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RISK ASSESSMENT MODEL FOR INDIVIDUAL PETROLEUM PROSPECTS

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ABSTRACT. The estimation of the oil and gas resources includes practically two phases: 1) construction of the general geological model of the prospect and 2) determination of the potential volume hydrocarbons distribution or so called "unrisked curve". The second phase is to assess the chance that this estimate is correct or the model is right. For this reason assessors must considering the basic group of factors (and their elements), that control the hydrocarbon occurrences: reservoir, trap, seal, charge, retention; P sr - weighed source rock group probability); Pt – weighed trapping group probability); Ps – weighed sealing group probability); Pr - weighed preservation group probability). The listed controls are independent during and after the oil and gas occurrences have taken place. For the final evaluation of the prospect probability or chance factor of existence (chance factor Pch) we implement the multiplication rule and express calculated value in range of 0 to 1.0 (or percent): Pch = Pr * Psr *Pt * Ps * Pp . An important practical piece of advice is to subdivide risk groups into 2 packages in order to deal with them in a proper manner. The author's suggestion is to aggregate reservoir, source and trap factors into one charging package – I package. The remaining seal and preservation factors could be the II package. Such a need is clear when we have unfavorable conditions for charging elements. Let us assume bad favorability for I package – then weighted probability will be below the critical value and practically there is nothing to be sealed. The described above procedure is applied on the prospect Kozarevets, situated into the Tarnovo depression, which is part of the south Moesian platform margin. The critical control on the reservoir properties is thought to be the post sedimentary compaction that has led to the strong porosity reduction. All the proposed above assessment steps have been implemented and the final result is that expected probability for the charging group risk factors occur under lower critical probability value – 0.12. Irrespective of the favorability of the preservation risk factors (above critical probability value), the prospect is inferred to have no chance to be charged. This pre-drill estimate is completely confirmed by the drilling results and well productive tests. No flows, only shows have been registered.

ОЦЕНКА НА ГЕОЛОЖКИЯ РИСК ПРИ ПРОУЧВАНЕ ЗА НЕФТ И ГАЗ НА ИНДИВИДУАЛНИ СТРУКТУРИ (ПРОСПЕКТИ)

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РЕЗЮМЕ. Съвременната практика за оценка на ресурсите от дадена проучвателна структура включва два основни етапа (стъпки): конструиране на геоложки модел на проспекта и построяване на вероятностна (безрискова) крива на очакваните обеми от въглеводороди. Втората стъпка изисква анализ и очертаване на основните критични фактори, които определят формирането на дадена акумулация. Прието е това да са фактори, контролиращи присъствието и ефективността на: резервоар, геокапан, механизъм на екраниране, зареждане и съхраняване на локализираните продукти. Крайната оценка за адекватност на модела се представя като произведения на посочените фактори, изразени във вероятностна скала от 0 до 1.0. С цел постигане на по-голяма надеждност авторът предлага посочените фактори да се обединят в два пакета: група фактори контролиращи зареждането (резервоар, зареждане и геокапан) и група фактори контролиращи съхраняването. Приоритет се дава на първата група и при негативна оценка на нея се приема, че проспектът е некондиционен. Изложената в работата процедура е приложена за проспект Козаревец, разположен в Търновското понижение. Тази структурна единица принадлежи на южната окрайнина на мизийската платформа и разкрива значително по-голяма дебелина на долно-средноюрските скали, характеризиращи се с надкритично съдържание на органично вещество. Анализът обаче на геоложкото развитие показва висока степен на следседиментационно уплътняване, в резултат на което е налице съществена редукция на резервоарните свойства. След приложение на възприетия методичен подход е пресметната подкритична стойност на първи пакет, което определя проспекта като подкондиционен. Проведените впоследствие проучвателни сондажни работи потвърдиха негативната оценка.

Introduction

Modern petroleum resource assessment methods are focused on the petroleum-play system components using the probabilistic approach for calculation the resource size uncertainty, as well as the chance that the model is correct or the chance that the occurrence really exist. From this standpoint, the risk analysis appears to be an important attribute to every exploration "wild cat" drilling venture. It should be implemented as equal importance for prospect evaluation as well as for play resource assessment. The purpose of this paper is to review the risk assessment procedure (models) for individual prospect and promote its key aspects, with respect to increase the efficiency of the petroleum exploration practice within the Bulgarian onshore and offshore territory, where a lot of wells have been drilled, but the level of success-ratios is quite unsatisfied.

