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METHOD FOR ESTIMATING THE PROBABILITY OF GEOLOGICAL SUCCESS: A CASE STUDY OF THE HRA-E PROSPECT, BLOCK 106, NORTHERN SONG HONG BASIN

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Summary

Petroleum exploration and drilling represent fields fraught with inherent uncertainties, consequently, geological assessment is significantly important for precisely selecting prospects and well locations. The geological evaluation of prospective formations predominantly relies on 5 elements of the petroleum system including source, reservoir, seal, trap, and migration.

This article introduces globally applied geological assessment methods, and proposes an applicable methodology for exploration targets across regions with varying levels of available data. Applying this method of evaluating risk criteria for pre-Cenozoic carbonate objects of HRA-E prospect in Block 106 shows that the evaluation results align with the actual probability of success in drilling exploration activities in the region and could be extended to other projects within the Petrovietnam Exploration Production Corporation (PVEP).

Key words: Probability of geological success, pre-Cenozoic carbonate, HRA-E prospect, Song Hong basin.

1. Introduction

Oil and gas exploration is considered a risky investment field, so it is very important to evaluate the possibility of geological success of a structure before drilling. The probability of geological success of a structure is one of the input parameters to evaluate the economic efficiency of oil and gas projects and plays a crucial role in making final decisions.

Each company has its own choice of geological factors and evaluation criteria, using an independent evaluation guide form. Therefore, it is necessary to develop criteria to evaluate the probability of geological success for prospects of sedimentary basins on the Vietnamese continental shelf.

In this study, by integrating documents and research works on the probability of geological success (POS) evaluation methods used by companies around the world, the authors propose appropriate methods and relevant criteria that can be applied for exploration objects in areas with different levels of documents, limiting the subjective factors of evaluators.

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2. Method for assessing the probability of geological success

The most common and general method to calculate the success probability of a structure is determined by multiplying the probabilities of important geological factors, which are independent geological factors that ensure generation, migration, and accumulation. Geological factors must simultaneously exist and be present to ensure the discovery of oil and gas. It will be impossible to discover oil and gas when one of these elements is missing or non-existent.

In fact, the selection of the number of independent geological factors to evaluate the probability of structural success is different for each oil and gas company/author. White A. David proposed 12 independent factors for evaluation, according to group risk of play and individual risk of structure [1]. The difficulty with this method is that care must be taken during implementation to avoid each risk factor being assessed twice (double risk). Otis & Schneiderman determined the probability of oil and gas discovery according to four main factors including mature source rocks, reservoir rocks, traps (including seals), and migration. Each risk factor is evaluated according to criteria based on a 5-level rating scale from favorable to unfavorable, based on the level of direct or indirect documents and good or bad geological information [2]. CCOP provided guidance on evaluating structural success based on four key factors including reservoir rock, trap, charge, and preservation. Each main geological factor is evaluated according to two aspects: existence and effectiveness. The probability of each factor according to the risk table is assessed subject to the level of documents and geological characteristics [3].

Although the approach is different, the foundation of the structural assessment process is basically geological knowledge, understanding and the petroleum system concept developed over time. Independent geological factors are selected to evaluate the probability of success including 5 parameters of source, reservoir, seal, trap, and migration. Each geological parameter is evaluated through geological criteria on a quantitative scale from good to poor. In this article, the author uses evaluation factors for each criterion proposed by the Petrovietnam Exploration Production Corporation (PVEP) in 2023 (Figure 1) [4].

When evaluating the probability of success of a prospect, Rose found that oil and gas companies tend to be over optimistic for structures in new areas. Whilst for structures with high reliability and many chances of success, predictions tend to be lower than actual results [5]. The "risk matrix" model proposed by Rose (Figure 2) evaluates the probability of success of geological factors according to many dimensions of information based on confidence levels of high (A) - medium (B) - low (C) according to the number of documents, knowledge/nature of geology (more or less) and according to geological information/exploration results from good (1) - average (2) - bad (3) [5]. The model has an advantage of flexibly applying to areas from a few to many documents, limiting the subjective factors of evaluators, being consistent with actual exploration results, and currently used by many foreign oil and gas companies such as Shell, Repsol, KNOC, JOGMEC etc. [6, 7].

