Pore radius distribution and fractal dimension derived from spectral induced polarization

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Introduction

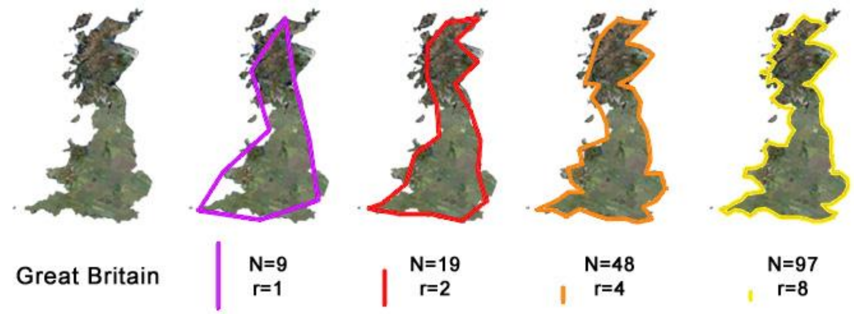
- Fractal theory is applied to describe the structure of geometric objects.

- At molecular-size and microscopic range, surfaces of most materials including those of natural rocks show self-similar features that can be quantified by the parameter of fractal dimension D.

Introduction

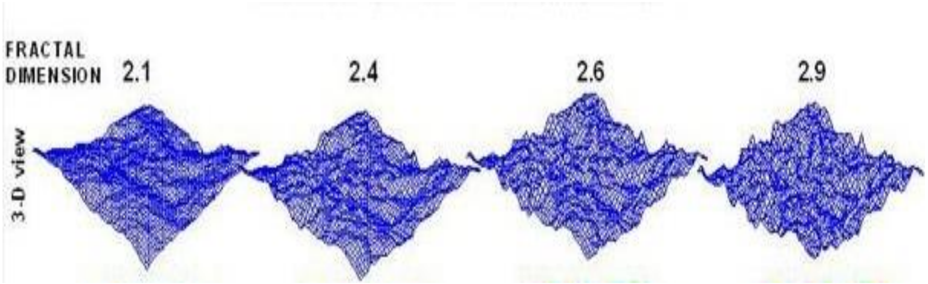
- For a straight line, *D*=1;

for a winding line, *D*>1

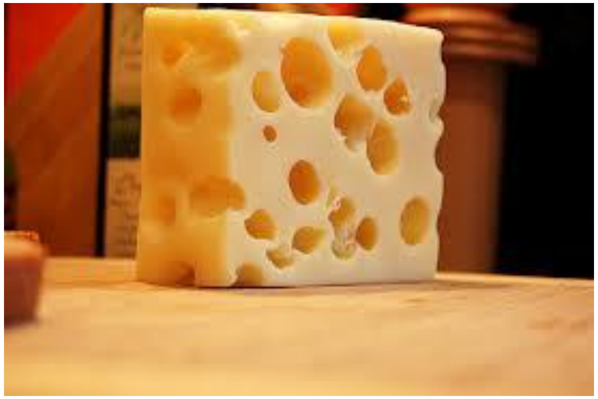


- For smooth surface, *D*=2;

for a rough surface, *D*>2



- For a not fully occupied volume, *D*<3



Introduction

- Lesmes & Morgan (2001) tried to relate SIP to fractal dimension.
- Here we demonstrate the use of SIP to determine the fractal dimension of the pore volume.
- We compare the fractal dimension and pore size distribution with the results of nuclear magnetic resonance (NMR) and mercury intrusion capillary pressure method (MICP).

Methods

- We transformed the relaxation time distribution of complex conductivity spectra determined by Debye decomposition (Nordsiek and Weller, 2008) into a curve showing the cumulative intensity as a function of increasing pore radius *r* calculated from relaxation time τ.
- It is assumed that the distribution of relaxation times is controlled by the distribution of the pore sizes.

Methods

- We adopt an equation proposed by Schwarz (1962) and applied by Revil et al. (2012) for the Stern layer polarization model:

$$r = \sqrt{2\tau D_{(+)}}$$

- *r* originally refers to radius of spherical particles
- diffusion coefficient of the counter-ions in the Stern layer. We assume a constant $D_{(+)} = 3.8\times10^{-12}$ m²/s as proposed for clayey material (Revil, 2013).

