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Geophysical services to the oil industry

Rune Inversion

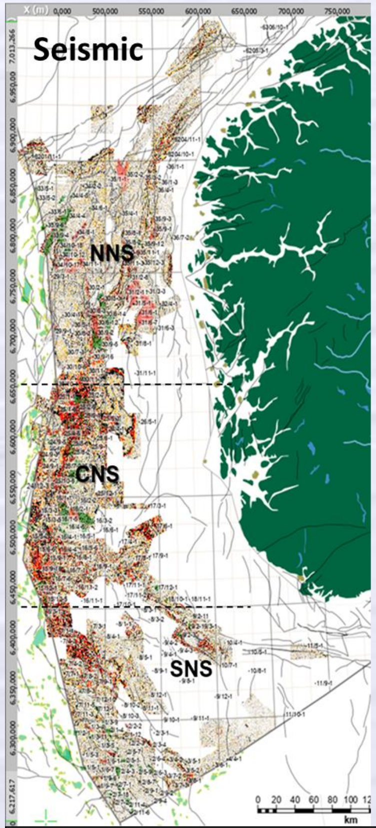
Solved fundamental problems in seismic inversion.

Resolving seismic signal for:
- non-linked parameters of velocity and density,
- post-stack velocity and density separation,
- and can be applied to non-NMO stretched data (full offset until diffracted energy)

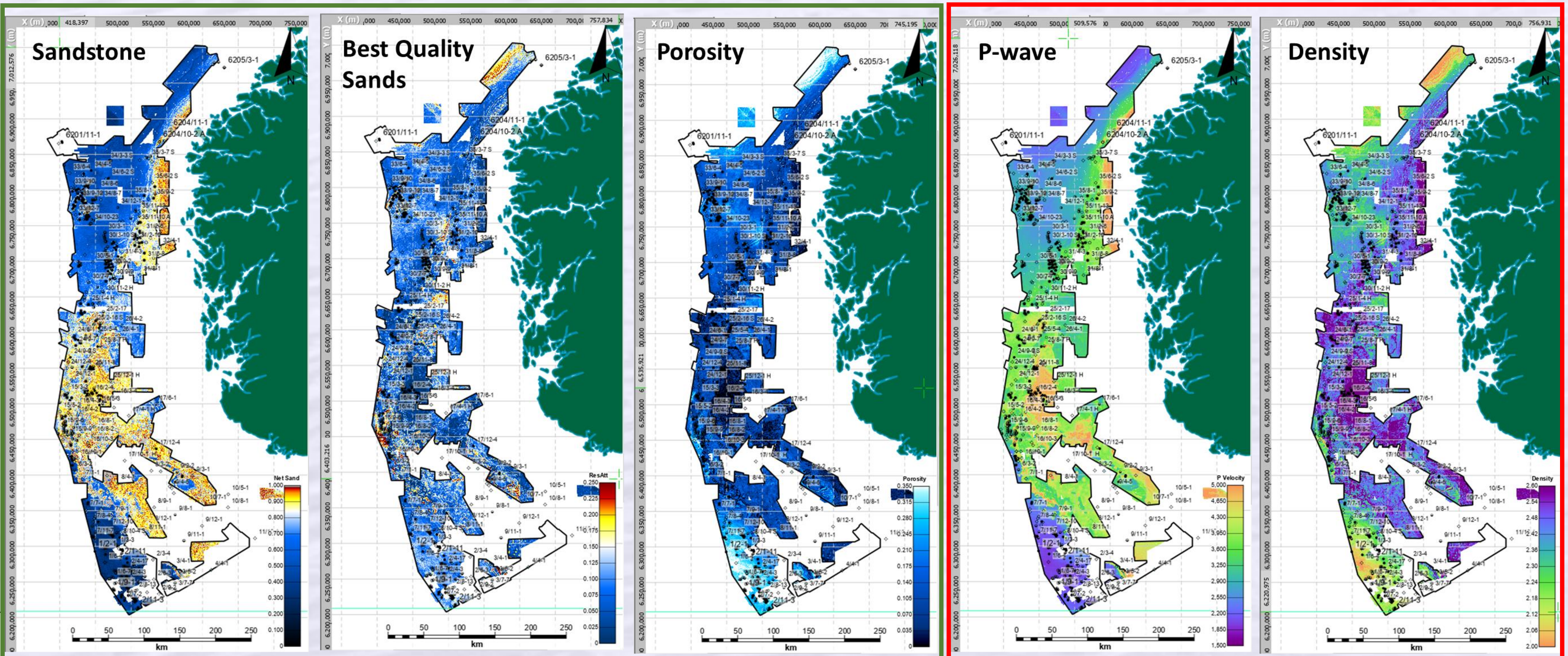
Contact person:
Vita Kalshnikova
vita@pss-geo.com

