Basin Analysis and Hydrocarbon Potentials of The Bristol Bay Basin, Alaska Peninsula

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ABSTRACT

In this study, basin analysis and hydrocarbon potentials of the Bristol Bay Basin, Alaska Peninsula, was evaluated to identify potential leads/prospects, estimate recoverable reserves and recommend possible key areas for further exploration activities. The method adopted involved detailed well-log interpretation, integrated petroleum system analysis, determination of petrophysical properties, seismic facies analysis, fault & horizon mapping, time-to-depth conversion, risk analysis of identified prospect(s) and reserve calculation. The basin is characterised by strike-slip faulting, extensional faulting and transpressional folding. Two horizons were mapped. Two plays were identified: Tertiary and Mesozoic age plays. Two genetic sequences were identified with their associated system tracts. Seismic facie was interpreted based on reflection amplitudes, reflection geometry and continuity. The continuous high and low amplitude facie (D) and the high and low amplitude convergent facie (Cbhl) correspond to the sands of LST and have the highest reservoir percentages. The petrophysical analysis gave porosity values ranging from 19% to 27% and Net/Gross values ranging from 0.70 to 0.90 for the Tertiary Tolstoi Formation, having 74.73 MCF of gas and 43% geologic chance of success. Risk analysis shows that the Tertiary Tolstoi prospect may be compromised by the presence of gas chimneys and the sealing integrity of the trap, which is a 3-way closure. Based on the limitations encountered in this study, acquiring 3-D seismic data with a dominant frequency of 30 Hz to 40 Hz, checkshot data and adequate fault-seal analysis could enhance the success rate of hydrocarbon exploration in the Bristol Bay Basin.

Keywords - Basin Analysis, Hydrocarbon, Seismic Facies, Petrophysics, Bristol Bay.

INTRODUCTION

The Bristol Bay Basin, situated along the Alaska Peninsula in southwestern Alaska, is a significant geological feature that has drawn considerable attention from the scientific community as a result of its potential for hydrocarbon exploration and production. The Bristol Bay Basin (BBB), called the North Aleutian Basin, located in Southwestern Alaska (Fig. 1), is encompassed in the Bristol Bay Area Plan, which contains high potential for oil and gas reserves. This sedimentary basin, which covers an area of approximately 25,000 square kilometres, has been the subject of extensive research and exploration efforts aimed at unravelling its complex tectonic history, stratigraphic architecture, and hydrocarbon prospects [1] - [3]. The basin is located on a back-arc setting of the southeastern Bering shelf. It is isolated from the Pacific Ocean by the Alaska Peninsula and formed due to the Pacific Plate subducted under the North American plate along the Aleutian trench at an oblique angle during the Mesozoic era [4]. The Basin lies between latitude 57 - 59°N and longitude 157 -162°W. It is roughly 300 km long, parallel to the Alaska Peninsula, and 75 km to roughly 200 km wide, with water depths ranging from 15 to 700 feet. The basin is remarkably asymmetric, trending northeast,

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extending onshore beneath the lowlands along the northwestern shore of the Alaska Peninsula and Bering Shelf, where several wells have penetrated it. It has a maximum basement depth of at least 6 km in the south [5] - [6] and gradually thins to less than 500 m north. Twenty-eight wells have been drilled onshore on the Alaska Peninsula to the southeast of the Bristol Bay Area Plan with at least modest shows of oil and/or gas since oil and gas exploration began in the region.

Greater resource potential may be found in the Bristol Bay basin, with a technically recoverable resource assessment estimated to be about 753 million barrels of oil and natural gas liquids and 244 million m^3 (8.6 trillion ft^3 [TCF]) of natural gas [3], [7]. Although past explorations have not yielded commercial production, there are strong indications that the necessary components of active petroleum systems exist [8]. This categoric history identifies the Alaska Peninsula-Bristol Bay basin as a frontier basin, generating continuing interest in the search for oil and gas. The purpose of this study is, therefore, to further evaluate the hydrocarbon potential of the Bristol Bay Basin using an integrated play-based approach in a bid to identify potential leads and prospects, encourage better prospect assessment, optimise well placement, and contribute to a better understanding of the basin's petroleum systems and potential for future exploration and development.

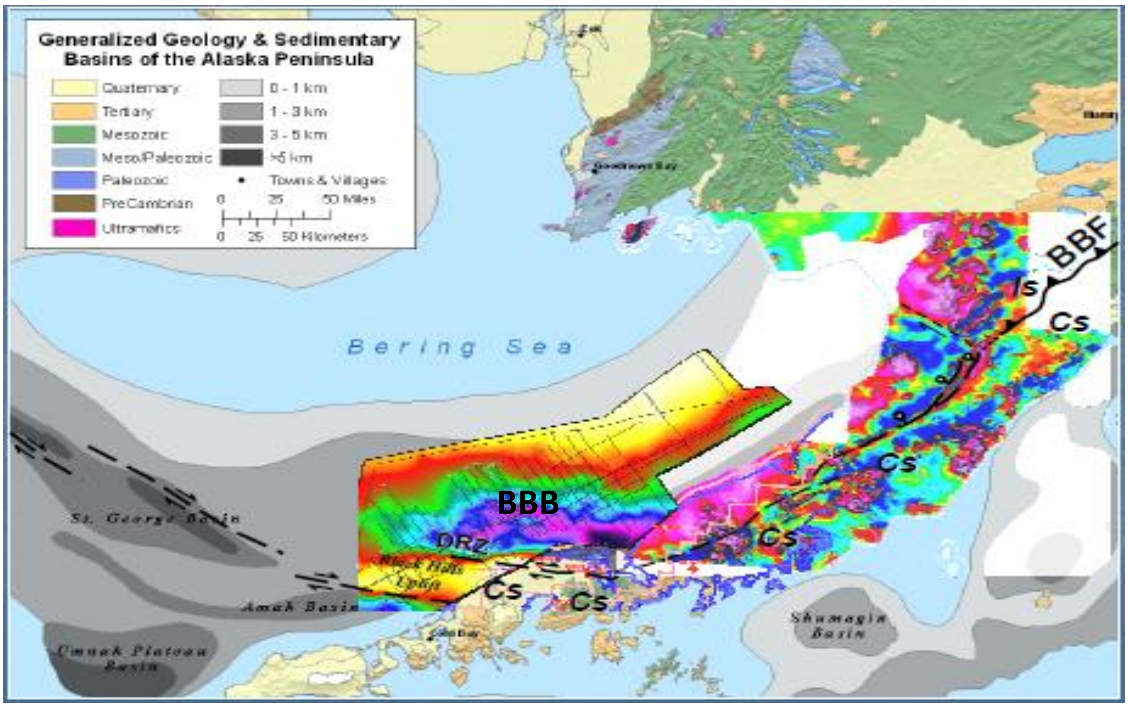

Fig. 1: Location map showing the regional setting of the Alaska Peninsula, Bristol Bay Basin (BBB) and the Basin Extent [1].

