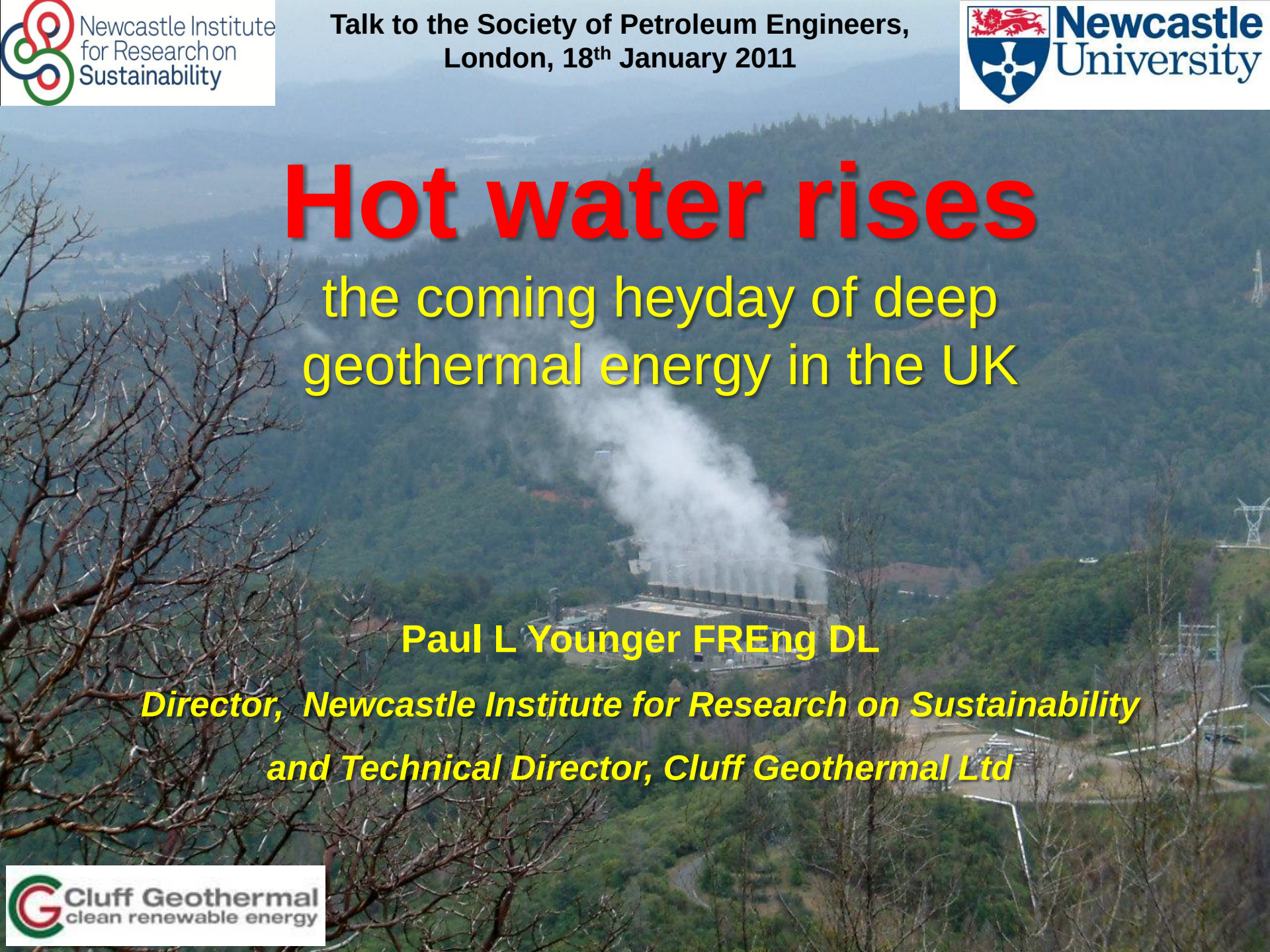
Talk to the Society of Petroleum Engineers,
London, 18th January 2011

Hot water rises

the coming heyday of deep geothermal energy in the UK



Paul L Younger FREng DL

Director, Newcastle Institute for Research on Sustainability

and Technical Director, Cluff Geothermal Ltd

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Geothermal Energy in Britain

- The story so far: response to 1970s Middle East Oil Crisis ...
  - Hot Dry Rock (HDR): experiments at Rosemanowes, Cornwall – Roy Baria *et al.*
  - Low-enthalpy resources: “geothermal aquifers” in Mesozoic basins - BGS

Commentary on UK research in 1970s – 80s

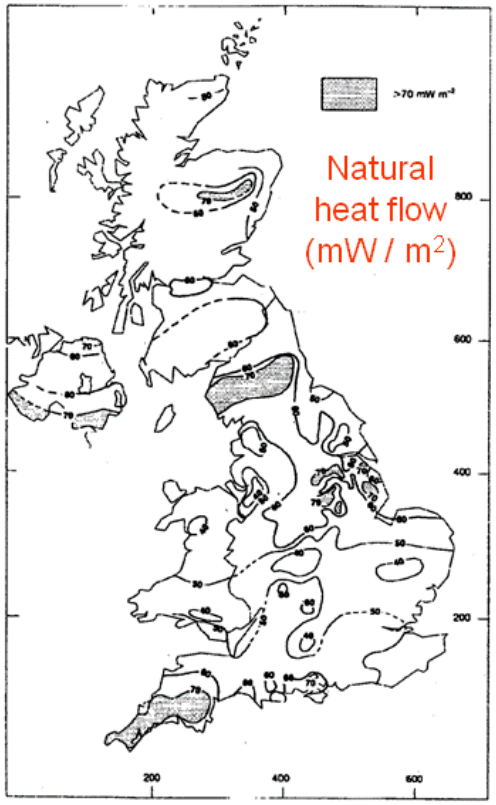
<u>Geology:</u>

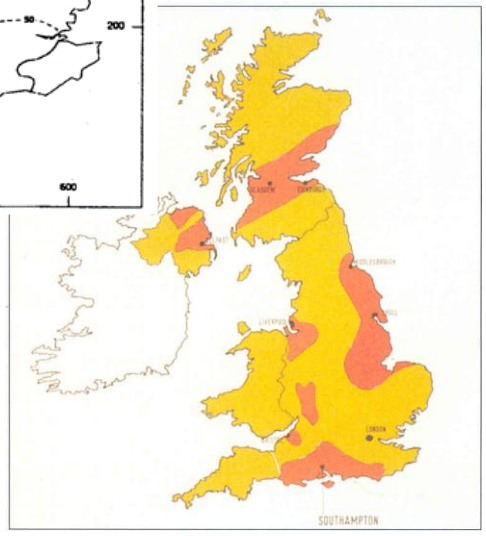
• inevitably based on sparse data – but remember:

absence of evidence is not evidence of absence

• HDR research started from pessimistic premise on granite hydrogeology

• basinal studies did not pay enough attention to geochemical and geophysical evidence of substantial deep convection





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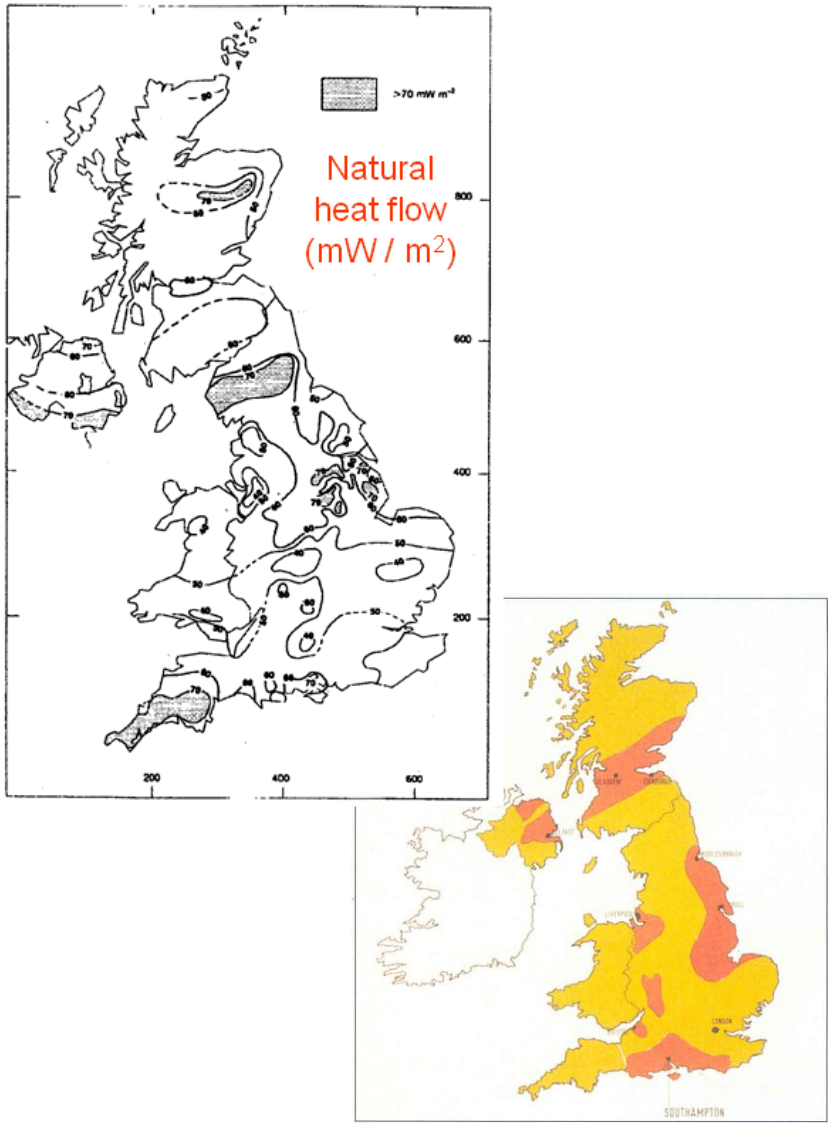
Commentary on UK research in 1970s – 80s

<u>Engineering</u>

- pre-dated:
  - -current drive for low-carbon energy in response to climate change concerns
  - - many recent advances in technology, particularly in:
    - directional drilling
    - binary power plants
- too focused on electricity generation; largely ignored direct use of geothermal heat



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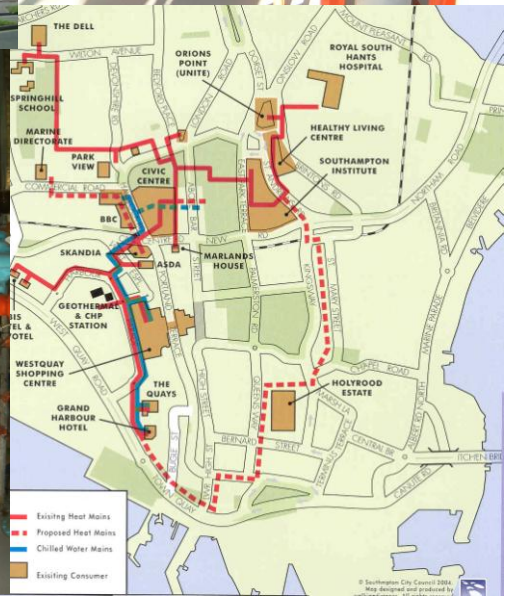

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Interval ...

