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Documenting Visual Quality Controls on the Evaluation of Petroleum Reservoir-rocks through Ontology-based Image Annotation

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Abstract. Depositional and post-depositional (diagenetic) processes control the distribution of porosity and permeability within petroleum reservoir rocks. The understanding of these controls is essential for the construction of models for the systematic characterization and prediction of the quality (porosity, permeability) of petroleum reservoirs during their exploration and production. The description and documentation of key petrographic features is an important tool for the evaluation of reservoir quality that try to minimize the uncertainty associated to visual recognition of the features. This paper describes the role of visual controls on the petrographic analysis of reservoir rocks, and presents a knowledge-based tool that supports a workflow for the collection and documentation of visual information. This tool allows the spatial referencing of significant features in thin sections of reservoir rocks and the association of these features to a complete ontology of description. The whole process allows the preservation of original information that would support reservoir evaluation and guarantees further analysis even when the original rock sample is not available.

Keywords: Visual knowledge, image annotation, reservoir quality evaluation.

1 Introduction

The most important intrinsic properties of petroleum reservoir rocks are their porosity – the percentage of their total volume occupied by fluids, i.e., oil, natural gas or water – and their permeability – the amount of such fluids that can flow through a rock section in a time unit. The values and distribution of porosity and permeability within reservoir rocks are conditioned by depositional and post-depositional (diagenetic) aspects, such as the depositional structures, grain size and selection, the types, textures and location of diagenetic processes and constituents. These parameters are

described during the systematic petrographic analysis of reservoir rocks, in order to provide the essential information for the creation of models for the characterization of the quality and heterogeneity of reservoirs under production, or for the prediction of quality of new reservoirs during exploration. Therefore, the acquisition and documentation of the key textural and compositional petrographic features has an enormous importance for the evaluation of effective or potential reservoir rocks. However, capturing information from images is a natural uncertain process. Image recognition involves previous knowledge and hypothesis about what is being seen, the progressive adjustment of the viewer in order to fit the understanding to the seen features during image scanning and, also, judgments about the significance of this features related to geological interpretation.

This paper describes an approach to overcome the difficulty in applying visual knowledge in reservoir evaluation. We formalize a workflow for the systematic description and storage of the key visual petrographic features, as seen in petrographic microscopes, and provide computer support by a system composed by a piece of software and hardware.

The treatment of uncertainty provided by the system was conceived to deal with the incomplete collection of information and the partial confidence of the expert interpretation rules. The system tries to offer the best support to overcome the information loose in image recognition. It provides a petrographic ontology to orient the feature recognition and, when it is done, saves the spatial locations of the key features and associates them both to ontological terms as well as to hyperlinks for other objects supporting the description, such as pictures, audio and video files, websites, etc. As a result, it produces a complete documentation of the features, in the form of a *virtual map* of the thin section, that preserves the evidences for the reservoir evaluation. The reasoning method searches over this description for the required features to prove one or other interpretation hypotheses.

The approach was implemented in the *PetroGrapher* system, an intelligent database application designed to support the detailed petrographic description and interpretation of oil reservoir rocks, and the management of relevant data using resources from both relational databases and knowledge-based expert systems. Systematic description through the system is facilitated by the use of flexible menus with standardized nomenclature and parameters, what radically reduces description time and errors. An integrated electromechanical microscope stage, the *StageLedge*, allows an optimized quantification, as well as the referencing of every point identified and/or photographed in the thin sections. The collection of qualitative features is driven by a domain ontology [1] that formalize the knowledge related to petrographic description and diagenetic interpretation. The main approaches of *PetroGrapher* system are described in [2-4]. In this paper, we present the basis for the automation of the process of quantitative petrographic analysis with the support of an electromechanical appliance [5] attached to the microscope and interfaced to the software system. This approach reduces the uncertainty associated to visual interpretation by improving the semantic capturing and allowing a better register for recovering the evidences that support inference. This information is used by the problem-solving method implemented in the system to propose the probable diagenetic environment where the rock where formed.

The petrographic analysis is accomplished through two stages. First, the petrographer analyzes the fabric, texture and structure of the rock, and identifies the main rock-forming constituents, pores and diagenetic relations. After that, he/she performs a quantitative analysis, through the systematic scanning of the rock, following a virtual grid of evenly-spaced points over the thin section. During this scanning, the petrographer identifies and annotates the constituents and the diagnostic features that may suggest interpretations of reservoir quality. In addition, important features may be captured through photographs, which can be annotated later on. All process is presented in Fig.1.

