# Magnetic Susceptibility Oil & Gas Application

Martin Cox CEng FIMMM FEI SPE[1984]

Aberdeen Drilling Management
(Advanced Downhole Petrophysics)

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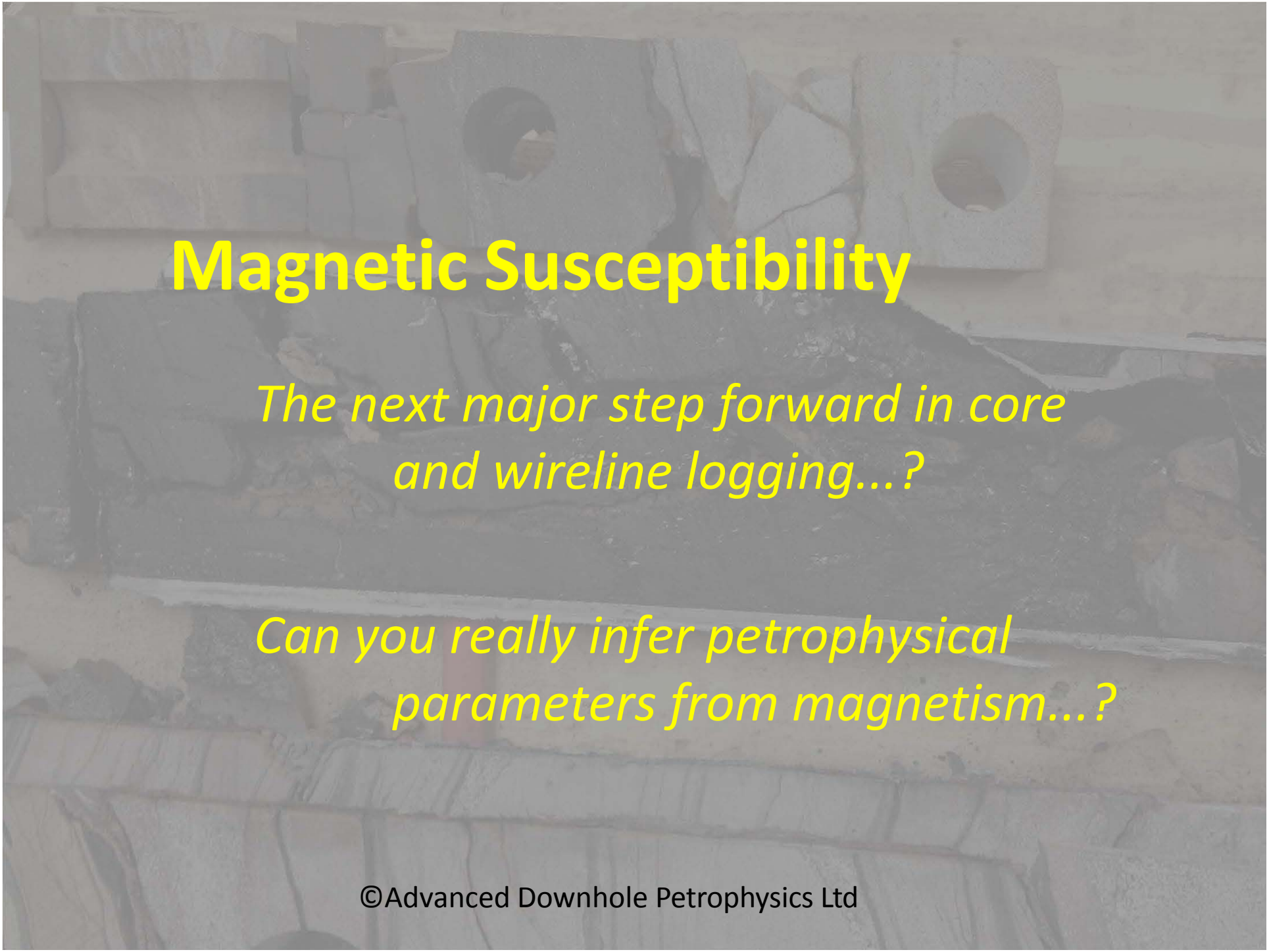

# Magnetic Susceptibility

*The next major step forward in core and wireline logging...?*

*Can you really infer petrophysical parameters from magnetism...?*

# *Yes! … for example:*

- O&G Operating companies and Service companies need to understand **permeability** – critical parameter in understanding how hydrocarbons will flow through rock formation
- $18.4bn p.a. spent on reservoir imaging (Speers)
- Failure wells cost $26bn p.a. (ITI Energy)
- Presently permeability is inferred from porosity, often from NMR logs, however there is a growing industry awareness that there are many imponderables associated with this approach leaving “the permeability question” unanswered –

***until now…***

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# Advanced Downhole Petrophysics Ltd. (ADP)

*.... is a new company commercializing novel interpretation of a naturally occurring phenomenon,* ***magnetic susceptibility*** *in order to estimate both permeability and mineralogy in a passive, non-destructive environment*

- Original research by Professor David Potter *(recipient of the SCA's (Society of Core Analysts) Darcy Lifetime Achievement 2015 Award)* and Dr. Arfan Ali, is the basis of the work currently undertaken by ADP

- One of ADP's first actions was to brand the technology: **MagPI™** (**Mag**netic **P**ermeability **I**ndicator) was born!

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# Value to O&G Operators

- Safety & Environmental
  - MagPI™ is intrinsically safe – no moving parts, no radioactive sources
- Increased Production
  - Better reservoir characterization – a recent job clearly identified the reason for 3 differing flow regimes in a mature, homogeneous reservoir that conventional well logs had failed to distinguish
  - Better understanding of shale plays and tar sands
- Cost Saving (potentially highly significant) – Examples include:
  - Reduced need for NMR / XRD and other costly Petrophysical routines
  - Possibly reduce needs for DST operations
  - Better, quicker determination of casing seats

***The list goes on – worthy of additional discussion…***

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# Introducing ADP – The Team

- **Ian Murphy** (Executive Chairman) - Considerable experience commercialising new technology. Initially defence avionics, later many sectors. Recent involvement in venture backed spin-outs
- **Andrew Tugwell** (Managing Director) - Previously COO of Aberdeen Drilling Management (ADM). Early career at Schlumberger. Previous experience in VC backed tool development (Cambridge Drilling Automation)
- **Martyn Greensmith** (Executive Director) – For 30+ years VP Worldwide Operations, Gyrodata specialising in precision wellbore placement. Likewise early career in Schlumberger
- **Professor David Potter** (Scientific Adviser) – Currently Director of the Integrated Petroleum Geosciences Program at the University of Alberta. Inventor of the method, his paper, "Magnetic Susceptibility as a Rapid, Non-destructive Technique for Improved Petrophysical Parameter Prediction" became the inspiration for the creation of this company
- **Robert MacAndrew** (Non-Executive Director) MD of Aberdeen Drilling Management, career includes senior posts with Chevron, Marathon & Ranger

