Dear Members, and Friends of the LPS;

On behalf of the LPS, I would like to thank Clive Sirju and the organising committee for making the SPWLA 59th Annual Symposium such a great success. All their effort and hard work was certainly worthwhile as I got lots of positive feedback from attendees, presenters, sponsors, exhibitors and SPWLA leadership. I really appreciate all that they have done in preparation for the event and during the Symposium.

At the Symposium, LPS and AFES had a meeting with SPWLA Leadership to discuss concerns with the new SPWLA Chapter Charter. The meeting was positive and, although there is still some work to do, we feel that between us we can find an equitable way forward that will work for everybody. We will not lose our charitable status and the heavy-handedness in the Charter wording will be softened. Some amendments will be required to the LPS Constitution and some of the wording of the Chapter Charter needs to be changed. SPWLA have asked for our help in suggesting amendments to the Charter and in fully understanding and complying with the GDPR.

Our next evening meeting is scheduled for 10th July, and will be “An Integrated Formation Evaluation Approach to Characterize a Turbidite Fan Complex – A Case Study from the Falkland Islands” to be presented by Maciej Kozłowski.

The topic for our next seminar is Seismic Rock Physics and a call for abstracts is on the website, so please put 27th September in your diary.

One of the great innovations in the LPS Newsletter in recent times is the inclusion of technical papers. If you have an interesting technical topic you like us to publish, please contact Jusmell Graterol or Jenny Rastogi.

Mike Millar - LPS President
Upcoming LPS Evening Lectures (6:30-7:30pm)

“An Integrated Formation Evaluation Approach to Characterize a Turbidite Fan Complex – A Case Study from the Falkland Islands”

Presented by

**Maciej Kozlowski**, Halliburton

**Tues 10th July 6:30pm—7:30pm**

The Geological Society, Burlington House, Piccadilly

- Free Entry -

http://lps.org.uk/events

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Tuesday 10th July 2018
6:30pm-7:30pm

“An Integrated Formation Evaluation Approach to Characterize a Turbidite Fan Complex – A Case Study from the Falkland Islands”

Maciej Kozlowski, Halliburton

**Evening Lecture**

Tuesday 4th Sept 2018
6:30pm-7:30pm

“Using Fractels to Determine a Reservoir’s Hydrocarbon Distribution”

Steve Cuddy, Baker Hughes

**Evening Lecture**
Call For Abstracts: Seismic Rock Physics

Seismic Rock Physics

Thurs 27th September 2018
The Geological Society, Burlington House, London

Call for Abstracts
Submission Date: by 15th August 2018

On Thursday 27th September the London Petrophysical Society will be holding a one-day seminar entitled “Seismic Rock Physics” at the Geological Society, Burlington House, London. The day will consist of a series of themed talks, on the integration between petrophysics and geophysics each lasting around 30 minutes with five minutes for questions.

We are looking for talks on geophysics and petrophysics integration, for example: case studies of fluid substitution; 4D seismic feasibility studies; rock physics and geomechanics studies; well ties; derivation of chi angles from log data etc.

This is a Call for Abstracts for presentations from Oil & Gas Companies, Service Companies, Independent Consultants, Academia and other interested parties, on topics related to seismic rock physics and the integration between geophysics and petrophysics.

The seminar is intended for general interest (as opposed to sales or marketing). We request that the talks are kept at a scientific level, with the use of generic rather than trade names.

Abstracts should be up to 300 words/one page of A4 and may include one or two illustrations, submitted in Word Document format.

Please send your abstracts to Dawn Houliston, Email: dhouliston@ercequipoise.com, or any member of the LPS Committee, by the 15th August. You can also contact Mike Millar if you have any questions, suggestions or to express interest in presenting.

£150 for delegates (Speakers exempt)
(LPS is not VAT registered)

Students can register for free
Includes lunch and post-seminar wine and savouries.
Doors open at 9am.

For more info or to register for this event please visit www.lps.org.uk/events/
Directional Permeability—how important is it and can it be measured reliably?

Author: Ernie Hailwood, Core Magnetics; David Bowen, Department of Petroleum Engineering, Heriot-Watt University

Directional permeability determinations are commonly limited to measurements of the vertical and horizontal permeabilities, $K_v$ and $K_H$. Depositional grain fabrics, particularly bedding-parallel laminations, usually cause the permeability in the direction normal to bedding to be significantly less than that parallel to bedding. Results from conventional core analysis show that $K_v$ is often up to 50 per cent lower than $K_H$. Depositional (and sometimes post-depositional) processes also produce preferred orientations of grain and pore long axes within the bedding plane, which are likely to cause variations in $K_H$.