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The Eastgate Geothermal Project

2004-2010

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Acknowledgements

Prof David Manning	**- Newcastle University**
Daniel Dufton & Ian Burdon	**- PB Power**
Rick W Smith	**- FWS Consultants Ltd**
Sorcha Diskin & colleagues	**- FORACO S.A.**
David Gowans & colleagues	**- Drilcorp**

The Eastgate Geothermal Exploration Project was supported financially and logistically by The Wear Valley Task Force, and in particular its members **Lafarge plc**, Durham County Council and One North East. Finance for Eastgate Phase 1 was provided from regional development funds administered by **One North East**, acting through Wear Valley District Council; Finance for Phase 2 was provided by the **Deep Geothermal Challenge Fund** of DECC - HM Government's **Department of Energy and Climate Change**.

Scientific work part-financed by Newcastle University and the **HSBC** Partnership for Environmental Innovation

Special thanks to Lloyd McInally,Richard Craig and Peter Greeno of the Lafarge Weardale Works

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Eastgate redevelopment project

- Closure of the Blue Circle Cement Works (Eastgate, Weardale) in 2002 prompted development of plans for regeneration of the former large industrial site as a 'renewable energy village' (mixed commercial / residential)
- We argued that there was a credible geothermal prospect beneath the site
- Exploration funding (£460K) was granted

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Basis for geothermal resource hypothesis

- Geophysical identification of likely Weardale Granite (Bott 1954)
- Rookhope Borehole (808m) proved Weardale Granite in 1960-61
- Granite found to be strongly radiothermal, explaining elevated geothermal gradient
- Evidence from last working mines:
  - Very steep geothermal gradient in Frazer's Hush
  - Tepid, saline water of geothermal affinities (equilibrated at 160^{o}C) in Cambokeels Mine

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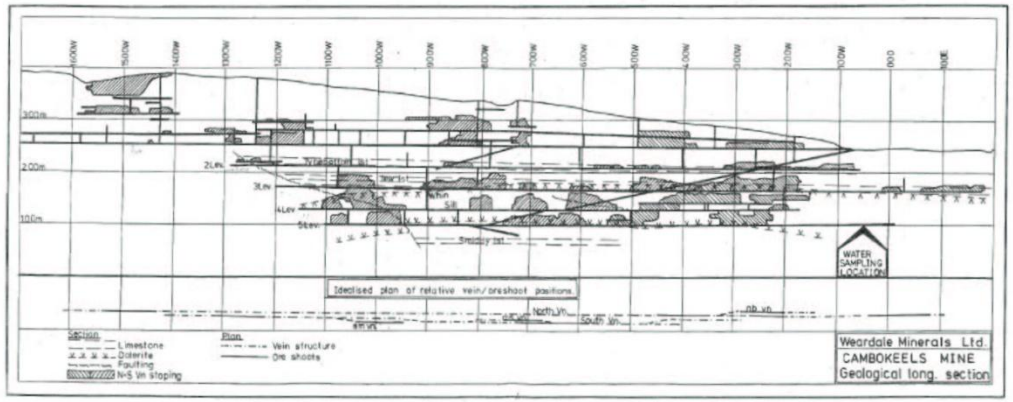
Slitt Vein



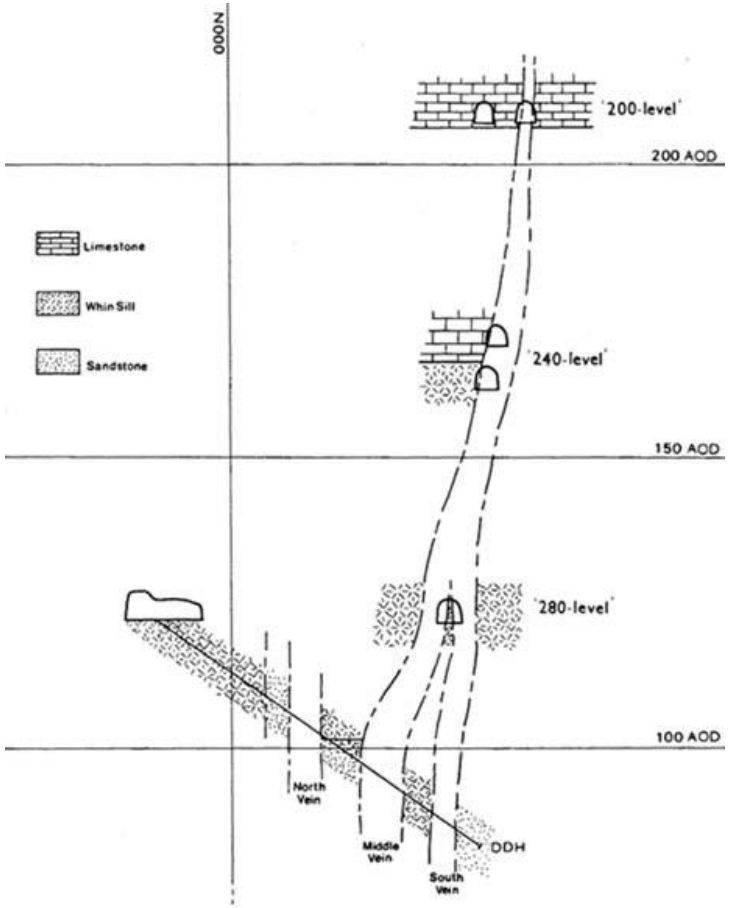


Fig.3.iii
CROSS SECTION of VEIN and MAIN LEVELS
at 800.W. Cambokeels Mine

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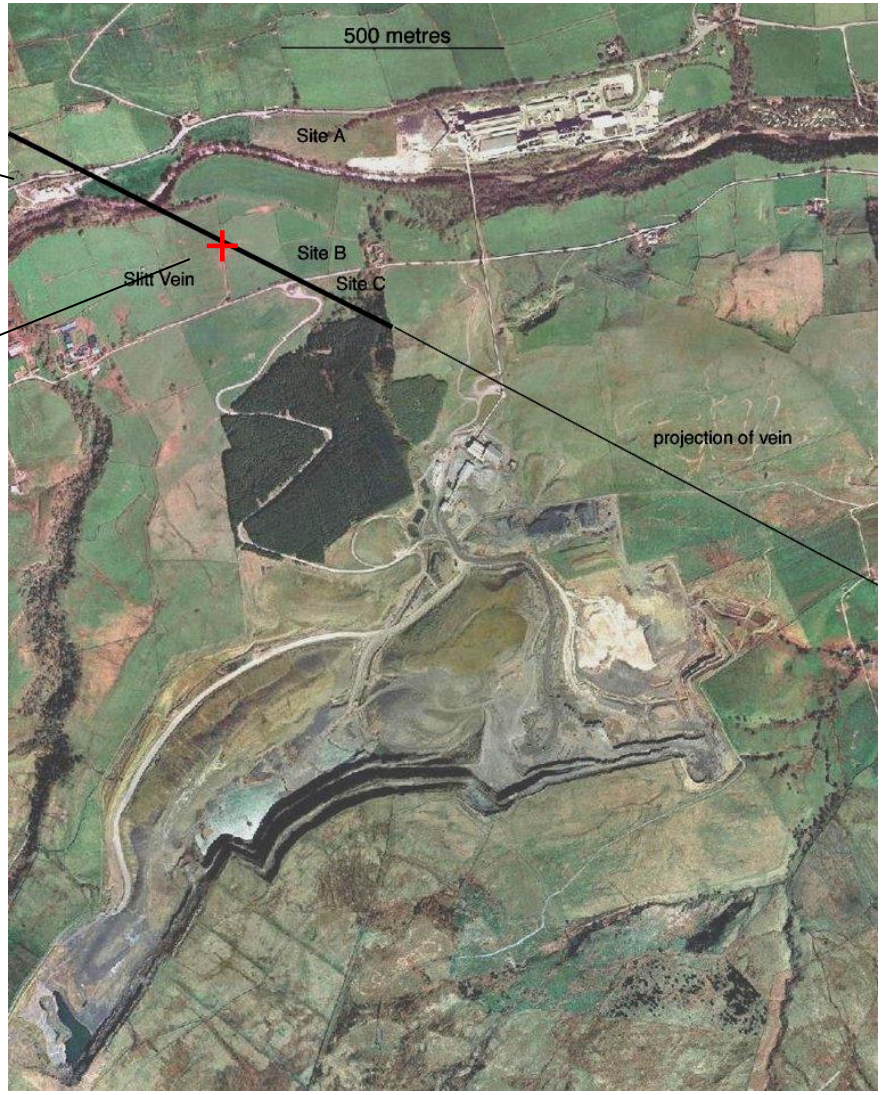
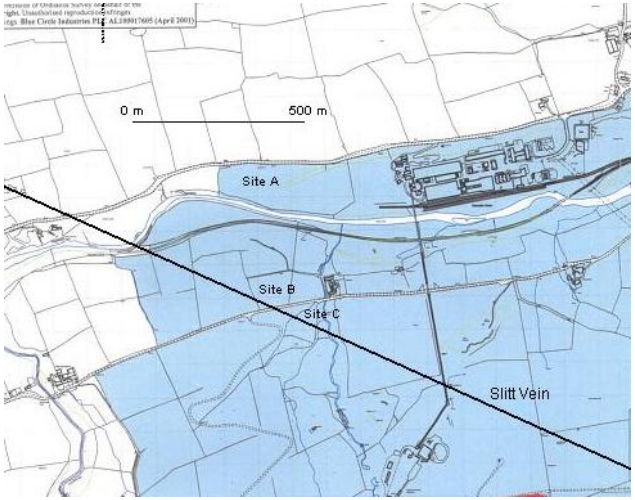
Slitt Vein at Eastgate

Cambokeels mine

Eastgate BH No 1





Eastgate No 1 Borehole

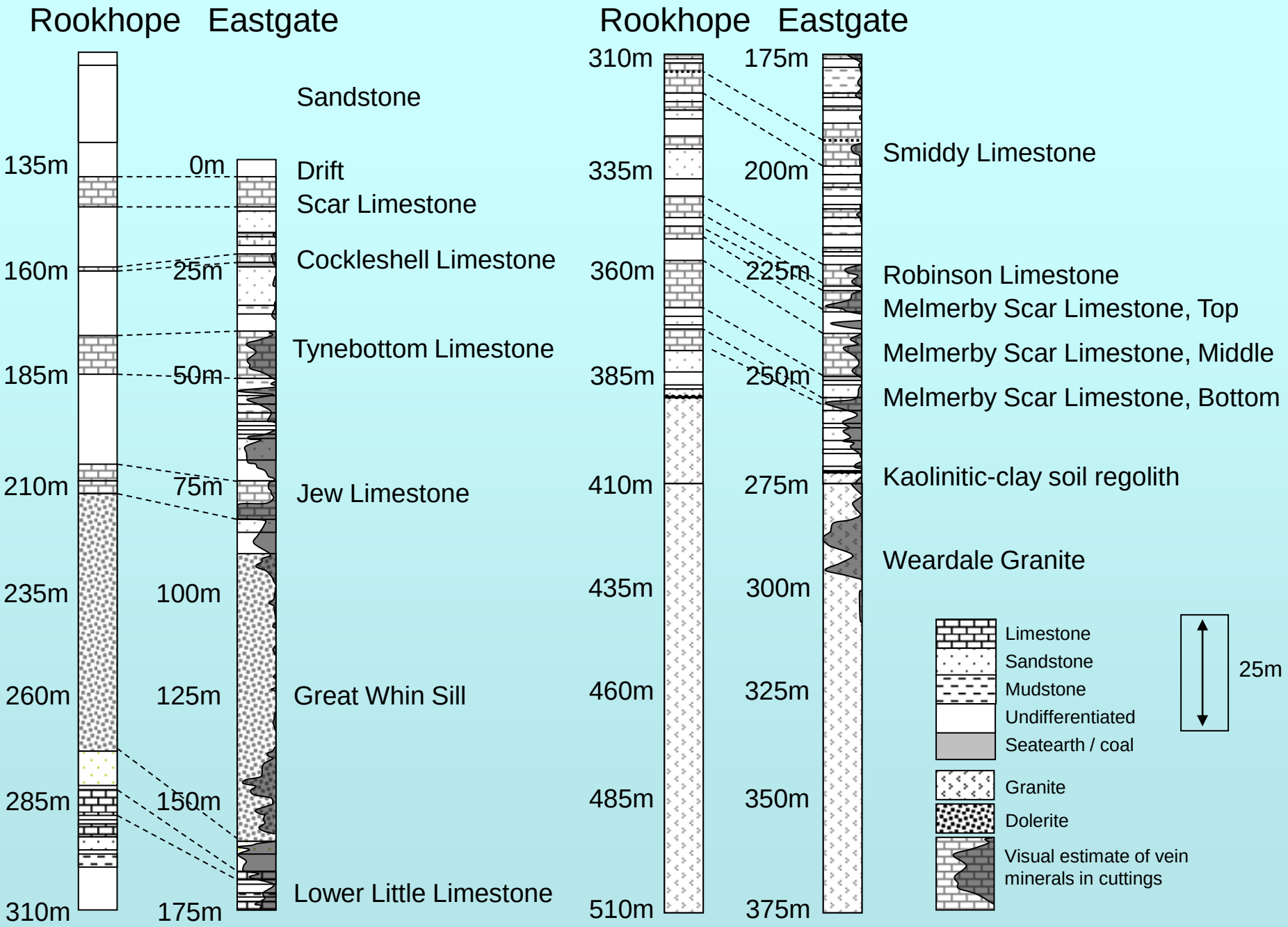
- Centred on Slitt Vein initially (sited from inclined bh data)