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# Introducing ADP – The Team 2

- **Dr Clive Ninnes** (Stakeholder) – previously an asset manager for Shell for a major North Sea field, reservoir engineer now working for a variety of small operators. Long term relationship with Aberdeen Drilling Management (ADM) for reservoir engineering reviews/input as required
- **Dr Arfan Ali** (Stakeholder) - Graduate of Lahore University. Original PhD Student working with Professor David Potter. Now with Shell Aberdeen in sub-surface reservoir evaluation activities
- **David Butler** (Stakeholder) - Holds engineering degree qualification, formerly worked in UK nuclear industry, now with Scottish Enterprise and up to date on government grant and support funding for UK companies (UK Innovate)
- **Martin Cox** (Stakeholder) – from mining industry, now 30+ years Worldwide Operations, Wireline formation evaluation, early career in operations and to R&D and management, Expro North Sea contract management and engineering projects, Now with Aberdeen Drilling Management (ADM)

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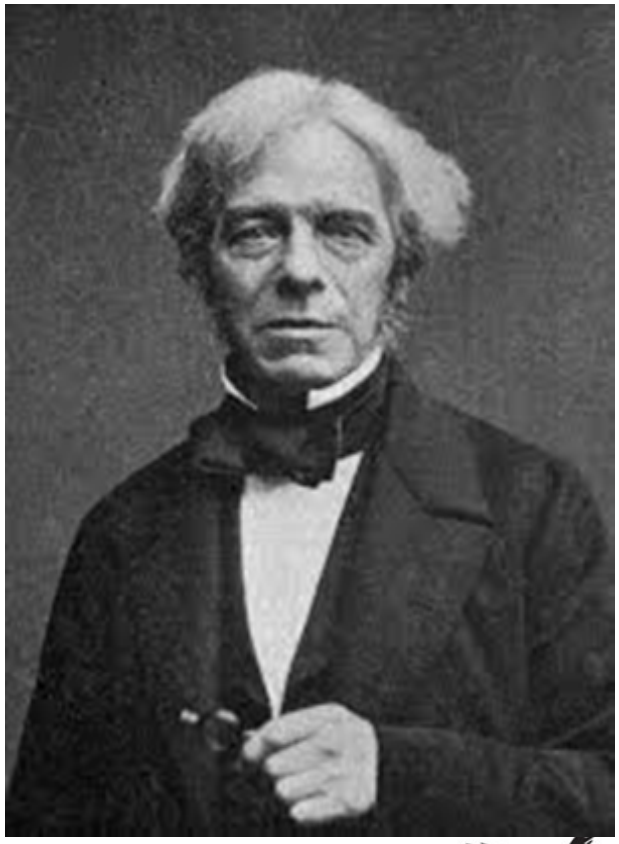
# Diamagnetics - Discovery

- Originally discovered by Dutch botanist & physician Sebald Justinius Brugmans
- 1778
- Diamagnetic materials create an induced magnetic field in a direction opposite to an externally applied magnetic field and are repelled by the applied field
- Paramagnetic materials exhibit opposite effect
- Both small (quantum) forces
- More familiar ferromagnetic materials – stronger forces and can be permanent (not just induced).

# Michael Faraday – developments based on investigations into electricity and magnetism

- 1845 Faraday discovered that many materials exhibit a weak repulsion from a magnetic field: a phenomenon he termed diamagnetism
- Determined a range of Paramagnetic materials exhibiting opposite effect
- Extensive investigation into diamagnetism, paramagnetism and more familiar ferromagnetism
- Farday's application of ferromagnetics part of the development of electricity (amongst others).



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# What is magnetic susceptibility?

- Apply an electromagnetic field
- Monitor how it varies when the sample is presented:
  - Diamagnetic (such as quartz)
  - Paramagnetic (such as Illite or Chlorite – permeability controlling minerals in typical reservoir formations)

*Next slide shows typical responses for O&G related minerals and fluids….*


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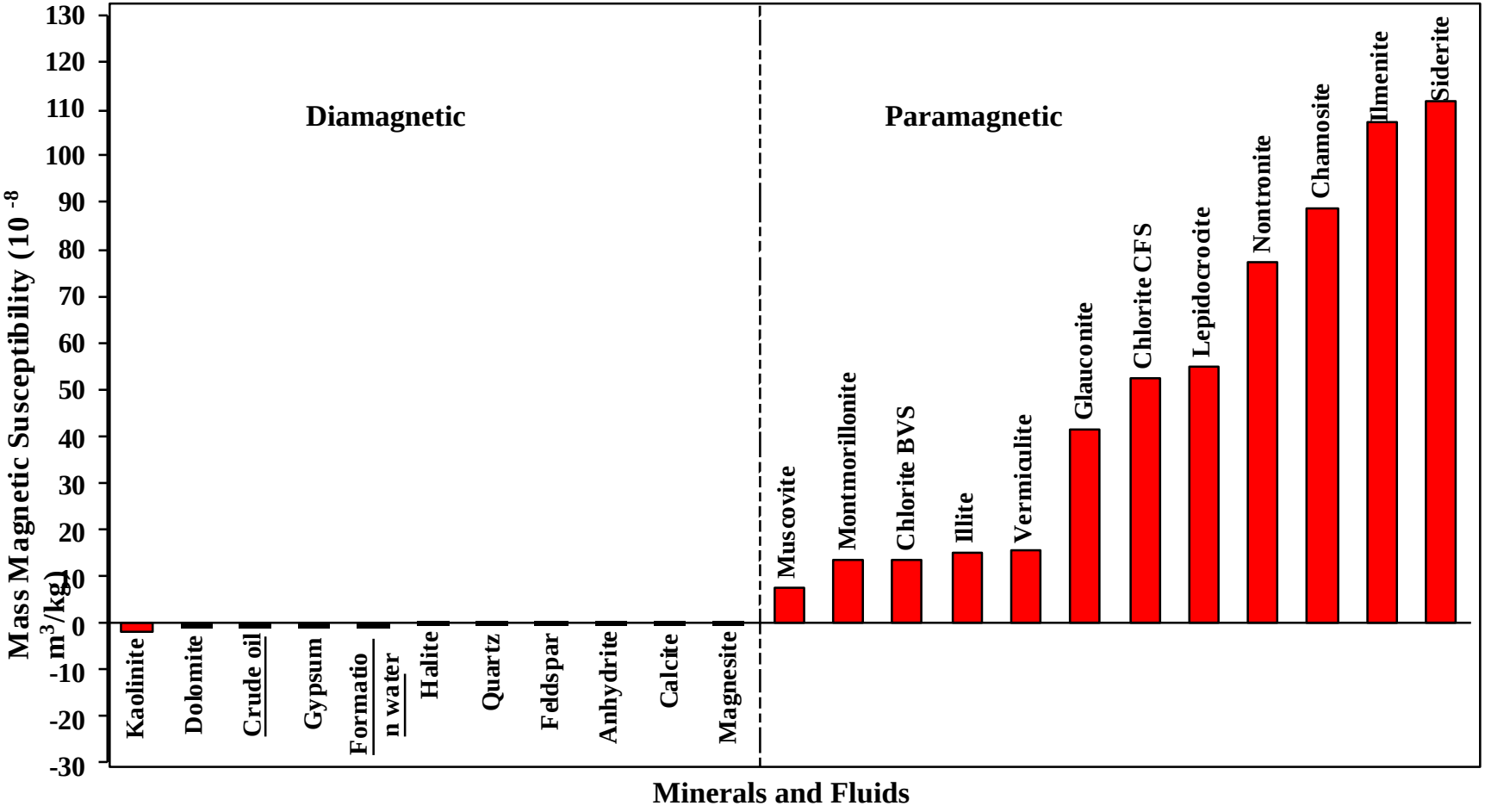
# Magnetic Properties of Reservoir Minerals and Fluids




