
● Short Communication

A NMR CHARACTERISATION OF A BANDED SANDSTONE

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¹H-nuclear magnetic resonance (NMR) measurements have been carried out on a banded sandstone to investigate the effects of structural inhomogeneities on the fluid dynamics of the sample as a whole. The results obtained from average propagator measurements (the probability of a displacement z in a time Δ or $P_\Delta(z)$) using pulsed-field-gradient techniques have been compared to those obtained from a study of a homogeneous sandstone. Relaxation has been used to derive the pore sizes for the differing bands and have been found to correlate with flow velocities within the bands. © 1998 Elsevier Science Inc.

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INTRODUCTION

The nuclear magnetic resonance (NMR) techniques for characterising fluid distribution and transport within porous solids are well established.¹ In this paper we use pulsed-field-gradient determination of displacement propagators, $P_\Delta(z)$, relaxation, and one-dimensional imaging methods to characterise a banded sandstone. The sample investigated was made up of a series of narrow bands of varying porosity, pore size, and permeability. All measurements were carried out at $S_{wi} = 0.05$ (the state obtained after the water-saturated rock was subjected to oil flow until no more water was produced); the oil phase was dodecane. ¹H-NMR was measured at 85 MHz using a GE-Ω spectrometer equipped with S-150 actively shielded gradients (GE Analytical Instruments, Fremont, CA, USA).

FLOW PROPAGATORS

Figure 1 shows the displacement distributions, $P_\Delta(z)$, for oil flow at 50 mL/h for the values of Δ indicated.

It is clear that, for this sample, significant fractions of the oil phase do not participate in the flow process. Although the interstitial velocity is $107 \mu\text{ms}^{-1}$, corresponding to a displacement of $66 \mu\text{m}$ in 616 ms, it can be

seen that significant probability exists at $400 \mu\text{m}$. This contrasts with the behaviour observed in a larger porosity, more homogeneous sandstone.²

RELAXATION MEASUREMENTS

T_1 and T_2 characteristics were measured using inversion recovery and Carr–Purcell–Meiboom–Gill (CPMG) multiple echoes, respectively. In both cases slice selection was used to avoid end effects.

T_1 relaxation behaviour gave rise to two distinct T_1 values, one at 800 ms (90%) and the other at 11 ms (10%). The values for these two relaxation times are consistent with the model of a water wet rock at S_{wi} . The water content is present in either the smallest pore spaces and/or as a thin layer in contact with the rock grain surfaces. The protons in these environments have ready access by diffusion to the paramagnetic impurities in the rock grains, hence causing a significant reduction (11 ms) of the relaxation time compared to that of the bulk phase. The dominant, longer, relaxation time is assigned to the oil phase, from both its T_1 value and its amplitude. The dodecane can maintain its longer relaxation time, as it is denied access to the paramagnetic impurities present in the grain surfaces by the thin film of water that preferentially wets the surface.

As expected, the CPMG decays were dependent on

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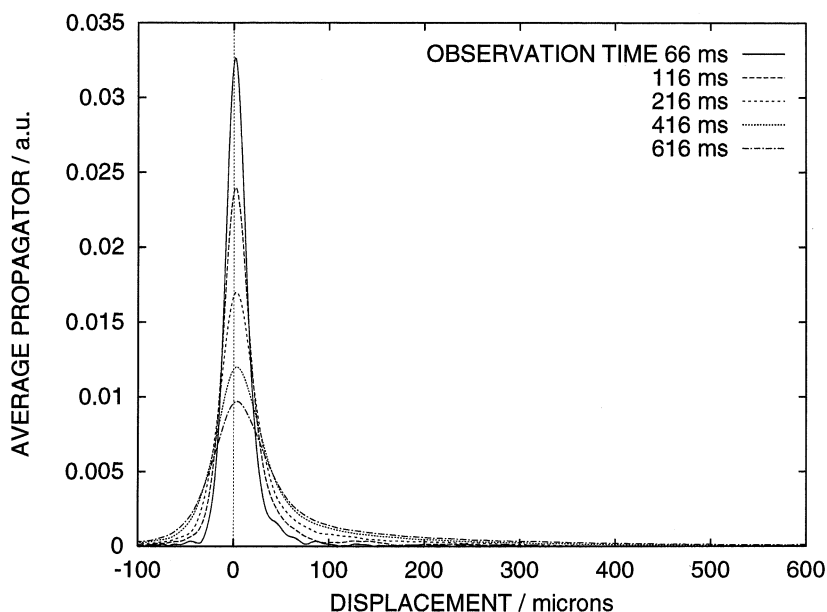


Fig. 1. The variation of the average propagator with observation time along the axial direction of the cylindrical sample of the banded sandstone.

pulse spacing τ and were multi-component, with T_2 values shorter than corresponding T_1 values.

