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Measuring the Activation Energy of Cartilage

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WELMEC, University of Leeds

Medical Engineering Centres Annual Meeting and Bioengineering14

Imperial College London, 10-11 September 2014

Motivation

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- Investigate if NMR parameters could be used to extract structural, functional and physical information through imaging techniques

- To investigate different methods of generating contrast within cartilage using MRI

- Learn about the local environment of the cartilage by using the water/fluid within it as a probe.

Arrhenius Activation Energy & T1

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- Simple model for relating reaction rate to temperature

$$k = Aexp\left(-{}^{E_A}/_{RT}\right)$$

- Can be used as a probe to determine sensitivity of a parameter to temperature
- T1 or Spin-lattice relaxation time is describes the rate at which the longitudinal magnetisation in a sample recovers towards thermal equilibrium
- Although there are many factors that contribute to T1 relaxation – rotation dynamics dominate to a good first approximation

Relaxation Time Mapping

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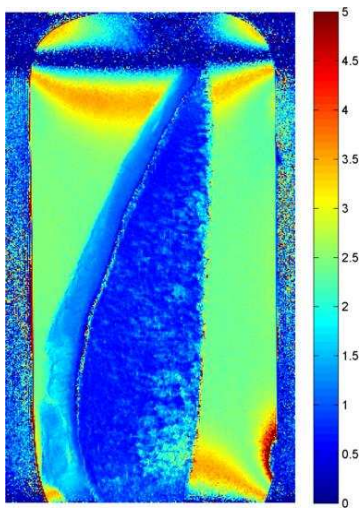
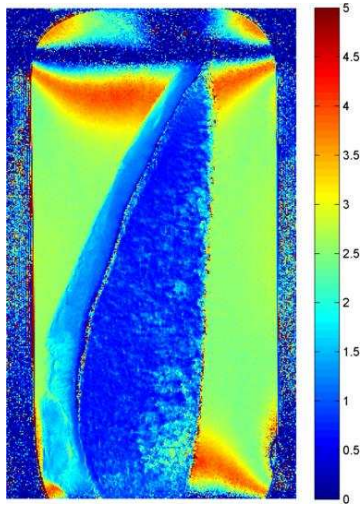


9.1ºC



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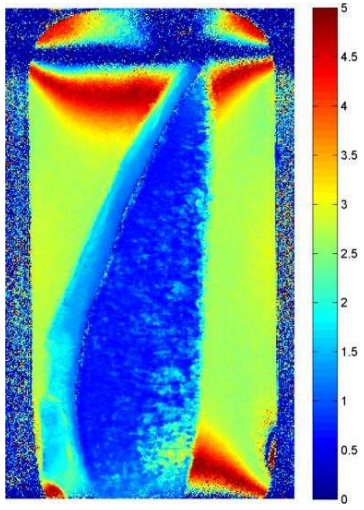
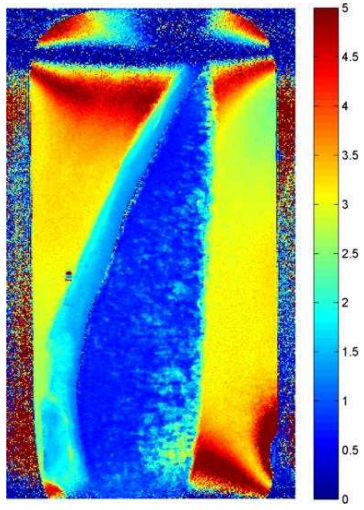
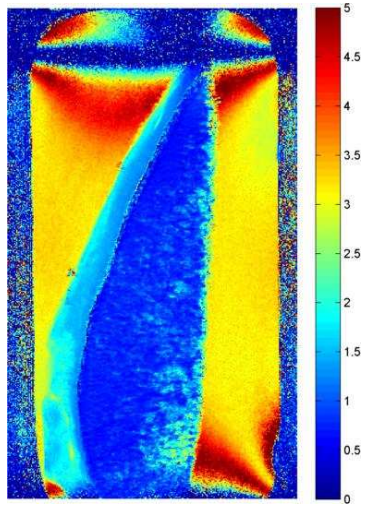


