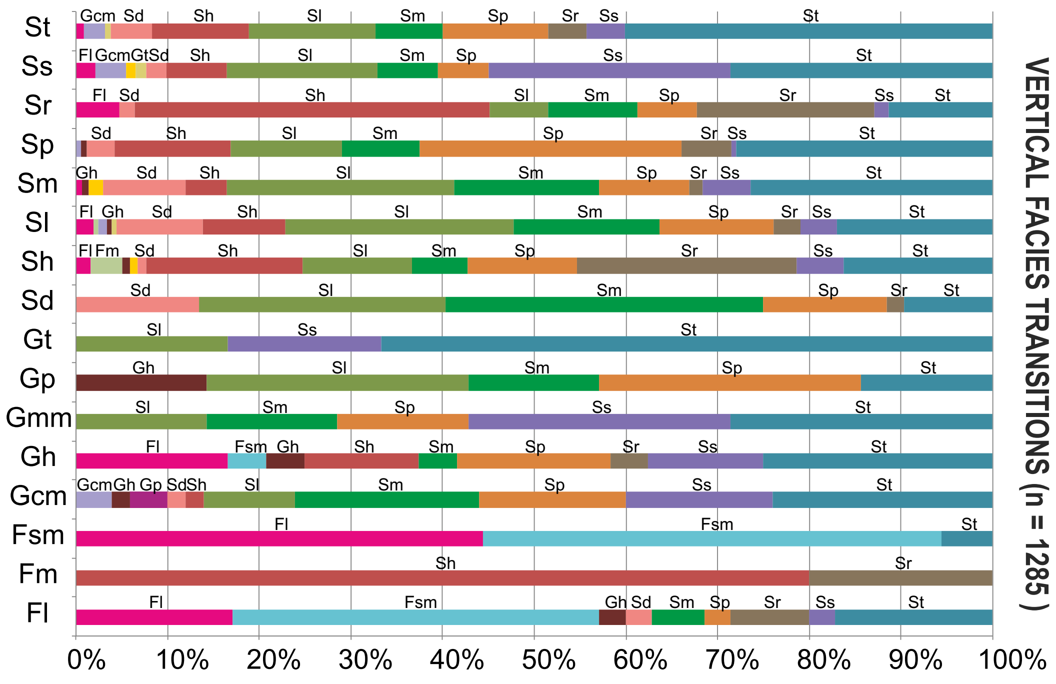
Model facies association for *CH* architectural elements

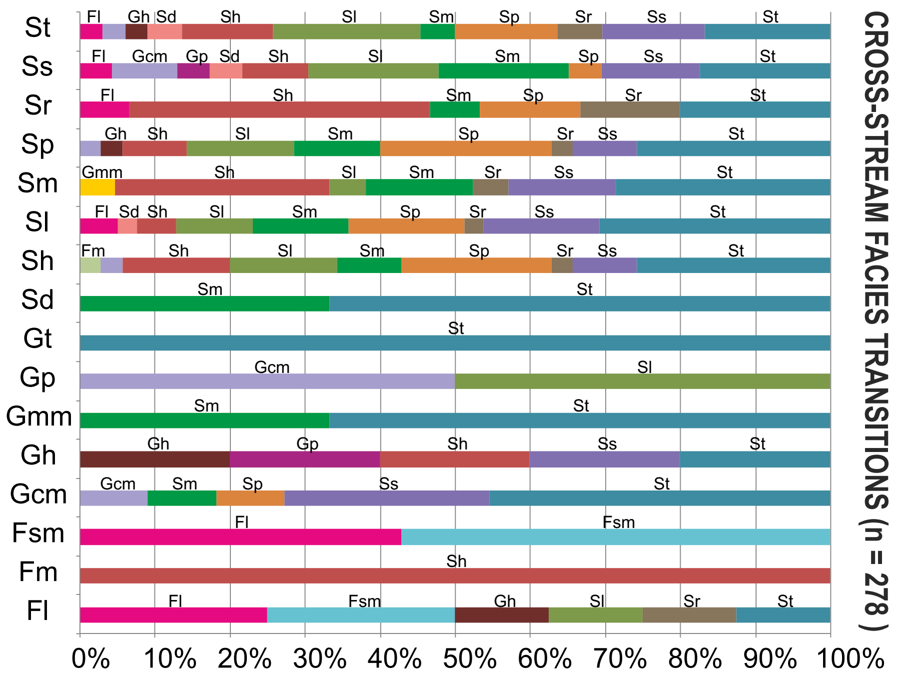
proportions based on facies-unit thicknesses
n = 2222