According to Rose (2001), the area has been explored in detail. Many documents, geological objects/models have been successfully confirmed through drilled wells. The evaluation objects tend to be separated into two differently successful fields: Field A1 possesses many good quality documents (high confidence - A) and geological information rated from good to very good (1), objects directly linked with truly geological nature having a high chance of success, from 80% to 100%. Field A3 has many good quality documents (high confidence - A), geological information re-evaluated from very poor - poor, evaluation objects having a low chance of success, 0 - 20%. In cases, where many documents have good quality but the geological object is very complex, the assessment results cannot distinguish the assessment factor into either field A1 or A3, then it will be included in the area with medium confidence - B, classified into success fields of B1 - B2 - B3.

Field B1 possesses average quantity and quality of documents (confidence - B), criteria for evaluating results from fair to good (1), chance of success of 60 - 80%; Field B2 (40 - 60%) owns confidence B and average assessment criteria (2) or cannot be clearly assessed (50/50 chance); Field B3 has confidence B of documents and assessment criteria below poor - very poor (3), chance of success from 20 - 40%.

Similarly, low confidence (C) is classified for basins/

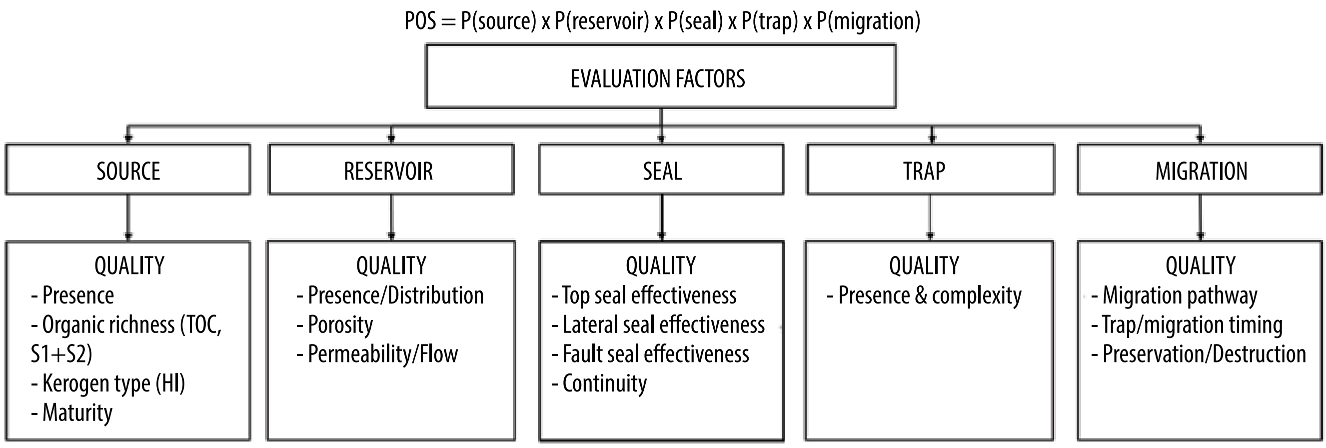
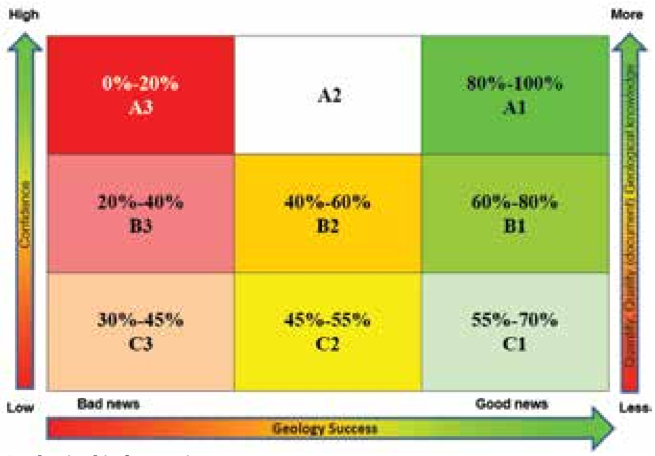