Solved problem – rock properties prediction from post-stack seismic data
Examples from the inverted merged post-stack seismic data of the North Sea. The Elephant Project.

69 660 sq. km



Two versions: True amplitudes and smoothed



2500 ms slices

Algebraically computed data from the inverted volumes

Inverted data

Main milestones in chronological order of rock properties estimation developments from seismic data

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~1900

Reflection amplitudes as a function of incident media, AVO

Knott, 1899; Zoeppritts, 1919

~1950-80

Approximations
Elastic parameters

Bortfeld, 1961

~1980-2000

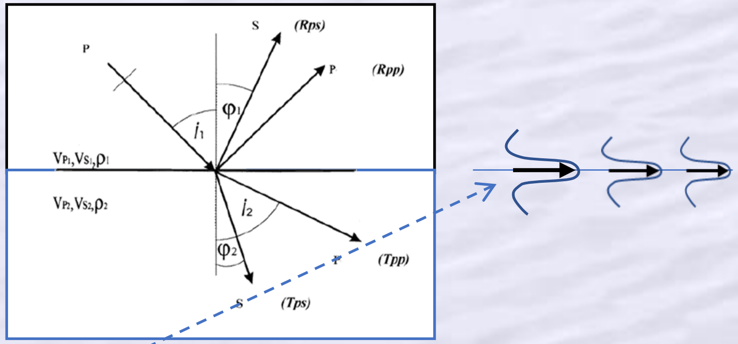
Approximation
Classification
Seismic Inversion

Aki Richards 1980,
Smith&Gildow, 1987
Goodway et al., 1997
Whitcombe et al. 2022
Bulan & More, 2003

~2000-2022

Complex mathematical solutions for achieving better accuracy within the same physical principals
et al.,2013

e.g., Johansen et al., 2013
Lehocki et at.,2019



$$R_P = \frac{I_{P2} - I_{P1}}{I_{P2} + I_{P1}} \approx \frac{1}{2}\frac{\Delta I_P}{I_P} \approx ln(I_{P2}/I_{P1}) \longrightarrow R_{PP}(i) = A + B\sin^2 i + \ldots$$

$$I_{P2} = V_2\rho_2 \qquad I_{P1} = V_1\rho_1$$

120 years of non-solved problem:

The conventional invention is based on principles formulated nearly 120 years ago. These main principles have not been changed; therefore, conventional inversion's limitations have remained unsolved. Scientists understood how to extract rock properties from a reflected seismic signal around 1900, Zoeppritts equation (1919). The solutions of the proposed equation are impedances of the rock layer. Impedance is the velocity at which a seismic wave travels through the rock layer multiplied by the density of this layer.

Later, the equation was rewritten to address offset critical angle and accuracy or express parameter issues, proposing working with approximation and elastic parameters (1950-2000).

