Using induced polarization measurements to derisk hydrocarbon exploration in the Fingerdjupet-Hoop area, Barents Sea, Norway

Kim Maver[1*], Phillip Hargreaves[1], Andrea Klubika[2] and Sergey A. Ivanov[3] describe the use of IP and its application as a derisking tool in general, and in the Barents Sea specifically.

Exploration for hydrocarbons has been ongoing in the Barents Sea since the 1980s. Until now, ten wells have been drilled within the Fingerdjupet-Hoop area with variable success, but with an overall disappointing outcome. Alternative technologies are now being employed by the oil exploration industry in an attempt to discover the hidden secrets of this promising region.

The Norwegian 23rd Licensing Round includes 14 blocks in the Fingerdjupet-Hoop area. As part of the prospect evaluation of the area and derisking of future wells, recently acquired induced polarization (IP) measurements, supported by 2D broadband-processed seismic, can provide valuable insight (Maver et al, 2015).

This paper will describe the use of IP and its application as an exploration de-risking tool in general, and in the Barents Sea specifically.

Induced polarization

The IP effect is measured as a frequency-dependent electrical resistivity, and is easily distinguished from the typical ohmic resistivity. While initially developed for characterization of mineral deposits, the application of this effect now ranges widely; including areas of hydrogeophysics, biogeophysics, environmental investigations, and is currently looking promising as an application for indirect hydrocarbon detection.

A current hypothesis on the key mechanism behind the IP effect is vertical micro-seepage from hydrocarbon reservoirs. The seepage causes a chemical reaction between the sulphur compound of the hydrocarbons and the iron in the rocks above the reservoir, creating a disseminated pyrite body. The resulting alteration of rock properties can be measured, and points toward deeper-lying hydrocarbon accumulations.

The disseminated pyrite body works in a similar way to a common household battery. When a current is applied, it will take some time for the battery to be charged and similarly there will be a voltage decay once the current has been turned off. The amount of overvoltage when 'charged' is a quantification of the IP effect, which is measured.

One hundred years ago, Conrad Schlumberger recognized the possibility of inferring subsurface structural information from measured voltage signals associated with 'provoked' polarization currents in the earth. It is claimed that IP was used for hydrocarbon exploration as early as the 1930s (Bleil, 1953), with a more commercial use in 1980s, as reviewed through four examples in scientific literature (Sternberg, 1991). The method has been more systematically used over the past 15 years, mainly in Russia, and with success.

To measure the IP effect, a marine acquisition streamer system is towed with a transmitter carrying two electrodes separated by 600-800m, the first one only a few tens of metres from the vessel. The detectors are a set of electrodes spaced 200m apart and organised into three sets of three electrodes, where each set measures the potential differences of the electric field.

The transmitted signal is a step pulse that is switched on, typically lasting 4-8 seconds, then off for the same period of time. This is repeated with the opposite polarity in order to keep noise steady.

The IP measurement is processed using inversion based on the Cole-Cole expression for electrical conductivity of fluid-saturated, mineralized rocks, which defines a relationship between electrical conductivity and the chargeability (Flekkøy, 2013). Two other parameters in the relationship are the relaxation time and an exponent, which can be derived from the decaying shape of the measured signal (Veeken, 2009). The measurements are inverted in an iterative manner for resistivity and chargeability in lateral layers that have been defined using seismic and/or well logs.

Barents Sea

In the Fingerdjupet-Hoop area, a combined survey was acquired in 2013/2014 consisting of 7500 km of broadband-processed 2D seismic and 3000 m of IP data tying nine wells