- Drilled open-hole by FORACO S.A. (France) from August to Dec 2004

-17.5" diam to Whin Sill; 12.5" into granite; 8.5" after casing (toe 403m)

- 995m vertical hole completed 4-12-2004 (geophysical logging by Reeves)

FORACO


Rookhope
Eastgate
Sandstone
135m
0m
Drift
Scar Limestone
160m
25m
Cockleshell Limestone
Tynebottom Limestone
185m
50m
210m
75m
Jew Limestone
235m
100m
260m
125m
Great Whin Sill
285m
150m
310m
175m
Lower Little Limestone
Rookhope
Eastgate
310m
175m
Smiddy Limestone
335m
200m
360m
225m
Robinson Limestone
Melmerby Scar Limestone, Top
Melmerby Scar Limestone, Middle
385m
250m
Melmerby Scar Limestone, Bottom
Kaolinitic-clay soil regolith
410m
275m
Weardale Granite
435m
300m
460m
325m
485m
350m
510m
375m
Limestone
Sandstone
Mudstone
Undifferentiated
Seatearth / coal
Granite
Dolerite
Visual estimate of vein minerals in cuttings
25m

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Borehole schematic – Eastgate No 1

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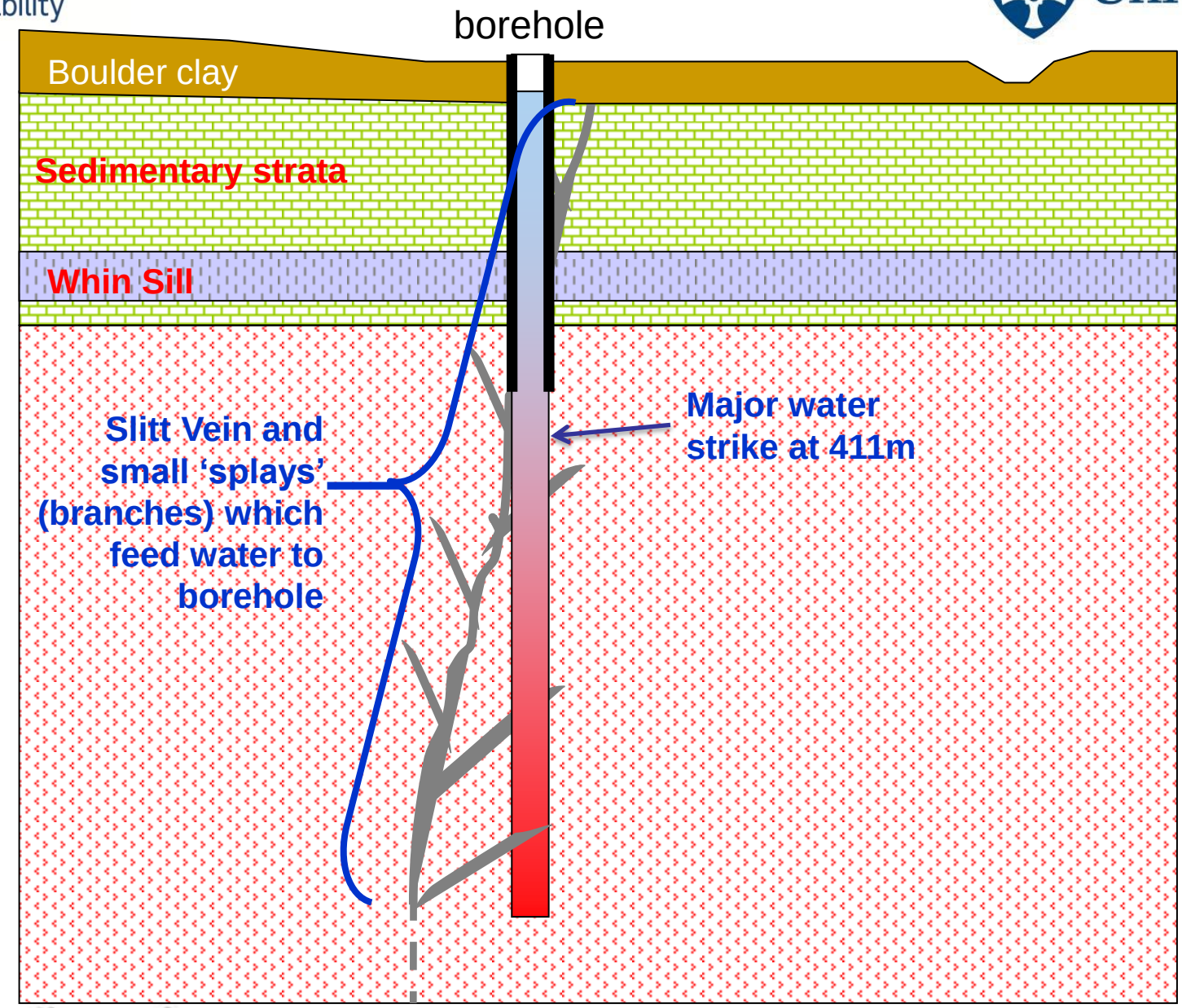

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CCTV stills: ~ 411.6m depth

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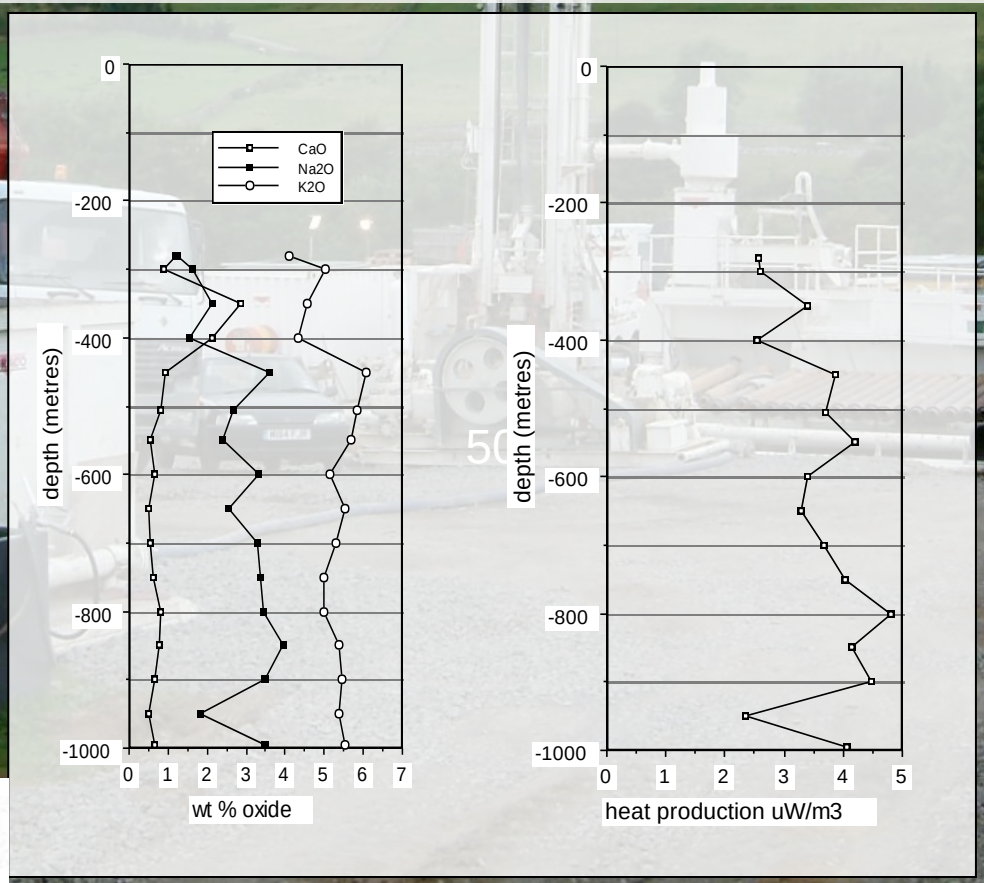
Eastgate No 1 Borehole: the Weardale Granite

Cuttings analysed by X-ray fluorescence (University of Leicester)