15.9ºC

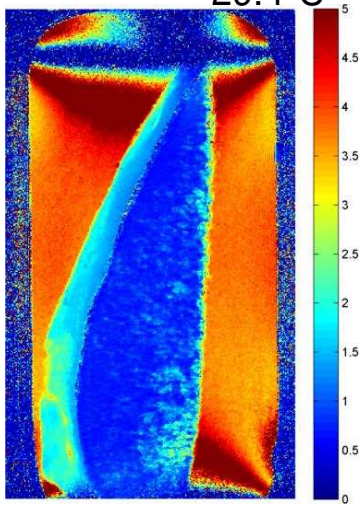


20.0ºC

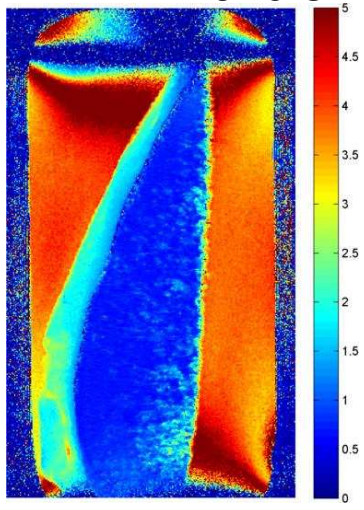


25.0ºC

29.4ºC



34.5ºC



Progressive saturation recovery sequence for Quantitative T1 mapping

