

Baking a cake, selling it  
twice, eating it once and  
keeping a little as inspiration  
for the next cake.

**Tim Senden**

Director

Research School of Physics



Australian  
National  
University

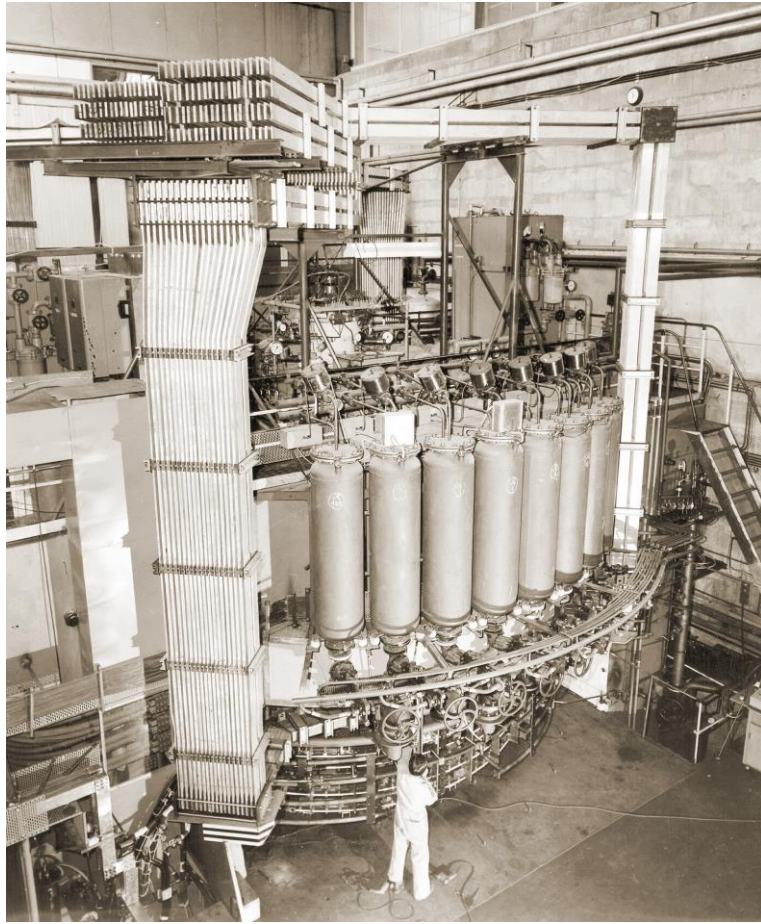
# Legacy and Innovation

There are two types of legacy we can leave.



With gratitude to  
Riaz and Sadia Akber





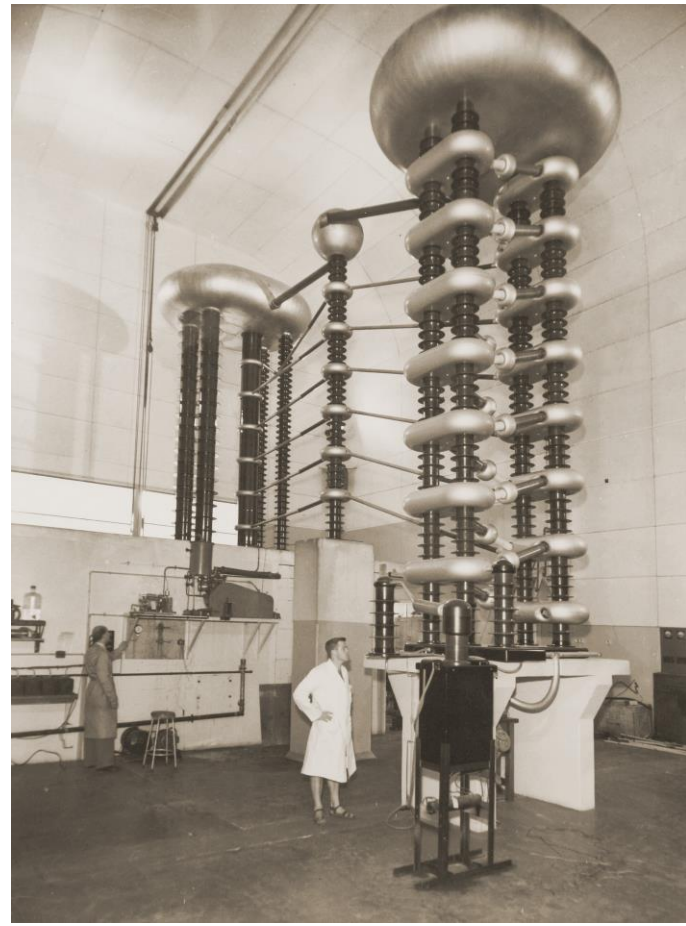
**Homopolar generator (1950's)**  
2 million amps for a few seconds