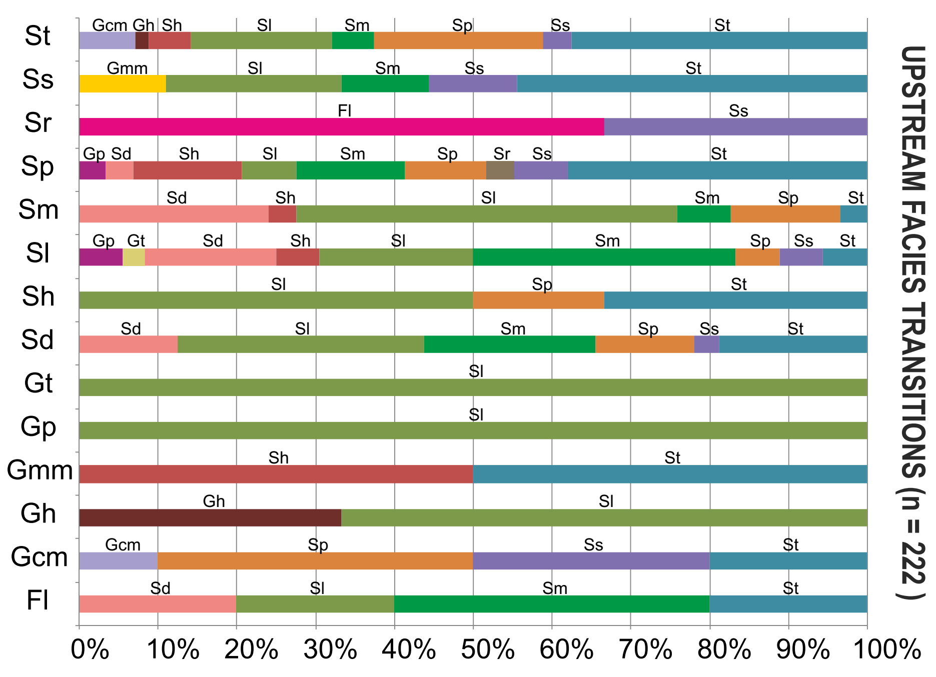


OVERALL PROPORTIONS OF FACIES-UNIT TYPES WITHIN *CH* ELEMENT

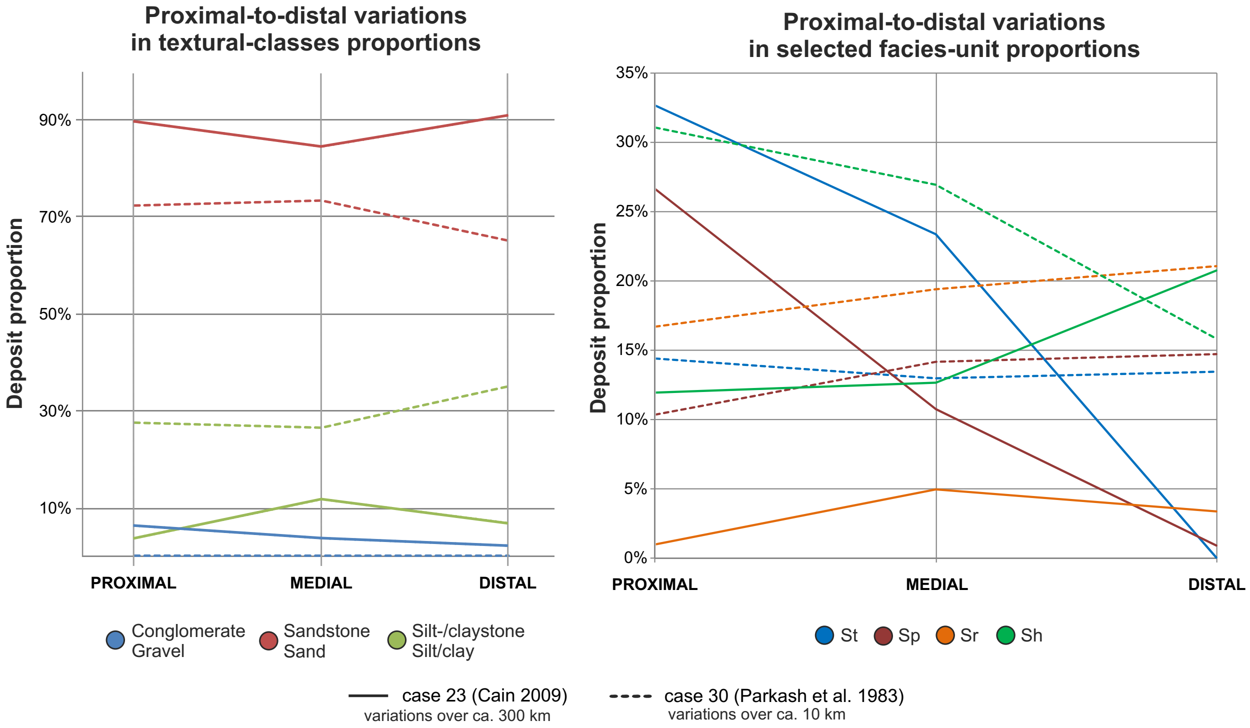

FACIES-UNIT GRAIN-SIZE DISTRIBUTION WITHIN *CH*


VERTICAL FACIES TRANSITIONS (n = 1285)

