Re-evaluation of the Hydrocarbon Potential of the Scarborough Field, Offshore Northern Carnarvon Basin, Australia.

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ABSTRACT

This study examines the detailed basin analysis and re-evaluation of the hydrocarbon potential of the Scarborough Field in the Northern Carnarvon Basin, offshore Australia, aiming to enhance energy reserves. The research integrates extensive datasets, including a 3-D seismic reflection volume, fifty-two 2-D seismic lines, well logs from six wells, checkshot surveys, and surface geologic maps. The Northern Carnarvon Basin, a significant hydrocarbon reserve in Australia, has experienced a multi-phase extensional history and exhibits a complex stratigraphy linked to six tectonic phases. The pressing need for increased energy reserves necessitates revisiting old hydrocarbon fields to boost their production capacity using integrated methods. Well-log interpretation and correlation have revealed the lateral extents of petroleum system elements. The stratigraphic analysis identified three sequences and associated system tracts using the Depositional Sequence Model IV. Structural framework interpretation highlighted faults as migration pathways and hydrocarbon traps. Time and depth structure maps were produced to identify leads and prospects. Four leads and three prospects were pinpointed using RMS amplitude surfaces. Porosity values range from 20% to 29%, with hydrocarbon saturation between 51% and 65%. Volumetric assessment indicates that NAU Deep-1 contains 10.6 bcf, NAU Deep-2 holds 4.24 tcf, and NAU Deep-3 has 6.22 tcf of gas. These significant gas volumes highlight potential for future exploration and development in the Scarborough sedimentary infill.

Keywords – Northern Carnarvon Basin, Scarborough, Seismic, RMS Amplitude, Sequence Stratigraphy.

INTRODUCTION

North Carnarvon Basin is a gas province with minor oily sweet spots in deepwater area with water depth more than 500 m, which is one of the hot spots of global petroleum exploration for its series of giant hydrocarbon discoveries in recent years [1], [2], [3]. The Scarborough field is located in the Northern Carnarvon Basin (NCB). The Palaeozoic-Recent Carnarvon Basin is a large, mainly offshore basin on the Northwest shelf of Australia. It extends from the Dampier Archipelago to the Murchison bioregion [3], [4], [5] and is a major hydrocarbon reserve in Australia[5]. The basin experienced a multi-phase extensional history associated with regional-scale uplift and erosion of individual footwall blocks. The basin contains a maximum of 15km of Palaeozoic to Recent sedimentary infill and covers approximately 535,000 km^2 with water depths up to 3500 metres [2], [3]. The basin

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consists of depocentres divided into Plateaus, sub-basins and shelves. In the Carnarvon Basin, the main sub-basins for petroleum exploration have been the Dampier, Exmouth and Barrow sub-basins [5], [6]. The breakup of Gondwana controlled the evolution of the Northern Carnarvon Basin [2], [7], [8]. The Northern Carnarvon Basin, particularly the Barrow and Dampier sub-basins, is regarded as the premier hydrocarbon basin in Australia and is one of Australia's intensely explored areas. Numerous oil and gas fields in the offshore Northern Carnarvon Basin demonstrate the region's petroleum potential. The total oil and natural gas liquids and natural gas and ethane reserves (proved and probable) for the Carnarvon Basin are 672MMbbls (106.84 GL) and 45669PJ, respectively [9].

This study aims to re-evaluate the hydrocarbon potentials of the Scarborough Field, Offshore Northern Carnarvon Basin, Australia, and the objectives are 1. To reassess the hydrocarbon potential of the field for increased energy reserves; 2. To delineate the lateral extent of the petroleum system elements using sequence stratigraphic analysis, and 3. To estimate and quantify the reserve volumes within the identified prospects, emphasising the potential for future exploration and development activities in the Scarborough Field.