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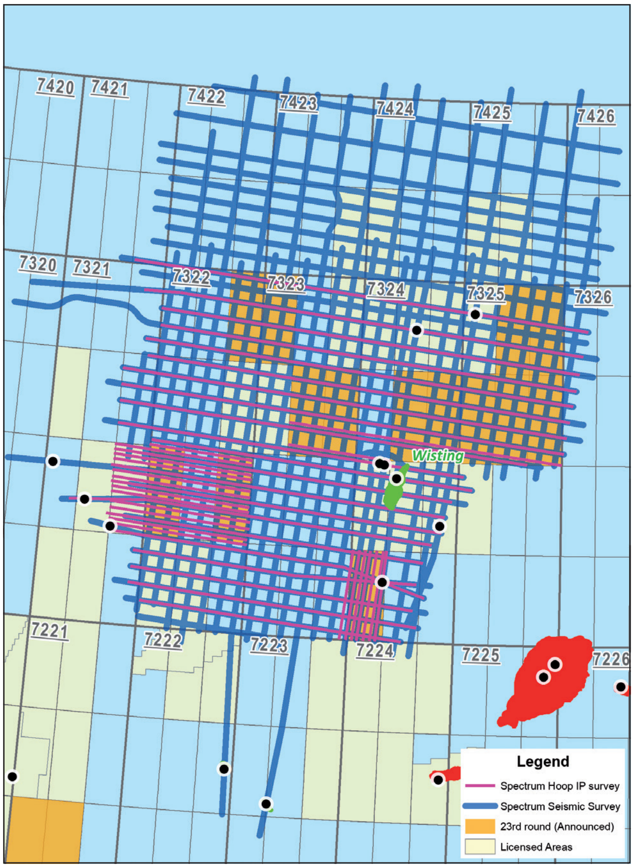

Figure 1 *Survey map of the Fingerdjupet-Hoop area.*

(Figure 1). A regional interpretation of the broadband 2D seismic, integrating well log data and using AVO inversions results, has been carried out and used to evaluate the IP results.

In Table 1, the well outcomes and the IP results are listed for the Fingerdjupet-Hoop area.

Figures 2 and 3 show examples of the IP results for the Wisting Central and Apollo wells. A strong IP anomaly both locally, but also in a regional context aligns with the main fault block of the Wisting discovery, with smaller anomalies associated with neighbouring fault blocks (Figure 2). As a comparison, the Apollo well was dry and a clear minimum with low IP aligns with the well location with fairly high neighbouring IP anomalies.

Of the nine wells tied with IP measurements, eight wells have been predicted (Table 1). Wisting Alternative had shows, but like Hanssen, the IP data predicted a discovery. This is classified as a false positive. However, as the well has shown, there may have been an earlier hydrocarbon accumulation that has resulted in an IP effect. Later, the reservoir seal had been breached, resulting in the hydrocarbons migrating away, but leaving behind a paleo IP anomaly (false positive).

Overall on the Norwegian Continental Shelf, more than 8500 km of IP data have been acquired since 2012. In 2012 and 2013 the outcomes of 38 of 42 wells were predicted. The outcome of pre-drilling IP data acquired over 13 well locations shows 12 correct predictions (both dry and discoveries).

Siberian Geophysical Research Production Company (SGRPC) has acquired 35,000 km of data in Russian areas since 2002 and has 90% success rate in its predictions of nearly 200 wells.

Well	Name	Year	Target reservoir	Well result	Induced polarization results (chargeability)
7321/8-1	----	1987	Middle-Early Jurassic	Shows	No anomaly
7321/9-1	----	1988	Late Triassic-Middle Jurassic	Shows	No anomaly
7324/10-1	----	1989	Lower Triassic	Shows	No anomaly
7324/8-1	Wisting Central	2014	Lower Jurassic	50-60 m oil column	Anomaly
7324/7-1S	Wisting Alternative	2014	Primary target, Middle Triassic	Dry with shows	Anomaly of the same magnitude as Hanssen well
7324/2-1	Apollo	2014	Jurassic and Late Triassic	Dry	No anomaly
7324/7-2	Hanssen	2014	Jurassic and Late Triassic	20 m oil column	Anomaly
7325/1-1	Atlantis	2014	Primary target, Middle Triassic	10 m gas column	Anomaly
7324/8-2	Bjaaland*	2015	Primary target, Mid Jurassic and Late Triassic	Dry	No anomaly but high back ground level