Geology And Structural Setting

The Bristol Bay basin was formed during the Mesozoic as a result of the collision between the North American and Pacific Plates and the subsequent subduction of the Pacific plate. Associated sub-environments identified include a Back-arc basin and the Bristol Bay Basin [9] – [10]. From the Mid Jurassic to late Cretaceous, the Kamishak, Kialagvik, Naknek, Stanickovic and Herendeen Formations were deposited in the Alaska Peninsula area of the basin. This period was mostly characterised by volcanism, uplift and erosional activities. Also, the Tolstoi, Stepovak, Unga, Bear Lake and Milky River Formations were deposited from Palaeocene to Pliocene. During the Paleogene and Neogene periods, the basin experienced a complex interplay of compressional and extensional tectonic regimes, resulting in the formation of various structural features such as folds, faults, and unconformities [9], [11] – [12]. These structural elements have played a critical role in the distribution and trapping mechanisms of potential hydrocarbon reservoirs within the basin. It is important to note that the Kamishak, Kialagvik and Tolstoi Formations served as the major source rocks in the basin. In contrast, the Bear Lake, Tolstoi and Naknek Formations served as the major reservoirs in the Basin [11] – [13]. Exploration efforts in the Bristol Bay Basin have revealed the presence of numerous potential source rocks, including coal-

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bearing intervals and organic-rich shales [14]. Various reservoir units, such as sandstones and conglomerates, have also been identified, making the basin an attractive target for hydrocarbon exploration [15].

METHODOLOGY

The data used for this study was provided by the American Association of Petroleum Geologists (AAPG), and the data include 73 2-D seismic lines, 17 wells with well log suites, geomagnetic, gravity map and surface geologic map, and a summary of geopolitical and geologic posters. The workflow applied in this study extends from basin analysis and Paleogeography, petroleum system analysis, well log interpretation, seismic interpretation, sequence stratigraphic interpretation, seismic facie analysis, prospect identification, volumetrics and reserve estimation. Basin analysis involved a detailed study of the basin tectonic framework as the primary influence on stratigraphic fill, play element distribution, and thermal history, thereby serving as the foundation for understanding the Bristol Bay Basin's inherent petroleum system(s). The well-log interpretation was carried out using the available well logs from which sand tops were mapped and correlated across the wells in the northwest-southeast direction. Using the density and sonic log from the OCS-COST-1 well, a synthetic seismogram was generated to tie the mapped sand tops to the seismic. Well-log sequence stratigraphic interpretation was done using the Galloway Sequence Model to identify genetic sequences and their corresponding system tracts. Seismic facies analysis was carried out based on three primary parameters, reflection amplitudes, reflection geometry and continuity of reflection [16] – [17], along key seismic traverses to identify the seismic facies indicative of exploration play facies. Seismic structural interpretation was also done on the seismic sections to generate a seismic time map, depth maps, fault planes and isochore maps. The petroleum play maps were generated and superimposed to identify the play sweet spot, which consisted of the leads and prospects. Based on this information, the volumetrics for the prospect identified were evaluated, and the risks involved in exploring the potential prospect and leads identified were identified. All the interpretations were done using the Petrel interpretation software in the Workstation available at the Petroleum Geoscience Laboratory, Nnamdi Azikiwe University, Awka.

RESULTS AND DISCUSSION

The well-log interpretation revealed an uplift in the Mesozoic Formations and subsidence in the Tertiary Formations. The source rocks and reservoir rocks as well as the seals were found to be extensive across the basin (Fig. 2). From the well log sequence stratigraphic interpretation using the Galloway Model, two genetic sequences and their associated system tracts were identified. The LSTs and sands of the HSTs are the potential reservoirs, and the TSTs and Shales of the HSTs constitute the source/seal units (Fig. 3).

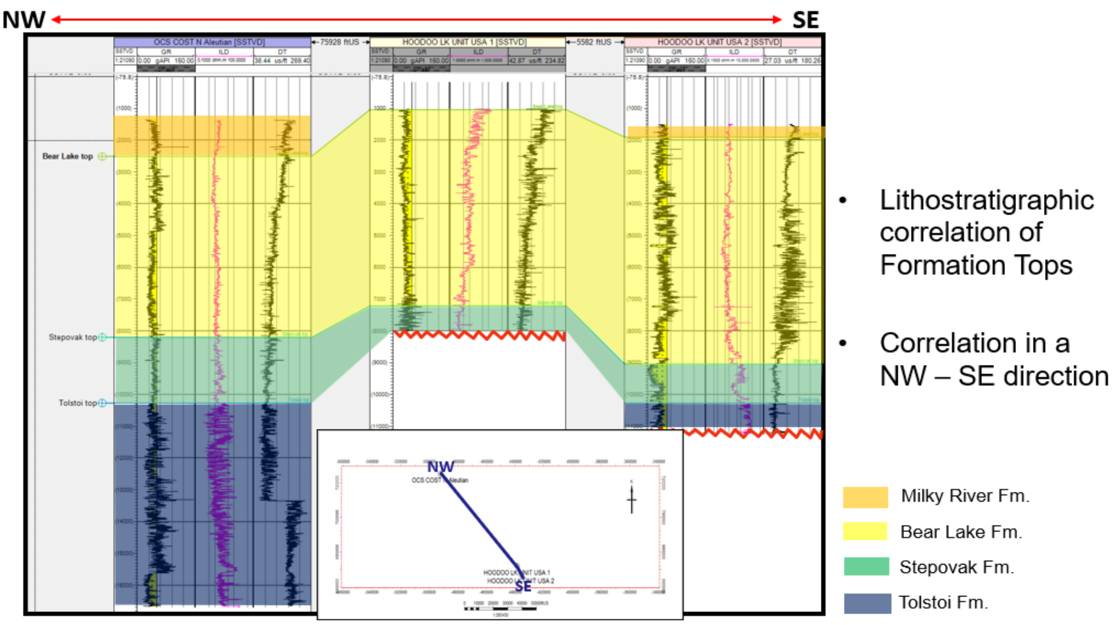

Fig. 2: Lithostratigraphic correlation between Cost 1, Hoodoo Lake 1 and Hoodoo Lake 2

