MRIS History UK

THE DEVELOPMENT OF MAGNETIC RESONANCE IMAGING AND SPECTROSCOPY

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Biography

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Extracted from Who's Who in Scotland 2022

Rex Richards was my supervisor in Oxford both for my Chemistry Part II and for my DPhil. I worked closely with him from 1965-1970 and have much to be grateful to him for. I worked on the NMR of the alkali halides in solution, looking at Na-23, Cl-35 and Cl-37, Br-81 and Cs-133 resonances. I used the first of the Oxford Instruments supercon-magnet NMR machines to make accurate measurements of Cs-133 chemical shifts. I collaborated with several of the outstanding postdocs, visitors and fellow research students, including Gary Haller, Jim Halliday, Don Kydon, Bob Sharp and Gerhard Schulz. Five journal papers came from that work, including two in Proc Roy Soc A. Later I wrote a review of halogen NMR for Quarterly Reviews of the Chemical Society.

As a research student around 1968, I set up the first NMR experiment for undergraduates in the Physical Chemistry Laboratory after Perkin-Elmer donated a spectrometer.

After a stint in the USA, not doing NMR, I was a research associate with Norman Sheppard at U East Anglia, and did some proton NMR on exchange kinetics in a molten hydrate salt. At UEA, I was in good contact with Robin Harris. After UEA, I went to Manchester/UMIST as a lecturer in materials engineering. I became interested in capillary water transport in porous materials, and around 1976 I thought that NMR imaging might be a powerful way to study water distributions and how they varied with time. Rex Richards put me in contact with Raymond Andrew, and so began the collaboration that is described in the short MRIS article. This work was done with Bill Moore, Neil Holland and Rob Hawkes and published in Nature.

In 1983, I went as head of rock and fluid physics to the new Schlumberger research laboratory in Cambridge. NMR was beginning to be of great interest in borehole logging. I also had responsibility for research in cement materials. Si-29 NMR was emerging as a powerful technique for investigating the silicate chain structure in cement hydration. On imaging of liquids in porous rocks and in particle beds, I worked for some years with Laurie Hall in Cambridge who built up a strong MRI facility. This work involved Edmund Fordham, Mark Horsfield and Eleanor Davies from Schlumberger and Adrian Carpenter and Rob Hawkes from the university. My work on Si-29 NMR spectroscopy was done mainly at Aarhus with Joergen Skibsted and Hans Jakobsen, and extended over some years.

In 1999, I went to Edinburgh as the university's first professor of materials. My NMR activity diminished after that, although there was some continuing work with Joergen Skibsted. I also collaborated with Bruce Balcom at New Brunswick who had strong interests in porous media imaging.

In total, I have published something like 25 papers using various NMR imaging and spectroscopic techniques over several decades and phases of my career.

From Newsletter of UK EPSRC Engineering Network for the Application of NMR

Techniques to Improve Concrete Performance, no 6 November 2001

MRI and Unsaturated Flow: The First Experiments.

Christopher Hall • Centre for Materials Science and Engineering • University of Edinburgh

In the mid-seventies, I started a new research project at UMIST on a topic which has occupied me on and off ever since. What set me off on this was reading a paper on capillary rise in walls. The author's analysis was unequal to the task but it made me realise that the phenomenon of capillary-driven flow is a general and important one in construction engineering. This did not seem so obvious at the time when *water transport* was more or less coterminous with *permeability*. I hunted around for a better approach and eventually found a way forward by adapting the Buckingham-Richards equation of soil physics to unsaturated flow in materials like brick and stone. In 1976, I involved my UMIST colleague Bill Hoff, with whom I have worked ever since, and we obtained an SRC grant. Fortunately we found a brilliant post-doc Bob Gummerson, who had just completed a PhD in ceramics at Sheffield. He proved to be an outstanding experimentalist. In this first research project, we showed that capillary potential, unsaturated conductivity and unsaturated diffusivity could be measured in brick and stone; and that these material properties provide the basis for modelling of capillary absorption and transfer in these materials.

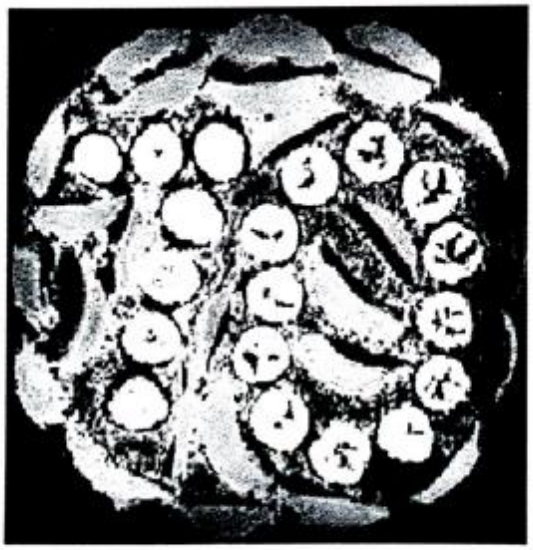

Fig 1 Updating the lemon: a 3D FLASH image of Lauterbur's 70th birthday cake with peaches and bananas by Maxton and Frahm [http://www.mpibpc.gwdg.de/abteilungen/NMR/conferences/2000_pcl.html]

