

Lithologic Logs in the Tablet through Ontology-Based Facies Description*

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Abstract

The definition of sedimentary facies through the description of cores and outcrops provides the basis for the construction of calibrated reservoir models, assembled via the anchoring of 3D geological objects. The realism and accuracy of such models depends on systematic and substantial information about the lithologies, including detailed description of sedimentary structures and textures. The major obstacle for the systematic definition and representation of depositional facies, and mostly, for their processing within computer-generated reservoir models, resides in the lack of a formal nomenclature of sedimentary structures and of agreement about what each term means. An advanced computer application developed to support the detailed and systematic description of lithology, sedimentary structures and texture of cores and outcrops combines resources from knowledge systems and human-oriented interfaces. Systematic description is facilitated by the use of a visual, intuitive interface in touch-screen tablet devices, supported by standardized nomenclature and parameters. Depositional and post-depositional structures were associated to visual representations (icons) that emulate the way in which geologists usually represent graphic logs, with a touch-select-draw interface. The descriptive nomenclature was formally defined based on ontology engineering methods and validated by a group of sedimentologists using a web collaborative portal. The application substantially improves data quality and reduces description time, and allows capturing the information into a relational database for further processing and exportation to several standard formats, essential for the efficient construction of realistic reservoir models for optimized recovery and quality prediction.

Introduction

The description of cores and analog outcrops provides essential information for the understanding of depositional environments and systems, as well as of their stratigraphic evolution, basis for the construction of realistic reservoir models as shown in the modeling workflow of [Figure 1](#). Nevertheless, in the whole reservoir modeling workflow, the most subjective and non-automatic data acquisition stage involves the analysis cores and outcrops, and the derived interpretation of sedimentary facies and facies associations.

Geologists perform drill core or outcrop descriptions based in a semi-formal vocabulary defining the lithology in terms of gross composition and textural information, the geometry and internal structures of layers and other bodies, and the spatial relationships among them. Such vocabulary is considered semi-formal, in the sense that it is incomplete (some of the visualized geological features have no defined name), or ambiguous (two or more features are described using the same name or a name can be used to describe more than one feature), lacking a full agreement inside the geological community regarding the names and the meaning of the applied terms. This is especially true when we consider the nomenclature for the description and classification of sedimentary structures, which lacks a taxonomy organized according to objective and homogeneous criteria. As a result, the nomenclature that is, in some cases, based on geometric aspects, in others, on genetic interpretations, or on the spatial position of the structures. An essential part of the descriptions consists of illustrations, sketches and photographs that complement the description where the terminology is not available.

Previous studies in Cognitive Science (Abel et al., 2005) have explained the need of illustration in geological reports. Most of the data relevant for the geological interpretation and modeling of petroleum reservoirs consist of visual information that cannot be described symbolically only through geometric components, such as size and format. Many of the aspects recognized by geologists during interpretation tasks have no formal denomination and are learned by building a body of visual knowledge through training and field experience. We have previously defined visual knowledge as “the set of mental models that support the reasoning process that operates over information related to visual aspects and spatial arrangements” (Lorenzatti et al., 2009). These objects constitute the implicit body of knowledge (Polanyi, 1966) that refers to the unarticulated knowledge that someone applies in daily tasks but is not able to describe in words. The visual aspects recognized in the rocks that match the mental model of the geologist are usually translated in outcrop or core descriptions into illustrations and sketches. However, this complementary information cannot be easily processed by computer systems, which are limited to process information that is described in numerical or propositional formats. Providing adequate tools for the systematic core and outcrop description will certainly increase the amount and quality of the acquired information and data, expanding the possibilities of their use through computer systems.

Articulated or explicit knowledge refers to unconsciously recognized objects and how these objects are organized. This portion of knowledge in the context of Artificial Intelligence (AI) is called ontology. The word ontology has been taken from the technical vocabulary of philosophy, where it means a systematic explanation of the world, which is shared by a community. Currently, the best-known definition of ontology is that of Gruber, as slightly modified by Borst in (Borst, 1997): “Ontologies are defined as a formal specification of a shared conceptualization”. It means that an ontology is a description (like a formal specification of a computer program) of the concepts and relationships that can exist for a community of people that shares the knowledge about some domain (such as Geology, or Stratigraphy) (Studer et al., 1998). A domain ontology includes the nomenclature and taxonomy of a domain of knowledge adopted by the scientific community.

