ANNUAL CONVENTION AND EXHIBITION
7–10 JUNE 2009 • DENVER COLORADO

Tackling complex reservoirs through systematic petrographic characterization

Luiz Fernando De Ros, Mara Abel and Karin Goldberg

Rio Grande do Sul Federal University – UFRGS & Endeeper Reservoir Knowledge Systems, Porto Alegre, Brazil;
lfderos@endeeper.com; mara.abel@endeeper.com; karin.goldberg@endeeper.com

Exploration of complex reservoirs in frontier and deep prospects

As exploration moves into deeper, depositional or tectonically-complex new frontiers, simple and conventional reservoirs are getting scarce. Despite the spectacular advances in seismic and log acquisition and interpretation, the risks involved in the exploration of new, deeper, depositional, tectonic or diagenetically-complex prospects remain large. 3D and 4D models incorporating sophisticated structural, thermal, generation and migration histories help to reduce exploration risks in new and tectonically complex settings, but they simply lack information on an essential part of petroleum systems: **the reservoir**. Most new prospects represent clastic, carbonate or other, unconventional reservoirs with strong diagenesis. For these, the conventional, indirect evidence of texture and composition provided by logs and conventional, simplified petrographic descriptions is simply not enough. Undiscovered and unproven hydrocarbon reserves are contained either in conventional clastic and carbonate reservoirs with strong diagenesis, such as the deep Gulf of Mexico and the sub-salt prospects in Brazil, or in unconventional plays, such as by tight sands, gas-shales and coalbed methane. As a matter of fact, about 35% of the technically recoverable reserves in the U.S. lie in unconventional reservoirs. There is an emerging trend for the integration of systematic petrographic analysis with petrologic, geochemical, wireline log, petrophysical and seismic analysis, in order to tackle the challenges involved in the reduction of the exploration risks and optimization of the development and production of such reservoirs.

Increasing recovery from old fields

A critical frontline in the struggle to supply the ever-growing demand for energy involves finding ways to squeeze more oil out of old fields with declining production. A performance breakthrough involving new concepts, new data and new technologies is needed to revert or decelerate the down sloping production trends. This involves achieving a better understanding of these reservoirs in order to redesign or adjust the secondary or tertiary recovery programs, or, in some cases, to extend, drill for or re-complete new, unconventional and/or previously neglected reservoirs. Both targets demand detailed, advanced reservoir characterization through high-resolution stratigraphy and systematic petrography. Enhanced recovery projects in mature oilfields demand detailed petrographic characterization in order to understand the heterogeneities and controls on pore geometry and permeability, such as in the lower Tertiary reservoirs of the Talara Basin, Peru (Fig. 1A). Detailed models of reservoir quality and heterogeneity incorporating detailed petrographic data are essential for the design of engineering solutions for optimizing reservoir exploitation.

The problem: understanding complex and unconventional reservoirs

Deep, unconventional and complex reservoirs are becoming the major exploration targets. Some indications of the new rules of the exploration game come from offshore areas in the Gulf of Mexico, and in the eastern Brazilian margin. In the Gulf upper Tertiary section, seismic amplitude anomalies very similar to oil-saturated sands have been unsuccessfully drilled since the late 70's. Only lately, it was discovered that these anomalies correspond to sands containing substantial amount of volcanic ashes, derived from large-scale eruptions in the Yellowstone area through the Mississippi system (Totten et al., 2005). The same type of false DHI (direct hydrocarbon indicator) led to dry wells in the eastern Brazilian marginal basins, where the anomalies were related to reworked, altered vitreous volcanic fragments produced by submarine eruptions (hyaloclasts; Fig. 1B). Large amounts of money could have been saved in these cases, had a proper petrographic characterization been performed for calibrating wireline logs and seismic immediately after the first dry well was drilled. In the Santos Basin, offshore Brazil, Upper Cretaceous reservoirs show anomalously high porosity preserved at great depths by the inhibiting effect of chlorite rims on quartz cementation and compaction (Anjos et al., 2003; Fig. 1C). The same effect was also identified in Jurassic reservoirs in the Gulf area (Thomson, 1982; Dixon et al., 1989) and in the North Sea (Ehrenberg, 1993). In these cases, the importance of systematic petrographic studies and petrologic analyses resides in modeling of the spatial distribution of chlorite (hence the related porosity preservation) relative to precursor materials, such as volcanic and other Fe-Mg grains, and early-diagenetic clays, such as smectite or odinite.