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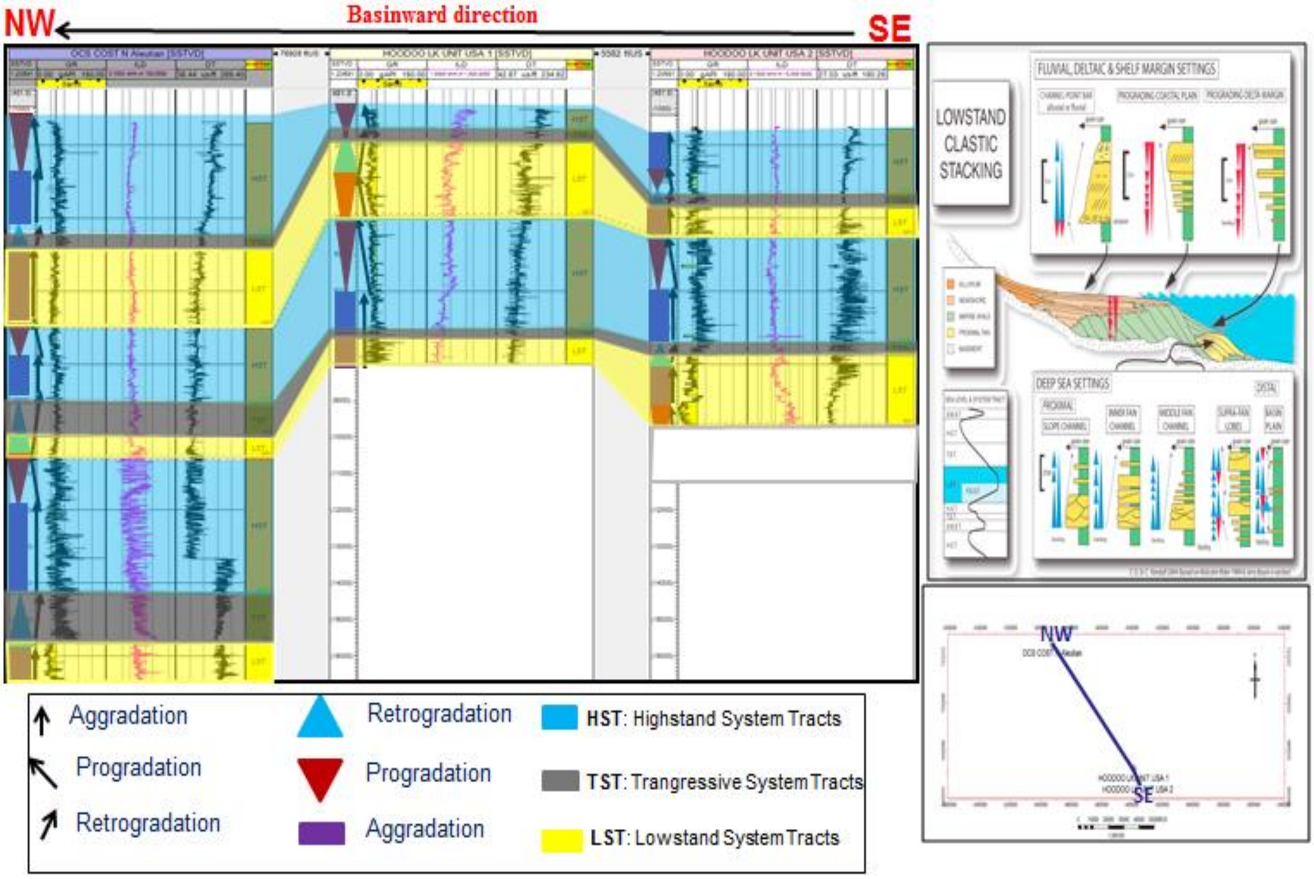

Fig. 3: Sequence Stratigraphic Interpretation using Galloway model

The seismic facies were interpreted based on reflection amplitudes, geometry and continuity of reflections. Five seismic facies were identified, and they include: high and low amplitude discontinuous, shingled to chaotic (Bhl), high amplitude discontinuous, shingled to chaotic (Bh), high and low amplitude convergent (Cbhl), high amplitude convergent (Cbh), and continuous high and low amplitude parallel (D) (Fig. 4 and Fig. 5)

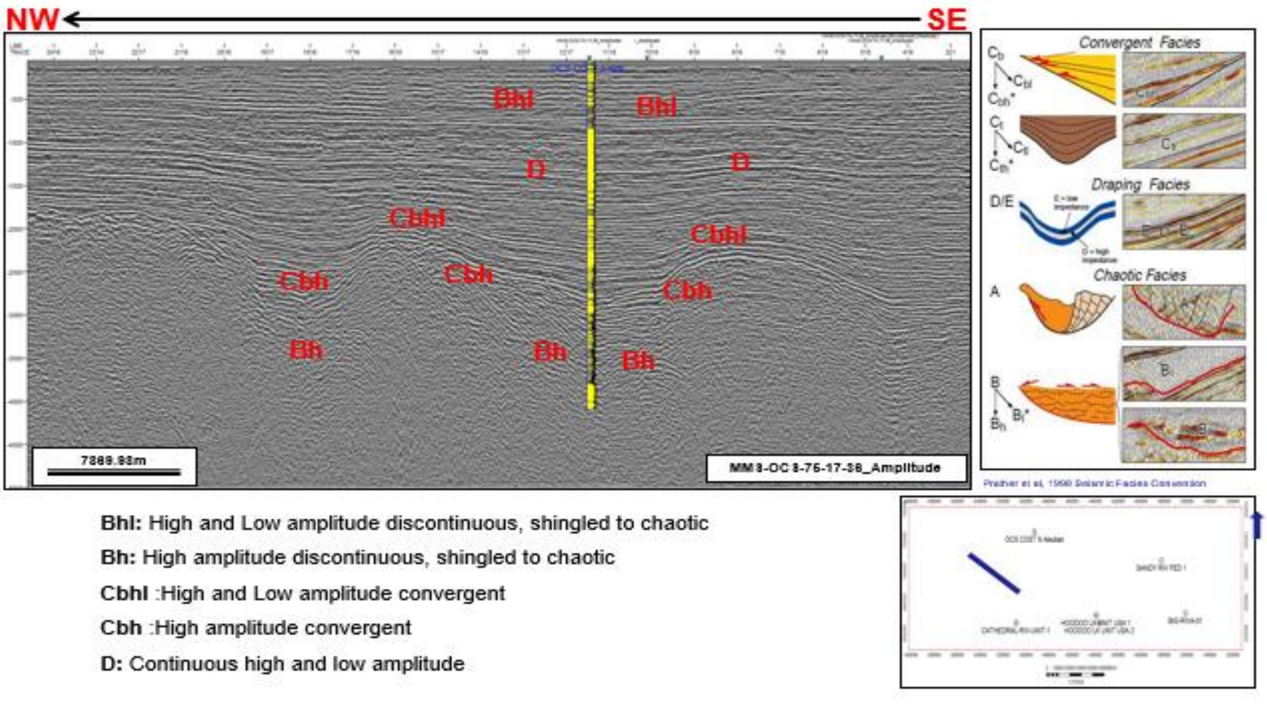

Fig. 4: Seismic Facie analysis on MMs-OCS-75-17--36_Amplitude

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Integration of sequence stratigraphic interpretation and seismic facies analysis indicated that the D and the CBHL seismic facie correspond to the Sands of the LSTs and have high reservoir percentages, with the D seismic facie ranking highest than the other seismic facies identified (Fig. 6).