General principles of a prospect risk assessment

The estimation of the oil and gas resources includes practically two phases (Meneley, 2003). First, we construct the general geological model of the prospect and then determine the potential volume hydrocarbons distribution or so called "unrisked curve", multiplying the certain volume factors together, implementing Monte Carlo simulations. As we assume that the geological model is right the received unrisked curve reflects the range of all possible values of hydrocarbons, recoverable at surface or available in-place. The second phase is to assess the chance that this estimate is correct or the model is right. For this reason assessors must fulfill the risk assessment procedure, considering the basic group of factors (and their elements), that control the hydrocarbon occurrences: reservoir, trap, seal, charge, retention. This procedure defines the risk as a measure of an uncertainty of the predictions, expressed as probability values ranging from 0 to 1. If any of these controls are missing, the result from drilling venture will be failure – dry hole. Thus, we can discount the unrisked curve, implementing the results of performed risk analysis. In the text below we will concentrate only on the basic concepts of risk assessment elements.

Database adequacy

The common approach for the prospect evaluation is based on the geophysical and geological data. The reliability of its interpretation depends on the database adequacy with respect to data quality, data density and relevance to the current geological setting upon the individual prospect under assessment. Consequently, the database extent and quality is critical for the every geological factor that should be assigned the probability value and finally to calculate the average waited probability. There are number of approaches for data adequacy definition and proper interval of the probability assignment, independent of each factor is under consideration. An appropriate for the Bulgarian practice could be the model, developed on the base of CCOP (CCOP, 2000) and Otis and Shneidermann (1997) concept. It states that data should be qualified as direct or indirect according to the existence (or not) in the near vicinity well confirmed analogue. If the objects are situated in the vicinity of 5-10 km and the controls are favorable - >0.8 value of probability may be assigned; if the distance is >10-15 km – 0.6-0.8. In the case of limited well and/or seismic data, the concerned factor may exist but may not exist – the probability interval is expected to be between 0.4-0.6. Occasionally direct data points that the geological factor is not known to exist within the trend. In this case the assessor must assign the value of probability < 0.3 - 0.4.

Prospect risk-matrix

In recent years leading exploration companies and organizations (World Petroleum Resources 2000 of the U.S.G.S.; Canadian Gas Potential Committee, Chevron Overseas Petroleum) register remarkable positive results implementing the play fairway analysis, describing the hydrocarbon occurrences as a sequence of processes, over the organic matter transformation into hydrocarbons, localized in pools (fields). These processes include inherent uncertainty, therefore the probability theory have to be applied in order to assess the arising risk. Risk evaluation must be performed under the one of the fundamental rules: the probability of the simultaneous occurrence of several independent events is equal to the product of their probabilities multiplication:

$$P = P_a * P_b * P_c * P_d * \ldots P_n;$$

P – probability value; a, b, c, d….n – input parameters (geological factors, controlling petroleum occurrences).

This rule is common for risk assessment of a prospect or plays in unknown areas. The important is that involved input parameters must be independent. Otherwise another analytical technique must be fulfilled.

In current company's practice there is varying opinion about which attributes (geological controls) have to be involved. A brief review on the check lists (Table 1) shows some differences. Fife alternatives are listed on the table, ranged from 3 to 5 attributes, but all the sited authors attached attributes to the same processes – reservoir forming, reservoir charging, trapping and preservation of the trapped hydrocarbons.

Discussing differences, special attention should be paid to the position of the migration which is described as an autonomy attribute or as a part of reservoir charge subsystem. It must be consider very carefully because of certain relationship between source rock maturation and expulsion processes. Cooles, Mackenzie and Quigley /1986/ have investigated this relationship and have shown strongly dependence between richness (kerogen concentration) of the source rock and expelled amount of petroleum, confirmed also by Allen & Allen (1990). Consequently, in order to be in accordance with probability theory, migration has to be discussed as a part of the petroleum charge subsystem. Therefore in our risk assessment model we consider migration together with source rock as an element of one risk group factors.

