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Oil & Gas Exploration and Development with the Reverse Time Holography Technology

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Abstract

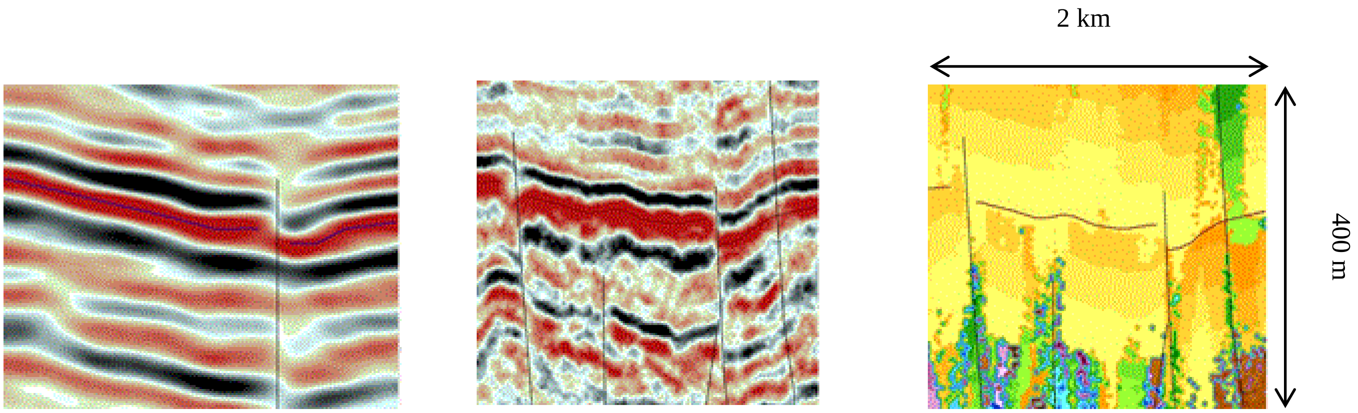
The article analyzes methods for constructing seismic attributes, which are based on two-stage data processing: on decomposition the initial common shot gathers in common image gathers, using the time-reversal algorithm and on synthesis a seismic attributes. It is shown that a detailed analysis of the joint behavior of two vectors: the velocity vectors in forward wave and the velocity vectors in time-reversed backward scattering wave provides detailed information about the medium. This is the essence of a new approach called RTH, which allows the acquisition of various seismic attributes at high spatial resolution. The new approach provides the solutions of prediction problems in oil and gas exploration, as well as problems in development using the drilling data and AI algorithms, at a new qualitative level.

Introduction

Technologies for processing seismic data based on methods of wave reversal in time are of significant interest, both in theoretical and practical seismic exploration. The study of angular scattering dependencies and analysis of the behavior of normal vectors to wave fronts is the subject of seismic solutions based on angular gathers and on a common image gathers (Yoon and Marfurd, 2006; Sava and Fomel, 2006; Zhang and McMechan, 2011, Yan, 2014). Such vector-based seismic data processing methods can be briefly called as vector-based seismic methods . Mathematically, time reversal is based on the solution of conjugate equstion and on the analysis of the vector characteristics of two wave fields: the reference wave field and the time-reversed wave field. The new Reverse Time Holography (RTH) method (Erokhin, 2022) also belongs to this type of method. The method is vector extensions of the well-known method of depth migration based on wave reversal in time RTM (Reverse Time Migration) (Baysal et.al., 1983; Whitmore, 1983, McMechan, 1983). The RTH method includes, as a special case, methods based on a common image point - Angle Domain RTM (Yoon and Marfurd, 2006; Alkhalifah, 2015), diffraction analysis methods ES360 (Koren and Ravve, 2011), CSP (Kremlev et .al., 2011), methods of angular anisotropy of reflection - Amplitude versus Offset (AVO) (Chopra and Castagna, 2014), acoustic inversion (Tarantola, 1984), velocity tomography based on full-wave inversion (Virieux and Operto, 2009) or based on beam tomography (Popovici et.al., 2016). RTH is a voxel-based method, that is, the assessment of seismic attributes is carried out in each cell (voxel) of geological space independently of each other. Voxels are of arbitrary size, and their coordinates are fixed in the space they fill. The set of seismic RTH attributes includes, in addition to all known attributes, a number of previously unknown ones. The total number of seismic attributes obtained based on the assessment of multidimensional (10-dimensional) statistical distribution in the RTH method reaches several hundred (Agafonov et al., 2022). In fact, the new RTH approach creates not only a new way of processing seismic data, but also its own interpretation graph, as well as recording systems, which together can be characterized as its own RTH technology.

