PS Tackling Complex Reservoirs through Systematic Petrographic Characterization*

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Abstract

Despite the spectacular advances in seismic and log acquisition and interpretation, and in 3D and 4D modeling, the risks involved in the exploration of new, deeper, depositional, tectonic or diagenetically-complex prospects remain large. This happens essentially because these sophisticated methods simply lack information on an essential part of petroleum systems: the reservoir. Most new prospects represent clastic or carbonate rocks 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. There is an emerging trend for the integration of systematic petrographic analysis, aided by petrologic and geochemical analyses, with log analysis, petrophysics, and seismic, to tackle the challenges represented by such reservoirs.

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. Such systematically-organized petrographic information can be effectively retrieved and integrated into 3D reservoir models and flow simulation software. Systematic petrographic characterization can be used to calibrate log and seismic attributes through reservoir petrofacies, defined by the combination of key petrographic parameters. Log and seismic facies and seismic reflectors calibrated by such reservoir petrofacies allow the realistic 2D and 3D representation of reservoir quality and heterogeneity, leading to enhanced

static and flow simulations during development and production, and increasing the precision and efficiency of seismic interpretation in deep, new or unconventional settings.

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.

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Exploration of complex reservoirs in frontier and deep prospects

Despite the advances in seismic and log acquisition and interpretation, 3D and 4D modeling, the risks involved in the exploration of new, deeper, depositional, tectonic or diagenetically-complex prospects remain large. Most new prospects represent clastic, carbonate or other, unconventional reservoirs with strong diagenesis, such as in deep Gulf of Mexico or in the sub-salt prospects of Brazil.

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.

The problem: understanding complex and unconventional reservoirs

Good examples of the importance of integrating systematic petrographic analysis into the workflow of exploration for complex reservoirs can be recognized in deep offshore areas from the Gulf of Mexico and from eastern Brazilian margin.

Deceiving volcanics

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 carried to the deep Gulf systems through the Mississippi system (Fig. 1).