Extracting the ontology of a knowledge domain is such an important objective of knowledge modelers, that it is sometimes misunderstood to be the only one. Along with the ontology, which represents the explicit part of knowledge, it is necessary to identify the dynamic mechanisms of problem solving. Geological interpretation essentially makes use of abductive reasoning, i.e. of a problem-solving method that mimics a detective investigation (Thagard and Shelley, 1997). Such process of problem solving is driven by the search of evidence to match some previously selected hypothesis that was chosen based on the geological models known by the geologist. Based on this, some geologists wrongly describe the evidence in terms of genetic interpretation, using inadequate terms like “fluvial facies” instead of purely geometric aspects, like “trough cross-bedding”.

Our experience has shown that on developing computer systems for the acquisition and processing of geological information, we need to be aware of three main aspects. The first aspect is providing support for the development of the ontology inside a domain (which means help the community to evolve the taxonomy and nomenclature of the domain). Second, it is necessary to identify the implicit visual knowledge usually expressed by geologists in their illustrations, and to create the appropriate model for representing it in the system. Third, it is crucial to understand the cognitive process behind the search for geological evidence, in order to separate interpreted evidence from the data objectively collected in the process of description. Interpreted evidences can reflect the understanding of the geologist at the moment and can change over time. Capturing data collected based only on visual, directly identified aspects, provides a trustable information database that is timeless and useful regardless the state-of-art and the currently accepted interpretation theory.

In the next session, we describe the Strataledge® system, conceived for supporting the detailed and systematic description of drill cores and outcrops, based in a controlled vocabulary of terms. Although our examples are based on siliciclastic rocks, the knowledge model of the system allows describing lithologies, textural aspects, internal structures, geometries and spatial relationships of bodies

of other sedimentary, as well as of igneous and metamorphic rocks. The system combines resources from knowledge systems and human-oriented interfaces.

Data and Knowledge Modeling

Strataledge®¹ supports the description oriented by a knowledge base comprising the standard description format (list of rock attributes to be described) and the full geological nomenclature, including all possible names for lithologies, textures, structures, body geometries and contacts. This structure and nomenclature were built based in the domain ontology acquired from a group of geologists through interviews and online collaborative work (Torres et al., 2011), besides the literature.

Considering geologists' requirements for recording visual aspects of the descriptions, (Lorenzatti, 2010) has proposed hybrid meta-constructs (pictorial and propositional) for modeling structures and textural attributes of the rocks. These consist in pairs - icons and names – that capture the visual expression of the geological feature in a way that is familiar for geologists and associate it to a propositional name that can be processed by common mechanisms of database consultation. In opposition to symbols, which represent a meaning defined by convention, icons are pictorial representations that keep some resemblance with the object that they represent. An icon is defined by observing the visual aspect of a feature and drawing a basic sketch representing its most striking visual aspects, as shown in [Figure 2](#) for the tangential laminae shape.

The initial icon library of Strataledge® was tested and validated through cognitive experiments carried out with 20 geologists. In the first experimental cycle, 70.8% of the icons were recognized as correctly associated to the name of the feature they represented. Those icons that were considered not representative of geological features were further replaced until we reached 85% of correctly performed association for the group of test. Considering that the group had no previous contact or training with the library, the easy by which the group associated the icons with the names of the features attests how intuitive the use of icons is for geologists.

In particular, the stratigraphy ontology was built by using two kinds of icons, one for the sedimentary structures and other for sedimentary facies attributes, such as sorting, roundness and laminae shape. Some examples of the icon-name pairs representing subclasses of sedimentary structures are shown in [Figure 3](#).

¹ www.strataledge.com

Examples of icons representing particular values of Sorting are exemplified in [Figure 4\(a\)](#) and some icons for Roundness values are shown in [Figure 4\(b\)](#).

Operation of the Strataledge® Core and Outcrop Description System

Drill core and outcrop descriptions are captured in the field or in the lab by using a touch screen interface operated on a tablet device, and can be stored in a corporate database for correlation and report generation. The idea of having a system running on mobile devices is to allow the geologist to perform a description in the way he is used to do on paper, but offering several additional advantages for information processing. The use of tablet eliminates the need of porting the paper description to a digital format using drawing tools, thus shortening the number of steps in the workflow of the geologist. The general architecture of the system is shown in [Figure 5](#). When a network connection is available on the spot of description, the user can access the corporate database system for complementary information regarding the borehole (e.g., log or petrophysical data), or geological site, or retrieve petrographic information from previously described rock samples, which may help in the description process.

