PLAY-BASED HYDROCARBON EXPLORATION UNDER SPATIAL UNCERTAINTY USING EVIDENTIAL THEORY

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Commission IV, WG IV/3

KEY WORDS: Evidential theory, GIS, Uncertainty, Risk, Play based Exploration (PBE)

ABSTRACT:

Hydrocarbon exploration is a process based on the prediction of existing hydrocarbon in the underground formations which is associated with uncertainties. A number of studies have been undertaken on the extent of these uncertainties in the risk maps concerned with hydrocarbon exploration. This paper has addressed this issue using a novel approach.
The differences of the proposed method are checked in a few cases. Firstly, the level of studying the hydrocarbon system is play which refers to an area with a potential for trapping hydrocarbon with a unique petroleum system. Second, the evidential theory was used to accurately examine the uncertainty in the maps of the hydrocarbon system. Finally, the model used to produce the final risk map is developed in a geospatial information system environment.
The results of the research show that the functions proposed in the model are accurately estimated the uncertainty in the prediction of the existence of hydrocarbon systems in the study area. The CCRS map outlines approximately 25.9% of the study area which is highly promising for the hydrocarbon potential reservation. According to the obtained results, around 61.2% of the prospects have low risk of hydrocarbon potential in the area having high belief and about 43.7% of the prospects are available with high risk of hydrocarbon potential in the regions with high uncertainty.

1. INTRODUCTION

Uncertainty in geospatial information clearly has the potential to expose users to undesirable consequences as a result of making incorrect decisions. Therefore, any attempt to cope with uncertainty should be able to express the uncertainty associated with an information product in meaningful terms and measures (Devillers et al. 2006). A conceptual model of uncertainty in spatial data which was proposed by (Fisher, 1999) is illustrated in Figure 1.

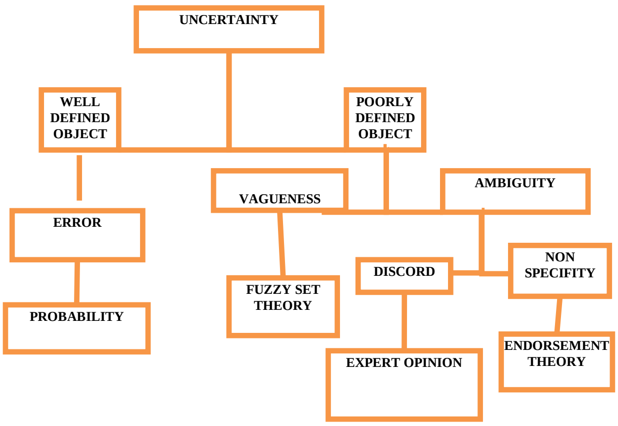

Figure1. The conceptual model of uncertainty in spatial data

Uncertainty may also arise because of ambiguity (the confusion over the definition of sets within the universe) owing, typically, to differing classification systems (Devillers et al. 2006). The concepts and consequences of ambiguity in geospatial information negatively affect hydrocarbon exploration in a play which refers to an area with a potential for trapping hydrocarbon with a unique petroleum system related to specific geological era. Ambiguity occurs when there is doubt as to how a feature should be classified on a map because of different perceptions of that feature. This is a problem which is very common for geospatial information system (GIS)-assisted play based exploration that is analyzed in more detail here.

Handling geoscience data for exploring mineral deposits in GIS environments was clarified in several researches such as (Bonham-Carter, 1994) and (Tangestani, 2009). Play Based Exploration is simply a method to build and leverage an understanding of the basins and petroleum systems in which we work, and the geological plays they contain. The Play based Exploration (PBE) methodology is encapsulated in the "Exploration Pyramid", where the initial focus is on the basics - the determination and description of the regional context and the basin framework leading to an understanding of the working petroleum system. Petroleum system understanding forms the basis for the subsequent play focus - quantifying the various aspects of the system within each play, and using tools such as common risk segment mapping to highlight sweet spots within each play.