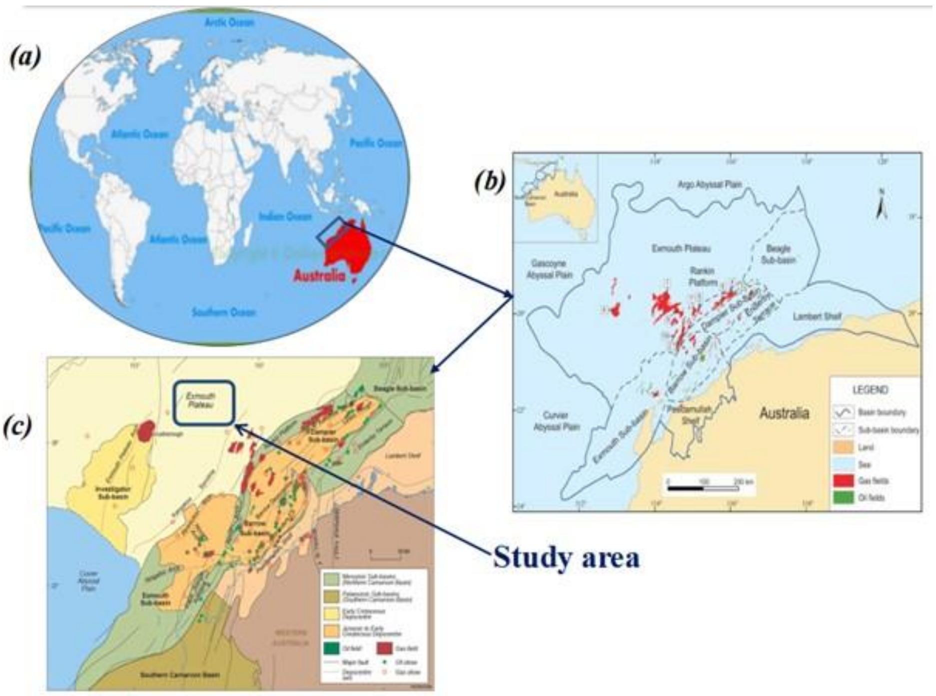

Fig 1: (a) Location of Australia (onthemap.com), (b) North Carnarvon Basin [5], (c) Structural representation of the study area [5]

GEOLOGY AND STRUCTURAL SETTING

The Carnarvon Basin is dominated by deltaic to marine siliciclastics and shelfal carbonates of the Mesozoic to Cenozoic age. The Northern Carnarvon Basin evolved from a broad intra-continental basin in the late Paleozoic through syn-rift sub-basins in the Jurassic to a passive margin carbonate shelf in the Cenozoic. A regional tectonostratigraphic model of the North West shelf, which includes the Northern Carnarvon Basin, has been developed by [4], [5], [9]. Multiple phases of extension, which culminated in the Jurassic to Early Cretaceous breakup of the Northwest Australian continental margin, produced a dominant Northeast structural gain, evident from the alignment of major faults and depocentres [10], [11]. The stratigraphy of the basin is related to six tectonic phases, which in turn are related to the rifting phases that occurred. These phases include pre-rift, early syn-rift, main syn-rift, late syn-rift Barrow Delta, post-breakup subsidence and passive margin. Thermal subsidence also contributed to the development of these phases [11], [12], [13].

The Northern Carnarvon Basin is dominated by a southwest-trending set of major depocentres - the Exmouth, Barrow, Dampier and Beagle sub-basins. The main source rocks of the Exmouth Plateau are the Locker Shale, deposited in the early Triassic. The Mungaroo fluvio-deltaic for-Barrow Delta (Early Cretaceous) are the main reservoirs. During the middle Cretaceous, post-rifting subsidence enables a thick deposition of the transgressive

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Muderong shale throughout the entire basin, which acts as a regional seal [5], [10], [14]. During the Tertiary, the Australian Plate drifted northward to warmer tropical zones, facilitating the development of carbonate sequences, including the Mandu Limestone formation [8], [11], [12]. Hydrocarbon generation, migration, and trap formation in the basin have been strongly controlled by syn-rift structuring, deposition, and post-rift reactivation. The major faults trend north or northeast and define a series of structural highs and sub-basins.