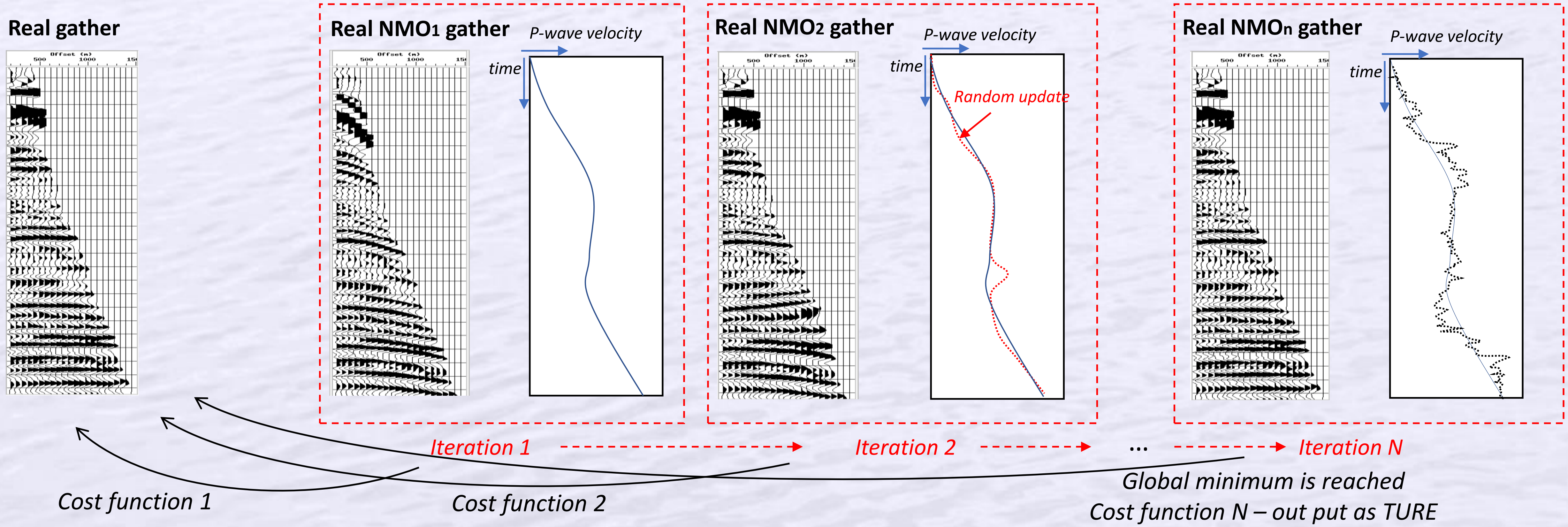
Offset seismic inversion is a generally non-unique process. Several answers can be found for the same equation of the same input data. To separate velocity and density, we need to have offset data and define regressions at the particular rock layer or layers for impedance versus, e.g., density. This regression provides a relation between the impedances of P-wave and S-wave and density - the main limitation of the conventional inversion process: linked parameters. If the P-wave increases, the predicted density will increase and vice versa; however, the environment does not live like this. Stochastic methods and diverse probability approaches help to clarify the uncertainties; however, still do not resolve for independent or non-liked properties.

Another limitation is offset stretching. The seismic inversion (and the Zoeppritz question and its approximations) assumes to have NMO-corrected data. The stretch that NMO causes is not unique, and its variations add additional variations to the solution.

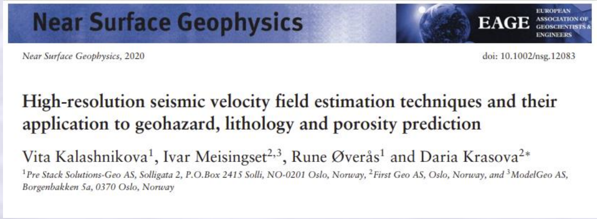
In convectional seismic inversion the result is impedances or elastic parameters where Vp, Vs and Density are limited by regressions.

- Hong Feng and John C. Bancroft. 2006. **AVO principles, processing and inversion** CREWES Research Report .V. 18
- Manzar Fawada, Jørgen André Hansena, Nazmul Haque Mondol. 2020. **Seismic-fluid detection-a review**. Earth-Science Reviews 210

The scheme of an alternative approach for rock properties estimation. Pre-stack case. P-wave search.



To understand how we alternatively can estimate rock properties from the seismic signal (without the concept of the generalized linear inversion (Smith and Gidlow, 1987), let's first look at the case of "the gather".
We want to estimate Vp, Vs, and Density of the full frequency band as independent parameters. We have a real, true amplitude migrated and processed seismic gather. Let's MNO correct it with a very smoothed or low frequent (e.g., 0-3 Hz) initial velocity model function. The result is shown in the iteration 1 picture. Now, we "compare" the gathers by searching a misfit object function #1 between the real gather and the generated at iteration 1. At iteration 2, we randomly update the velocity function by creating artificial kinematic constraints, and then we create a gather of iteration 2. Also, by comparing it to the real gather, we compute the misfit object function #2. We repeat the same steps in the following iterations. We aim to approximate the global optimum and minimize the cost function associated with seismic traces mismatch by using a probabilistic technique. For this, we can use global optimization algorithms. When the global minimum is approached, we output the P-wave velocity of the iteration #N as a true solution.
We have published in the Near Surface Geophysics the concept of finding high-res velocity in this way (Kalashnikova et al., 2020). We showed that it could be done kinematically or dynamically. However, this approach can lead to parameter overestimation. We need to add density to control the P-wave estimation.