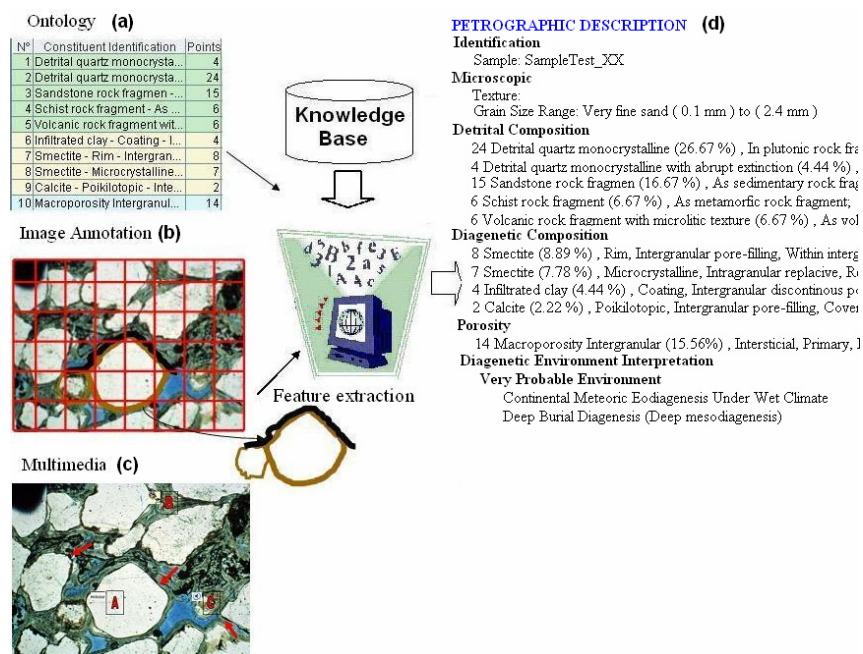


Fig. 1. Thin section of rock sample description process. The system uses: (a) qualitative and quantitative description using a domain ontology; (b) virtual map of thin section allowing annotation to identify objects on image (feature extraction); (c) hyperlinks and observations are used for documentation. The system provides a textual report with all information (d).

Although the qualitative and quantitative description is a systematic process, it is strongly affected by different styles of descriptions and subjective factors. Petrographers with distinct levels of expertise can produce quite different descriptions, mainly because the spatial relationships among the constituents, or *paragenetic relations*, as well as uncommon minerals are not properly recorded. Even the same petrographer when recalling a previous description may find it difficult to check some of its specific aspects, because the original position and described points over the thin section cannot be found again with precision. Our approach helps in minimizing the information loose typical of the visual-based interpretation process by providing a standard description based on a complete formal vocabulary and

petrographic support tables. It also supports the capture of all features along with the original spatial position in the rock, and allows the re-utilization of information, even in the absence of the original object.

2 Preliminary Concepts

The structuring and the representation of the knowledge for problem solving in domains that require image pattern matching and then high level of abstract inference is a challenge for knowledge engineering although is essential for many critical tasks, such as automatic surveillance in intensive care units [6], recognition of biological organisms [7], and biochemistry [8]. The uncertainty in the task are related mainly to the follow factors: (1) the collection of information is not complete because the observer does not posses the knowledge to recognize what is being seen providing incomplete or wrong descriptions; (2) even with the adequate capture of the diagnostic features, the level of significance of these features in indicating a particular interpretation may not provide a fully trustful solution.

Our system helps in making available the knowledge by supporting the feature recognition through a domain ontology and providing a problem-solving method to deal with significance and confidence factors of the interpretation task.

2.1 Ontology and Image Annotation

Ontologies that formalize the visual concepts of the domain are shown as the alternative to reduce the gap between the knowledge representation and image features, as presented in [9] and also in this paper. The most common definition of ontology asserts that an ontology is a formal, explicit specification of a shared conceptualization [10]. Formal refers to the fact that the ontology should be machine-readable, and shared reflects the notion that an ontology captures consensual knowledge, accepted by a group. Ontologies express the descriptive knowledge and also the way in which the evidences support the conclusions. Usually, they are combined with problem-solving methods [11] to provide reasoning features to expert systems, like we done in our system.