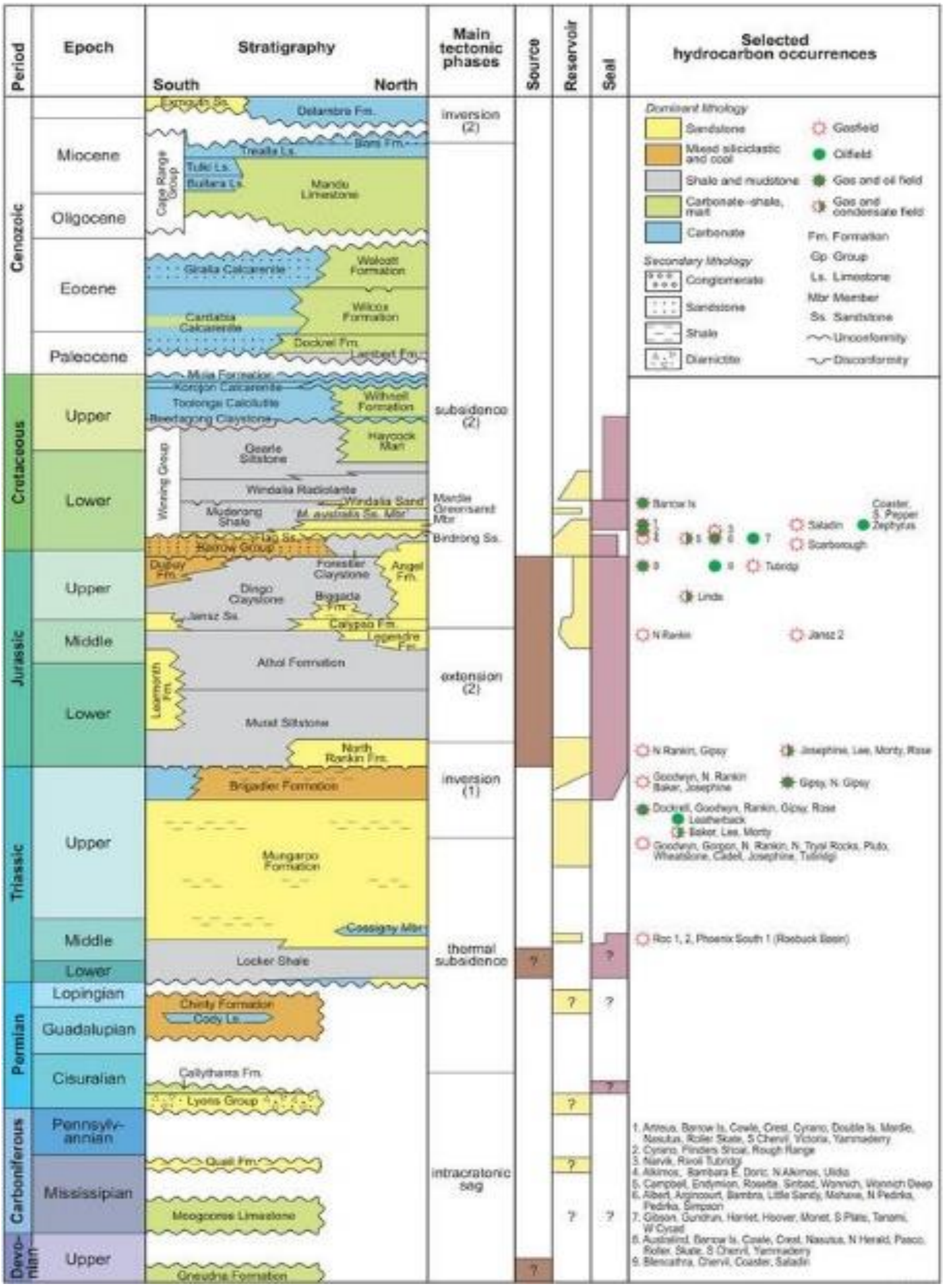

Fig 2: Stratigraphy and petroleum systems of the Northern Carnarvon Basin [14]

METHODOLOGY

The American Association of Petroleum Geologists (AAPG) provided the data for this study. The data include one 3-D seismic reflection volume, fifty-two 2-D seismic reflection lines, six wells with well-log suites, a checkshot survey for the available wells and a surface geologic map. The methodology employed in this study covers basin analysis, well-log interpretation, seismic interpretation, petrophysical analysis, prospect analysis and risk assessment.

