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Investment Risk Assessment of Potential Hydrocarbon Discoveries in a Mature Basin

Case Study from the Bjelovar Sub-Basin, Croatia

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Abstract

The first part of the paper considers the basic principles of geological risk calculation (POS) based on regional geological analysis. It includes estimation of expected value for outlined potential hydrocarbon discoveries, and eventually calculation of so called 'risk money' for available company budget. The described methodology of geological probability calculation is often applied and adapted for characteristic geological settings in different petroleum provinces around the world. It was tailored and validated for a comprehensive input dataset collected in the petroleum province of the Bjelovar Sub-Basin, adapted by dividing up geological events into five probability classes as follows: 1.00 for proven, 0.75 for highly reliable, 0.50 for fairly reliable, 0.25 for unreliable and 0.05 for an undefined event. The methodology is applied to evaluate a potential hydrocarbon discovery of 200,000 m^3 (1,258,000 barrels) of recoverable oil in the analyzed area. The POS of the potential discovery is 28.48% (in Paleozoic-Middle Miocene play).

The second part considers the calculation of net present value for the size of potential discovery, which is 13.52 million USD. The investment risk for such a prospect (in mentioned play) was evaluated by using an exponential utility function based on the company's budget of 50 million USD. The amount of 850,000 risk-neutral dollars is calculated as the certain equivalent to be invested into potential discovery of the expected value of 2.42 million USD. The presented methodology could be easily applied to other Croatian parts of the Pannonian Basin System.

1 Introduction

Exploratory mature basins are generally characterized by the limited number of remaining undrilled prospects and by the smallish size of hydrocarbon volumes which can be reasonably expected to be discovered. In the case of exploratory success, the decision to appraise and develop the small sized mature basin discoveries would obviously depend on the discoveries' economic viability. As a consequence, proving the economic viability is, in a mature basin setting, of primary importance.

The authors of this article have, for some time, assessed prospects of the Bjelovar Sub-Basin. The sub-basin, located in North-east Croatia, is part of the Pannonian Basin System. The Bjelovar Sub-Basin shows all the elements of an exploratory mature basin and thus is considered the appropriate target for economic viability analyses in mature basin environments.

Following industry standards, the authors' evaluations particularly addressed the risks associated with hydrocarbon plays and prospects. To adequately honour the specifics of mature basin conditions, those analyses were complemented by assessments covering the investment risk and the related investment optimization.

In hydrocarbon exploration and production, geological, economical and technical risks are the main, yet not only risks to be dealt with in the assessment of investment risks. In a mature petroleum province, minimizing the geological and economic risks is the key to success.

To adequately honour the mature basin conditions in our investment risk assessment, we went back to, i. e. chose the approach of Cozzolino [2], which allows an estimate of acceptable risk money for selected expected monetary values (EMVs; [4]) of postulated discoveries. Obviously, the "Cozzolino approach" complements the standard economic risk assessment which comprises (i) the assessment of the geological risk, and (ii) the assessment of the economic risk, whereby the latter – based on net present value (NPV) calculations – represents the integration of economic value and geological risk calculations.

To arrive at the aimed assessment of the investment risk and investment optimization in the Bjelovar Sub-Basin, an integrated study was performed, dealing with the following issues in consecutive order:

(1) the regional and petroleum geology of the sub-basin, with emphasis on the critical factors
(2) the geological risk, expressed as percentage probability of finding hydrocarbons in the target
(3) the economic risk, by integrating NPV, risk money and geological risk, and
(4) the investment risk, by essentially reviewing the risk money involved.

The data available for the investigation dealing with the investment risks relative to projects of the Bjelovar Sub-Basin, and as inventoried by the above items (1) to (4), are exclusively publicly accessible data. Obviously, the study benefited from the investigations performed by one of the authors (Malvic) to obtain his master (1998) and PhD (2003) degrees [6, 7].

In the above context it is also noted that none of the considered probabilities and financial values were taken from official or company owned reports.