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There are a variety of researches about assessing hydrocarbon systems in a play. For example, (Grant et al. ,1996) explained a methodology for play fairway analysis and calculated the risk for play and prospect. (Snedden et al, 2003) described exploration play analysis from a sequence stratigraphic perspective. Recently more researches were undetakened such as (Zhongzhen et al ,2017) which based on hydrocarbon accumulation factors analysis, including source rock, reservoir, trap, migration, seal and preservation have evaluated and ranked plays by using double factors method of resources-geological risks. (Quirk et al. ,2017) investigated a combined deterministic – probabilistic method of estimating undiscovered hydrocarbon resources or YTF[1] for a conventional play. This research proposes a GIS-based framework using Dempster-Shafer theory (Shafer, 1976) to manage spatial uncertainties in the hydrocarbon exploration play CCRS map.

As shown in (Figure 2) the fundamental elements or building blocks of the PBE methodology are represented by the PBE Pyramid. It is organized into levels of Basin, Play and Prospect focus with appropriate key inputs and activities identified.

In Basin focus, the essential ingredients for the petroleum system are verified by examining the basin as a whole. Elements such as the plate setting, tectonostratigraphic framework and basin history are applied to determine the fill, stratigraphic sequences and potential for generating and trapping hydrocarbons (Royal Dutch Shell, 2014).

By play focus, an understanding of the petroleum system in the basin leads to the identification, mapping and quantification of plays within the basin. Existing knowledge is summarized in play element, summary play maps, and CRS[2] maps, leading to the identification of sweet spots. (Royal Dutch Shell, 2014).

And finally in prospect focus, most of the play execution activities are concerned with defining prospects, seismic evaluation and other maturation activities, and eventually drilling selected prospects from a portfolio. A geological model is built and then volumetric technical risk and confidence are assessed for a range of models and prospects (Royal Dutch Shell, 2014).

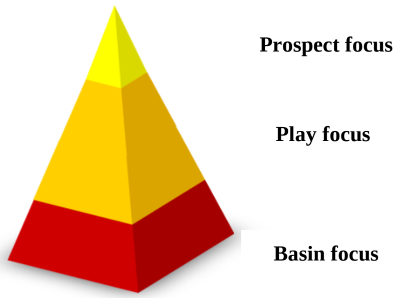


Figure 2. PBE Pyramid (Royal Dutch Shell, 2014)

In this workflow for finding hydrocarbon (Figure 2), concentrations must be more around play focus. The reasons of this assertion were discussed in a number of researches such as (Rose, 2000).

Spatial data is one of the most important components of PBE. In this work, spatial data fusion refers to the synthesis of spatial data from multiple sources related to each parameter of hydrocarbon system of play to extract meaningful information with respect to mapping hydrocarbon resources. There are four main methods to hydrocarbon resource potential mapping including probabilistic, regression-based, artificial intelligence-based (AI-based) and Dempster-Shafer-belief-theory-based methods.

This research proposes a GIS-based type of the Dempster–Shafer belief structure and discusses how it provides a formal mathematical framework for representing various types of uncertain information in play-based exploration. We provide some fundamental ideas and mechanisms related to these structures.

2. METHODS AND MATERIALS

The theory of belief functions also referred to as evidential theory or Dempster–Shafer Theory (DST) (Dempster, 1967; Shafer, 1976) is a mathematical theory of evidence which is used to combine separate pieces of information (evidences) to calculate the probability of an event. It is an approach based on Bayes rule for combining data to predict occurrence of events (Armas¸ 2012). The method uses the concept of prior (unconditional) probability and posterior (conditional) probability. A detailed description of the method is available in (Bonham-Carter, 1994). The EBF[3] model contains Bel (degree of belief), Dis (degree of disbelief), Unc (degree of uncertainty) and Pls (degree of plausibility) in the range of [0, 1] (Althuwaynee et al., 2014). These functions have relationships which are represented in Figure 3.

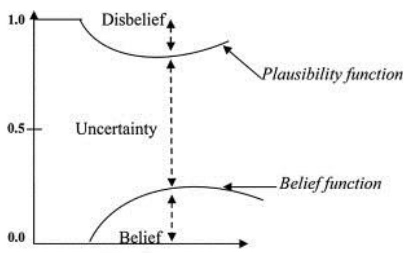


Figure 3. Evidential theory function’s relationships (Fisher, 1999)

Suppose X is a finite set and P(X) is a power set of X (the collection of all the subsets of X). A function m is defined as

$$m: P(x) \rightarrow [0,1] \qquad (1)$$

which satisfies two conditions:

$$m(\emptyset) = 0 \qquad (2)$$

and

$$\sum_{A \subset X} m(A) = 1 \qquad (3)$$

Equations 2 and 3 are functions of basic probability assignments. The value m(A) is a basic probability assignment for predicate A. It represents a level of support for A containing one element in X.