Signs of weathering in uppermost granite

U, Th and K contents used to calculate heat production capacity



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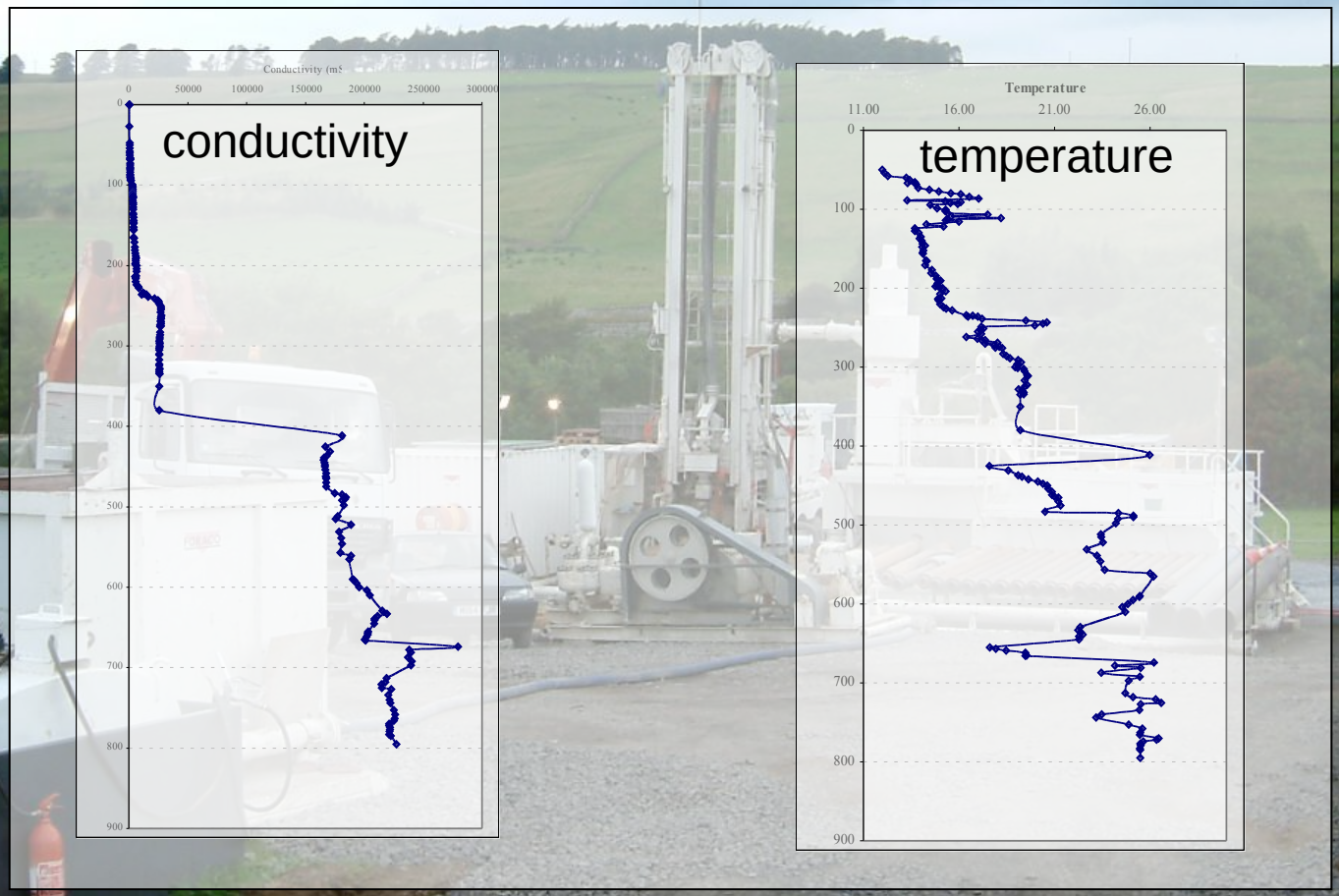
Changes in conductivity and temperature of groundwater air-lifted during drilling



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Geothermometric evaluation of water composition

Geothermometer used	Apparent equilibration temperature (°C)
Silica (Quartz)	38
Na-K (Fournier)	184
Na-K (Truesdell)	146
Na-K-Ca	191

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Packer testing (2006)

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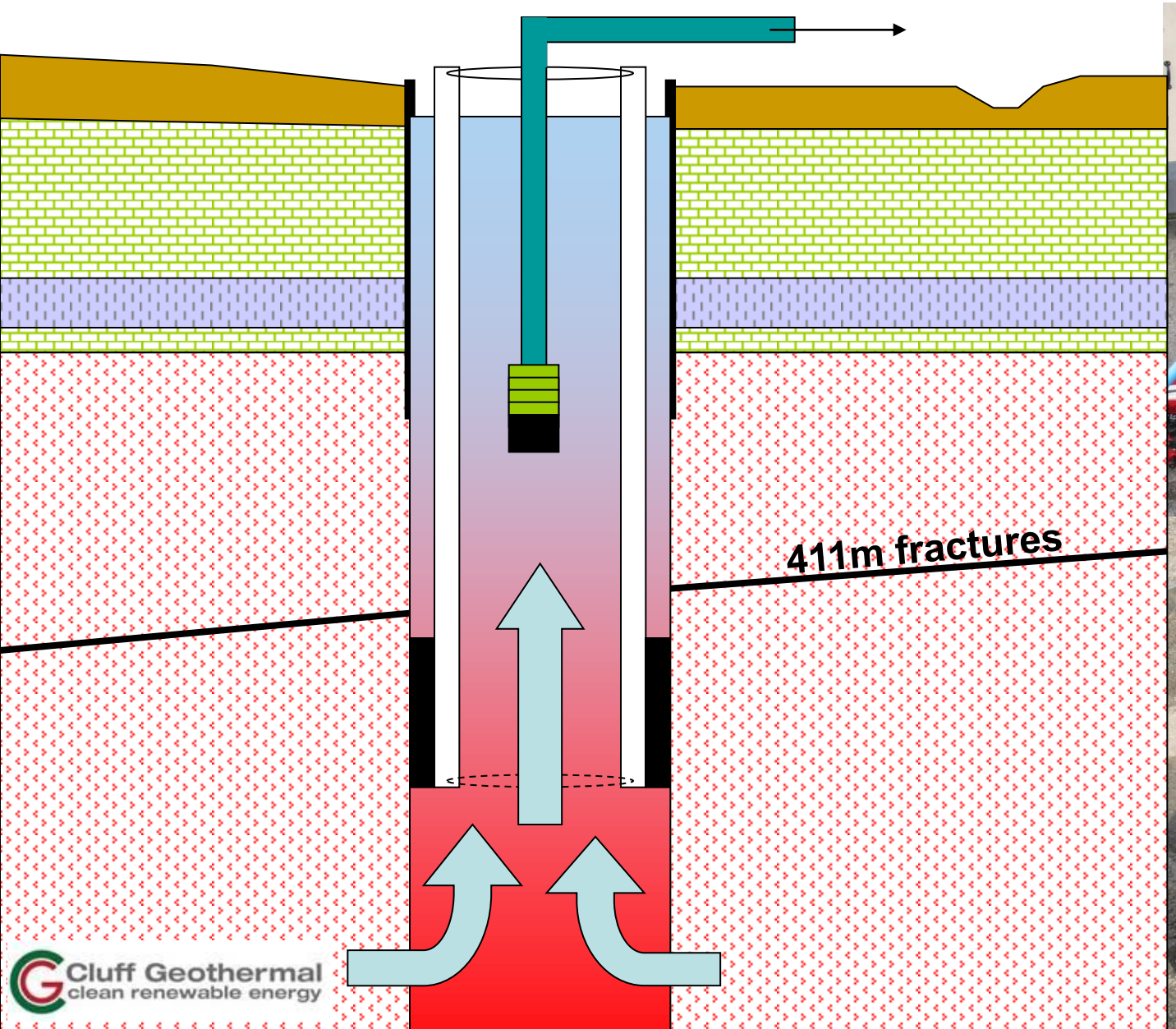

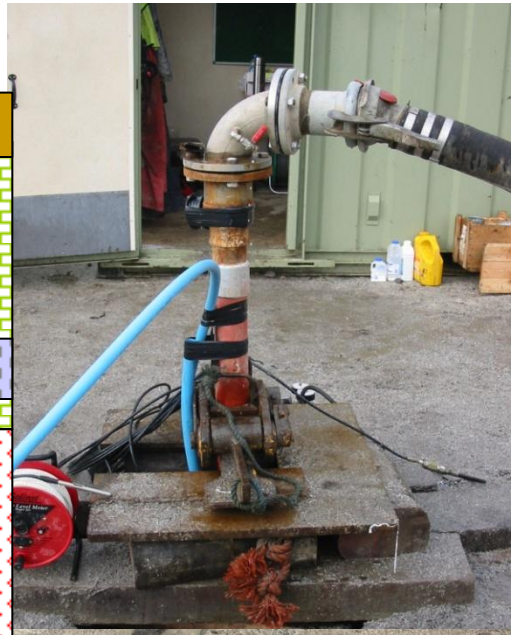

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Packer test results - summary

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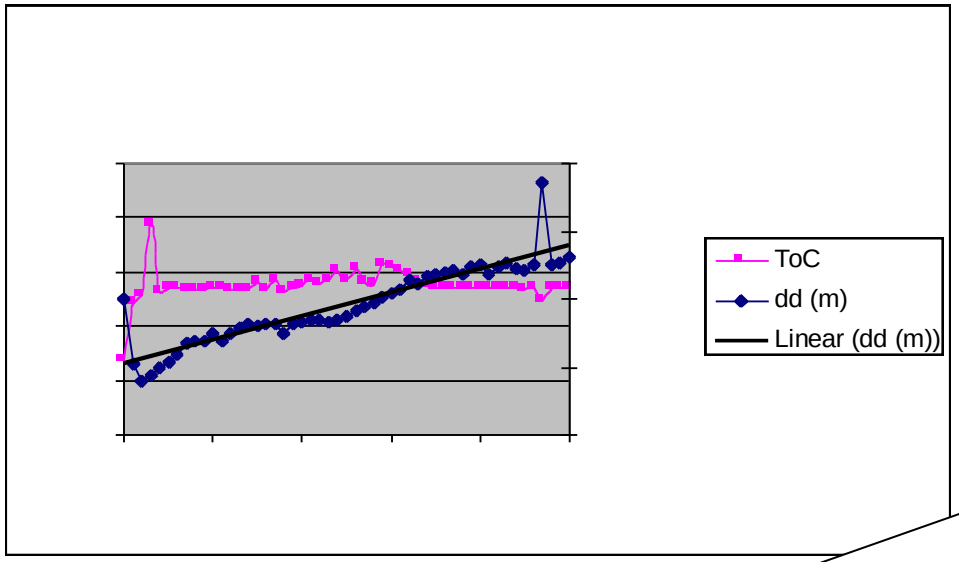
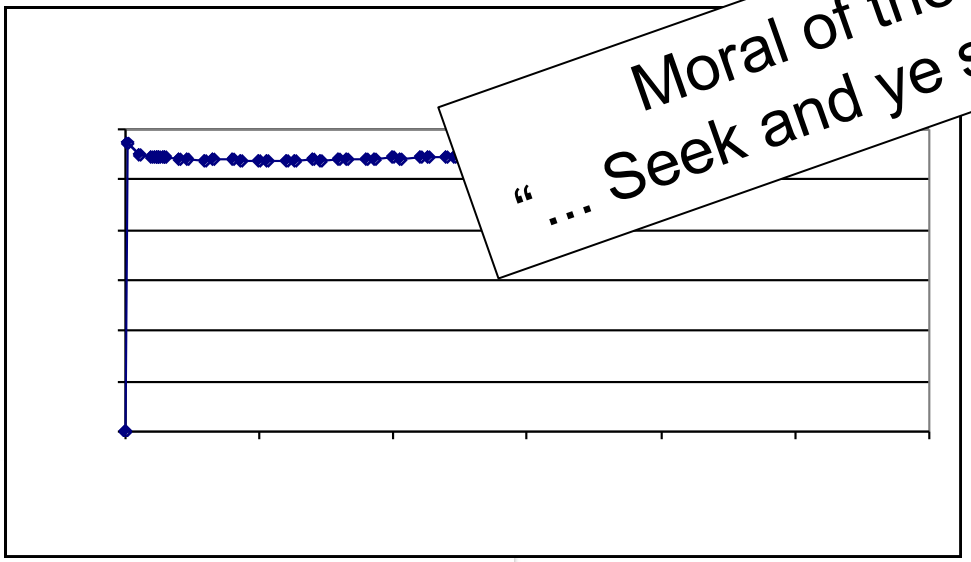
	Phase 1 - entire open hole (403-995m)	Phase 2 - packer in place (432-995m)
Pumping rate	880 m^3/d	518 m^3/d
Drawdown after 0.5 hour:	- 0.48m	+ 27.37m
Drawdown after 12 hours:	- 0.16m	+ 27.27m
Drawdown after 24 hours:	+ 0.25m	+ 27.17m
Transmissivity	4000 darcy-metres	26 darcy-metres
Permeability	170 darcies	0.05 darcies

Packer-test results: hyper-permeable granite





Without packer: 37 m^3/hour

Transmissivity of 4000 darcy-m
- When 411m feature is included in the test interval, we encounter **the highest permeability ever reported from granite anywhere** (as far as we can find …)