Near Surface Geophysics — EAGE

Near Surface Geophysics, 2020 — doi: 10.1002/nsg.12083

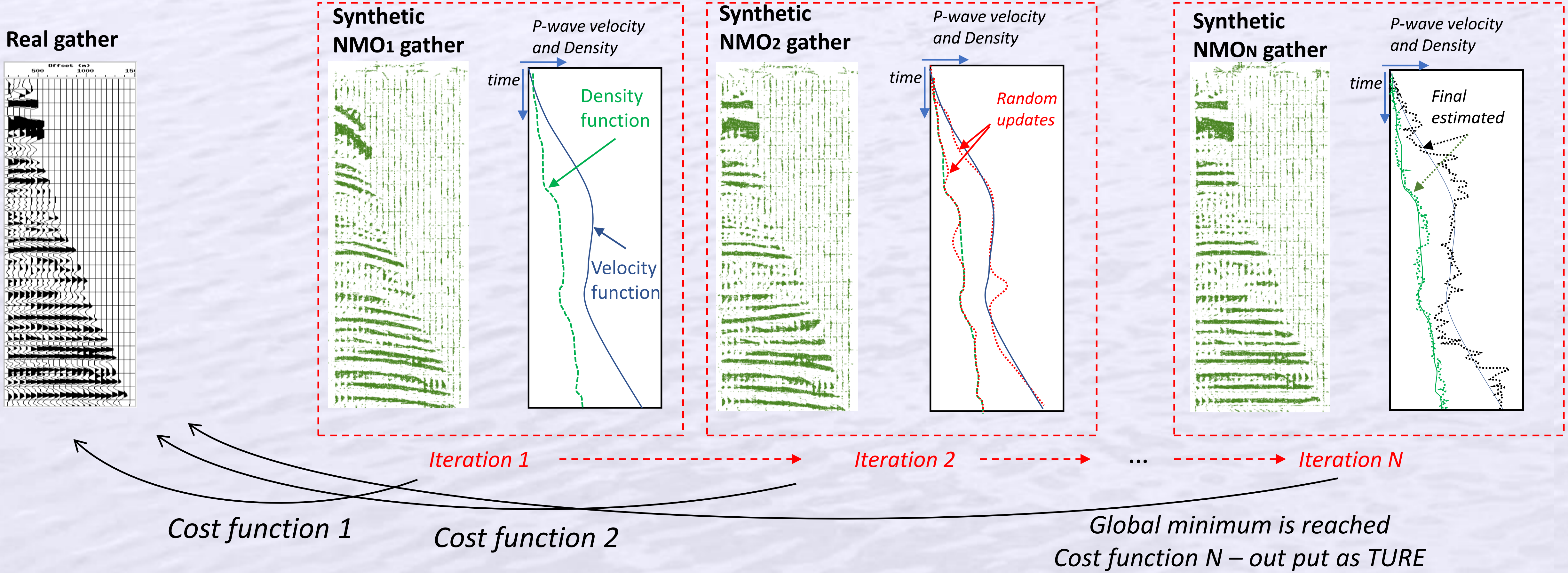
High-resolution seismic velocity field estimation techniques and their application to geohazard, lithology and porosity prediction

Vita Kalashnikova[1], Ivar Meisingset[2,3], Rune Øverås[1] and Daria Krasova[2]*

The scheme of an alternative approach for rock properties estimation. Pre-stack case. P-wave and density parameters search.

Rune Inversion
- Computation power
- AI algorithms

Random search for Vp, Vs, Density. Up to 2 000 000 iteration per gather.

