High Resolution EM and RALF 1 software

The Editorial team of The First Magazine was the first who met Vadim Chernov in Norway. The geoscientist who has many publications and experience in thousands of kilometers of of processed data, sensationally attacked the exploration world in LinkedIn by giving away his core software free and offered his expertise to Norwegian society, since the end of April 2017. We wanted to use the chance to ask Vadim Chernov about the High Resolution EM method he worked on and advantages of his software.
Also, the editorial team contacted former colleagues of Vadim Chernov, Peter Dubinin, leading Geophysicist in Geoneftegaz and present Chief Specialist KruKO (HRES-IP EM equipment developer) to tell us about Vadim achievements and to comment HRES-IP method and its advantages.

Vadim Chernov, *independent geoscientist in 4th generation, the author of the original inversion program for a high-resolution inversion of the electromagnetic (EM) field, certified author of the computer program RALF 1[3] (cert.№2011612714) and certified co-author of EPIS 2.0 (cert.№2002611378) by Russian state registration for prospecting fossil fuels. He holds Master of Sciences in Geology from the Moscow State University. 2000-2010, he worked in the Scientific Production Centre of JSC RPC Geoneftegaz where he developed the original program. The base of inversion program forms the part of the software system for data processing and interpretation of a high-resolution induced polarization exploration method (HRES-IP). He has been awarded a Diploma of Merits by the Russian Federal Ministry of Natural Resources for his work.*

THE CERTIFICATE

About the state registration of the computer program

№2011612714

Reflection on Actions of Lorentz Forces-1 (RALF-1)

(Whether) the legal owner: *Chernov Vadim Vadimovich (RU)*

The author (s): *Chernov Vadim Vadimovich (RU)*

The demand № 2011611050 Date of receipt on February, 22nd, 2011

It is registered in the Register of the computer programs

On April, 6th, 2011

B.P.Simonov

The head of Federal Agency of intellectual property, patents and trade marks

Picture 3. Vadim Chernov's certificate for RALF 1 software

High Resolution Geoelectric Prospecting, Inversion Software RALF 1 and Its Success Rate

The history of method presented in this article began in 1970s. Alexander Kulikov is Russian scientist who worked at the Research Institute of Geophysics in Moscow, created the IP based method with phase measurements at infra-low frequencies (near 1 Hz), one of the most effective method to search for ore deposits. He discovered relationship between phase of the IP and the apparent polarizability. This analysis allowed to determine the presence of polarized objects in the geological structures. Later, Andrey Goryunov and Evgeny Kiselev from the same institute, suggested using this method for exploring hydrocarbons (HC). They believed that HC rocks behave as polarized objects on the edges. Since 1995, Vadim Chernov has been working on development of this method. The method was the basis of later created inversion EPIS program complex (2002), where Vadim Chernov is co-author, and the method was renamed to High-Resolution Sounding with Induces Polarization (HRES-IP). The HRES-IP was applied from 2002 to 2011 in different regions of Russia and abroad. The rights to the method belonged to the company JSC RPC Geoneftegaz (not active today). Now this technology is under Russian Federal State Unitary Enterprise FGUP VEI («VEI GEO")
In 2011, the set of programs RALF-1 was developed to process and interpret the field material as result of Vadim Chernov's many years' experience. RALF-1 was tested in Western Poland, Iran, Kazakhstan, Moscow region. The set allows to make changes depending on EM acquisition geometry. Vadim Chernov was adjusting developed method being directly involved in conducting many field studies in Russia and abroad. The method was used in conjunction study with 3D and 2D seismic surveys. Studies were conducted on 60 prospects and acquisition length exceeded 20 000 km. The rights for the RALF 1 software belong to Vadim Chernov, Picture 3.
Forecasts for HC presence were confirmed by drilling more than two hundred wells with more than 80% success rate. As the result of this work about 30 new oil and gas deposits were discovered for commercial exploitation.
Picture 4 illustrates Geoneftegaz accomplished projects. They presented statistical work of performed studies in the book [8] including HRES-IP method. Authors describe several methods there, and refer to the HRES-IP method which is managed to get wide approbation. Effectiveness was proved on the fields for Lukoil (acquired EM data 6500 km2), YUKOS, Rosneft (in Kazakhstan acquired EM data 2000 km2), Gazprom (acquired EM data 3000 km2), Surgutneftegaz, MNR RF, TNK BP, FIOK (Kazakhstan), NIOC (Iran), EPR and BGP CNPC (China) and others. The largest of these companies have their own research institutes and scientific centers. Companies which performed at least 1-2 thousand km2 data studies based on HRES-IP provided their independent examination jointly with well and seismic studies, and proved it by "carpet" drilling (hundreds of wells per year). The Table 1 shows available statistic for HRES-IP method.
Today the basis of HRES-IP is registered as FTEM-3D under RU patent (2446417 and US Trade Mark, 2011).