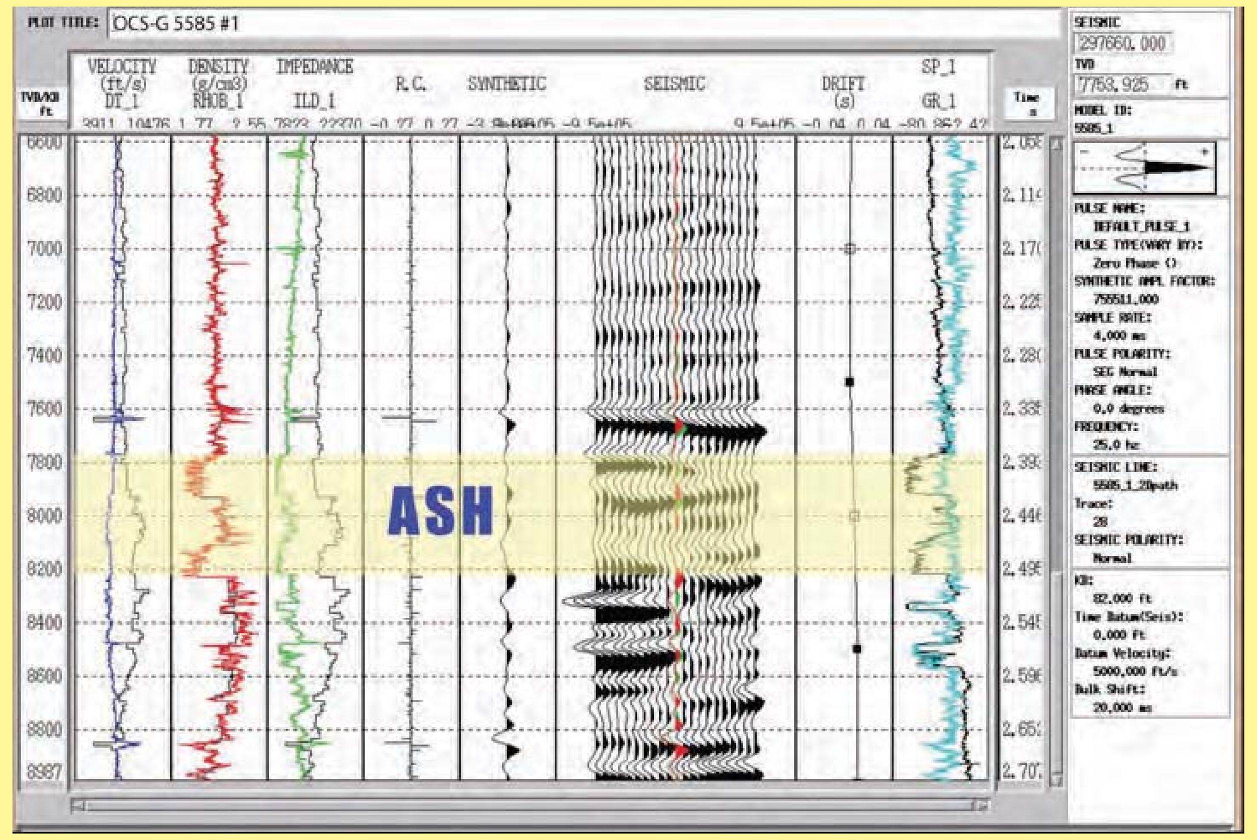

Figure 1 – Synthetic seismogram for Mobil OCS-G 5585 #1 in Ship Shoal 358, where the base of two ash-rich layers generate a fake DHI acoustic response. Graphics by Mathew Totten; AAPG Explorer December 2006.

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. 2).