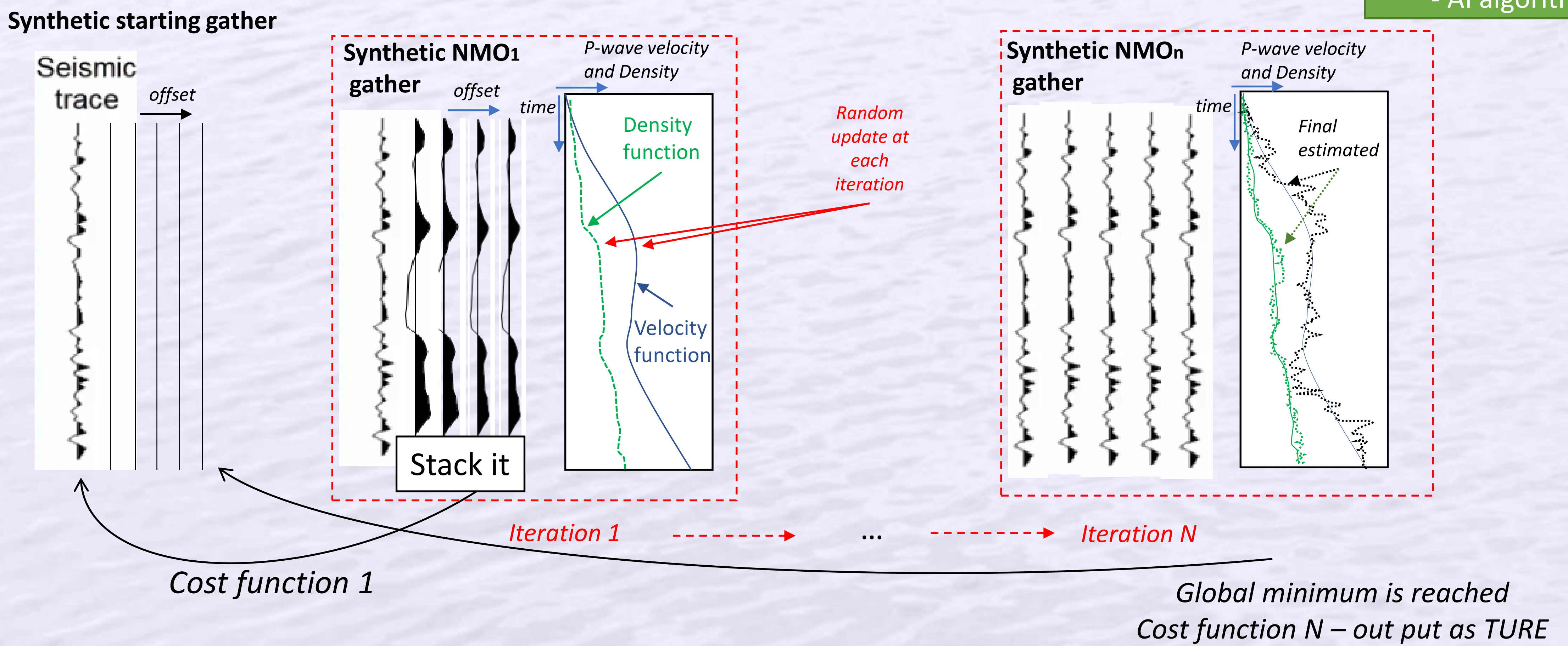


Now, we repeat the same steps as on the previous slide but add the initial low-frequent model of a density function for the first iteration.
Instead of using real gather, we generate the synthetic gather based on the initial velocity and density models (in green). For each next iteration, we create the updated synthetic gather, which is generated by using new velocity and density, which in turn were constructed by adding artificial kinematic constraints; a random update of the initial functions of velocity and density in random start and length windows.
Adding density function gives control over the real AVO rocks effect and avoids overestimation of the P-wave parameter in the process. The S-wave velocity can be added to the searching process and synthetic gather simulation to achieve better accuracy in estimating the parameters.

The scheme of an alternative approach for rock properties estimation. Post-stack case.