The next questionable problem is the position of the trap and seal. Some authors and companies recommend block assessment, describing them as a reservoir-trap-seal subsystem. This approach is also acceptable, but it is a little coarse, because eliminates the differences between reservoir, trap and seals. From practical view it is better they to be assessed autonomy, expecting to increase objectiveness of the estimates. This is because some basins illustrate independent development of the reservoir, trap and sea and their describing as individual factors seems to be more correct. Typical example is the section of the West Forebalkan area (Bulgaria), where we have well defined reservoir rocks, but intensive vertical fracturing is the main cause for absence of valuable topseal, consequently absence of large commercial fields (Монов, 2005). Almost the same is the situation within the tertiary section of the Lower Kamcia depression - onshore and offshore (West Black Sea basin). Absence of topseal, as well as distribution of a local reliable overlying cap rocks has led to a large number of dry holes within this area. Substantial distinction between reservoir, trap and seal we can see among the Triassic-Jurassic unconformity in the central part of the North Bulgaria that control the oil and gas occurrences (Georgiev, Atanasov, 1993; and others). That is why we recommend in the scheme for risking procedure to choose separate appraisal of the reservoir, trap and seal (Table 2).

The timing of trap formation versus timing of charge is also a questionable factor. Some authors describe it as a part of petroleum charge subsystem (CCOP, 2000) or as an autonomy attribute together with migration (Otis, Schneidermann, 1997). White (1993) offers to assess it in combination with trap and seal risking. Rostirolla et al. (2003) includes it into preservation group factors.

Considering this control we will relay on the Rose (1987) observations on drilling activity, showing the very limited importance of this control. Less then 3% of dry holes are due to incorrect hydrocarbon charge prediction, including timing of trap formation. Based on mentioned above we do not attribute timing as an individual group of factors in risk assessment procedure. Summarizing, we construct a scheme for Bulgarian practice on the base of five group factors for assessment of adequacy (Table 2): factors controlling reservoir existence and effectiveness – (P_r - weighed reservoir group probability); factors controlling existence of source rock and effectiveness of its maturity and migration processes - (P_{sr} - weighed source rock group probability); factors controlling mapped structure (geometry) and trap mechanism - (P_t - weighed trapping group probability); factors controlling seal existence and seal mechanism effectiveness - (P_s - weighed sealing group probability); factors controlling effective preservation after accumulation - (P_r - weighed preservation group probability).

We assume that listed controls are independent during and after the oil and gas occurrences have taken place. For the final evaluation of the prospect probability or chance factor of existence (chance factor P_{ch}) we implement the multiplication rule and express calculated value in range of 0 to 1.0 (or percent):

$P_{ch} = Pr * P_{sr} * P_t * P_s * P_p$ (abbreviations are according to the text above)

Practical recommendations for the risk assignment procedure (assessment practice)

An important step in the risk assessment procedure is the establishment of a set (system) of general qualitative descriptions of the responsible geological factors. It will help to assign the relative probability scale of their natural variation and operate in more objective and repeatable manner. Difficulties of description arise through lack of data and uncertainty introduced mainly by the technique of data acquisition (White, Gehman, 1979; Lerche, 1997; Ампилов, Герт, 2006; and others). In order to avoid multiple interpretations some common rules are recommended. They are derived from the practice and reflect the methodologies implemented by leading companies and institutions. That's why a parameter behavior pattern should be constructed for every individual factor, accounting for its existence and effectiveness. The base milestone is focused on the relation between proven (existing) geological model and constructed analogue. Besides direct correlation, assessor very often uses interpolation and extrapolation. Then the stress should be addressed to parameter mapping. Stacking all the maps, a play fairway analysis can be fulfilled and finally a probability value can be assigned.

The main disadvantage of all these practical recommendations is the problem of bias. It cannot be avoid completely. It is well known that no one approach is appropriate for all situations and each one has particular advantages and disadvantages. Probability assignment procedure must be explicit, transparent, and systematic while dealing with data available. Peer review is also vital. Postdrill calibration adjustment will be appreciated. Mentioned above explanations and recommendations could be summarized into a simple work plan that will help assessor to operate in the better manner with database available for a prospect. Recommended steps (totally 7) are only the author's suggestion and the real practice certainly will verify and improve them:

I step – collecting relevant geological, geophysical, petrochemical etc. data, and its adequacy assessment;

II step – prospect geological model construction (maps, profiles, burial history etc), accounting for every control that is responsible for oil and gas occurrences);

III step – estimation of the prospect in-place resources (volumetric calculations, presented by unrisked volumetric curve);

IV step – assignment of probability value for every individual risk factor accounting for existence and effectiveness and then estimation of the risk group probability;

V step - assignment of probability value for prospect entirely;

VI – step – risk-adjusted cumulative volumetric curve (risked resources curve);

VII step – decision tree analysis for company strategy formulation.