***The striking differing responses are the basis of MagPI™ technology***

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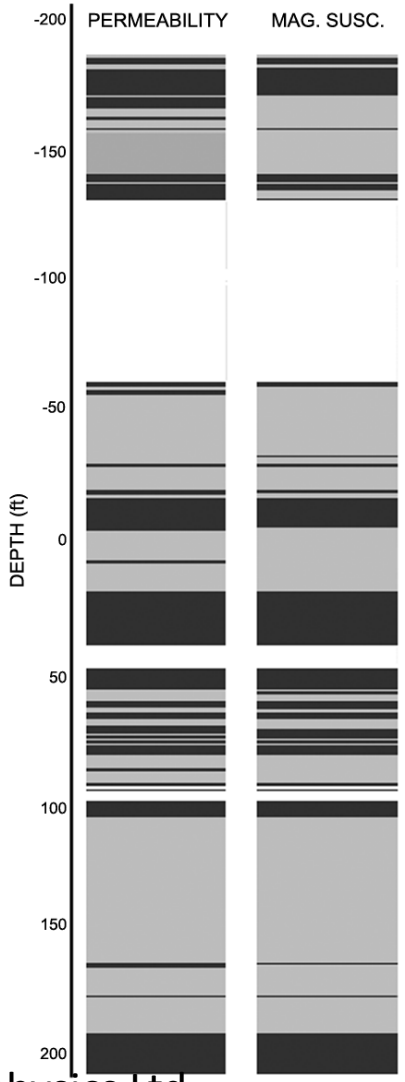
# Raw Magnetic Susceptibility Signal – Correlation with Fluid Permeability Zones

<u>Example from N. Sea Oil Well</u>

Net negative susceptibility (grey shading) corresponds to high permeability clean sand (diamagnetic quartz).

Net positive susceptibility (black shading) corresponds to low permeability muddy sand or shale containing increased amounts of permeability controlling clay (paramagnetic illite)



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**Reference Paper for details**

**SCA2014-077**

# CORRELATION BETWEEN MAGNETIC PROPERTIES AND PERMEABILITY: RESULTS FROM A NEW CASE STUDY IN THE NORTH SEA


## ABSTRACT

A new case study on a siliciclastic North Sea shoreface reservoir has shown correlations between magnetic susceptibility, paramagnetic clay content and permeability, consistent with previous work.


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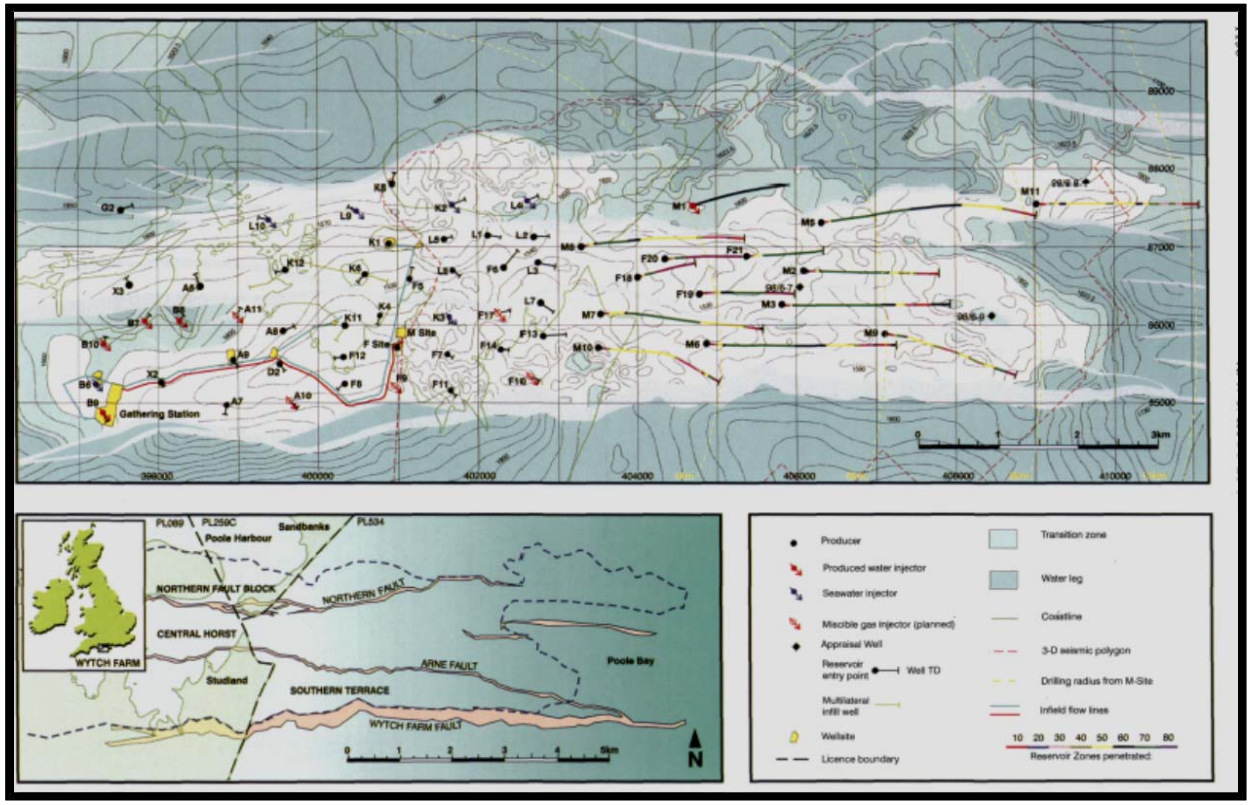
Following results from recent MSc project sponsored by ADP...

