



Magnetic Basement Depth from Marine Magnetic Data in Cendrawasih Bay Hydrocarbon Prospect Area, Bird Head, Papua, Indonesia

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Abstract - The magnetic basement and structural segmentation of the eastern Bird Head region, Papua, were investigated using marine magnetic data and frequency-domain inversion (MagB_Inv). The studied area includes The Cendrawasih and Yapen–Biak Basins, both were influenced by the Yapen strike-slip fault and transtensional tectonics. Processing involved reducing to the pole, spectral depth estimation, and 3D magnetic inversion to delineate basement geometry, and to infer the sediment thickness. Three structurally bounded subbasins were identified: (1) between Cendrawasih Bay and Num Island, (2) between Cendrawasih Bay and Yapen Island, and (3) between Yapen and Biak Islands. These subbasins exhibit magnetic basement depths ranging from 0.4 to 7 km and sediment thicknesses exceeding 3 km. Magnetic highs around Yapen Island correlate with Miocene volcanic and ultramafic outcrops, interpreted as shallow high-magnetization crustal blocks. The subbasins are bounded by ridges and faults, including the Yapen Fault Zone and fold-thrust systems, which deform both basement and sedimentary cover. The basement morphology controls sediment distribution, and defines fault-bound sedimentary zones, consistent with regional tectonic trends. Seismic cross-sections and shallow earthquake hypocentres, and further supports this structural segmentation. These results provide a structural framework to understand the basin structure, and to support preliminary hydrocarbon evaluations in this underexplored region. Despite these insights, interpretations are constrained by the non-uniqueness of magnetic inversion process and the absence of well and high-resolution seismic data.

Keywords: Cendrawasih Bay, hydrocarbon, MagB_Inv, magnetic basement, Papua

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INTRODUCTION

Background

Cendrawasih Bay is a triangular embayment that separates the Bird Head and Bird Body regions along the northern coast of Papua, Indonesia. This area is located within a tectonically complex zone

formed by the convergence of the Indo-Australian and Pacific–Caroline Oceanic Plates (McAdoo and Haebig, 1999; Harahap, 2012; Watkinson and Hall, 2017; Babault *et al.*, 2018; Sabra, 2021; Saputra and Fergusson, 2023). As a result of this plate interaction, major structural features such as The Yapen Fault Zone (YFZ) has developed, influencing the

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formation of the Cendrawasih and Yapen-Biak sedimentary basins. The Cendrawasih Basin is of particular economic interest as it has been identified as an active hydrocarbon province (ESDM, 2022; Kusnida *et al.*, 2023). Understanding the depth and configuration of sedimentary fill, as well as the morphology of the underlying basement, is essential for evaluating petroleum systems, since sediment thickness and thermal maturation are closely related to basement geometry (Florio, 2018; Mohamed *et al.*, 2022).

This study focuses on the understanding basement relief and its relation to hydrocarbon potential in Cendrawasih Bay. The basement rocks are composed of highly heterogeneous crystalline formations that influence subsurface structural configurations and the potential for hydrocarbon accumulation. Various geophysical methods have been applied in such studies. Gravity-based approaches are used to delineate structural boundaries and estimate basement depth variations (Florio *et al.*, 2021; Oksum, 2021; Geng *et al.*, 2022; Dahrin *et al.*, 2022; Xu *et al.*, 2023). Seismic methods offer high-resolution subsurface imaging and stratigraphic correlation (Grad and Polkowski, 2016; Xu *et al.*, 2019). Magnetic methods are widely applied in tectonically complex or seismically sparse areas, and have been used to map basement geometries in various global basins (Teknik and Ghods, 2017; Abdullahi *et al.*, 2019; Salawu *et al.*, 2019; Pham *et al.*, 2020; Eshanibli *et al.*, 2021; Ekwok *et al.*, 2022; Eldosouky *et al.*, 2022; Xu *et al.*, 2023; Masror *et al.*, 2025).