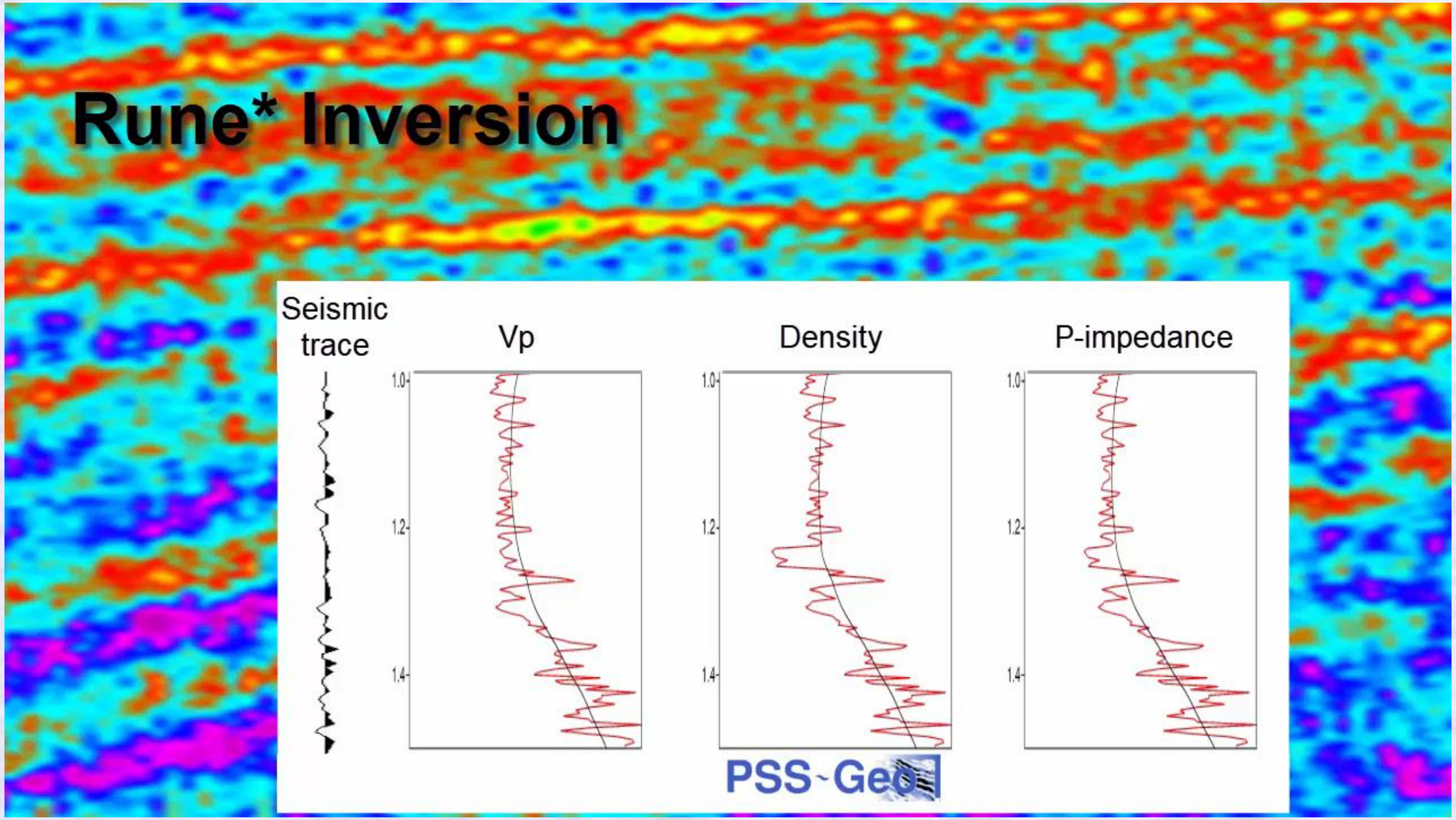
Rune Inversion
- Computation power
- AI algorithms

Random search for Vp, Density. Up to 500 000 iteration per trace.



For the post-stack case, we repeat the same scheme as for the pre-stack case. The difference is that we generate empty traces next to the stacked trace as a simulated offset. Then, we create the synthetic gathers and stack traces in them at each iteration. The misfit object function, in this case, is computed "when comparing" the real trace and the stacked traces in the synthetic gather. The accuracy of the stacked trace defines the technique limitation.