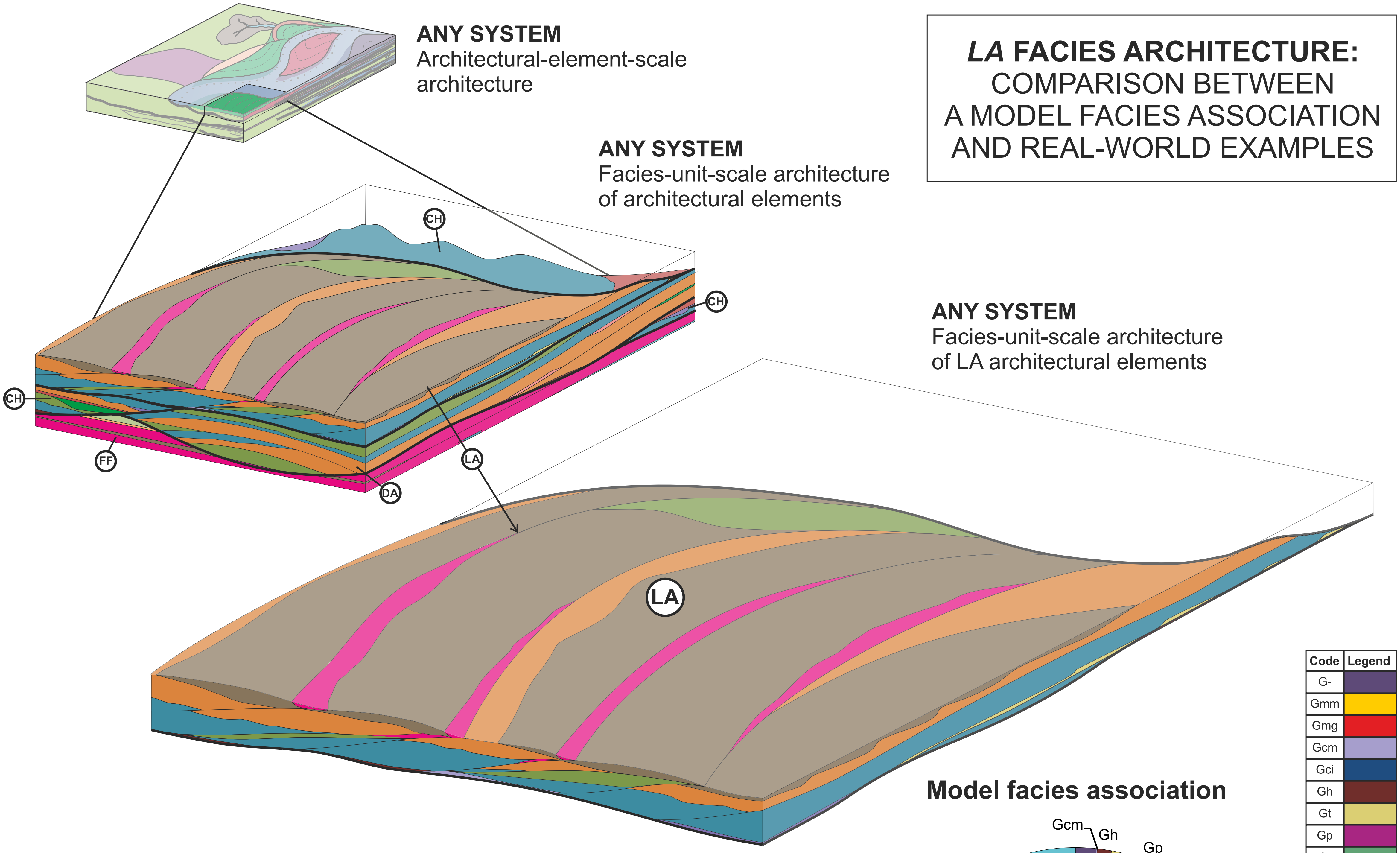

CROSS-STREAM FACIES TRANSITIONS (n = 278)


UPSTREAM FACIES TRANSITIONS (n = 222)

COMPARISON BETWEEN SYSTEMS CLASSIFIED AS TERMINAL FANS



LA FACIES ARCHITECTURE:
COMPARISON BETWEEN A MODEL FACIES ASSOCIATION AND REAL-WORLD EXAMPLES



ANY SYSTEM
Architectural-element-scale
architecture

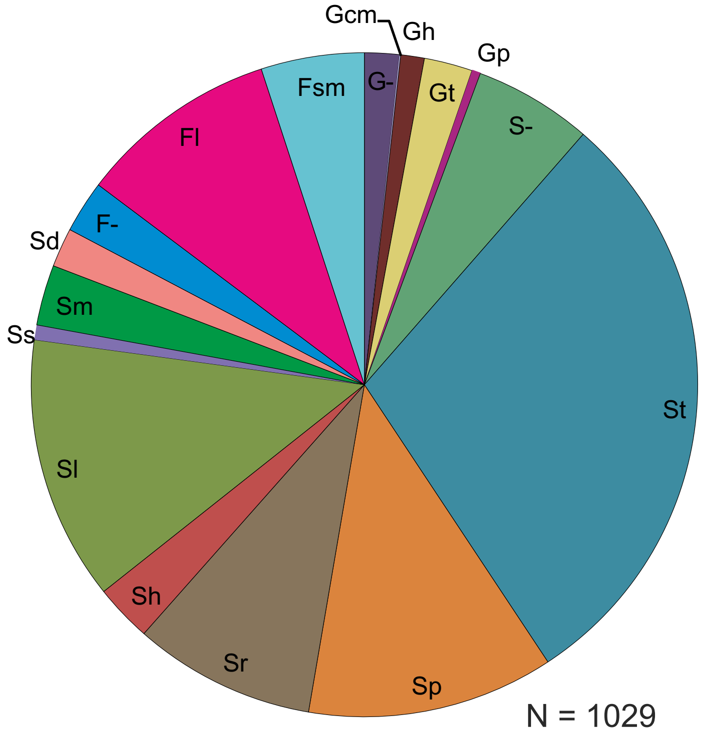
ANY SYSTEM
Facies-unit-scale architecture
of architectural elements