Moral of the story:
"… Seek and ye shall find …"

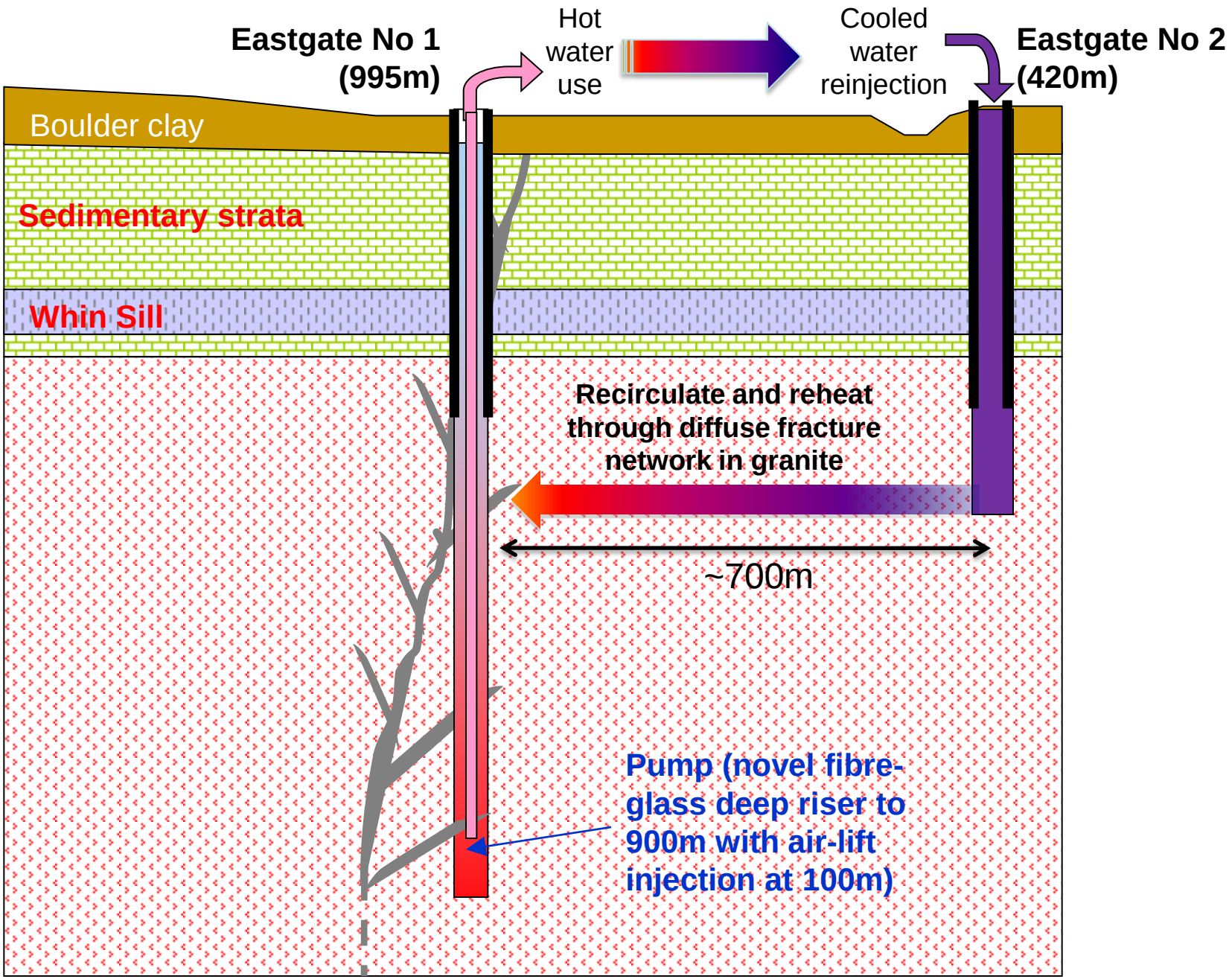
With packer: 22 m^3/hour

Transmissivity of 26 darcy-m
- Granite below main feeder fractures still more permeable than most, but not extreme

Eastgate Phase 2: 2010

- Drilling Eastgate No 2
- Fitting-out Eastgate No 1 for Productive Use

DECC Deep Geothermal Challenge Fund competition, November 2009
£461K awarded to Newcastle University-led bid (also involved PB Power and Durham University)



Production cycle concept

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Drilling of Eastgate No 2 - commenced 19th February 2010

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Drilling of Eastgate No 2

- Located ~300m N of Slitt Vein
- Major challenges in drilling and grouting unexpected **major** karst in Carboniferous overburden
  - Planned 6-week work plan ended up taking 16 weeks
- Eastgate No 2 finally completed at 420m (~ 140m into granite)
- Granite was relatively low permeability (as I expected)
  - Useful evidence of structural affinity of high permeability found in Eastgate No 1

Fitting-out Eastgate No 1 for productive use

- Step 1: inspection survey (checking for corrosion of mild steel casing):
  - Geophysical and CCTV logging
  - Revealed negligible corrosion risk (due to lack of O_2 ingress and freshwater leakage into shallower runs of casing)
- Step 2: fit-out borehole for production pumping:
  - Standard pumping approaches disfavoured by need for permanent packers, corrosion worries and motor performance issues
  - Rest water level is shallow; favours novel approach based on air-lifting using 900m GRP riser

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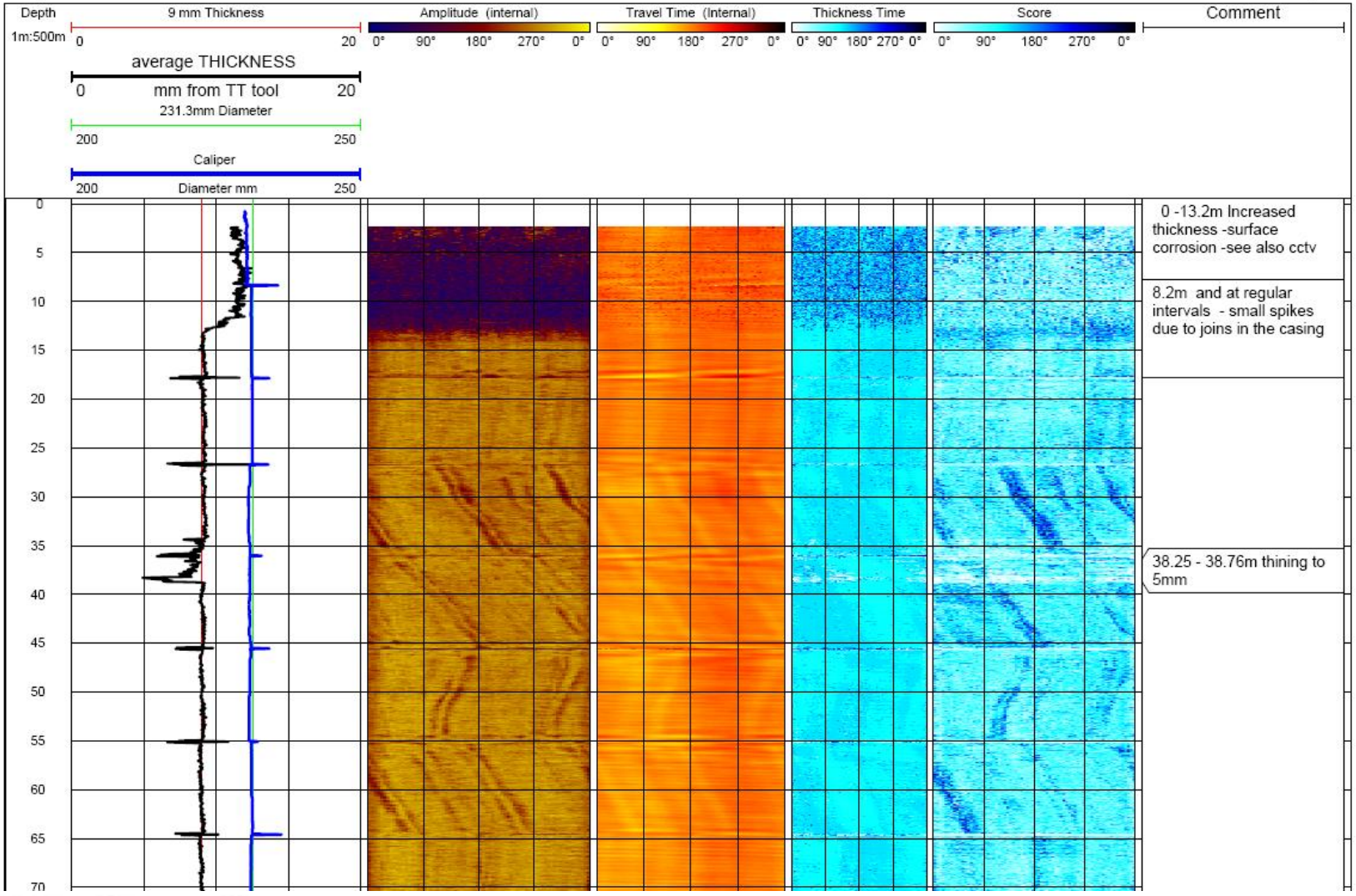
Geophysical condition survey of Eastgate No 1 cased interval (0 – 403m)



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Installing GRP riser to 900m







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Brief performance test of GRP riser system after installation

- Purpose:
  - to evaluate any beneficial effect on produced water temperature
  - to see if GRP riser introduces significant turbulent upflow head losses
  - to give stakeholders an opportunity to experience warm waters first-hand

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Performance testing GRP riser system

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Performance testing GRP riser system

- Pumping rate 34 m^3/hr
  - cf 37 m^3/hr in Phase 1 open hole test
- Drawdown after 46 mins: 0.85m
  - cf eventual drawdown of about 0.25m in Phase 1 open hole test
- Specific Capacities:
  - ~ 3520 m^3/d/m drawdown without GRP riser
  - ~ 960 m^3/d/m drawdown with GRP riser
  - turbulent upflow losses are significant, but well so productive still don't matter

Performance testing GRP riser system

- Water temperature reached maximum of about 37°C after about 15 minutes (cf maximum of 27°C in Phase 1 test)
- Conductivity climbed steadily from about 0.25 mS/cm at start of test to 80 mS/cm after 20 mins
- In later parts of test, breakthrough of water from 411m fracture zone was detected, taking temperature back to about 30°C and conductivity back to 68 mS/cm (i.e. same as in Phase 1 and 2 tests)

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Eastgate Geothermal Spa

the first iteration

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Future Geothermal Energy Use at Eastgate

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Future Geothermal Energy Use at Eastgate

Initial proposals – direct use:

- Geothermal spa – first genuine natural thermal water spa in UK since the Romans built Bath!
- Tilapia (cod replacement) fish farm
- Sports shoe manufacture
- Other commercial and residential space heating

Future Geothermal Power Generation at Eastgate

- Will require:
  - further drilling to 2.5 km or more - could re-enter Eastgate No 1 or No 2
  - construction and use of a binary power plant
- 66 KVa National Grid connection already at site

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Geothermal upon Tyne?