There are many approaches to ontology-based content annotation of images, based on a standardized vocabulary defined by a domain ontology that allows further processing [11] [6] [12]. Images must be annotated with keywords and content-based combined queries and refinements [13]. During annotation, a lot of information can be expressed, helping to improve the understanding and to reduce ambiguity.

The images can also be annotated with links over the image to any kind of multimedia content like it was done in [14]. It is possible to associate data under analysis to different resources, in order to provide a complete documentation.

2.2 Spatial Referencing

A spatial reference system provides an association of the object with its location related to a specific coordinate system. A coordinate system can reference a particular point in an n-dimensional space defined by an origin, directions of the axis and a distance scale. The quantitative analysis of a thin section in an optical microscope is usually done referring each identified feature to an imaginary net of points along a sequence of evenly-distanced steps, corresponding to successive positions marked by the cross lines of the microscope eyepiece. In some cases, this net is scanned with the help of some equipment, such as performed in [5] and in [15]. However, the complete association of the net of points to a spatial coordinate system with an *anchor* linked to a real reference of a physical object, as developed in this work, is a new proposition.

3 Petrographic Analysis Using Software Control and the *StageLedge* Device

In order to support the systematic quantitative analysis in the *PetroGrapher* system, we have developed an electromechanical device, called *StageLedge* [5], to be attached to the optical microscope and connected to a software control. The quantification of the constituent elements requires a uniform scanning of the thin section, so we have defined an automatic method. This approach not only guarantees that the thin section can be completely explored, but most important, that the entire process can be repeated, preserving the spatial coordinates of each point of the virtual map.

3.1 Virtual Thin Section

Our approach is based on the creation of a digital version of the thin section, on top of which virtual feature maps can be created. Although it does not completely eliminate the need for the real thin section, it has some significant advantages over the traditional approach that uses the original section both for description and for later verifications. This virtual thin section allows the recording of reference features through an existent ontology. For instance, our electronic version of the section can be sent over the Internet to an arbitrary number of petrographers, who can independently go over the reasoning process previously applied in the original documentation. Besides reducing the risks associated with a possible loss of the physical section, it also eliminates the costs associated to shipping the real thin section.

Moreover, the virtual thin section has the potential for unlimited documentation via hyperlinks to images, video, audio, and text provided by expert petrographers, as well as to other resources available on the Internet and related to the contents of the section. This sets the stage for a new level of rich documentation, turning the virtual thin sections into ideal training tools. This situation is illustrated in Fig. 2, which shows an image corresponding to a portion of a thin section containing links to different media formats: audio, video, other images, websites, and other observations. These resources intent to complement the information that is captured by the user,

minimizing the lack of comprehension about what is seen in the description time. The images should have less than two megabytes to not slow down the system execution.

3.2 Complete Description Process

The analysis of a thin section starts with its positioning in the petrographic microscope, which has a rotating stage that allows the examination of the optical properties of minerals when examined with polarized light. The direction of the transect lines across which the points are quantified during analysis is defined transversally to the structures and fabric of the rock, and the modal size of grains indicates the adequate size of the step to be used with the StageLedge.