[1] Yet-to-find
[2] Common risk segment
[3] Evidential belief function

For any A ϵP(X), A is said to be a focal element if m(A) ≠ 0. Let F be a collection of all focal elements. A pair (F,m) is called the body of evidence.
Every basic probability assignment m has a belief measure and a plausibility measure given as (Shafer, 1976):

$$Bel(A) = \sum_{B \subset A} m(B) \qquad (4)$$

and

$$Pl(A) = \sum_{B \cap A \neq 0} m(B) \qquad (5)$$

respectively. The belief measure represents the belief that elements belong to A as well as subsets of A. The plausibility measure represents the belief that elements belong to any set overlap A, including A and its subset. These two measures are interrelated; for all A ϵP(X), (Shafer, 1976):

$$Pl(A) = 1 - Bel(\bar{A}) \qquad (6)$$

where $\bar{A}$ is a complement of set A.

In Dempster-Shafer theory, Dempster's combination rule plays an important role in the process of information fusion. Specifically, the combination (called the joint mass) is calculated from the two sets of masses m_1 and m_2 as shown in Equations 7,8 and 9 (Shafer, 1976) :

$$m_{1,2}(\emptyset) = 0 \qquad (7)$$

$$m_{1,2}(A) = (m_1 + m_2)(A) = \frac{1}{1-k} \sum_{B \cap C = A \neq \emptyset} m_1(B)\, m_2(C) \qquad (8)$$

where

$$K = \sum_{B \cap C \neq \emptyset} m_1(B)\, m_2(C) \qquad (9)$$

K is a measure of the amount of conflict between the two mass sets. With these functions, each CRS map is accompanied with four maps and the final CCRS map would be produced by applying Dempster-Shafer combination rule.

The anticlines in Fars region, which are located in Zagros fold-thrust belt, south of Iran, are valuable because they possess several hydrocarbons and this area is easily recognized by the NW–SE trending parallel anticlines that verge to the SW (Maleki and Jahadgar, 2015).

According to the geological classification, the study area includes Interior Fars, Sub Coastal Fars, Coastal Fars and Bandar-Abbas area. Four hydrocarbon systems include Permian, Jurassic, Tertiary and Cretaceous could be found in Fars region.

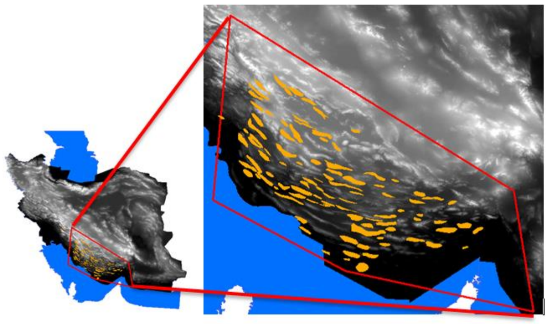


Figure 4. Location map of the study area

Over the years, the hydrocarbon system in Fars embayment has been studied in several researches. (Leturmy and Robin, 2010) surveyed tectonic and stratigraphic of Zagros and Makran during Mesozoic-Cenozoic as a program for Middle East Basins Evolution. (Piryaei et al., 2011) studied sedimentary evolution of Fars region by investigation of marked changes in fades and thickness of upper cretaceous succession in Bandar Abbas area. Bordenave (2014) described hydrocarbon systems and distribution of the oil and gas fields in the Iranian part of the Tethyan region. Some other useful researches of hydrocarbon system in Fars Region are (Motamedi et al. 2012) and (Ringenbach et al., 2011)

Most of the known reservoirs in the area are carbonated and Asmari and Khami group formations outcrop in the area. Dehram formation group that belongs to Permian forms most of the exploration target in Fars area and Khami, Bangestan and Asmari which are in the subsequent ranks.