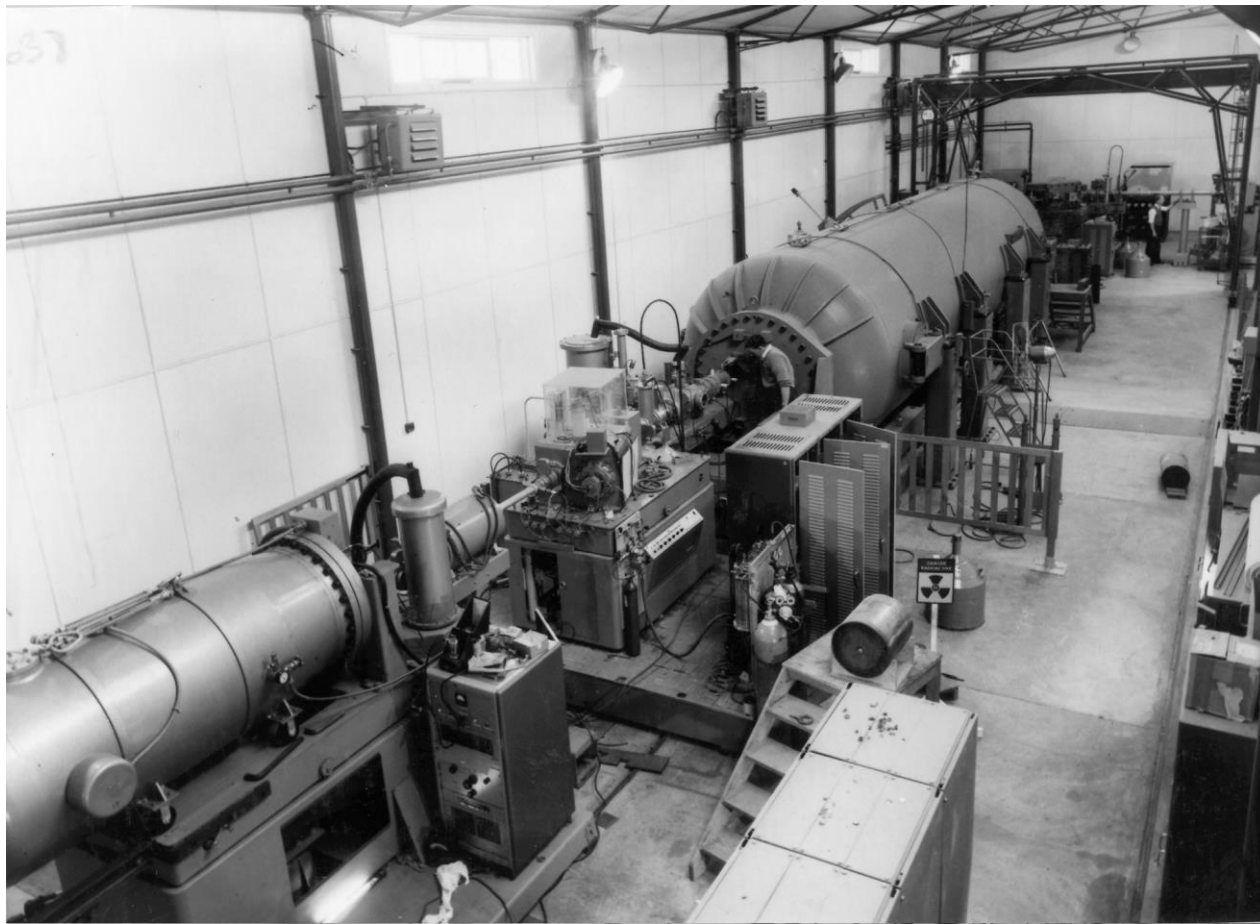




600kV Cockcroft-Walton (1950's)



1.2MV Cockcroft-Walton (1950's)



The 2MV van de Graaff tandem accelerator (1960's)



14MV Pelletron Accelerator (1970's)



*Invitation to see HIAF on Thursday*



# The Homopolar Generator today



What's the legacy? Where's the cake?

# The Fundamentals

- ◆ Dept of Applied Mathematics
- ◆ Founded by Prof Barry Ninham in 1971
- ◆ Chemists, physicists, mathematicians and engineers
- ◆ Theoreticians and experimentalists working together
- ◆ Complex and hierarchical (multiscale)
- ◆ Always built instruments for research
- ◆ **Vision** - fundamental understanding of disordered and porous materials with the aim of predicting *properties* via imaging, visualisation, theoretical and computational modelling
- ◆ Need to keep creative people focussed around research mission





- Foamed materials • Sedimentary Rock • Fibre composites
- Fossils • Wood • Bone • Implants • Insects

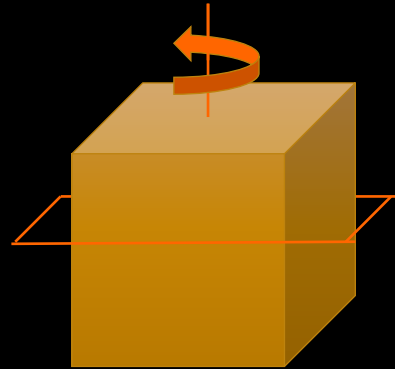
In team since 2000

- |                            |                            |                      |
|----------------------------|----------------------------|----------------------|
| • <i>Christoph Arns</i> ** | • Andrew Kingston          | • Vanessa Robins     |
| • Tomaso Aste              | • Munish Kumar             | • Rowan Romeyn       |
| • Holger Averdunk          | • Mark Knackstedt          | • Mohammad Sadaatfar |
| • Gareth Crook             | • Shane Latham             | • Arthur Sakellariou |
| • Ron Cruickshank          | • Evgenia Lebedeva         | • Tim Sawkins        |
| • Andrew Fogden            | • Ajay Limaye              | • Adrian Sheppard    |
| • Abid Ghous               | • Jill Middleton           | • Rob Sok            |
| • Stephen Hyde             | • Glenn Myers              | • Michael Turner     |
| • Anthony Jones            | • <i>Val Pinczewski</i> ** | • Trond Varslot      |
| • Alexandre Kabla          | ** UNSW                    | • Paul Veldkamp      |