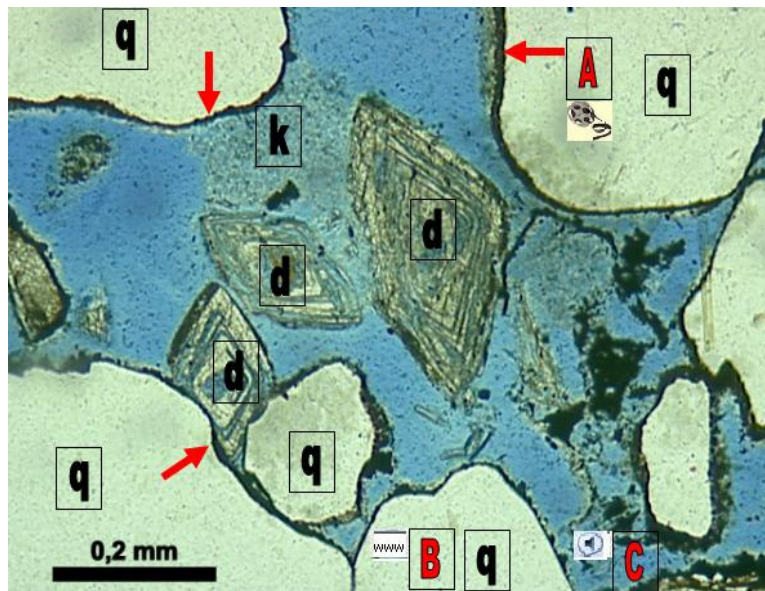


Fig. 2. A rock thin-section image with links and observations: A: Video file C:\video.mov; B: WEB link; C: Sound file C:\quartzExplain.mp3; Observations: Grains of quartz (q) covered by coatings of iron oxide (arrows); zoned and partially dissolved crystals of dolomite (d); microcrystalline kaolinite (k) partially filling the intergranular pores (impregnated by blue epoxy resin); uncrossed polarizers.

In the process of creating a digital map of the rock, we digitize a physical thin section using a regular flatbed scanner and use the resulting image as a base map on top of which the additional documental information will be placed. This stage requires the careful correction of the scale, tilt and coordinates of origin of the scanned image, in order to provide a correct association with the origin and scale provided by StageLedge. Once the image has been captured and associated to the actual position in the equipment, the documentation can be referenced to the real spatial coordinates. Since flatbed scanners can capture images at different resolutions, it is necessary to

specify the selected resolution in points per inch (ppi), thus relating pixels to real distances in the thin section. According to our experience, the use of 600 ppi provides satisfactory results. In order to support the petrographic description, the *PetroGrapher* system controls the steps of the *StageLedge* and allows the user to select constituents and features described in the domain ontology and associates them to the current position under analysis in the thin section. Fig. 3 illustrates the interface of the *PetroGrapher* system, showing the constituents of a given rock sample and a partial menu providing specific ontology terms.

The quantitative petrographic analysis identifies and saves the location of every constituent positioned in each of the coordinates in the virtual net, controlled by *StageLedge*. The *PetroGrapher* interface depicts different minerals using colors, as presented in Fig. 4. Thus, with just a quick glance, the geologist can have a good idea of the spatial distribution of the constituents and pores identified in the thin section.

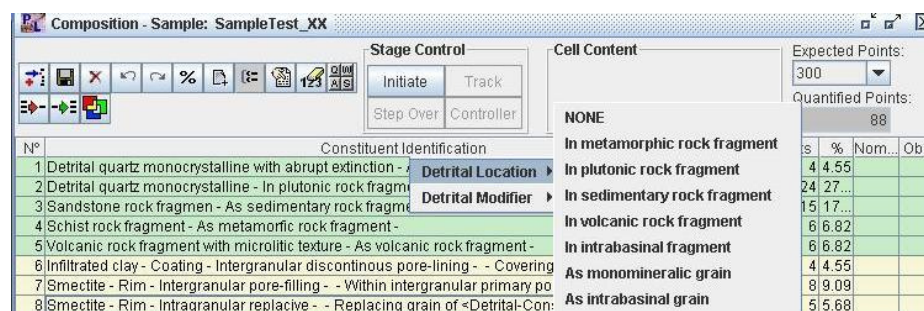


Fig. 3. Rock sample composition interface with the description ontology for constituents.

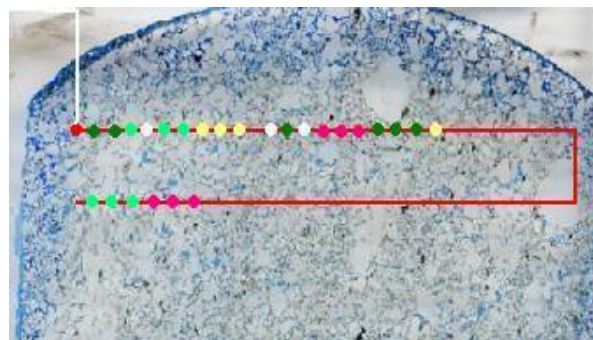


Fig. 4. Thin section with points of different constituents, identified by different colors.

The possible constituents and pores that can be found in a thin section are fully described in a domain ontology, as well as the attributes and domain of values of them. The ontology also describes in which way the instances of qualified constituents can indicate the rock-formation environment. This is expressed by

knowledge graphs, a one-level tree where the root node represents the interpretation hypothesis and the leaf nodes represent visual chunks identified by the experts in the image of rock as pieces of evidence necessary to support the interpretation. The uncertainty of interpretation is represented in the knowledge-graph by a threshold value that represents the minimum amount of evidence needed to indicate it. Also, the chunks have an influence factor and are combined to increase the influence and the certainty of the interpretation stated. By their side, the chunks represents in an AND-OR tree the several ways in which way an evidence can be recognized in the rock, such as, possible minerals, possible habits, locations, etc. The knowledge model and problem-solving method of the system is extensively described in [3].