2 The Regional Setting of the Bjelovar Sub-Basin

The Bjelovar Sub-Basin covers an area of 2900 km^2 and represents the southern part of the Drava Depression, i. e. the western margin of the Pannonian Basin System (Fig. 1). It is considered a mature hydrocarbon province.

The thickness of Neogene–Quaternary clastics, overlying Mesozoic and Paleozoic rocks, reaches a maximum of 3000 m. The most significant hydrocarbon potential is attributed to Lower and Middle Miocene clastic, coarse-grained reservoirs. Those reservoirs, of which the Middle Miocene reservoirs are the main ones, are associated with underlying reservoir units, which are fractured and weathered basement rocks. Both Miocene and Basement reservoirs are controlled by a common hydrodynamic system. The Lower and Middle Miocene reservoirs and traps are situated at depths between 800 and 1500 m. Additional reservoir potential may exist in the remains of algal reefs and siliciclastic breccia (Fig. 2).The second group of reservoirs is that of Upper Miocene sandstones. These sandstones are characterized by very variable reservoir properties. The reservoirs occur at depths of less than 1000 m. The prospectivity of the reservoirs is negligible, reflecting poor reservoir properties and the shallow depth of burial, whereby the latter obviously causes hydrocarbon degradation by meteoric waters (Fig. 2).

Source rocks of Ottnangian to Sarmatian age are postulated to be present within two major synclines of the sub-basin at depths from

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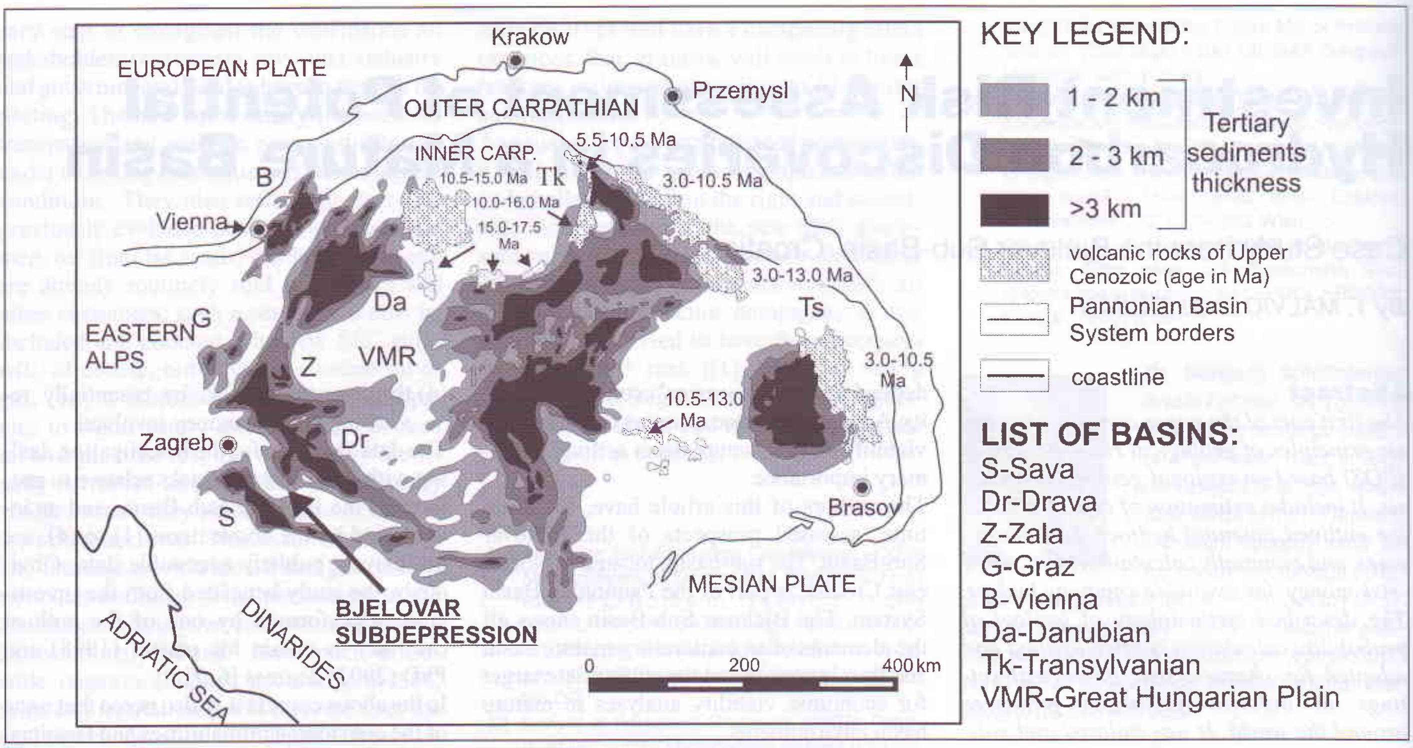