ANY SYSTEM
Facies-unit-scale architecture
of LA architectural elements

Facies type/proportion database output - individual elements

Identifier	Facies association
436	St/0.11,Sp/0.44,Sr/0.44
439	S-/0.13,St/0.13,Sp/0.72,F-/0.02
443	St/0.28,Sp/0.45,S-/0.07,Sh/0.13,F-/0.06
447	S-/0.50,Fl/0.33,St/0.17
1233	Sl/0.43,Sh/0.24,Sp/0.10,St/0.24
1257	Sl/0.43,Ss/0.29,St/0.29
1388	Sl/0.72,Sm/0.14,St/0.15
1420	Sr/0.17,St/0.15,Ss/0.17,Sm/0.22,Sl/0.20,Fl/0.09
1428	Sm/0.50,Sp/0.50
1484	St/0.14,Sr/0.86
1498	Sp/0.37,Sl/0.63
1499	Sl/0.47,St/0.53
1513	St/0.43,Gcm/0.12,Sl/0.45
1555	Sp/0.35,Sr/0.02,Sm/0.04,Sd/0.09,Sl/0.32,St/0.18
2646	St/0.66,Sr/0.06,Sd/0.15,Fl/0.12
2647	Sr/0.26,St/0.55,Ss/0.02,Sl/0.03,Sd/0.03,Fl/0.10
2678	F-/0.10,S-/0.76,Sp/0.14
2705	F-/0.14,Fl/0.14,G-/0.05,St/0.41,Ss/0.04,Sp/0.05,S-/0.16
2723	Fl/0.02,G-/0.08,Gh/0.01,Gp/0.02,Gt/0.04,S-/0.02,Ss/0.02,Sr/0.07,St/0.61,Sp/0.05,Sm/0.02,Sl/0.02,Sh/0.01,F-/0.02
[...]	[...]