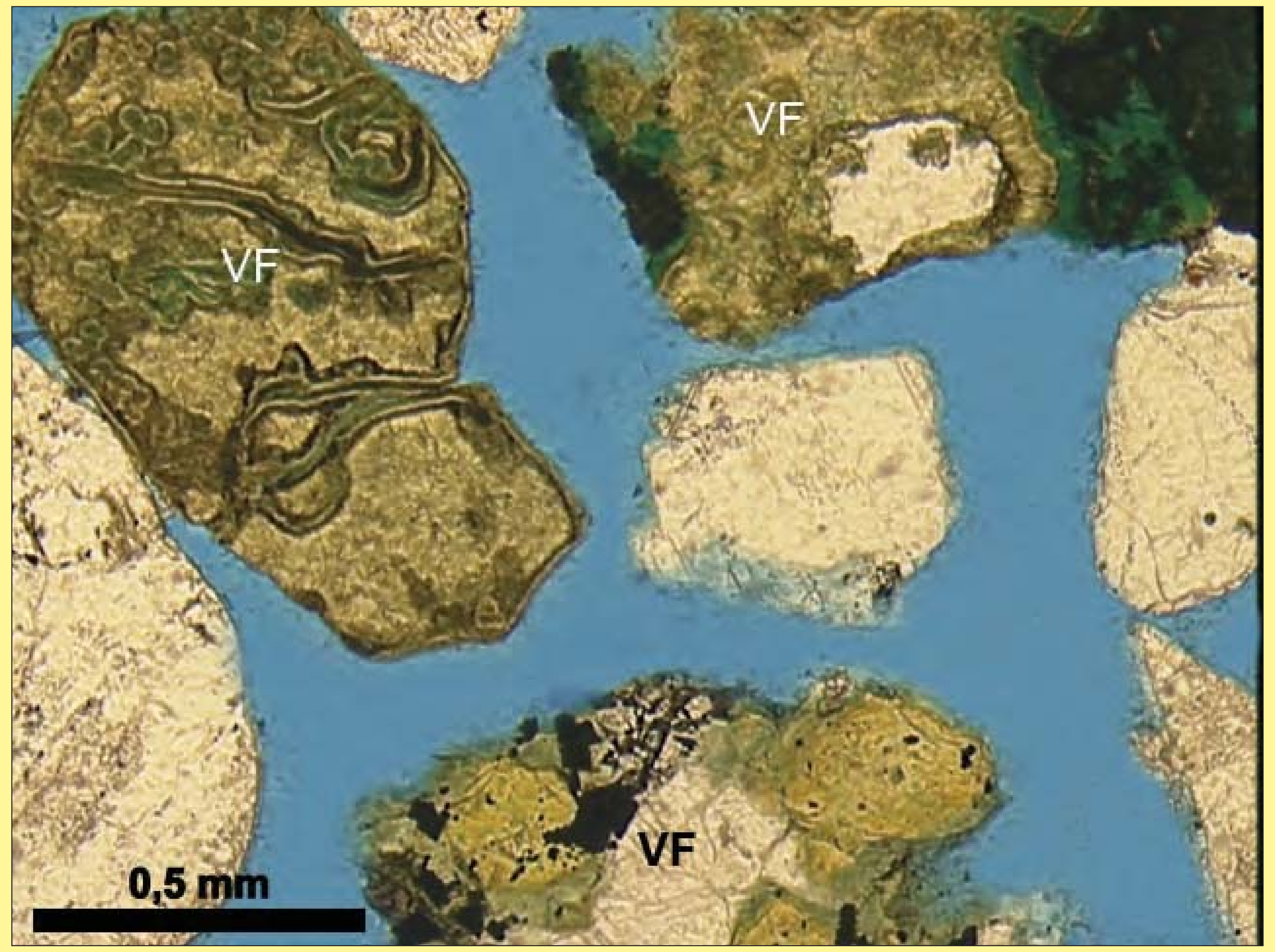

Figure 2 - Optical photomicrograph of vitreous volcanic fragments (hyaloclasts) altered to smectitic and chloritic clays in upper Cretaceous sandstones of the Santos Basin, Brazil, where they can mimic seismic amplitude anomalies very similar to oil-saturated sands. Uncrossed polarizers.

Chlorite magic

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 (Fig. 3). The same effect was also identified in Jurassic reservoirs in the Gulf area and in the North Sea. 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.

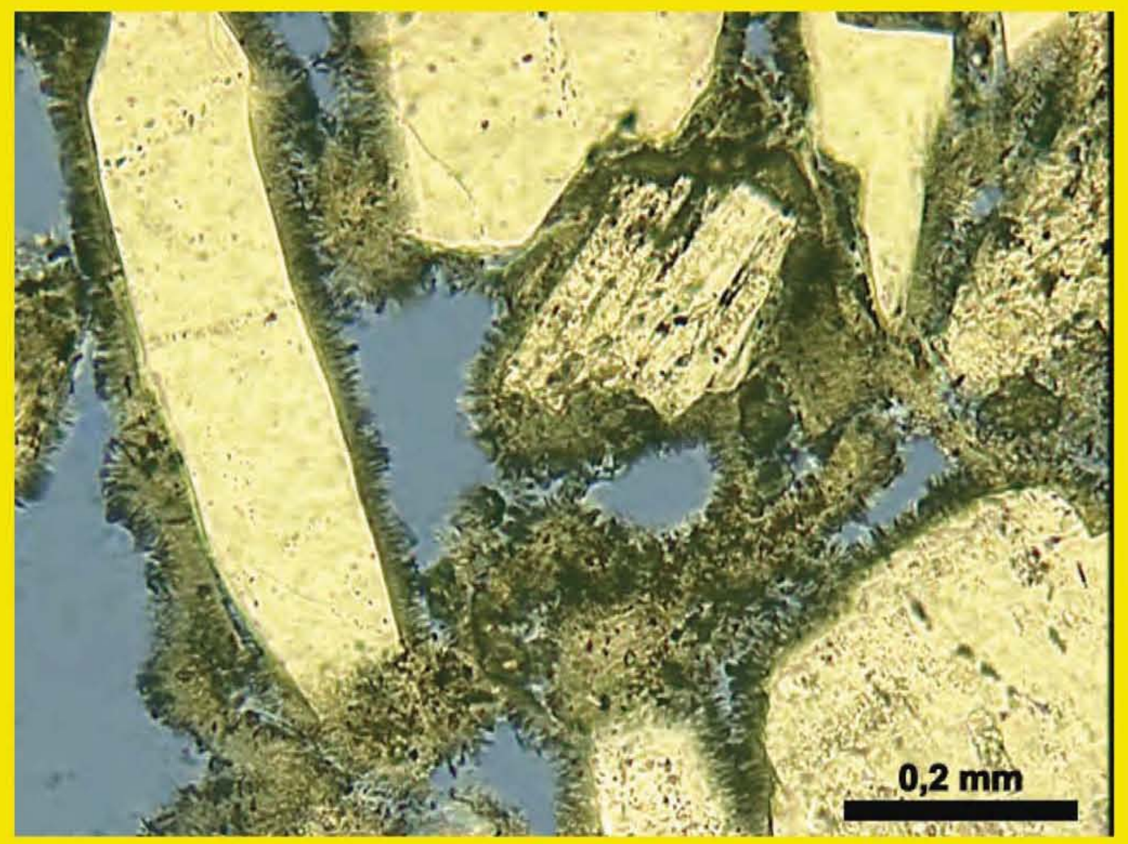

Figure 3 - Chlorite rims (green) help to preserve anomalously high porosity (blue) values in deep (→ 4000m) upper Cretaceous sandstones of Santos Basin, although reducing permeability and resistivity. Uncrossed polarizers.