The most important play in the study area is related to Permian era. As illustrated in Figure 5 the source rock in Permian play for this area is related to *Faraghan* formation. *Dalan* has the potential of reservoir formation and *Dashtak* and *Kangan* are cap rocks.

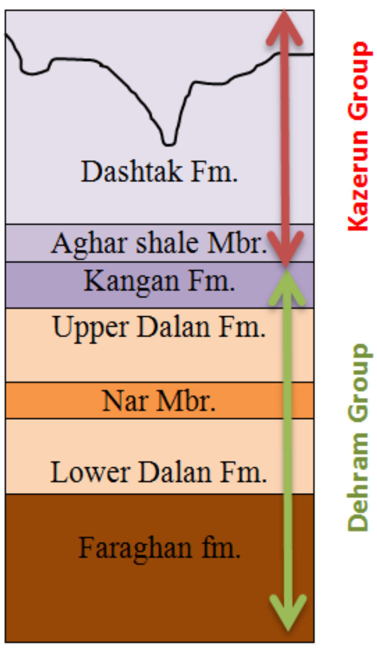


Figure 5. Chronological chart of Fars domain (Bordenave, 2014)

A CRS map is essentially result of an integration function that relates a set of geological features as input variables to the presence of the targeted hydrocarbon reservoirs as output variable.

Fars area located in the Zagros fold belt of Iran (Figure 4) is the main target for hydrocarbon exploration related to Permian geological era. It contains approximately 15 % of the world’s proven gas reserves (Motamedi et al., 2012).

As (Porwal and Carranza, 2015) mentioned the input geological features are termed predictor or evidential maps. The integration functions that are used in PBE include logical operators. The model which is applied for producing CRS s and final CCRS is presented in Figure 6.

For representation of integrated spatial evidence of “source rock quantity, the EBFs of “TOC[4]” and “potential yield for hydrocarbon generation” were logically combined. The OR operation is used because either set of geochemical indicators could represent source rock quantity.

On the other hand, The EBFs of “source rock quantity” and “thermal maturity” were combined by OR operation to represent integrated spatial evidence of “source rock/geochemistry.” The OR operation is used because at each point, it is likely that the effect of one of the two evidences will dominate.

Also, the EBFs of “proximity to anticline axes” and “geological formations” were combined to represent integrated spatial evidence of “surficial geology.” In Fars domain *Dehram* and *Khami* are two most important groups which represents reservoir, so EBFs of these groups were calculated. The OR operation is used because at each location, it is probable that the effect of one of the two evidences will dominate.

Then, the integrated EBFs of “surficial geology” and EBFs of “presence or proximity to high gravity areas/geophysics” are combined via the OR operation to represent integrated spatial evidence of “reservoir/trap.” The OR operation is used because either criterion could represent reservoir/trap.

Then, the integrated EBFs of “source rock/geochemistry” and EBFs of “reservoir/trap” are combined finally via the AND operation to represent integrated spatial evidence of “hydrocarbon potential.” The AND operation is used because the two pieces of the evidences are needed to support the proposition.

According to this model for each parameter of hydrocarbon system, this research produces four CRS maps including belief, plausibility, disbelief and uncertainty. At last final CCRS map will be produced by overlaying CRS maps in a GIS environment. The values of EBF function for each of the petroleum system parameters were calculated simultaneously as shown in Table 1.