The basement rocks beneath Cendrawasih Bay consist of igneous and metamorphic rocks with relatively high magnetic susceptibility compared to the overlying sediments. This contrast allows magnetic methods to be used to estimate basement depth and structure (Zheng *et al.*, 2021; Dong *et al.*, 2023). Similar approaches have been applied in other geologically complex settings where seismic coverage is limited. For instance, basement depth mapping using magnetic data has been successfully conducted in The Mygdonia Basin in Greece (Ibraheem *et al.*, 2018), The Benue Trough of Nigeria (Abdullahi *et al.*, 2019),

mainland China (Sheng-Qing *et al.*, 2015), and across Gharb Basin, NW Morocco (Masror *et al.*, 2025), demonstrating the reliability of spectral and inversion-based techniques in delineating subsurface basin structure.

However, interpreting magnetic data presents several challenges. Magnetic anomalies are dipolar in nature, which complicates the identification of basin centres based on low magnetic amplitude. Additionally, variations in basement lithology result in lateral changes in magnetization, which can obscure anomaly patterns and affect interpretation accuracy (Florio, 2018). To address these limitations, magnetic data must undergo a series of processing steps, including Reduce to the Pole (RTP), Radially Averaged Power Spectrum (RAPS), and inversion modeling. These techniques are particularly valuable in areas where seismic data are sparse and the basement is deeply buried (Salawu *et al.*, 2019; Pham *et al.*, 2020).

In this study, marine magnetic data was used, collected in the offshore region of Cendrawasih Bay, including the areas around Yapen and Biak Islands. The objective is to determine the depth and morphology of the magnetic basement using the MagB_Inv inversion programme developed by Pham *et al.* (2020), which applies frequency-domain spectral analysis. The results aim to characterize subbasin boundaries to estimate sediment thickness, and to evaluate the structural segmentation of the eastern part of The Bird Head Papua. This approach contributes to a better understanding of basement-controlled basin development, and supports ongoing hydrocarbon exploration efforts in the area.

Geological and Stratigraphical Settings

The tectonic framework of eastern Indonesia is governed by the complex interaction among The Indo-Australian, Eurasian, and Pacific–Caroline Plates. These interactions give rise to subduction zones and active collisional deformation belts, particularly in the Papua region. This convergence has produced a mosaic of geological provinces, as described by Hamilton (1979), Dow and Sukanto

(1984), and Charlton (2000). Papua is generally divided into three major geological provinces (Peters *et al.*, 1983; Davies, 2012; Harahap, 2012): (1) the Oceanic Province, composed of ophiolites and island-arc complexes of the Pacific Plate origin, occupying the northern region; (2) The Continental Province, made up of sedimentary sequences derived from The Australian Plate; and (3) the Transition Province, a metamorphic domain marking the interaction between the oceanic and continental crusts. The Bird Head region of Papua experienced southward-directed compression until The Late Miocene, driven by oblique convergence between The Indo-Australian Plate and The Pacific–Caroline Plate (Dow and Sukanto, 1984; Harahap, 2012; Zhang *et al.*, 2022). This compression shaped much of the current lithotectonic

configuration observed in the Bird Head Peninsula and surrounding areas (see Figures 1a, 1b).

Stratigraphically, the northern margin of Papua exhibits rocks with strong affinity to the Pacific–Caroline Plate, including pre-Tertiary ophiolites, volcanic arcs, and ultramafic complexes (McAdoo and Haebig, 1999; Babault *et al.*, 2018). These are unconformably overlain by Tertiary sedimentary rocks, deposited during fore-arc and back-arc basin development. Volcanic-arc remnants such as the Arfak Volcanics and the Yapen–Biak sequences (Yapen Volcanic and Auwewa Formation) constitute the basement of the offshore subbasins in Cendrawasih Bay (Gold *et al.*, 2017).