Model facies association

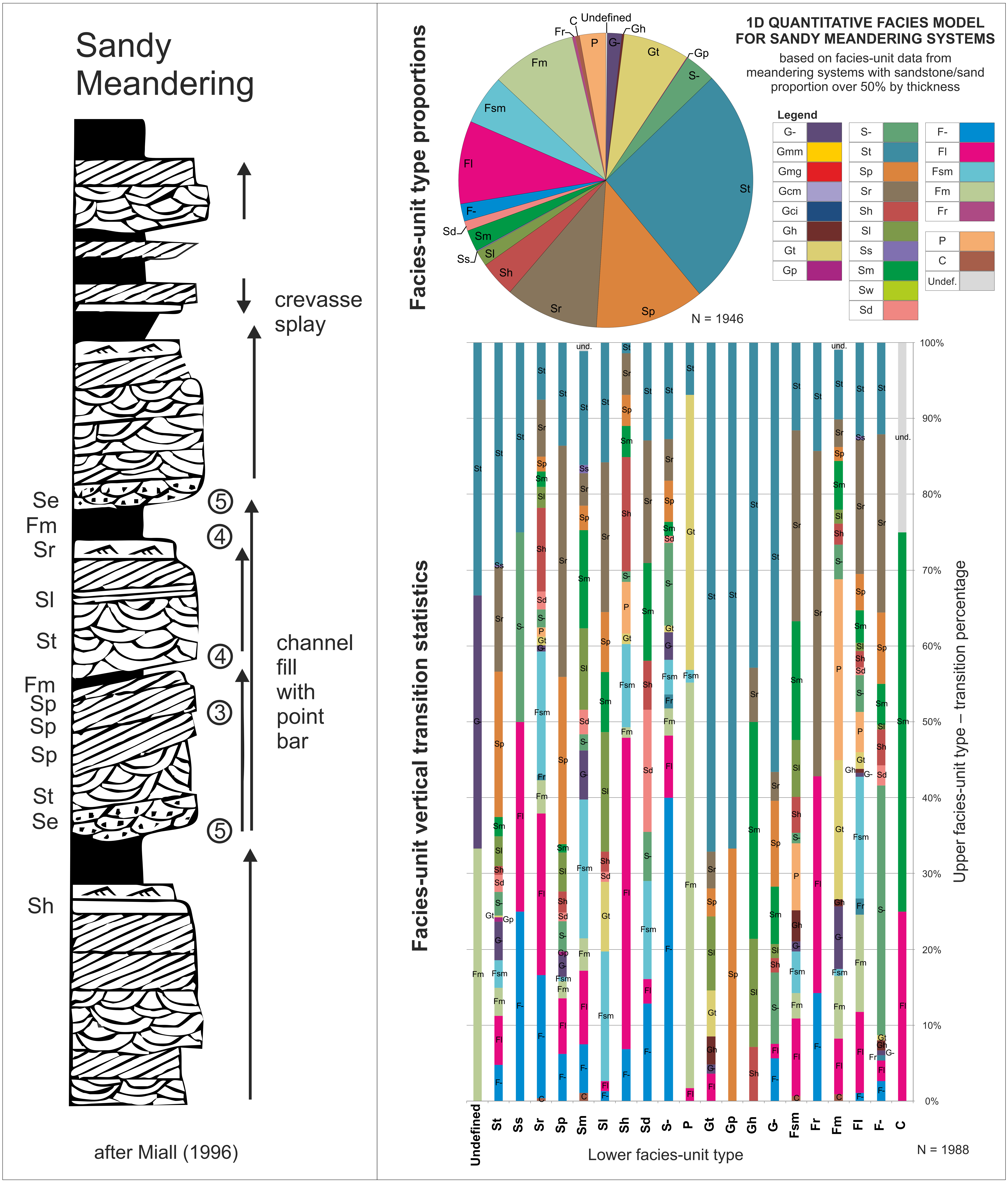


N = 1029

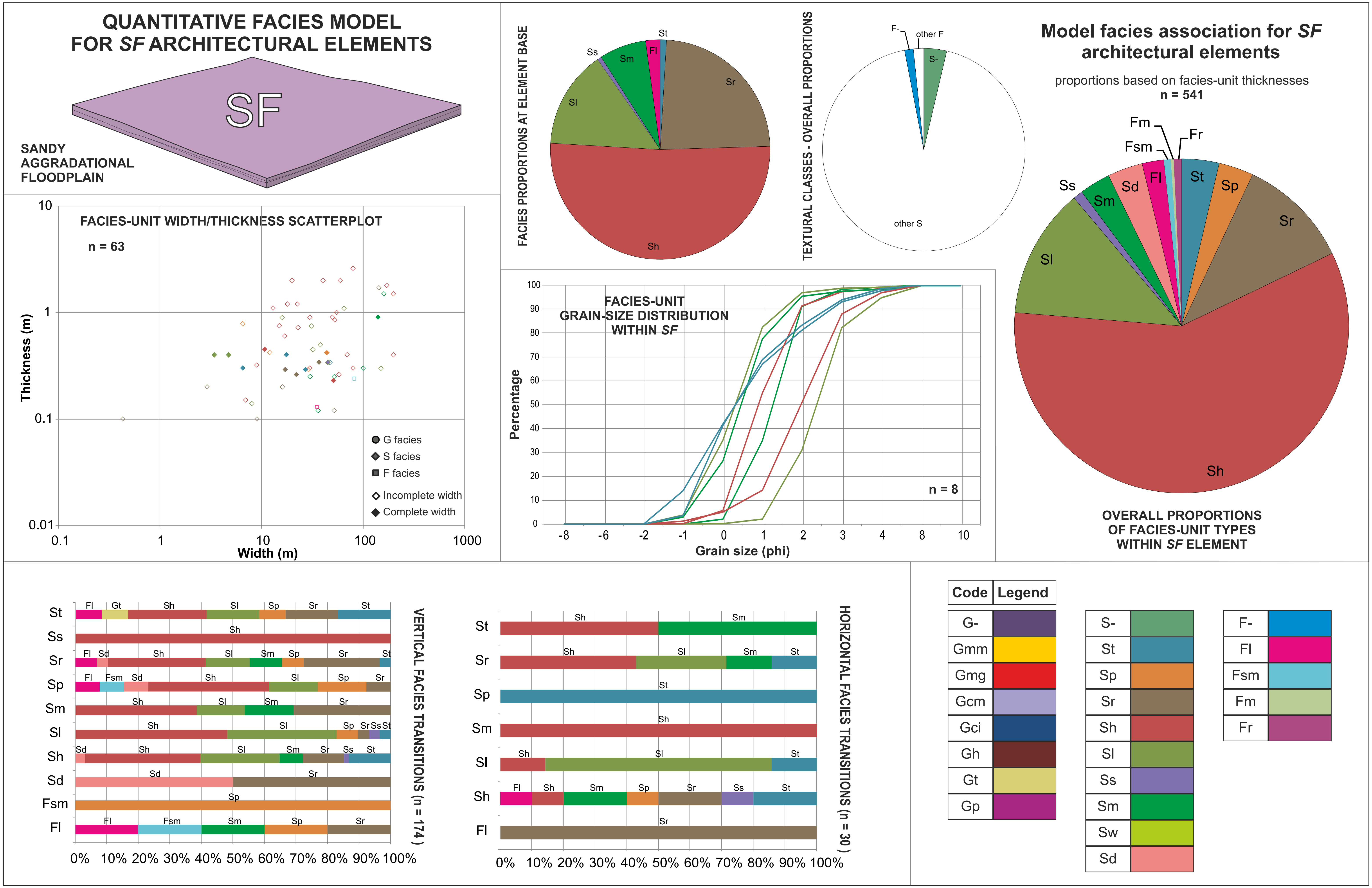
Proportions based on facies-unit thicknesses

Code	Legend
G-	🟪
Gmm	🟨
Gmg	🟥
Gcm	🟪
Gci	🟦
Gh	🟫
Gt	🟨
Gp	🟪
S-	🟩
St	🟦
Sp	🟧
Sr	🟫
Sh	🟥
Sl	🟩
Ss	🟪
Sm	🟩
Sw	🟩
Sd	🟥
F-	🟦
Fl	🟪
Fsm	🟦
Fm	🟩
Fr	🟪
P	🟧
C	🟫

