The ART NMR Carbonate Rock Catalogue: A Library of NMR Response Characteristics in Carbonate Rocks.

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Introduction

Strategies for the evaluation of sandstone pore space geometry using NMR and special core analysis are well founded. Models have been developed to interpret pseudo pore sized distributions obtained from NMR data. These include models to separate free/mobile water from capillary bound and clay bound water. Such studies on carbonate pore systems are rare. The ART NMR carbonate rock catalogue was established to provide an extensive database of rock properties for a wide range of carbonate rock types. The catalogue can be used to provide useful information for the evaluation of pore geometry. As well as guiding the acquisition, processing and interpretation of NMR logs in carbonate hydrocarbon reservoirs. Experimental analysis includes:

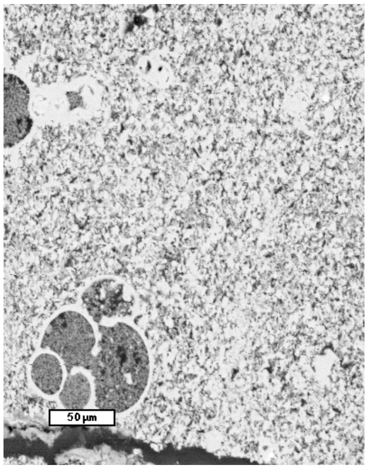
- 2MHz NMR experiments (T1 and T2 data)
- 10MHz MRI experiments
- Routine core analysis data (including air/brine centrifuge)
- X-Ray CT
- Core photographs
- Back-scattered Electron Image (BSEI) analysis (digitised SEM images)
- Mercury Injection Capillary Pressure (MICP) experiments
- Traditional thin-section petrography
- Magnetic susceptibility data

The Samples

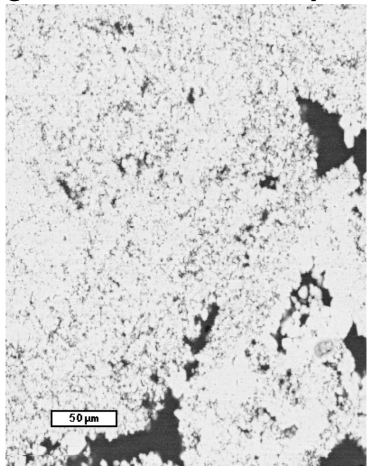
The catalogue contains laboratory data from core plugs and whole cores in brine-saturated and desaturated state. The samples were selected to capture variation in pore geometry. The table below illustrates the sample types analysed and their variation in porosity and permeability.

Sample Type	**Origin**	**Porosity Range (% P.V.)**	**Permeability Range (mD)**
Chalk	North Sea	12 - 44	0 – 3.8
Diagenetic Chalk	Abu Dhabi	18 - 28	0.6 – 449
Microcrystalline Dolomite	Texas	1 - 21	0,04 – 29
Oolitic Limestone	Tunisia & Kansas	14 - 37	0.4 – 19
Sucrosic Dolomite	Oklahoma	4 - 8	0.01 – 0.09
Vuggy Dolomite	Alberta	2 -15	0.2 - 1333

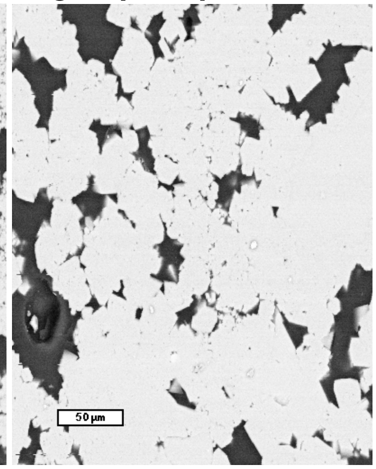
Back- scattered scanning electron microscope images (BSEI) of selected samples