Prediction of geological properties as the basis for exploration and production

The main difference between RTH attributes and traditional ones, which are calculated after the migration transformation, is their voxel nature and hyper-attributability. Figure 1 shows examples of depth sections of 3 cubes of seismic attributes. Figure 1a shows a cross-section of a traditional PSDM depth migration cube. The vertical line indicates the author's identification of the fault using this attribute. The horizontal curved thin line corresponds to the roof of the foundation. Figure 1b shows one of the "phase" attributes of the RTH, and Figure 1c is a cross-section of the RTH velocity cube. Here the thin wavy line corresponds to the velocity inversion - the boundary of high (top) and low values of the medium velocity (bottom). The inversion boundary coincides with the roof of the foundation. The joint interpretation of the RTH attributes of Fig 1b, 1c allows us to clearly detail the faults that are associated with fracturing and a sharp decrease in velocity (green-burgundy colors in Fig 1c). The size of spatial cells (voxels) in which the values of RTH attributes are estimated in Fig. 1b, 1c here are taken to be 12.5 meters by 12.5 meters laterally and 2.5 meters in depth. This example shows only two RTH attributes out of more than 300 obtained simultaneously during processing.



a b c

Fig 1—Comparison of PSDM depth section (a) and RTH Phase attributes (b) and RTH velocity attributes (c) for fractured foundation. Voxel size is 12.5x12.5x2.5 meters.

It turned out that such hyper-attributability and high spatial resolution of the method are the key advantages of RTH as a method of processing seismic data over traditional migration methods such as RTM in solving prediction problems using artificial intelligence methods. Based on the calculated voxel-based attributes and well data, information pairs are quite naturally formed in voxels encountered along the well trajectory: a set of RTH attributes - a set of well data that are used for machine learning (Fig. 2). This technologically advanced construction of a training sample allows spatially precise (within voxel size) prediction of various lithofacies, petrophysical and other properties, as well as any parameters of a hydrocarbon field, using artificial intelligence methods.

With this approach, two important tasks arise. The first important task is to build a statistically significant set of voxels with pairs of input data for training by a neural network: “RTH attributes” - “well data”. This is achieved by the number of wells involved in training and the voxel size. The more wells and the smaller the voxel size, the more effective the learning result. In addition to well data, in Lithotypes prediction tasks it is important to use a priori geological information and stratigraphy. The second important task is to select the optimal set of attributes that provides a stable and accurate prediction for each specific parameter. This is achieved by studying the correlation dependencies of RTH attributes, selecting the most significant attributes that provide the greatest accuracy. The selection tool can be the methods of principal components, independent components, etc.

The RTH prediction roadmap consists of three stages. The first stage of RTH involves seismic data processing and interpretation. As a result, RTH attribute cubes, stratigraphic boundaries, fracture zones, fault zones, angular scattering anisotropy, etc. are obtained. Figure 3 shows one example of the result at this stage. The Figure shows a map of fracturing in a productive gas horizon, built using the RTH Fracture attribute. At the second stage of prediction, a data set of pairs is prepared for training by a neural network: “RTH attributes” - “well data”. And at the third stage, the neural network itself is trained and the target geological attributes are predicted. Training is carried out based on either MLP (Multylayer Perceptron) or RF (Random Forest) algorithms.