In 1973 Paul Lauterbur had of course published his famous letter to *Nature* on NMR imaging, and the idea of what Lauterbur originally called zeugmatography was in the air. On the cover of the Christmas 1977 issue of *Nature* there appeared a beautiful proton NMR image of an intact lemon from the University of Nottingham (fig 1). In our UMIST laboratory Bill Hoff, Bob Gummerson and I could measure capillary water absorption rates gravimetrically, but we badly needed to know something about the water content *distributions* in our materials. We used various destructive methods, but needed a good way to watch distributions change with time in experiments with well controlled initial and boundary conditions I wrote to Rex Richards who had been my research supervisor at Oxford to suggest that NMR zeugmatography might be the answer. He wrote straight back to say that he thought it was a good idea but that he was not doing such measurements yet and that I should talk to Raymond Andrew at Nottingham who was "now a real authority on this and has equipment capable of working on very large objects." Raymond (the co-imager of the lemon of course) was very enthusiastic and later in 1978 we did some initial experiments in Nottingham with Bill Moore (a reader in the Physics department who worked closely with Raymond Andrew), Neil Holland and Rob Hawkes. We set up some glass tubes containing Chelford sand and let water rise into them. The experiments were a complete failure, since we seemed to able to see only the capillary fringe but had poor signal from the more or less saturated regions below. Later we went back with some brick samples which also failed. Bill Moore thought that this was because the pores were too small, but I knew enough about NMR relaxation in water and the pore size of bricks to think this was unlikely to be the explanation. I suggested to Raymond Andrew that we perhaps had a problem with magnetic impurities in brick. Initially I worried about paramagnetic impurities in the pore water, but we measured its dissolved iron content which was only about 1 ppm. However the large amount of iron in the matrix seemed likely to provide a powerful relaxation mechanism.

We agreed to have one more go on other materials and Bob Gummerson prepared a new set of samples in the form of long bars, to one end of each of which he attached a perspex water reservoir. We chose a wide range of materials, including brick ceramics (again), Kerridge and Corsehill sandstones, Portland limestone, several gypsum/lime plasters and a 1:3:12 cement/lime/sand mortar. At the beginning of April 1979, we drove over to Nottingham with a car full of bits and pieces and this time obtained more or less exactly what we had hoped for. We set up each sample by filling the water reservoir

and we then measured NMR signal intensity (measured on an oscilloscope) along the bar at various elapsed times. For each we normalised the signal by its value close to the reservoir. We knew the porosity of each sample, so we were in effect measuring the normalised water content distribution along the bar. We failed again with the brick and also with the Kerridge sandstone, but all other samples gave outstanding results. Everything was done in a couple of days. Back in Manchester, we showed that the water content distributions scaled as $t^{1/2}$, the square root of the elapsed time. We calculated from the master curve for each material a hydraulic diffusivity function. For these materials, the diffusivity was approximately an exponential function of the normalised water content, as Wilfried Brutsaert had proposed for soils. This was the first time that the fundamental concepts of unsaturated flow had been tested directly by monitoring the evolution of water content distributions with time. We wrote it up as a letter to *Nature*, which was accepted without demur and published in September 1979 (R J Gummerson *et al*. "Unsaturated water flow within porous materials observed by NMR imaging", *Nature* **281**, 56-57, 1979). Fig 2 is one of the figures which we published. This work was certainly one of the very first non-biological applications of MRI.

Right from the start, Bill Moore was kind enough to think our experiments were well worth doing and wanted to do more.

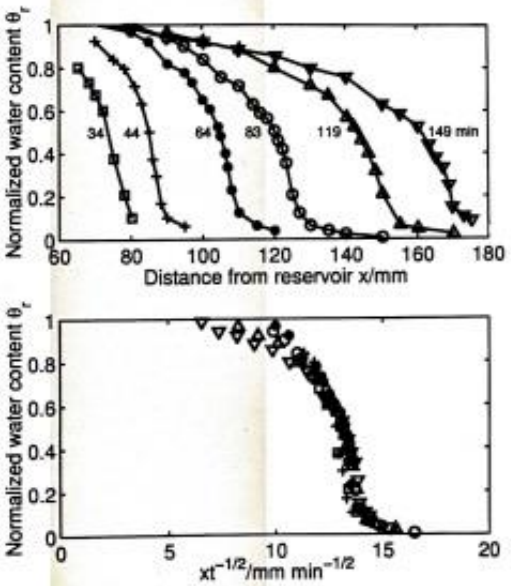

Fig 2 "Water content profiles obtained by NMR during capillary absorption of water by a plaster bar. Elapsed times *t* are shown. The bar (235 x 33 x 33 mm) was cast from a mix (1:2 by volume) of a commercial hydrated lime and a commercial retarded hemihydrate plaster (class B, type b2 gypsum building plaster). After setting and drying, all side faces were sealed with an epoxy coating. Inset sketch shows bar with attached reservoir R to supply water to the inflow face during the experiment. Signal amplitude is scaled to the range 0-1. [Porosity] ~ 0.45 cm^3 water per cm^3 dry solid."

He wrote in June 1979 to say that "the results don't really make it clear what's so funny about bricks" and again in August that "he was trying to interest British Gypsum, who have plenty of money, in testing setting plaster". By this time, Neil Holland had managed "to make quite nice composite time-series pictures of the rapid flow of water through fine sand, taking each profile in about 1 second, on the new machine". Not long afterwards, Bill moved to Harvard but shockingly he died soon after arriving, a great loss to all who knew him. Had Bill Moore lived, I wonder if MRI of construction materials might have made more rapid progress.

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