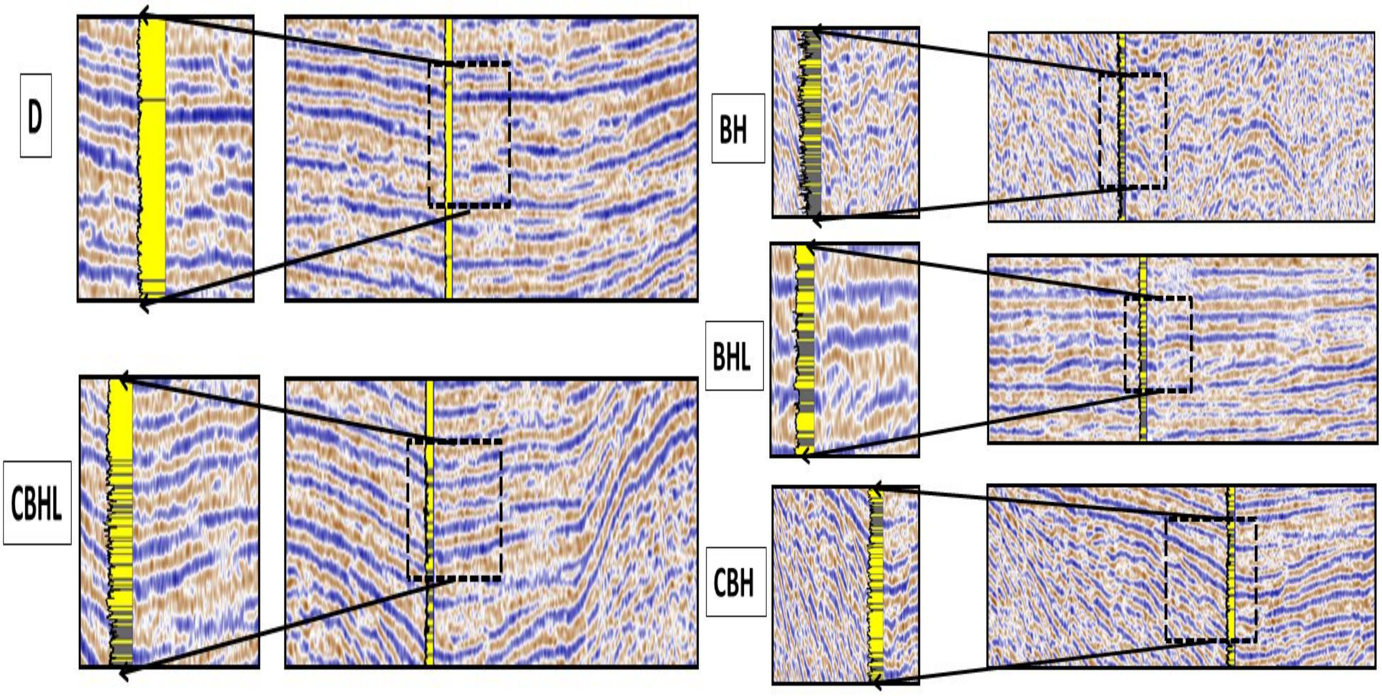

Fig. 5: Detailed view of the interpreted seismic facies

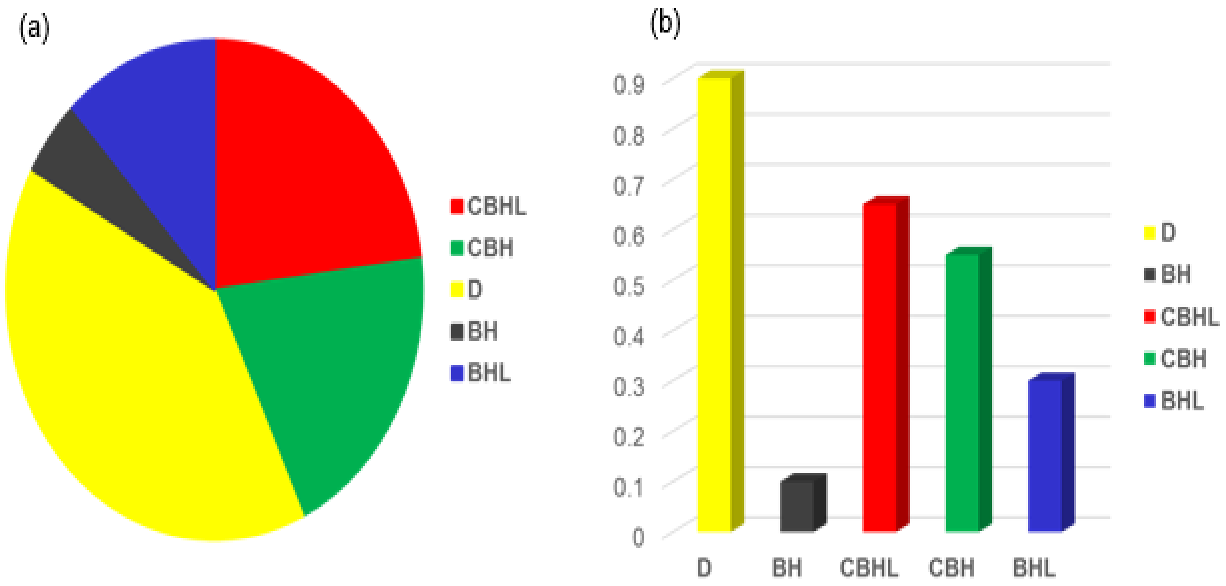

Fig. 6: Reservoir percentage ranking of the interpreted seismic facies

Using the Petrel software to interpret the 2D seismic sections, an age model was generated, which consists of geologically consistent and more detailed stratigraphic layering on every section across the seismic lines (Fig. 7). Stratigraphic correlation across the seismic sections indicated uplift toward the northwest of the Basin, which is as a result of the Black Hills Uplift. The structural framework interpretation indicates the presence of normal and thrust faults playing essential roles as migration pathways and hydrocarbon traps.