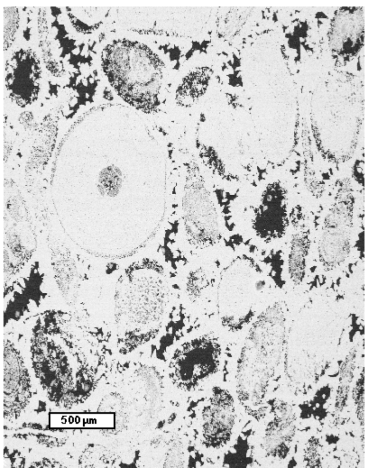
Chalk



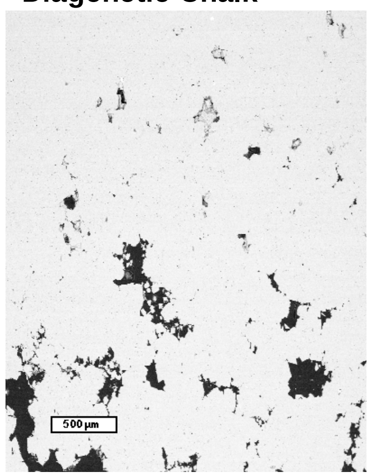
Diagenetic Chalk



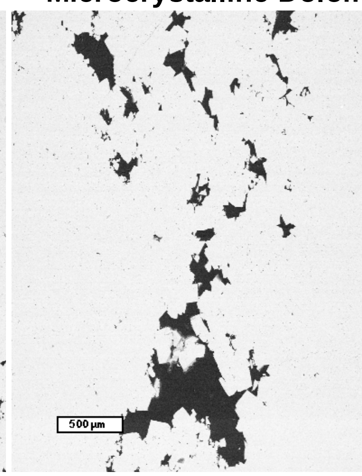
Microcrystalline Dolomite



Oolitic Limestone



Sucrosic Dolomite



Vuggy Dolomite

Whole Core Versus Core Plugs

Carbonate rocks are known to contain extreme heterogeneity. Test samples must be of a correct scale to capture all the heterogeneity. It is interesting to compare NMR data from a whole core and core plugs. A fully saturated chalk whole core sample of porosity 43% and permeability 3.8mD was analysed in a 10MHz NMR spectrometer. The resulting T_2 distribution was found to have the same shape as the T_2 distribution obtained from a 38mm diameter plug cut from the whole core. See figure 1. The difference in the major T_2 peak location for the chalk whole core and plug samples is only 5 milliseconds.

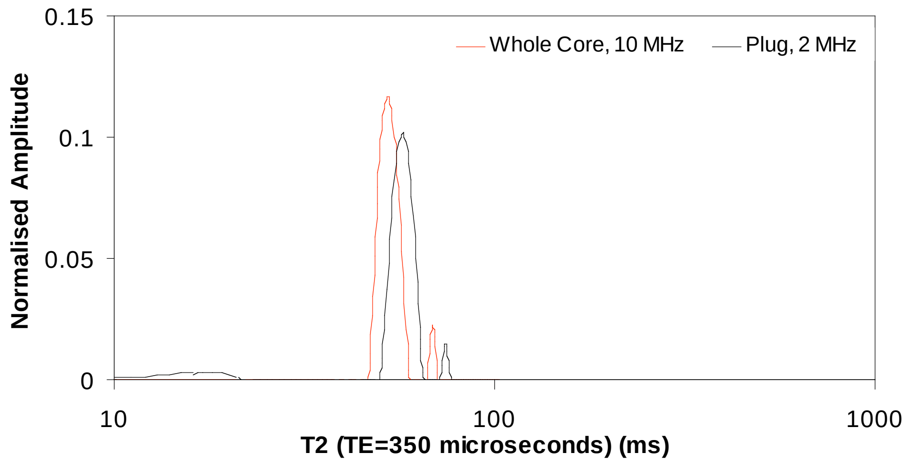


Figure 1: NMR T_2 Distributions for Whole Core and Core Plug Chalk Samples.

The same analysis was performed on a vuggy dolomite whole core sample. The location of major peaks within the T_2 distribution are almost identical to those of the core plugs cut from the whole core , figure 2. Note that the core plugs contain longer time T_2 responses than the whole core sample this is probably due to plugging opening large, previously inaccessible, vugs.

