Induced polarization: detecting HC signatures in reservoir overburden

by Vitaliy V. Yurchenko, PhD, Senior Geoscientist, VP of Sales and Marketing at ORG Geophysical AS

Vitaliy V. Yurchenko
PhD, Senior Geoscientist,
VP of Sales and Marketing,
ORG Geophysical AS
vyu@orggeophysical.no

In the exploration business, where more than half of the projects end up with dry exploratory wells, inherent financial risks often reach eye-watering levels. At the current downturn, when the exploration budgets suffer substantial cuts, the industry should be on the lookout for efficient ways to mitigate these risks. Measurements of induced polarization (IP) can make the quesswork much easier by catching epigenetic alterations that occur in a plume above petroleum reservoirs. The method is certainly not a panacea to all explorationist's headaches, and the mechanisms that provide anomalous IP responses are often debated. Nevertheless, the blind tests proved it to be one of the most efficient tools to detect presence of hydrocarbons.

It all started in 1912, when Conrad Schlumberger patented a method of ore prospecting by induced polarization. Later he admitted that his experiments in the field were unsuccessful. 100 years later and with better luck, ORG Geophysical launched its first survey in the North Sea in 2012, detecting presence of petroleum reservoirs with 90% success rate. That year ORG introduced a highly efficient method of detecting IP anomalies called Differentially-Normalized Method of Electrical Prospecting (DNME), a technology originally developed by Russia's Siberian Geophysical Research and Production Company (Davydycheva et al. 2006, Veeken et al. 2009).
The method relies upon the fact that no cap rock is perfectly sealing, so minor amounts of hydrocarbons will always seep into the overburden. This will result in a formation of reduction zone in the halo above HC reservoirs. Among other effects it facilitates formation of epigenetic pyrite, growth of bacterial cultures and onset of the so-called self-potential. While all the mentioned effects produce measurable IP, iron sulfides provide the most distinctive footprint on the electro-magnetic signal in time domain.

The physics of the IP effect is as follows (Telford et al. 2004). When a mineral grain with electron and/or hole type of electric conductivity (as in the case of pyrite, for instance) is immersed in electrolyte with ionic conductivity (such as pore fluid, i.e. brine) a contact potential will occur at their interface. Consider the two pore passages (Figure 1): in the upper one the current is entirely electrolytic. In the lower pore, the presence of a mineral with net surface charges on either face, results in an accumulation of ions in the electrolyte adjacent the facets. Because ionic charge transfer in the electrolyte is much slower than in the metallic (or semiconductor) grain, the pileup of ions is maintained by the external voltage. When the current is interrupted, the residual voltage decays as the ions diffuse back to their original equilibrium state. For this reason the IP effect is observable as a relatively long-lived imprint of the imposed DC-field after the current is shut off.

IP is quantified by a chargeability η and a characteristic relaxation time τ. These parameters enter into the Cole-Cole expression for the frequency dependent conductivity of mineralized porous media (Flekkøy 2013)

$$\sigma(\omega) = \sigma_\infty \left(1 - \frac{\eta}{1 + (i\omega\tau)^c}\right)$$

and are obtained from inversion of field data: the electric *potential* and the *electric potential gradient*. The former one appears to be particularly sensitive to IP. Inversion parameters are typically constrained within a geo-electrical model, which includes up to 7 or 8 layers with distinctively different electrical properties. Technically it is possible to substantially increase the number of layers, thus refining the model, but it is redundant for practical reasons.