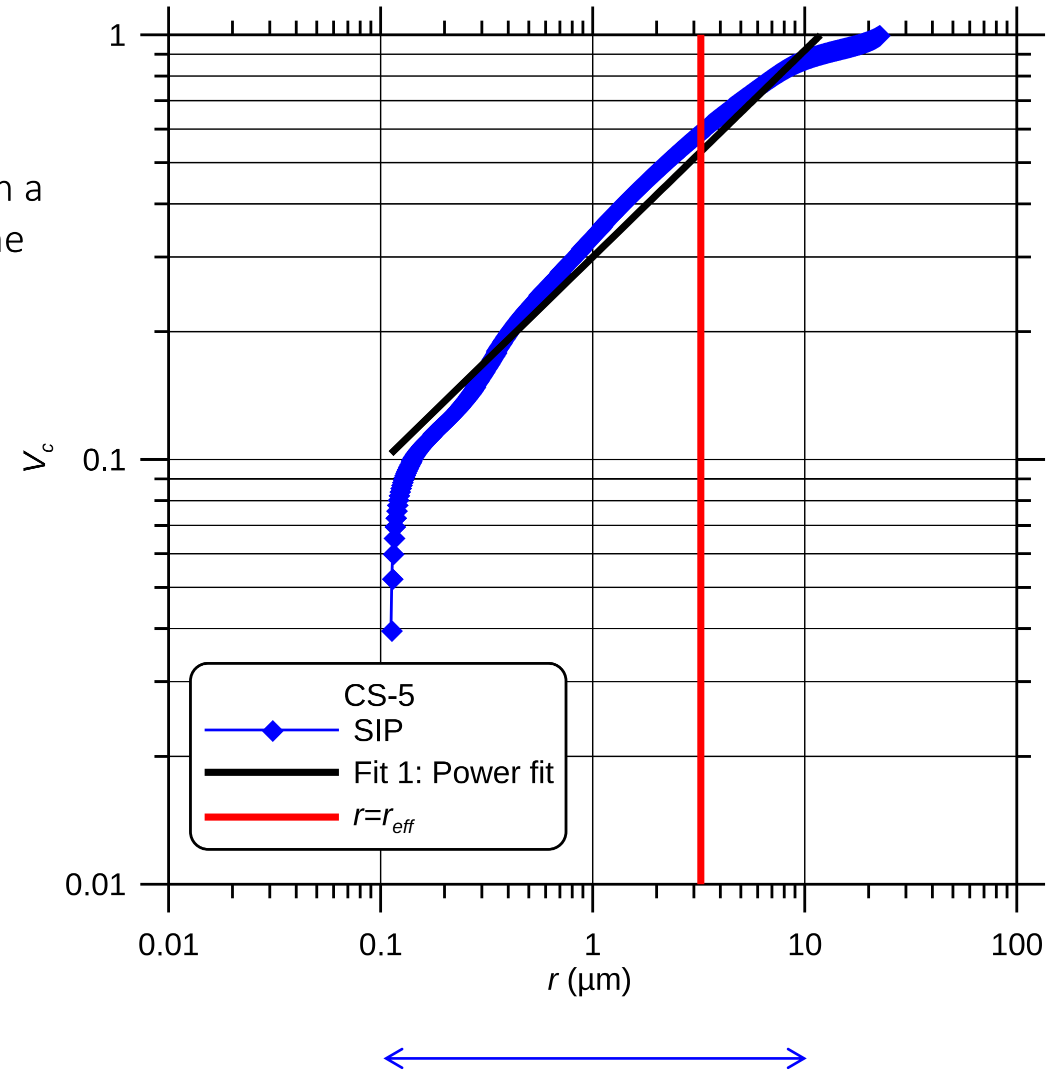
Samples

- This approach was applied to 24 rock samples from an Eocene sandstone formation in China (Zhang and Weller, 2014).

Results

The cumulative curve is presented in a double logarithmic plot showing the relation
$\log(V_c) \sim \log(r)$.

$V_c = V(<r)/V$ is the cumulative volume fraction of pores with radii less than r, which corresponds to the ratio of cumulative intensity to total intensity. The total chargeability is attributed to the total pore volume.