Table 1 *Wells drilled in the Fingerdjupet-Hoop area and the corresponding IP measurements.*Well offset by 1.1 km to the IP measurement.*

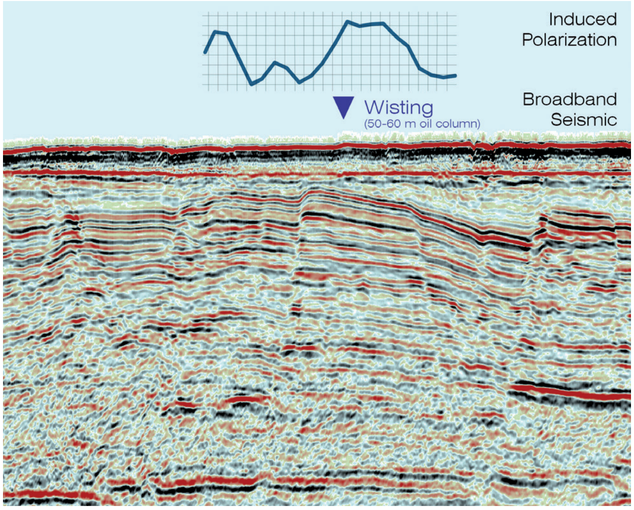

Figure 2 *Broadband processed seismic and IP measurements at the Wisting well.*

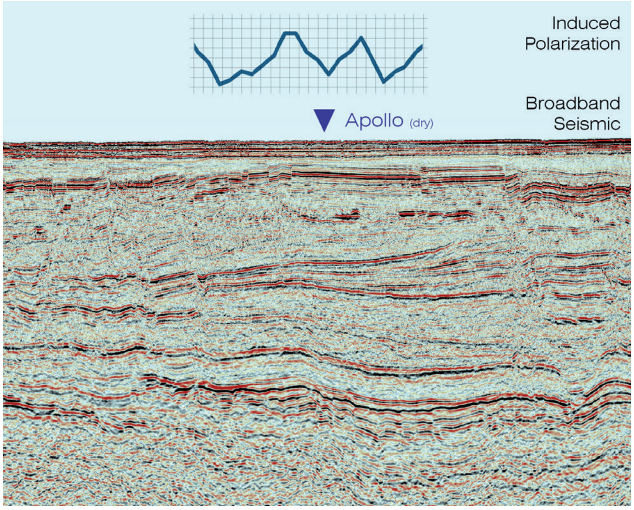

Figure 3 *Broadband processed seismic and IP measurements at the Apollo well.*

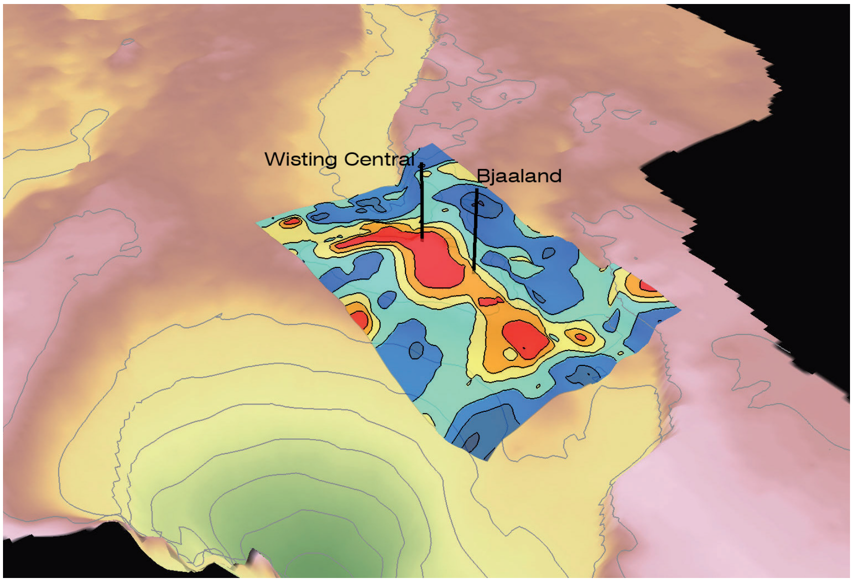

Figure 4 *Gridded 2D IP measurements draped across the Base Cretaceous unconformity and with the Wisting discovery well (red anomaly) and Bjaaland dry well (yellow anomaly) shown. Colour scale: Red indicates strong IP anomaly. Orange is the uncertainty band of the anomaly. Yellow to dark blue is regarded as background level.*