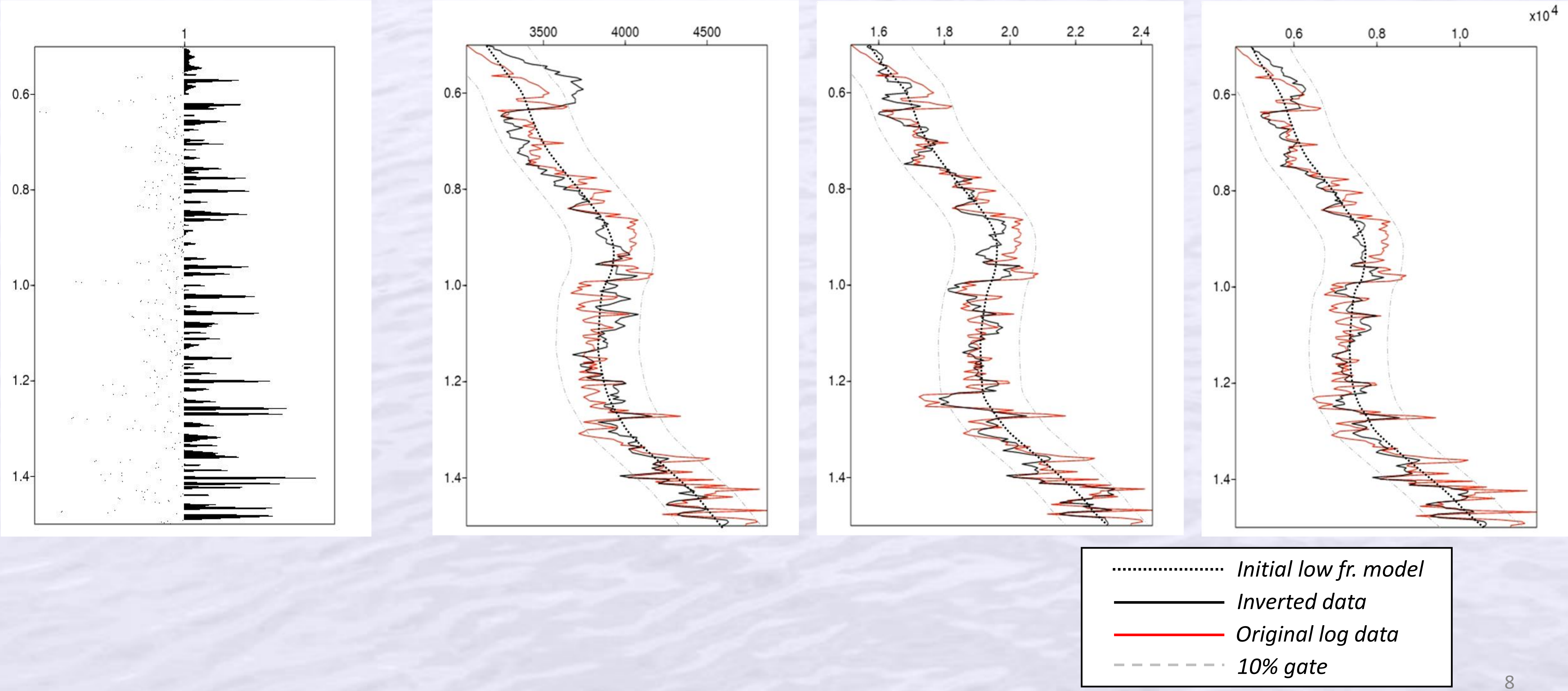
Post-stack implementation on fly computation



The post-stack realization of the Rune Inversion algorithm on the fly. In black - are initial models, and in red are real logs data. The seismic trace is shown on the left. About 50 k iterations.