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Basin analysis involved a literature review of the basin encompassing the tectonic framework, stratigraphy, structures and the Petroleum system of the Exmouth basin. The well-log interpretation was carried out using the available well-logs from which reservoirs were mapped and correlated across the wells in the northwest-southeast direction. A seismic-to-well tie was done using the density and sonic logs. Well-log sequence stratigraphic interpretation was done using the Depositional Sequence Model IV to identify the sequences and their corresponding system tracts. Seismic facies analysis was carried out using the seismic data. Structural interpretation, including fault and horizon mapping, was done using the seismic data integrated with the well logs through a seismic-to-well tie process to generate structural time maps, which were depth-converted using a layer-cake velocity model. RMS Amplitude analysis was applied to the depth structural maps for prospect analysis. Based on the attribute analysis result, the prospect's volumetrics were evaluated, and the risks involved in exploring the potential prospect and leads were identified.

RESULTS AND DISCUSSION

From the well log interpretation, we were able to interpret the lithostratigraphy by correlating them across the wells based on the formation tops, thereby revealing the lateral extents of our petroleum system elements, which are the source rocks, the reservoir rocks and the seal rocks) in the basin. These correlations occurred in the NE-SW direction (Fig. 3).

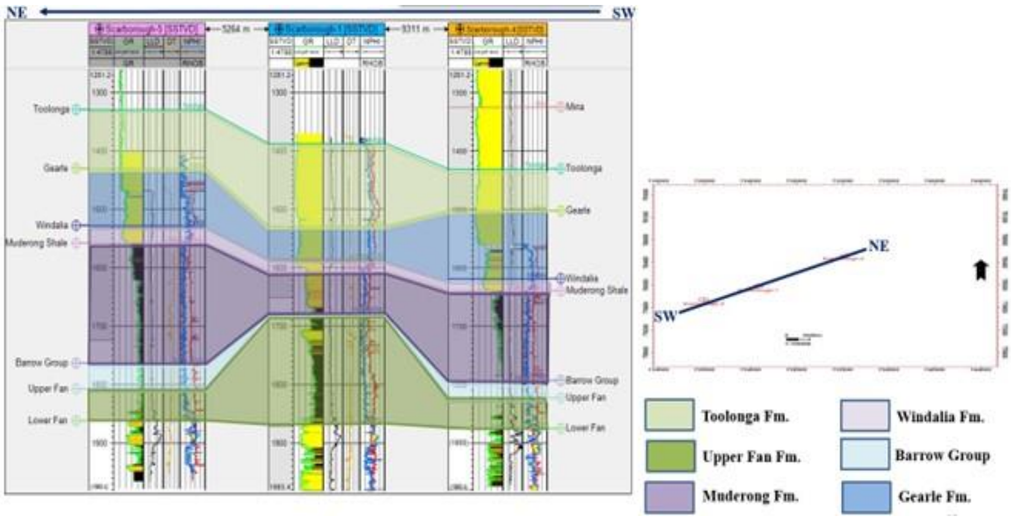

Fig 3: Lithostratigraphic correlation between Scarborough-5, Scarborough-1 and Scarborough-3

We interpreted three sequences and their relative system tracts defined by Sequence Boundaries (SBs) using the Depositional Sequence Model IV (Fig. 4). From the interpretation, we have the source rocks and seal rocks as the shales of the HSTs and the TSTs. At the same time, the reservoirs are the sand units of the HSTs and the TSTs.

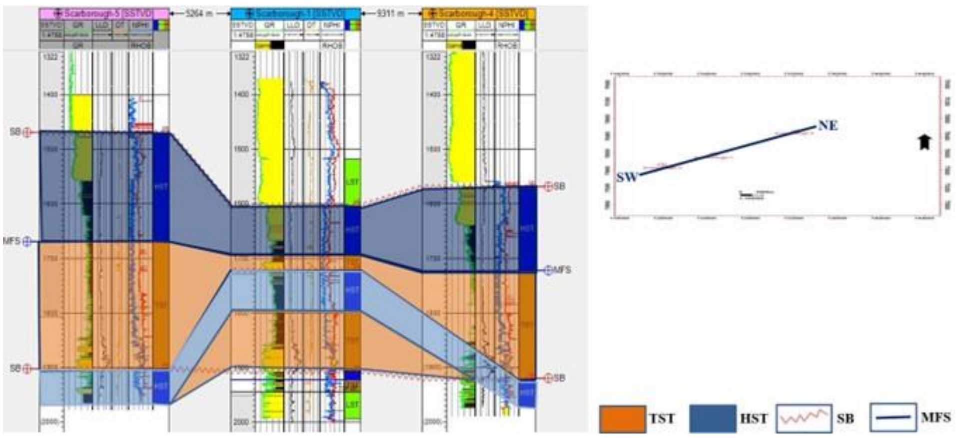

Fig 4: Sequence Stratigraphic Interpretation using Deposition Sequence model IV.