***They show similar correlations to dozens of other studies taken from many diverse world-wide locations***

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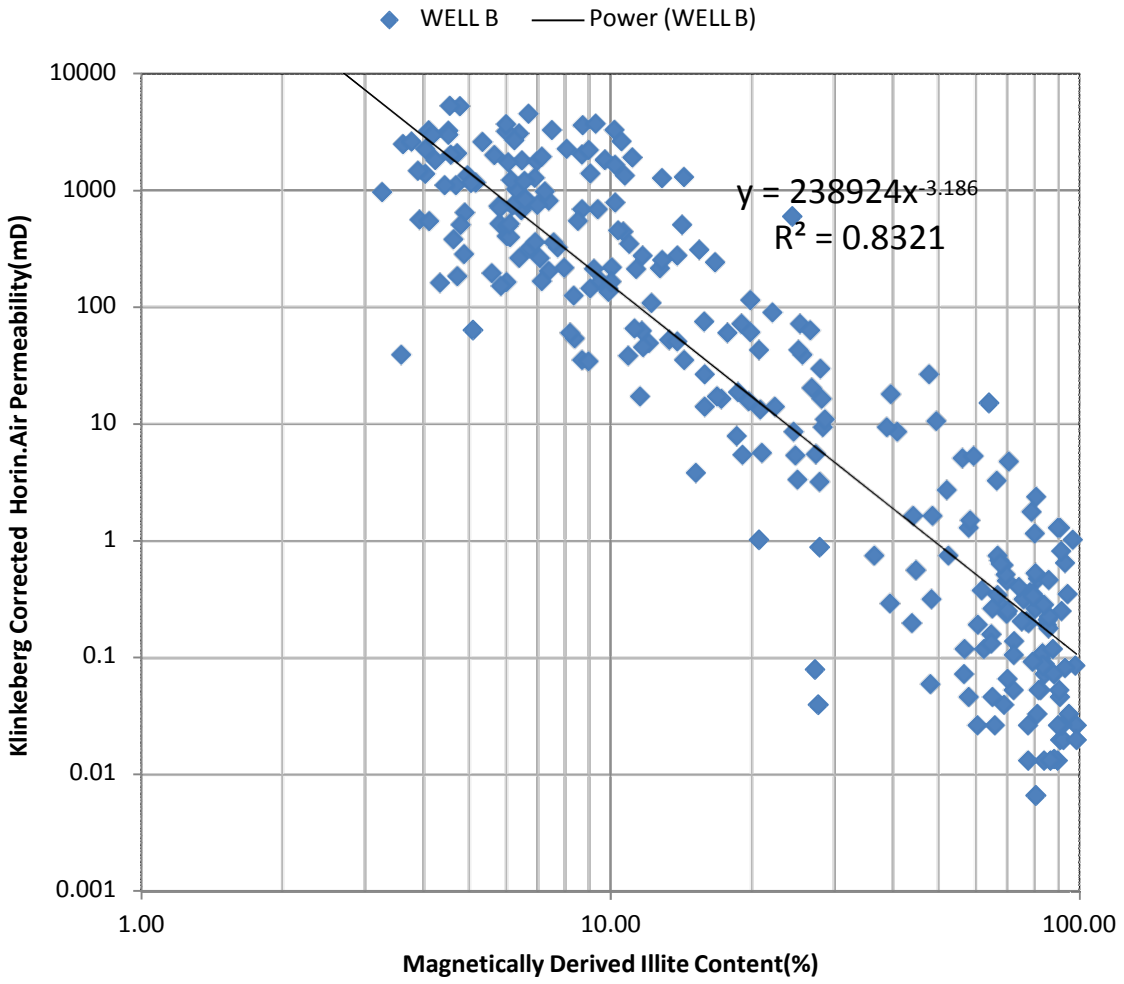
Here showing that Magnetically derived illite (MDI) content (%) and Klinkenberg corrected Air horizontal permeability correlated very strongly with a power coefficient of determination **$R^2 \approx 0.83$!**

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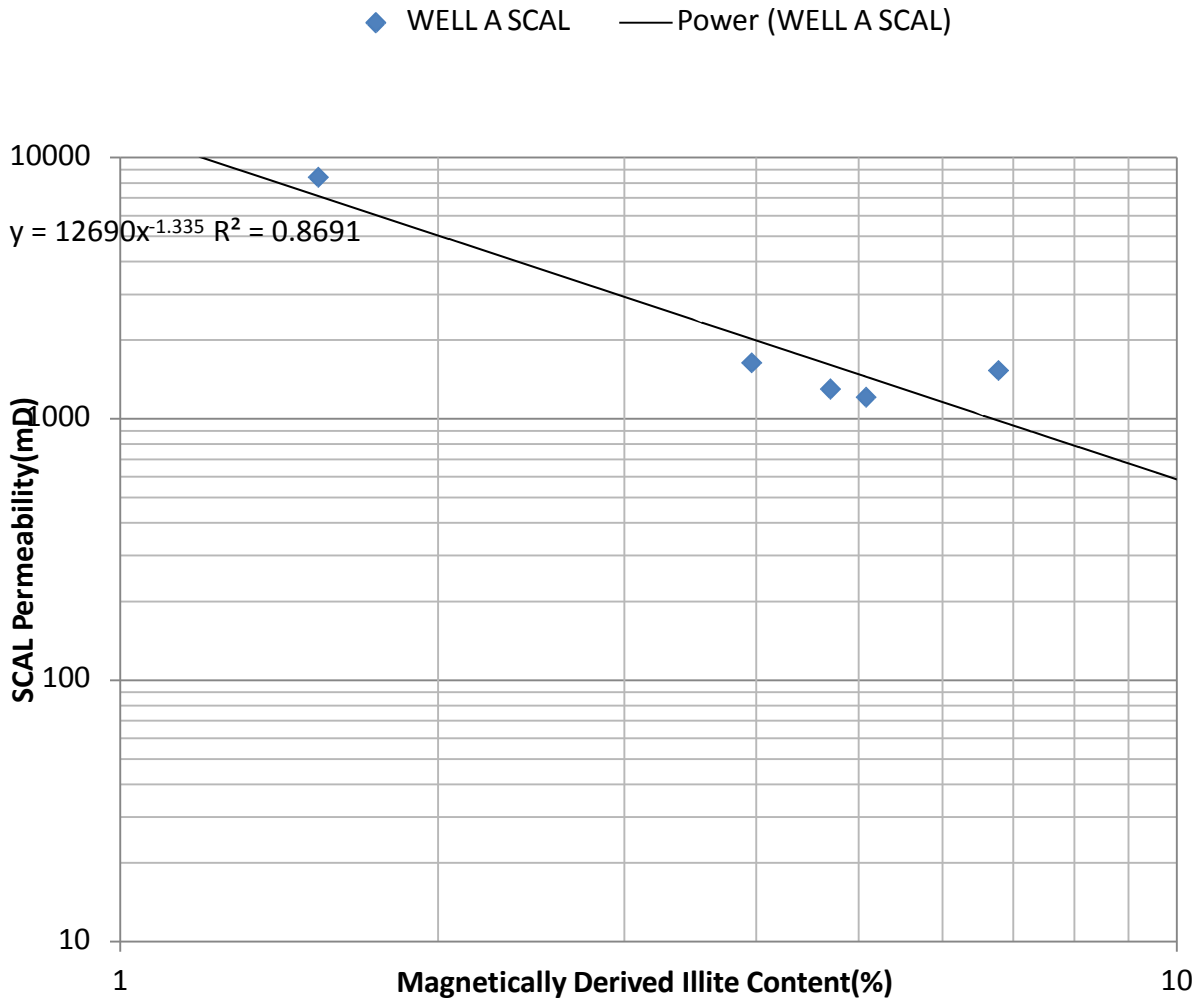
# Here MDI content (%) and SCAL permeability very strongly correlated with a power coefficient of determination $R^2$ ≈0.87