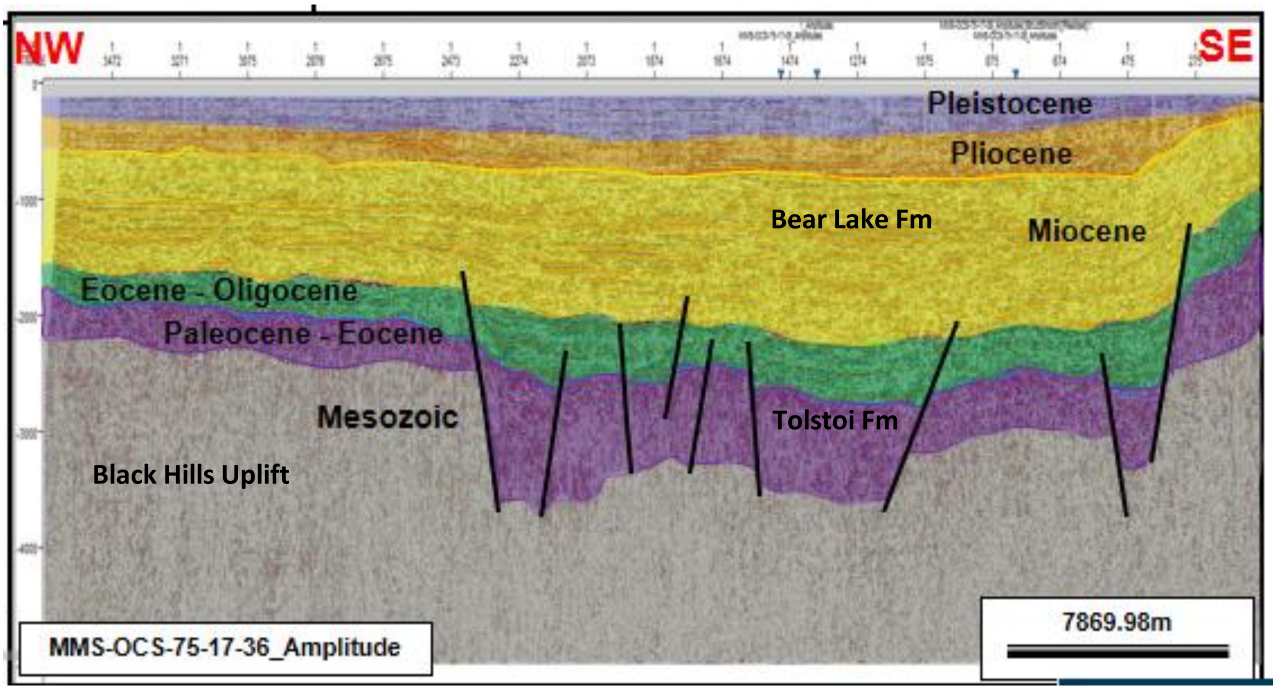

Fig. 7: MMS-OCS-75-17-36 Amplitude seismic line showing an age-modelled section, interpreted faults and horizons.

Two horizons were mapped across the 73 2-D seismic lines: the Tolstoi Reservoir and the Bear Lake Reservoir (Fig. 8). Surface maps were generated for the interpreted horizons (Tolstoi and Bear Lake Formations). These surfaces generated in the time domain were then converted to depth maps using a look-up function. The depth maps helped identify prospects and possible areas for further hydrocarbon exploration. Time and depth structure maps of the mapped horizons highlight the closure and trap mechanism for the interpreted reservoirs (Fig. 9).

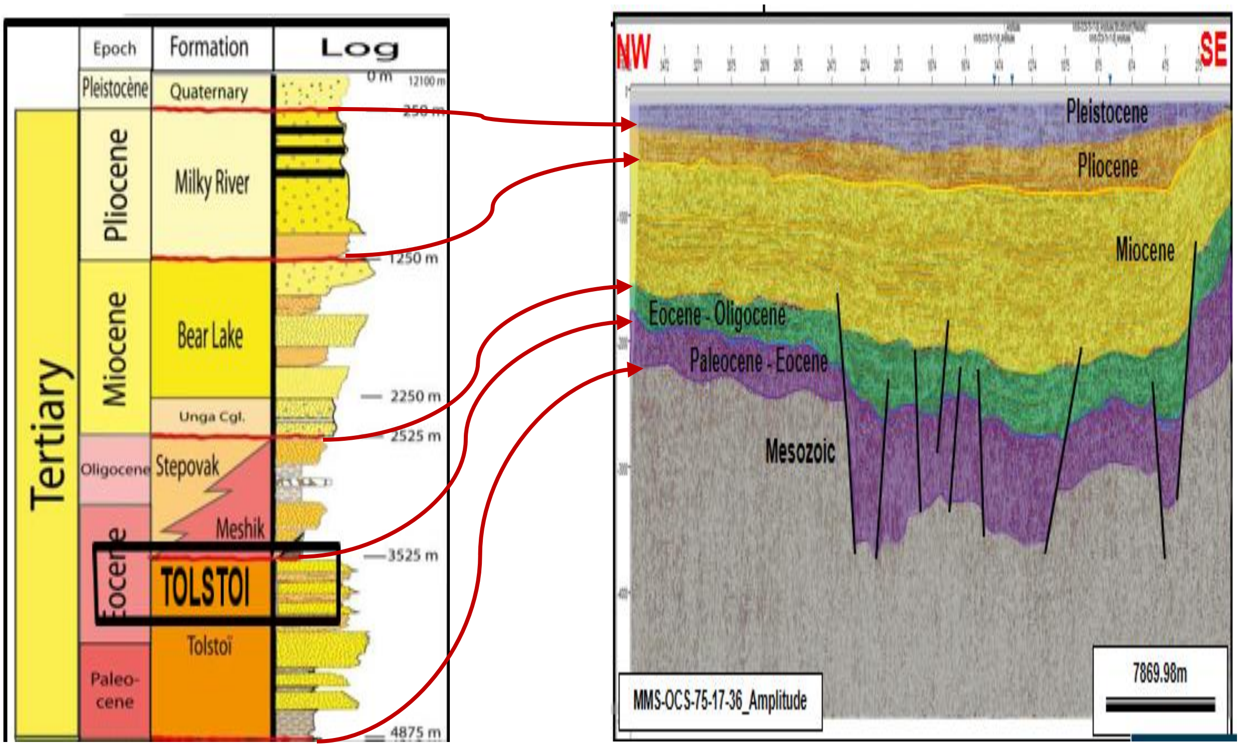

Fig. 8: Seismic section with interpreted faults and horizons correlated to the basin stratigraphic-fill chart.