The northern part of Papua exhibits stratigraphic affinity with the Pacific–Caroline crust, characterized by pre-Tertiary basement rocks overlain by

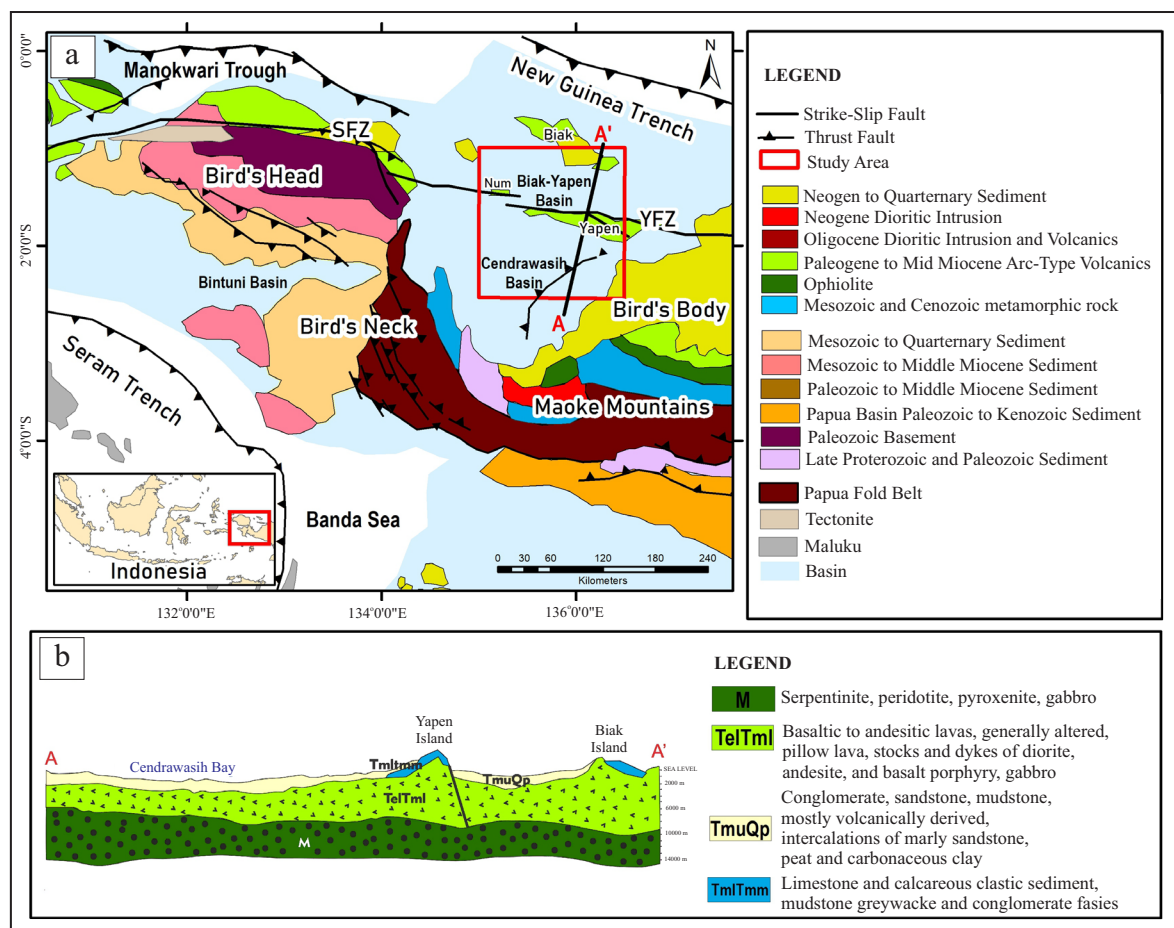


Figure 1. Regional geological configuration of Bird's Head, Papua, and its surroundings, following tectonic elements derived from Dow and Sukanto (1984), Dow *et al.* (1986), McAdoo and Haebig (1999), Atmawinata *et al.* (1989), and Davies (2012): (a) A regional geological map of the study area and its surroundings The red box represents the study area, and the black solid line indicates the geological section, and (b). The modified geological section from Dow *et al.* (1986).