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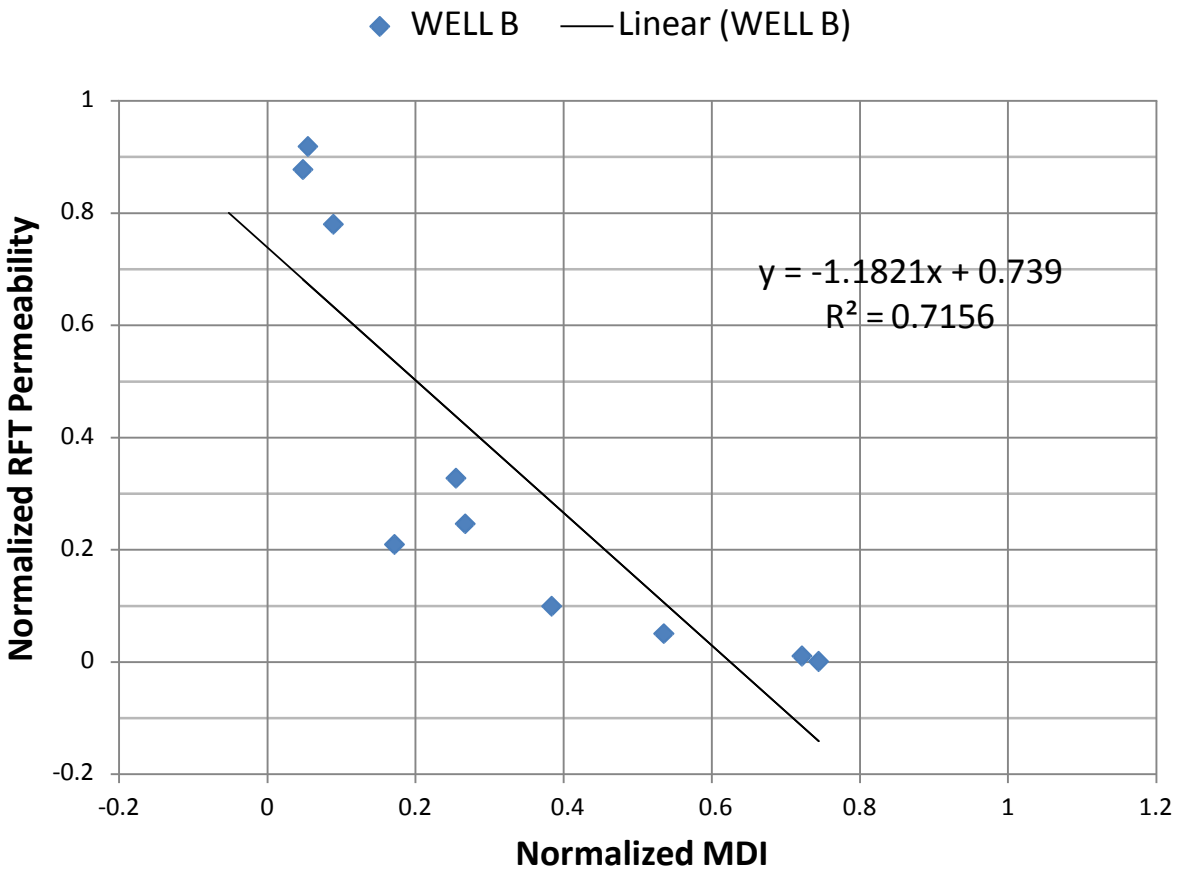
# Here normalized RFT permeability and normalized MDI strongly correlated with a linear coefficient of determination **R2 ≈ 0.72**

