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Automatic Detection of the Degree of Compaction in Reservoir Rocks Based on Visual Knowledge

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Abstract

A low-cost method is proposed for evaluating the degree of compaction in reservoir rocks by using automatic inference methods on optical photomicrographs. In order to reproduce the visual interpretation performed during petrographic analysis, a hybrid method was developed combining image processing algorithms with knowledge representation and reasoning models. The method proposed was inspired on *visual attention,* the mechanism used by the human brain for dealing with visual information. This mechanism allows the brain to filter the huge amount of information that comes through the eyes, selecting the relevant elements to be further analysed by the highly abstract level of reasoning. The process involves the decomposition of scenes, and the competition among their different aspects in order to isolate and select the relevant areas. In other words, the eyes of petrographers initially examine a thin-section by capturing and isolating the grains borders (outlines), and then focus on the grains. The outlines are essential to separate each grain from other grains and their interstices, because petrographic analysis is performed in the two-dimensional universe of thin-sections. The knowledge at this level is modelled in terms of *Sections* (grains)*, Outlines* (borders of grains)*,* and *Interstices*, which may be *Pores* (empty) or *NonPores* (e.g. cement, matrix). The shapes of the outlines (mainly concave or convex), complemented by the detection of the impregnation blue resin, indicates if they contain *Pores*, *NonPores* or *Sections*. The types of contacts between grains are then used to define the degree of compaction of the rocks. The system provides a preliminary identification of the objects that can be interactively refined by the user when the grain outlines are unclear in the images. The evaluation of compaction degree provided by this method is far more sensitive and precise than those based on the intergranular volume or number of intergranular contacts. This formalized interpretation method shows better results for the complex tasks of reservoir quality characterization and prediction.

Introduction

The quality of a rock as a petroleum reservoir is strongly affected by the post-depositional (diagenetic) processes that modify the original porosity and permeability of the sediments. Petrographic analysis allows the capture of relevant aspects for determining the depositional and diagenetic history and for understanding how the sequence of processes has affected reservoir quality. Petrographic descriptions provide fundamental information for petroleum exploration and production.

In the last years we have developed a software suite named Petroledge® that allows the acquisition and management of detailed petrographic information of siliciclastic and carbonate reservoir rocks. Petrographic information is selected and modelled based on visual features recognized during description, to which Petroledge® provides a symbolic representation, formalizing the whole vocabulary of petrographic description in a domain ontology. With this information, and based on artificial intelligence methods, Petroledge® performs diagenetic interpretations that help in the characterization and prediction of reservoir quality (De Ros, Goldberg *et al.*, 2007).

In this paper, we explain how the Petroledge® suite was improved in order to provide the evaluation of compaction degree of reservoirs by using optical photomicrographs and inference methods. In order to reproduce the geological visual interpretation as it is done in petrographic analysis, we developed a hybrid method that combines image-processing algorithms with knowledge representation models and reasoning methods. The method was proposed inspired on the human brain mechanism of dealing with visual information. *Visual attention* (Meur e Al., 2006) is the mechanism that allows the brain to filter the huge amount of information that comes through the eyes and to select the relevant elements to be further analysed by the highly abstract level of reasoning. The process involves the decomposition of a scene and the competition among its different aspects, in order to isolate and select the relevant areas of the scene. It is partially a physical process that occurs in the retina and a cognitive process handled by the cerebral cortex.

Compaction evaluation of siliciclastic rocks

The quality of a rock as a petroleum reservoir is essentially defined by its porosity and permeability values. Basically, three diagenetic processes are responsible by the modification of the intergranular volume from clastic rocks during burial: mechanical compaction, chemical compaction and cementation. The mechanical compaction causes the reduction of the intergranular volume by rearrangement, fracturing or ductile deformation of the grains. Chemical compaction reduces the intergranular volume by dissolving the grains along their contacts. Cementation causes obstruction of the intergranular pores by the precipitation of new minerals, mostly without reducing the intergranular volume. The intensity of mechanical and chemical compaction defines the degree of proximity – or packing – of the grains, which can be *loose*, *normal* or *tight*. As the packing changes from loose to tight, the types of contacts between grains change from *point* contact, to *long*, to *concave-convex* and to *sutured* (Taylor, 1950).

Other method for evaluating the degree of compaction involves comparing the present intergranular volume (IGV) with the original IGV, measured using the grain size and selection (Beard and Weyl 1973). Based on these parameters, the degree of compaction is calculated considering how much of the original IGV was lost during burial. Samples with less than 50% of reduction of the original intergranular volume are considered *loosely-packed*, while those with more than 70% of IGV reduction are considered *tightly-packed*, with *normally-packed* samples in the interval between these values.

Our system performs the evaluation of compaction degree based on the number and types of contacts detected in optical photomicrographs and described by user, as well as on the evaluation of intergranular volume. Table 1 shows examples of inputs and outputs of the system, for two samples with different degree of compaction.

Table 1 – Example of inputs and outputs used in the evaluation of compaction of two samples with different packing.