TE = 14ms
TR = 200/500/1000/1500/2500/4000/8000ms

1mm slice
In-plane resolution 100µm/pixel

T1 profiles

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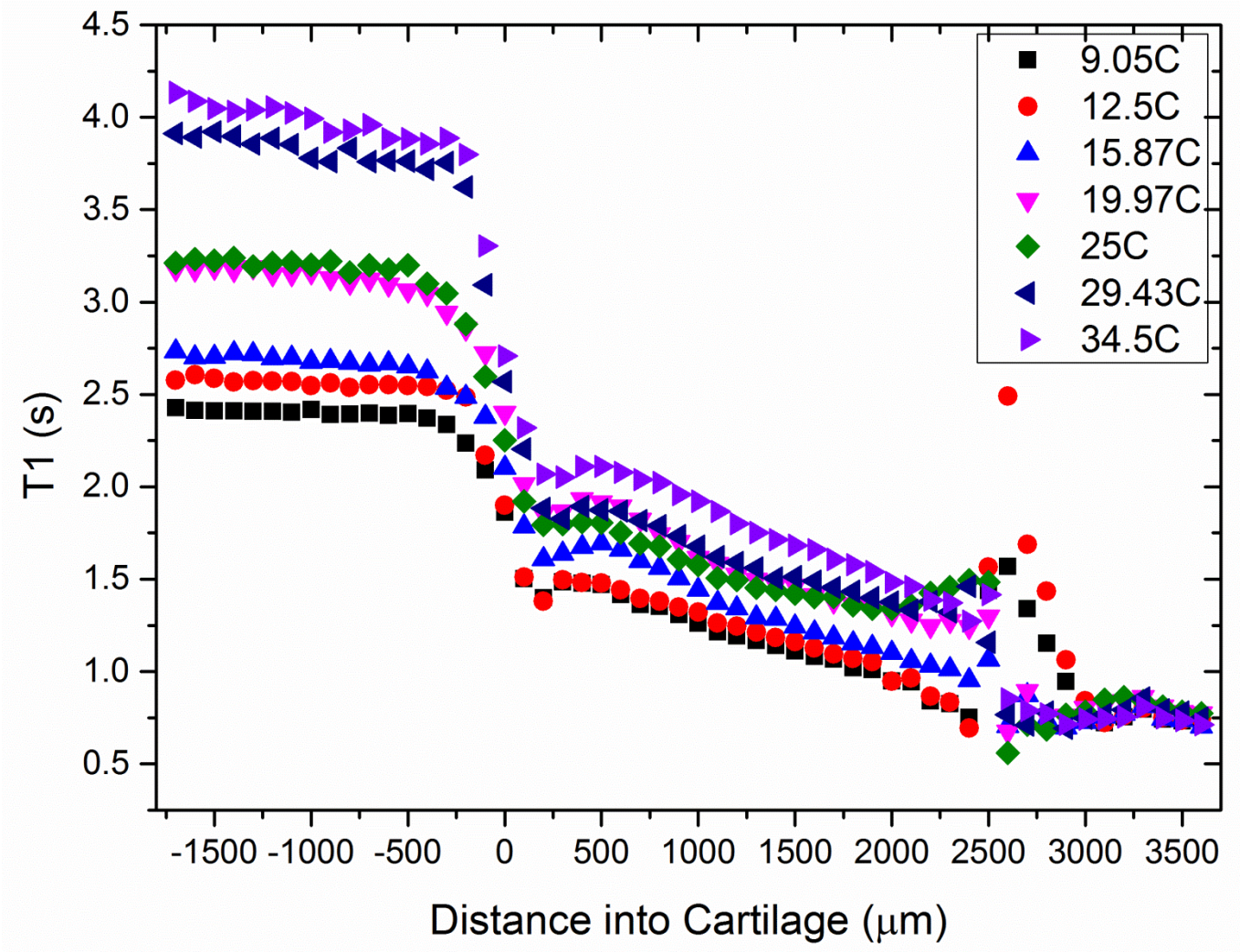