The two major data sets available, the seismic and well log data, are two sets of data measured using two different parameters: time and depth. A seismic-to-well tie helps integrate these two parameters and is done through a model known as a synthetic seismogram. Using the deterministic approach with the extended white algorithm, the synthetic seismogram generated using the Scarborough-1 well shows that the reservoirs correspond to the troughs, indicative of negative impedance sands (Fig. 5).

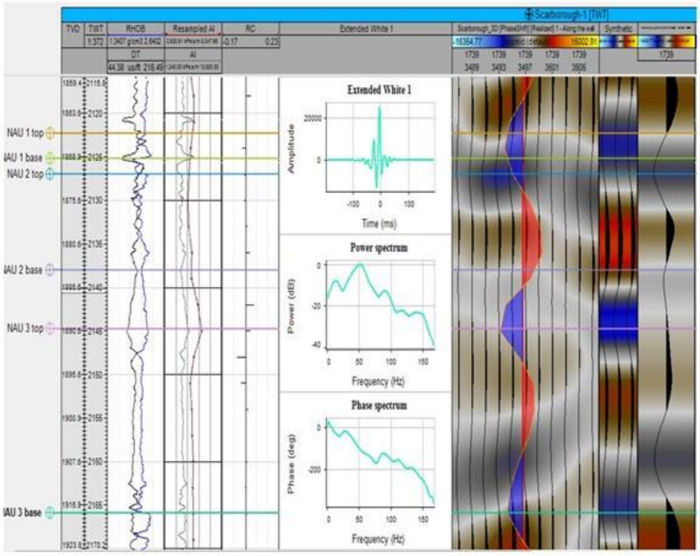

Fig. 5: Showing the seismic-to-well tie generated synthetics and tied to Scarborough-1

The structural framework interpretation indicates the presence of faults playing essential roles as migration pathways in some areas and as hydrocarbon traps in some areas. These faults and horizons were interpreted across the 3D seismic reflection volume with the aid of a variance (edge) seismic volume attribute and RMS Amplitude volume attribute (Fig. 6). A total of twenty-six faults comprised one major fault that cut almost across the entire stratigraphy and a series of antithetic and synthetic faults characterised the structural configuration of the Scarborough Field. Analysis of the RMS Amplitude volume showed three prospective zones, which were mapped as three horizons, NAU-Deep 1, NAU-Deep 2, and NAU-Deep 3 (Fig. 7)