Sub-salt peculiars

The recent discoveries of giant, early Cretaceous, sub-salt oil and gas accumulations in the deep and ultradeep 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, which evolution and relationships with facies and primary compositional controls, or with burial history are yet to be understood. Many of these sub-salt reservoirs correspond to microbialites similar to the stromatolitic or tufa deposits of some Quaternary lacustrine environments (Fig. 4).

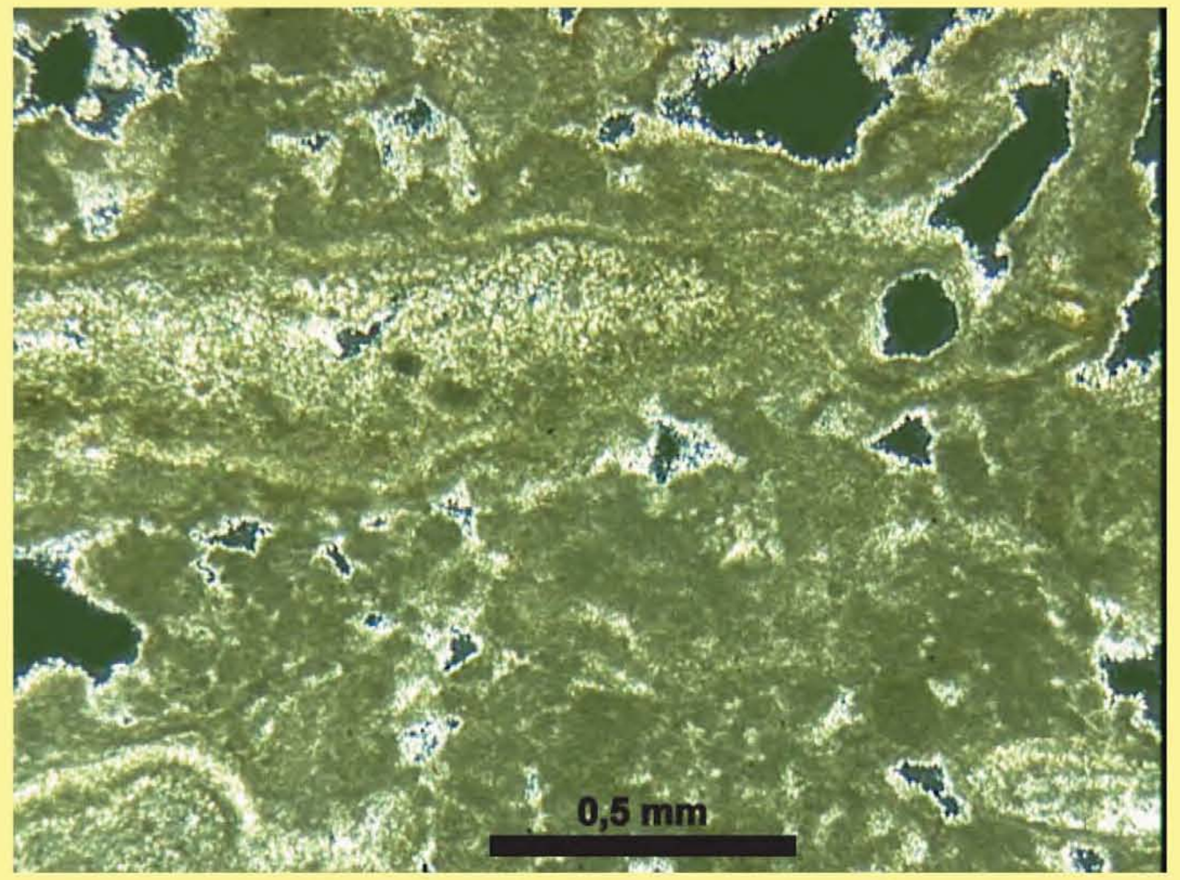

Figure 4 – Pleistocene lacustrine microbialite with petrographic features similar to some of the pre-salt reservoirs from Brazil. Crossed polarizers.

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. 5). Systematic petrographic, geochemical and stratigraphic studies will have to be developed for **reservoir quality prediction**, as well as for planning the **production strategies**.