Results

- In the case of fractal behaviour of the pore volume distribution, the slope *s* of the fitting line is used to get the fractal dimension $D_{SIP} = 3 - s$. The resulting fractal dimension D_{SIP} varies for the investigated samples in a range between 2.507 to 2.761.

- The red line marks the effective hydraulic radius, which has been determined from permeability *k* and formation factor *F*:

$$r_{eff} = \sqrt{8Fk}$$

Results

permeability range of the samples:
0.02 to 60 mD

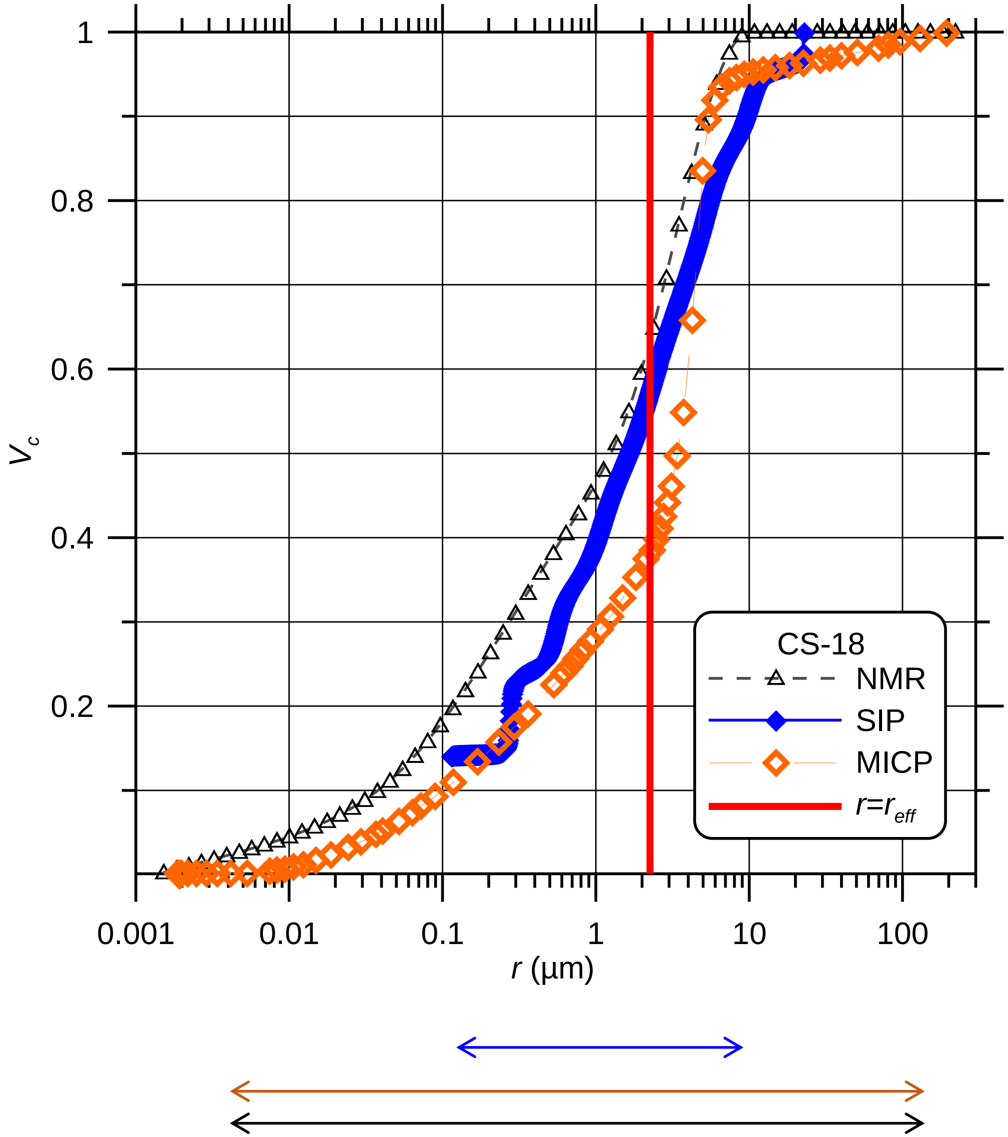
High permeability (H-samples)	Medium permeability (M-samples)	Low permeability (L-samples)

↓ (H-samples): low clay and carbonate content and a good sorting

↓ (L-samples): either a strong compaction or a rich sedimentation of carbonates in the pore space that results in low porosity and small pore radii