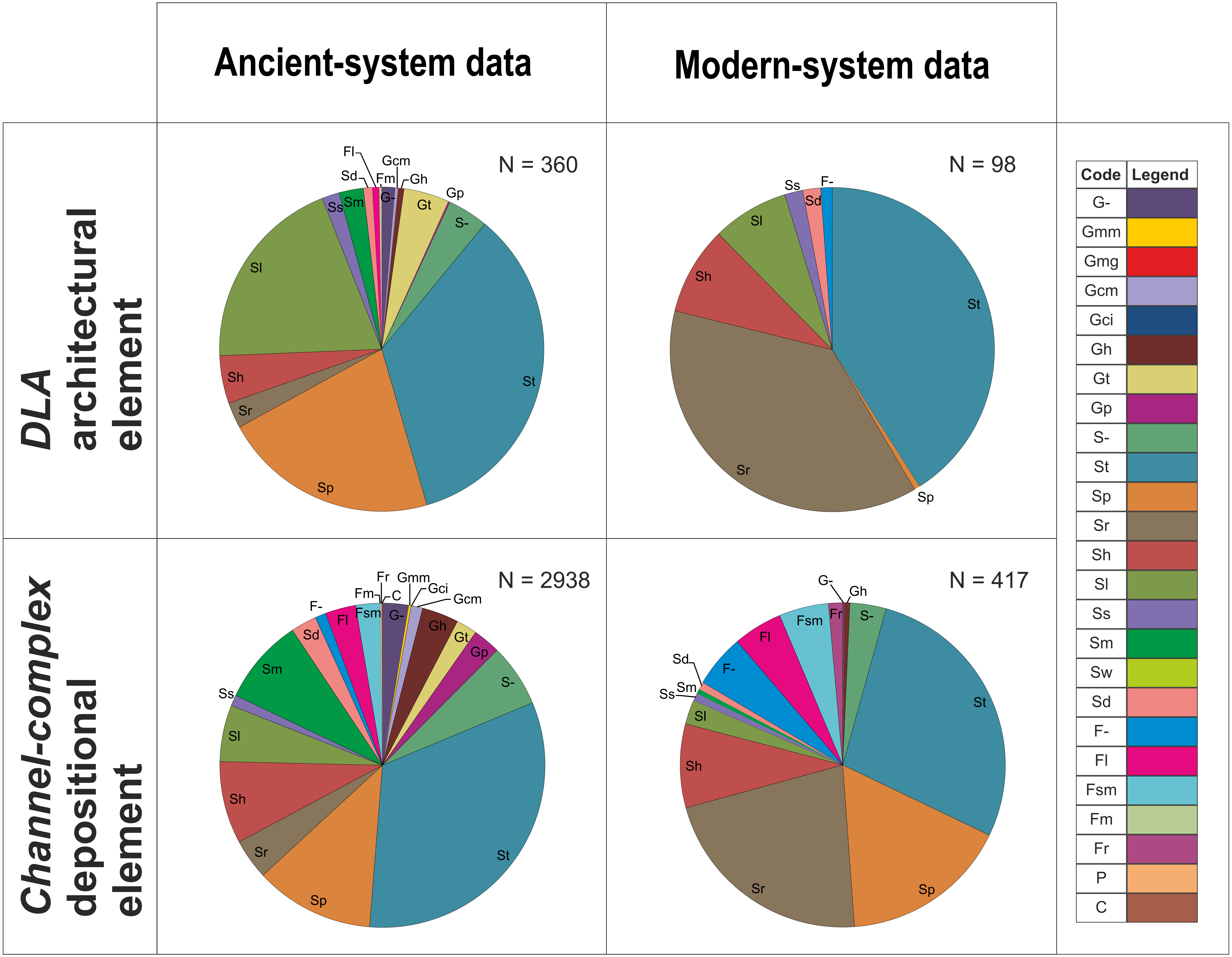
Models of architectural-element spatial relationships, in the form of pie-charts depicting transition counts between architectural-element types in the upwards, downwards, up-gradient, cross-gradient and down-gradient directions. a) transition statistics referring to downstream-accreting barforms; b) 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.



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 Fig. 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 2).



Partial quantitative information constituting a small-scale facies model of aggradational sheetflood-dominated sandy floodplain elements (SF architectural elements). As in Fig. 11, 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.



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 Fig. 2 and in the text).

case_ID	reference_citation	lithostratigraphic_unit
1	Miall A. D. (1988) Architectural elements an	Kayenta Fm.
2	Hornung J., Aigner T. (1999) Reservoir and a	Middle-Upper Stubensandstein
3	Amorosi A., Pavesi M., Ricci Lucchi M., Sarti	-
4	Dalrymple M. (2001) Fluvial reservoir archite	Straight Cliffs Fm.
5	Carter D. C. (2003) 3-D seismic geomorphol	Talang Akar Fm.
6	Meadows N. S. (2006) The correlation and s	Ormskirk Sandstone Fm., Sherwood Sandstone Gp.
7	Pranter M. J., Cole R. D., Panjaitan H., Somm	Lower Williams Fork Fm.
8	Johnson S. Y. (1984) Cyclic fluvial sedimenta	Bellingham Bay Mb., Chuckanut Fm.
9	Jones S. J., Frostick L. E., Astin T. R. (2001) Br	Rio Vero Fm.
10	Hjellbakk A. (1997) Facies and fluvial archite	Seglodden Mb., Båsnæring Fm.
11	Bristow C. S. (1993) Sedimentary structures	-
12	Robinson J. W., McCabe P. J. (1997) Sandsto	Salt Wash Mb., Morrison Fm.
13	Tye R. S. (2004) Geomorphology: an approa	-
14	Tye R. S. (2004) Geomorphology: an approa	-
15	Tye R. S. (2004) Geomorphology: an approa	-
16	Bridge J. S., Jalfin G. A., Georgieff S. M. (200	Bajo Barreal Fm.