Fig. 1 **Geotectonic position of the Bjelovar subdepression [from 12; modified and published in 9]**

1600 to 2500 m. In those, oil maturity (ΣTTI = 15) was likely to have been reached in the deepest parts [6, 7]. A significant part of the hydrocarbons was derived from the northwestern part of the Drava Depression (Fig. 1). Within the Drava Depression, the proven source rocks are represented by mudstones, marls and siltstones of Lower Miocene to Badenian age. With burial depths greater than 3000 m [1], they reached a high level of thermal maturation.

The sub-basin hosts a great number of hydrocarbon fields and – as a mature basin – has been intensely drilled. Consequently, this is reflected in the wealth of data. They provide a reliable geological database of the studied area. This is particularly the case for field and reservoir data. The reservoirs' porosities vary in Miocene sandstones between 15 and 25%, in the breccia between 5 and 15%, whilst the fractured basement rocks are characterized by secondary porosities from 1 to 5%. Horizontal permeabilities vary from 0.05 to 336 millidarcies (mD). The effective thicknesses of the reservoirs are between 1 and 15 m, they are related in sandstones mostly with fluvial subfacies, in breccias (and partially conglomerates) with alluvial fan subfacies.

The majority of analyzed fields are in the late stage of production. Production started from the late sixties to early eighties. Total original hydrocarbon in place (OHIP) in the sub-basin is estimated at approximately 44 x 10^6 m^3 of oil and 4250 x 10^6 m^3 of gas. In the fields, the water cut varies from 50 to 90%.

The studied area is defined by several plays and related prospects. Each play can be characterized by several prospects having similar geological features [11, 15]. Two main plays have been identified:

(1) the Paleozoic basement rocks and Middle Miocene breccia play, and

(2) the Upper Miocene sandstones play.

The stratigraphic position of both plays is shown on Figure 2. As will be shown below, the geologic risks of both plays were calculated.