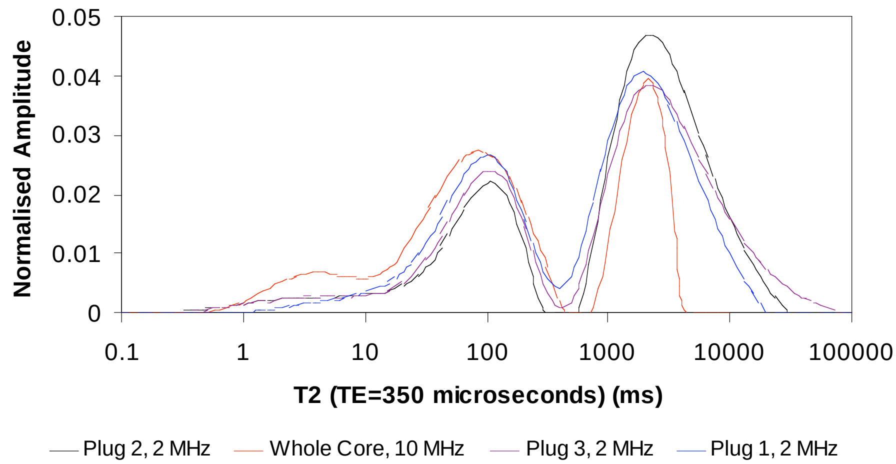


Figure 2: NMR T_2 Distributions for Whole Core and Core Plug Vuggy Dolomite Samples.

- The whole-cores are often heterogeneous.
- Unexpected similarity between bulk T1 and T2 distributions from whole-core (10MHz) and core-plugs (2MHz).
- The similarity in NMR response between whole-cores and core-plugs demonstrates two important issues:

i) First, core-plug selection has successfully captured the variation in pore-size within whole-cores.
ii)Second, broad similarity exists between NMR experiments conducted on different sample volumes measured at different frequencies.

Pore Space Analysis

The data within the carbonate rock catalogue allows us to analyse pore size information obtained from different measurement techniques. A comparison of pore size distributions obtained from mercury injection, BSEI and NMR T_2 measurements can be made. It is possible to match peaks in mercury injection pore size distributions with those in T_2 distributions. Figure 3 shows data for a chalk sample. The sample has pores from 1 micron down to 0.1 micron as well as isolated large, open pores formed by open forams.

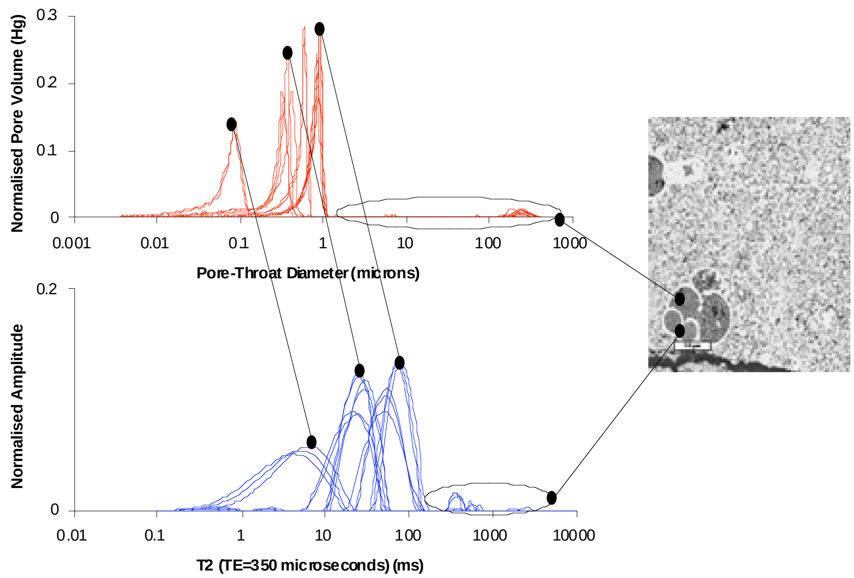


Figure 3: Comparison of Mercury Injection Derived Pore Size Distribution and T_2 Distribution for North Sea Reservoir Chalk Samples.

Vuggy dolomites contain large numbers of small pores below 10 microns as well as large pores greater than 100 microns. Fluids within this type of pore system can move from the macro to the micro porous regions, this is known as diffusive pore coupling. The effects of diffusive pore coupling on the T_2 distributions measured on a vuggy dolomites sample are shown in figure 4. The T_2 distribution for a fully saturated vuggy dolomite sample, has a bi-modal distribution indicating two distinct pore size ranges. The sample was de-saturated to irreducible water saturation and the T_2 distribution re-measured. The de-saturated T_2 distribution lacks any long time signal, due to drainage from large pores. The de-saturated T_2 distribution also has a significantly reduced short time signal compared to the saturated T_2 distribution. This indicates either drainage from the micro-pores or diffusion pore coupling from macro to micro pores. Drainage of water from the micropores is unlikely at the pressures used to desaturate the sample. Thus enhancement of the short time saturated sample T_2 peak due to diffusive coupling from macro to micro pores probably occurs.