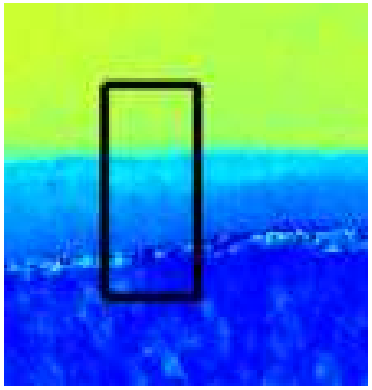

Human Cartilage

Average T1 across each row as function of Temperature

Arrhenius Relationship

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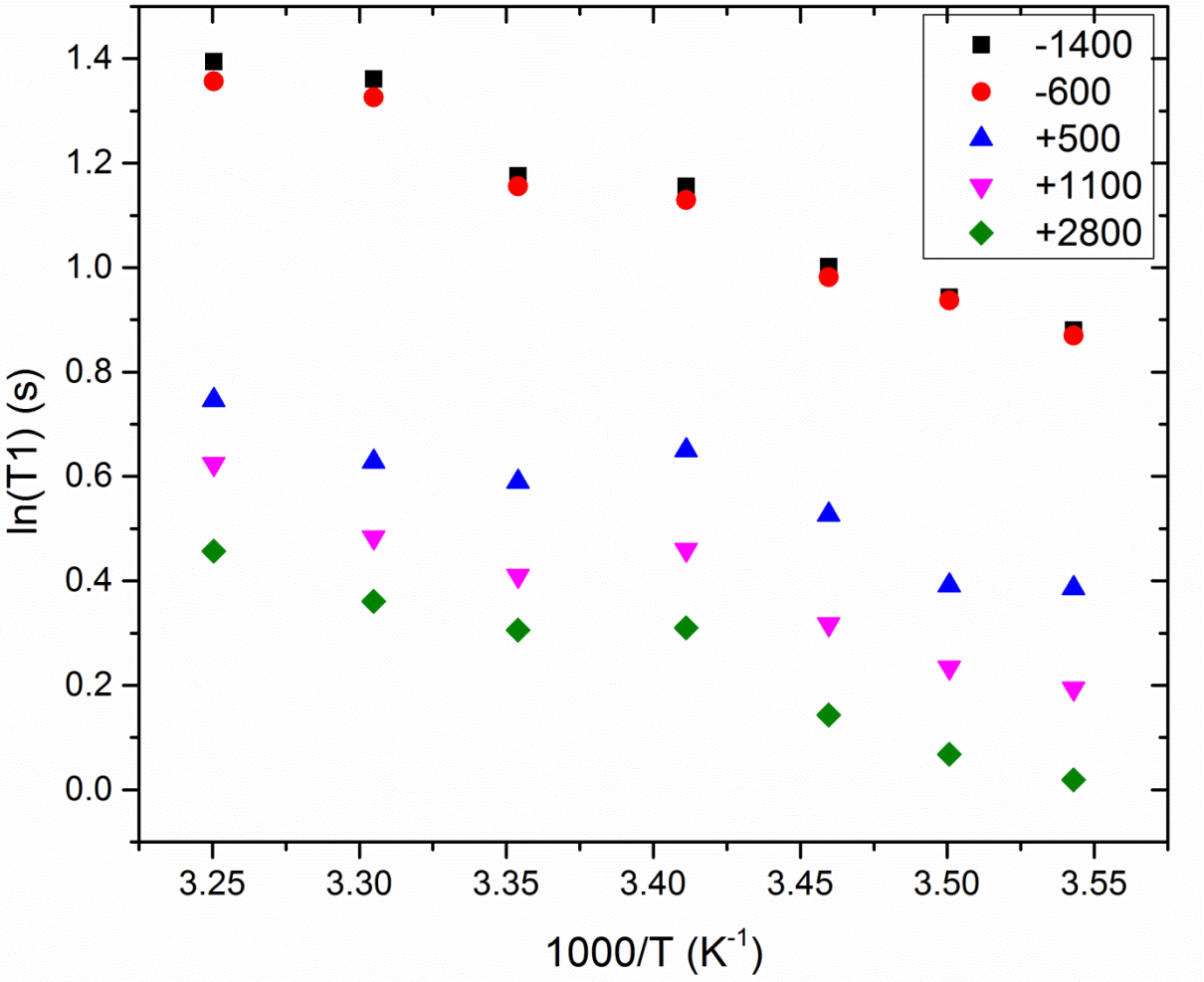

Arrhenius relationship

$$\frac{1}{T_1} \propto exp\left(\frac{-E_A}{RT}\right)$$

Data is linear

Activation energy given by gradient

2 pixels in PBS
1 pixel near surface of cartilage (blue)
1 middle (pink)
1 deeper (green)