Figure 1. *Geological criteria to evaluate the probability of success [4].*



Geological information

(1) - Good geological information; (2) - Average geological information or 50/50

(3) - Bad geological information

Evaluate the level of confidence

(quantity/quality of documents, geological knowledge)

(A) - High confidence:

- Many documents (dense 2D seismic/3D, many wells)
- Good quality of documents; proven analog model
- Near analog/directly linked object
- Good geological understanding of object

(B) - Medium confidence:

- Average quantity and quality of documents (sparse 2D seismic), few drilled wells
- Evaluated analog model
- The linked/analog object is relatively far away.
- Geological nature is complex and not well understood.

(C) - Low confidence:

- No/limited documents (no/few seismic documents)
- No wells; linked/analog object very far away
- Understanding of geological objects is limited.

Figure 2. *"Risk matrix" model according to Rose [5].*

areas that have not been explored, with no or very few documents, preliminary geological models/concepts, assessment factors falling into success field C1 (30 - 45%) - C2 (45 - 55%) - C3 (55 - 70%) with a chance of success corresponding to evaluation criteria of good (1) - average (2) and poor (3) (Figure 2).

Based on the analysis of models for assessing the probability of geological success proposed by different authors in the above section, the authors will apply the assessment of the probability of geological success according to the "risk matrix" model by Rose for the pre-Cenozoic carbonate prospect HRA-E in the Northern Song Hong basin. The chance of success (risk) of geological factors is assessed in the following steps: (i) Evaluate the reliability of documents, geological models/understanding; (ii) Evaluate the geological information results according to the quality scale from good – poor, and (iii) Evaluate the chance of success according to the matrix model, combining evaluator experience and exploration results/regional success rate.

3. Evaluating the probability of success of prospect HRA-E

3.1. Location and geological information of HRA-E

Prospect HRA-E belongs to Block 106, which is located in the Northern Song Hong basin,

