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Remote Sensing and Geological/Geophysical Data Integration for Oil and Gas Prospecting

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Abstract

Model for remote sensing and geological/geophysical data integration based on Bayesian probabilistic inference is described. The proposed model has been tested on example of the Khukhra oil and gas condensate field territory in Ukraine. The results of testing are accorded well with previous geological forecasts.

Key words: oil and gas prospectively, geospatial data integration, Bayesian probabilistic inference, Khukhra oil and gas condensate field.

Introduction

Oil and gas fields forecasting and exploration is a complex and knowledge-intensive problem. Effective solution to this problem requires all available data consideration using new geoinformation technologies for geospatial analysis.

Direct methods for oil and gas prospecting, such as drilling and seismic measurements, require considerable expenses. Therefore, the modern satellite technologies for the new hydrocarbon deposits detection and mapping can reduce cost and time of exploration.

The main goal of exploration is to improve the accuracy and reliability of oil and gas fields forecasting. Satellite-based geological research is conducted to assess tentatively the oil and gas potential of study area before exploratory boring. At the moment, significant amount of various necessary information (remote sensing imagery, geological maps, geophysical data, etc.) are involved to implement such assessment in shorter time and with the least financial costs. However, large amount of data from different information sources, on the one hand, complement each other, and, on the other – require adaptive and flexible scientific and methodological tool for integration and joint processing.

State of the art

A number of studies are addressed to data integration problem. The simplest approach to integration and joint processing of data from different information sources is a summation of data of the same physical nature [1]. In other cases the development of effective model for data fusion is a great challenge. Models for statistical-based and ontology-based data integration are considered in [2-4]. Such models are quite efficient; they are implemented in existing software.

Modern technology of remote sensing application in geological prospecting is based on the integration of remote sensing data with other geospatial data – cartographic, geological, geophysical, geochemical and other available ones [5, 6]. This approach dampens a subjectivity, inherent the visual interpretation of satellite imagery. Integration of remote sensing and other geoscience spatial data computerizes the study area evaluation and calculates its similarity to a reference sites (deposits) [7]. Classification of remote sensing and geological/geophysical data hypercube maps the probability of oil and gas occurrence inside study sites and ranks them by its prospectivity.

Method

In this paper the model of integration of remote sensing and geological/geophysical data based on Bayesian probabilistic inference is proposed.

The Bayesian probabilistic inference in oil and gas prospecting involves a priori and conditional probability estimates of data hypercube dots membership in positive or negative reference patterns to calculate the posterior probability of each dot membership in positive one.

The posterior probability of a positive reference pattern $P^{+}(x)$ for the current dot $x \in X$ of data hypercube X is estimated by the Bayesian rule:

$$P^{+}(x) = \frac{P^{+} \cdot P(x \mid X^{+})}{P^{+} \cdot P(x \mid X^{+}) + P^{-} \cdot P(x \mid X^{-})} \tag{1}$$

where P^{+}, P^{-} are a priori probabilities of positive and negative reference patterns, $P(x/x^{+})$, $P(x/x^{-})$ are conditional probabilities of x membership in positive X^{+} and negative X^{-} reference patterns of data hypercube [8].

The information divergence $D(x/y)$ between normalized values of hypercube vectors is used to estimate conditional probabilities $P(x/x^{+})$ и $P(x/x^{-})$ in oil and gas prospecting using remote sensing and geological/geophysical data [9]:

$$D(x/y) = \int_{u \in U} f[x(u)] \cdot \log_2 \frac{f[x(u)]}{f[y(u)]}\, du \tag{2}$$

where $f[\cdot]$ is a probability density distribution of values in hypercube vector, U is the range of possible values.

Probability density distributions of vectors values both of hypercube single dots $f(x)$ and positive $f(X^{+})$ or negative $f(X^{-})$ reference patterns can be estimated by matching histograms of data hypercube [10]. Information divergence (2) is uniquely associated with a counterpart conditional probability [11]:

$$P(x/x^{+}) \cong 1 - 2^{-n+ \cdot D(x/x+)} \tag{3}$$

where $n+$ is a statistical sampling size of corresponding reference pattern.