T1 Activation Energy Profiles

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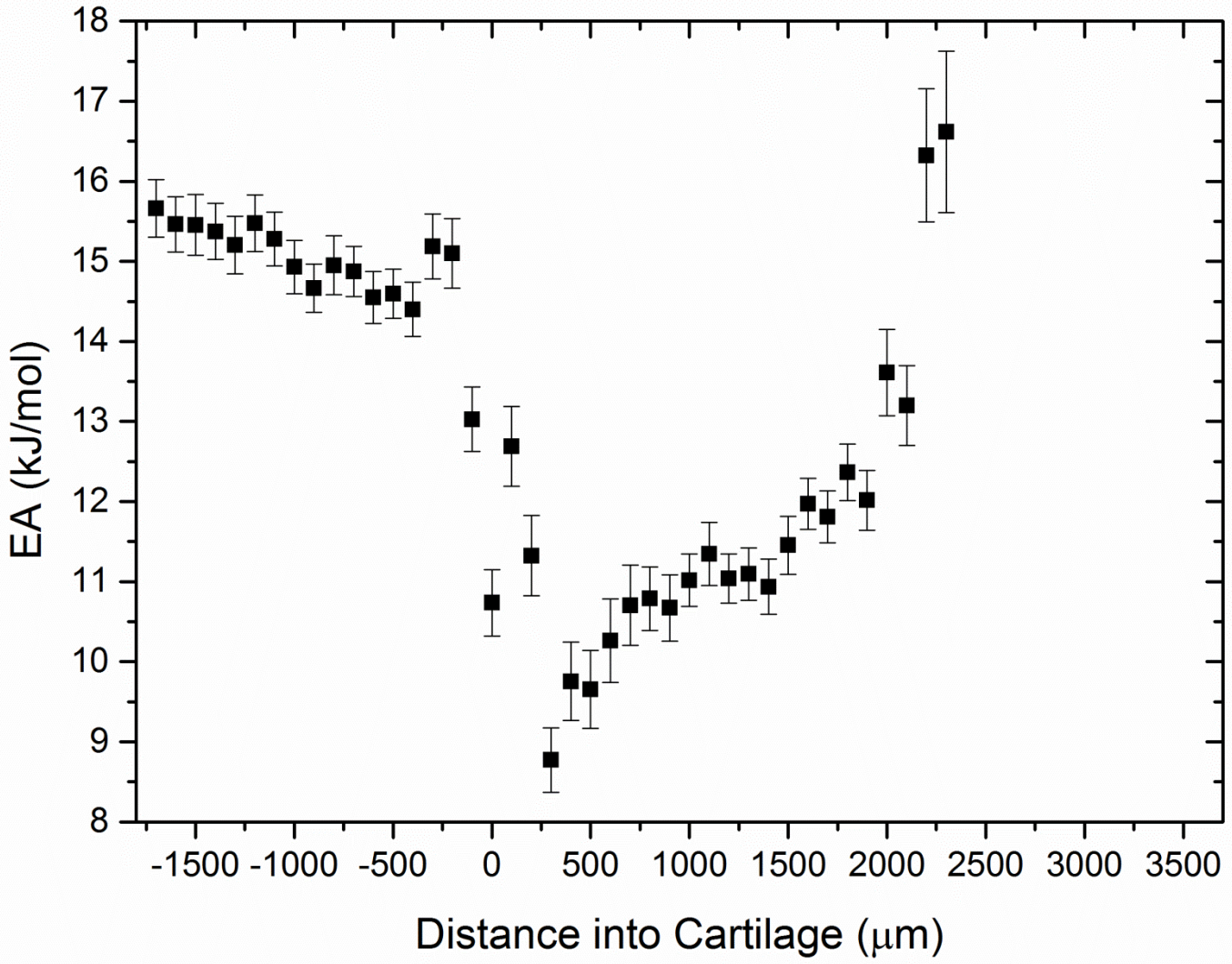

T1 EA shows variation with depth

EA value in cartilage lower than that of PBS/water

EA gradually increases with depth (as opposed to T1, which decreases)