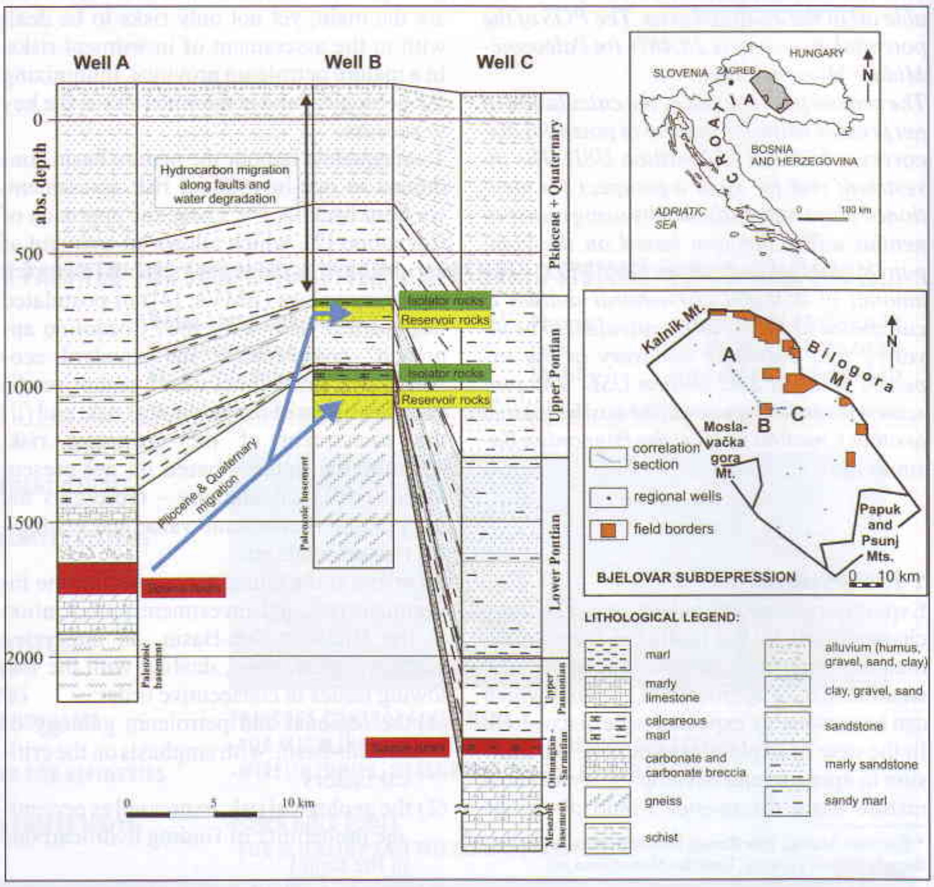

Fig. 2 **Geological section with includes five geological categories – central part of the Sub-Basin [modified from 8; published in 9]**

Using regional structural maps and palinspastic restorations of the sub-basin [6, 7], a detailed structural analysis was made. Data analysis showed that a new prospect would be smaller in size than previous discoveries, as it is expected to contain on average some 200,000 m^3 of recoverable oil reserves (1.26

TRAP		RESERVOIR		SOURCE ROCKS		MIGRATION		HC PRESERVATION	
Structural		**Reservoir type**		**Source facies**		**HC shows**		**Reservoir pressure**	
Anticline and **buried hill** linked to basement	1.00	**Sandstone** clean and laterally extended; **Basement** granite, geiss, gabbro; **Dolomites and Algae reefs** (secondary porosity)	1.00	**Kerogen** type **I and/or II**	1.00	**Production** of hydrocarbons	1.00	**Higher** than hydrostatic	1.00
Faulted anticline	0.75	**Sandstones,** rich in silt and clay; **Basement** with secondary porosity, limited extending; **Algae reefs**, filled with skeletal debris, mud and marine cements	0.75	**Kerogen** type **III**	0.75	Hydrocarbons **in traces**; **New gas detected >10 %**	0.75	**Approximately** hydrostatic	0.75
Structural nose closed by fault	0.50	**Sandstone** including significant portion of silt/clay particles, limited extending;	0.50	**Favourable palaeo-facies** organic matter sedimentation	0.50	**Oil** determined **in cores** (luminescent analysis, core tests)	0.50	**Lower** than hydrostatic	0.50
Any "positive" faulted structure, margins are not firmly defined	0.25	**Basement rocks**, including low secondary porosity and limited extending	0.25	**Regionally known** source rock facies, but not proven at observed locality	0.25	**Oil** determined **in traces** (lumin. anal., core tests)	0.25		0.25
Undefined structural framework	0.05	Undefined reservoir type	0.05	Undefined source rock type	0.05	Hydrocarbon are not observed	0.05		0.05