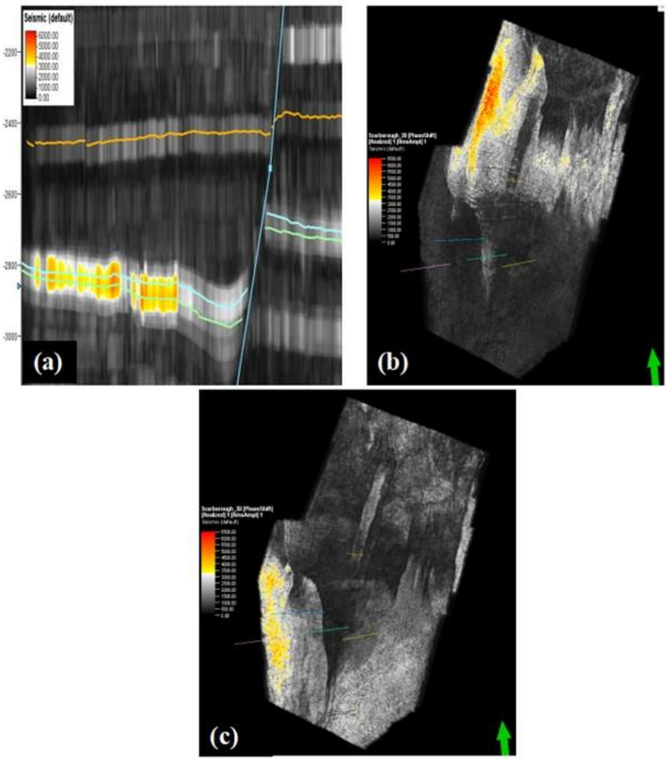

Fig. 6: Showing localised high RMS Amplitudes conforming to structures displayed on (a) seismic section inline 12745, (b) time slice 2585 ms and (c) time slice 2701 ms.

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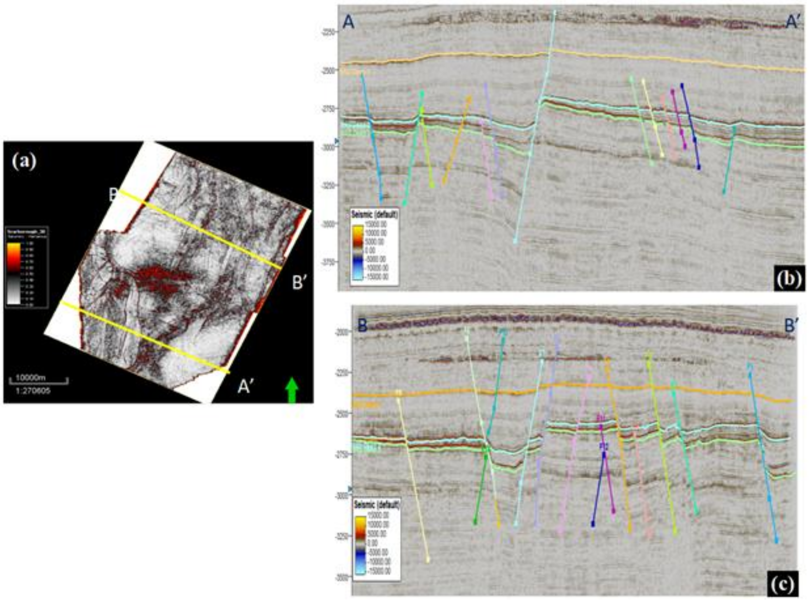

Fig 7: (a) Variance (edge) attribute time slice at 2701 ms showing the structural configuration of the study area. (b) Seismic lines showing interpreted faults and horizons.

Time and depth structural maps of the mapped horizons clearly highlight the closure and trap mechanism for the interpreted reservoirs (Fig. 8 – 9). The depth surface maps reveal structural closures interpreted as leads and prospects.

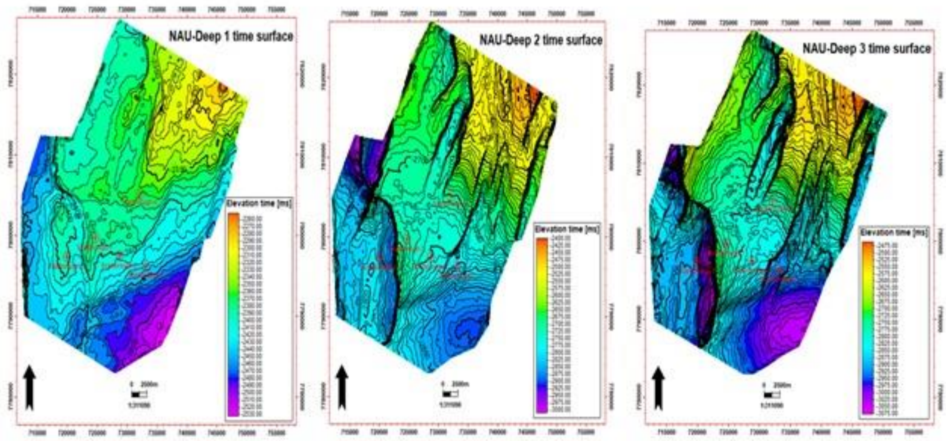

Fig. 8: Showing the time structural maps of the reservoirs.