EA of pure water 16.6kJ/mol

Simpson & Carr
Phys Rev 111 (1958) v5 1201

Bovine Cartilage

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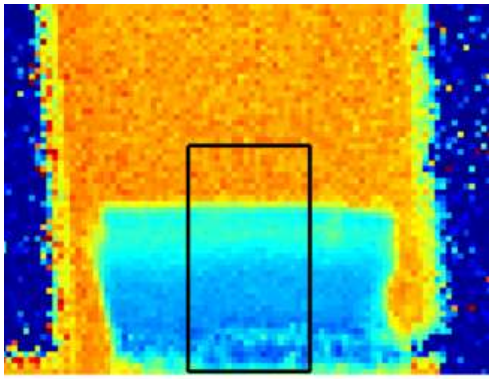
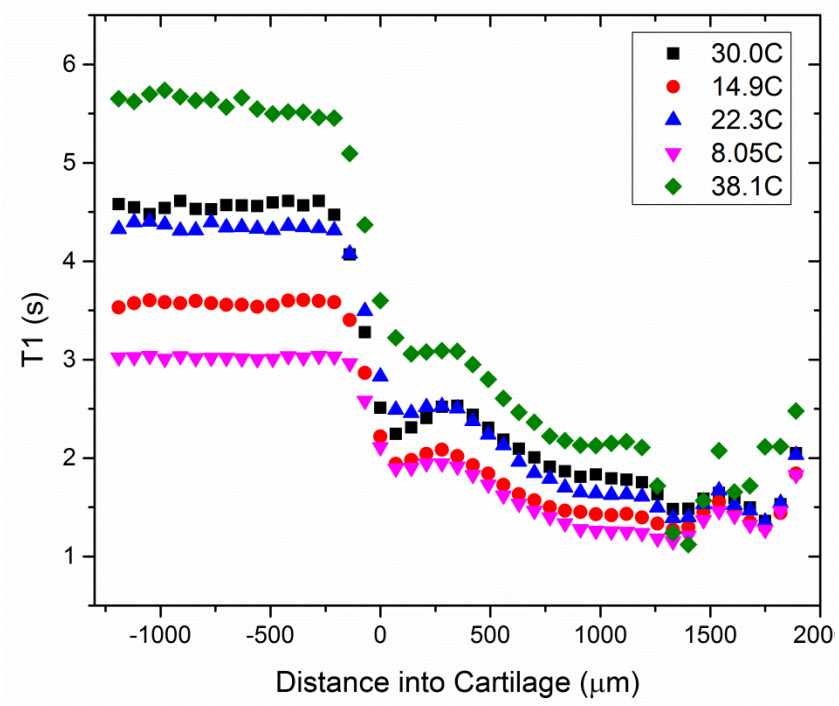
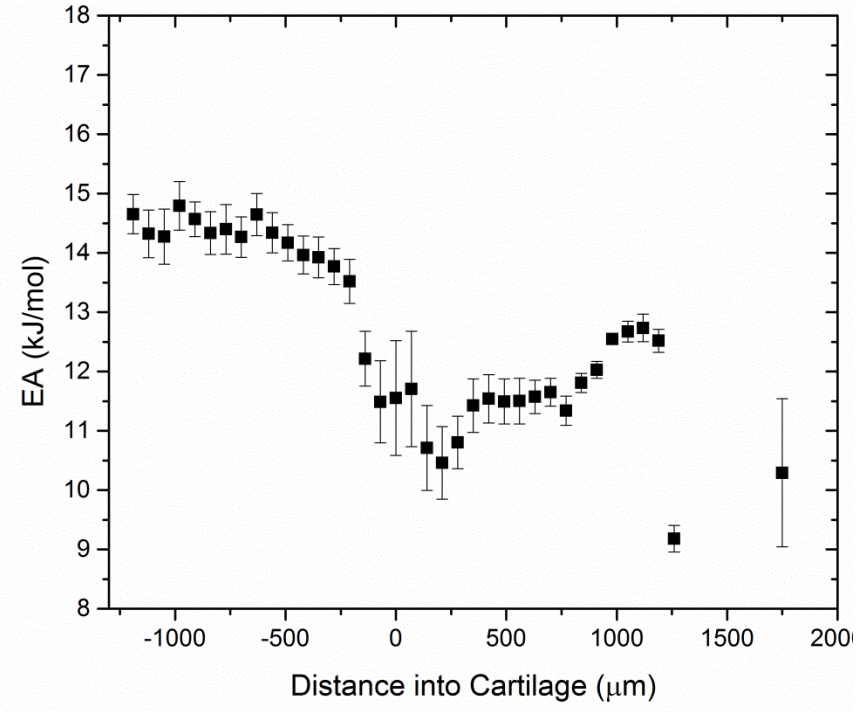


Bovine cartilage exhibits similar behaviour





Aggrecan activation energy

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- Aim: look at the microscopic origins of EA – investigate GAG concentrations as a function of temperature
- Range of solutions of aggrecan EA in solution from 0.7% to 5.3% w/w
- T1 NMR (i.e. non-imaging) at a range of temperatures 8ºC to 38ºC
- EA calculated from measured relaxation rates