For each significant feature identified in the thin section, the user can capture a photograph and associate it to the coordinates of the described point or annotate the captured image itself, describing the special characteristics that must be considered. Thus, the quantitative analytical process generates a map containing the documentation of the most important diagnostic features for reservoir evaluation. According to the user interest, the system can selectively show the location of the special features, as exemplified in the left window of Fig. 5, where the segments indicate the trajectory of the analysis and the white dots shows the position of the selected constituent. As the user moves the mouse over a point for which a picture has been taken, it is automatically shown in right side window (Fig. 5). This documentation will provide further validation to the reasoning process or may show possible errors in feature identification.

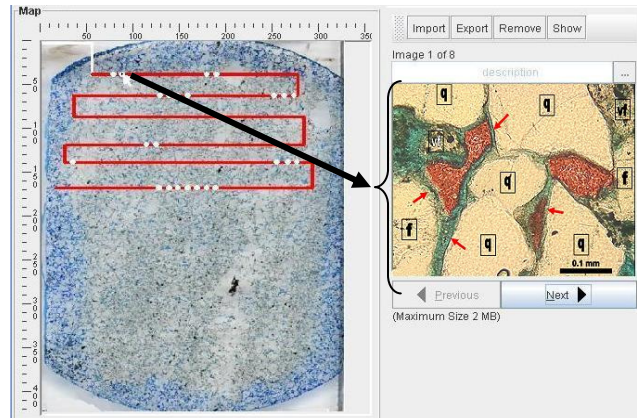


Fig. 5. Interface showing the virtual thin section with a superimposed map of the analytical pathways and points (left). As the mouse cursor passes over a feature point (white dot) for which a picture has been taken, the photograph is shown on the right. Note that the photograph itself contains a series of annotations in the form of hyperlinks.

The digital map of the rock uses the digital thin section image as a base map on top of which the additional documental information will be placed. This stage requires the careful correction of the scale, tilt and coordinates of origin of the scanned image, in order to provide a correct association with the origin and scale provided by

StageLedge. Once the image has been captured and associated to the actual position in the equipment, the documentation can be referenced to the real spatial coordinates.

At the end of the process, an extensive documentation of the thin section is provided. For example, it is possible to locate where the 10th detrital quartz is located and then visualizing it. Moreover, the system guarantees that all descriptions would be performed based on a formal and complete petrographic vocabulary, defined in the domain ontology. This feature will provide extra capabilities by allowing the automatic geological interpretation and correlation with the captured information.

3.3 The interpretation process

The features described are stored in a database, along with the spatial coordinates of their position in the virtual map. The reasoning method loads each knowledge graph and match the chunk representation from the knowledge base against the user descriptions on the database. When the set of features that describes a chunk is found, the reasoning accumulates the related influence factor. When the sum reach the threshold of the graph, the conclusion is stored in the database in the description record and presented to the user. More than a conclusion can be associated to one rock, since more than one environment can act in rock consolidation.

4 Conclusions

The tool described in this paper has been tested by a group of six geologists from the Geosciences Institute at the Federal University of Rio Grande do Sul (Brazil), who works usually with petrographic analysis. The group has long time experience with the manual method and has migrated recently to *PetroGrapher* system. The goal was measuring the time expending in the task description and the amount of information that was collected in each method in normal work condition. Each participant received six different rock samples to be described. Each sample was described by four geologists, two using the *PetroGrapher* system, two using an electronic spreadsheet and a mechanical stage. According to these experiments, the use of the *PetroGrapher* system with the StageLedge has led to a reduction of 25% in the time required for a full petrographic description. Otherwise, the descriptions are longer and contain more information than those made by manual method.

The spontaneous comments from *PetroGrapher*'s users include: (1) the system guarantees a standard documentation without losing semantic of feature description; (2) the possibility of recovering the original position of some specific feature provides a better framework for reservoir understanding; and (3) the information can be easily queried and reused. As a result, one can draw further correlations between petrographic data and well logs, seismic profiles and core descriptions. These capabilities are essential for a powerful tool used for advanced reservoir characterization.

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