Dataset	Range	Bel	Dis	Pl	Unc
S1S2 (mgHC/g rock)	0-3	0.31	0.33	0.67	0.36
	3-6	0.30	0.34	0.66	0.36
	6-12	0.40	0.32	0.68	0.28
	12-24	0	0	1	1
	>24	0	0	1	1
TOC (wt. %)	0-0.5	0	0	1	1
	0.5-1	0.16	0.36	0.64	0.48
	1-2	0.35	0.33	0.67	0.32
	2-4	0.48	0.30	0.70	0.22
	>4	0	0	1	1
Tmax (°C)	<435	0.25	0.25	0.75	0.50
	435-445	0.27	0.24	0.76	0.49
	445-450	0.05	0.28	0.72	0.67
	450-470	0.42	0.22	0.78	0.36
	<435	0.25	0.25	0.75	0.50
Outcrop	U-Khami	0.53	0.25	0.75	0.22
	L-Khami	0.30	0.31	0.69	0.39
	Dehram	0.16	0.43	0.57	0.41
Proximity to Structure Centreline (meter)	0-700	0.68	0.02	0.98	0.30
	700-1500	0.22	0.03	0.97	0.75
	1500-2600	0.07	0.08	0.92	0.85
	2600-3950	0.01	0.15	0.85	0.84
	3950-5500	0.01	0.22	0.78	0.77
	5500-7500	0.02	0.24	0.76	0.74
	>7500	0.01	0.25	0.75	0.74
Porosity (wt. %)	2-10	0.33	0.20	0.80	0.47
	5-30	0.24	0.38	0.52	0.58
Permeability (millidarcy)	10^{+4}	0.29	0.26	0.74	0.45
	10^{+3}	0.19	0.38	0.62	0.53
	10^{+2}	0.08	0.41	0.59	0.51
Thickness of Trap (meter)	65-170	0.16	0.35	0.65	0.49
	170-280	0.11	0.47	0.53	0.42
	280-390	0.53	0.24	0.76	0.23
Proximity to High Bouguer Gravity Anomaly	0-1000	0.63	0.20	0.80	0.17
	1000-2000	0.44	0.37	0.63	0.19
	2000-3000	0.46	0.24	0.76	0.30
	3000-4000	0.13	0.44	0.56	0.43
	>4000	0.07	0.26	0.74	0.67

Table1.EBF’s functions quantities assigned for petroleum system parameters

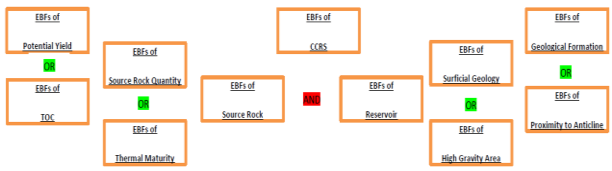


Figure 6. The proposed model for producing CCRS map with uncertainty measures in GIS environment

3. CONCLUSION

PBE is a kind of MADA[5] (Malczewski, 2007) where uncertainty can be seen in all its phases. This study verified that the use of GIS as a basis for modeling uncertainty in petroleum system of play is a useful approach. GIS provides an environment to produce CRS maps with better precision. The modified EBFs as a tool for modeling reasoning behavior under uncertainty stemming from ignorance were applied in order to integrate all related spatial data for PBE in a GIS environment. The most important benefit of evidential theory is that not only it models belief about evidences related to hydrocarbon existence but also it models complementary information as disbelief, cautionary information as plausibility and related uncertainties. This work described a knowledge-guided data-driven conceptual model. It considers uncertainty of PBE and determines the geologic risk. The importance of this becomes clear when it turns out to know that the cost of drilling an off-shore well is about 10 Million US dollar. So any mistake in

[4] Total organic carbon

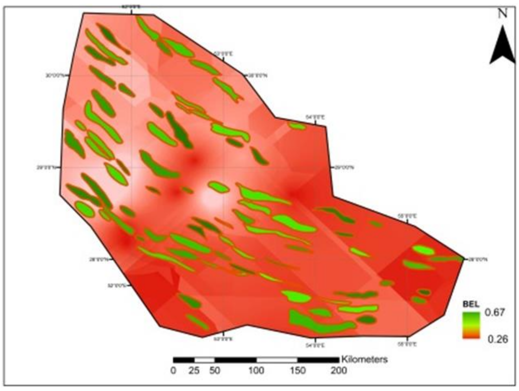
[5] Multi attribute decision analysis

https://doi.org/10.5194/isprs-annals-IV-4-193-2018

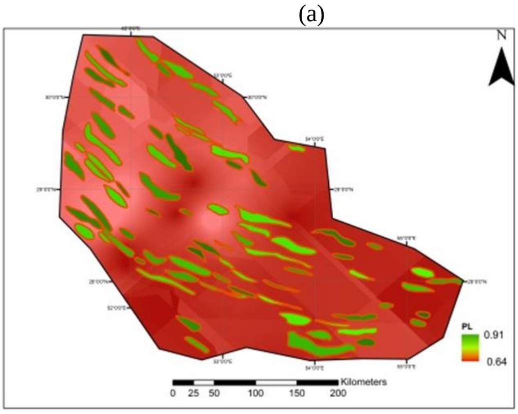
estimation of drilling place will lead to wasting a huge capital and time and this study could help to reduce these risks.