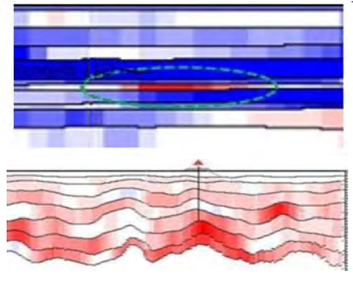
Picture 4. Sours JSC RPC Geoneftegaz. Area of performed work

[3] RALF-1 - Reflection on Actions of Lorentz Forces-1

Table 1. Recorded success rate statistic for HRES-IP method

Company (Fields)	Number of Objects	Discovery, wells	Success %	Dry well , %	Missed reservoir ,%
UdmurtNIPINeft (Eseney, Kaysegurt, Baikuzin, Chuzhegovsk and Zaborsk areas - tops: Tula, Tournaisian, Visei, Bashkir)	41	18	>70	<20	-
Rosneft daughter (in complex tectonic lithological traps of the northern side of the West Kuban trough)	21	-	>67	14	19

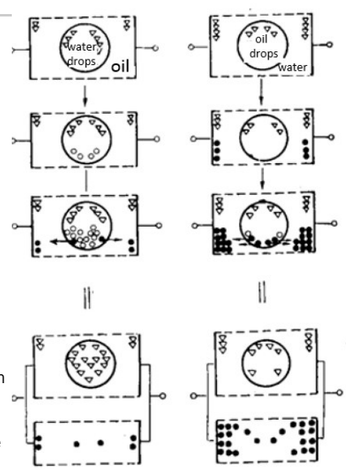
Software complex RALF 1. Main principles for solution
The author claims that accuracy of performed studies is more than 85%, and the possible layer resolution 3-5 meters for land data. In the sea this complex has no experiences prior to 2017.



Picture 6. Examples of inverted result. a) Section of Polarizability for very thin layers (3-5 m), where red means low polarizabilities- HC indication (proved gas). b) Anisotropy. Red colour means high anisotropy - HC indication. Rough estimation (500-1000ms thickness, proved oil)

Method principle
HC saturated rocks have very low polarizabilities compared to surrounded rocks, and mineral water with just a small HC mix have a very big polarizabilities in a low frequency range, Picture 5. The accumulated electrostatic charge in a changed polarity external field causes currents, which looks like an appearance of negative resistances in the section or an appearance of zones with negative polarizabilities. In same zone such system can be considered as current emitter. HC rocks behaves like a condenser and is distinguished by minimal polarizabilities at frequencies of 1 Hz. At the same time, surrounded rocks behave like rocks having double dialectical layer properties and can be described by Cole-Cole formulas with constant time relaxation in 1 second [9]. In addition, the oil-saturated layer is very anisotropic object. Vadim Chernov refers to Kerr effect (NOLIMOKE) [10] as a variant of this nature interpretation. It has a magneto-optical properties (heavy oil is optically anisotropic substance in the electromagnetic field). It is known that the electromagnetic field in a layered medium has two components: flat incident wave (wave part) and the current component, which are connected to each other through a system of Maxwell's equations, and can be associated non-linearly in the presence of rocks exposed to Kerr effect.
Thus, if to calculate the components of the electromagnetic field **Ex** (compare to ***dBz/dt***[4]) over a multilayer medium, a recurrent functions are used simultaneously, and these functions describe the laws of the horizontal and vertical distribution of resistivity in a section. In this case, there is an opportunity to study both directions. Also, if rocks contain thing high resistivity HC layer then longitudinal resistance does not give a noticeable changes, but transverse resistance increasing making rock layer super anisotropic. Noticeable changes in anisotropy also can be caused by fraction and optical active C19-C35 HC components that cause already mentioned Kerr effect. In fact, an actual received amount of change of the anisotropy is 30-50% rather than obtained in the simulation- 2-3%.
Summarizing it, the simultaneous analysis of vertical and horizontal current components of EM field, make possible to find an area of such non-uniformity at reservoir. As result, it makes a conclusion about the presence or absence of HC at a given point of geological section, Picture 6.