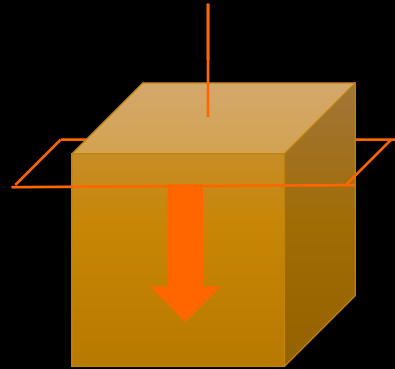


# X-ray micro-Tomography (CT)

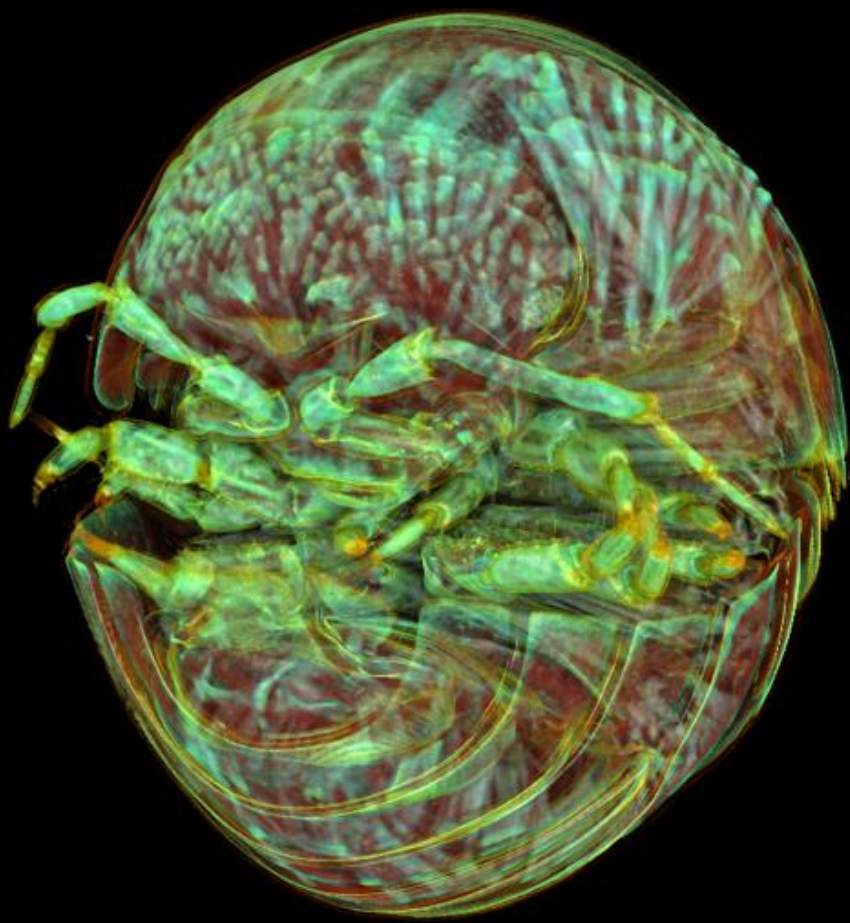






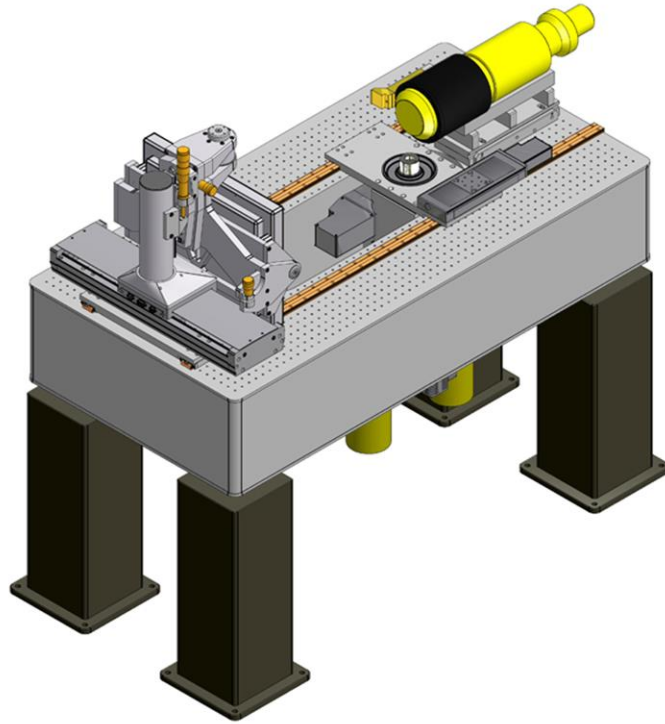




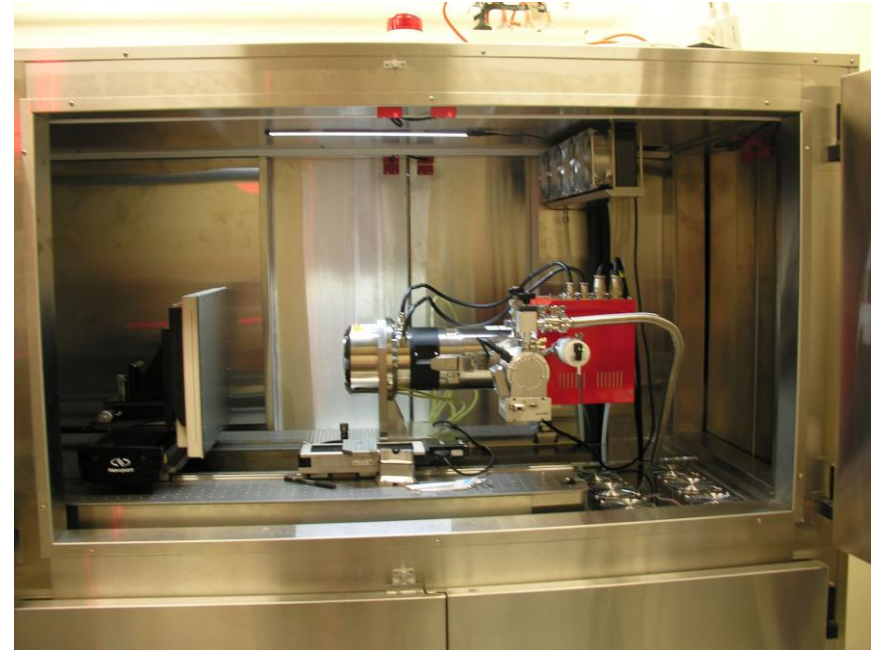


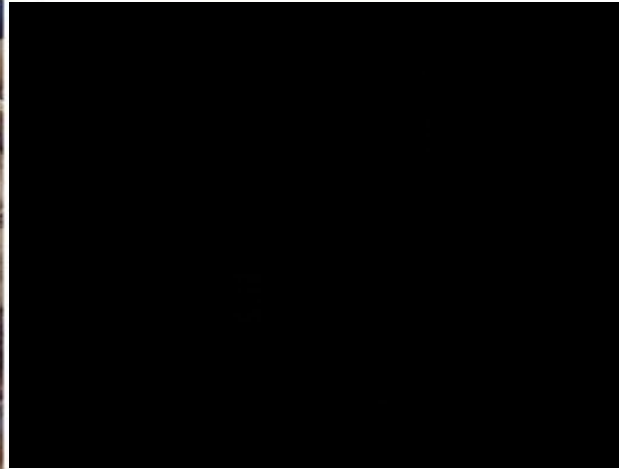
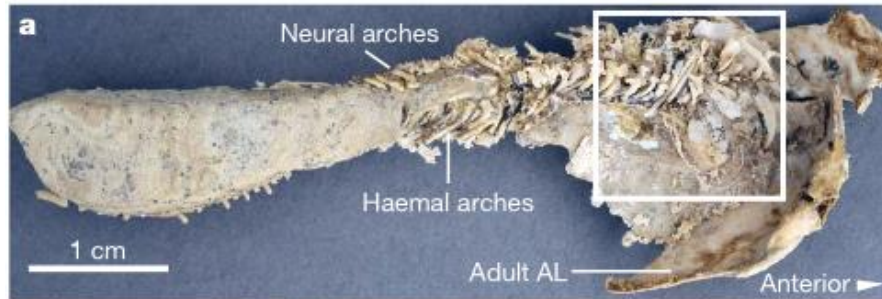