The amount of belief, plausibility, disbelief and uncertainty of the hydrocarbon system in Permian play of Fars Domain were calculated as shown in Figure 7. Experts who work in a PBE can use these maps to find out the range of uncertainty for existence of hydrocarbon at each point of the play. A CCRS map (Figure 8) was produced with fusion of all the factor maps according to the obtained evidential belief functions in Fars sedimentary region. The reference map was produced from the subjective knowledge based process to compare the results from our conceptual PBE model with real world. It is shown that applying a novel conceptual model which is based on evidential theory could be used to fuse the multisource data during a PBE in a GIS environment. It proposes areas in a play with different hydrocarbon system and its uncertainty.

In Fars Domain according to Permian play for Dehram Reservoir 88 prospects were applied. The produced favorability map delineates about 45.2 % of the study area as high favorable for hydrocarbon potential reservation and predicts more than79.6 % for training and 73.4% for testing data respectively as illustrated in Figure 9.



(a)



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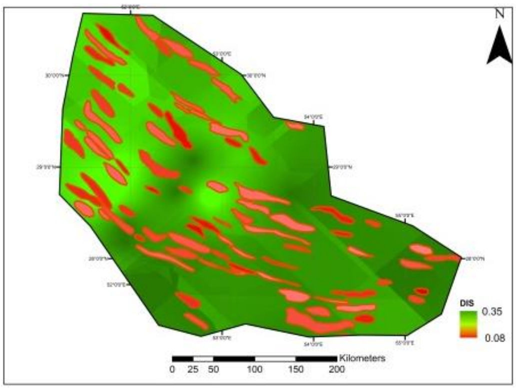
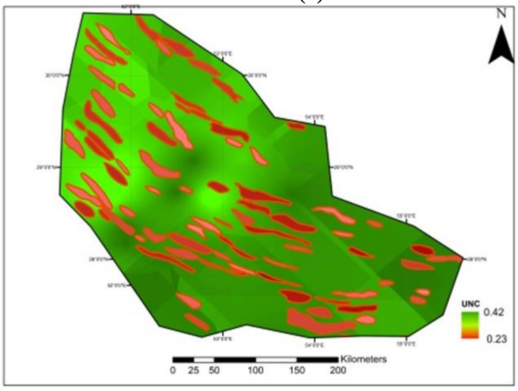


(c)



(d)

Figure 7. Integrated maps of evidence theory functions for PBE: (a) Belief map, (b) Plausibility map, (c) Disbelief map, and (d) Uncertainty map

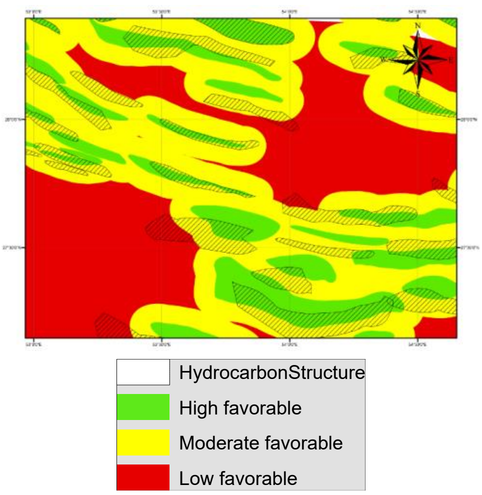


Figure 8.Final CCRS map

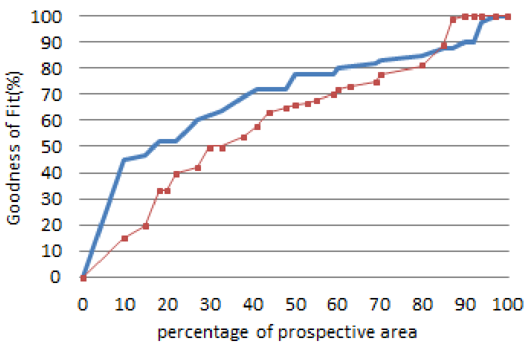


Figure 9. Petroleum potential success and prediction rates

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