Stage	Time after constant current field applied	Charge distribution	Corresponding field of alternating current
a	t=0	Inducted charge	High frequency
b	↓	Conductive charges	↓
c	t=∞	Many conductivity charges, its minority only can left the drops	Low frequency
d	t=∞	Equivalent condition, observed on acquisition equipment	Components which are not able to be born Components which are able to discharge



Picture 5. Explanation of interphase polarization in dispersed system of spherical particles.

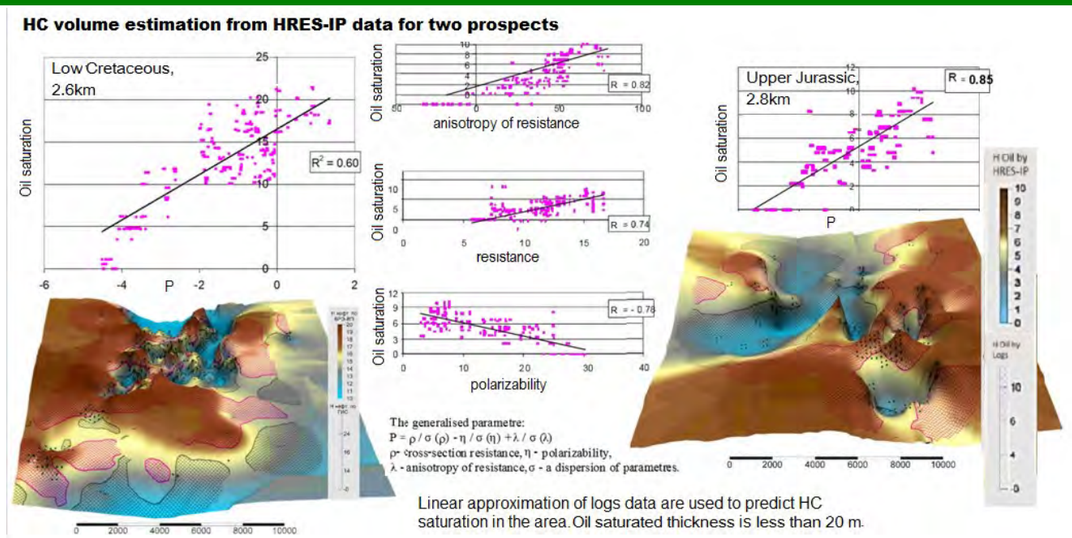
∇ - *Electrostatic inducted charge.*

● - *Conductive charge which is able to move through phase borders.*

○ - *Conductive charge which is not able to move through phase borders*

From the book Emulsion Science [11], as a basis of explanation why we study effects on the frequencies less than 1 Hz.