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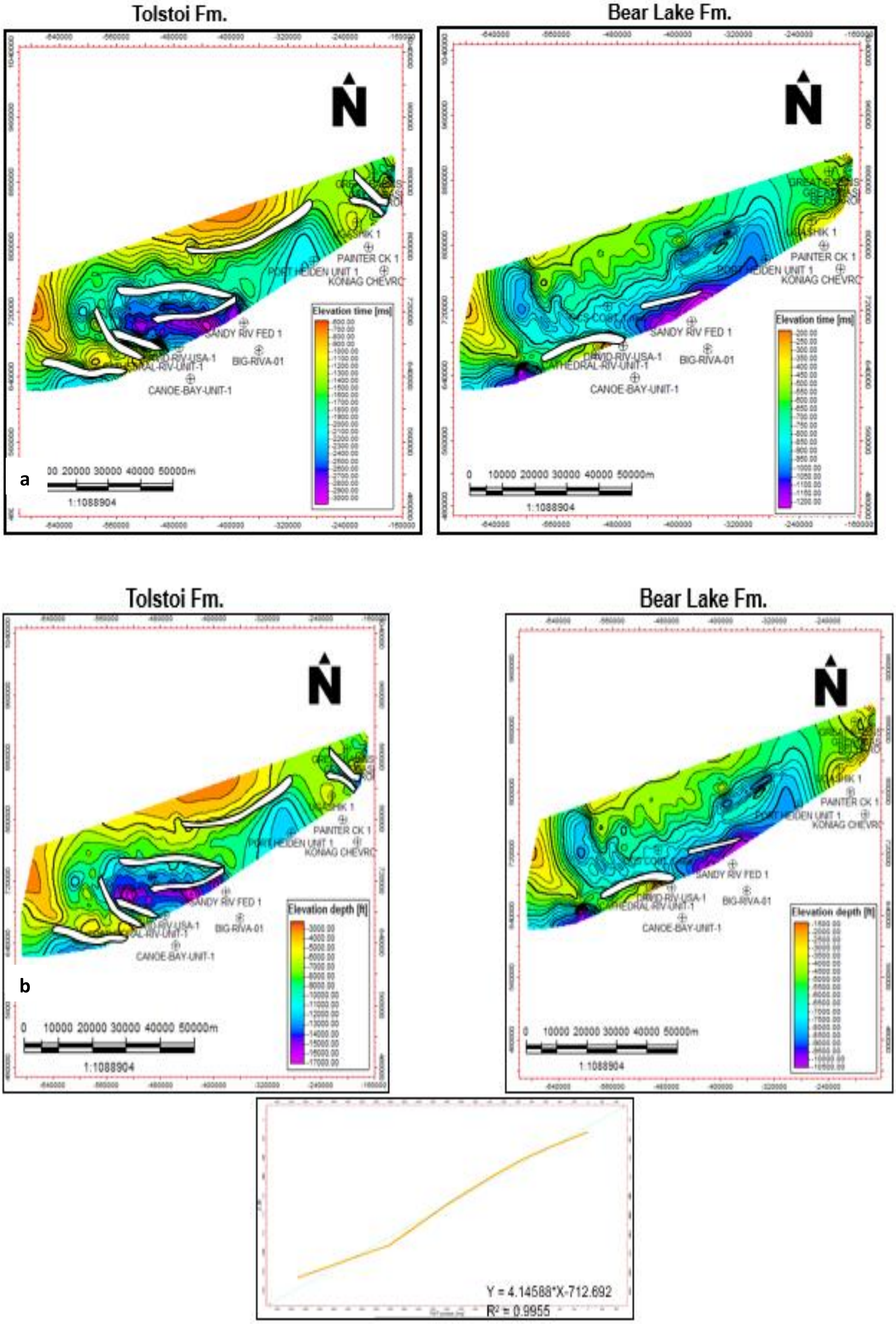

Fig. 9: (a) Time structure map for Tolstoi Formation and Bear Lake Formation, (b) Depth structure map for Tolstoi Formation and Bear Lake Formation.

One prospect and two leads were identified in the Tolstoi formation. The prospect is a 3-way dip fault-dependent closure (Fig. 10). Two leads were identified for the Bear Lake Formation.

