Heterogeneities Characterization of Carbonates: A ‘Multi-scale Challenge’*

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Abstract

The geoscientists face significant technological challenges in characterizing, modeling, and producing the carbonate reservoirs due to the genesis of carbonate rocks, their burial history and successive transformations (diagenesis). Those challenges centre on the tools and methodologies used for both studies and analyses, and concern all the players in the geoscience studies’ workflow. In the course of the operational studies for evaluating and optimising our reservoirs, geological heterogeneities, whatever their scale, have to be characterised, quantified, and modeled, taking the associated uncertainties into account.

Carbonate reservoirs, originating from fossilized living beings and multiple paleoenvironmental contexts, reflect the full complexity of the processes that formed them: variety of sedimentary facies and of the fauna and flora within; diversity of the original climatic conditions and successive diagenetic events that have shaped them since early lithification and throughout burial. All of these phenomena contribute to their highly complex geology and intrinsic heterogeneity.

Geological heterogeneity comes in several types and can be found at several scales:

- at microscopic rock texture scale, it is essentially related to the size of the rock’s grains and pores, and therefore stems directly from the facies and the diagenetic history of the deposits. This scale of heterogeneity is studied *via* cores and logs and can have a drastic effect on reservoir quantification.

The microporous reservoirs for instance, may display specific facies described in rock core studies as resembling a “leopard like” (Figure 1), and corresponding in fact to subtle differences in the pore texture. These differences have to be quantified and modeled, and compared with the apparent inconsistencies between saturation calculations and production.

The challenge is therefore to reconcile geological and petrophysical facies. This is the objective of the rock-typing process (Figure 2), where the rock type is a combination of the geological facies and its petrophysical behavior quantified in terms of porosity, single-phase permeability, capillary pressure, wettability and relative permeability.

A specific workflow has been then developed by Total, based on both in-house and Commercial software applications and drawing on 30 years of Total group experience on carbonate reservoirs worldwide plus more than 10 years of R&D work in sedimentology, diagenesis, and petrophysical synthesis. It reflects an integrated approach incorporating different specialties.

- at plurimetric scale, that of the sedimentary body or stratigraphic sequence, heterogeneities of several types must also be described and quantified: those which will inhibit flow in the reservoir during production and those which, on the contrary, represent preferential drains. In the case of carbonates, the first are chiefly related to two phenomena:
  1/ a fine-grained and muddy source deposit which generally loses all intercrystalline porosity during burial and is only rarely affected by secondary dissolution
  2/ the circulation of diagenetic fluids, which cements the original porosity and partially or completely destroys permeability.
  The characterization and extension of permeable drains demand an approach combining information from several sources: core descriptions, log interpretation, the field's dynamic data, seismic, and analogue data. It has been shown that the presence of drains is mainly related to:
  1/ diagenetic phenomena, such as the very permeable dolomite levels of the Khuff reservoirs in the Middle East,
  2/ fracturing, or
  3/ karstification phenomena as found on many carbonate fields worldwide.

In all cases, the heterogeneities have to be characterized in terms of permeability and their extension determined before they can be represented in 3D reservoir models. Quantifying heterogeneities at reservoir or field scale lie in a sound knowledge of the concepts, in studies of analogous reservoirs past and present, and in a suitable policy for acquiring data from the field. A successful reservoir characterization is one which describes the heterogeneity of the reservoir properties, but above all which relates the static description to the current or future dynamic behavior of the field.

To establish that relationship, the analysis of the different dynamic data available (from the laboratory, the well, or the field) must be quickly integrated into the static characterization, so as to gain adequate insight into the flow patterns in the reservoir, and define the scale of the major heterogeneities to be modeled.

Considerable technological stakes revolve also around the contribution of seismic to this process in carbonates. Effectively, the multi-scale heterogeneity of carbonate reservoirs and their geological environment often combine to interfere with their seismic signature.

During the last few decades, the quality of seismic data has constantly improved in response to these reservoir characterization issues. The 1990s witnessed the advent of 3D seismic technology, the only method capable of imaging all the reservoirs as a single, continuous spatial whole. The endless leaps forward in data recording capabilities, available for operational use since the 2000s, have enabled us to design "wide azimuth" and "high fold" acquisition geometries that can perform structural imaging with greater spatial resolution and less unwanted artifacts and background noise. And with seismic information as reliable as this, we can make ever more quantitative use of 3D seismic data set.