An important practical advice is to subdivide risk groups into 2 packages in order to handle with them in proper manner. Author's suggestion is to aggregate reservoir, source and trap factors into one "charging" package – I package. The rest seal and preservation factors could be the II package. Such a need is clear when we have unfavorable conditions for charging elements. Let's assume bad favorability for I package – then weighted probability will be below the critical value and in fact there's noting to be sealed. If in such a case we have excellent favorability for the seal and preservation, the assessor will introduce false into the assessment for a prospect entirely by weighting the probability over both risk packages. Enclosed example at the end of this paper is an attempt to illustrate the described approach. As it can be seen, the probability calculations for the charging package show the probability below the critical value (Table 4), irrespective of the preservation favorability.

Conclusion

One of the technological progresses in prospect resources assessment during the last decades is the petroleum-play concept using the risk analysis techniques. Common approach for the appraisal of the prospect associated risk is to deal with number of risk-factor groups (four of five) related to generation, migration and preservation of hydrocarbons. With respect to increase the efficiency of the exploration ventures, a model (set) of five group factors is constructed. The base group factors for assessment of adequacy are as follows: factors controlling reservoir existence and effectiveness; factors controlling existence of source rock and effectiveness of its maturity and migration processes; factors controlling mapped structure (geometry) and trap mechanism; factors controlling seal existence and seal mechanism effectiveness, and factors controlling effective preservation after accumulation. We assume that listed controls are independent during and after the oil and gas occurrences have taken place. For the final evaluation of probability or chance factor for the individual prospect (*prospect chance factor* P_{ch}) multiplication rule is implemented, assign a value in range of 0 to 1.0 (or percent). Practical estimate of the Kozarevets prospect associated with North Bulgaria Lower-middle Jurassic petroleum play illustrates a good appliance of the proposed procedure.

Appendix

Case test. Described above procedure is applied on the prospect Kozarevets, situated into the Tarnovo depression, which is a part of the south Moesian platform margin (Fig. 1). The depression is filled by tick lower-middle Jurassic sedimentary deposits (near 800 m), including kerogen reached black shale, widely known as source rocks. Number of geological and geophysical investigations has been fulfilled, as well as 3 “wild cat” drillings, spudded during the 1980-1984: R-1 Kozarevets, R-2 Djolunitsa and R-3 Pisarovo. All three wells are “dry”, irrespective of existence of trap and reservoir facies, presented by shallow marine biodetrital limes (Dolni Lukobvit, Suhindol member of Ozirovo formation) and Lopian member clastics of Etropole formation. The critical control on the reservoir properties is thought to be the most depositional processes that have led to the strong porosity reduction. All the proposed above assessment steps have been implemented and the final results is that waited probability for the charging group risk factors occur under lower critical probability value – 0.12 (Table 3). Irrespective of the favorability of the preservation risk factors (above critical probability value), the prospect is inferred to have no chance to be charged. This predrill estimate is completely confirmed by the drilling results and well productive tests. No flows, only shows have been registered.

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Table 1. *Check list review of the risk assessment models*

Diagnostic factors	Authors, companies							
	Otis & Schniedermann, 1997	**Rose, 1987**	**CCORP, 2000**	**USGS, 2000**	**White, 1988**	**White, 1993**	**Rostirolla et al., 2003**	**Some companies (personal communication)**
	Source rock	Hydrocarbon charge	Petroleum charge	Geological charge	Source, maturation	Source maturation, migration	Generation	Existence of source rock
							Charge	Sufficient level of maturity of source rock
	Reservoir	***Reservoir***	***Reservoir***	***Reservoir, trap***	***Reservoir***	***Reservoir***	***Reservoir***	***Reservoir rock with porosity and permeability***
	Trap	***Structure***	***Trap***	***Seal***	***Trap, seal, timing***	***Trap, seal, timing***	***Retention, (Trap, Seal)***	***Existence and persistent of seal***
								Migration path to reservoir
	Timing and migration	Entrapment (trapping conditions)	Retention after accumulation	Favorable timing	Preservation	Preservation, hydrocarbon quality and recoverability	Efficiency (+ Retention)	-