TRAP		RESERVOIR		SOURCE ROCKS		MIGRATION		HC PRESERVATION	
Stratigraphic or combined		**Porosity features**		**Maturity**		**Position of trap**		**Formation water**	
Algae reef form	1.00	**Primary** porosity **>15 %**; **Secondary** porosity **>5 %**	1.00	Sediments are in **catagenesis phase** ("oil" or "wet" gas-	1.00	Trap is located in proven **migration distance**	1.00	**Still aquifer** of field-waters	1.00
Sandstones, pinched out	0.75	**Primary** porosity **5-15 %**; **Secondary** porosity **1-5 %**	0.75	Sediments are in **metagenesis phase**	0.75	Trap is located **between two source rocks** depocentres	0.75	**Active aquifer** of field-waters	0.75
Sediments changed by **diagenesis**	0.50	**Primary** porosity **<10 %**; **Permeability <1x10**(-3)** micrometer**2	0.50	Sediments are in **early catagenesis phase**	0.50	**Short migation pathway** (<=10 km)	0.50	**Infiltrated aquifer** from adjacent formations	0.50
Abrupt changes of petrophysical properties (caly, different facies)	0.25	**Secondary** porosity **<1 %**	0.25	Sediments are in **late diagenesis phase**	0.25	**Long migration pathway** (>10 km)	0.25	**Infiltrated aquifer** from surface	0.25
Undefined stratigraphic framework	0.05	Undefined porosity values	0.05	Undefined maturity level	0.05	Undefined source rocks	0.05		0.05

TRAP		RESERVOIR		SOURCE ROCKS		MIGRATION		HC PRESERVATION	
Quality of cap rock				**Data sources**		**Timing**			
Regional proven cap rock (seals, isolator)	1.00		1.00	Geochemical analysis on **cores and fluids**	1.00	**Trap** is **older than** matured **source** rocks	1.00		1.00
Rocks without reservoir properties	0.75		0.75	Analogy with **close located geochemical analyses**	0.75	**Trap** is **younger than** matured **source** rocks	0.75		0.75
Rocks permeable for gas (gas leakage)	0.50		0.50	**Thermal modeling** and calculation (e.g. Lopatin, Waples etc.)	0.50	**Relation** between trap and source rocks is **unknown**	0.50		0.50
Permeable rocks with locally **higher silt/clay content**	0.25		0.25	**Thermal modeling** at just a **few locations**	0.25		0.25		0.25
Undefined cap rock	0.05		0.05	Undefined data sources	0.05		0.05		0.05

Fig. 3 Geological events classified in five probability classes [9]

x 10^6 barrels). The USGS [14] published a similar value of 1 x 10^6 barrels as minimal recoverable oil in the potential discoveries of the Zala-Drava-Sava Mesozoic and Neogene petroleum systems. As indicated by Figure 1, the Bjelovar Sub-Basin is part of the Drava Depression petroleum system.

3 Assessment of the Geological Risks in the Bjelovar Sub-Basin

Since many years probability calculations are in use to assess the geological risk of E&P ventures. Expert teams estimate the probabilities of a group of particular geological risk factors by using numerical values ranging from 0.0 to 1.0. Optionally, experts may also decide to employ geological probability tables published for different petroleum provinces around the world or to use those probability tables, yet correct them within certain ranges, reflecting their own data and knowledge base.

Obviously, introducing the probabilistic approach reflects the lack of certainty when predicting the presence or absence of geologic factors ("play parameters") which contribute to the success in finding hydrocarbons. The probabilities arrived at have to however likewise be considered as a subjective value reflecting the applied methods, the database or the human factor. It means that different companies, teams and experts will use different approaches or databases, and obtain different results for the same play or prospect.

The geological probability is represented by the simple multiplication of five geological risk factors (Equation 1). The result represents the Probability of Success (POS) and describes the probability that hydrocarbons could be discovered.

$$POS = p(trap) \cdot p(reservoir) \cdot p(source\_rocks) \cdot p(migration) \cdot p(HC\_preservation) \qquad (1)$$

From equation (1) it is obvious that the approach applied in this article is based on the evaluation of five risk factors, i. e. trap, reservoir, source rocks, migration and hydrocarbon preservation. Exploration experts are partly used to employing seven risk factors, i. e. employing in addition the factors seal and coincidence. Yet, this risk identification which was taken from White [16], proved adequate to cover the Bjelovar Sub- Basin conditions. Moreover, similar calculations, based on five factors, were previously carried out for some potential discoveries in selected parts of the Sava and Drava Depressions. Maintenance of that approach rendered a valuable means of comparison.