We will show how Total geoscientists teams face the technological challenge of characterizing the adequate scale of heterogeneity from different examples of its Carbonates fields portfolio.

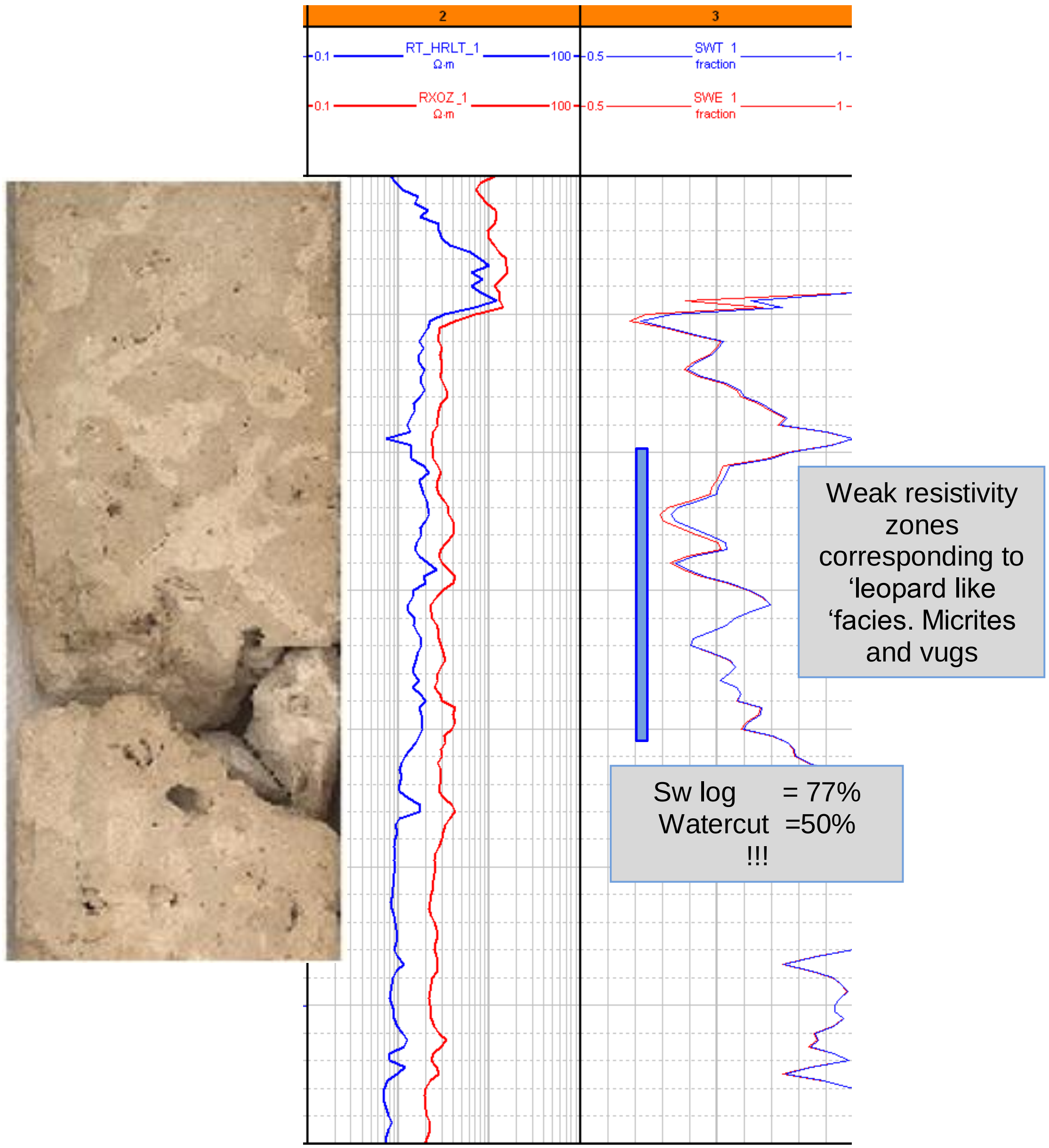

Figure 1. 'Leopard like' textures heterogeneous facies

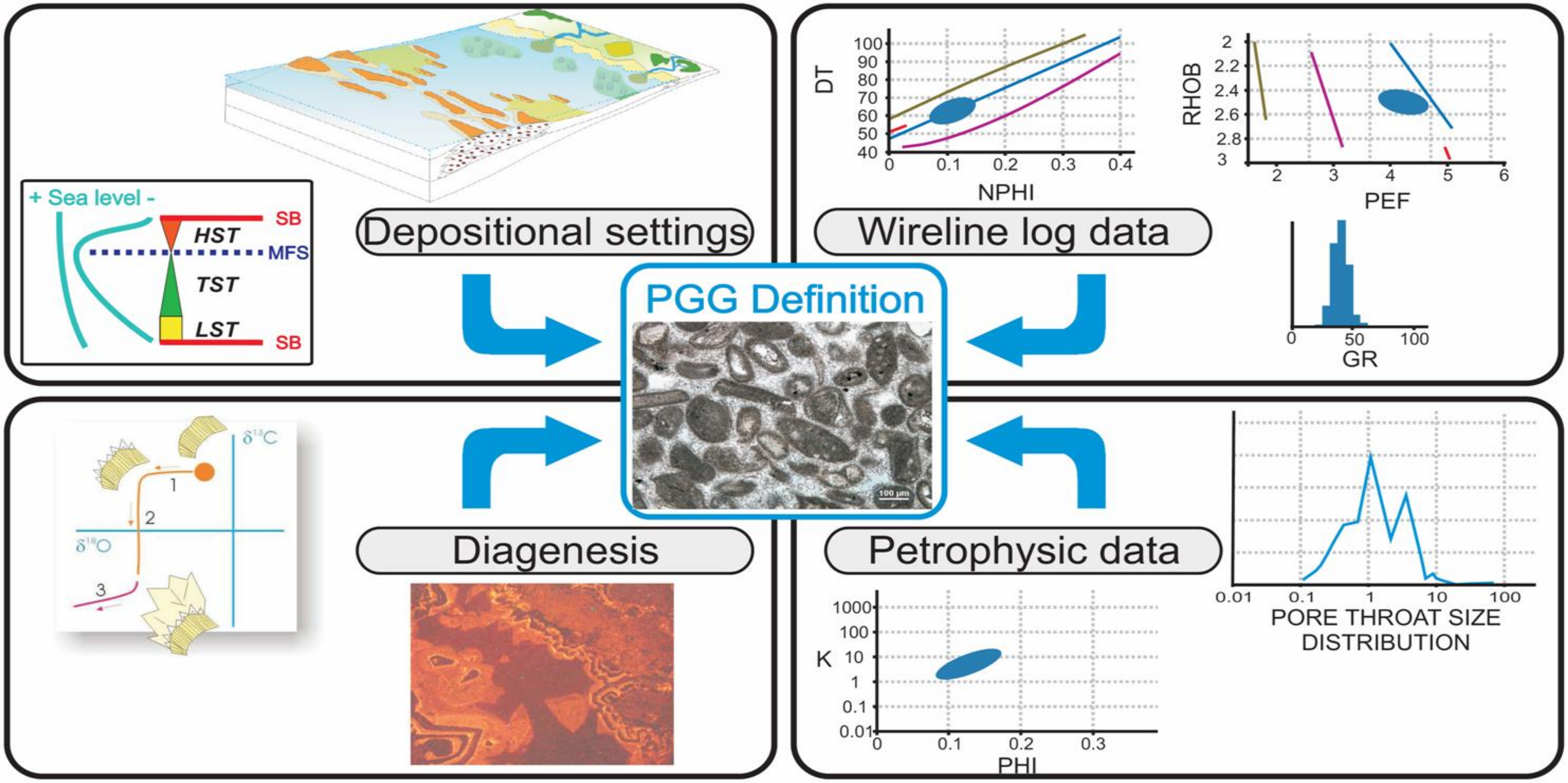

Figure 2. The rock typing workflow.