Samples		**01**	**02**
Input		**Number of Contacts**	
	Punctual Contacts	12	88
	Long Contacts	24	30
	Concave-Convex Contacts	25	8
	Sutured Contacts	14	2
Output (Packing)		**Tight**	**Loose**
Input	Present intergranular volume	4,42	30,69
	Grain size	Coarse	Medium
	Selection	Poor	Moderate
Intermediate values	% Lost intergranular volume	84,46	11,17
Output (Packing)		**Tight**	**Loose**

Knowledge modelling of visual aspects

In order to identify evidence for image interpretation in the physical level to be used to support the reasoning process in the knowledge level, we propose a knowledge representation model in three levels of abstraction, summarized in Figure 1. In the first one, the Image Processing Level, we have the basic elements of the image, which are *pixels* and *image entities*. Each image is referenced to a spatial coordinate system that preserves a real correspondence with the rock thin section. The correspondence is controlled by an electromechanical microscope stage (Victoreti, Abel *et al.*, 2007) developed to help in the point-counting for quantitative petrographic analysis. The processing in the lower level starts with the image segmentation using a wavelet (Acharayya, De *et al.*, 2003) that is sensitive to any abrupt change of frequency. The wavelets identify the borders of grains, providing a rough segmentation that needs to be refined manually by the user, especially when the rock texture and fabric are complex. This image processing produces the individualization of the grains in the image that will be analyzed in the next level.

In the Visual Level, we provide representation primitives to be associated to the elements of the image that are separated by visual attention object recognition. Knowledge acquisition experiments showed that the visual attention system first isolates the objects from the background, mostly based on their colour and shape. In other words, when a petrographer firstly exams a thin-section, his eyes will capture and isolate the borders that separate minerals and pores, and then will focus on the grains. The outlines are essential to separate the grains because petrographic analysis is performed in the two-dimensional universe of thin-sections. The knowledge in this level is modelled in terms of *Section* (inner part of the grains), *Pore* (empty spaces in a thin-section), *NonPore* (e.g. cement, matrix), *Outline* (borders of grains) and *Interstice* (higher level abstraction of pores and non pores). The higher level object in that level is the *Image*. The shape of the outlines and the dominance of the impregnation blue resin indicate if it contains a *Pore*, a *NonPore* or a *Section*. The geometry of the connection segments between *Sections* is used to define the contact types and is further interpreted to define the rock compaction level. The system provides the first identification of objects that are interactively refined by the user when the shape of the grain does not correspond to the expected by the classification rule.

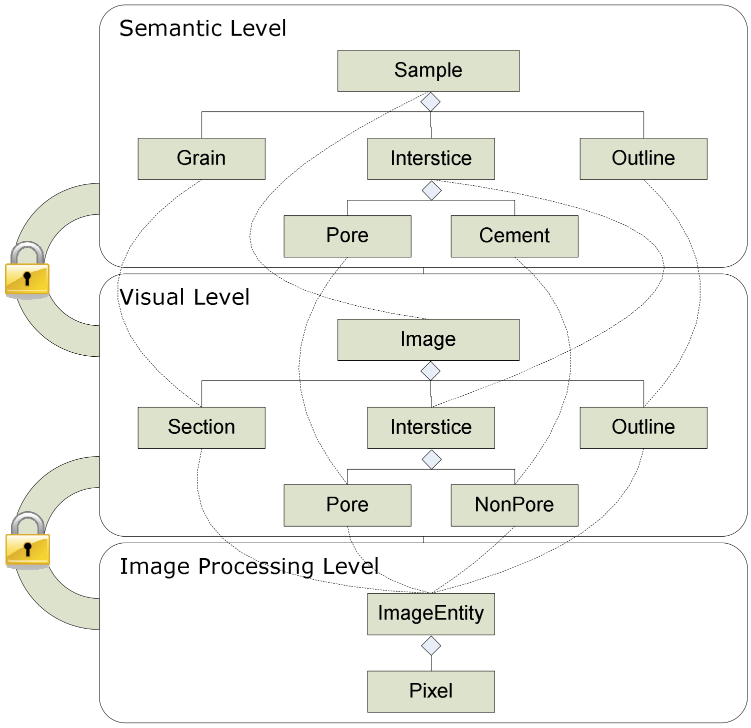

Figure 1 – Visual knowledge representation levels.

The objects captured and labelled in the visual level are then processed in the Semantic Level, in order to extract the meaning of shapes and contacts for compaction interpretation. The system correlates the captured objects to the concepts defined in the domain ontology on Petrography defined in (Abel, Silva *et al.*, 2005) and implemented in the Petroledge® system. In our ontology, the objects captured by visual attention are associated to *Grain, Cement, Pore, Outline* and *Interstice.* The higher level object in that level is the *Sample.*

A *domain ontology* is a formal representation of the consensual meaning of the objects in a particular domain (Gómez-Pérez, Fernández-López *et al.*, 2004). Ontologies are being used to define a standard vocabulary and to formalize the shared meaning of it in such a way that it can be understood and applied by computers. Ontologies have been shown a strong approach in representing the knowledge used to support automatic inference processing in expert system or to be shared through the WEB (e.g. to support e-commerce, semantic search based on geological ontologies such as in (Mello, Abel *et al.*, 2007)).