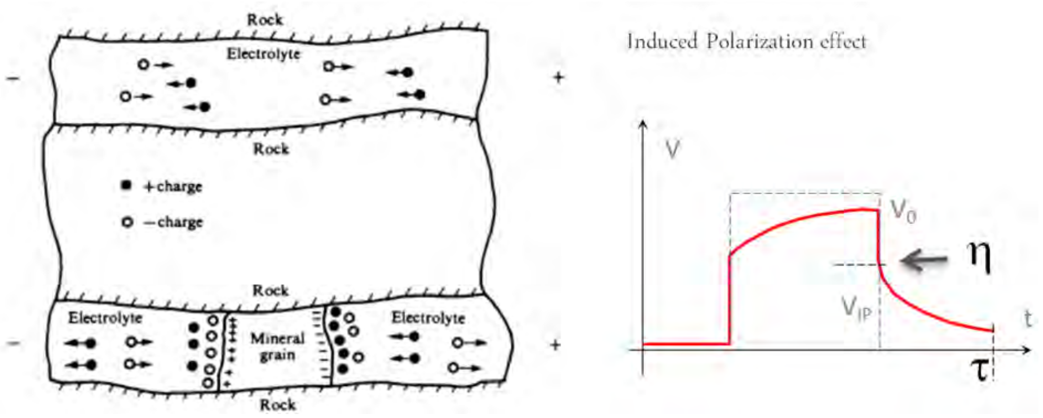

Figure 1. Induced polarization. Left: Electrolytic charge flow in the upper pore and contact potential at the grain interface (adopted from Telford et al.) Right: IP shows up as a slow voltage decay after a current pulse

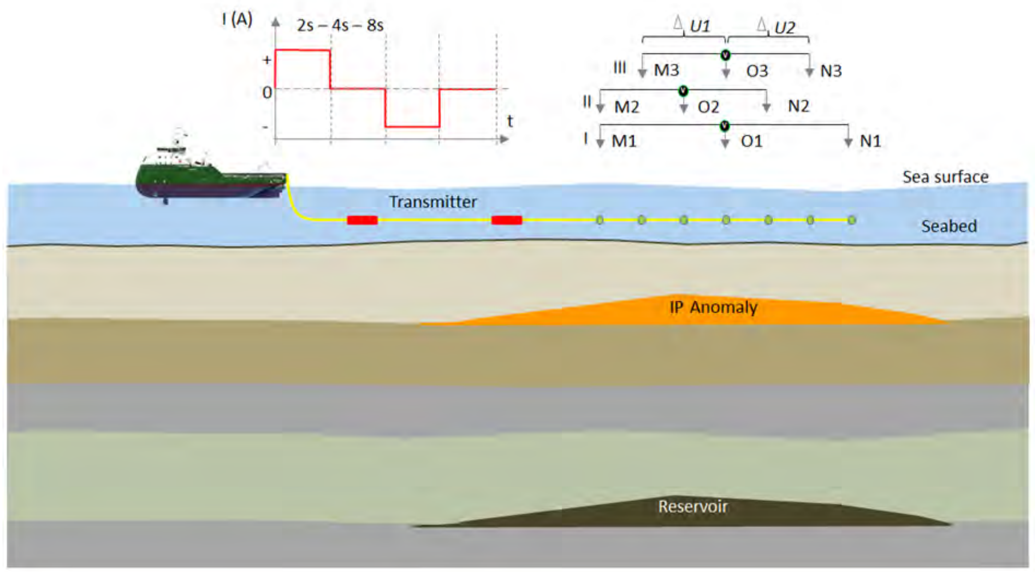

Figure 2. Acquisition system. Towed dipole-dipole array. Current is applied between the two transmitting electrodes. Potential differences are measured by receiver electrodes MON with three different offsets I, II, III

The layers are selected based on *a priori* information, such as seismic and electric well logging, whenever available.