This azimuthal permeability anisotropy has seldom been measured in the past, but a recent programme of measurements carried out at Heriot-Watt University has demonstrated that differences of 10 to 15 per cent are quite common in reservoir formations. Differences of this magnitude are sufficient to warrant incorporation of azimuthal permeability data into reservoir models in order to more completely represent the fluid flow properties of the formation.

The principal factor that has limited the acquisition of azimuthal permeability data in the past is the relative difficulty of carrying out full three-dimensional permeability anisotropy determinations. This difficulty has been overcome by the MAGPORE technique, which provides a rapid and precise determination of the 3D pore fabric of the formation, from which the permeability anisotropy can be derived.

Permeability anisotropy measurement techniques

It has long been recognized that azimuthal variations of permeability may be important in many hydrocarbon reservoirs, yet surprisingly few attempts have been made to obtain reliable permeability anisotropy information. Early approaches involved radial permeability measurements on large core samples, or drilling a set of plug samples with different orientations from the core (Figure 1). Permeability measurements were then made on the plug samples using standard gas permeability methods and the azimuthal variation was determined from the results. Data from these measurements revealed significant azimuthal variations (e.g. Greenkorn et al. 1964). However, this method suffers from the disadvantage that the core plugs usually span a core depth of several tens of centimetres or more. Thus, apparent azimuthal variations will reflect the effects of heterogeneities due to lithological changes compounded with any true permeability anisotropy, making the latter difficult to determine precisely. Furthermore, the results are insufficient to define the full 3D permeability tensor.
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Full determination of the permeability tensor requires measurements along three principal orthogonal axes as well as along a set of complementary diagonal axes. As far as possible these measurements should be made on the same volume of sediment. It is usually impracticable to carry out such measurements on plug samples and is necessary to use cubic samples instead. However, reliable gas permeability measurements on samples of square cross-section are difficult to accomplish because of the problem of fully confining the sample under pressure and preventing gas leakage along the cube edges.

This problem has been overcome using a novel cubic sample sleeve. This is constructed from polyurethane rubber. It incorporates a combination of a more rigid outer cylindrical layer which fits into a standard Hassler permeability cell holder, together with a softer inner layer with a square-section hole which contains the cubic sample. The inner layer is designed in such a way that the application of confining pressure causes the apices of the hole to form to the sample, thus providing a very effective seal along the cube edges.

Figure 1: Measuring azimuthal permeability anisotropy, using sets of plug samples drilled in different orientations.
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Two different approaches have been used to obtain the required set of permeability measurements along orthogonal and diagonal axes (Figure 2). The first involves making permeability measurements across the three pairs of faces of an oriented cubic sample, then cutting a smaller sample from within this with the required oblique orientation (Figure 2A). Permeability measurements across the faces of this inner cube then provide the required diagonal measurements. A disadvantage of this approach is that geometrical considerations mean that the volume of the inner cube is less than one-quarter that of the outer one. This can lead to problems in scaling and combining the data from the two sets of measurements in order properly to determine the permeability tensor.

The second approach involves cutting three separate cubic samples, all of the same size, from a single bed (Figure 2B). The first cube defines the three principal permeability axes, the second provides diagonal measurements within the adding plane and the third provides diagonal measurements out of this plane. Experiments and theoretical considerations indicate that this approach provides the most reliable 3D permeability anisotropy data. This method has been used in our own studies.

Figure 2A: One of two methods for measuring permeability anisotropy using sets of cube samples.
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Figure 2B: The second of two methods for measuring permeability anisotropy using sets of cube samples.

The MAGPORE Method

Although the above method provides reliable permeability anisotropy data, the measurements are very tedious and time consuming. In the first place, cutting the three cubic samples with the correct orientations is a relatively slow process that requires careful use of a special cutting jig. Secondly, carrying out the nine individual gas permeability measurements typically requires several days’ work for a single full permeability anisotropy determination. Thus, although the method provides important base-line data, it is not practicable to apply it to the relatively large sample sets required to fully characterize the permeability anisotropy of a typical reservoir formation. Instead, a more rapid method is required for routine acquisition of permeability anisotropy data that can be calibrated against direct measurements made by the above method.

The technique that we have developed to achieve this is termed 'MAGPORE' because it effectively defines the pore fabric of the formation using a rapid method based on magnetic anisotropy measurements. We have demonstrated in a study of several different reservoir types that the pore fabric provides a direct measure of the permeability anisotropy.