# Redesign tomographic system from maths to machinery



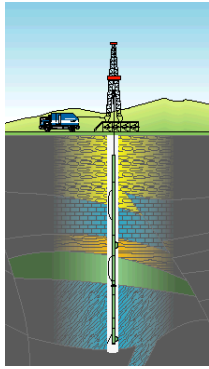
*Developers:*  
Trond Varslot  
Andrew Kingston  
Glenn Myers  
Adrian Sheppard  
Tim Sawkins



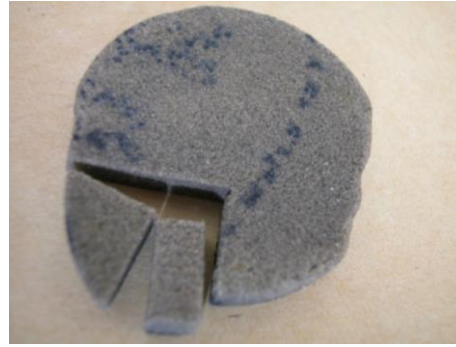


- This find tells us;
- Internal fertilisation
  - Stable ecosystem
  - Sexual dimorphism

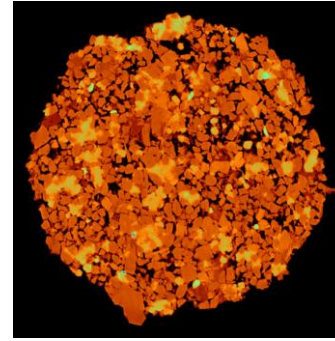
*Materpiscis attenboroughi* - a 380 Mya old embryo



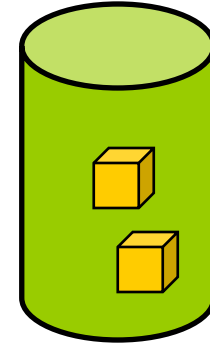
Log & sample



select



image



model

*Physical Parameters*

Electrical Conductivity  
Dielectric Permittivity  
Neutron  
Borehole Pressure  
Sound Velocity  
NMR Response  
Gamma-ray x-section  
Capillary Pressure

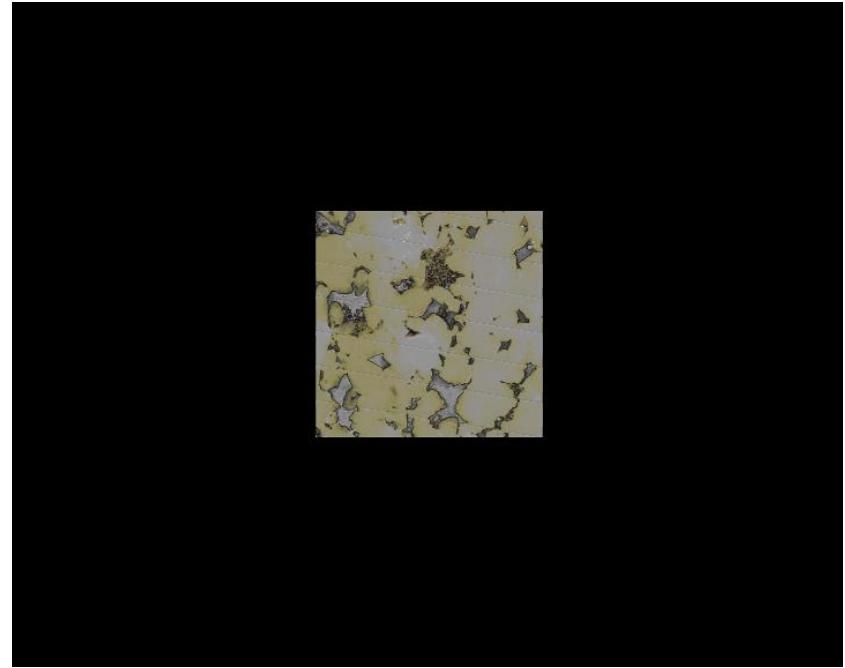
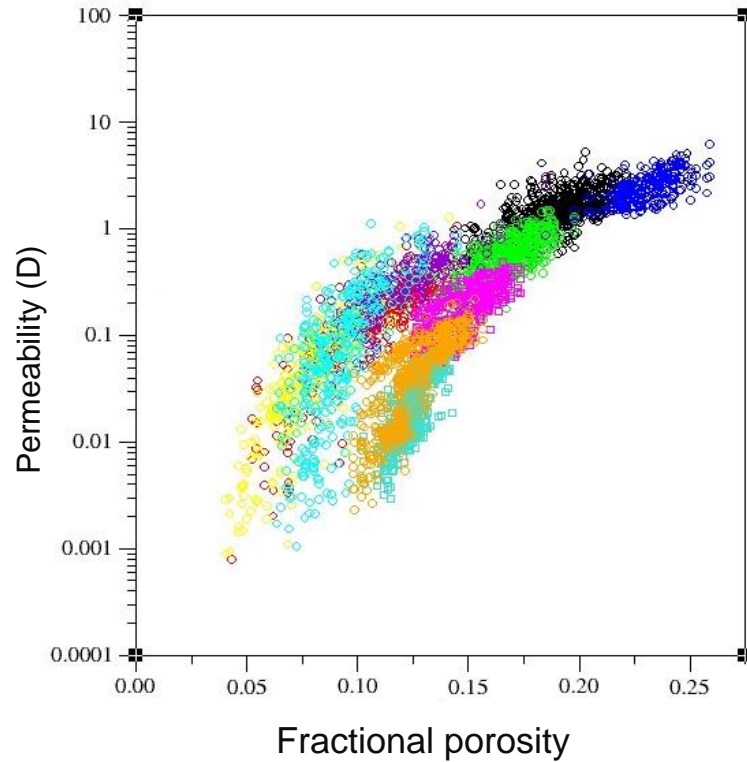
*Reservoir Descriptors*

Oil Saturation  
Water Saturation  
Gas Saturation  
Porosity  
Permeability

An image alone does not capture the mineralogy, wettability, heterogeneity....