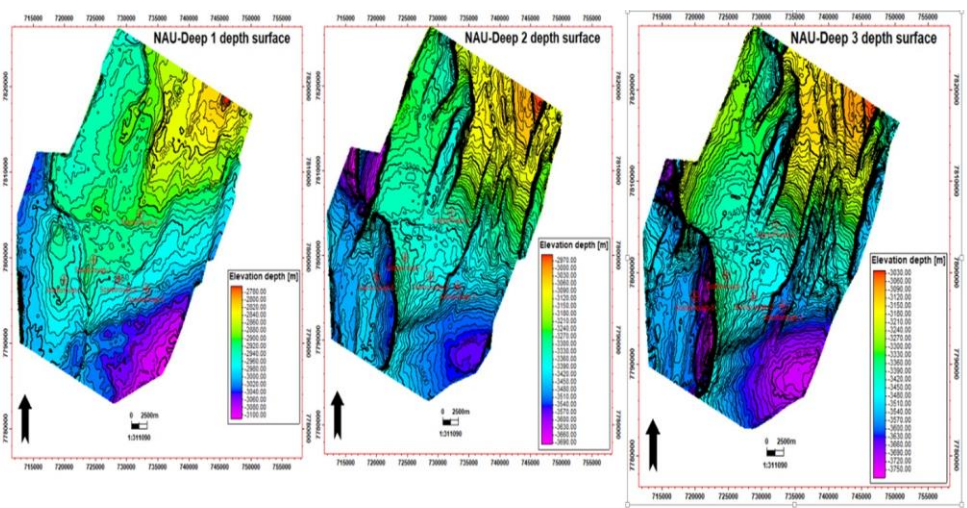

Fig. 9: Surfaces generated in Depth Domain

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From the depth surface maps, four leads and three prospects were identified. The areas circled in red are where the prospects were identified, while the yellow broken lines signify the identified leads (Fig. 10). These surfaces were created using the RMS amplitude, which has helped create a better view of the potential hydrocarbon accumulation zones because the localised high amplitude conforms to structural closures.

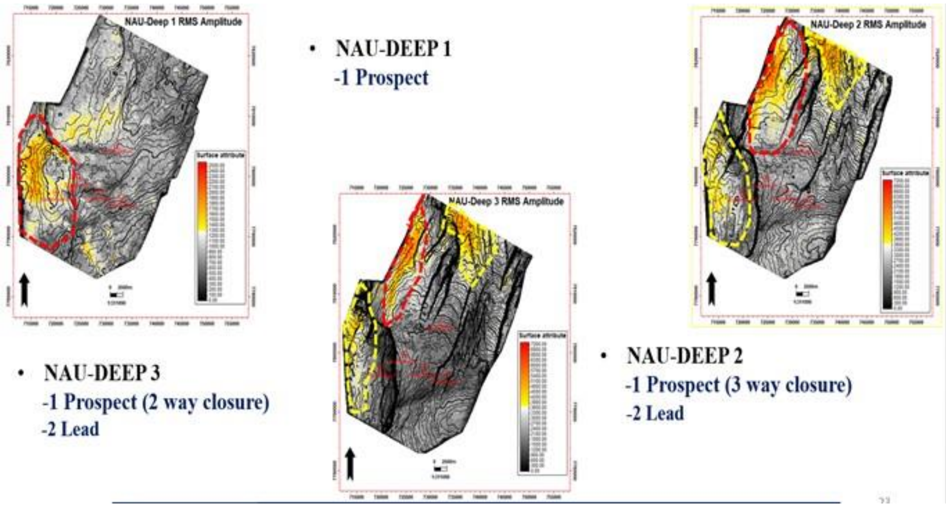

Fig. 10: Showing the identified leads and prospects.

A petrophysical analysis was conducted for the three reservoirs identified in this study. These reservoirs were correlated across three wells using the Techlog software (Fig. 11). Table 1 shows the results of the petrophysical parameters calculated for the reservoirs: the porosities (PoroE), the water of saturation (Sw), the volume of shale (Vsh) etc. Calculated porosity values range from 20% to 29%, with hydrocarbon saturation range of 51% to 65% (Table 1).