Results

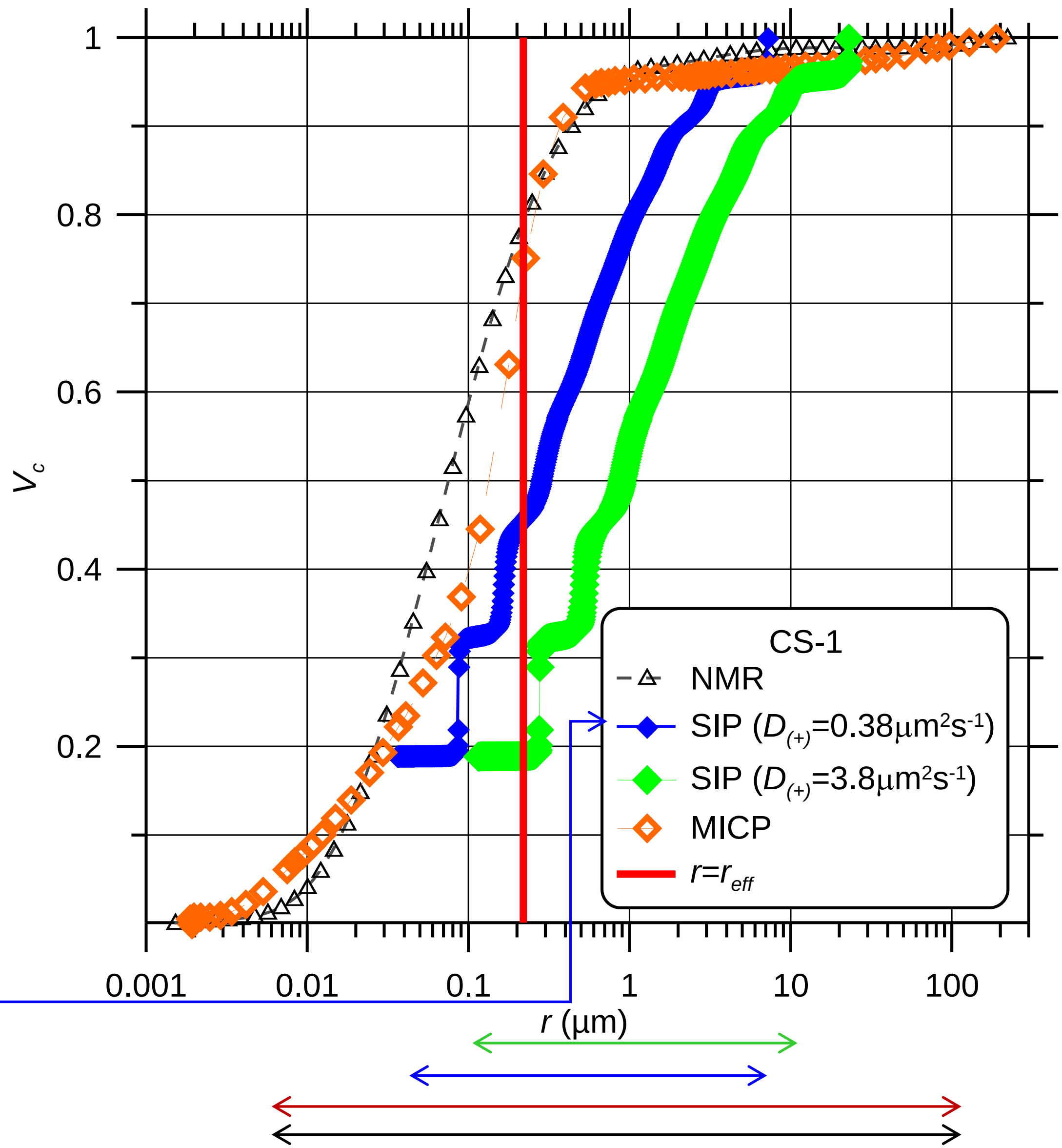
H-Samples:
the V_c-r curves of the methods NMR, MICP and SIP show similar characteristics