# Tomography provides the framework for simulation



~ 1 mm<sup>3</sup> sandstone showing flow simulation

~ 1 million lines of C++ code on NCI (now open access to PFR)



# Digicore Consortium

A joint industry consortium (**established 2006**) – together with



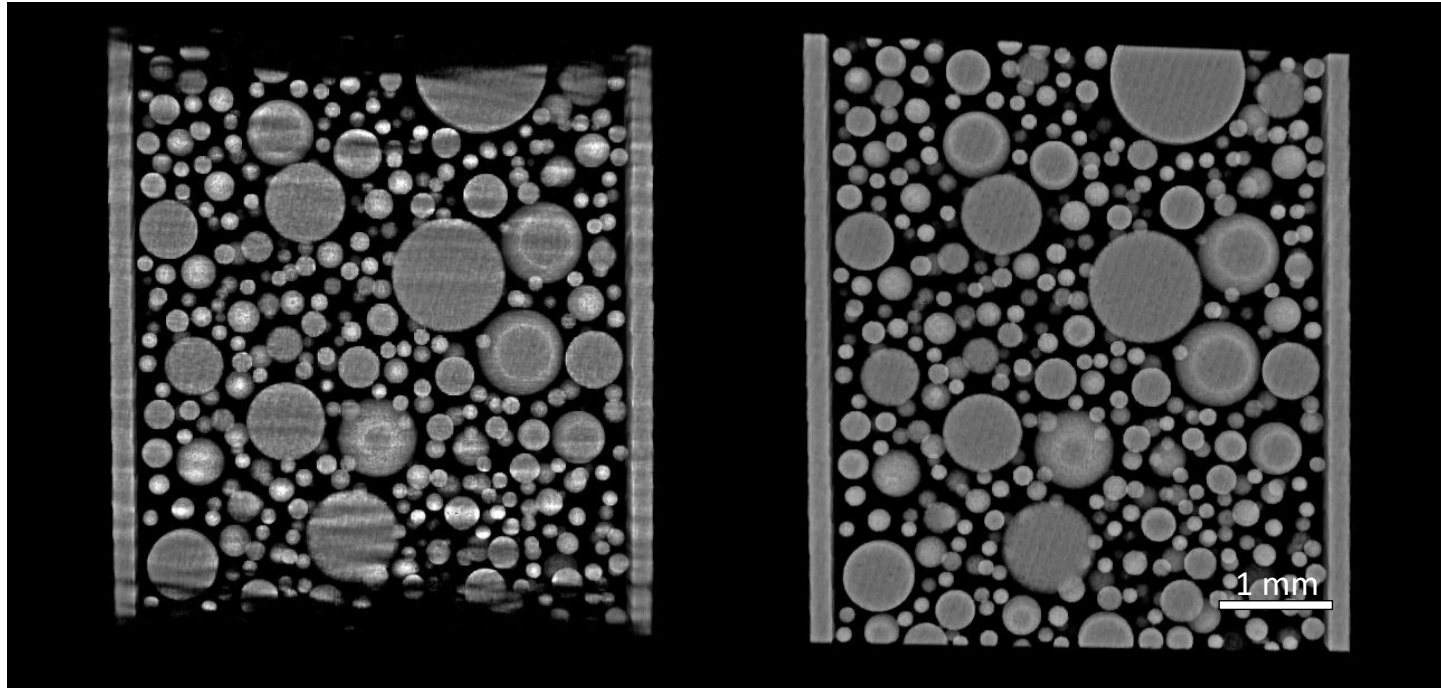
Primarily in field of oil/gas but inclusive of all materials research.  
Conventionals, Unconventionals, carbon sequestration



BG  
BP  
Conoco  
EOG  
FEI  
JOGMEC  
Maersk  
OMV  
ONGC  
Petronas  
PetroBras  
Shell  
Total  
Whiting  
Saudi Aramco  
ExxonMobil  
Chevron  
Schlumberger  
Baker Hughes  
Abu Dhabi Onshore  
BHP



# Need precise reconstruction and no geometric distortions



**Conventional circular scanning**

cone  $<10^\circ$

*Kingston et al Med. Phys. 2011*

**Helical scanning**

cone  $\sim 110^\circ$

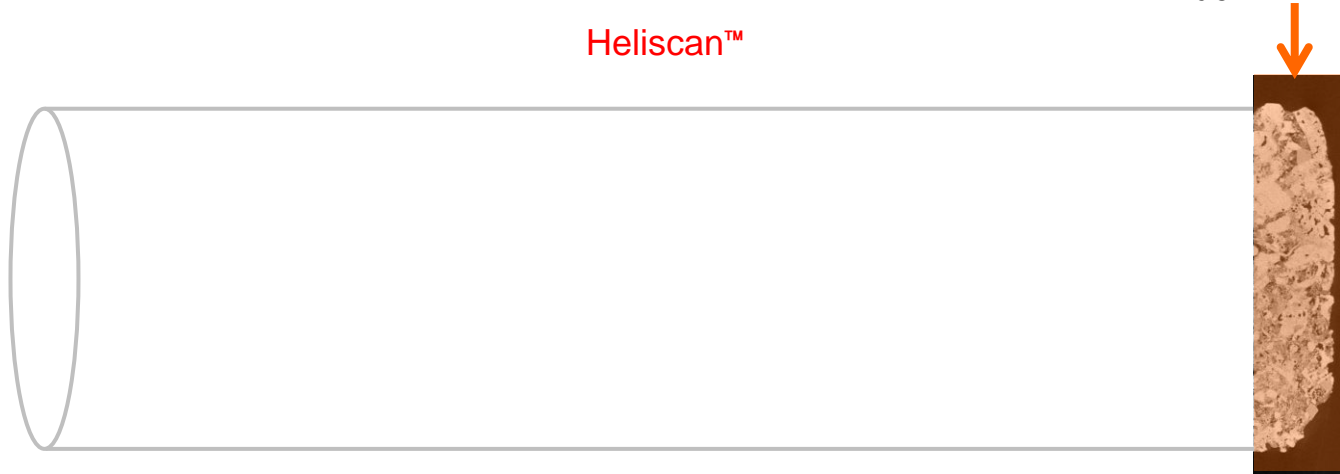
*Varslot et al SPIE 2012*



- Higher geometric and signal fidelity
- > 3 to 10 times faster than conventional CT
- Larger length scales at highest resolution