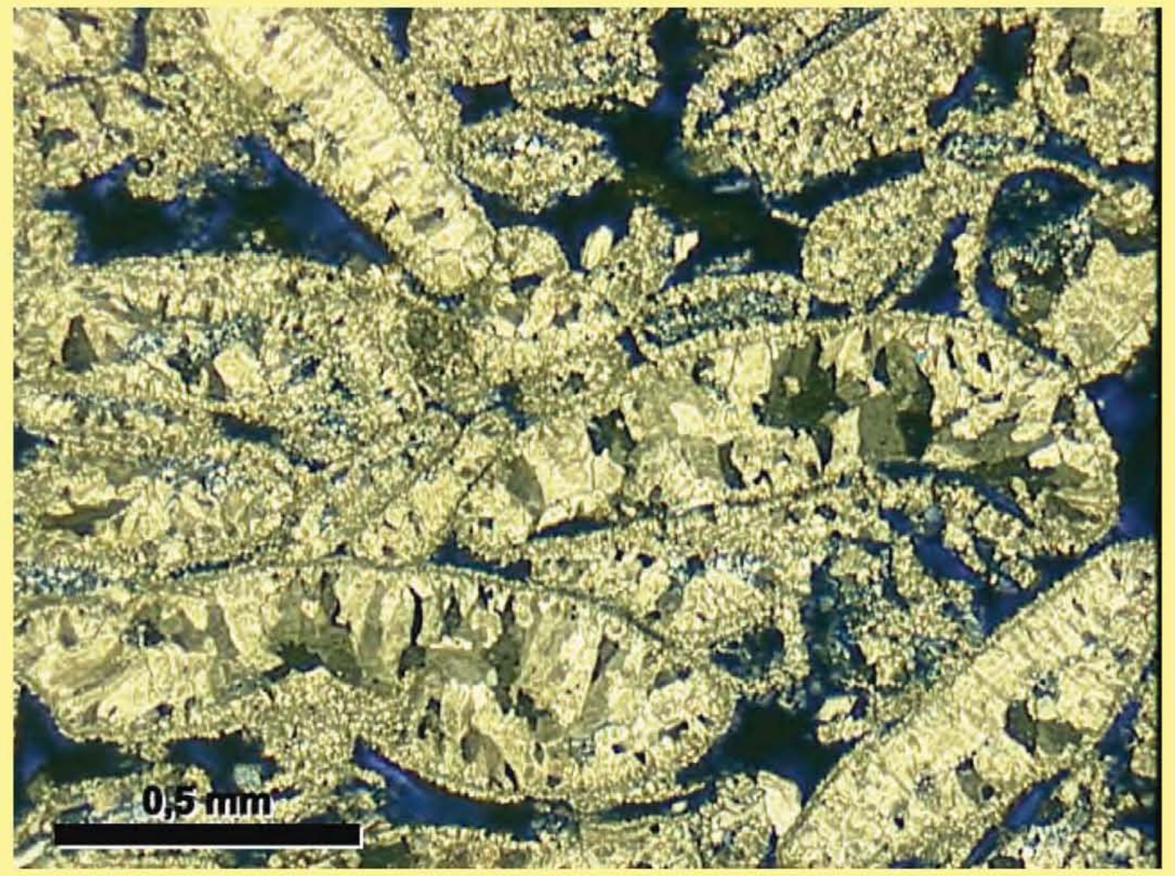

Figure 5 - Recrystallized mollusk bioclasts provide the heterogeneous framework for a lacustrine, lower Cretaceous, sub-salt reservoir in Campos Basin, Brazil. Crossed polarizers.

Increasing recovery from old fields

Another critical frontline involves finding ways to squeeze more oil out of old fields with declining production. This involves:

- achieving a better understanding of these reservoirs to redesign or adjust the secondary or tertiary recovery programs, or,
- 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 to understand the heterogeneities and controls on pore geometry and permeability, such as in the lower Tertiary reservoirs of Talara Basin, Peru (Fig. 6). Detailed models of reservoir quality and heterogeneity incorporating systematic petrography are essential for the design of engineering solutions for production optimization.