The system was conceived for user facility. By touching the options in the device menu, the user can, as shown in [Figure 6](#), define a block of information for describing a stratigraphic interval and then associate textural and structural rock descriptions to this block. Each block of information is related to one facies, individualized by a particular combination of lithology- structure-texture. Accordingly, for each facies, the user can specify lithology, rock color, grain size (or crystal size in the case of chemical sedimentary, igneous or metamorphic rocks), sphericity, roundness, selected primary and secondary structures and types of contacts and record some particular aspects to be annotated. The level of detail is not predefined, and the user can dynamically change the scale of description for any interval, in which a more detailed description is desirable. The granularity of information will be recorded according to the user's definition for each interval, which allows shortening the description of intervals with undifferentiated rocks and providing greater detail in intervals of interest. Zoom in and zoom out options are available for optimizing visualization. This allows the user easily navigating over the description and choosing the portion to be analyzed in detail, as well as getting an overview of the complete description with a very intuitive approach, since the zooming operations are controlled directly on the touch screen.

The Strataledge® system can efficiently produce graphical descriptive logs, instantly exported from the inserted data. The strength of Strataledge®, however, lies in the use of the standard vocabulary with an associated set of icons based on the domain ontology for supporting the description and the storage of the description blocks in a relational database. This allows producing automatically textual reports, in any of the supported idioms, to be exported (which is usually a time-consuming task for geologists) and allows overcoming the difficulty of formulating queries over the information contained in log of drill core descriptions. Thanks to the

propositional vocabulary associated to the iconic representations, the user may scan the blocks of description stored in a database, building complex queries such as, for instance:

“Retrieve the intervals in the selected set of wells that show fine- grained sandstone with cross-bedding, intense bioturbation, fining- upward grain-size and erosive top contact.”

In other words, the correlation that is visually operated by geologists on the graphic logs describing an oil or gas prospect can be automatically inferred by the system. Thanks to the database management capability, the reservoir geologists and engineers can efficiently examine the geological information and identify patterns and possible causes of reservoir quality changes along the oilfield. Particular features, such as interlayering, grain-size gradation associated to geometry, or conspicuous diagenesis, can be searched over the database for testing hypotheses, suggesting stratigraphic sequences and parasequences, or for providing a consistent geological interpretation of the prospect. When compared with the human capacity of visually scanning stratigraphic logs looking for pertinent information, the search and comparison capabilities of the system appear unlimited.

The application substantially reduces description time and errors, besides setting a high-quality standard of description. It allows capturing the information into a relational database, making the knowledge about drill core and outcrop description independent of any software application. The relational data model facilitates the further processing and exportation to several standard formats, essential for the efficient construction of realistic reservoir models for optimized recovery and quality prediction.

Moreover, as all ontology-based systems, Strataledge® is, by nature, conceived for data fusion and system integration, since the intended meaning of each recorded term is explicitly described in the ontology, making easy the alignment through different applications and information repositories.

Conclusions and Ongoing Work

Ontology-based description tools, such as the Strataledge®, provide standard workflows for the detailed and quantitative description of rocks in core and field scales. These tools are not only able to produce reports but, more importantly, they offer to the geologist unlimited possibilities for evaluating models and testing hypotheses, making more efficient the human reasoning over geological information. Consequently, the Strataledge® system can be used for identifying depositional units having similar characteristics, but also for individual genetic interpretation.

Carbonera and co-workers (Carbonera et al., 2011) are developing a problem-solving method that allows inferring the depositional processes that generated the siliciclastic rocks described using Strataledge®. The relation between geological evidence defined using the stratigraphy ontology and the depositional process are described as a predefined set of triplets with the format “*sedimentary structure + produced by + depositional process*” in the knowledge base. A module of software scans the user description comparing with the triples and finds the process that is indicated by the larger number of evidence, which is presented as the most probable genesis of a described lithofacies. This and other geological interpretation features are under development inside the project that has produced the Strataledge® system.