An appropriate geological database, including the characteristic geological events, was derived from available data published in previous regional studies of the Bjelovar Sub-Basin [6, 7]. The database was created in Access and linked to the executive computer code program in the Delphi™ language.

The probabilities of each of the risk factors are described by several probability classes (mostly five or more, depending on approaches). Each class has unique discrete numerical values in the range between 0 and 1 that describe the probability of occurrence of selected events. Five probability classes are defined here in order to indicate equal importance of all possible geological events. We have defined the five probability classes in our own system describing the geological events as follows:

1.00 – proven geological event,
0.75 – highly reliable predictable event,
0.50 – fairly reliable predictable event,
0.25 – unreliable predictable event, and
0.05 – missing event/undefined parameter.

It will be noted that our system gives special attention to the lowest probability class, i. e. to the 0.05 event. The "undefined parameter" addresses the lack of information. It does not primarily identify an event of low probability, but suggests that the probability can not be estimated from the available dataset. This attribution to the lowermost probability class recognizes that we are dealing with a mature basin, where the per se unusual lack of data and/or knowledge is likely to reflect poor conditions (of whatever type).

Based on the approach described above and considering the inventory of geological events as depicted in Figure 3, the main plays of the Bjelovar Sub-Basin were assessed for their risks – with the following results:

(1) the play called "basement rocks and Miocene breccia" has a geological probability value of 28% for a new hydrocarbon discovery,

(2) the "Upper Miocene sandstone" play is characterized by a significantly lower value of 13% (not promising).

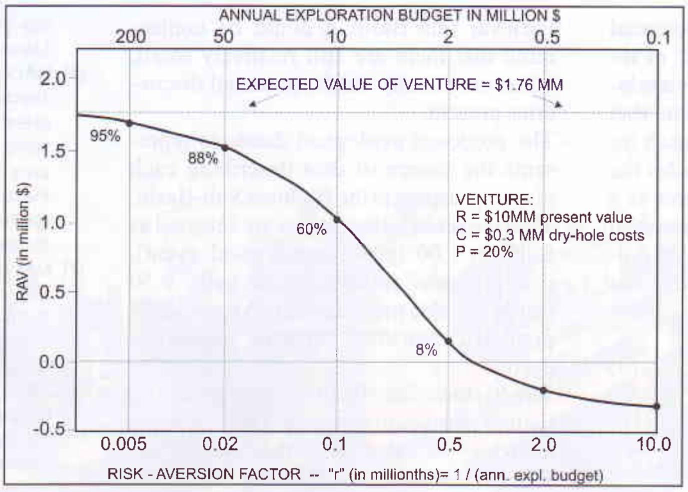

Fig. 4 Exploration budget and RAV ratio [10]

4 The Economic Risks of Potential Discoveries in the Bjelovar Sub-Basin

Essentially, the objective of assessments of the economic risks in E&P projects is to ascertain the project's economic viability. Largely, the anticipated economic viability of the project depends on the geological risks (see Section 3.) relating to the project. The prediction of economic viability, i. e. the calculation of the expected monetary value is in simple terms based on the assessments of geologic risks, of the risk money involved, and of the present value and net present value respectively.

The present value (PV) is, by definition, the current value of one or more future cash flows, converted at some appropriate discount rate. The discount rate is used to convert the future value of an income stream to a present day value (considering inflation, currency exchange rate etc.). By analogy, the net present value (NPV) is defined as the present value of an investment's future net cash flows minus the initial investment. If positive, the investment should be made, otherwise it should not.

Eventually the integration of the geological risk into the economic calculations renders the expected monetary value (EMV), whereby, simplified, the NPV is coupled with the geological risk (POS), which in our case is .28, whilst the risk money, being subtracted from the NPV, is coupled with 1 minus the geological risk (POS), which in our case is 0.72.

