Foreword

As its name implies, petrophysics is the study and measurement of the physical properties of rocks. As soon as you start to take an interest in this field, you are struck by the duality between the "Physics" aspects and the "Geology" aspects. In most publications, the "Physics" aspect prevails, in other words the quantitative description of the laws governing the phenomena affecting the rocks subject to various stresses: hydraulic, mechanical, electrical, etc. The rock itself is generally no more than a "black box" whose microscopic structure is never described, or at best very briefly, as a model sometimes far remote from reality. This is because the evident rich diversity of the natural porous media scares the physicist, as expressed so well by G. Matheron [in French, 1967] *"…ces millions de grains et la variété inépuisable de leurs formes et de leurs dimensions…."* ("…these millions of grains and the inexhaustible variety in their shapes and dimensions…".

Yet, how can we understand the anomalies sometimes observed in fluid flow or capillary equilibria within a rock without a vital piece of information, the description of a feature in the geometry of the pore space? But above all, if we are to scale up highly isolated petrophysical observations to an entire oil reservoir or an aquifer, it is essential to implement the powerful extrapolation tool of "geological interpretation". This is clearly based on a good understanding of the relations between the petrophysical parameters studied and the petrological characteristics of the rock considered. *This "Geological" approach of Petrophysics is at the hub of our project.*

Firstly, however, we must define our perception of the field of petrophysics and clarify the terminology, since two virtually identical terms, "Rock Physics" and "Petrophysics" coexist.

The term "Rock Physics" was popularised by Amos Nur, who developed a famous "Rock Physics" laboratory at Stanford University in the 70's. The field assigned to Rock Physics is basically both quite simple to define… and extremely vast: study the physical properties of geological materials, focusing in particular on the properties implemented in the various applications: electrical, hydraulic, nuclear, mechanical (static and dynamic) properties. The term "Petrophysics", which is older (G. Archie?), initially referred to the study of "reservoir" properties in an exclusively petroleum environment. At the present time, both terms coexist and are used in slightly different ways (although the distinction remains vague): "Rock Physics" is used mainly in university environments, often concerning mechanical or magnetic properties; "Petrophysics" is preferred by the oil exploration-production community, with a strong emphasis on hydraulics. A quick search for these two key words on an Internet search engine gives approximately the same number of hits for “Petrophysics” and “Rock Physics”.

A relatively recent terminological evolution is noticeable, resulting in the inclusion of “Log Analysis” in “Petrophysics”. In 2000, the journal “The Log Analyst” published by the Society of Petrophysicists and Well Log Analysts (SPWLA), was renamed “Petrophysics”.

In this book we will only use the term “Petrophysics” and consider it in its usual common meaning, which is slightly restrictive: study of the physical properties of rocks focusing on the storage and flow of the fluids contained within them. We will investigate more specifically the properties related to the greater or lesser presence of a porous phase inside the rocks. This porosity will play a central role in our descriptions. The *raison d’être* of Petrophysics, as we will describe it, lies mainly in its relation to petroleum, hydrogeological and civil engineering applications.

The book is divided into two sections of unequal size:

The first section (by far the largest in terms of the number of pages) describes the **various petrophysical properties of rocks**. *Each property is defined, limiting the mathematical formulation to the strict minimum but emphasising, using very simple models, the geometrical (and therefore petrological) parameters governing this property*. The description of the measurement methods is restricted to an overview of the principles required for good communication between the geoscientist and the laboratory petrophysicist. For each property, we detail one or two aspects of the relations between petrophysics and geology which we feel are of special interest (e.g. the porosity/permeability relations in carbonate rocks for single-phase permeability, or irregular water tables and stratigraphic traps for capillary equilibria).

The various properties are classified into three subsets according to their main use in the study of oil reservoirs or aquifers (this organisation also allows us to consider the cases of perfect wettability and intermediate wettability separately, making it easier to expose capillary phenomena):

a) Calculation of fluid volumes (accumulations); **Static properties:** *Porosity* and C*apillary Pressure* in case of perfect wettability.

b) Fluid recuperation and modelling; Dynamic properties: *Intrinsic permeability*, *Wettability*, *Relative Permeability* and End Points.

c) Log and geophysical analysis; *Electrical properties*: Formation factor and saturation exponent, *Acoustic properties:* Elastic wave velocity, *Nuclear Magnetic Resonance* and its petrophysical applications. This third subset acts as a link with log analysis, a technique which is increasingly considered as being part of petrophysics. We provide a description of the most general principles without discussing log analysis as such.

The second section, which concentrates on methodological problems, provides a few notions which are at the root of the problems on the understanding and applicability of petrophysics.

It concerns, above all, **the representativeness of the measurements and the size effects,** so important for extrapolation of results and characterisation of reservoirs.

In this context we describe a few general points on the *effect of stresses and temperature* on the petrophysical characteristics. These effects are described separately for each property, however, in the first section. We therefore decided, perhaps rather over-simplifying matters in the process, to consider compressibility as "the effect of stresses" on the porosity.

The notions of *Representative Elementary Volume, Homogeneity, Anisotropy* provide a better understanding of the problems of *up-scaling*, for which a few examples are given (plug, core, log analysis, well test). After giving the most pragmatic definitions possible, we give a few examples concerning *permeability anisotropy* or the consequences of *saturation inhomogeneity* on the acoustic or electrical properties. The consequences of these size effects in reservoir geology are particularly spectacular in the contrast between matrix property (centimetric scale) and bulk properties (plurimetric scale) as observed in the fractured reservoirs, which will only be discussed briefly.

We then mention the extrapolation of petrophysical properties and characterisation of reservoirs using the *Rock Typing methods* which still remain to be defined, a clear consensus not having yet been reached.

Lastly, we provide a description of several **Porous Network investigation methods**. We describe in short chapters the methods used to observe these networks at various scales: *Thin sections, Pore Casts, Visualization of capillary properties, X-ray tomography*. Each method offers an opportunity to give a few examples of porous geometries. A brief overview of *X-ray diffraction* technique is proposed.

Concerning the **Bibliography**, we decided not to follow a certain inflationist trend. We restricted the list to the English texts explicitly referred to in the document. We made occasional exceptions to this language rule for some "reference" documents or for French documents from which we have extracted data.

We wanted to pay special attention to the **Index**, mainly since we know from experience just how important this is for readers. But also since a detailed index simplifies the plan. Rather than trying to produce a perfect logical order to introduce various notions, which rapidly turns out to be a very difficult task, we decided instead to insert numerous cross-references in the text, allowing readers to obtain all the details they need. The numerous porosity terms are often confusing, we try to clarify this in a "*porosity terms glossary-index*".