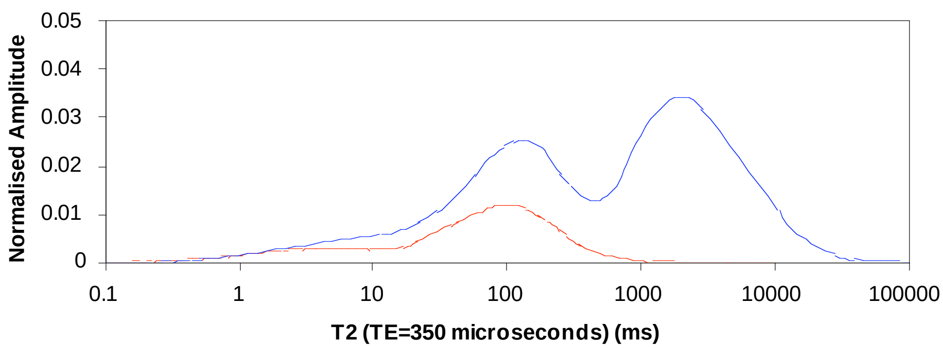


Figure 4: Saturated (blue) and Desaturated (red) T_2 Distributions for a Vuggy Dolomite Sample.

Paramagnetic Samples

Analysis of NMR data often ignores the existence of paramagnetic minerals. Figure 5 illustrates the effect of paramagnetic minerals on the T_2 response. Paramagnetic minerals within pores of chalks and sucrosic dolomites have fast T_2 responses for a given pore diameter. Diamagnetic samples such as diagenetic chalks and vuggy dolomites have longer T_2 responses for a given pore size.

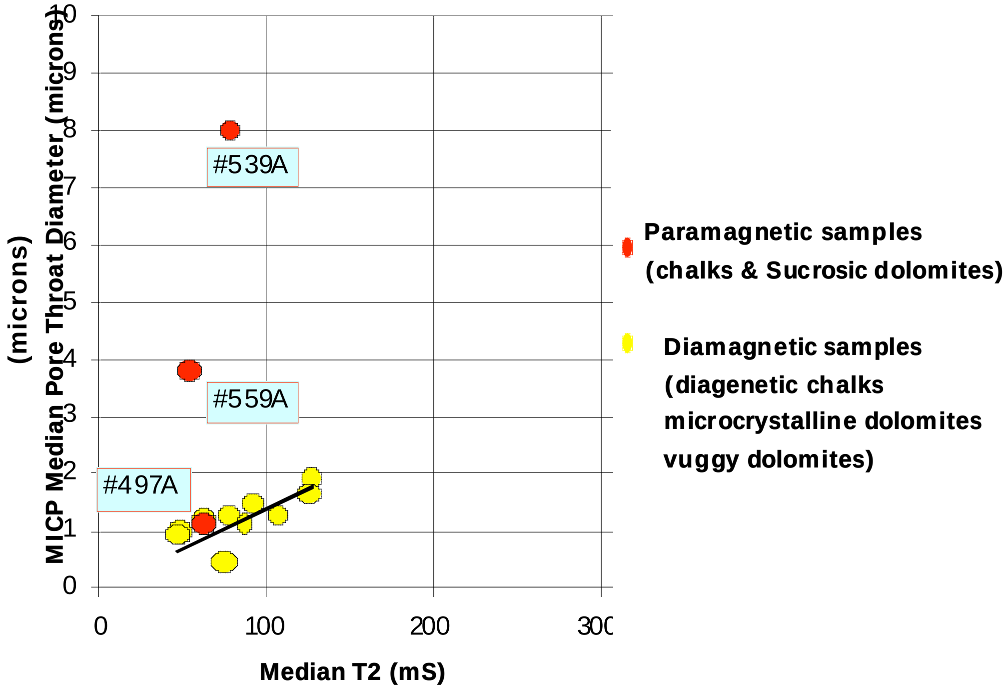


Figure 5: Mercury Injection Derived Pore Size Against T_2 Time for Paramagnetic and Diamagnetic Samples.

Conclusions

- Similarity between bulk T_1 and T_2 distributions from whole-core (10MHz) and core-plugs (2MHz).
- Core-plug selection has successfully captured the variation in pore-size within whole-cores.
- Diffusion pore coupling may occur in samples with micro and macro pores.
- Paramagnetic minerals can influence T_2 distributions.