In our case study, we arrived at an EMV of 2.42 million USD. The result reflects the probabilities as listed above and is based on a 14.15 million USD NPV, which in turn is based on a 10% discount rate, on an oil price recorded in early 2006, and on drilling and completion costs per well of some 2.0 million USD. The risk money is obviously made up of the drilling costs less completion. According to the definition of our base case, the economic calculations refer to developing and producing a discovery with 2×10^5 m^3 of recoverable oil.

5 Investment Risks and Investment Optimization

In the late 1970's, Cozzolino [2, 3] presented calculations by which the author correlated the results obtained from basic economic calculations (see above) with oil companies' concerns, i. e. investment risks and the impact of economic risks on companies' budgets. Relative to the identified risks related to E&P activities in a mature basin, we found the Cozzolino approach very helpful, in providing guidance for investments in an economically potentially risky environment – with the uncertainty of making profits or losses.

Fundamentally, according to Cozzolino, the amount of potential profit or loss is related to the companies' attitude towards taking a risk. In general, there are three possible categories of attitude towards the risk: (a) a risk-neutral attitude, (b) a risk-tolerant attitude, and (c) a risk-averse attitude. Usually, the majority of company experts are risk averse and prefer to avoid insecurity (economists use a marginal utility analysis to explain why that is so).

Cozzolino derived the so called *utility function* ("r"). The first approximation of "r" function is a reciprocal value of the company's exploration budget in million USD, i. e. r = 1/annual exploration budget. The attitude "keeping money" is a stronger motivator than "making profit", or that most people would prefer to take a loss by "standing pat" than to take action which could be equally non-profitable [5]. In both cases, the expected value, i. e. probability weighted value of all possible outcomes, is equal. Cozzolino's formula [2, 3] is based on the utility theory to determine the risk-adjusted value (RAV) by using the risk-averse function in Equation 2. It indicates an optimal and consistent investment level related to the company's budget and objectives, and to its chances, risks and rewards. It is a term synonymous with "certain equivalent" (CE), which is equal to the expected value less a risk discount or, simplified, the minimum amount of money somebody would rather have for certain, instead of taking some risk. Rose [10] demonstrated the use of "r" function in the RAV calculation, which we adopted in Figure 4.

$$RAV = -\frac{1}{r}\cdot \ln\left[p\cdot e^{-r(R-C)} + (1-p)\cdot e^{r\cdot C}\right] \qquad (2)$$

Where:
R – gross reward in million USD
C – cost in million USD
p – probability of success
r – risk aversion function in millionths.

The example of Figure 4 is relevant for an expected value of the hypothetical prospect worth 1.76 million USD, and a company's working interest of 100%. The company with 200 million USD of annual exploration budget is characterized by a RAV of 95%. It means that for a risked play or prospect with the expected value of 1.76 million USD such a company may invest up to 95% of the value of play/prospect (equal to 1.67 million USD). However, an annual budget of 0.5 million USD generates a negative RAV. From a mathematical point of view this means that a small company will only make the investment if the RAV decreases to some lower value or via a joint venture with other (bigger) companies.

5.1 The expected monetary value and risk-adjusted value of a potential discovery in the Bjelovar Sub-Basin

The following list displays the basic assumptions employed in our case study:

(1) A company intends to develop a strong and focused portfolio with the aim of securing long-term reserves growth, part of that being the constant acquisition of new concessions

(2) The company scenario is that, within the Pannonian Basin System, i. e. in the Bjelovar Sub-Basin, such acquisition will result in the discovery of new reserves – by pursuing the concept of identifying significant by-passed reserves or smaller fields

(3) The company prefers pursuing the project in a joint venture. The partner is expected to be of similar »medium« size. Jointly the companies have an E&P portfolio budget of 50 million USD per year.