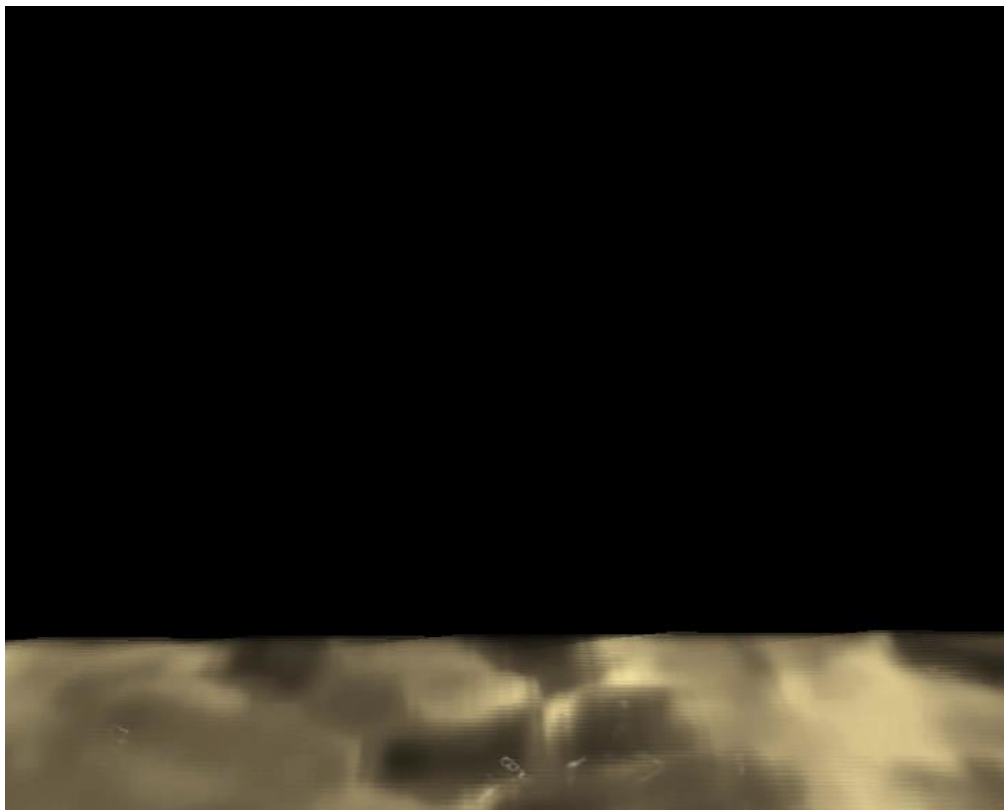
**Hardware team:** Andrew Kingston, Trond Varslot, Adrian Sheppard, Shane Latham, Glenn Myers, Paul Veldcamp, Tim Sawkins, Ron Cruikshank

Under the same conditions a conventional micro-CT might only scan this much.

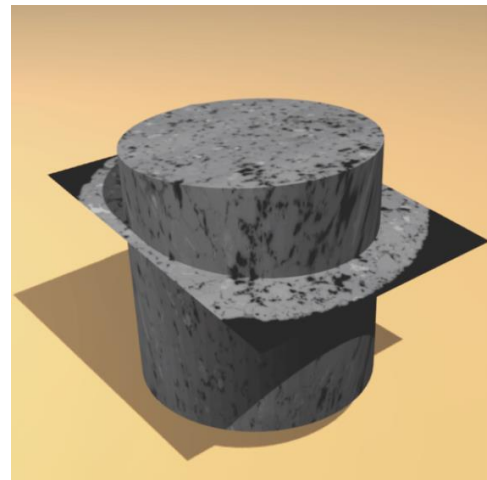


40 Gbyte scan of carbonate core (5mm diameter, 20mm long, 3.5 micron resolution)

# Image registration



- Metric-based method, affine or rigid
- relatively resource intensive when applied to large datasets
- scalable implementation



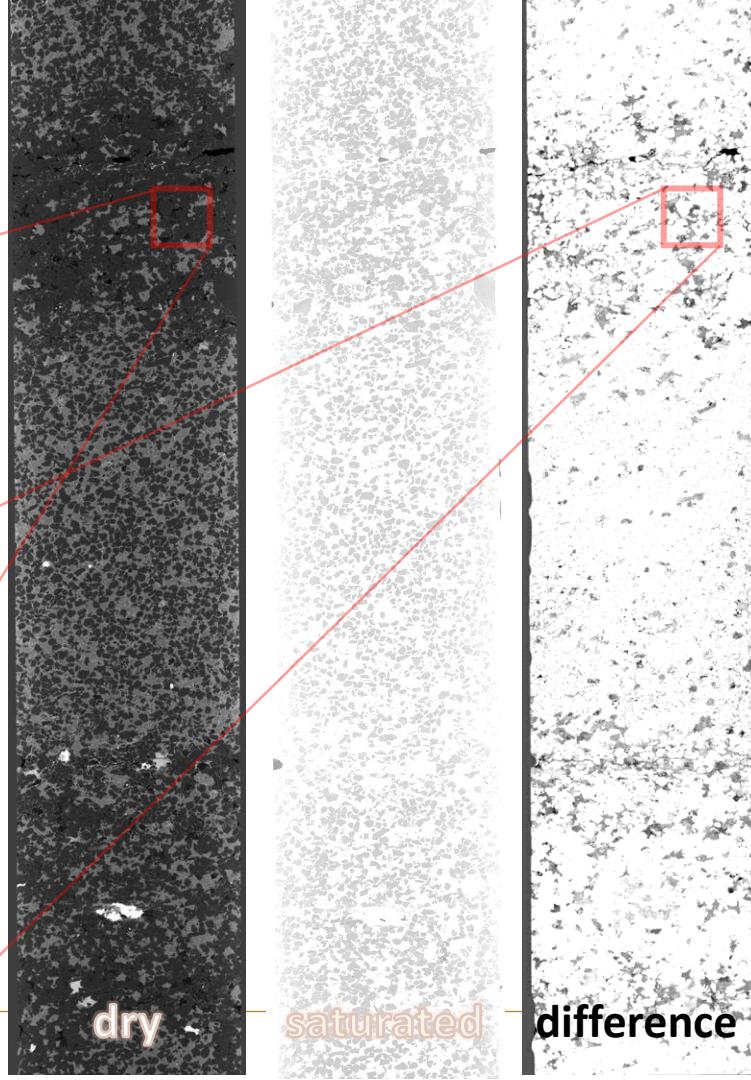
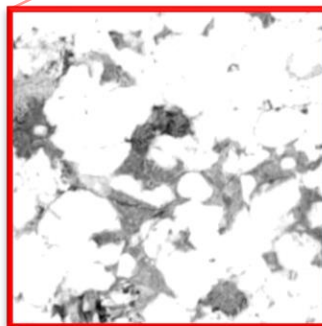
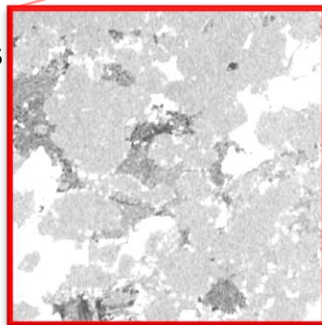