Unlike the EM methods that tend to detect resistive anomalies at reservoir depth, this method's target is the geochemical alteration zone situated in sedimentary rocks, some distance above hydrocarbon accumulations. The fact that the target volume is quite shallow, and the IP signature quite pronounced, allows a towed system with relatively short offsets (see Figure 2) to be used. Marine IP measurements are performed by towing a streamer at 2-4 knots and applying 4 to 8 seconds long current pulses of alternating polarity (± 1000 - 1250 A). Time decay of voltage gradients is measured during pauses of the same length. The streamer consists of 2 transmitting electrodes and 7 receiving electrodes with 200 m spacing, as shown in Figure 2. Upon denoising and de-trending, the data are stacked in pickets with the centers approximately 1 km apart (Figure 3), each of which are inverted either separately or using cross-picket regularization algorithms. When the survey area is dominated by complex 3D structures, a 3D inversion can be performed. The final result is a distribution of chargeability in the target layer. Right panel in Figure 3 shows an extract from a 2012 case study on the Norwegian Continental Shelf (NCS): clear IP anomalies were observed over discoveries.

To the date, ORG has successfully tested the method on different play models typical for NCS; fields with the reservoir depth from less than 200 m (Peon) down to 4000+ m, including carbonate reservoirs (Hod, Valhall), which pose an almost unpassable challenge for EM methods (see the map in Figure 4). So far in more than 20 blind tests, i.e. when the outcomes of IP surveys were presented prior to drilling, there have been basically only two disappointments, marked red in the table in Figure 5. Both cases are thoroughly scrutinized and we at ORG Geophysical hope to return to SPE readers soon with detailed analysis. Besides an obvious practical value for the company, such an analysis might also provide an important insight into the true origins of IP anomalies.