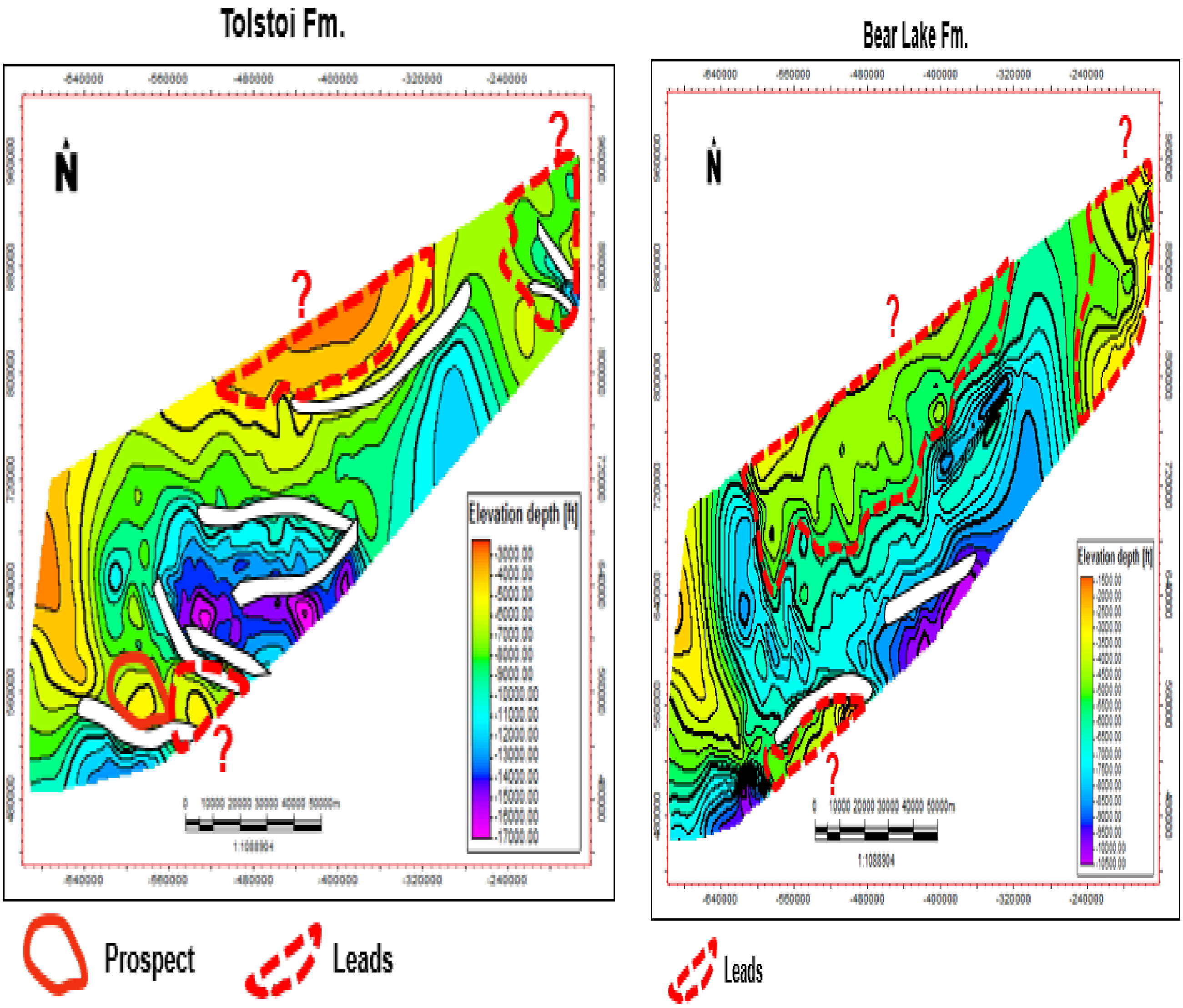

Fig. 10: Prospect and Leads identified for Tolstoi and Bear Lake Formations

The Petroleum play element maps absorbed within the depth structure maps using results from interpreted seismic sections and well log data were used to conduct the petroleum fairway analysis (Fig. 11). The Tolstoi source/reservoir rock and the Bear Lake reservoir rock were seen to be extensive. The seal was seen to be regional and extensive but absent towards the black hill uplift area. Due to buoyancy along faults, the migration pathway is interpreted to be up-dip and lateral. Structures include faults and anticlines. There is a perfect timing between trap formation and hydrocarbon generation, migration and accumulation within the Bristol Bay Basin.

Superimposing the play elements clearly defines the play sweet spot where all the petroleum key elements coincide, confirming a working hydrocarbon system. Three leads and one prospect identified for the Tolstoi Formation and Bear Lake Formation coincided with regions of sweet spots (Fig. 11f). Careful study of the seismic sections indicates the presence of prominent gas chimneys occurring due to the presence of an uplifted basement (Black Hills Uplift) which have greatly compromised the sealing integrity of the Bristol Bay basin and might explain the presence of naturally occurring oil seeps in the region.

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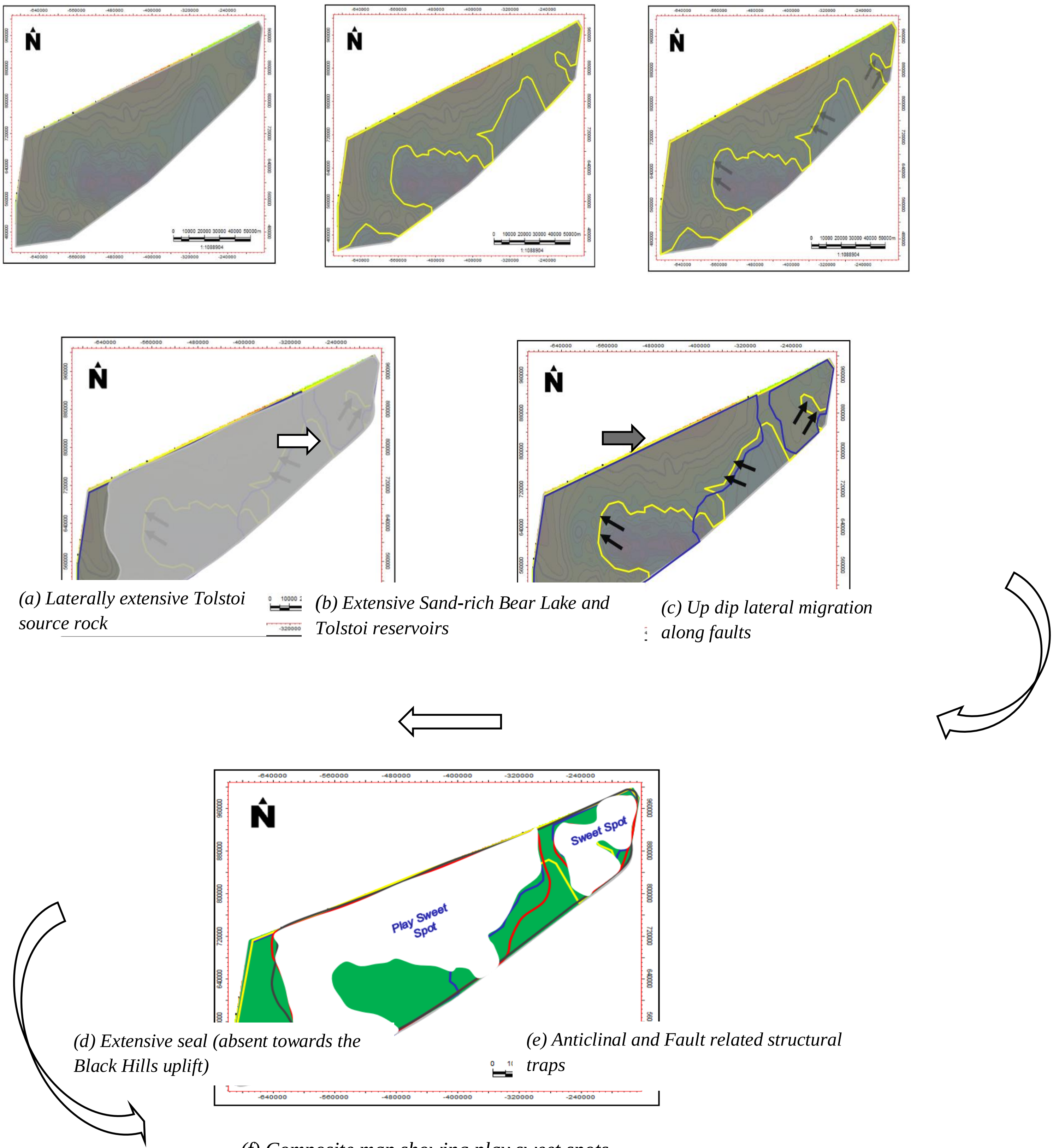

(a) Laterally extensive Tolstoi source rock

(b) Extensive Sand-rich Bear Lake and Tolstoi reservoirs

(c) Up dip lateral migration along faults

(d) Extensive seal (absent towards the Black Hills uplift)

(e) Anticlinal and Fault related structural traps

(f) Composite map showing play sweet spots

Fig. 11: The areal play outline showing the approximate vertical coincidence of all the elements of the petroleum system for the Tertiary Play

Based on the risks associated with the gas chimney and considering all the key petroleum elements, the area was divided into blocks (NAU-460, NAU-461 and NAU-470) and ranked based on the identified lead and prospects (Fig. 12). The integrity of the petroleum elements was ascertained by assigning confidence values

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with which the play chance of success (POS) and geologic chance of success for the prospect were calculated (Table 1).