The recent discoveries of giant, early Cretaceous, sub-salt oil and gas accumulations in the deep and ultra-deep areas of the eastern marginal basins in Brazil have brought petrographic studies to the center arena. The sub-salt reservoirs are very complex and intensely affected by diagenetic processes, and their genetic conditions and relationships with facies and primary compositional controls are yet to be understood. Sub-salt clastic and carbonate reservoirs previously drilled in the shallow-water portion of the Campos Basin are characterized by extreme variation in porosity, as well as in diagenetic processes and products (Fig. 1D). Systematic studies considering petrologic, geochemical and stratigraphic evidence and models will have to be developed for risks assess through reservoir quality prediction. In these studies, advanced petrographic characterization will be of key importance.

The solution: effective, systematic petrographic studies

As the porosity and permeability of most complex, unconventional and mature reservoirs (as well as their log and seismic signatures) are strongly controlled by diagenesis, the importance of incorporating petrographic characterization into the exploration and production culture becomes obvious. Within this new scenario, the systematic acquisition and use of petrographic data to calibrate the indirect characterization and evaluation of reservoir quality provided by seismics and logs allows the attribution of real rock meaning to log facies and to seismic units and reflectors. Reservoir quality studies on complex reservoirs have shown that the habits, location, space and time distribution of diagenetic phases are more important than the types of constituents. Therefore, there is an emergent trend of integrating micro-scale petrographic analysis with log analysis, petrophysics, and seismics. The integration of petrography into reservoir quality models is a crucial breakthrough that is going to guide exploration and production from now on.