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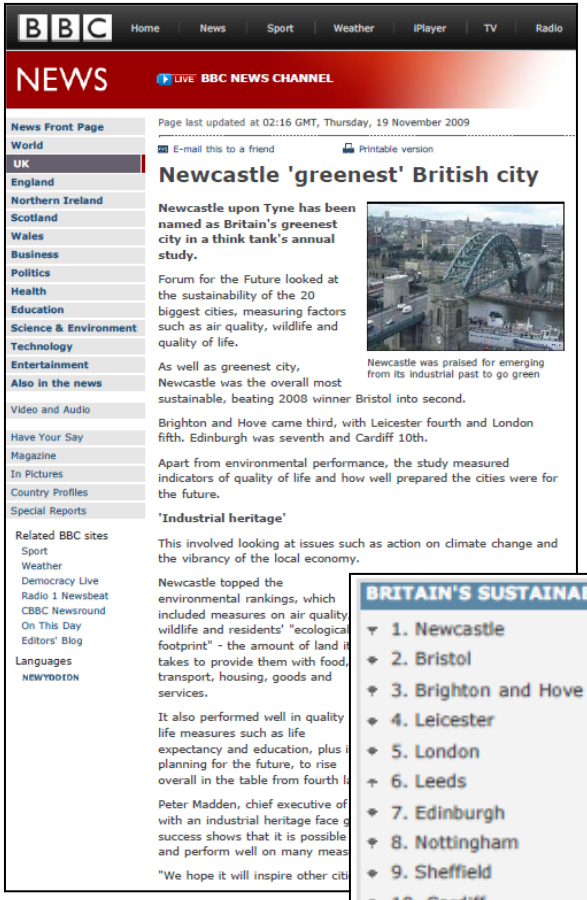
Newcastle – the UK's most sustainable large city

- 'Forum for the Future' league tables
- Compare the performance of the UK's twenty largest cities
- Newcastle 1st:
  - Nov 2009
  - Nov 2010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Page last updated at 02:16 GMT, Thursday, 19 November 2009

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Newcastle 'greenest' British city

Newcastle upon Tyne has been named as Britain's greenest city in a think tank's annual study.

Forum for the Future looked at the sustainability of the 20 biggest cities, measuring factors such as air quality, wildlife and quality of life.

Newcastle was praised for emerging from its industrial past to go green

As well as greenest city, Newcastle was the overall most sustainable, beating 2008 winner Bristol into second.

Brighton and Hove came third, with Leicester fourth and London fifth. Edinburgh was seventh and Cardiff 10th.

Apart from environmental performance, the study measured indicators of quality of life and how well prepared the cities were for the future.

'Industrial heritage'

This involved looking at issues such as action on climate change and the vibrancy of the local economy.

Newcastle topped the environmental rankings, which included measures on air quality, wildlife and residents' "ecological footprint" - the amount of land it takes to provide them with food, transport, housing, goods and services.

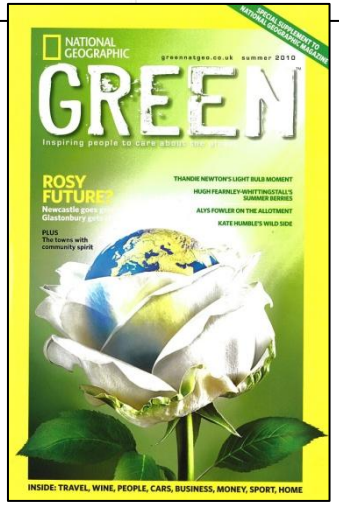
It also performed well in quality life measures such as life expectancy and education, plus i planning for the future, to rise overall in the table from fourth l

Peter Madden, chief executive of with an industrial heritage face g success shows that it is possible and perform well on many meas

"We hope it will inspire other citi

BRITAIN'S SUSTAINABLE CITIES

1. Newcastle
2. Bristol
3. Brighton and Hove
4. Leicester
5. London
6. Leeds
7. Edinburgh
8. Nottingham
9. Sheffield
10. Cardiff



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Not resting on laurels: NewcastleGateshead 1Plan

- 1Plan sets forth a 20-year vision for NewcastleGateshead to become a great northern European city, through pursuit of a programme of ‘sustainable urbanism'
- The urban core will be transformed on a sustainable basis
- The Twin Cities’ knowledge economy will be expanded, with associated skills development and talent attraction
- Newcastle University is crucial to this programme, and is a primary partner in one of the principal vehicles for it: Newcastle Science City

NewcastleGateshead 1Plan Economic & Spatial Strategy

Transforming the urban core: NewcastleGateshead as an Urban Laboratory

- *"Act local, think global":* Newcastle University researchers are working strategically with civic partners to develop exportable innovations to achieve sustainability in old industrial cities
- The '**Science Central**' redevelopment site is one particularly coherent arena in which to do this, developing state-of-the-art research facilities, shared with industry, alongside sustainable affordable homes
- The wider urban laboratory will radiate sustainable urbanism throughout the conurbation, re-developing NewcastleGateshead as a global exemplar

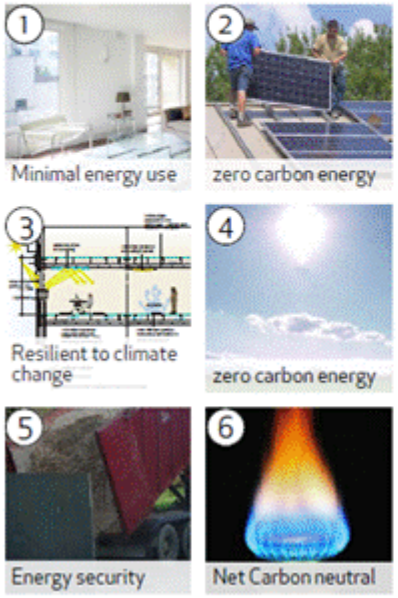
Science Central: the opportunity

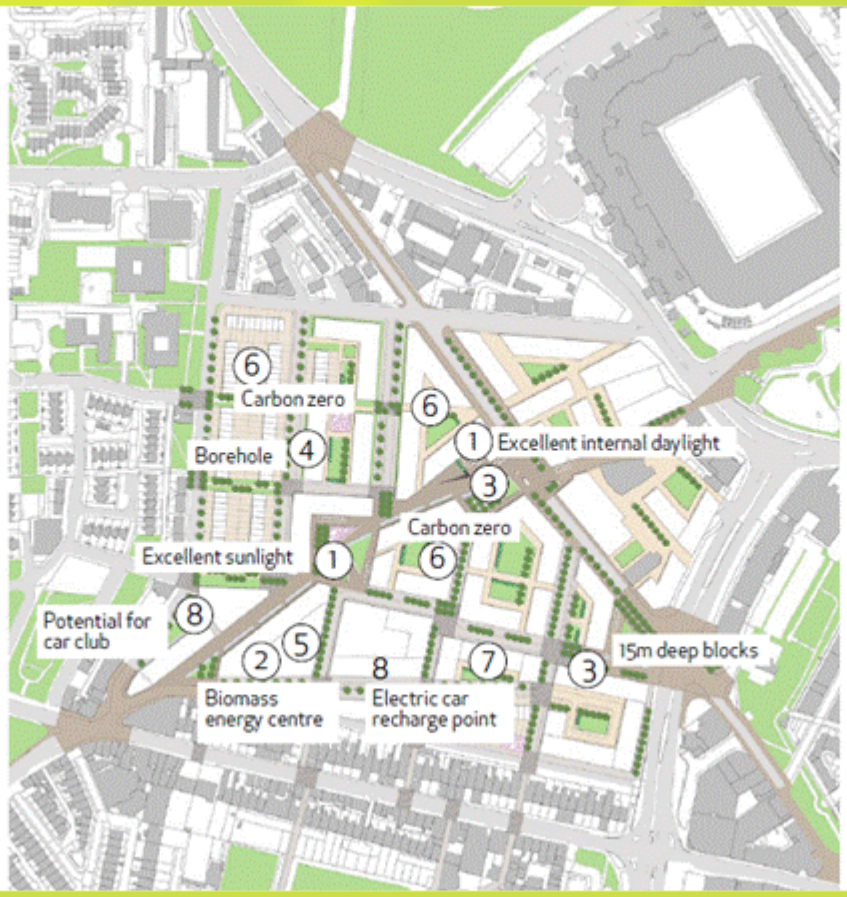
- Former site of Newcastle Brown Ale brewery
- 20 acres - UK's largest city-centre redevelopment site
- Land in joint ownership: Newcastle City Council, Newcastle University, ONE
- Masterplan for 15-year site development emphasises state-of-the-art in sustainable urbanism
- Commitment to CHP site grid development, into which geothermal fits very well
- Site close to Eldon Square – UK's largest city-centre indoor mall; owners (CSC) have expressed very strong interest in using geothermal CHP

Newcastle Science City
TRANSFORMING TOMORROW

Science Central – sustainably co-locating engineering science with industry

Efficient Use of Energy





Ecologically friendly

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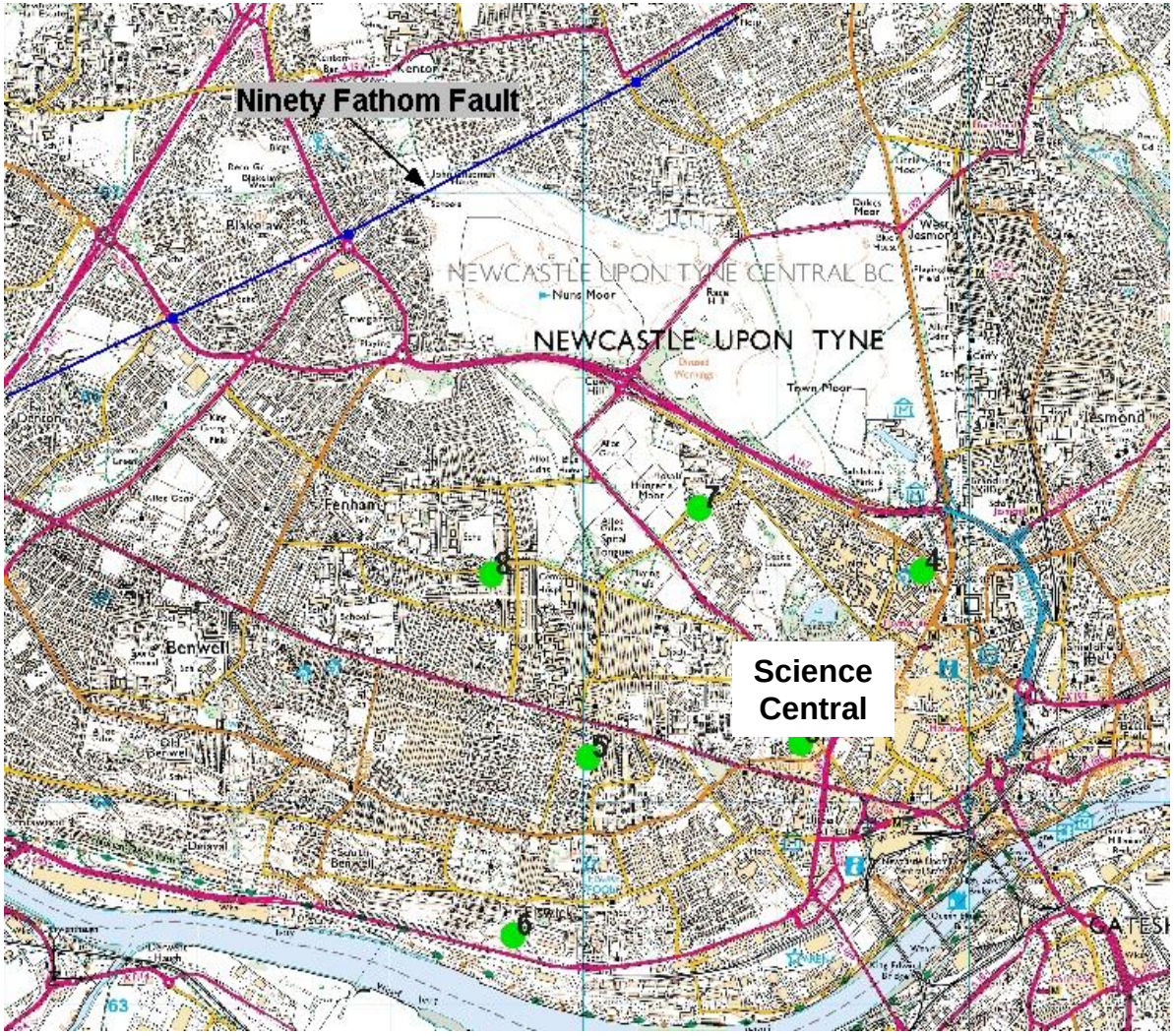
Science Central - location