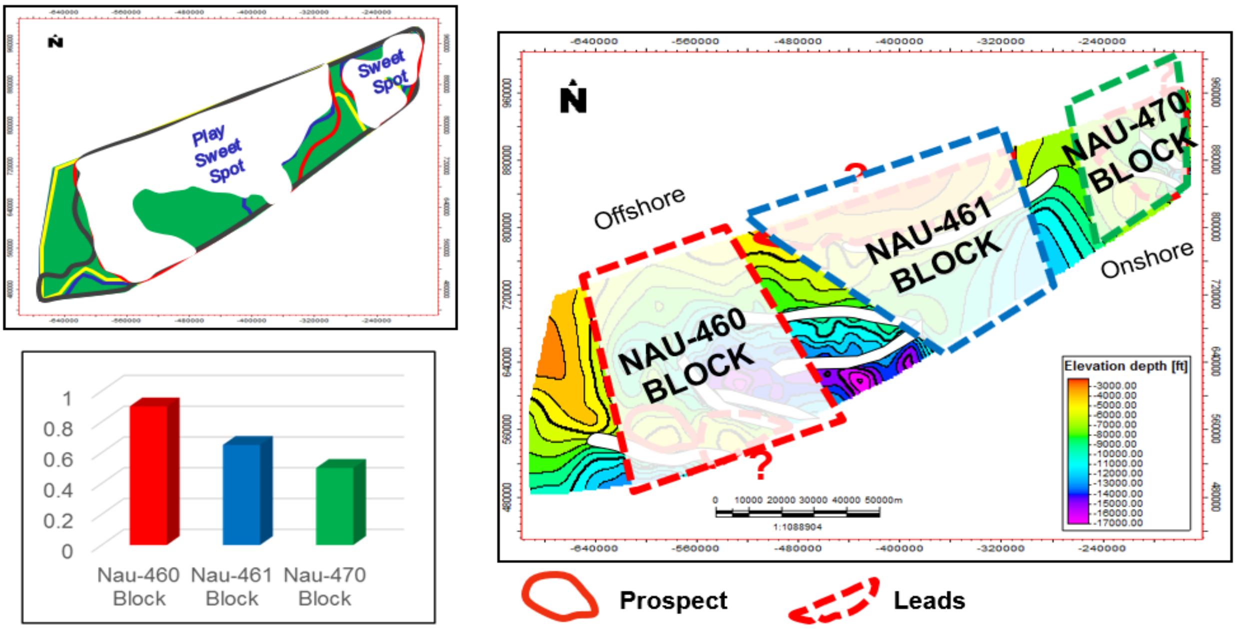

Fig. 12: Block ranking of the Assessed area.

Table 1: Calculation of geologic

S/N	Petroleum System Element	Assigned confidence value
1	**NAU Play-1 (Tertiary)**	
	Source (Tolstoi Formation)	1.0
	Reservoir (Tolstoi sand member, Bear Lake Formation)	0.9
	Trap (3-way fault assisted closure)	0.7
	Seal (Tolstoi Shale member, Milky River Formation)	0.8
	Timing	1.0
	Play Chance of Success	**0.50**
2	**NAU Play-2 (Mesozoic)**	
	Source (Kamishak Formation, kilgvik Formation)	1.0
	Reservoir (Naknek Formation)	0.5
	Trap (fault dependent traps)	0.7
	Seal (Staniukovich Formation)	0.7
	Timing	1.0
	Play Chance of Success	**0.25**
3	**Prospect (Tertiary Tolstoi Sand Member)**	
	Source (Tolstoi Shale)	1.0
	Reservoir (Tolstoi Sand member)	0.9
	Trap (3-way dependent closure)	0.6
	Seal (Tolstoi shale member)	0.8
	Timing	1.0
	Prospect Chance of Success	**0.43**

Reserve estimation was carried out on the identified prospect, bearing in mind the risks and uncertainties, which were expressed as P90 (low estimate), P50 (best estimate) and P10 (High estimate). The volumetrics evaluation for prospect yielded 74.73MCF, 164.62MCF and 394.05MCF for P90, P50 and P10, respectively (Table 2). Based on the Play sweet spot area, the study area was divided into three blocks (Fig. 10): NAU 460, NAU 460 and NAU 470, with NAU 460 ranking the highest, containing the identified prospect and one lead and highest prospect chance of success based on the assessment of the key requirements for a working hydrocarbon system.

Table 2: Reserve Estimation of the Identified Prospect

Reservoir (Tolstoi Fm.)	**P90**	**P50**	**P10**
GRV (Acre ft.)	102.17	125.35	154.85
Net/Gross	0.70	0.82	0.90
Porosity (%)	19	22	27
Hydrocarbon Saturation	0.55	0.65	0.77
Formation Volume Factor	0.93	1.12	1.36
GIIP (mcf)	74.737	164.62	394.05

CONCLUSION

The integration of multiple datasets resulted in the identification of two Plays, within which one prospect and three leads were interpreted. NAU Play-1, which is Tertiary in age, has a 50% Play Chance of Success; NAU Play-2 is Mesozoic and has a 25% Play Chance of Success. The Prospect is Tertiary Tolstoi Formation with a Prospect Chance of Success of 43%. Three reservoirs, three source rocks, extensive but non-regional seals, and normal and thrust faults acting as migration pathways & traps have been identified. Two genetic sequences were identified with their associated System Tracts. The LSTs and HSTs are potential reservoirs. The shales of TSTs and HSTs constitute the source/seal units. The D and Cbhl seismic facies correspond to the sands of LST and have high reservoir percentages. Although the prospect presents a great Hydrocarbon potential, 3D seismic data with a dominant frequency of 30 - 40Hz should be acquired for NAU-460 block, 470 block and 461 block. Checkshot data should also be acquired for more accurate time-depth conversion. Due to the compromised sealing integrity in the study area, fault seal analysis should be conducted to ascertain the integrity of the trapping faults. Implementing these will greatly maximise the hydrocarbon potentials of Bristol Bay Basin.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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