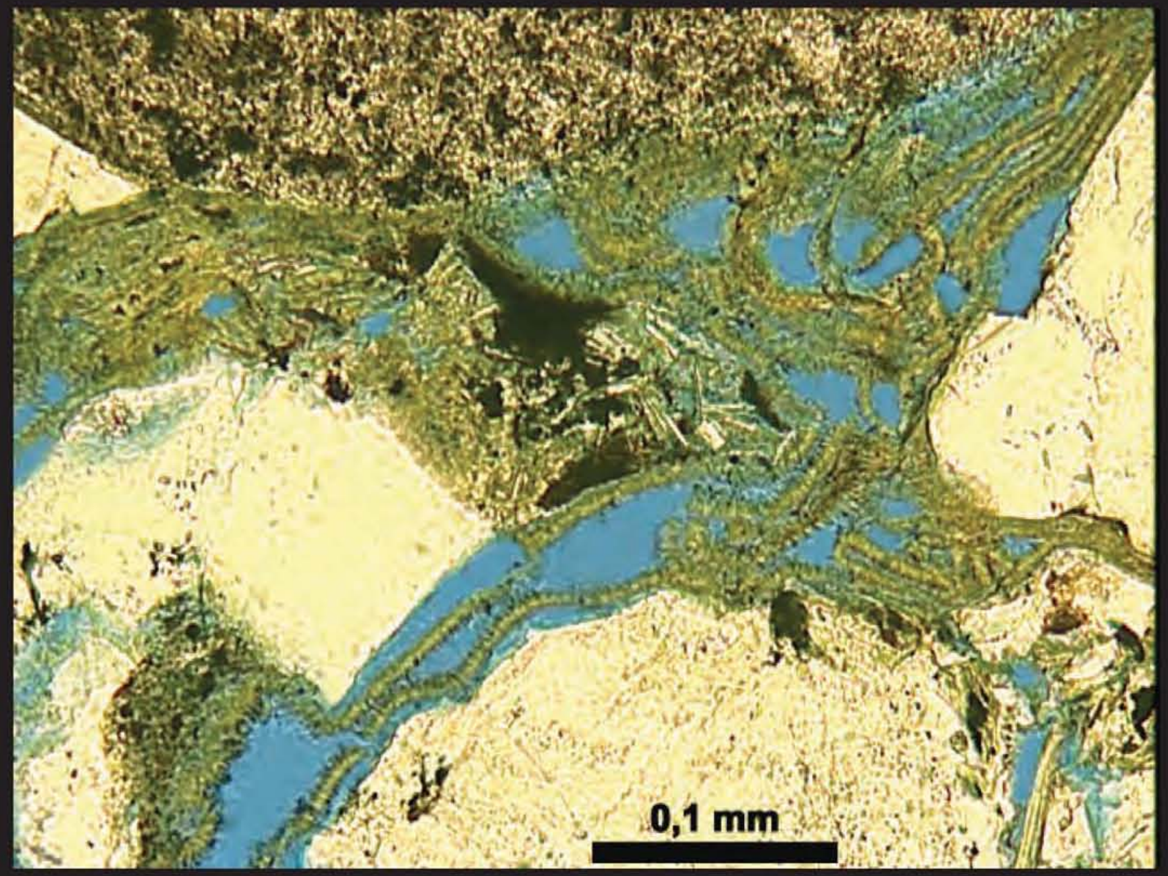

Figure 6 - Optical photomicrograph of multiple smectite rims (green) generating a very complex pore system (blue) and a challenge to the enhanced oil recovery from the mature oilfields producing from the Echinocyamus Formation (Eocene) in the Talara Basin, Peru. Uncrossed polarizers.

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 is obvious. Systematic **petrographic** data must be used to **calibrate** the indirect characterization and evaluation of reservoir quality provided by **seismic** and **logs**, so that log facies and seismic units and reflectors can be **related to real petrophysical attributes**. Therefore, there is an emergent trend of integrating petrographic analysis with log, petrophysical and seismic studies.

The need of organizing detailed petrographic data for effective, systematic use in E&P has led to the development of Petroledge®, an **intelligent database system** combining resources from relational databases and knowledge-based expert systems. The system supports 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 (which are commonly more important than the types of constituents themselves), and pore types (Fig. 7). Such systematically-organized petrographic information can be effectively integrated into reservoir models and flow simulation software.