Figure 4 shows the results of the prediction of 4 Lithotypes in the Lower Vendian. Here Horizon 2 is a productive gas horizon in which porosity indicators are predicted for the entire volume (Fig. 5)

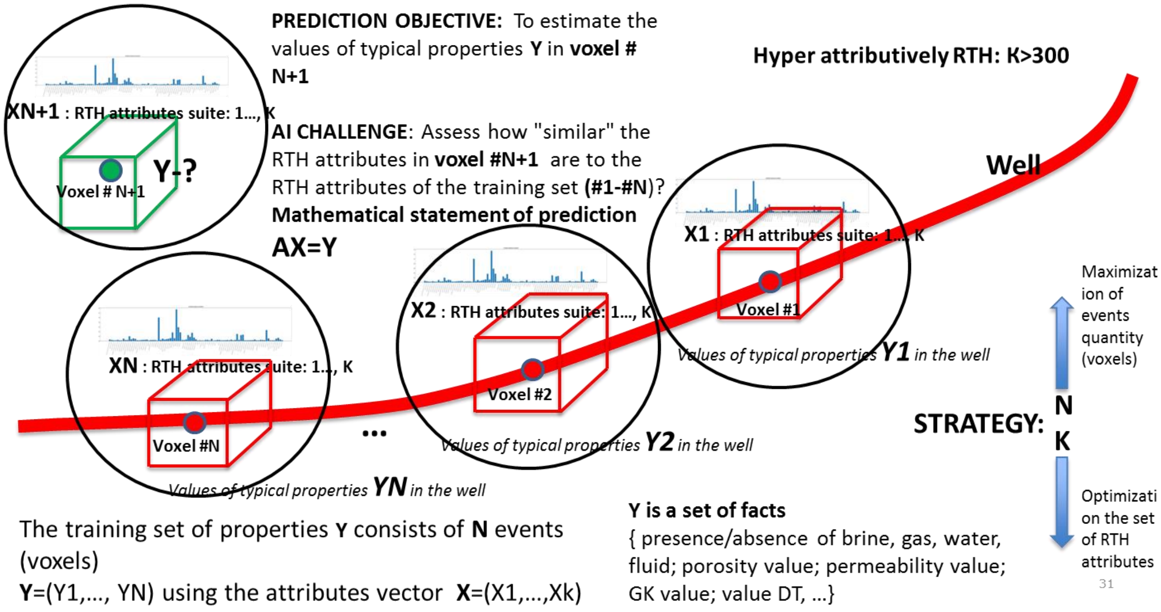


Fig 2—**Prediction technique based on RTH attributes and well-log data using AI approach**

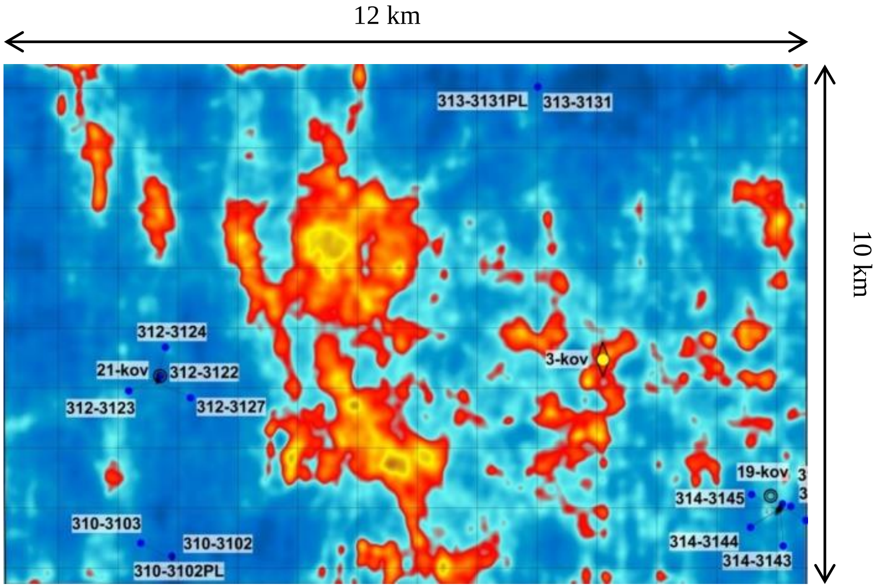


Fig 3— **Map of fracturing in the productive gas horizon, built only using the RTH Fracture attribute. Red color corresponds to zones of maximum fracturing.**