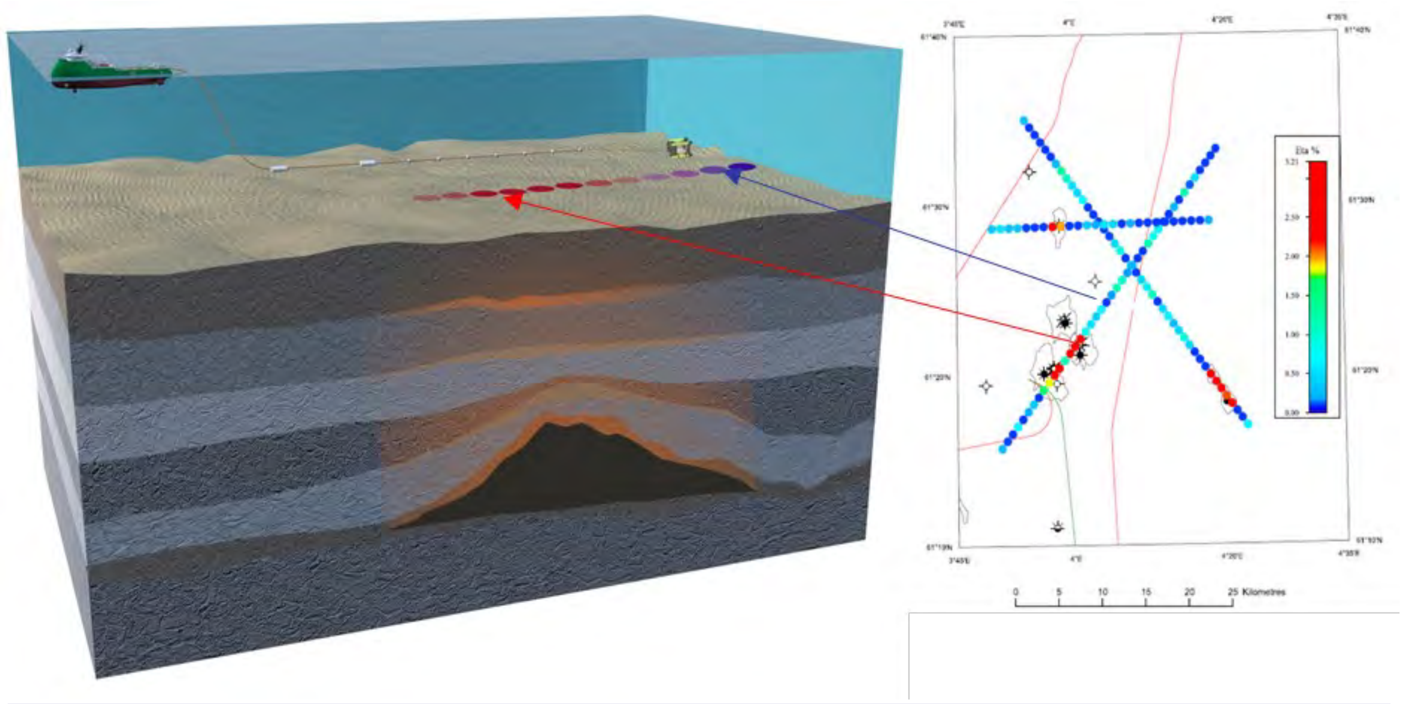

Figure 3. Data are stacked into pickets. The map on the right hand side shows distribution of chargeability in the target layer

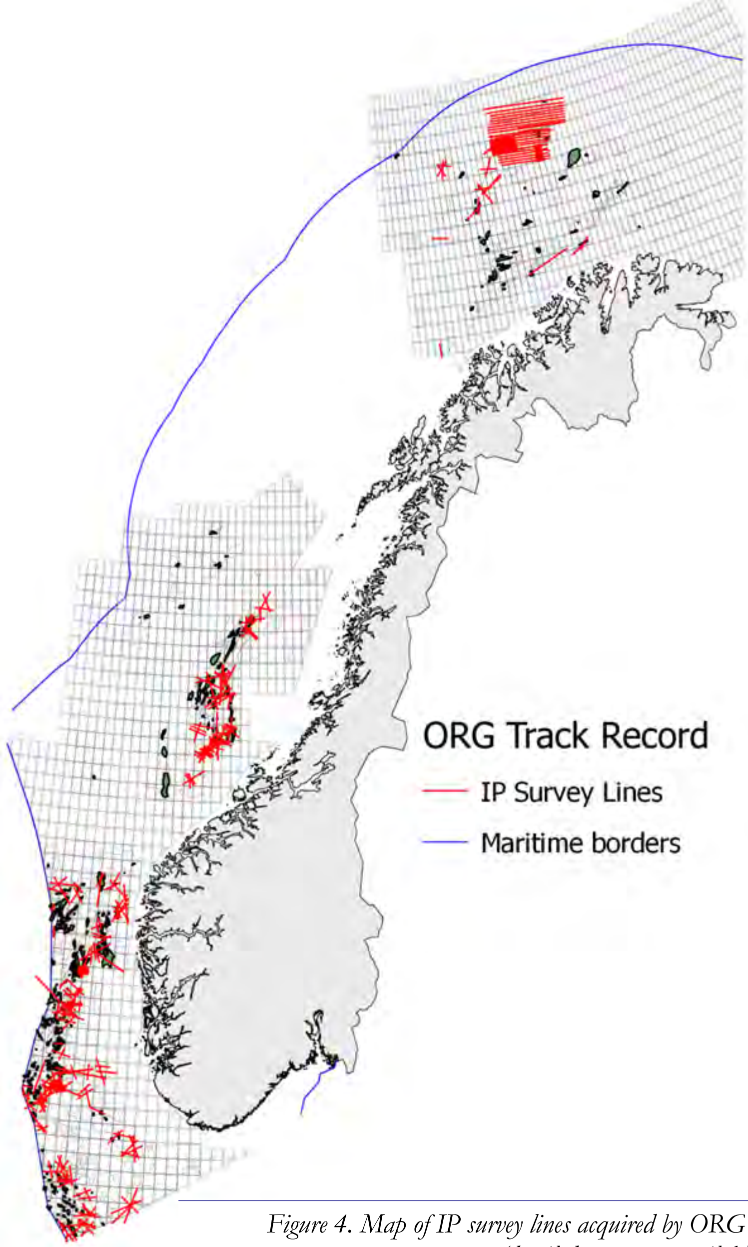

Figure 4. Map of IP survey lines acquired by ORG Geophysical (detailed maps are available on request)