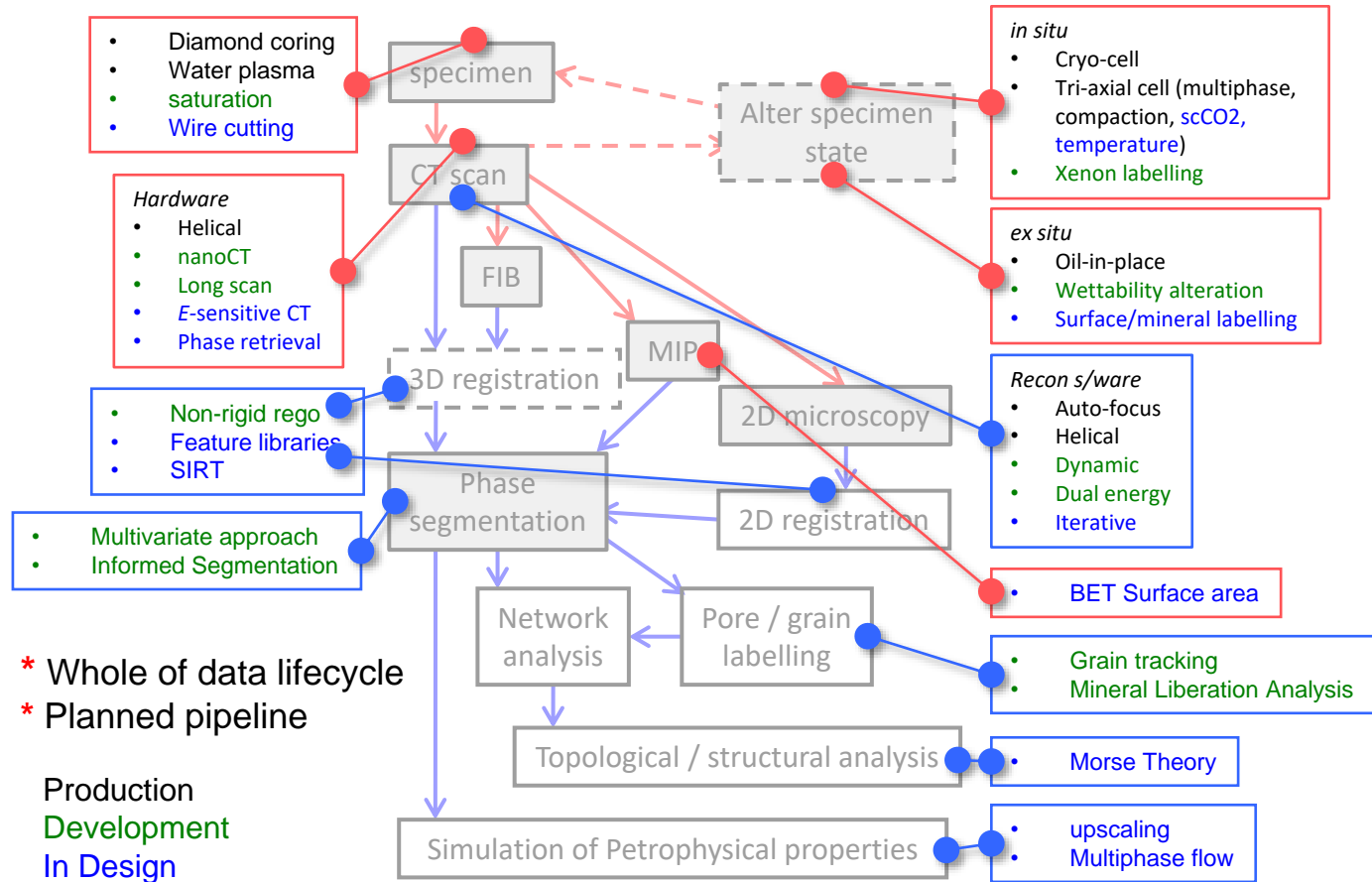
# 3D-3D Registration: Porosity mapping

Heterogeneous  
tight sand  
36x8mm

Imaged at  
 $7200 \times 1600^2$   
5 $\mu$ m voxels

Difference  
between  
saturated and  
dry image yields  
porosity map





Workflows illustrated how fundamentals connected to applications





## ***Digitalcore created May 2009***

Shareholders signing



- \* Rigorous due diligence
- \* Continuous multi-level university support
- \* Field limited software license (no hardware!)





Sometimes the deals worked  
– Knackstedt and Pantano in Qatar, 2011

A vertical banner for Lithicon. At the top is the Lithicon logo, which consists of a yellow circle with a white cube inside. Below the logo is the word "LITHICON" in white capital letters. Underneath is an equals sign, followed by the "digitalcore" logo (a green and white cube) and a plus sign, followed by the "numericalrocks" logo (a blue and yellow cube). At the bottom is the website address "www.lithicon.com".