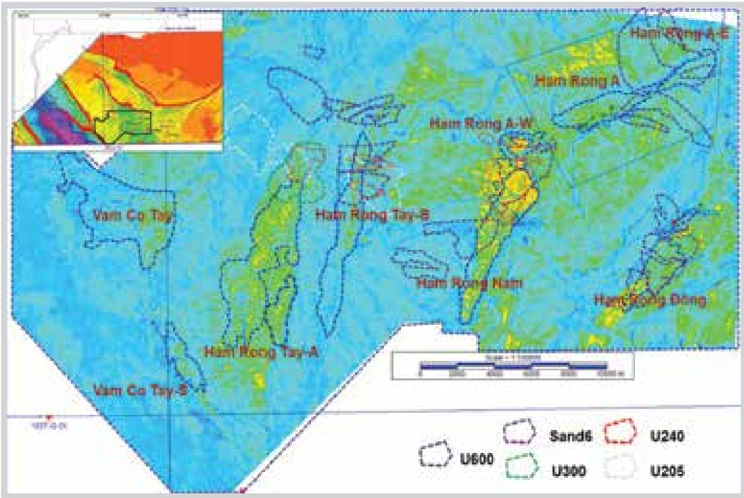


Figure 3. *Location of HRA-E in Ham Rong trough [9].*

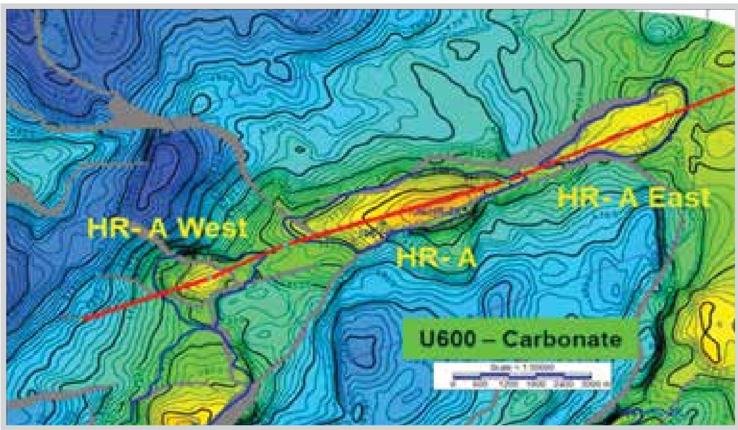


Figure 4. *Map of carbonate basement structure (U600) of structural clusters HRA-W, Ham Rong & HRA-E.*

about 50 km from Hai Phong port at a water depth of 25 - 30 m. Block 106 borders Ha Noi trough to the northwest, Blocks 100 & 101/04 to the northeast, Blocks 103 & 107 to the south. From 1983 to present, by different operators, there are 14,476 km of 2D seismic and 2,224 km^2 of 3D seismic acquired and 13 wells drilled, of which 5 wells drilled into Miocene - Oligocene sandstone and 8 wells targeting pre-Cenozoic carbonate basement. In Block 106 area, there are important discoveries in carbonate basement objects such as Ham Rong field, discovery Ham Rong Nam, discovery Ham Rong Dong [8, 9].

HRA-E is adjacent to the northeast of Ham Rong field of Block 106 (Figure 3). The study area is covered by 650 km^2 of 3D seismic that were PSDM reprocessed by PVEP in 2014 with the object being deep pre-Cenozoic carbonate basement rocks. In addition to seismic data, well logs, reservoir testing documents, sample analysis results, well summary reports, and regional geological reports of the block and neighboring areas are also used to assess the probability of success for the prospect.

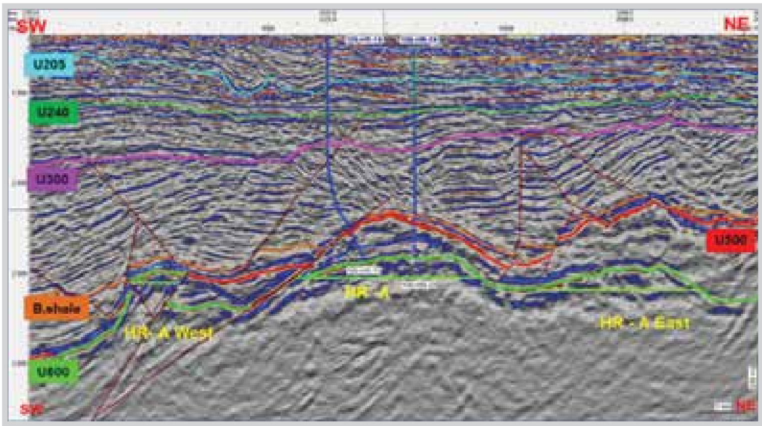


Figure 5. *Seismic section through structural clusters HRA-W, Ham Rong & HRA-E.*

The HRA-E basement structure is an extension of the Ham Rong structure trend to the northeast and separated from the Ham Rong field by a saddle (Figure 4). The carbonate basement is identified reliably on the U600 reflection surface map with a depth nearly equivalent to the Ham Rong discovery (about 3,290 m), a closed area of 3.75 km^2, structure height of 270 m (lower than Ham Rong). The basement object is completely covered by the sedimentary set below the U500 reflection boundary. The petroleum system has been proven by successfully drilled wells in the area.