The identities of the objects in each level are guaranteed by mapping tables that associate the primitives of each level of representation, such as, *Section* in the visual level and *Grain* in the semantic level. These tables allow recovering the reasoning process by showing how a particular petrographic feature recognized in the thin-section was used to support the inference on degree of compaction.

Our inference mechanism receives the rock image, the segmented image and the size scale. The sections in the segmented image are individualized, and the main shape, concave or convex, is determined. Grains, defined by their convex shapes are identified, and their largest axes are measured. Pores are identified by the blue resin colour. After the physical processing of the image, the elements are associated to the objects in the visual level. In that level, the outlines are analysed in terms of topology and the type and number of contacts are defined (Figure 2). Currently, the process of contact type definition is manually performed, however an implementation to automatic detect them based on the geometry of outlines at the contacts is under development. The whole set of information are applied to determine the compaction level and the intergranular volume.

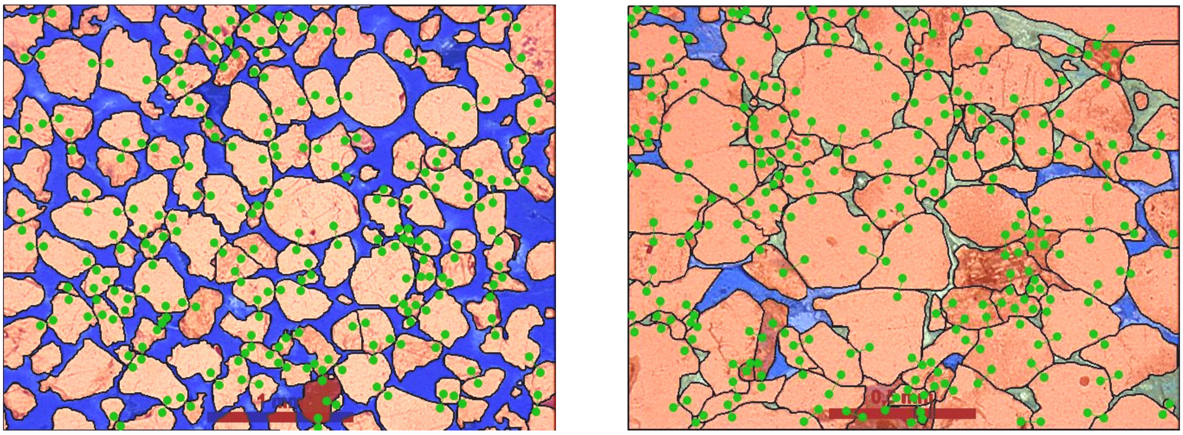

Figure 2 – Identification of the contacts (in green) between the grains based on topological relations. Intergranular volume in blue and gray.

The workflow at Figure 3 shows how the data processing is done in our approach, since the rock description using the Petroledge® system until the inference of compaction degree.

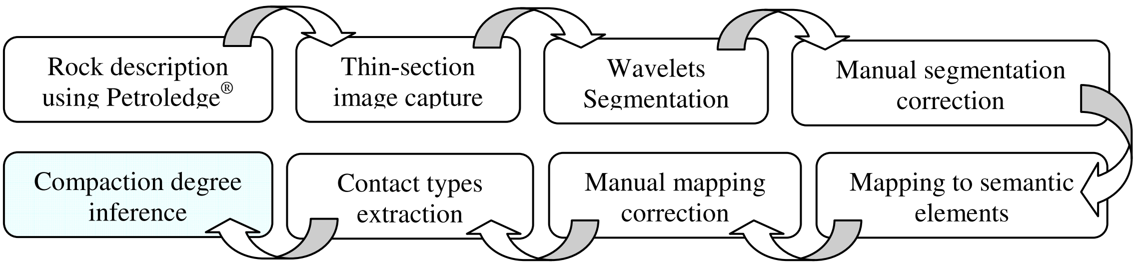

Figure 3 – Workflow of the compaction degree inference process.

Conclusions

The automatic interpretation of visual content is still an area under study that does not offer largely accepted technical solutions due to difficulties to extract meaning from images in different domains. In order to perform automatic image interpretation, it is necessary to provide a symbolic representation of visualized objects, so that this information can be processed. The use of ontologies stands out for that purpose, as they allow visual knowledge representation in a very similar way to human image interpretation process.

We use this approach in order to interpret the level of compaction of petroleum reservoirs, based on photomicrographs collected during petrographic description. Since our approach is based on the shape of the contact between grains, it is not affected by the common deformations of the image caused by optical capture. These deformations, such as the parallax, that augment the area of the grains as far as are the grains from the center of the optical system, invalidate direct measures over the image.

Although the system occasionally requires human intervention in some critical steps, such as to improve the segmentation of the images, it significantly reduces the time of the process applying a low-cost algorithm in terms of processing, while allowing a formalization and implementation of a very subjective method. A formalized interpretation method supports better correlation of the results along with the complex tasks of characterization and prediction of the quality of petroleum reservoirs.

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