Finally, we are presently addressing the issue of the convergence of vocabulary within a community of geologists by developing a WEB tool to support collaboration in ontology construction. The tool allows geologists to negotiate the meaning of a particular geological term with the support of foundational ontology metatypes. The users can modify the terms and show their interpretation on the geological term by uploading pictures, icons and sketches. Each step of negotiation is recorded, allowing the management of the evolution of the ontology versions, and the convergence of term definitions. The collaborative environment is available in the Internet in a free access open source model. Its major objectives are to offer a better support for academic and professional researchers in the task of creating consensual vocabulary in stratigraphic description, and to make available an atlas of sedimentary structures.

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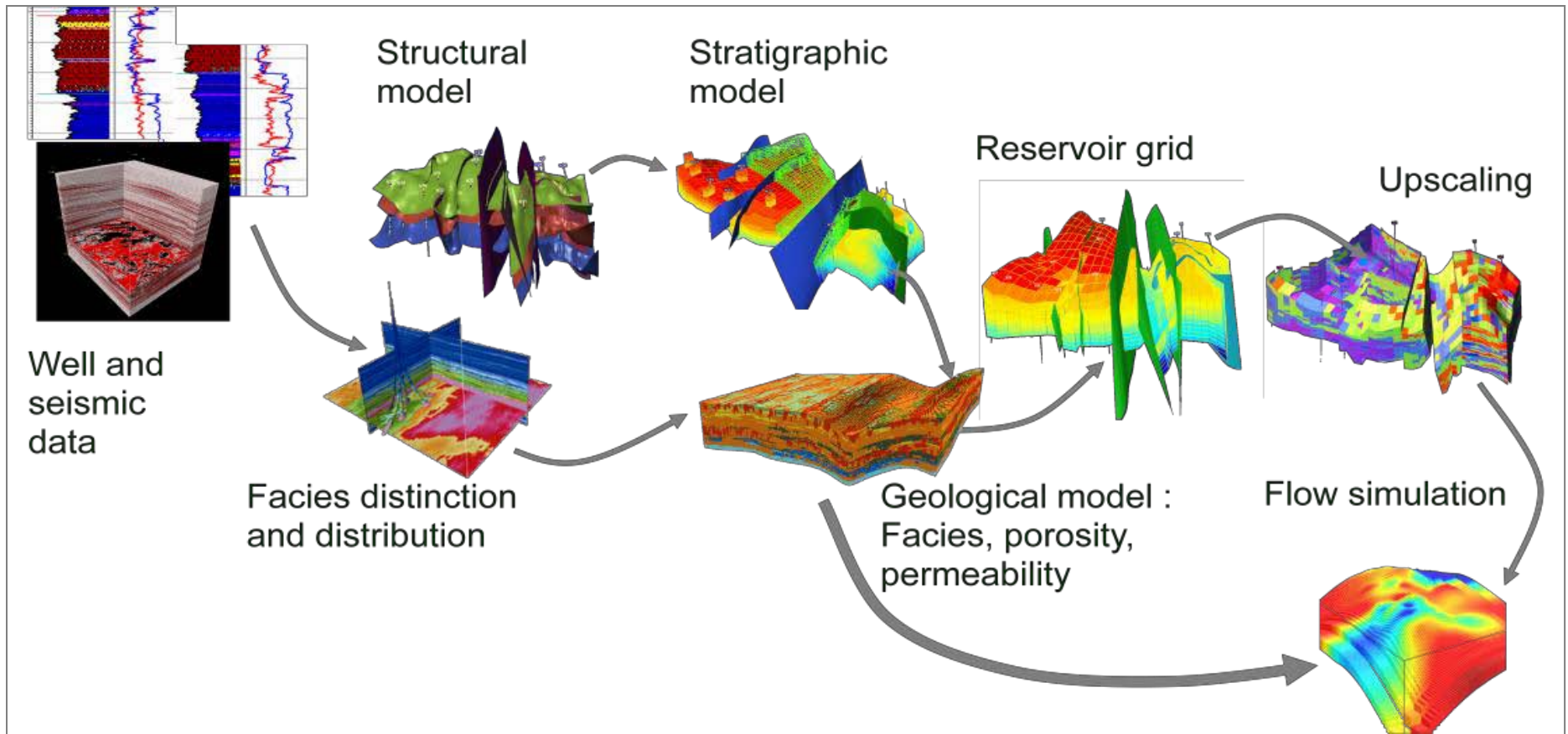


Figure 1. The reservoir modeling workflow showing the sequence of stages in data acquisition and interpretation (First presented in Perrin et al., 2007).