IP anomalies can be used as a strong indirect hydrocarbon indicator. However, they provide less insight into the commerciality of a well as no information is provided about the amount of hydrocarbons, reservoir properties and the timing of the filling of the reservoir. Furthermore, the IP anomaly may be a paleo effect above a leaked reservoir, which although difficult to identify through processing of IP data, can be further de-risked either through sea floor sampling/drop cores or satellite/airborne seep surveys detecting active hydrocarbon seepage.

Geological chance of success using IP measurements

IP measurements can be used as input to estimate the geological chance of success, which consists of assigning fraction probabilities to the following parameters:

structure * reservoir * charge * retention = geological chance of success

The measurement is a strong indicator of *structure* as the anomaly in general coincides with the field outline and indirectly, and to a lesser extent, points to the presence of a *reservoir*. It is an indicator of *charge*, as hydrocarbons most often contain sulphur which is one of the constituents involved in the generation of pyrite. Finally, IP normally does not provide any information about the present time *retention,* as all hydrocarbons may have leaked.

For recent wells drilled in the Barents Sea (Ørnen, Pingvin, Langtiden, Novarg and Heilo), the geological chance of success has been in the 0.20 to 0.85 range. Assuming a certainty of 90% for the IP results, when hydrocarbons are predicted and applied to *structure* and *charge*, the overall geological chance of success will only increase marginally for the wells utilizing the measurement. However, when there is no IP anomaly indicating no hydrocarbons present, the impact on the geological chance of success is mainly on the *charge,* which again assuming a 90% reliability of the measurement will set it to 0.1. There is no change to the *structure* parameter as that cannot be assessed when there is no anomaly. But with a *charge* of 0.1, the representative geological chances of success listed earlier for Ørnen, Pingvin, Langtiden, Novarg and Heilo will be reduced to only 0.03 to 0.10, making most prospects uncommercial.

The IP results can therefore be used in three ways:

- To confirm prospects that have a positive IP effect, but do not really impact the overall geological chance of success
- To significantly downgrade prospects when no IP effect is present, resulting in a very low geological chance of success
- To identify areas with new potential prospects that have previously not been identified based on conventional mapping and interpretation.

Concluding remarks

The IP method has been known for 100 years, but it has only been used systematically in hydrocarbon exploration for the past 15 years and in Norway only for the past three years. When using IP for exploration derisking, it is important to understand the measurement, limitations and pitfalls, a process which is similarly applied to any other geophysical method.

An IP anomaly points to a deeper-lying hydrocarbon accumulation, however no information is provided about the depth of such an accumulation. The size of the anomaly can't be used to quantify the amount of hydrocarbons in place, as it depends on the hydrocarbon sulphur content, the iron content in the shallow section as well as the time for the micro-seepage to take place. The erroneous IP result may be a consequence of a number of factors. In case of a hydrocarbon accumulation resulting in an IP anomaly and then later migrating away as the seal has been breached, it is difficult to distinguish between a real anomaly and a false positive. If the hydrocarbons have recently migrated into a reservoir, not leaving enough time to create an IP anomaly, or if the hydrocarbon reservoir seal is exceptionally tight limiting micro-seepage, the outcome is a false negative effect.

Even though there are both false positive and false negative IP effects, a 90% certainty for a correct prediction makes the measurement valuable in hydrocarbon derisking, which can be shown in the geological chance of success concept.

With more IP data acquired in a systematic manner in the future, it is predicted that the use of this method will increase, especially as a better understanding of the basics develops.

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