Tertiary sedimentary cover. This sequence reflects prolonged basin infill from The Paleogene to The Neogene, with a notable hiatus in deposition during The Late Miocene. The pre-Tertiary basement consists of ophiolites, volcanic-arc rocks, schists, basalts, gabbro, and serpentinitized ultramafic units (McAdoo and Haebig, 1999; Babault *et al.*, 2018). In particular, the Arfak Volcanics in the eastern Bird Head, and the Yapen Volcanic and Auwewa Formations exposed on Biak and Supiori Islands, represent remnants of island-arc volcanism. These volcanic basement units constitute the structural foundation beneath the sedimentary basins in Cendrawasih Bay and adjacent islands, as confirmed by Gold *et al.* (2017).

Cendrawasih Bay forms a prominent physiographic depression in northern Papua, bounded by the Bird Body to the south and east, The Bird Head to the west, and Yapen Island to the north. The bay is morphologically expressed as a triangular embayment separating The Bird Head from the main Papuan landmass (Charlton, 2000). Hydrocarbon occurrences have been reported along the eastern Papuan mainland and within The Cendrawasih Bay region (Sapiie and Hadiana, 2007; Noble *et al.*, 2016; Nurwati *et al.*, 2017). Several islands occupy the northern sector of the bay, including Yapen, Biak–Supiori, and Num. Yapen Island is characterized by an east–west-trending mountainous belt, with elevations exceeding 1,500 m. The island exposes ophiolitic sequences composed of serpentinite, peridotite, and schist, interpreted as the oldest lithologies. Supiori Island, with elevations reaching 1,020 m, also exhibits ophiolitic assemblages. The dominant lithologies across the island chain include limestone and marl, occasionally interbedded with thin, fossiliferous layers (McAdoo and Haebig, 1999).

The area mentioned above includes modified primary volcanic formations, such as island-arc volcanism and oceanic basalts dating from The Paleogene period. Pieters *et al.* (1983) and Dow and Sukanto (1984) have shown that sediments covered island arc volcanism from the middle to Late Miocene. The YFZ, as depicted in Figure 1a, exerts control over this sedimentary basin through

leftward movement, potentially serving as an extension of The Sorong Fault Zone. Strike-slip motions primarily explain the current predominant motion between The Caroline Pacific Ocean Plate and The Indo-Australian Continent (Dow and Sukanto, 1984; McAdoo and Haebig, 1999; Charlton, 2000; Decker *et al.*, 2009; Sapiie *et al.*, 2010; Gold *et al.*, 2014; Noble *et al.*, 2016; Babault *et al.*, 2018, Kusnida *et al.*, 2023). This movement is expected to display the distinctive characteristics of the Sorong-YFZ. Before The Miocene period, the YFZ formed (McAdoo and Haebig, 1999; Hall and Wilson, 2000; Web *et al.*, 2019; Zhang *et al.*, 2022). The thrust-fault system also affects the structural arrangement of this region in Cendrawasih Bay.

METHODS AND MATERIALS

Methods

Pham *et al.* (2020) propose an iterative algorithm based on the Fourier transform of marine magnetic data to determine the magnetic basement relief in The Cendrawasih Bay and its surrounding areas. This study employs the MagB_Inv programme, which features a graphical user interface (GUI) to assist users in modeling. The programme can use gridded data in binary or text grid format (grd), which is supported by Golden Software Surfer, as well as ASCII files with gridded easting/northing/magnetic data columns (dat, *.txt, *.csv). The MagB_Inv programme initializes the depth and iterates it multiple times based on specified iteration criteria. In divergence mode, the iterative process concludes when the magnitude of the root mean square (RMS) error exceeds the previous value.

In contrast, in convergence mode, the iteration stops when the RMS error is below the previously set value. When the iteration reaches its maximum number, it indicates the presence of unresolved parameters, leading to an unsatisfactory resulting model. The MagB_Inv programme requires the entry of several initial parameters, including inclination (IncF/M), declination (DecF/M), magnetization (M), roll-off frequency range defined

by stop high (SH) and window high (WH) values, iteration criteria (RMS criteria), maximum number of iterations (Maxiter), and the estimated average depth of magnetic sources ($\text{Avg}Z_o$). The slope of the wave amplitude to the wave number can estimate the average depth (Kebede *et al.*, 2020). The average depths were calculated using the formula in Spector and Grant (1970). The radially averaged power spectrum (RAPS) was used to estimate the average depth for inversion modeling in the studied area.

$$h = -\frac{1}{4\pi} \left(\frac{\text{Log } E_1 - \text{Log } E_2}{K_1 - K_2} \right) \dots\dots\dots(1)$$

where:

h is the depth,

E is the amplitude, and

K is the wave number (rad/km).