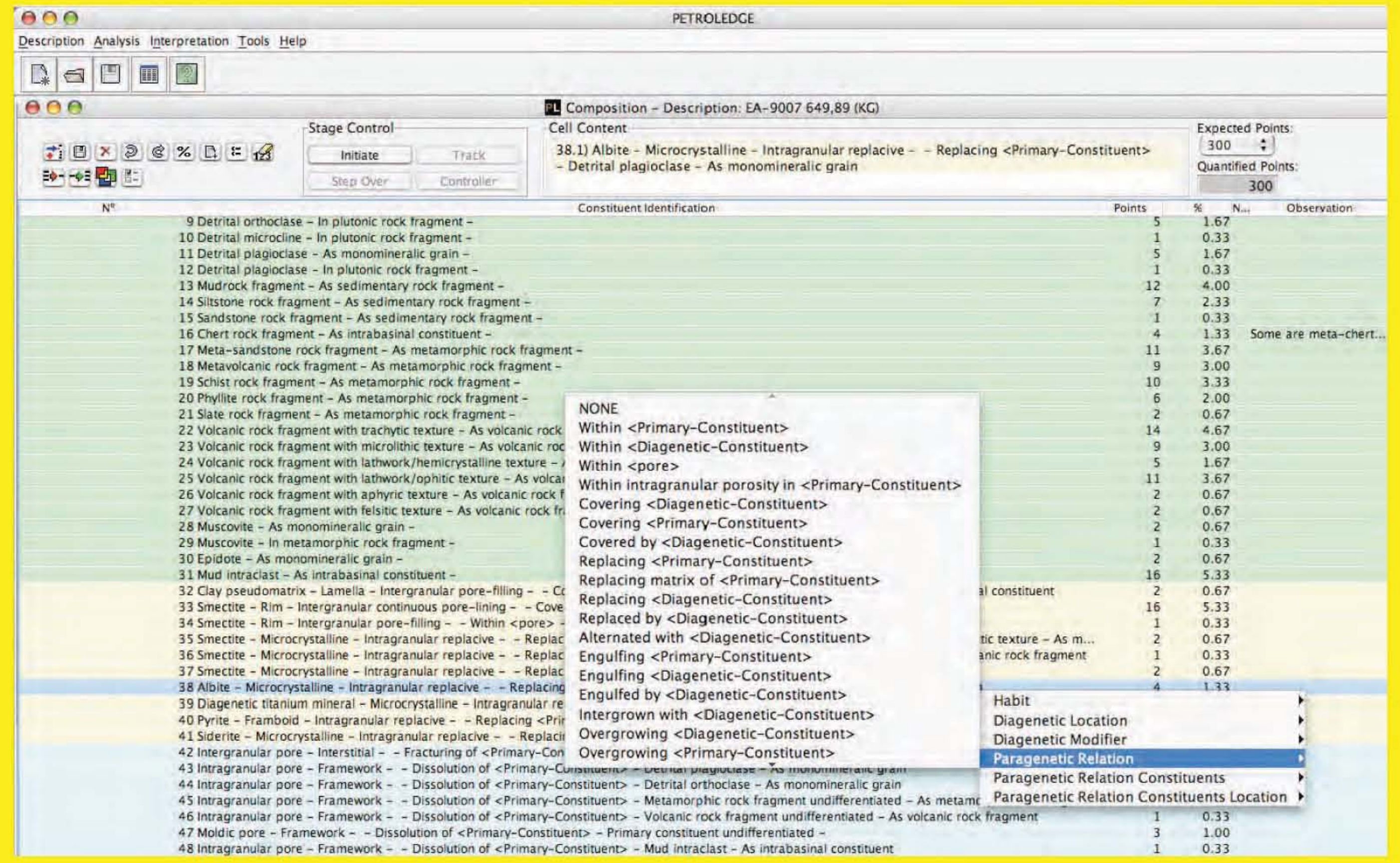

Figure 7 - Example of a Petroledge® system compositional screen, showing the degree of description detail allowed by the system and demanded for the systematic petrographic characterization of complex reservoirs.

Reservoir petrofacies

The intrinsic quality of petroleum reservoirs (porosity, permeability) is controlled by key petrographic parameters, comprising 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. Reservoir petrofacies defined according to these quality-controlling parameters can be effectively used 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 seismic attributes with true rock properties (Fig. 8).