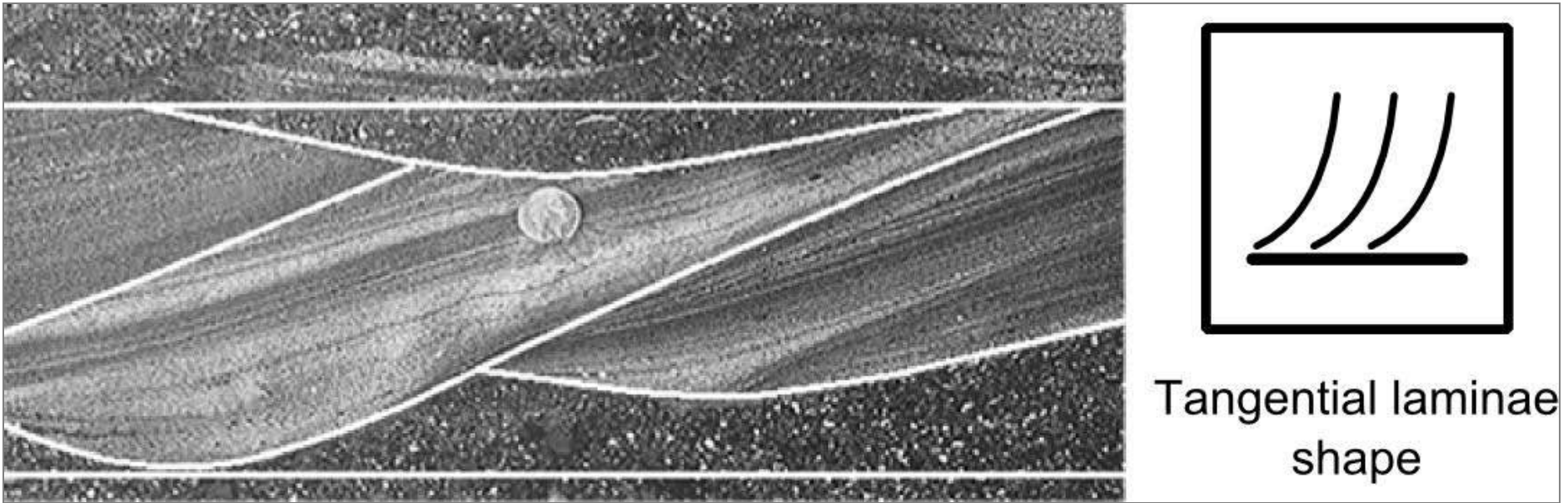


Figure 2. The observation of the sedimentary structure allows defining icons that express the visual relation emphasized by geologists (Lorenzatti, 2010).