3.2. Evaluating the probability of prospect success

3.2.1. Source rock evaluation

The probability of existence of mature source rock is assessed through the criteria of presence, quality (richness, kerogen type) and maturity according to the steps described in Section 2. Source rock assessment data from direct sample analysis results of drilled wells YT-1X, HR-1X, 2X, HRD-1X, HRN-1X (Figure 6) in the area shows that the source rock is of good quality with highly reliable assessment data - A.

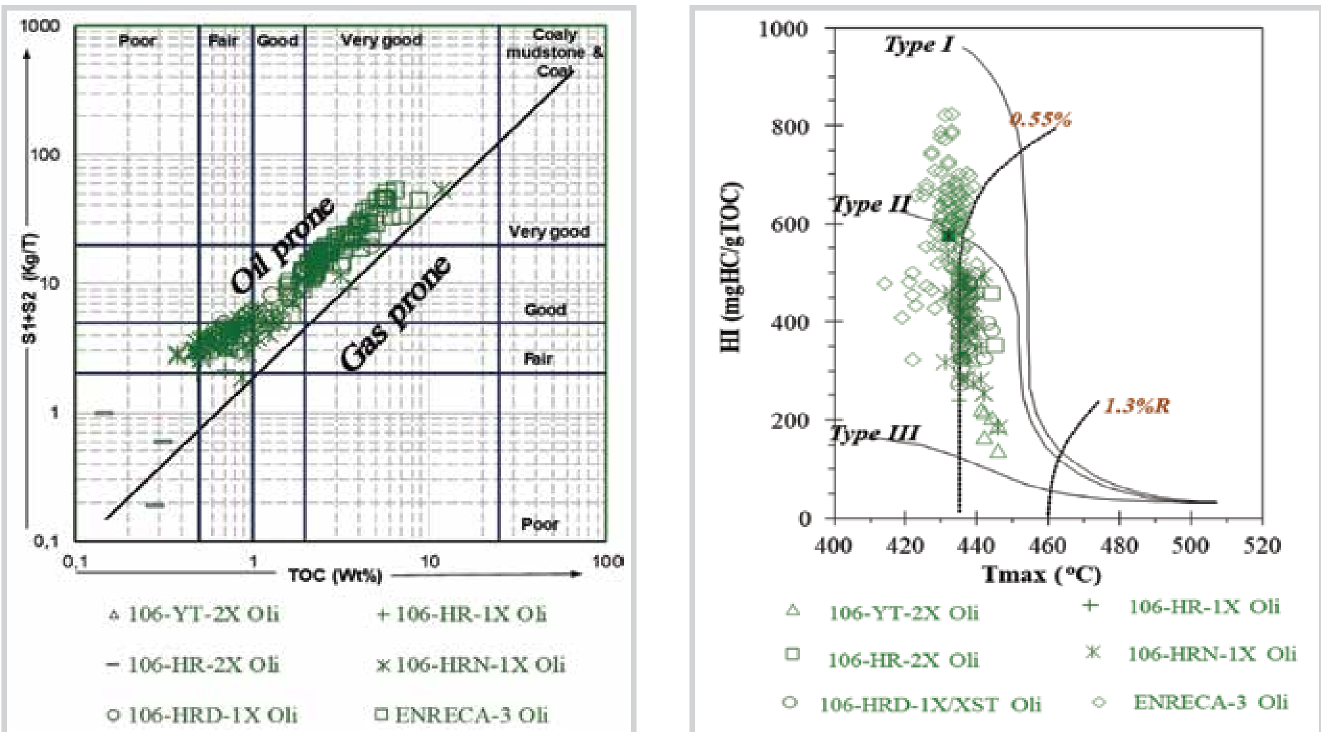


Figure 6. *Result of geochemical analysis of Oligocene source rock in Ham Rong area.*

Exploration results have shown many discoveries of good oil and gas flows, proving the presence of mature source rock set in the area. Geochemical analysis of Oligocene source rocks (Figure 6) shows that most samples have good to very good organic matter (TOC > 2%); good producing potential (S1 + S2 > 5mg/g). Kerogen belongs to types I and II; the maturity level is at the threshold of producing oil and wet gas (Ro = 0.75 - 1.2%). All criteria for evaluating the quality of source rock range from good - very good (1), assessed directly from well data, with good connectivity, close to structure, and high reliability (A). The criteria for evaluating source rock quality are classified into field A1 (Figure 2), the effective probability of existence of source rock is assessed as 100% (Psource = 1).