The MAGPORE method involves filling the pore space of small core samples (typically 5cc mini-plugs) with ferrofluid using a specially designed saturation cell. The ferrofluid comprises a suspension of ultrafine magnetite particles in a suitable hydrocarbon carrier fluid. This effectively produces a 'magnetic cast' of the pore network in the sample. The directional properties of the network are then quantified by subjecting the sample to anisotropy of magnetic susceptibility (AMS) analysis.
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The method provides a rapid specification of the pore fabric in three dimensions in a fraction of the time taken for standard petrofabric analyses.

For a sample in which the pore space is completely filled with magnetic ferrofluid, the AMS will be controlled by the shape anisotropy of the individual pores (Figure 3). For each individual non-equidimensional pore, the magnetic susceptibility will have a maximum value in the direction of the pore long dimension and a minimum value in that of the pore short dimension. The statistical alignment properties of the whole pore network within the sample then determine the measured AMS. The maximum susceptibility axis of the whole sample defines the direction of preferred orientation of the pore long dimensions and the minimum susceptibility axis that of the pore short dimensions.

Figure 3: Relationship between maximum and minimum susceptibility axes and preferred orientations of pore long and short axes in a sample in which the pore space is filled with magnetic ferrofluid.

Results from three cubic specimens with 2cm edge lengths taken from a 20cm thick Permian Aeolian sandstone reservoir unit are shown in Figure 4A. Permeability measurements were carried out across the three pairs of faces of these cubes and all three samples show typical azimuthal permeability anisotropy of about 10 per cent. In these initial determinations, single cubes were used without diagonal measurements, so that the full permeability tensor was not defined at this stage. Nevertheless, the results indicate a strong correlation between pore fabric and permeability anisotropy. Thus, the maximum susceptibility axes (circles), which represent the preferred orientation of pore long axes, always lie closest to the maximum permeability axis of the cube.
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Results from full 3D permeability anisotropy measurements on sets of cubic samples from a Deepwater sand reservoir are shown in Figure 4B. In all three cases, the measured maximum permeability axis (arrows at perimeter of plot) corresponds closely with the pore long axis alignment defined by the MAGPORE method and is shown contoured. These and other measurements confirm that the MAGPORE method provides a rapid and precise definition of the 3D permeability tensor from which the direction of easy fluid flow within the reservoir can be accurately predicted.

Figure 4A: Comparison between 2D permeability anisotropy and pore fabric in three samples of Permian Aeolian sandstone.

Figure 4B: Comparison between pore long axis alignments (contours) and maximum permeability axis (solid arrows) in samples from three wells in a deep water sand reservoir.
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Conclusions

In the light of the above, answers can now be given to the two leading questions posed in the title of this presentation. Firstly, directional variations in permeability are certainly important. In addition to differences between Ky and KH of up to 50 per cent, azimuthal permeability differences (i.e. systematic variations in KH) of 10 to 15 per cent have been observed in a range of different reservoir types. These differences are sufficiently great to exert a significant influence on fluid flow in the reservoir and it is clear that they should be incorporated into new generations of reservoir models in order to represent fully the fluid flow characteristics of the reservoir.

Secondly, using a suitably designed Hassler cell system with an appropriate holder sleeve, high-quality permeability anisotropy measurements can now be obtained from cubic samples by carrying out such measurements on sets of cubes with appropriate orientations, the full 3D permeability tensor can be reliably defined. Results from such measurements have been used to calibrate the MAGPORE method, which itself provides a rapid determination of the 3D pore fabric of the formation. It has been demonstrated that the fluid permeability tensor corresponds closely with the magnetic susceptibility tensor for ferrofluid-saturated samples, so that the latter can be used to predict the former. In particular, the direction of preferred orientation of pore long axes defined by the maximum susceptibility axis corresponds with the maximum permeability axis of the formation.
SPWLA Membership

SPWLA has played a major global role in strengthening petrophysical education and strives to increase the awareness of the role petrophysics has in the oil and gas industry and the scientific community.

The LPS is a chapter of SPWLA and we encourage you all to become members of our parent organisation and join the "Home" for Formation Evaluation and Petrophysics.

Remember that professional and student membership has many benefits including;
- The Petrophysics Journal
- The new SPWLA Newsletter magazine
- Access to online literature resource
- Discounted registration for two "Topical Conferences" each year
- Access to monthly Webinars
- Access to and use of training facilities located in Houston
- Discounted registration for the Annual Symposium and its associated short courses
The LPS wish to extend our sincere appreciation to the generous companies who continue to be our Sponsors.

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