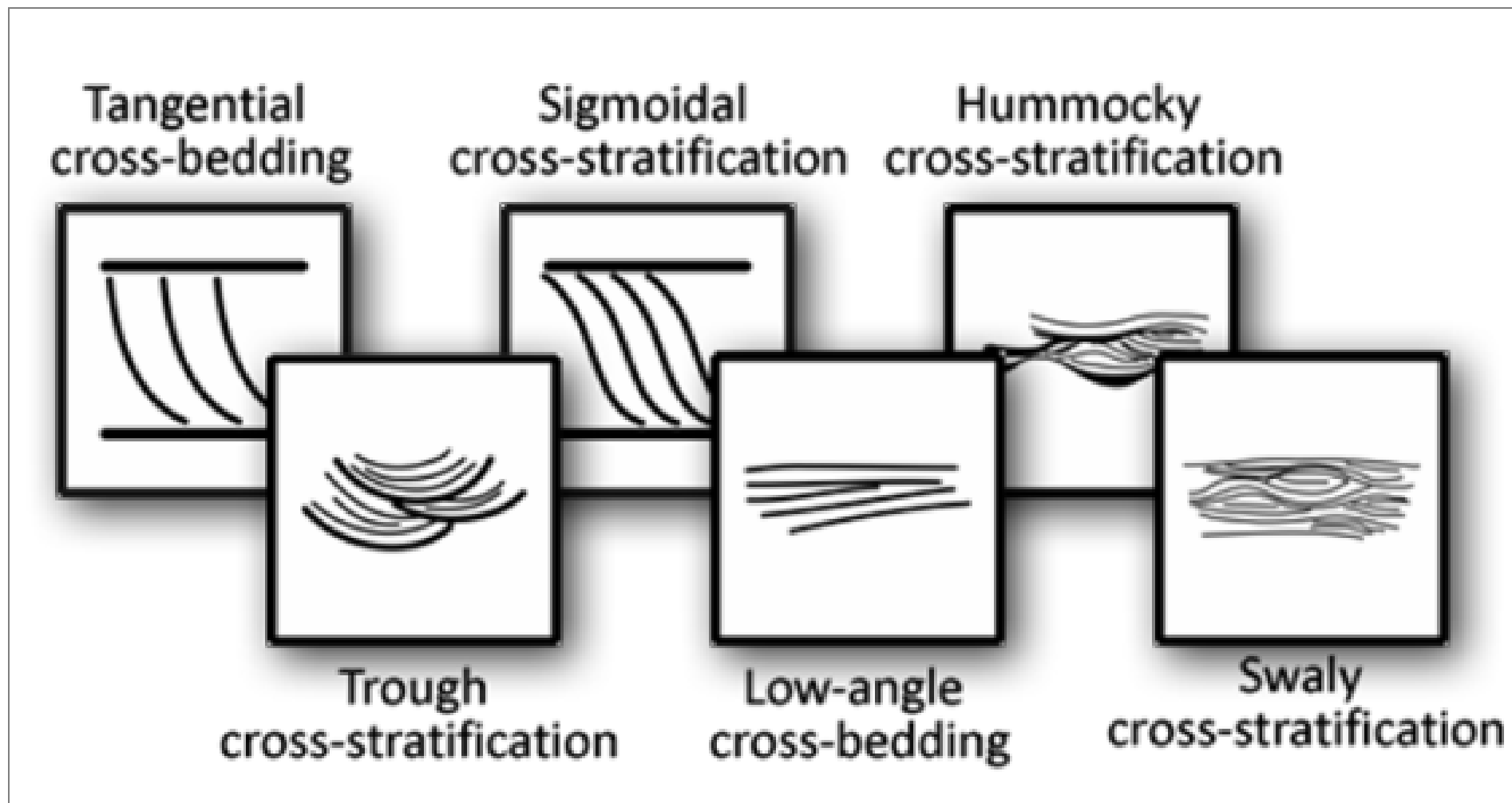


Figure 3. A subset of the library of icons for sedimentary structures from Strataledge®.