[4] dBz/dt– changes in magnetic component of the field



Picture 7. Tevlinsky area (Western Siberia), Kogalymneftegaz & Lukoil-Western Siberia. Acquisition - 750-800km, increments 50m, distance between profiles 300-600m. The results contain distributions over the area resistance, polarizability and anisotropy of resistance in perspective layers. The predicted thickness by the method and real thickness of the reservoir match consistently. Source of this picture — NefteGasTEK, Tumen International Innovation Forum-Exhibition, September 2010

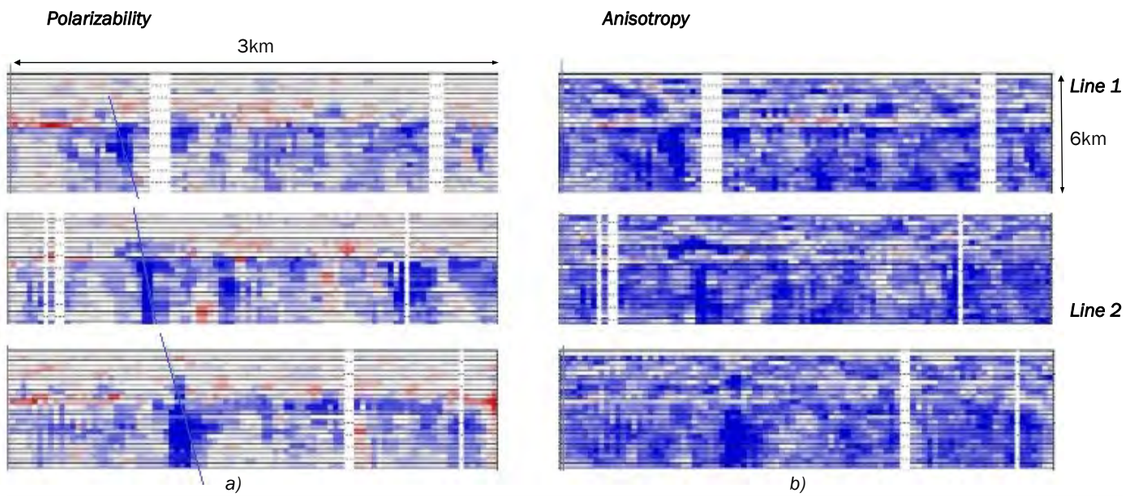
Inversion principle of RALF 1 which makes solution precise

"Everyone knows that inverse problems are incorrect, and the effects that we observe are just decimals of a degree. Even its derivatives with respect to the desired parameters are smooth and weakly differentiated functions. Many scientists gave up their work because of this. I did not give up for many years. And I know how to work with these smooth functions so that they give such a differentiated picture. ***Now it is not only me, who can do it. My inversion software of RALF 1 is in the public domain. This can be done by everyone in an automatic mode.***[5] *Another question - how does it work? But this is not physics problem, but mathematics", - says Vadim Chernov.*

RALF 1 makes possible to obtain the distribution resistances, resistance anisotropy, and the IP processes for 2D and 3D. The algorithm can give not only electrical parameters of geological layers but also quite precise depths. Using big samples of parameters is making solution of inversion problem more clear in borders of Shennon theorem[6] [12].

"The uniqueness of my solution is that I get independent solutions for all unknown parameters that are not correlated with coefficient of correlation 100%. On the RALF 1, you can see not the most exact solution, but something that does not correlate, Picture 7, 8, 9. This is specific of each parameter. So, I remove the background. It is some kind of filtering, not spatial, not time-frequency, but logical. Based on the formula you saw[6] (but note that formula is incomplete). Nonetheless, the exact solution is sought for every point of probing. In the program table you see the exact solution, but it does not mean that the 2D section should look like an exact solution. You can always remove the background. This is standard practice. The background prevents seeing details. To prove it, enter into this formula[6] Ki=1 the inverse problem that you have, and compare the results without this formula. We checked this in 2007. It was another 3 years, before RALF 1. I think that even with Ki=1 you will get an indelible impression. In fact, my help won't be needed.