A posteriori probability (3) of positive reference pattern mapping over hypercube as a matter implements the remote sensing and geological/geophysical data integration in oil and gas prospecting.

Data

The proposed model for remote sensing and geological/geophysical data integration based on Bayesian probabilistic inference was tested over the Khukhra oil and gas condensate field territory, which is located in the Akhtyrka district within the Sumy region of Ukraine. The field is characterized as complex geological media. It consists of layers of Paleozoic, Mesozoic and Cenozoic sedimentary rocks that overlie the crystalline rocks of Precambrian basement. There are multiple stratigraphic discordances inside the sedimentary cover.

In tectonic terms, the south-western part of the field lies within the northern cutoff edge of the Dnieper graben while the north-eastern part lies within the northern edge of Dnieper-Donetsk depression. They are separated by marginal disruption zone. The basement topography of northern edge and northern cutoff edge are significantly different [12, 13]. Productivity of Mesozoic and Devonian petroleum systems is proved for this territory. Deposits are layered, tectonically and lithologically screened. They form a multilayer field with different combination of gas-bearing and oil-bearing stratums at depths over 5000 m [14].

Available heterogeneous geospatial data have been incorporated into the integrated geological model of Khukhra oil and gas field (Fig.1): bore-wells (both productive and non-productive) positions; map of provincial and regional faults; lineament zones and lineaments; maps of lineaments density in different directions; map of the residual gravity; field outline according seismography; thermal anomalies within the territory; neotectonic (depression and ridge) blocks; geochemical anomalies; optical anomalies; routes of soils and vegetation ground spectrometry; structural horizon B_{21} isohypses; maps of sedimentary strata; digital terrain elevation data; surfaces of terrain vertical and horizontal dissection.