GAG activation energy

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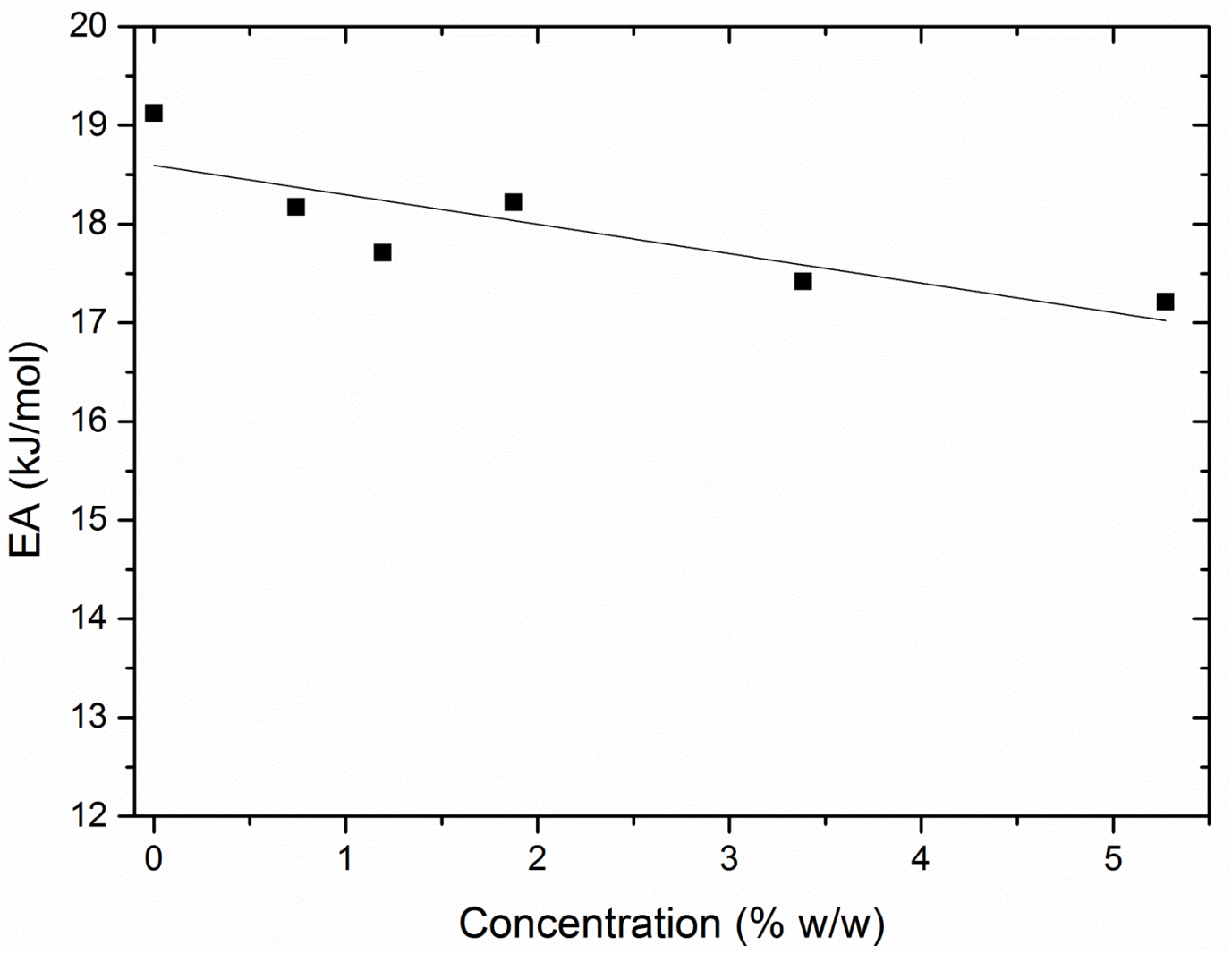

T1 EA in Aggrecan samples show little variation in EA with concentration

Suggests EA flavour in cartilage must be due to other constituents

Conclusions

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- Activation Energy from quantitative T1 mapping changes with depth through cartilage
- The EA through the main bulk of the cartilage is lower than that in water (PBS)
- Loss in ‘structure’ of the water molecules through the cartilage matrix due to confinement lowers EA
- We suggest that in the deeper parts of the cartilage, EA increases due to increased binding
- No variation in EA from T1 with Aggrecan concentration – other constituents influencing EA

Acknowledgements

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