17	Jordan D. W., Pryor W. A. (1992) Hierarchica	-
18	Bromley M. H. (1991) Architectural features	Kayenta Fm.
19	Luttrell P. R. (1993) Basinwide sedimentatio	Kayenta Fm.
20	Jo H. R. (2003) Depositional environments, a	Sindong Gp.
21	Cuevas Gozalo M. C., Martinius A. W. (1993)	Upper Unit, Tortola fluvial system
22	North C. P., Taylor K. S. (1996) Ephemeral-flu	Kayenta Fm.
23	Cain S. A. (2009) Sedimentology and stratigr	Organ Rock Fm.
24	Sanabria D. I. (2001) Sedimentology and Seq	Kayenta Fm.
25	Stephens M. (1994) Architectural element a	Kayenta Fm.
26	FAKTS in-house study	Kayenta Fm.
27	Abdullatif O. M. (1989) Channel-fill and shee	-
28	Cuevas Martinez J. L., Cabrera Perez L., Marc	Caspe Fm.
29	Fabuel-Perez I., Redfern J., Hodgetts D. (200	Oukaimeden Fm.
30	Parkash B., Awasthi A. K., Gohain K. (1983) L	-
31	Fabuel-Perez I., Hodgetts D., Redfern J. (200	Oukaimeden Fm.
32	Tunbridge I. (1984) Facies model for a sandy	Trentishoe Fm., Hangman Sandstone Gp.
33	Fielding C. R., Falkner A. J., Scott S. G. (1993)	Rangal Coal Measures
34	Best J. L., Ashworth P. J., Bristow C. S., Roder	-
35	Fielding C. R., Crane R. C. (1987) An applicati	-
36	Friend P. F., Sinha R. (1993) Braiding and me	-

37	Friend P. F., Sinha R. (1993) Braiding and me	-
38	Friend P. F., Sinha R. (1993) Braiding and me	-
39	FAKTS in-house study	-
40	Weerts H. J. T., Bierkens M. F. P. (1993) Geo	-
41	FAKTS in-house study	Guarda Velha Fm.
42	Steel R. J., Thompson D. B. (1983) Structures	Bunter Pebble Beds (Chester Pebble Beds Fm. and Can
43	Tirsgaard H., Øxnevad I. E. I. (1998) Preserva	Majût Mb., Eriksfjord Fm.
44	Pranter M. J., Ellison A. I., Cole R. D., Patters	Lower Williams Fork Fm.
45	Donselaar M. E., Overeem I. (2008) Connecti	Sariñena Fm.
46	Corbeanu R. M., Wizevich M. C., Bhattachar	Ferron Sandstone Mb., Mancos Shale
47	Raynal J.-P., Kieffer G., Bardin G. (2004) Gar	Melka Kunture Fm.
48	Tooth S., Nanson G. C. (2004) Forms and pro	-
49	Tooth S., Nanson G. C. (2004) Forms and pro	-
50	Hampton B. A., Horton B. K. (2007) Sheetflo	Potoco Fm.
51	Labourdette R. (2011) Stratigraphy and stati	Olson Mb., Escanilla Fm.
52	Holzförster F., Stollhofen H., Stanistreet I. G.	Omingonde Fm.
53	Fillmore D. L., Lucas S. G., Simpson E. L. (201	Mauch Chunk Fm.
54	FAKTS in-house study	Hawksmoor Fm. and Hollington Fm.
55	FAKTS in-house study	Wilmslow Sandstone Fm. and Helsby Sandstone Fm., S
56	Brookfield M. E. (2008) Palaeoenvironments	Annan Sandstone Fm., Sherwood Sandstone Gp.

57	Cowan G. (1993) Identification and significa	Sherwood Sandstone Gp.
58	Olsen H. (1989) Sandstone-body structures	Dinosaur Canyon Mb., Moenave Fm.
59	Catuneanu O., Elango H. N. (2001) Tectonic	Balfour Fm., Beaufort Gp.
60	Catuneanu O., Bowker D. (2001) Sequence s	Middleton Fm. and Koonap Fm., Beaufort Gp.
61	Miall A. D., Turner-Peterson C. E. (1989) Vari	Westwater Canyon Mb. and Brushy Basin Mb., Morriso
62	FAKTS in-house study	Sainshand Fm.
63	FAKTS in-house study	Bayanshiree Fm.
64	FAKTS in-house study	-
65	Kjemperud A. V., Schomacker E. R., Cross T.	Morrison Fm.
66	Darmadi Y., Willis B. J., Dorobek S. L. (2007)	Muda Fm.
67	McRae L. E. (1990) Paleomagnetic isochrons	Chinji Fm.
68	Friend P. F., Raza S. M., Geehan G., Sheikh K	Chinji Fm.
69	Olsen T. (1995) Sequence stratigraphy, alluvi	Price River Fm. and North Horn Fm.
70	Fielding C. R. (1986) Fluvial channel and ove	Durham Coal Measures

71	Opluštil S., Martínek K., Tasáryová Z. (2005)	Kladno Fm. and Týnec Fm.
72	Reynolds A. D. (1999) Dimensions of paralic	-
73	Stewart D. J. (1983) Possible suspended-loac	Wessex Fm., Wealden Gp.
74	Stewart D. J. (1983) Possible suspended-loac	Fairlight Clay and Ashdown Beds Fm., Hastings Beds Gp
75	FAKTS in-house study	Undifferentiated Cutler Fm.
76	Hume T. M., Sherwood A. M., Campbell S. N.	Hinuera Fm.
77	Ori G. G. (1982) Braided to meandering char	-
78	Martinius A. W., Nieuwenhuijs R. A. (1995) G	Upper Unit, Tortola fluvial system
79	Martinius A. W. (2000) Labyrinthine facies ar	Upper Unit, Tortola fluvial system
80	Rygel M. C., Gibling M. R. (2006) Natural geo	Joggins Fm.
81	Singh A., Bhardwaj B. D. (1991) Fluvial facies	-
82	Kirk M. (1983) Bar development in a fluvial s	Lower Coal Measures
83	Shukla U. K., Singh I. B., Sharma M., Sharma	-
84	Ori G. G., Penney S. R. (1982) The stratigrapl	Templetown Fm. (Brownstown Head Mb. and Beenlea
85	Wood L. J. (2007) Quantitative seismic geom	-
86	Sadler S. P., Kelly S. B. (1993) Fluvial process	Gun Point Fm., Old Red Sandstone
87	Tunbridge I. (1981) Sandy high-energy flood	Trentishoe Fm., Hangman Sandstone Gp.
88	Olsen H. (1987) Ancient ephemeral stream d	Upper Bunter Sand, Bunter Sandstone Fm., Bacton Gp.