The mechanism for the T_2 behaviour at the field strength used in this study is likely to be diffusion through the non-uniform internal field gradients. A theoretical model for this has been given by Le Doussal and

Sen,³ which can relate the long time relaxation behaviour to pore scale. Figure 2 shows the variation across the sample, in the direction perpendicular to the parallel bands, of the pore size, derived using Le Doussal and Sen's equation A25. The input data was the one-dimensional imaged profile of the CPMG T_2 behaviour (spatial

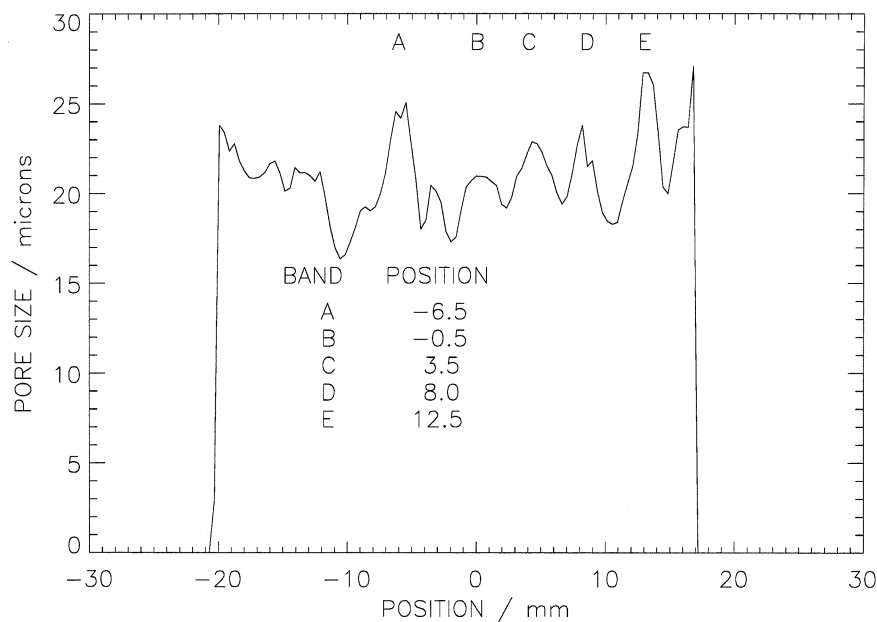


Fig. 2. Profile of pore sizes across the banded sandstone obtained using the Le Doussal and Sen parabolic gradient model.

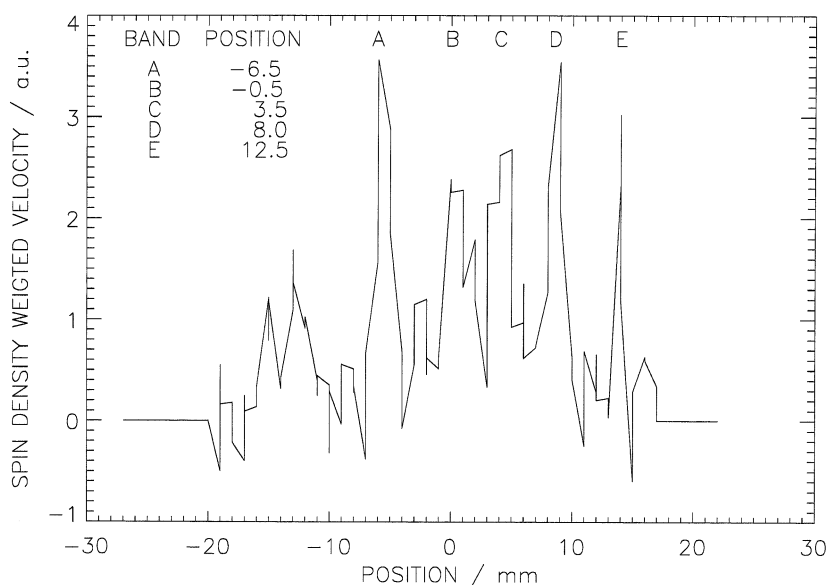


Fig. 3. Profile of bulk flow carried in each band of the banded sandstone sample.

resolution $\sim 400 \mu\text{m}$) taken in the the short time limit ($\tau = 1.4 \text{ ms}$) and using the long time dominant component.

ONE-DIMENSIONAL IMAGING OF AVERAGE FLOW VELOCITY

Because of the inherent constraints of signal-to-noise with increasing spatial resolution, it is usually not practical to determine flow propagators on a pixel basis. However, the measurement of an average displacement (or velocity), which is the first moment of the propagator, $P_{\Delta}(z)$, is readily achieved. Figure 3 shows the spin-density-weighted, one-dimensional resolved velocity image for oil flow at 50 mL/h . There are five main peaks that show a close correlation with similar peaks (A–E) in Fig. 2. Thus, these results show that within this sandstone, flow along the different layers correlates strongly with pore size.

This observation, that the majority of the bulk flow is

carried by only five high permeability bands, is supported by x-ray computed tomography studies on the same sample carried out at British Petroleum Exploration.

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