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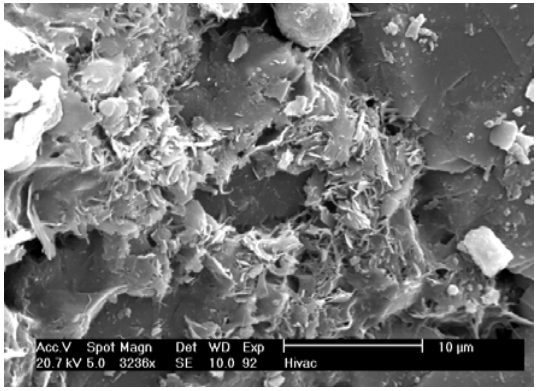
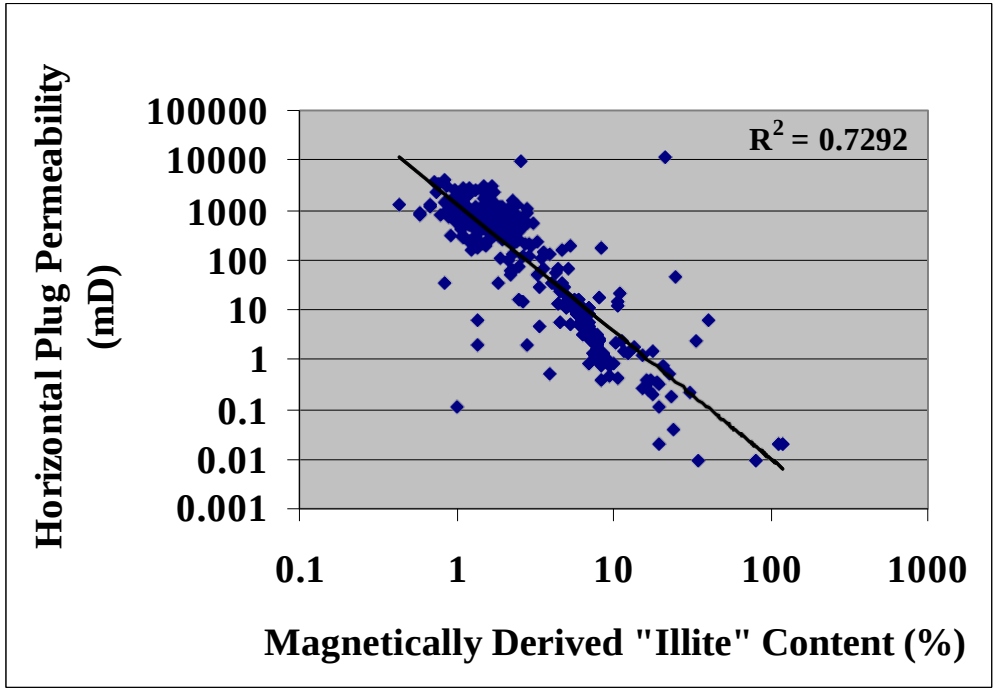
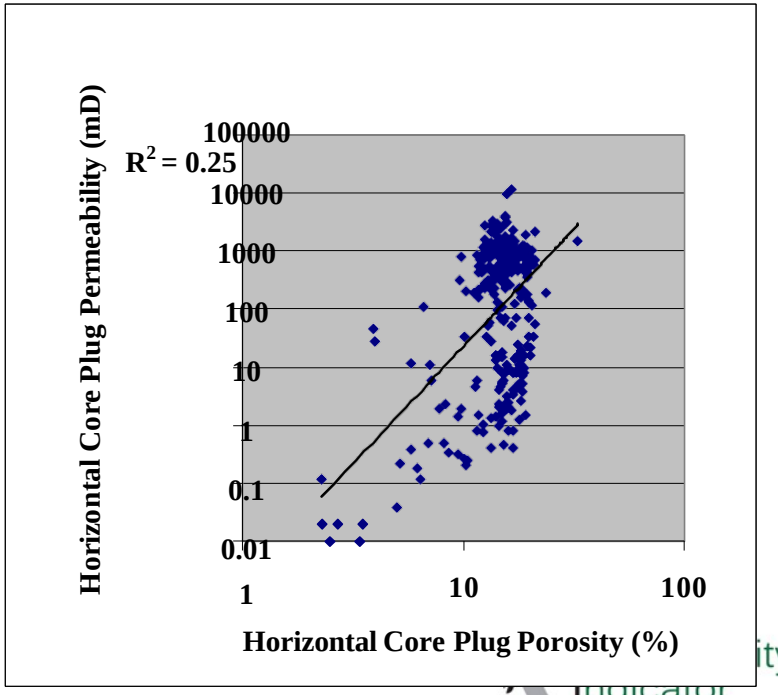
# *The problem of using porosity in permeability determination is that…*

- Conventional poro-perm relation *(bottom right)* is poor due to microporous illite rims *(top right),* whereas…
- Magnetically derived "illite" correlates well with permeability *(bottom left)*

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**Reference Paper for details**

MAGNETIC SUSCEPTIBILITY Wytch Farm Application Extended Study

# MAGNETIC SUSCEPTIBILITY SIGNATURE VIABILITY: AN INSIGHT IN IMPROVED PREDICTION OF PERMEABILITY IN WYTCH FARM


## ABSTRACT

This research elucidates the viability of magnetic susceptibility signature in the prediction of permeability in the Wytch Farm oil Field. Five suites of data including raw and processed measured Volume magnetic susceptibility of Sherwood reservoir core slabs integrated for the purpose of the research.


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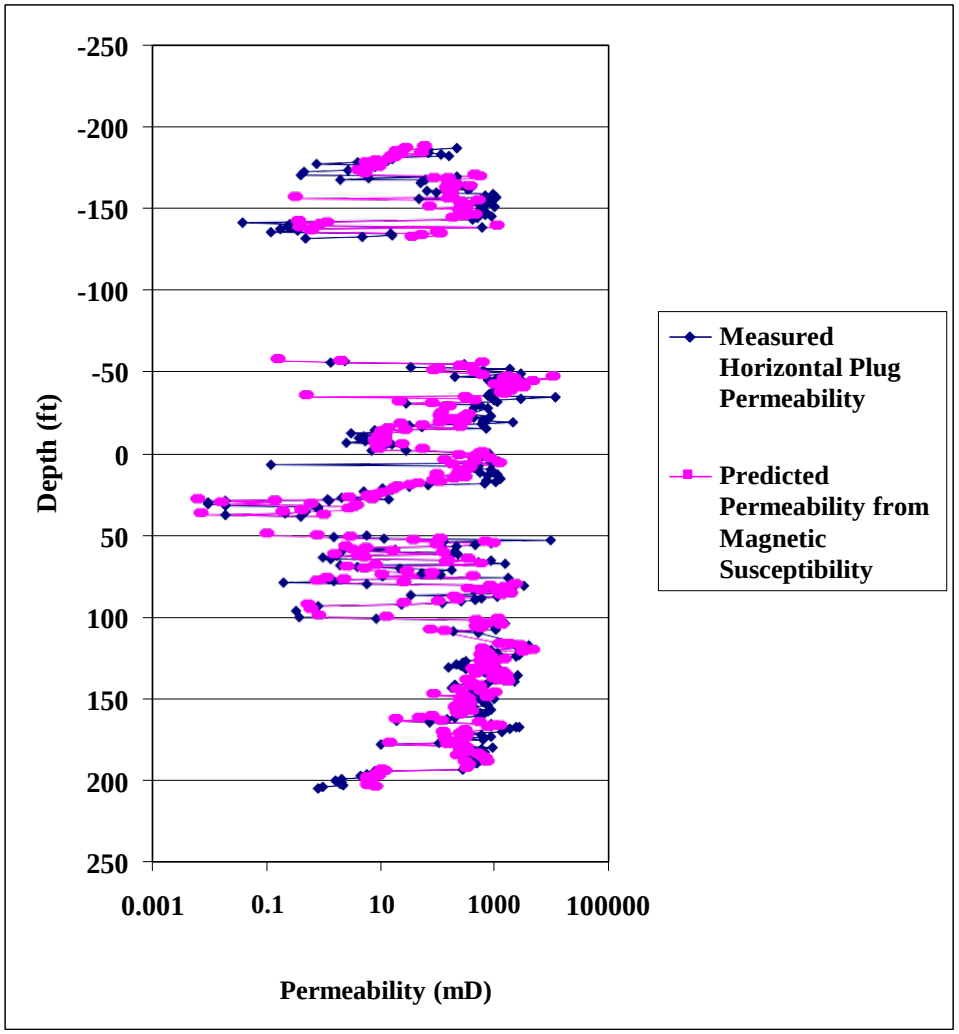
# Magnetic Susceptibility - Improved Permeability Prediction