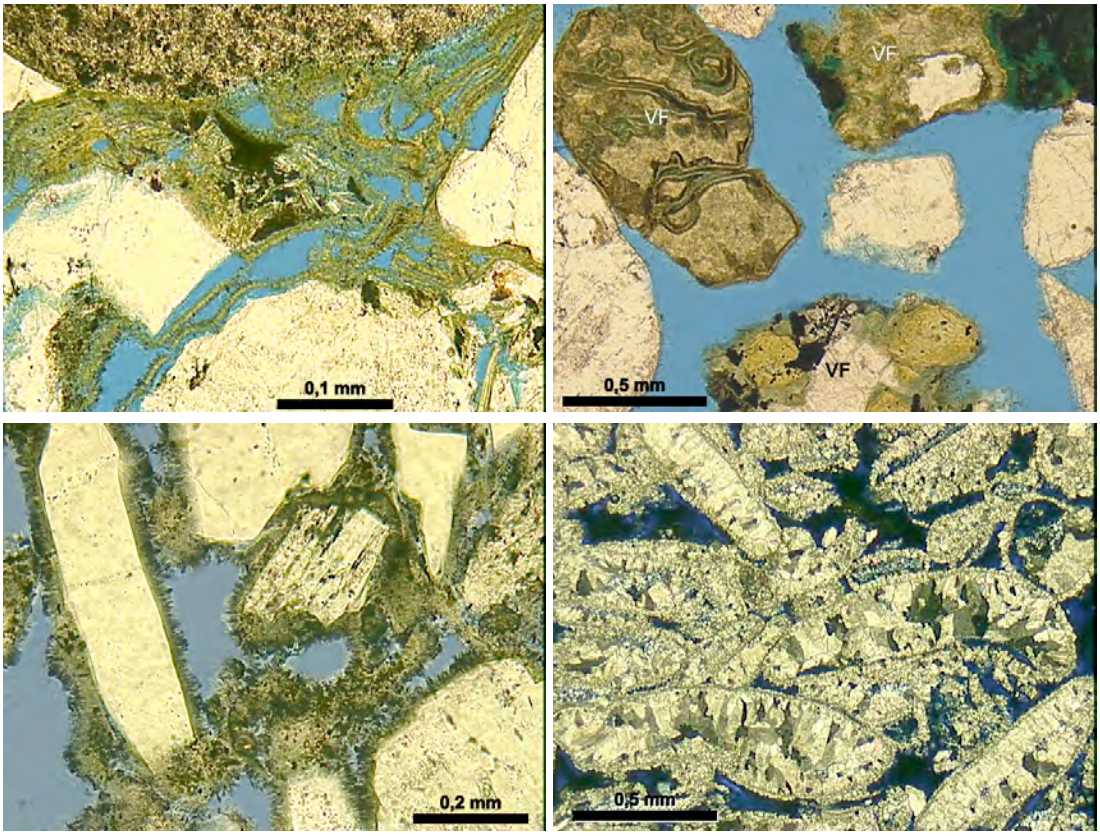

Figure 1: Optical photomicrographs of complex reservoirs under crossed (XP) and uncrossed polarizers (//P). A) Multiple smectite (swelling clay) rims (green) generate very a very complex pore system (blue) and a challenge to the enhanced oil recovery from the mature oilfields producing from the Echinocyamus Formation (Eocene) in the Talara Basin, Peru (//P). B) Vitreous volcanic fragments (hyaloclasts) altered to smectitic and chloritic clays in upper Cretaceous sandstones of the Santos Basin, Brazil, where they can mimic seismic amplitude anomalies very similar to oil-saturated sands (//P). C) Chlorite rims (green) help to preserve anomalously high porosity (blue) values in deep (> 4000m) upper Cretaceous sandstones of Santos Basin, although reducing permeability and resistivity (//P). D) Recrystallized mollusk bioclasts provide the heterogeneous framework for a lacustrine, lower Cretaceous, sub-salt reservoir in Campos Basin, Brazil (XP).

There are two major limitations for the effective integration of petrographic information into E&P: (i) most of the petrographic data is dispersed in spreadsheets and/or text reports, with variable format and frequently imprecise organization and terminology, and (ii) the software packages commonly used for well-log analysis, seismic interpretation and 3D modeling do not import petrographic data in these formats. The need of organizing detailed petrographic data for effective, systematic use in E&P has led to the development of the Petroledge® system (De Ros et al., 2007). Petroledge®, an intelligent database system combining resources from relational databases and knowledge-based expert systems, was created to support systematic analysis, storage and processing of detailed petrographic information on primary structures, textures and constituents, and mostly on the habits, location and paragenetic relations of diagenetic constituents and pore types (Fig. 2). Such systematically-organized petrographic information can be effectively integrated into 3D reservoir models and flow simulation software.

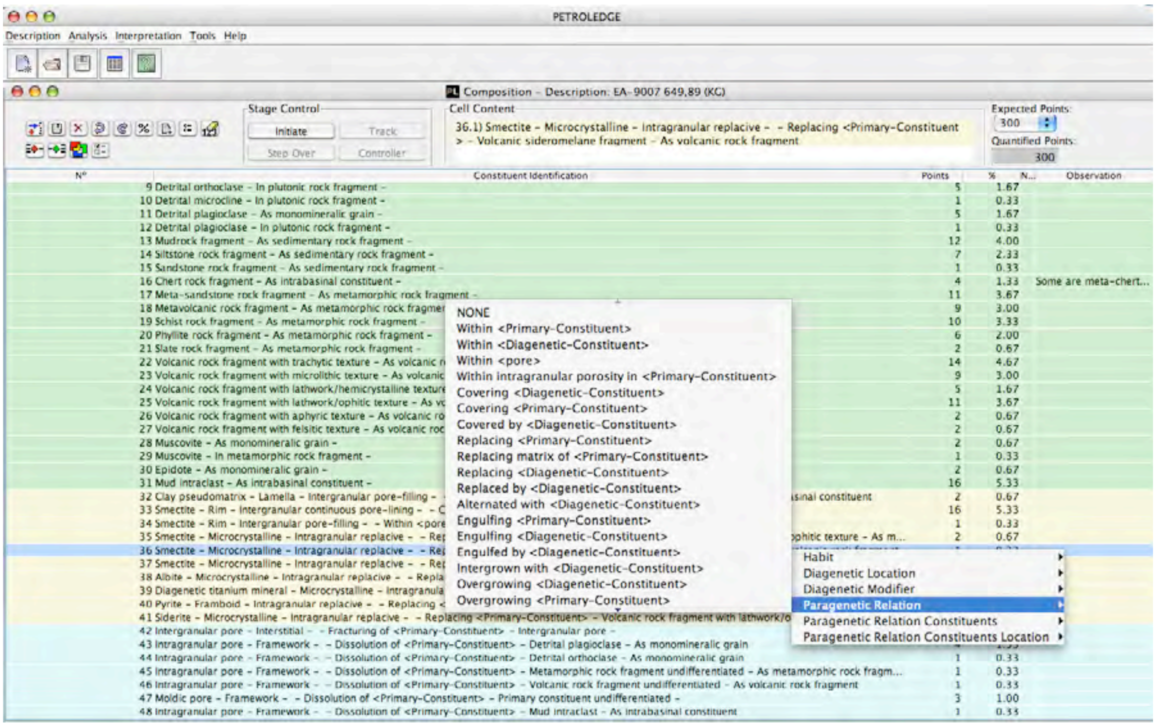

Figure 2. Example of a Petroledge® system compositional screen, showing the degree of description detail allowed by the system and demanded for the petrographic characterization of complex reservoirs.