Pham *et al.* (2020) provide a method for calculating the h -interface depth from magnetic anomaly data via an iterative inversion process.

$$F[h] = \lim_{t \rightarrow \infty} F[h] = \frac{F[\Delta T]}{2\pi M |k| \Theta_f \Theta_m C_m e^{-|k|Z_o}} - \sum_{n=2}^t \frac{(-|k|^{n-1})}{n!} F[h^n] \dots\dots\dots(2)$$

The symbol F represents the Fourier transformation, whereas M represents the magnetization contrast. The variables Θ_m and Θ_f represent the directional factors for the magnetization direction and magnetic field direction, respectively. The symbol C_m represents the magnetic permeability, while k is the wave number, as defined in Equation (2). Z_o refers to the average interface depth of the magnetic slab, h represents the depth of the magnetization layer, and n is an integer representing the natural number of h .

Materials

The studied area encompasses the eastern part of the Bird Head region in Papua (Figure 2a). The marine magnetic data used in this study were obtained from The Marine Geological Institute of Indonesia, and cover Cendrawasih Bay and its surrounding offshore regions, including the areas adjacent to Yapen, Biak, and Num Islands. The original anomaly values were digitized and interpolated

using the minimum curvature gridding method to generate a georeferenced and continuous grid of total magnetic anomaly data. Figure 2b shows the resulting anomaly map covering Cendrawasih Bay and its surrounding regions, including Yapen, Biak, and Num Islands, with the ship track displayed to indicate the geomagnetic survey route in Figure 2a. The red rectangle in Figure 2a outlines the spatial extent of the studied area. No further interpolation was applied prior to spectral and inversion analysis.

To support three-dimensional modeling and depth estimation, bathymetric data were retrieved from the Tanah Air Indonesia geospatial platform (<https://tanahair.indonesia.go.id/>) by specifying the geographic boundaries of the studied area (Figure 2c). These data were integrated into the magnetic modeling workflow, and used to constrain the shallow topographic surface in the subsurface model, to and to assist in estimating sediment thickness within basin structures. In addition, earthquake epicentre data were collected from the USGS Earthquake Catalog (<https://earthquake.usgs.gov/earthquakes/map>) to identify active tectonic domains, and to validate the presence of major fault structures, such as the YFZ.

Following data compilation, a series of marine magnetic data processing steps were conducted to support quantitative basement depth modeling. Given the studied area low-latitude location, the observed magnetic anomalies were influenced by the inclination and declination of the earth magnetic field, resulting in spatially skewed patterns. To correct this distortion and to enhance geological interpretability, the dataset was processed using the RTP transformation. This step reorients the anomalies as if recorded at the magnetic pole, effectively centering them over their causative sources. The resulting RTP anomaly map (Figure 3a) provides a more geologically consistent representation than the uncorrected total magnetic anomaly map (Figure 2b). In particular, the RTP anomalies enhance anomaly symmetry and highlight the correspondence between magnetic highs and uplifted basement blocks (*e.g.* around Yapen Island), as well as magnetic lows that delineate subbasin depocentres. These features