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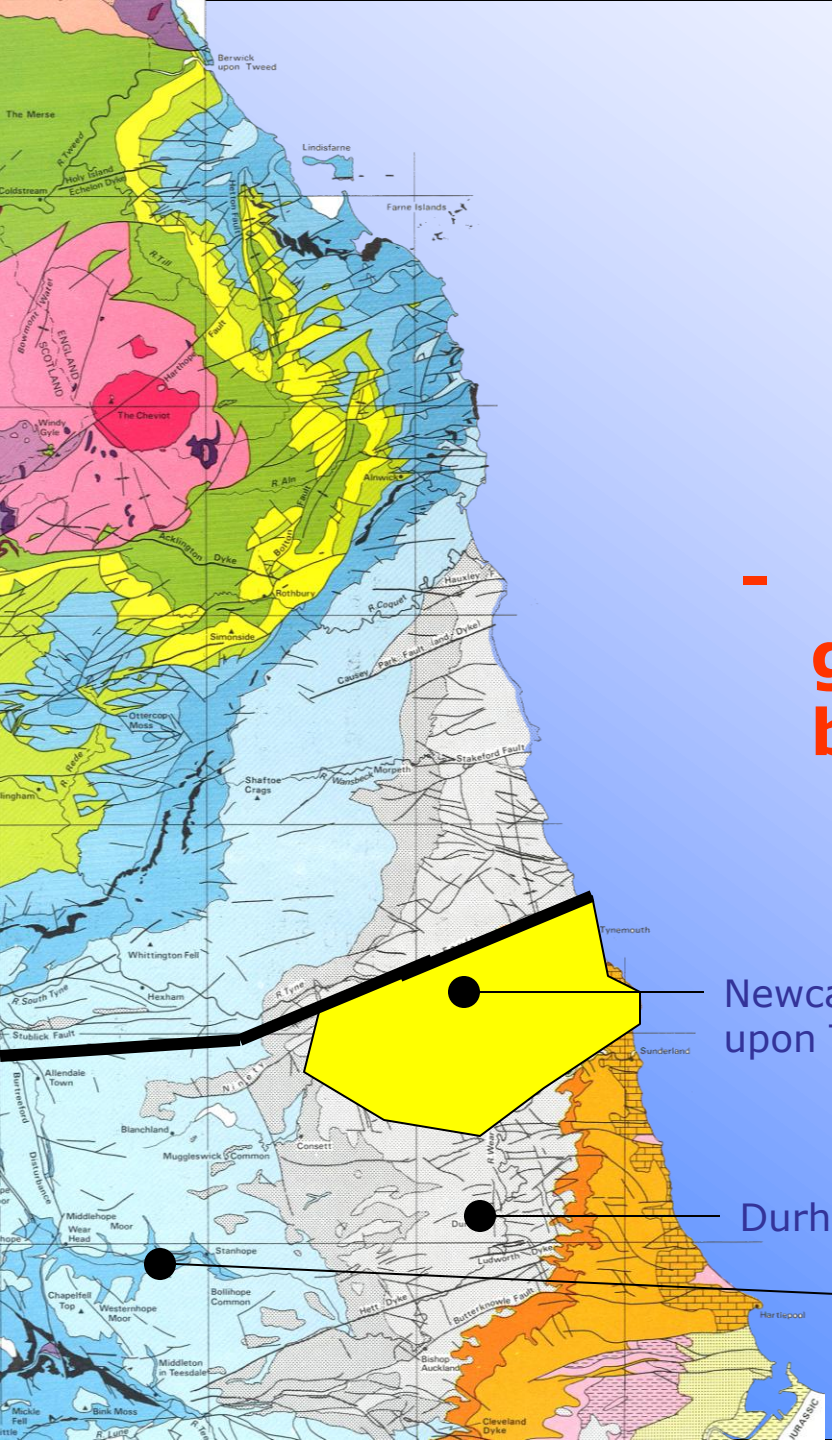
90 Fathom Fault

- **Is there a major geothermal prospect beneath urban Tyneside?**



Target: 2000 m depth in the footwall splays of 90 Fm Fault zone

- Ninety Fathom Fault System surface trace strikes ENE through urban Newcastle
- Evidence of ancient and recent hydrothermal circulation in main fault and footwall splays:
  - BaCl brines in Rising Sun and Backworth Collieries, North Tyneside (≤ 1.8 Ml/d pumped until 1978)
  - Barite cementation of Basal Permian Sands at Cullercoats
- Why 2000m depth? To establish geothermal gradient, prove any permeable formations accessing fault laterally at depths of interest, and maximise chances of intersecting splay-faults

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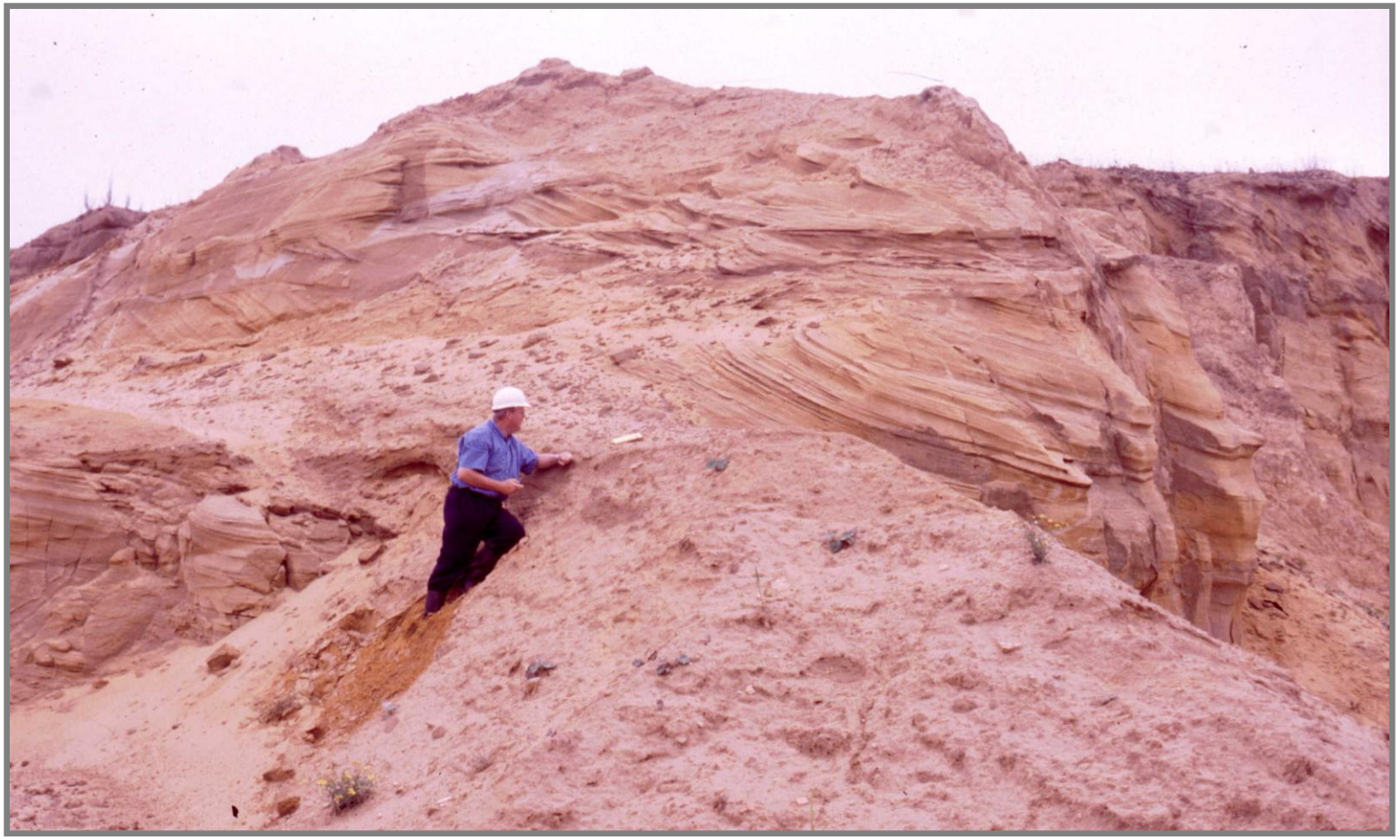
Basal Permian Sands – usual uncemented state



Crime Rigg Quarry, Sherburn, Co Durham

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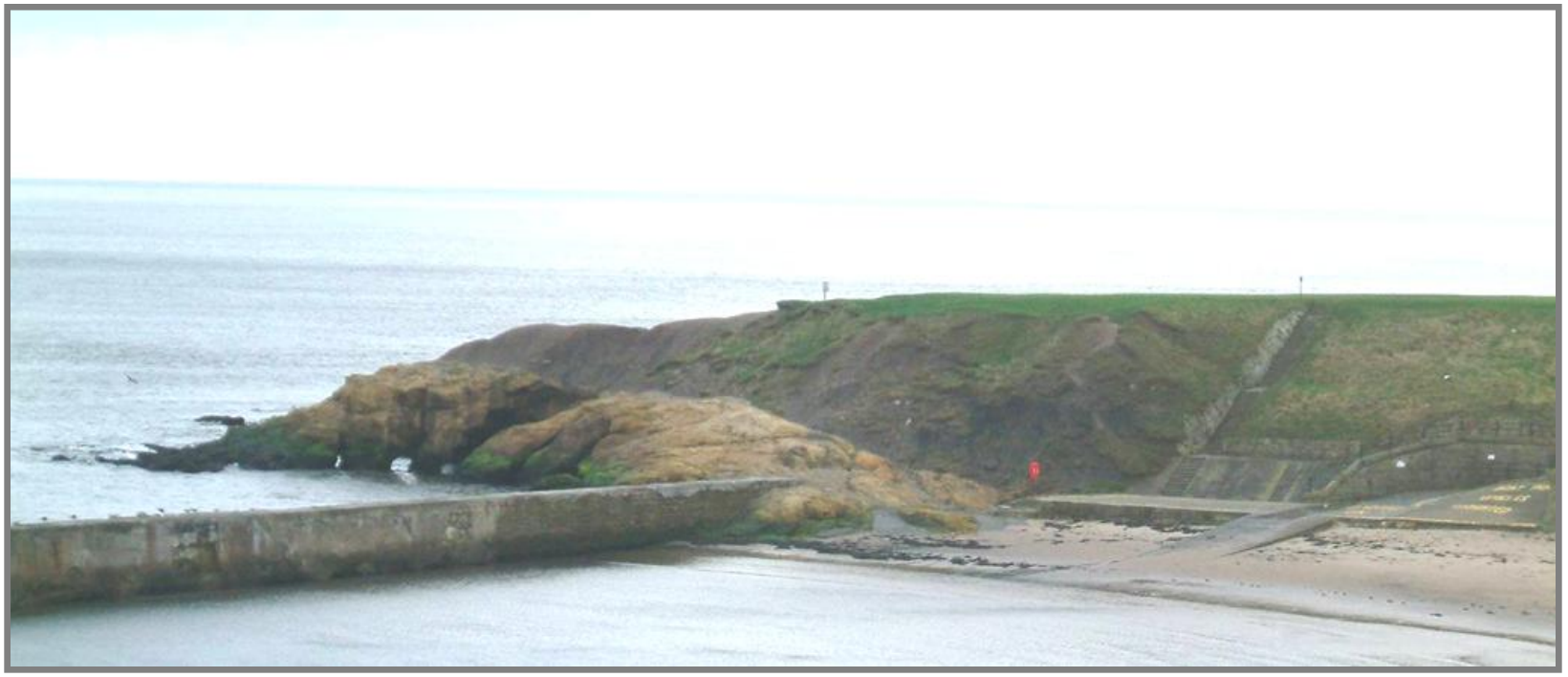
Basal Permian Sands – solidly cemented with barite along 90 Fm Fault