***Another example showing the striking correlation***



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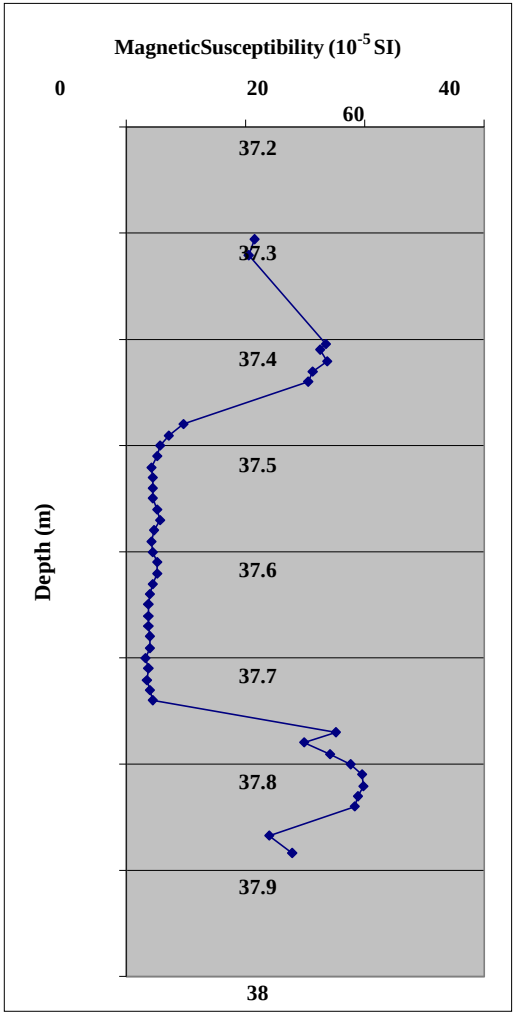
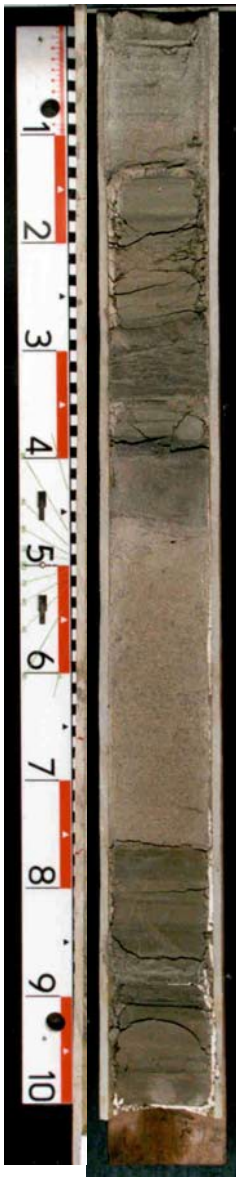
# Probe Magnetic Susceptibility on “Uniform” Turbidite Sand

***Our Scientific Director, and technology inventor, Professor David Potter performing measurements on slabbed core***



# Advantages of Magnetic Susceptibility over other Core Analysis Techniques (1)

- Rapid, portable (wellsite, core store or laboratory), and can be measured at various scales:
  - Drill cuttings
  - Core plugs
  - Slabbed core
  - Whole core
- Can use cleaned, uncleaned and even fractured samples
- Non-destructive, environmentally friendly
  - no need to cut core plugs
  - useful for unconsolidated core



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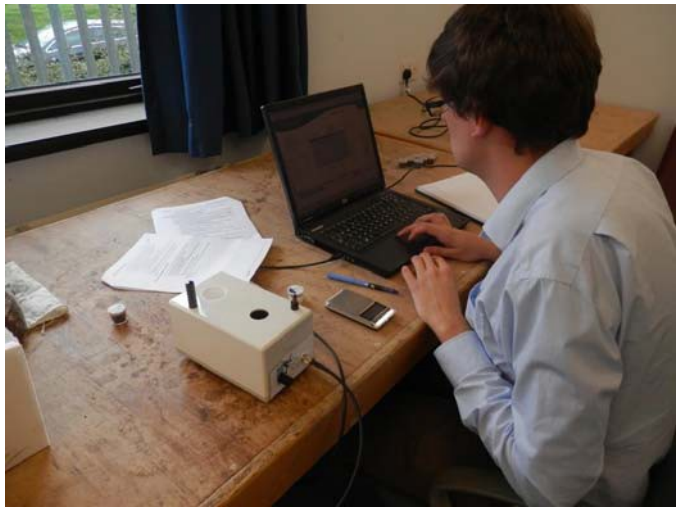
# Measuring Drill Cuttings…



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**Reference Paper for details**

**ADP Case Study** - Magnetic susceptibility measurements on Drill Cuttings
UKCS Well Sept 2014


**ABSTRACT**

Bags of wet drill cuttings were provided for analysis, from a specific interval of interest in a North Sea production development well. A total of 421 measurements were performed on drill cuttings from all the sample bags. A set of LWD log data has been provided by client Operating Company and which forms the basis of this analysis and report.


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# Advantages of Magnetic Susceptibility over other Core Analysis Techniques (2)

- Higher resolution than core gamma ray

- Compared to laboratory NMR it is:
  - Quicker
  - Requires no sample preparation
  - Has correlated better with permeability in samples where there is a poor relationship between porosity and permeability

- Quicker than X-ray diffraction (XRD), and can use larger sample volumes



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# Downhole Magnetic Susceptibility Applications

Downhole (wireline, LWD) high resolution magnetic susceptibility profiles would provide:

- *In situ* improved petrophysical parameter predictions (permeability, clay content etc).
- Improved interpretation of downhole gamma ray.