May be, 90% of EM land based on high-frequency induced polarization. It means, we are looking for polarizability in the upper layers. Usually, a zone of oxidation-reduction reactions and pyrites zone are formed above HC reservoirs. People do not bother and look for pyrites in the upper 500 meters. But what about situations of multi-layer deposits? The problem is that nobody tried to solve inverse EM problem for such volume of frequencies and parameters as we did it. Now we can get information about more than 100 parameters from one sounding in one physical point. Such parameters as polarizabilities, anisotropies, resistivity and thicknesses for each layers. In most cases of EM frequency probing all polarizabilities are fixed, except one in the perspective depth interval. I suggested mathematical solution. My depths increment is 100-200 m, and for each layer polarizability, resistivity, anisotropy of resistance and polarizability are selected. It is an incorrect problem and hard to understand how is possible in principle. For example, I have 45 parameters are searched on 70 frequencies, which differ very little in derivatives. 2.6 km and 2.8 km are completely different contours. Normally EM can see only one common contour. I see everything separately in a frame of Shannon theorem. This is possible because there is a difference still present between the derivatives of the parameters, when there is enough measured data. This difference is enough to work with. For most of EM methods, granite rocks will be something unified without precise depths, but not for my method. And now, you can see it too. That is the difference. RALF 1 also can see anomalies in prospective layers as low polarizabilities in small areas in a big massive of rocks with highly saturated mineral water and in high level of polarizabilities. RALF 1 can also see hydrocarbon reservoirs in depths of 3-4 km under 1 km of granites, Picture 9." - says Vadim Chernov.



Picture 8. Data Available to test RALF 1 by public. Inversion result. a) Polarizability. Red and blue colours mean low and high polarizabilities. b) Anisotropy. Red colour means high anisotropy (possible HC). Blue and white colours mean low anisotropy. Blue line indicates detected fault

[5]Test data given by Vadim Chernov to test his RALF 1 software is presented on Picture 8.

[6]Shannon's theorem - information capacity, i.e. "volume" of the observed data, should not be less than the "volume" of the desired data. It means that the "more complex" geophysical profile, the more sustained is the result of its interpretation (if the observed data capacity is sufficient). Shannon's theorem also asserts the principle of "block" encoding and decoding as universal means of interference elimination. On a practical level, there is an understanding that block coding and decoding in geophysics is not only speed up the process of interpretation, but also makes it more resistant - the modern theory of inverse problems of geophysics [12]. Thus, the instability of the inverse problem solution decreases with increasing complexity of the explored section.

AFSIP3D[7] Method and its main features

Today Vadim Chernov suggests AFSIP3D method. It is modern technique based on RALF 1 program algorithm, allows producing a layer-by-layer analysis of IP, including an anisotropy of resistivity.

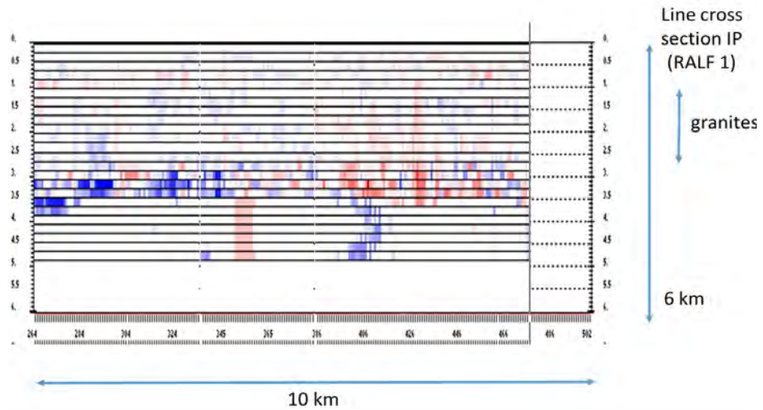
The main feature of the AFSIP3D is a possibility to obtain stratification in three-dimensional space of the three main characteristics of reservoir interval - *resistivity, resistivity anisotropy, polarizability, and additionally, thickness for each layer.*

It is analogous to the High-Resolution Time-frequency EM Surveying Method, but modified in accordance with the technical features of MHD[8] generators to increase the power of the generated signal. It is intended to calculate HC reserves at the work site, and to perform measurements on an irregular grid.