Table 2. *Critical risk factors (risk matrix)*

Risk Factor Groups		
Groups	Subgroups	
	Abbreviation	Questions to be answered
Factors controlling reservoir existence and effectiveness (P_r - reservoir group probability)	P_r (1) Elements controlling reservoir facies existence	Are there reservoir rocks of adequate quality concerning: lithology, area distribution, depositional model, sedimentary wedge construction etc.?
	P_r (2) Elements controlling reservoir effectiveness (porosity, permeability, thicknesses etc.)	Are there reservoir rocks of adequate quality concerning: lateral continuity, large enough thickness, heterogeneity, overcritical porosity and permeability, size and density of fracturing, favorable diagenetic alteration etc.?
Factors controlling existence of source rock and effectiveness of its maturity and migration processes (P_{sr} - source rock group probability)	P_{sr} (1) Elements controlling sours rock presence	Is there petroleum charge system of adequate quality concerning: presence and volume of mature sours rocks, thickness, continuity, proper type of kerogen etc.?
	P_{sr} (2) Elements controlling capacity of HC generation and charging	Are there overcritical HC expulsion, seeps, shows, leakages, HC from well tests, position of the trap with respect to migration, migration distance etc.?
Factors controlling mapped structure (geometry) and trapping mechanism (P_t - trapping group probability)	P_t (1) Elements controlling trap type and mechanism	Is there sufficient adequate seismic and well data to confirm the existence of a mapped structure (closure with adequate geometry) and does the closure cover enough area and magnitude?
	P_t (2) Elements controlling trap mechanism	Is there sufficient adequate data to confirm the reliability of the trap mechanism with respect to trap type, existence of closure to the all ways etc.?
Factors controlling seal existence and seal mechanism effectiveness (P_s - sealing group probability)	P_s (1) Elements controlling seal existence	Are there impermeable rocks of adequate quality concerning: lithology and ductility, area distribution, depositional model, degree of microfracturing etc.?
	P_s (2) Elements controlling seal mechanism efficiency	Are there impermeable rocks of adequate quality concerning: lateral continuity, sufficient thickness, proper capillary pressure curve, under critical pore diameter, heterogeneity etc., that may seal hydrocarbons of at least critical size?

Table 3. *Prospect Kozarevets probability estimation*

Prospect name and risk packages		Predrill probability assessment (prognosis)				
		Risk factors (groups)	Subgroups	Probability factors estimation	Weighed probability	
Kosarevets (Djulunitsa)	I package - charging	*Reservoir group*	Existence	Seismic profiles draw existence of reservoir facies, including basal layers, packages of carbonate rocks, as well as regressive successions. There is certain analogue with the North Knega structural terrace sections, where productive pays have been outlined.	0.8-0.9	0.42
			Effectiveness	Based on the analogy with the near vicinity sections large scale heterogeneity is expecting to have place. There is a possibility of strong porosity reduction as a result of post depositional changes. Very often reservoirs have porosity below the critical value. In this case we expect strong impact of the depth that will increase the carbonization, cementation etc.	0.5	
		Source rock group	Existence	Certain favorability is recognized concerning existence of the source rocks. Black shale and coal seams are penetrated in near vicinity sections. All the areas with lower Jurassic basal layers have shown oil and gas generation potential. The only problem is the thickness of the source rock and TOC concentration.	0.9-1.0	0.62
			Effectiveness	Certain favorability is supposed to kerogen transformation, but very often TOC concentration is critical. Additional the limitation of the reservoir properties will play strong negative impact on the secondary migration and concentration. Formation of the autonomy hydrocarbon phase is problematic.	0.6-0.7	
		Trapping group	Existence	No negative features are expected to the trap existence. TWT interpretations are favorable. The only questionable problem is the velocity models that very often introduce uncertainty. The current practice shows discrepancy between predrill and postdrill structural interpretations.	0.8-0.9	0.42
			Effectiveness	The trap model is more likely than all other interpretation, however, unfavorable is also likely. The current practice often shows discrepancy between predrill and postdrill structural interpretations. No certain data about structure amplitude.	0.5	
				Weighted probability for the charging package is 0.11 which is under critical value for the package – 0.12 (lower limit 0.5*0.5*0.5 = 0.12)		0.11
	II package - preservation	*Sealing group*	Existence	The element is assessed as completely favorable because of broad extent of the shale.	1.0	0.75
			Effectiveness	Their seal capacity is proven, however, the main sealing rocks are brittle that's way an unfavorable models are also likely.	0.7-0.8	
		Preservation group	Existence	The element is assessed as favorable but great preupperjurassic unconformity may have had some negative impact. A possible unfavorable process could also be related to the Austrian orogeny.	0.8-0.9	0.85
			Effectiveness	The favorable model is more likely than all other interpretations.	0.85	
				Weighted probability for the preservation package is 0.64 which is over critical value for this package – 0.25 (lower limit 0.5*0.5 = 0.25)		0.64
Final weighted probability for the Kozarevets prospect			Weighted estimation of the prospect probability for the charging package is below the lower critical value; consequently the object should be classified as a very risked, according to the geological risk factors and especially for petroleum charging processes.			