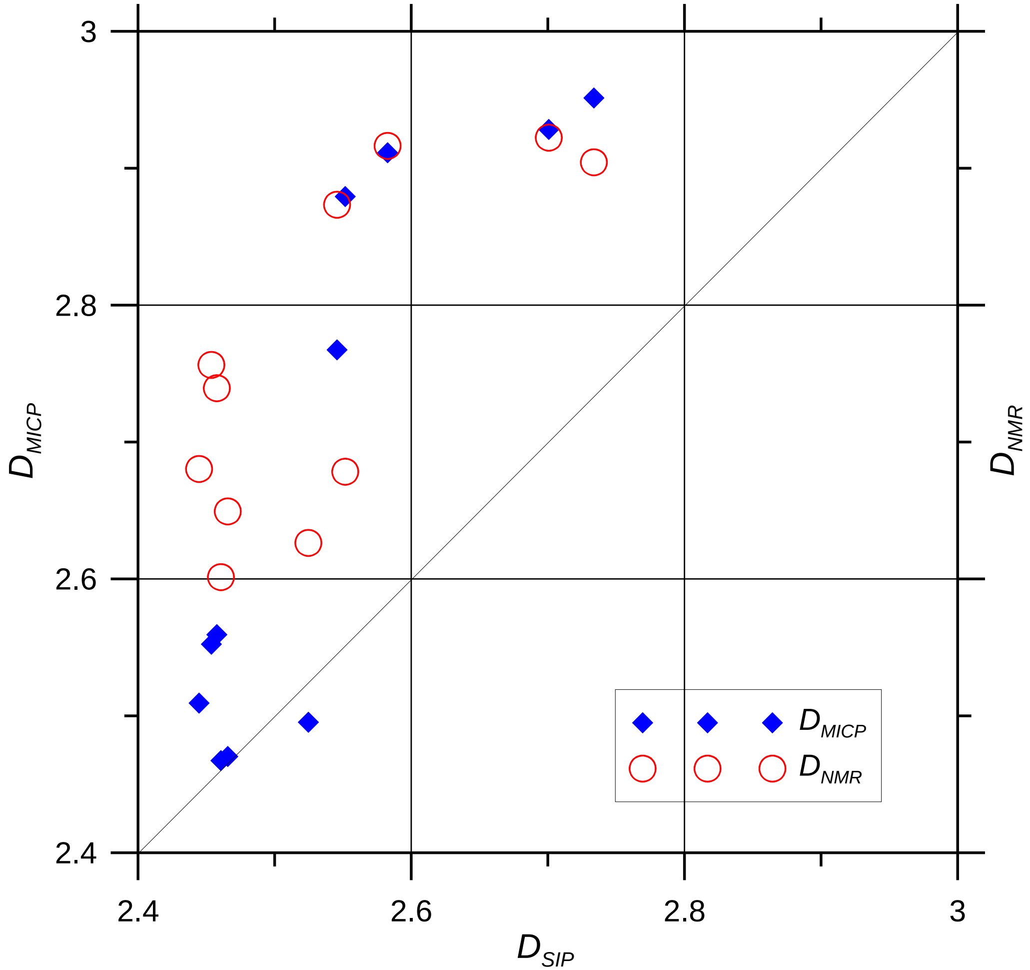
Results

L-Samples:
good agreement between MICP and NMR with r_{eff} close to r_{50}. However, the SIP-curves appear at a much higher *r*-range.