Analogues and their limitations

Editorial team asked Vadim Chernov if there are any analogues of his method and inversion techniques are present in the World, and what is their success rate. He told, that there is an analogue. Induced polarization used in different configuration. For example, Spectral Induced Polarization - Resistance Complex - SIP - CR (SIP or CR) is an electrical method that can be used to display changes in the electrical properties of the rocks that are associated with geochemical phenomena of alteration and associated with HC. Positive anomalies caused by polarization in oil fields have been long time observed in Russia. Since 1990 China conducted detailed studies with 74% success rate. More than 103 structures were drilled in the Eastern part. They used high-power SSIP method. In North America technique were used in Cement, Chickasha, Velma and in Oklahoma (USA), and the David Field site was one of the first successes in Alberta (Canada).

"It would be very interesting to work in Norway. EM marina task, e.g. in Arctic region, is very interesting way for RALF-1 hydrocarbon exploration. Here is future. I would like to prove it",– said Vadim.



Picture 9. HC indication under ***granites*** *in red (low polarizabilities zones)*

[6] The additional step which were added to the RALF1 algorithms in order to increase an accuracy of depth computation. The step has an automatic limitation of a weak-effect parameter selection and subsequent comparison of a standard and modified algorithm results. Mathematically, this was done by means of introducing all parameters of average increment in each increment of residual parameter. The formula is presented here:

$$\Delta J_i^* = K_i \cdot \left[\Delta J_i + \overline{\Delta J} \cdot \left| \frac{\sigma(\Delta J_i - \overline{\Delta J})}{\sigma(\Delta J)} - 1 \right| \right]$$

where

ΔJ_i - original increment of the residual on the i-th parameter,

ΔJ_i^* - changed increment of the residual on the i-th parameter,

$\overline{\Delta J}$ - average increase residuals for all parameters,

$\sigma(\ )$ - operator variance,

K_i - normalization factor for the modified residual

[7]Anisotropic Frequency Sounding of Induced Polarization

[8]The invention relates to geophysical methods for oil and gas exploration. A three-dimensional time-frequency exploration method, where an arbitrary shape electric current flows through a mounted supply source made as a grounded line, and generated by a powerful source such as a type magnetohydrodynamic (MHD) generator or similar.

Peter Dubinin, the Chief specialist, KruKo LLC (ООО "Фирма КруКо"), independent expert in electrical prospecting, formerly leading geophysicist in Geoneftegaz provided information about HRES-IP technique and Inversion solution of Vadim Chernov on the request of The First Editors.

Russian geophysicist, researcher Vadim Chernov, after graduating the Geological Faculty of the Moscow State University, joined like-minded team of JSC RPC Geoneftegaz, electrical exploration department in 1998. HRES-IP was developed at JSC RPC Geoneftegaz, combining the most promising EM methods used in the world practice for HC prediction.

The basis for the development of this technology was the theoretical and methodological development of the Russian leading research institutes of the early 1990s: VNIIGeofizika (Moscow), NVIIGG (Saratov), SNIIGGiMS (Novosibirsk). The technology allows to study a specific electric conductivity and an induced polarization of rocks which anomalies are associated with hydrocarbon deposits, in the frequency domain. In the time domain, it allows to perform an analysis of the time and dynamic characteristics of the nonstationary field, and to perform depth tie of electrical anomalies, based on a joint analysis of EM exploration, logs data and seismic surveys.

To carry out field exploration, a hardware-software complex developed by KruKo company (by the order of JSC RPC Geoneftegaz) was used. The complex includes a set of field meters AGE-xxl and a number of universal current switches for generator set.

The processing and interpretation of the HRES-IP data is carried out on the basis of a specialized software package for processing and interpreting - EPIS developed by the specialists of JSC RPC Geoneftegaz (Volkova NB, Dubinin PA, Kalachev AA, and Chernov VV).

In the team, Vadim Chernov was responsible for developing the program of electrical exploration inversion, an extremely important tool for interpretation. In the period of 1998-2010, Chernov developed a one-dimensional inversion program in frequency domain FSIT widely used as part of the EPIS complex to interpret the data of the HRES-IP both in Russia and abroad. Continuously improving the inversion algorithms, he achieved significant success in solving the basic problem of inversion - increasing the accuracy of estimating geoelectric parameters, their depth and lateral tie, even in conditions of a three-dimensional inhomogeneous medium. The results of his research of HRES-IP field interpretation were repeatedly published and reported at international conferences.