The targeted Bjelovar Sub-Basin potential discoveries will be small (2 x 10^5 m^3 of recoverable oil) and be characterized by a relatively low geological probability. For that reason we applied a risk-averse approach for estimating the financial risk. It includes the use of the exponential utility function as a special form of the utility function described by Equation (3). This function converts dollars into arbitrary units called »utils« expressed in risk neutral dollars.

$$U(x) = rtc \cdot (1 - e^{-x/rtc}) \qquad (3)$$

Where :

U – utility units in million risk neutral USD

x – present value of potential discovery discounted with appropriate discount rate

rtc – risk averse function or risk tolerance coefficient ("rtc") reflects the company attitude toward risk, and is represented by an exponential curve.

In our calculation, the value of "r" is, as is commonly the case, set at 1/5 or 1/6 of the company's net worth [13]. Here the term 'net worth' is considered as the money that the company could plan to spend in the Bjelovar Sub-Basin, i. e. 50 million USD, expecting to gain at least such a profit for all potential discoveries. Consequently r is 10^7.

Our case study calculations gave us 2.52 million USD as EMV (see above) and U(x) 7.57 million USD. The next step was to calculate the value of expected units or EU = 0.85 using the simple expression [U(x)·POS–(RM·(1–POS))]. The value RM is risk money decreased for selected-exponential function shape (here 1.81). The last step was to calculate a certainty equivalent (CE) by using Equation 4. Certainty equivalent is the maximal amount of money that a company is willing to invest in potential discovery.

$$CE(in\$) = -r \cdot \ln\left(1 - \frac{EU}{r}\right) \qquad (4)$$

The value of CE is 0.85, i. e. 850,000 USD. This is the risk-free amount, according to Cozzolino [2, 3] and Rose [10, 11]. From that calculation it may be concluded that a company with a 50 million USD E&P budget has good reasons, upon exploring the proposed prospect with a geological probability 28% (Paleozoic-Middle Miocene play) at a cost of 850,000 USD, to expect a potential profit of 2.42 million USD (RAV= 35.1%).

Conclusion

This is currently the most comprehensive work to include regional geological analysis, geological risk calculation, economical analysis of drilling costs and expected value of potential discovery, and eventually investment risk related to the Croatian part of the Pannonian Basin System, and it is readily applicable to the Bjelovar Sub-Basin. The following conclusions can be drawn:

- Based on geological settings of the Bjelovar Sub-Basin it could be conjectured that there are still relatively small, but economically viable, potential discoveries present.
- The proposed geological database represents the source of data describing each play or prospect in the Bjelovar Sub-Basin. The five probability classes are selected as follows: 1.00 (proven geological event), 0.75 (highly reliable predicted), 0.50 (fairly reliable predicted), 0.25 (unreliable predicted) and 0.05 (missing geological event).
- The Bjelovar Sub-Basin is considered as a mature petroleum province. Due to this the analysis included the risk-averse approach, i. e. exponential utility function.
- The utility function was applied to calculate risk neutral dollars which a hypothetical company would be willing to spend in the exploration of new discoveries (size 2 x 10^5 m^3 of oil equivalent and POS 28.48%) consistent with an expected monetary value (EMV) of 2.42 million USD.
- The amount of 850,000 risk-neutral USD is estimated as the investment limit for a company with a 50 million USD budget, and accompanied by RAV of 35%.
- Most of the methodology utilized in this article is well known, and can justifiably be applied to provide a clear evaluation of the geological and economical risk in the Bjelovar Sub-Basin (Northern Croatia), where a database was collected.
- The relatively small RAV showed that in smaller mature petroleum provinces such as the Bjelovar Sub-Basin, the exploration for the remaining economical reserves demands the joint-venturing of two or more companies with shared total risk.
- It could be relatively easily modified using additional geological data and applied in similar petroleum provinces in the Croatian part of the Pannonian Basin System.

We would like to thank Dr. Ulrich Schmitz (LO&G Consultants), who substantially helped with critical comments and suggestions regarding the overall concise presentation of our work.

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