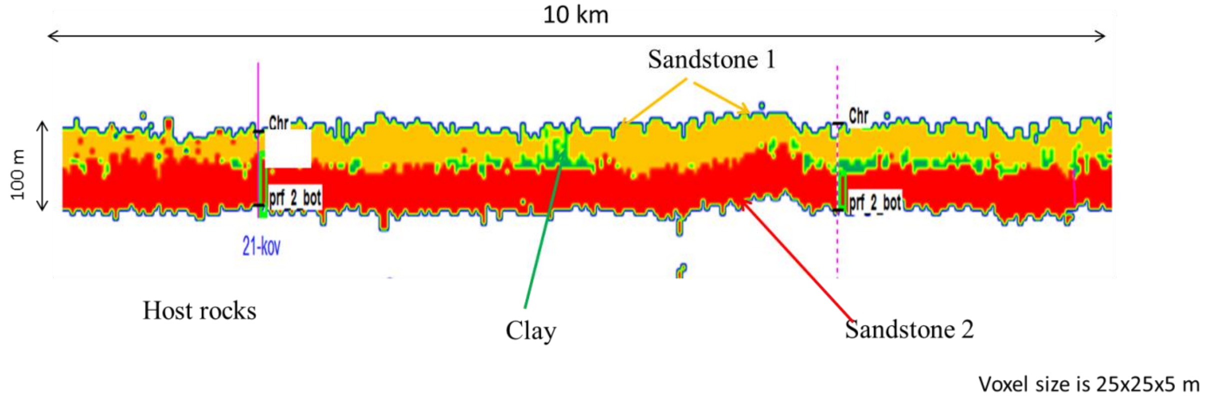


Fig 4—**Lithotypes Prediction of Lower Vendian based on RTH attributes and well-log data**

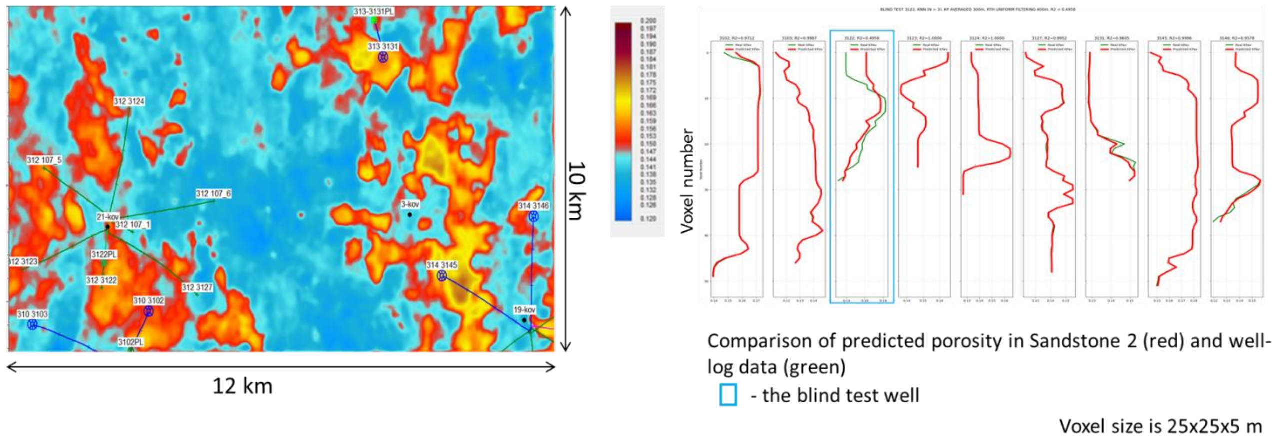


Fig 5—**Porosity prediction in Sandstone 2 based on RTH attributes and well-log data**

Conclusion

A new technology for processing and interpreting seismic data, called RTH, allows us to assess the geological structure of the Earth at a new qualitative level, helping to optimize exploration and development costs. RTH technology reduces the cost of carrying out some special studies, such as building a depth-velocity model, constructing structural horizons, identifying zones of open fracturing, anomalous zones of angular scattering, anomalous zones of the frequency domain and others. RTH technology, in fact, aggregates many methods into one, thereby sharply reducing the costs of using a dozen separate specialized programs. In addition, the inherent hyper-attributability and voxel-based orientation of the results dramatically increases the spatial resolution of seismic attributes and allows for prediction of rock properties based on the use of drilling data and neural network algorithms.

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