3.2.2. Reservoir Evaluation

Pre-Cenozoic fractured cavernous carbonate rock were discovered in 8 exploration and appraisal wells of DS-1X, YT-1X, YT-2X, HL-1X, HR- 1X, HR-2X, HRN-1X, HRD-1X at Block 106. According to seismic facies, the basement rocks in HRA-E are closely connected and quite similar to the Ham Rong basement zone. This parameter is rated with high reliability - A.

The quality of fractured basement rock is evaluated based on the following main criteria: Porosity, Phi*NTG coefficient, permeability criteria, flow capacity, thickness, and secondary changes. Carbonate basement rock has a total porosity of 5 - 7%. The thickness of the reservoir rock set is from 100 - 150 m. The ratio of effective thickness to gross thickness (NTG) is from 10 - 35%. Calculation results from DST data show that the permeability value varies greatly from ~11 - 500 mD, and the flow rate is very good. All evaluation criteria range from good to very good.

The structures near the discovered wells of HR-1X, 2X, HRN-1X and HRD-1X develop in the same structural zone, about 2 - 4 km apart, have a high level of reliability, similar to the result of wells in the area. The value of reservoir success probability is at 90% (Preservoir = 0.9).

3.2.3. Seal evaluation

Seal are evaluated based on the criteria of presence and effectiveness through lithological characteristics, thickness, continuity and fault seal capacity.

The basement structure is covered by thick sediment U500 on the flanks and top of the structure (Figure 5). Overlying HRA-E, there exists a top seal layer that is clearly and directly proven through HR-1X & HR-2X well documents. Top seal rocks are claystone, 20 - 30 m thick, found at drilled wells, good correlation with 3D seismic data.

The fault seal capacity is assessed at a good level (1), similar to the normal seal faults found in the structures Ham Rong and Ham Rong Nam. However, the object U500 has a complex geological nature; the reliability of the fault seal ability and the continuity of the clay set are assessed at average level (B). The criteria for effective seal risk assessment with successful zone is at level B1 (Figure 2). POS for the seal element is determined to be 80% (Pseal = 0.8).

3.2.4. Trap evaluation

Traps are evaluated based on criteria such as quality, level of certainty in seismic data and other documents, velocity conversion, trap type assessment map, complexity,