Reservoir petrofacies

The intrinsic quality of petroleum reservoirs (porosity, permeability) is controlled by key petrographic parameters, namely by depositional structures, textures and composition, diagenetic processes and products (volume or intensity, habits and distribution), as well as by the types and distribution of pores (De Ros & Goldberg, 2007). The concept of reservoir petrofacies is the most effective way to integrate and incorporate such key petrographic information into reservoir characterization and quality prediction. Reservoir petrofacies correspond to defined value ranges of porosity and permeability, as well as to characteristic log and seismic signatures. Consequently, they can be used for calibrating logs and seismics with true rock properties. Logs calibrated by reservoir petrofacies can then be applied to realistic representation in 2D sections and 3D models of reservoir quality and heterogeneity, leading to enhanced static and flow simulations during development and production. Seismic facies and reflectors calibrated by reservoir petrofacies will enhance the precision of seismic interpretation in deep, new or unconventional settings.

Challenges

The construction of sensible 3D and 4D models incorporating RQ prediction through advanced petrographic characterization is indeed a new frontier in exploration. Such developments will allow a much more sophisticated risk assessment during the exploration for complex and unconventional reservoirs in frontier and deep areas. Another challenge involved in the use of advanced petrographic characterization is the integration of geological knowledge. The effective up-scaling and integration of data generated with different tools (and stored in different formats), such as seismics, logs, petrophysics and petrography will involve much more than merely the integration of files and formats. A much more complex problem will consist in the semantic integration required in the level of applications. Different tools have not only distinct representation of the geological objects to be processed, but also capture different views and even meanings of these objects. Knowledge-level integration is required in order to offer an uniform view of the data that supports exploration decisions. However, with the increasing awareness of the need for a petrographic database that can supply the different software packages commonly used in exploration and production, the gap between petrography and modeling will be shortened.

The appropriation of systematic petrographic characterization into realistic reservoir quality models will allow a better assessment of exploration risks and optimized production procedures. The challenges involved in the exploration and production of complex reservoirs will be surpassed with the intelligent integration of petrography into the operational E&P workflow.

References

Anjos, S. M. C., L. F. De Ros, and C. M. A. Silva, 2003, Chlorite authigenesis and porosity preservation in the Upper Cretaceous marine sandstones of the Santos Basin, offshore eastern Brazil, *in* R. H. Worden, and S. Morad, eds., Clay Cements in Sandstones: IAS Special Publication, v. 34: Oxford, UK, International Association of Sedimentologists - Blackwell Scientific Publications, p. 291-316.

De Ros, L.F. and Goldberg, K. 2007, Reservoir petrofacies: a tool for reservoir characterization and prediction. AAPG Annual Convention and Exhibition 2007, Houston, Extended Abstracts Vol., 6 pp.

De Ros, L.F., Goldberg, K., Abel, M., Victoretti, F., Mastella, L., and Castro, E. 2007. Advanced Acquisition and Management of Petrographic Information from Reservoir Rocks Using the Petroledge® System. AAPG Annual Convention and Exhibition 2007, Houston, Extended Abstracts Vol., 6 pp.

Dixon, S. A., D. M. Summers, and R. C. Surdam, 1989, Diagenesis and preservation of porosity in Norphlet formation (Upper Jurassic), southern Alabama: Am. Ass. Petrol. Geol. Bull., v. 73, p. 707-728.

Ehrenberg, S. N., 1993, Preservation of anomalously high porosity in deeply buried sandstones by grain-coating chlorite: examples from the Norwegian continental shelf: Am. Assoc. Petrol. Geol. Bull., v. 77, p. 1260-1286.

Thomson, A., 1982, Preservation of porosity in the deep Woodbine/Tuscaloosa trend, Louisiana: Jour. Petrol. Tech., v. 1982, p. 1156-1162.

Totten, M.W., Jurik, M.A., and Hanan, M.A., 2005, the Occurrence and Seismic Expression of Volcanic Ash Beds in the Gulf of Mexico: Gulf Coast Association of Geological Societies Transactions, v. 55, p. 810-820.