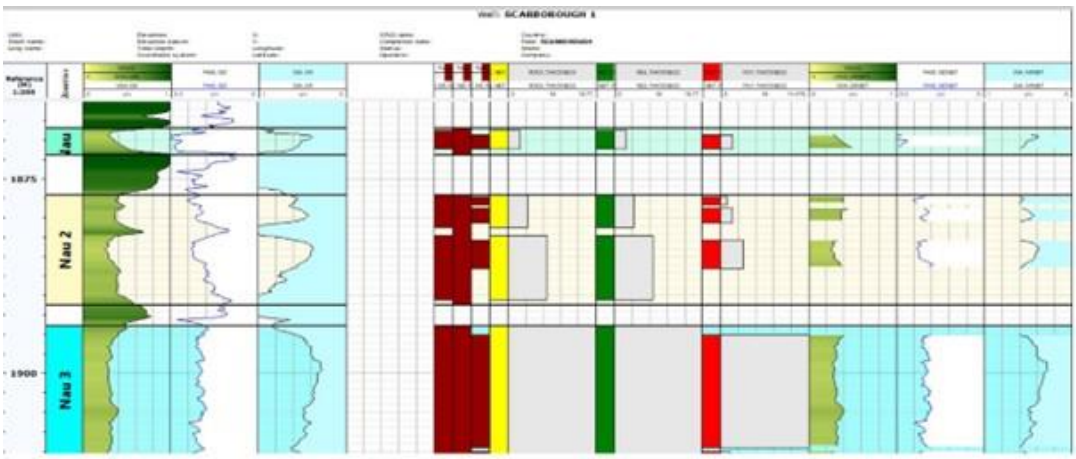

Fig. 11: the reservoirs in the field of study and some parameters calculated from the reservoirs.

Table 1: Results of the petrophysical analysis

Reservoir	**Top (m)**	**Base (m)**	**Gross Thickness (m)**	**Net Thickness (m)**	**Effective Porosity**	**Water Saturation**	**Net/ Gross**	**Volume of Shale**	**Hydrocarbon Saturation**
NAU-1	1868.38	1871.89	3.51	1.83	0.29	0.49	0.521	0.38	0.51
NAU-2	1877.09	1891.22	14.13	6.56	0.21	0.35	0.46	0.34	0.65
NAU-3	1893.85	1917.82	23.97	16.46	0.20	0.43	0.69	0.32	0.58

The volumetric assessment shows that NAU Deep-1 has a volume of 10.6 bcf, NAU Deep-2 has a 4.24 tcf, and NAU Deep-3 has a 6.22 tcf of gas. NAU Deep-3 has the biggest reserve, followed by NAU Deep-2 and should be the focus of further exploration activities.

CONCLUSION

The re-evaluation of the hydrocarbon potential of the Scarborough Field in the Northern Carnarvon Basin has provided significant insights into its capacity to increase energy reserves. This study has comprehensively analysed the basin's stratigraphy and structural framework by integrating diverse datasets, including one 3-D seismic reflection volume, fifty-two 2-D seismic lines, well logs from six wells, and checkshot surveys. The Northern Carnarvon Basin's complex stratigraphy, shaped by a multi-phase extensional history and six tectonic phases, was meticulously examined to understand the lateral extents of petroleum system elements.

Sequence stratigraphic analysis, employing the Depositional Sequence Model IV, identified three sequences and their corresponding system tracts, while structural interpretation highlighted faults serving as critical migration pathways and hydrocarbon traps. The generation of time and depth structure maps revealed four leads and three prospects, utilising RMS amplitude surfaces to pinpoint areas of interest.

The study's volumetric assessment and risk analysis identified significant gas volumes in the NAU Deep-1, NAU Deep-2, and NAU Deep-3 prospects, with calculated porosity values ranging from 20% to 29% and hydrocarbon saturation between 51% and 65%. The reserves' volumetric estimates underscore the field's potential, with NAU Deep-1 holding 10.6 bcf, NAU Deep-2 containing 4.24 tcf, and NAU Deep-3 comprising 6.22 tcf of gas.

These findings demonstrate the substantial untapped hydrocarbon potential within the Scarborough Field, advocating for further exploration and development. This re-evaluation emphasises the importance of revisiting old fields using integrated methods. It provides a foundation for increasing the production capacity of existing hydrocarbon reserves, thereby contributing to the region's energy security and economic growth.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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