Post-Stack Rune Inversion for one trance at the well location

Seismic trace | P-wave velocity | Density | P-impedance



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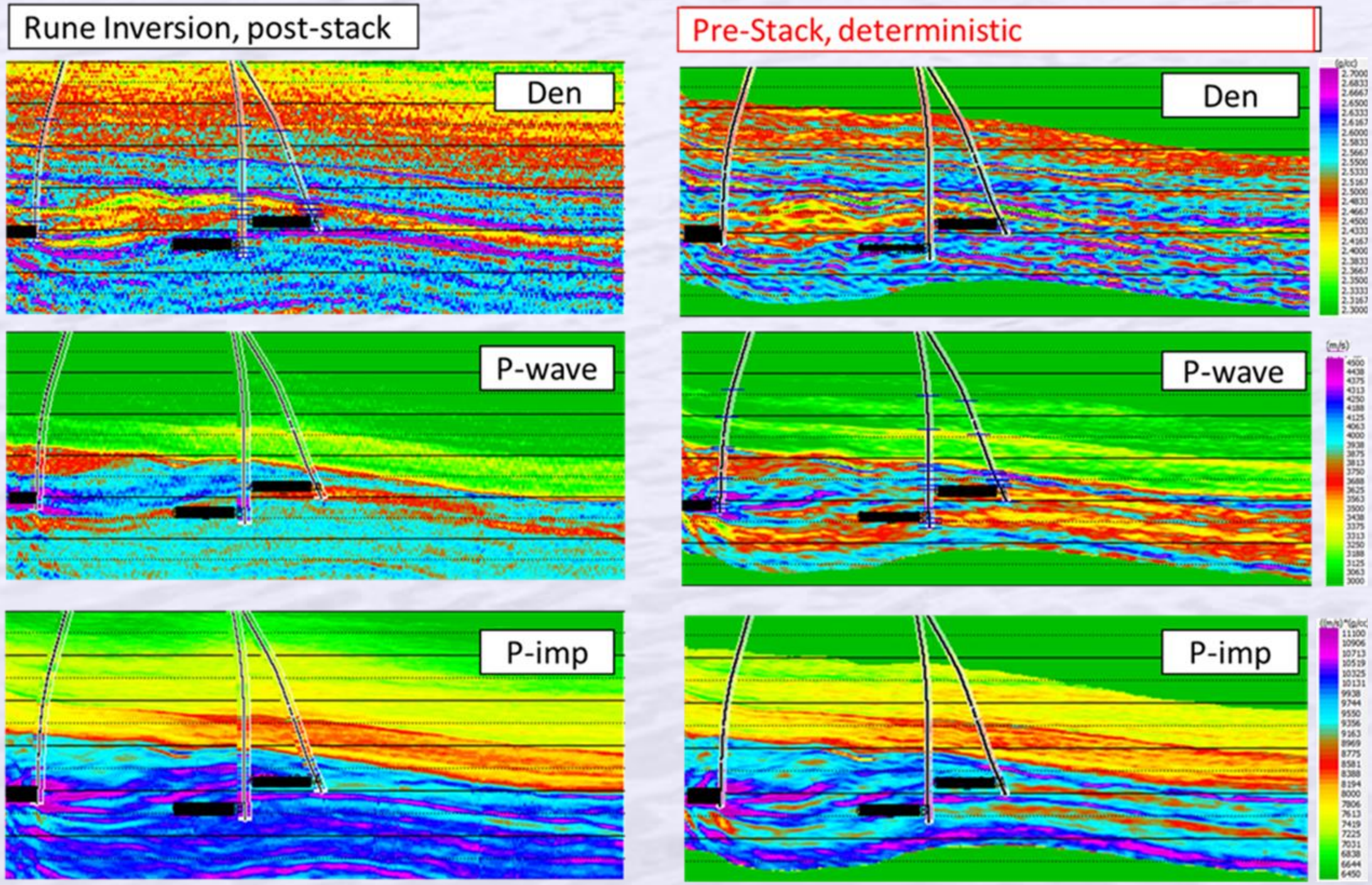
Comparison Post-Stack Rune inversion and Pre-Stack deterministic

Computing time 50 km2 - 2 hours



From Inverted volume

From EAGE Conference Presentation March 2021, Tumen’

Application of Rune Inversion to the mega merges of the Norwegian and North Sea

The technology has already been applied to more than **100 000 sq. km of publicly available data** and **about 1000 sq. km of modern data**.

About **72 hours** of computing and **500 cores required** to convert the mega seismic 3D volume (4200ms section) **into lithology.**

For the North Sea we found 78 450 sq. km of publicly available post-stack data (North Sea), where only **69 660 sq. km** were true amplitudes suitable for attributes and rock properties extraction. We denoise and deghosted it and adjusted the phase to zero by tying the wells and QC by cross-survey correlation. To the merged data, we tied 722 wells of verified check shots (cross-correlation wavelet is phase zero in the random window) and built the initial models for AI-driven inversion.

The examples can be viewed here:
https://www.pss-geo.com/elephant
https://www.pss-geo.com/runeinversion