Well name	Top reservoir(m)	Reservoir age	Tecnology prediction	Drilling result	Operator	Spudded	Completed
8/10-05S	2750	LJurassic	No HC	Dry	Centrica	01.01.2014	06.03.2014
8/10-05A	2263	LJurassic	No HC	Dry	Centrica	06.03.2014	22.05.2014
8/10-06S	1945	LJurassic	No HC	Dry	Centrica	31.05.2014	06.07.2014
25/05-09	2240	Palaeocene	HC	21m oil	Total	01.01.2014	25.02.2014
31/10-01	2357	Palaeocene	No HC	Dry	Tullow	01.07.2014	25.07.2014
31/02-21S	3217	LJurassic	No HC	Dry	Tullow	27.04.2014	04.06.2014
31/03-04	2082	LJurassic	No Hc	Dry	Tullow	23.11.2013	05.01.2014
6407/01-06S	4250	LCretaceousc	HC	9m gas	Wintershall	07.12.2012	24.01.2013
6407/01-07,07A	3345	LCretaceous	No HC	9mgas/12m cond	Wintershall	23.03.2014	20.04.2014
6506/09-03	4692	MJurassic	HC	47m gas/cond	Statoil	16.06.2013	27.08.2013
6507/10-02S	1957	MJurassic	HC	12m oil/12m gas	Faroe	10.11.2013	10.02.2014
25/06-05S	<2500	MJurassic	HC	10m gas/cond	Total	13.03.2015	10.04.2015
10/04-01	<2400	MJurassic	NoHC	Dry	Wintershall	22.06.2015	13.07.2015
02/11-11	<3400	LCretaceous	No HC	Dry	Edison	21.06.2015	27.07.2015
30/11-10/10A	<3900	MJurassic	No HC	100m oil	Statoil	02.11.2014	31.12.2014
6407/08-07/07A	<3000	MJurassic	No HC	Dry	Statoil	27.04.2015	14.05.2015
6507/11-11	<2900	MJurassic	No HC	Dry	Tullow	25.05.20155	01.07.2015

Figure 5. Results of the blind tests on NCS. The first column is the NPD well name (http://factpages.npd.no/factpages/), the second column is the depth of the top reservoir, the third column is the age of the corresponding formation, the fourth column is the IP forecast, followed by the drilling outcome in fifth column, operator in the sixth and start/completion dates in the remaining two columns. The list is currently updated

Another great advantage of the IP time domain method is that it is suitable for shallow water. So far the best results have been obtained for the seas up to 450 m deep, though deep water systems are under development and soon to be tested.

Towed streamer gives a clear operational advantage too. Eventually it makes the technology more time efficient. This, along with the company's modest pricing policy, explains how ORG managed to gain a valuable experience at such a high pace. From the start in 2012, more than 12 000 km of survey lines have been acquired, most of which belong to our multi-client library.

Finally, on behalf of ORG Geophysical, I would like to wish all SPE members and their loved ones happy holidays and all the best in the New Year!

References:

Davydycheva, S., Rykhlinski, S. N., and Legeydo P., Electrical prospecting method for hydrocarbon search using the induced-polarization effect, Geophysics, 71 (4), pp. G179-G189, July 2006

Veeken, P. C.H., Legeydo P. J., Davidenko Y., Kudryavceva E., Ivanov S., and Chuvaev A., Benefits of the induced polarization geoelectric method to hydrocarbon exploration,Geophysics, 74 (2), pp. B47-B59, January 2009

W.M. Telford, L.P. Geldart, R.E. Sheriff, Applied Geophysics. 2nd Edition, Cambridge University Press, 2004

Flekkøy, E.G., A physical basis for the Cole-Cole description of electrical conductivity, Geophysics, 78 (5), pp. D355-D368, September 2013