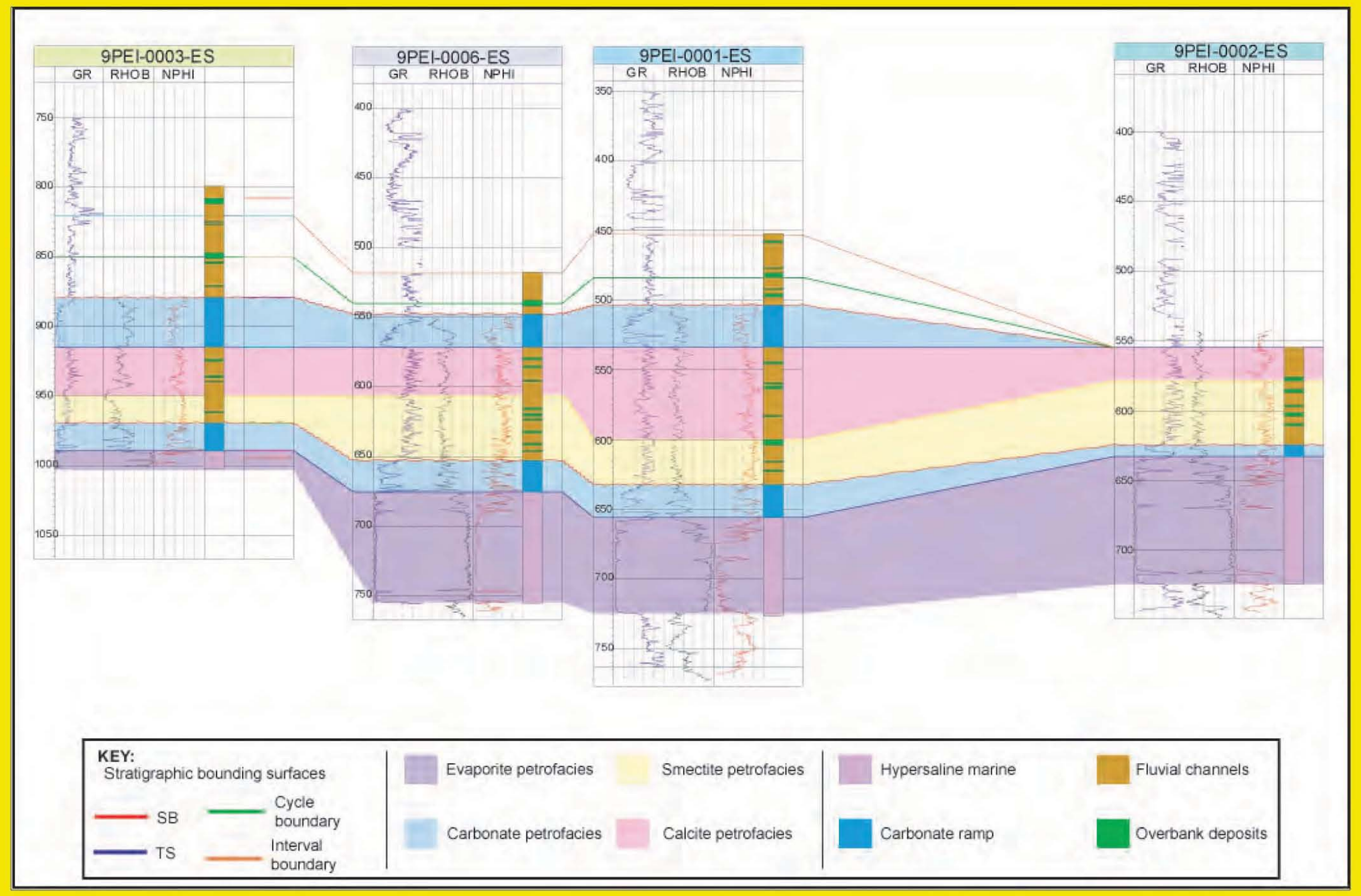

Figure 8 - The clastic smectitic and calcitic, the evaporitic and the carbonate petrofacies defined for the Albian São Mateus Formation, Espirito Santo Basin, eastern Brazil, are readily identified in wireline logs by their gamma-ray, density and neutron signatures.

Logs calibrated by reservoir petrofacies can then be applied to realistic representation of reservoir quality and heterogeneity in 2D sections and 3D models, 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 enhanced **3D and 4D models incorporating RQ prediction** through advanced petrographic characterization 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 seismic, log, petrophysical and petrographic data will involve much more than merely the integration of files and formats, but also the semantic integration at the level of applications. Different tools have not only distinct representation of the geological objects, but also capture different views and meanings of these objects.

Conclusions

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.