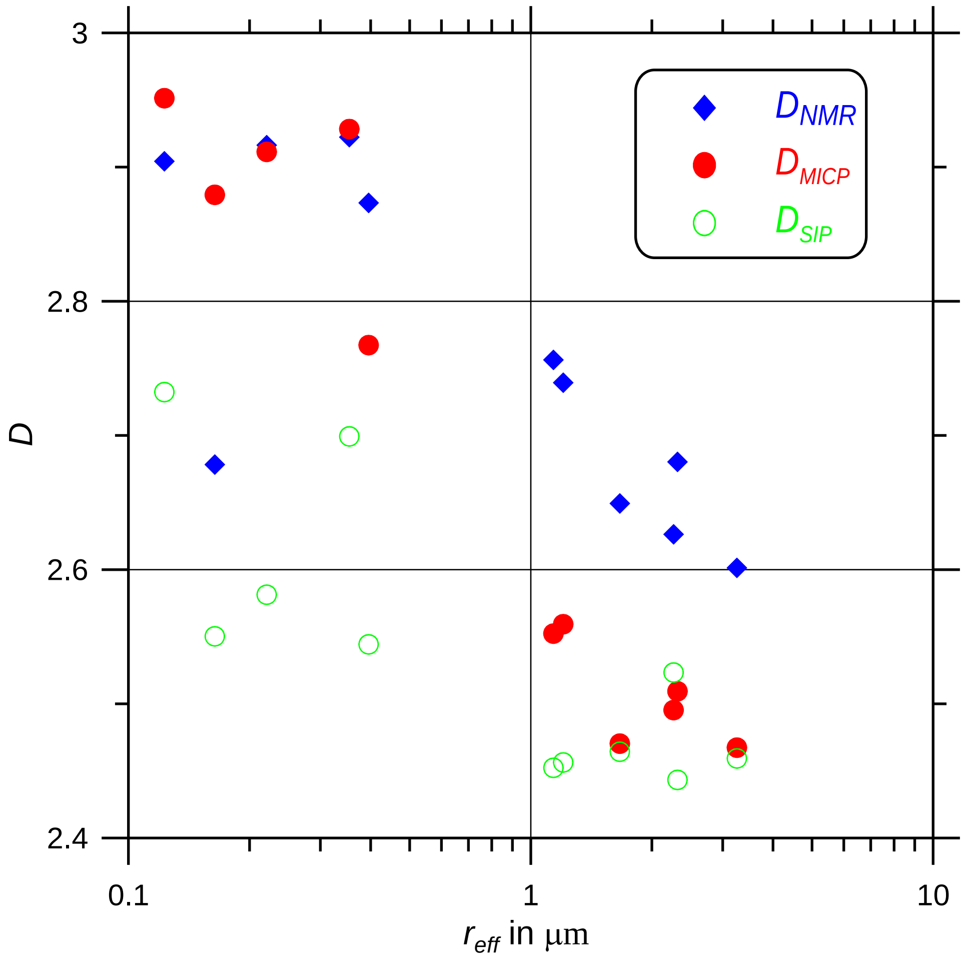
$D_{(+)}$ determined using r_{eff} and τ_{peak} that results from the frequency of the maximum of the imaginary part of conductivity $\sigma''(f)$ (Weller et al. 2016)



Results



Results



Conclusions

- A fractal dimension can be determined on the basis of an IP relaxation time distribution.
- If we use a constant diffusion coefficient a good agreement can be observed with the V_c–r curves of MICP and NMR for samples with $r_{eff} > 1$ µm.
- Samples with smaller pore radii indicate larger deviations in the resulting V_c-r curves. This problem can be overcome if instead of a constant diffusion coefficient the apparent diffusion coefficient is used.
- Further investigations will demonstrate the integration of fractal dimension in models of permeability prediction.

Thanks for your attention!

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References

- Lesmes, D. P., and Morgan, F. D., 2001, Dielectric spectroscopy of sedimentary rocks: Journal of Geophysical Research: Solid Earth, 106, 13329 –13346, doi: 10.1029/2000JB900402.
- Nordsiek, S., and Weller, A., 2008, A new approach to fitting induced-polarization spectra: Geophysics, 73, No. 6, F235-F245, doi: 10.1190/1.2987412.
- Revil, A., Koch, K. and Holliger, K., 2012, Is it the grain size or the characteristic pore size that controls the induced polarization relaxation time of clean sands and sandstones?: Water Resources Research, 48, W05602, doi:10.1029/2011WR011561.
- Revil, A., 2013, Effective conductivity and permittivity of unsaturated porous materials in the frequency range 1 mHz-1GHz: Water Resources Research, 49, 306-327, doi: 10.1029/2012WR012700.
- Schwarz, G., 1962, A theory of the low-frequency dielectric dispersion of colloidal particles in electrolyte solution: Journal of Physical Chemistry, 66, 2636-2642, doi: 10.1021/j100818a067.
- Weller, A., Zhang, Z., Slater, L., Kruschwitz, S., and Halisch, M., 2016, Induced polarization and pore radius - a discussion: 4th International Workshop on Induced Polarization, Aarhus.
- Zhang, Z., and Weller, A. 2014, Fractal dimension of pore-space geometry of an Eocene sandstone formation: Geophysics, 79, No. 6, D377-D387. doi: 10.1190/geo2014-0143.1.