89	McKee E. D., Crosby E. J., Berryhill H. L. Jr. (1	-
90	Williams G. E. (1971) Flood deposits of the s	-
91	Williams G. E. (1971) Flood deposits of the s	-
92	Williams G. E. (1971) Flood deposits of the s	-
93	Williams G. E. (1971) Flood deposits of the s	-
94	Williams G. E. (1971) Flood deposits of the s	-
95	Bhattacharyya A., Morad S. (1993) Proteroz	Dhandraul Sandstone Fm., Kaimur Gp.
96	Singh I. B. (1977) Bedding structures in a channel sand bar of the Ganga River near Allahabad, Uttar	
97	Long D. G. F. (2002) Aspects of Late Palaeop	Uairén Fm.
98	Sønderholm M., Tirsgaard H. (1998) Protero	Rivieradal Sandstones, Rivieradal Gp.
99	Dam G., Andreasen F. (1990) High-energy ep	Holmestrand Fm., Ringerike Gp.
101	Yu X., Ma X., Qing H. (2002) Sedimentology	Yungang Fm.
102	Sánchez-Moya Y., Sopeña A., Ramos A. (199	Bundsandstein
100	Viseras C., Soria J. M., Durán J. J., Pla S., Garr	-
103	Limarino C., Tripaldi A., Marenssi S., Net L.,	Vinchina Fm.
104	Ferguson R. J., Brierley G. J. (1999) Levee m	-
105	Ghazi S., Mountney N. P. (2009) Facies and	Warchha Sandstone Fm., Nilawahan Gp.
106	Mack G. H., Leeder M., Perez-Arlucea M., Ba	Abo Fm.
107	Adams P. N., Slingerland R. L., Smith N. D. (2	-
108	Adams P. N., Slingerland R. L., Smith N. D. (2	-
109	Roberts E. M. (2007) Facies architecture and	Kaiparowits Fm.
110	Kraus M. J., Middleton L. T. (1987) Contrasti	Willwood Fm.
111	Kraus M. J., Middleton L. T. (1987) Contrasti	Glenns Ferry Fm.

river	nr_of_depositional_elements	nr_of_architectural_elements
-	2	11
-	31	274
-	83	38
-	241	-
-	-	-
-	16	-
-	-	-
-	-	-
-	0	37
-	2	7
Brahmaputra (Jamuna)	1	3
-	85	47
Colville	-	-
Kuparuk	-	-
Sagavanirktok	-	-
-	3	0

Mississippi	1	15
-	0	22
-	0	8
-	62	30
-	0	72
-	54	6
-	103	397
-	0	4
-	0	41
-	1	330
Gash	2	0
-	85	23
-	20	147
Markanda	0	0
-	0	289
-	3	54
-	22	39
Brahmaputra (Jamuna)	0	1
-	277	1
Gandak	24	-

Burhi Gandak	28	-	
Baghmati	25	-	
Thomson (Cooper Creek)	3	-	
-	14		305
-	11		73
-	6		33
-	0		0
-	2		3
-	19		72
-	1		7
-	0		0
Plenty	4	-	
Marshall	27	-	
-	14		21
-	297		15
-	28		69
-	0		0
-	0		0
-	0		0
-	5		24

-	14	28
-	14	23
-	16	36
-	4	23
-	7	51
-	0	0
-	0	0
South Saskatchewan	5	-
-	601	-
-	45	-
-	203	-
-	195	0
-	551	5
-	32	13

-	5	137
-	175	112
-	4	21
-	14	29
-	0	0
-	0	0
Reno	3	16
-	115	49
-	86	0
-	89	40
Ganges	10	0
-	2	7
Ganges	0	2
-	21	34
-	31	-
-	0	4
-	0	0
-	22	8

Bijou Creek	7	9
Paralana Creek	1	0
The Wooldridge	1	0
Goyder Creek	1	0
Palmer Creek	1	0
The Finke	1	0
-	1	1
Ganges	1	1
-	2	0
-	0	0
-	0	0
-	7	20
-	128	64
-	2	4
-	9	23
Tuross	2	13
-	0	15
-	15	16
Columbia	24	12
Saskatchewan	62	31
-	148	56
-	3	22
-	3	3

nr_of_facies_units	nr_of_statistical_parameters
38	-
463	-
72	-
-	-
-	8
-	-
-	3
-	110
155	-
472	-
103	-
-	-
-	6
-	5
-	5
260	-

	253	-	
	51	-	
	10	-	
	237	-	
-		-	
	57		2
	5265	-	
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	128	-	
	1763	-	
	117	-	
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	86	-	
	477	-	
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	77	-
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	681	-
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	46	-
	36	-
	85	-
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	109	-
	65	-
	255	-

	142	-
	1	-
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	70	-
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