LITHICON

=

digitalcore

+

numericalrocks

www.lithicon.com

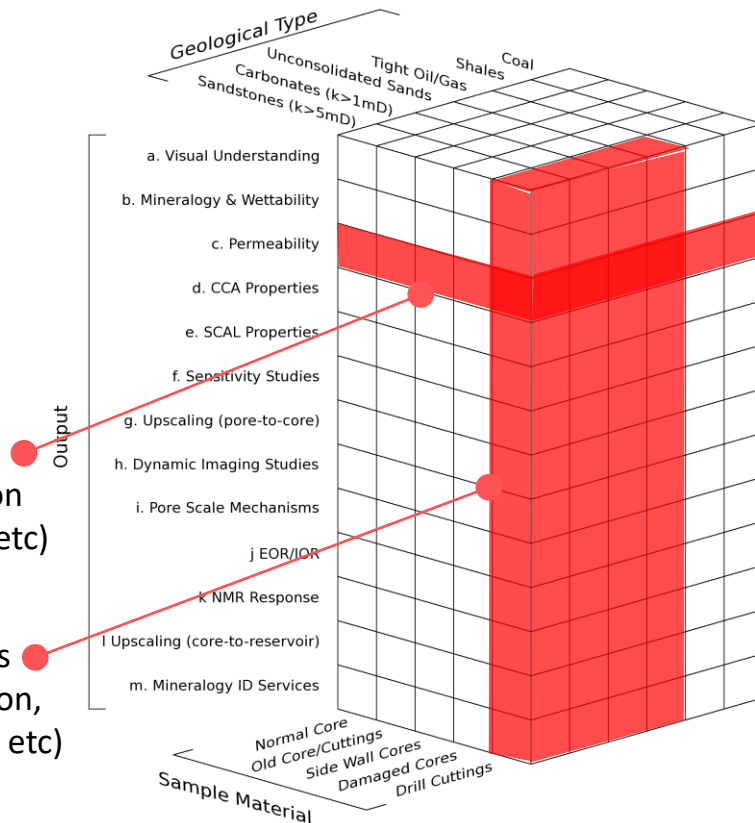
# analysis vs. material vs. configuration

## A collaborative process

1. Distillation of the problem
2. Method design
3. Process validation
4. Transfer of knowhow

eg. Tools  
(image segmentation  
Lattice Boltzmann, etc)

eg. Methodologies  
(sample preparation,  
material labelling, etc)





OUTSIDE FIELD (not Oil' n' Gas)

INSIDE FIELD (Oil' n' Gas)

NON-COMMERCIAL

Publicly funded research orgs. (NICTAR, etc)

Government

Digicore Consortium

ANU / UNSW (carve out)

CTLab

ANU

Limited CT sales & software licences

\$ (R&D to partners)

Licensed IP or access

\$ (R&D, Licence fees)  
Licensed IP

\$ (R&D)  
\$ (invest)  
Licensed IP

Hard & software

Limited CT sales

\$ (manufacture & maintenance contract)

Lithicon

1:1 & 1:n

Mining, materials, etc R&D (no service work)

FEI / Thermo Fisher

\$ (service contract)

Analyses & equipment

Helical CT co.

Hard & software

\$ (sales, licence fees)

\$ (royalties & royalties)  
Options on BIP (outside field)  
BIP (inside field)

Reports & analyses

\$ (service contract)

CT customer

DCA customer

COMMERCIAL

Core group  
Continuing 4  
Contingent 16  
Students 6



# The Exit

<b>2009</b>	<i>Digitalcore Pty Ltd</i>	
	- ANU / UNSW / <i>Inventors</i>	\$2.5M
<b>2011</b>	new investment	\$3.5M
<b>2013</b>	Merger to form <i>Lithicon AS</i>	
	- <i>Numerical Rocks AS</i>	\$10M
	- new investors	\$10M
<b>2014</b>	Lithicon acquired by FEI	\$78M
	- broad field CT license	

**\* Inventors raised >\$1M**



# 15 year pathway

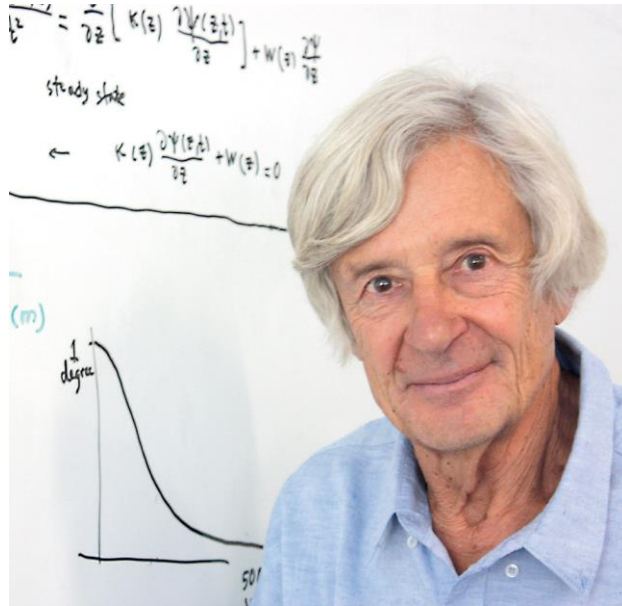
## The 2:1 rule

- curve-outs preserved: research and service
- \$40M research funding (<25% Govt)
- 12 CT Facilities sold
- Funded 100 FTE
- >170 publications
- 9 patents
- 2 endowments (\$3M)

...but the value is keeping a  
eye on the fundamentals



# Endowments



Stjepan Marcelja  
Visiting Fellowship scheme  
(25 international visitors to date)



Proof-of-concept fund  
(8 spin-offs supported)

# CTLab

- visualisation room & colour 3D printers
- Large body scanner (300kV)
- Four ANU-built 180kV CTs / Two Thermofisher Heliscans
- SEM-based mineral mapping, mechanical core mapping
- Sample prep equipment
- Partnership with Centre for Advanced Microscopy and National Computational Infrastructure





# The next 5 years

- CO<sub>2</sub> Sequestration
- ARC Training Centre for *Multiscale 3D Imaging, Modelling and Manufacturing*—led by Professor Mark Knackstedt
- Multimodal tomographic imaging – new types of instrumentation
- Mining

# Legacy and Innovation are linked through...

- Culture and facilities
- Research training and apprenticeships
- Constant *out-of-field* challenges



- 25 ultra-stable labs
- 800 sqm clean room
- 260 staff/students
- 250 seat auditorium

*Open in March*



The HPG stands sentinel

What is 'cake'?

# ACKNOWLEDGEMENTS

- Australian Research Council
- National Collaborative Research Infrastructure Strategy
- National Computational Infrastructure
- NeCTAR
- Education Infrastructure Fund
- *Digicore* Consortium of companies
- Thermo Fisher and partners
- Strategic ANU funding and commercialisation support