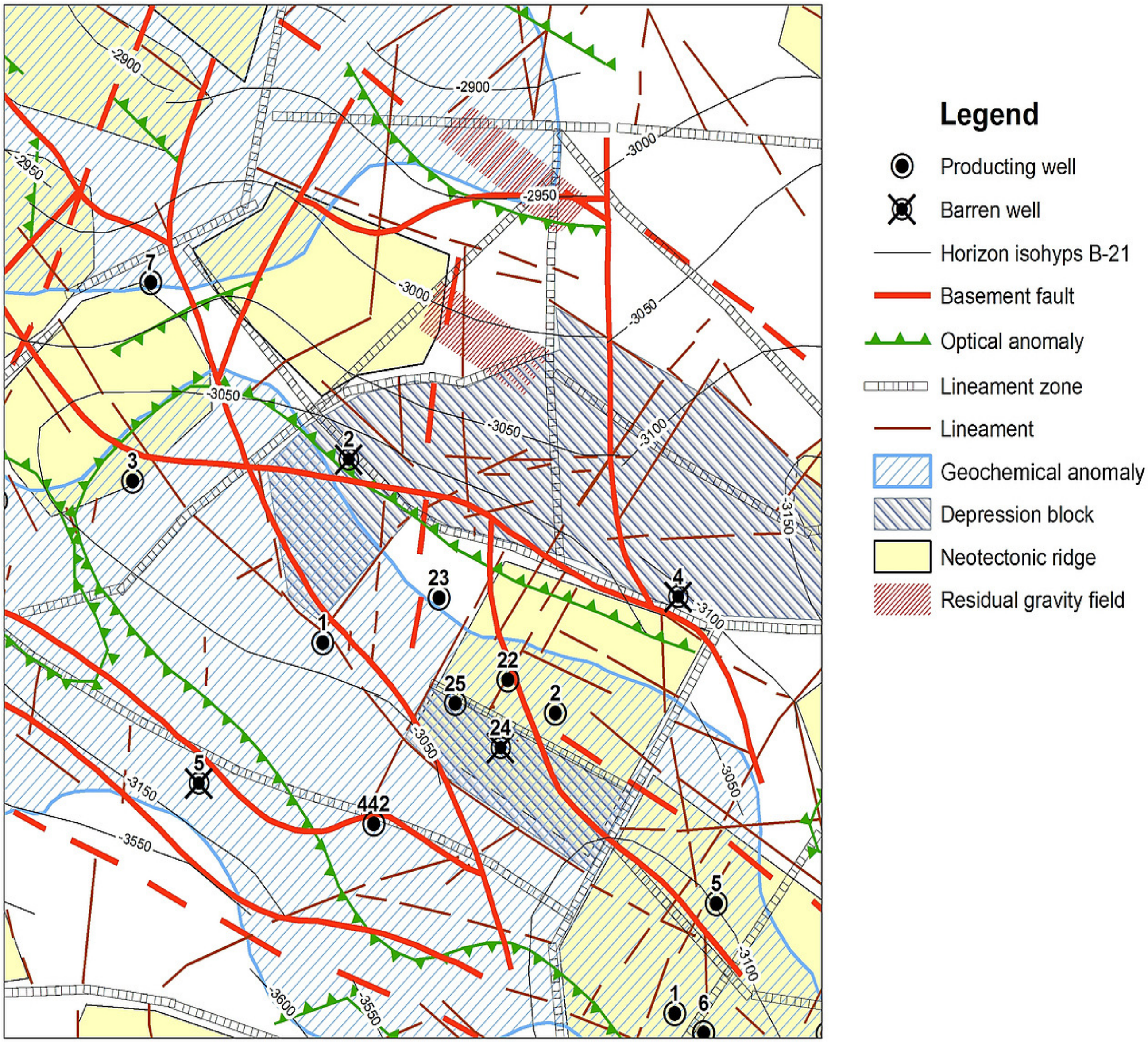

Fig.1. Geospatial database for the Khukhra oil and gas condensate field territory (Ukraine)

All geospatial data were georeferenced, rasterized and converted to 30 m spatial resolution for the further stacking into hypercube.

Result and discussion

As a result of performed remote sensing and geological/geophysical data integration the spatial distribution of a posteriori probability is obtained (Fig.2*a*), which can be interpreted as an integral rating of oil and gas prospectivity inside the study area.