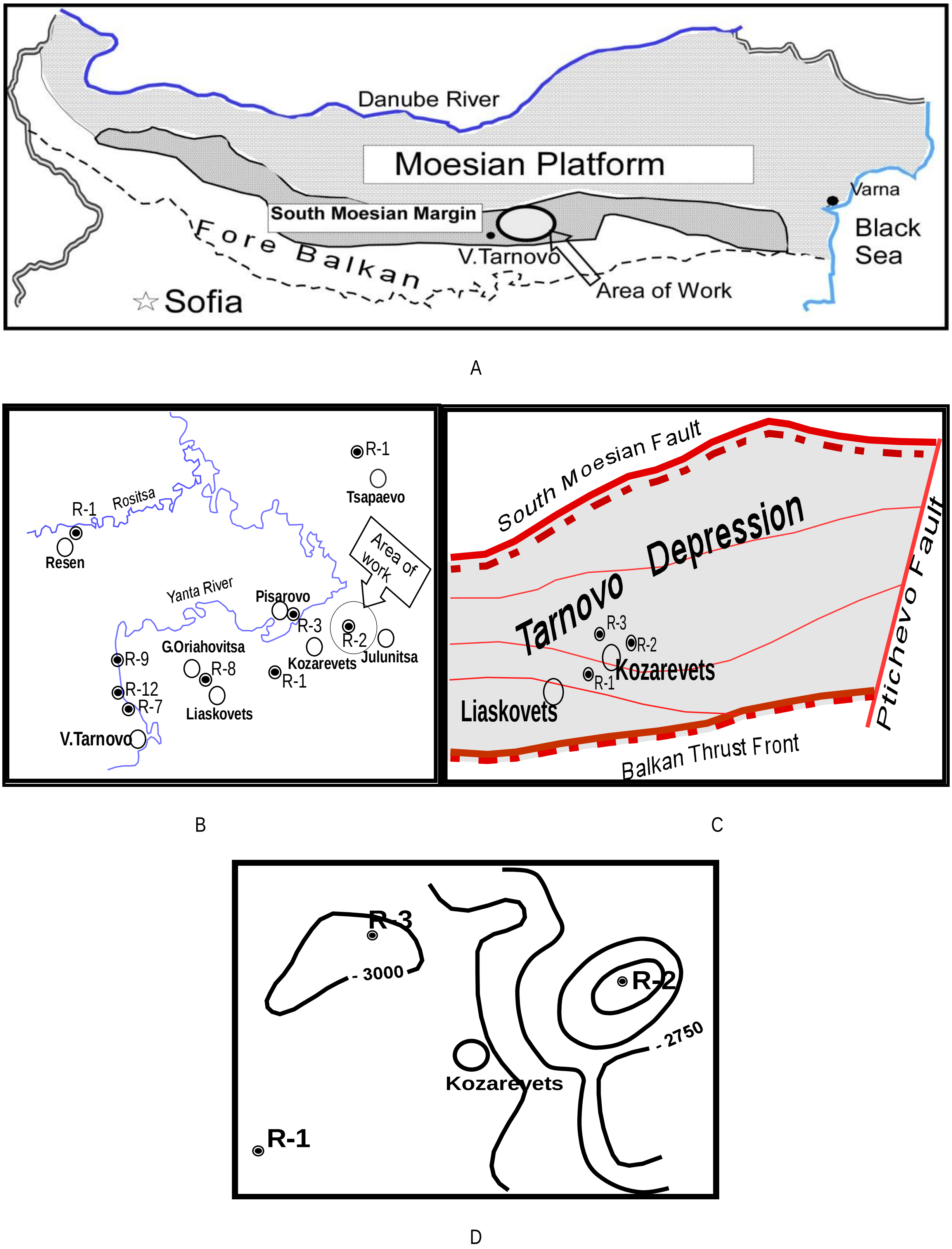

Fig. 1. Area of work: A and B – location within the Moesian platform; C – location within the Tarnovo depression; D – structural map of the main target (the depths are under confidential restrictions)