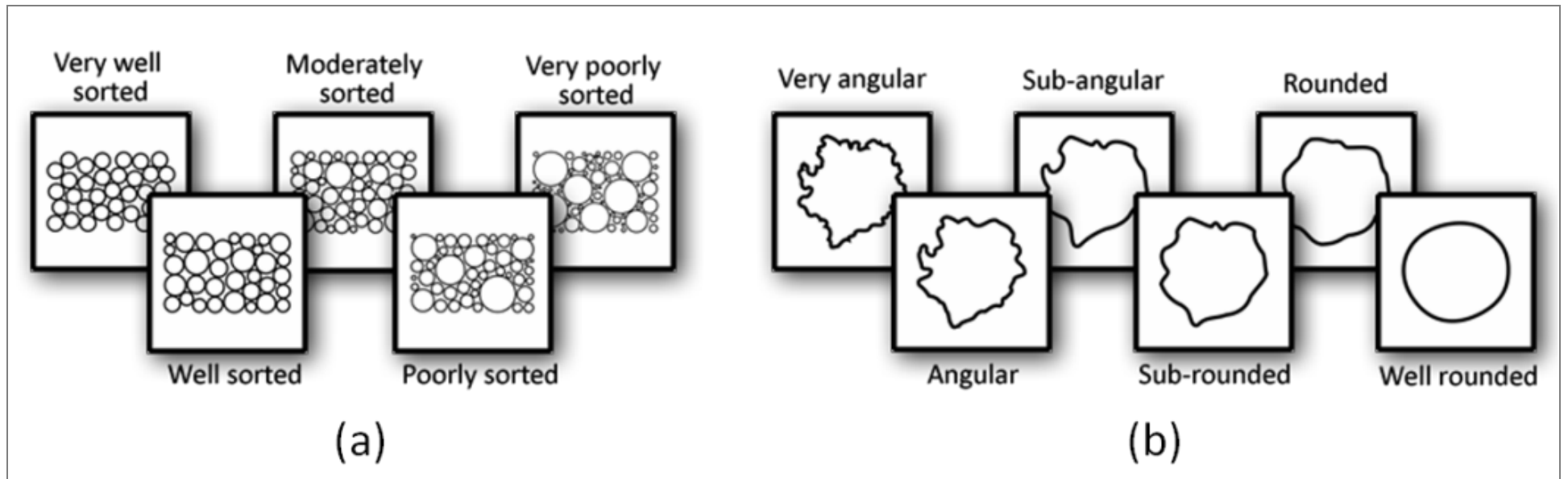


Figure 4. A subset of the library of icons of Strataledge® , showing icons and names for Sorting values in (a) and Roundness in (b).

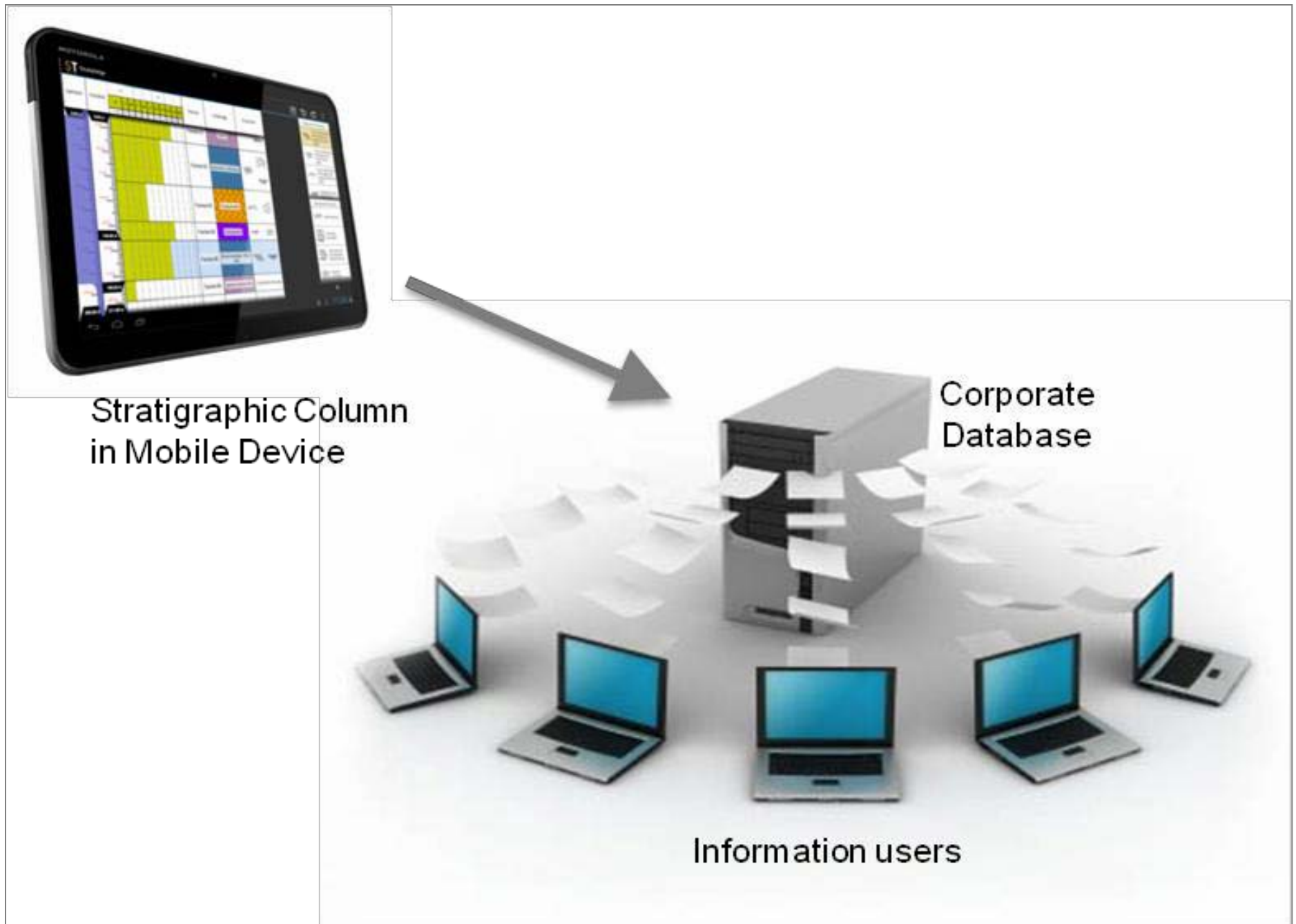


Figure 5. General using architecture of Strataledge® system.