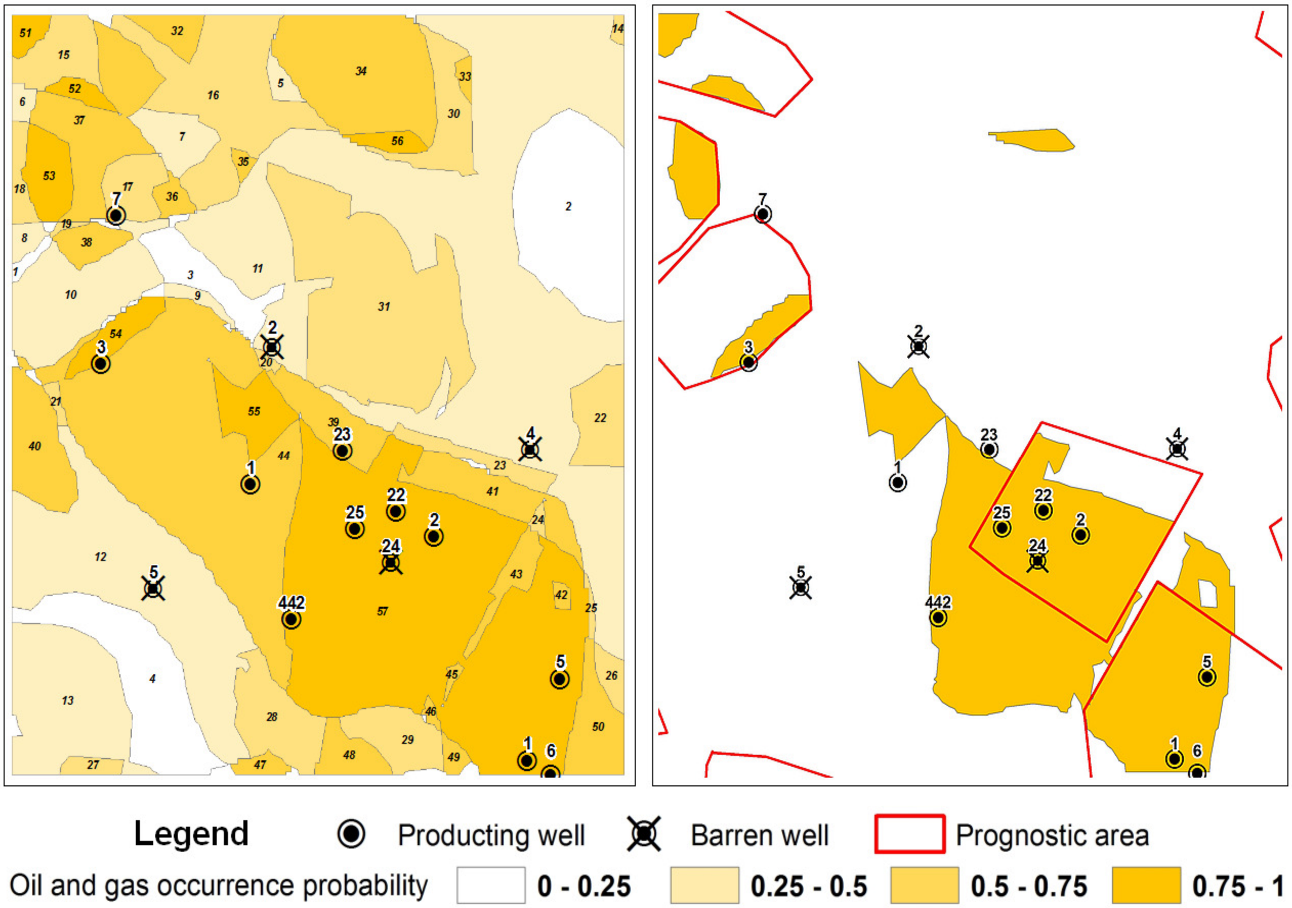

Fig.2. Probability distribution of oil and gas occurrence by result of geospatial data integration

There are several medium and small sites (plots 51, 52, 53, 56) with a high probability of oil and gas occurrence were detected in the northern area of Khukhra field. In addition, plots 32, 33, 34, 35, 36 can be recommended for further detailed exploration. This result correlates well with the previous geological forecasts and available structural and geomorphological data interpretations (Fig.2*b*); also it provides a subsequent area reduction of sites, which are recommended for drilling.

The occurrence or lack of hydrocarbon deposit in the forecast point was determined by the results of exploration drilling. Because reliable quantitative specifications of hydrocarbon reservoirs are not available yet, the rank correlation between the distribution of a posteriori probability and the location of productive/non-productive bore-wells was estimated. The Spearman's rank correlation coefficient, according to 13 exploration bore-wells data is equal to 0.786. This fact demonstrates a reasonable efficiency of carried out data integration [15].

Conclusion

Thus, the remote sensing and geological/geophysical data integration is an efficient and descriptive tool for overall assessment of oil and gas prospectivity within the territory of interest.

Approach to data integration based on Bayesian probabilistic inference provides mapping of spatial distribution of similarity to known similarity to a reference oil and gas bearing sites. Such maps are very important for decision-making information support on detailed exploration strategy.

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დისტანციური და გეოლოგიურ–გეოფიზიკური მონაცემების ინტეგრირება ტერიტორიების ნავთობგაზპერსპექტიულობის შეფასებისას

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რეზიუმე

აღწერილია დისტანციური და გეოლოგიურ–გეოფიზიკური მონაცემების ინტეგრაცია ბეიესის ალბათური დასკვნის საფუძველზე. შემოთავაზებული მოდელი აპრობირებულია უკრაინის ტერიტორიაზე არსებული ნავთობგაზკონდენსატის საბადოს მაგალითზე. აპრობაციის შედეგები კარგ თანხვედრაშია ადრეარსებულ გეოლოგიურ პროგნოზებთან.

Интегрирование дистанционных и геолого-геофизических данных при оценивании нефтегазоперспективности территорий

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Резюме

Описана модель интеграции дистанционных и геолого-геофизических данных на основе байесовского вероятностного вывода. Предложенная модель апробирована на примере нефтегазоконденсатного месторождения на территории Украины. Результаты апробации хорошо согласуются с предшествующими геологическими прогнозами.