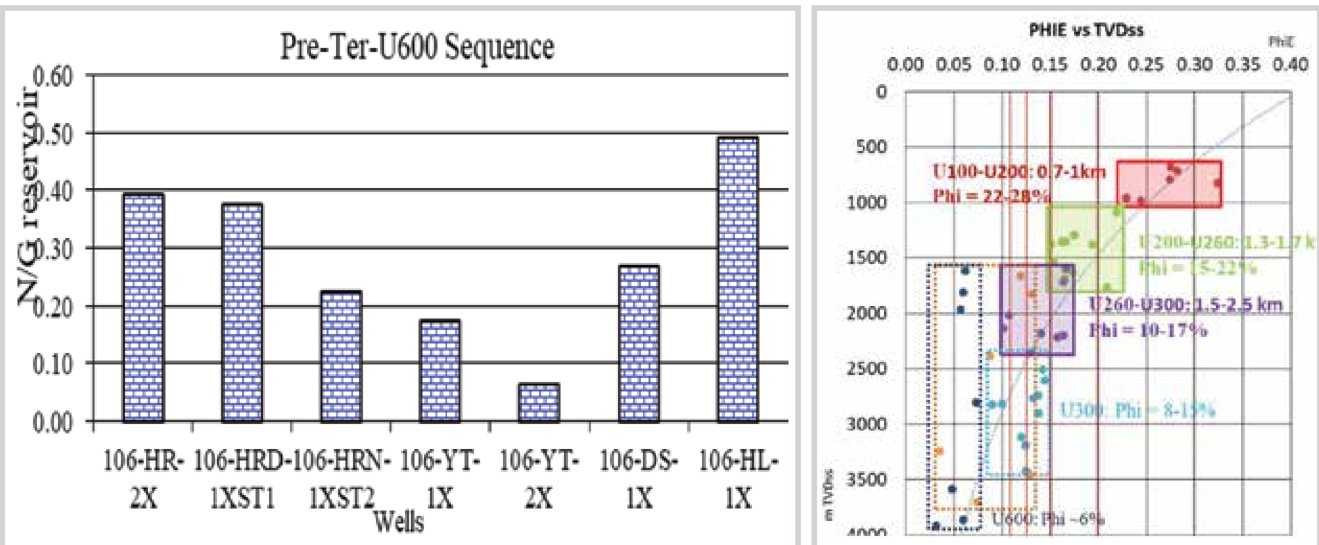


Figure 7. *Property of carbonate basement rock in Ham Rong area.*

and trap closure. Figure 5 shows the seismic correlation from prospect HRA-W to HR-A and HRA-E. Interpretation and correlation of seismic documents are clear. The conversion of time to depth to accurately determine the depth of the structural top is considered reliable.

The basement surface U600 is well observed on the seismic section and quite reliable on the U600 map with the depth nearly equivalent to the Ham Rong discovery. The trap was the 2-way closured structural trap and completed at the end of the Oligocene and. The trap develops in the same northeast - southwest structural trend, similar to the discovery of oil/gas as in the structures Ham Rong, Ham Rong Nam and Ham Rong Dong.

The trap evaluation criteria is good - very good (1), with high reliability (A). The probability for presence of trap is 90% (Ptrap = 0.9).

3.2.5. Migration evaluation

The prospect HRA-E has a favorable location, near the source of oil and gas generation (Figure 4). However, the basement block is covered on both sides by the U500 sediment layer, which limits the direct migration of oil and gas into the trap.

The traps formed early are cavernous, fractured carbonate basement blocks that were buried before the Cenozoic, so they are favorable in terms of receiving oil and gas. The trap is located in an area stable in tectonic activity and good in cumulative preservation.

Time, migration, and preservation factors are evaluated according to the evidence of oil and gas discovery in the same structural zone of Ham Rong and Ham Rong Nam; the trap was formed and completed before the main hydrocarbon migration time; tectonic activities stabilized after traps were formed.

Criteria for evaluating the migration line are quite favorable, average reliability (B), success field B1 (Figure 2). The probability of success is 70% (Pmigration = 0.7).

3.2.6. POS evaluation result

The probability of discovering oil and gas in the basement block of the structure HRA-E by applying the risk matrix model and the evaluation criteria of 5 geological factors gives a success propability of 45%. The rate of exploration wells encountering carbonate basement objects is 6/6 wells (100%), of which 3/6 exploration wells discover oil and gas (50%). The results of the probability of geological success (POS) assessment of the structure HRA-E are consistent with the exploration result in the area.

4. Conclusion

Assessing the probability of geological success according to the level of confidence in geological information and understanding of the object is currently used by many oil and gas companies. By applying the method to evaluate the probability of geological success of the structure HRA-E in Block 106, north of the Song Hong basin, each independent geological element is analyzed in detail with specific geological criteria. The assessment results are consistent with the reality of the probability of success of exploration drilling in the area and can be applied to structural assessment for PVEP projects.

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