It should be emphasized once again that Chernov's program of FSIT inversion is an integral part of the EPIS program complex and the HRES-IP technology, which are methodically integrated in on piece.

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Additional

**Electromagnetic geometric sensing with bottom nodes streamers for HC exploration in shallow water. Dissertation, M. Malovichko for HRES methods.*

** A. Gorunov, E. Kiselev, I. Kondratiev, A. Safonov, K. Tertyshnikov and V. Chernov, The role of high-resolution electrical survey (HRES-IP) in complex of geophysical methods during exploration, prospecting and exploitation of oil and gas deposits. Geophysics of the 21st Century - The Leap into the Future.*

** V. Chernov, and A. Goruonv, HC Exploration in the crystalline basement by high-resolution electrical survey methods in the example of the Kurgan region. Tyumen 2009 - EAGE International Conference and Exhibition (in Russian).*

** Modern search of oil fields and gas a method of high resolution electroinvestigation in Russia, V. V. Chernov, 9th EAGE International Conference on Geoinformatics - Theoretical and Applied Aspects, 11 May 2010.*

Acknowledgment

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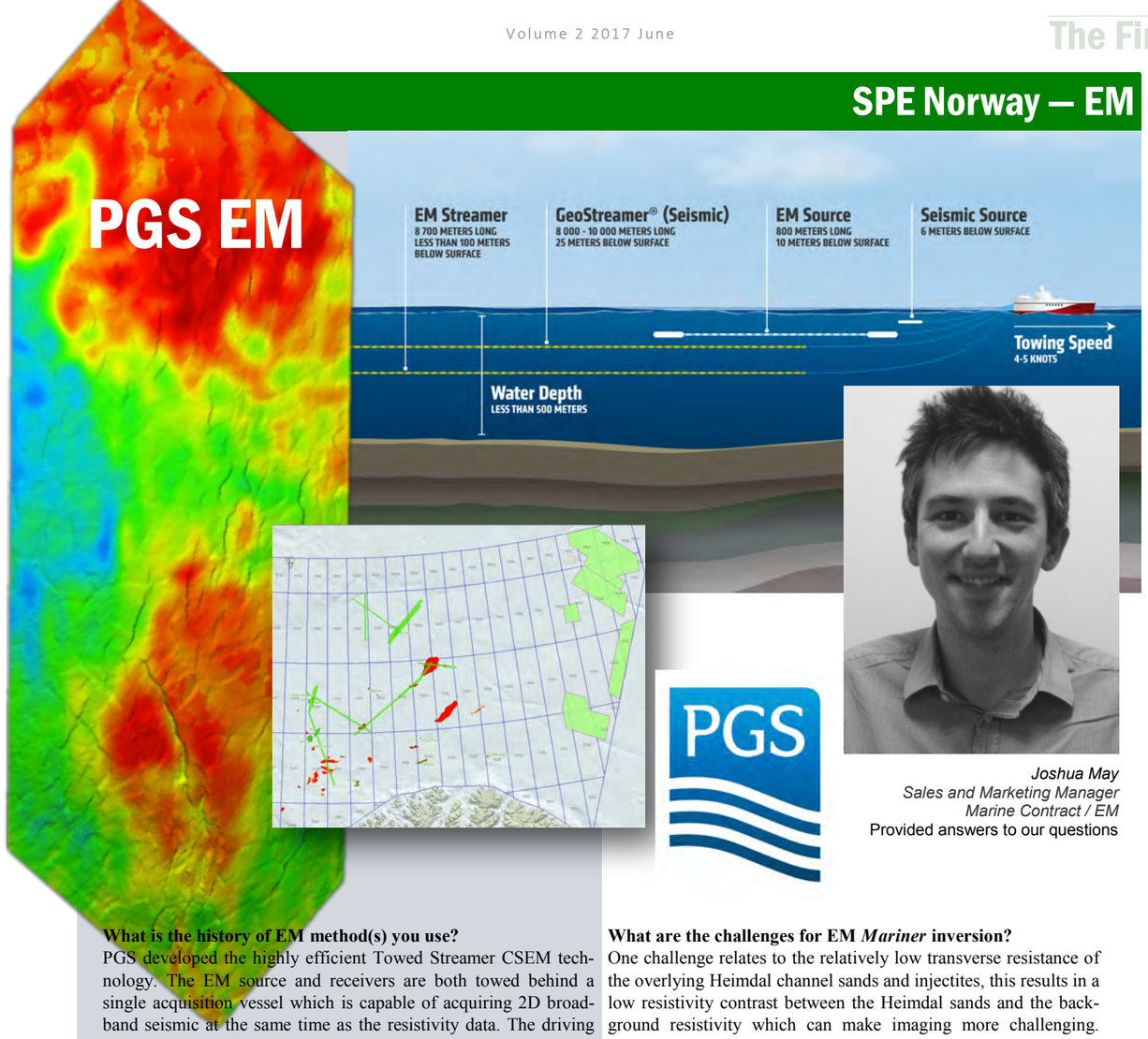
If you order EM data, remember