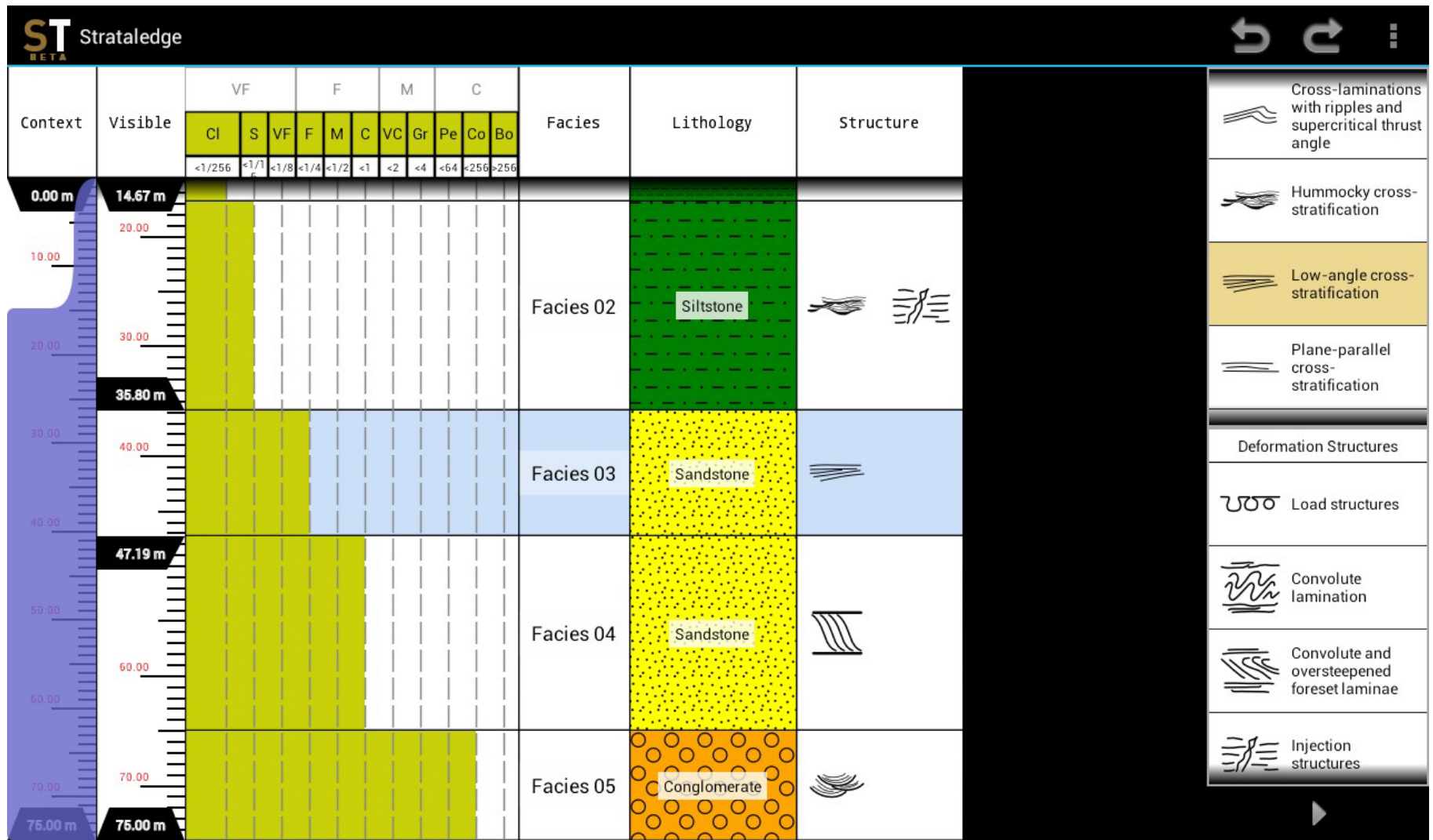


Figure 6. A general view of the user interaction of the Strataledge® system showing the correspondence between formal vocabulary and sedimentary structure icons.