Cullercoats Bay from the Dove Marine Lab

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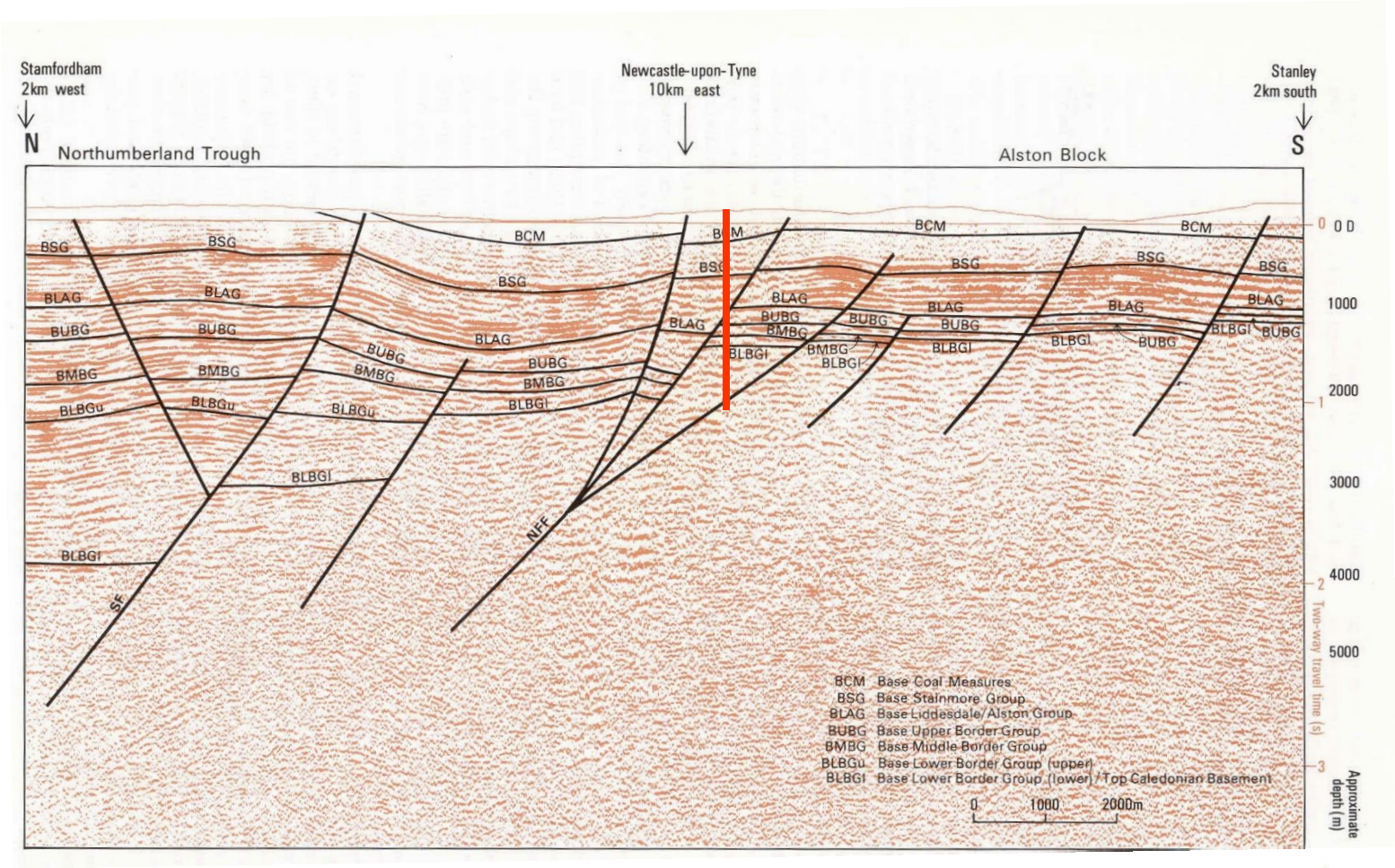
Splays as plays



Seismic profile source: BGS

Talk to SPE, London, 18th January 2011

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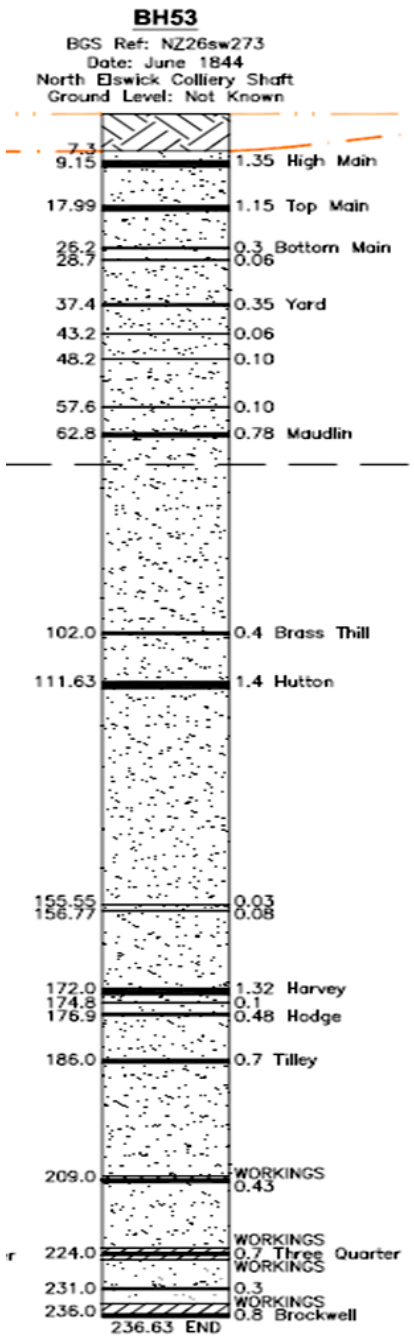
Science Central – geology proven to date (first 236m)



Cluff Geothermal clean renewable energy

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Next steps

- £0.9M drilling programme commencing January 2011: 2 km vertical hole to be drilled and geophysically logged in coming months
- Funded jointly by Science City partners (£500K) and **DECC Deep Geothermal Challenge Fund Phase 2** (£400K)
- Scientific direction: Newcastle and Durham Universities

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Conclusions

- North East England is proving to be a fruitful subsurface laboratory for the pursuit of new paradigms in deep geothermal energy:
  - Deliberately targeting high natural permeability in radiothermal granite
  - Targeting localised convection along major faults in areas of high geothermal gradient
- Taken together with exciting developments in Cornwall and Scotland, this represents real promise for a future boom in deep geothermal in the UK

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Is suarach uisge teth a shireadh fo chloich fhuair

It's daft to look for hot water beneath a cold stone

… or is it?

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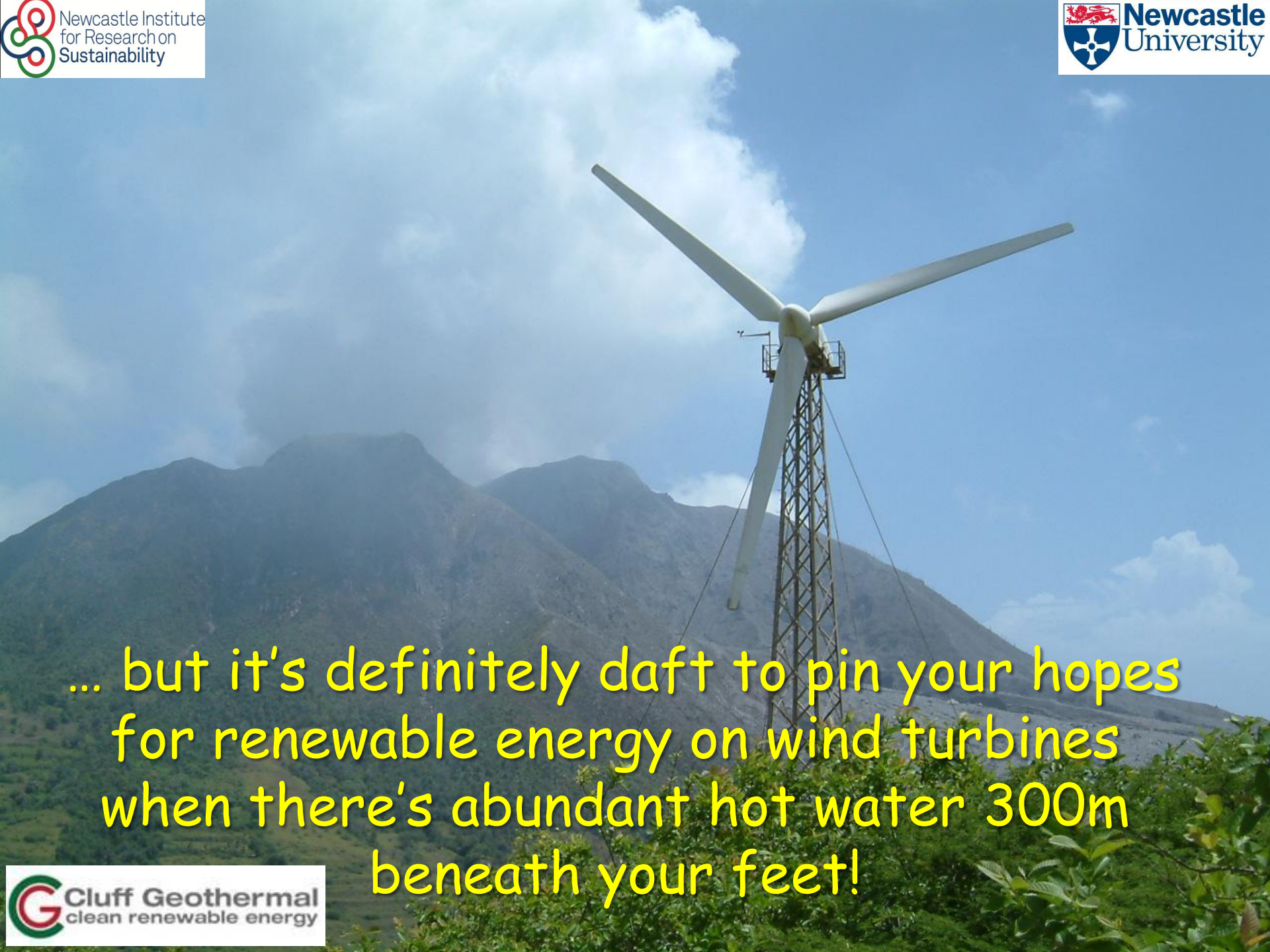
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… but it's definitely daft to pin your hopes for renewable energy on wind turbines when there's abundant hot water 300m beneath your feet!
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Thank you
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clean renewable energy