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# Advanced Downhole Petrophysics Ltd

- Current offering:
  - Assessment of slabbed and plug cores
  - Rig based assessment of cores / drill cuttings / sidewall plugs

- Under development:
  - Presently developing a programme for development of a prototype downhole tool



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# What can mag sus uniquely add to the shale gas question...?

- It can help to quantify (either in the lab or potentially downhole) the clay content and to some extent the type of clay (diamagnetic kaolinite vs paramagnetic clays like illite). It can do this even in the presence of high gamma ray emitting drilling muds (like KCl), which would be a problem for the gamma ray tool alone
- The amount and type of clay will determine how easily or otherwise it is to frac the shale
- Recent work on magnetic anisotropy in the lab is showing useful results: different types of shale have different anisotropies (it's actually quite a complex mix of mineralogy, organic content etc). Again knowing the correct principal magnetic anisotropy axes (which relate to the rock fabric) should help optimise fracing procedures. Magnetic methods are one of the few ways that you can obtain a full 3D anisotropy ellipsoid from just one plug. For permeability anisotropy and most other anisotropic properties, one needs to take multiple plugs in different directions to obtain the full 3D anisotropy (as the measurements for permeability are 1D for instance), which is very time consuming and difficult practically

# Finally - Activity Update

- Extended trialling of technique
  - Drill Cuttings Magpi readings calibrated to core plug derived readings
  - Drill Cuttings Magpi readings calibrated to core slab derived readings
- Good correlation drill cuttings v SCAL derived permeabilites

- Increased understanding of geological models
- Identification of pay-zones previously missed (High gamma reading but clay controlling permeability not as it seems)
- More information being obtained from SCAL activities
- Potential to targeting coring programme in further developments
- Extensive use of cutting analysis by Magpi – early interpretation/indicator of change in formation (clay distribution and/or clay type) and permeability

- Future complex reservoirs – Magpi offers a low cost route to gaining a higher density of information, calibrated to conventional SCAL techniques (shaly sand, HP/HT, etc;)
- Offers a low cost method to re-evaluate data stored – drill cuttings, core slabs and plugs

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# Finally - Activity Update 2

- ADP is close obtaining its first long term contract as part of a subsurface data analysis campaign supporting a field development

- It has established a place in the tool box available for the subsurface team to evaluate, cross-check, re-evaluate, extend understanding of a field, the controlling mechanisms on permeability, and add understanding to the geological models developed in the early stages of field life with quicker access to initial quick-look data which can later be calibrated as conventional SCAL activities produce field information.

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# Publications


- Potter, D. K. et al, 2004. Quantification of illite content in sedimentary rocks using magnetic susceptibility - a rapid complement or alternative to X-ray diffraction. *Journal of Sedimentary Research*, 74, 730-735.

- Ivakhnenko, O. P. and Potter, D. K. 2004. Magnetic susceptibility of petroleum reservoir fluids. *Physics and Chemistry of the Earth*, 29, 899-907.

- Potter, D. K. 2005. Magnetic susceptibility as a rapid, non-destructive technique for improved RCAL and SCAL parameter prediction. *2005 International Symposium of the Society of Core Analysts, Toronto, Canada*, Paper SCA2005-02 (Voted 2nd Best Paper).

- Ivakhnenko, O. P. and Potter, D. K., 2006. The use of magnetic hysteresis and remanence measurements in rapidly and non-destructively characterising reservoir rocks and fluids. *2006 International Symposium of the Society of Core Analysts, Trondheim, Norway*, Paper SCA2006-08 (Voted 2nd Best Paper).


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# Publications cont.

- Potter, D. K. 2007. Magnetic susceptibility as a rapid, non-destructive technique for improved petrophysical parameter prediction. Petrophysics, 48, (issue 3), 191-201. (Paper included as reference paper)*

- Potter, D. K and Ivakhnenko, O. P., 2007. Clay typing - sensitive quantification and anisotropy in synthetic and natural reservoir samples using magnetic susceptibility for improved petrophysical appraisals. 2007 International Symposium of the Society of Core Analysts, Calgary, Canada. Paper SCA2007-05 (Voted Best Paper).

- Ivakhnenko, O. P. and Potter, D. K., 2008. The use of magnetic hysteresis and remanence measurements for rapidly and non-destructively characterizing reservoir rocks and fluids. Petrophysics, 49, (issue 1), 47-56.

- Potter, D. K and Ivakhnenko, O. P., 2008. Clay typing - sensitive quantification and anisotropy in synthetic and natural reservoir samples using low- and high-field magnetic susceptibility for improved petrophysical appraisals. Petrophysics, 49, (issue 1), 57-66.

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# Attached Reference Information


- Potter, D. K. 2007. Magnetic susceptibility as a rapid, non-destructive technique for improved petrophysical parameter prediction. Petrophysics, 48, (issue 3), 191-201. (Previously Referenced)*

- Potter, D. K, Al-Ghamdi, T.M, and Ivakhnenko, O. P., 2007. Sensitive carbonate reservoir rock characterisation from Magnetic Hysteresis Curves and Correlation with petrophysical properties. Petrophysics, Vol 52, No.1 (February 2011) 2007

- **ADP Case Study** - Magnetic susceptibility measurements on Drill Cuttings UKCS Well Sept 2014

- **ADP PHD Study** – Magnetic Susceptibility Signature viability: An insight in improved prediction of permeability in Wytch Farm

- *Arfan Ali, †David K. Potter and ‡Andrew Tugwell *Shell UK Limited, Aberdeen, UK †Department of Physics, University of Alberta, Edmonton, Canada ‡Advanced Downhole Petrophysics Limited, Aberdeen, UK.
  Correlation between Magnetic Properties and Permeability: Results from a New Case Study In the North Sea. *This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Avignon, France, 8-11 September, 2014* SCA 2014-077


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# Attached Reference Information - Continued

- *Benjamin C. Agbo and David K. Potter,* University of Alberta, Edmonton, Canada
  Novel high resolution probe magnetic susceptibility and comparison with wireline gamma ray and grain size in an Albertan oil sand well.
  SEG Technical Program Expanded Abstracts 2014: pp. 2590-2594.

- Magpi Brochure (2014)

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# Questions & Feedback

- *If you have further questions and/or comments you would like to raise with ADP regarding the technology, maybe after studying the reference material, please feel free to contact as follows;*

- To: Andrew Tugwell - ADP Managing Director atugwell@magpiglobal.com

  Cc: Martin Cox mcox@drillingmanagement.com
  Cc: mcox@magpiglobal.com

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