1. Method shows resistivity properties, not HC. HC related anomalies are interpretation.
2. QC your inversions carefully before interpreting.
3. If you've never dealt with EM before, take your time to understand the data.
4. Use the expertise available to you (service provider, in-house specialist, consultant) to discuss your interpretation.



Joshua May
Sales and Marketing Manager
Marine Contract / EM
Provided answers to our questions

What is the history of EM method(s) you use?
PGS developed the highly efficient Towed Streamer CSEM technology. The EM source and receivers are both towed behind a single acquisition vessel which is capable of acquiring 2D broadband seismic at the same time as the resistivity data. The driving force for advancing EM acquisition technology was to improve efficiency and to enable resistivity and seismic data to be acquired simultaneously.

What geometrical configuration do you use to acquire data?
Towed streamer EM technology is based on tried and tested streamer seismic operations, the EM cable is 8700 m long and contains 72 electrode pairs (receivers), it is towed at a depth of up to 100 m. The EM source is 800 m in length and is towed by the same vessel as the EM streamer (image above). When acquiring 3D EM data PGS designs EM surveys with a line spacing of <1.5 km, enabling the delivery of both 2.5D resistivity sections, and 3D resistivity volumes.

Who and when solved direct and inverse problem used for PGS EM configuration?
Inversion codes have been developed internally (3D Gauss-Newton code) and externally (2.5D MARE2DEM from the SCRIPPS Institute of Oceanography) with a focus on efficient and accurate implementation, PGS has worked closely with third parties to ensure optimal inversion code performance for high density Towed Streamer EM data. This flexible approach enables PGS to deliver unconstrained and seismically guided resistivity sections and volumes while also enabling our customers to invert and analyze the field data themselves.

What are the challenges for EM *Mariner* inversion?
One challenge relates to the relatively low transverse resistance of the overlying Heimdal channel sands and injectites, this results in a low resistivity contrast between the Heimdal sands and the background resistivity which can make imaging more challenging. With regard to the Maureen reservoir, proximity to highly resistive underlying geology is the primary challenge. This is a good example of imaging uplift provided by Towed Streamer EM data, the high density data acquired simultaneously with seismic enables PGS to integrate the two to distinguish and characterize more challenging targets than when more sparse data is acquired.

Does your software (name it) allow flexibility to invert other acquired configuration sets?
PGS' own internal code (iTEM) has been designed specifically for Towed Streamer EM data, but as we recognize that the market wants flexibility it has potential to be able to handle node based data as well.

What is the total data acreage PGS acquired today and what is the success rate for Confirmed discoveries, Missed aims, False predictions %?
PGS' 3D EM MultiClient data library currently stands at >15000 sq. km, plus >3000 line km of 2D EM data. We have conducted EM surveys over known discoveries as well as in frontier areas like the Barents Sea Southeast (see attached image) but as a service provider we do not record success rates. There are however many published articles which address this questions and it's well accepted in the industry that the addition and integration of complementary resistivity data to seismic when exploring for hydrocarbons significantly improves chances of success.