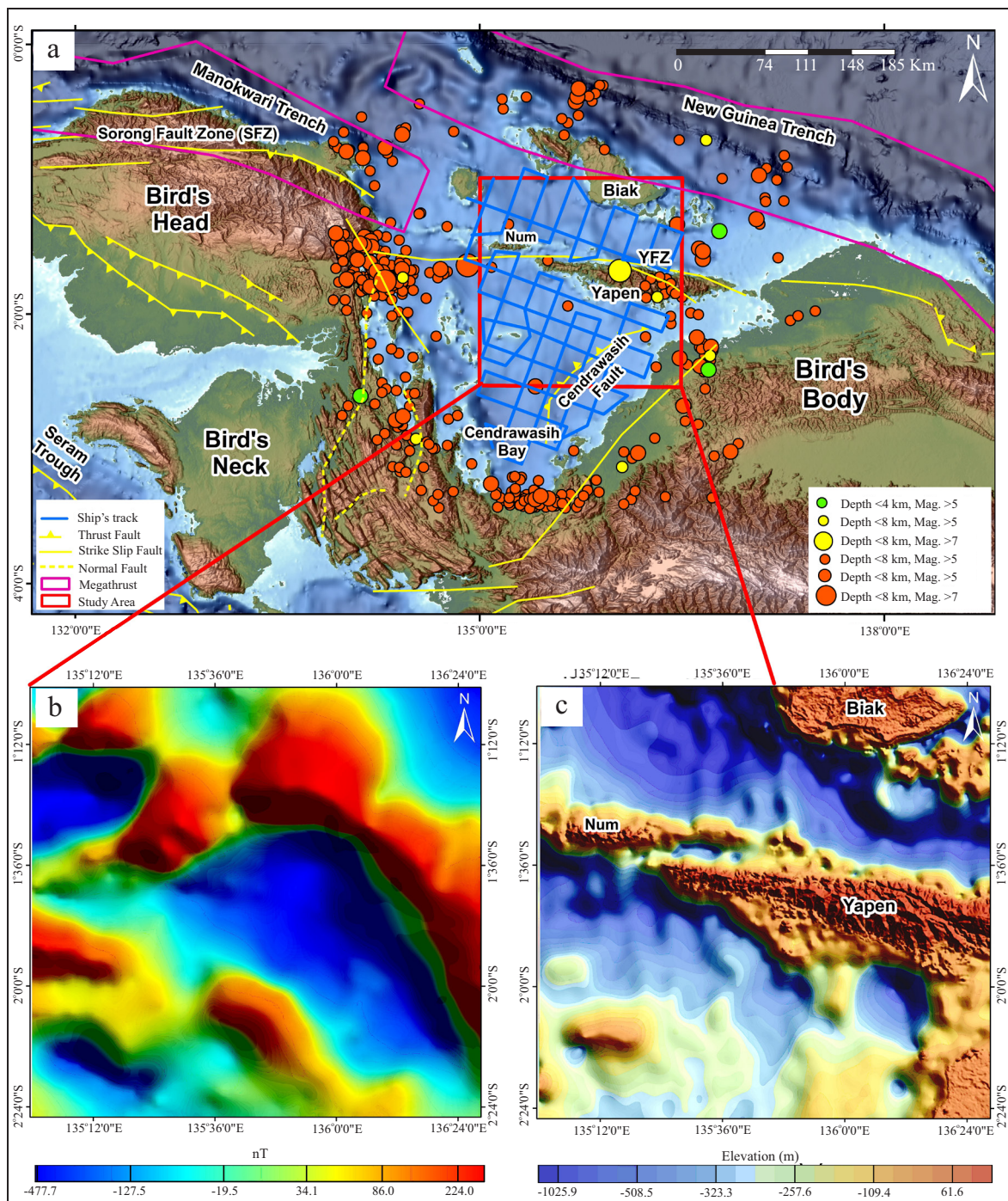


Figure 2. (a) Tectonic and seismic setting of the studied area in the eastern Bird Head region, Papua, Indonesia. The red box outlines the studied area encompassing Cendrawasih Bay and adjacent islands (Yapen, Biak, and Num). Blue lines represent ship's track. yellow lines represent major thrust faults, pink lines indicate strike-slip faults (including the YFZ), and orange dots show earthquake epicenters categorized by depth and magnitude. (b) Total magnetic anomaly map showing observed magnetic anomalies before RTP, and (c) Bathymetric elevation map illustrating morphology and the position of Yapen and Num Islands, providing spatial context for interpreting the magnetic data.

are spatially aligned with major tectonic trends, including the YFZ and surrounding fault-bounded basin structures, thus providing a more reliable geological framework for interpretation. The RTP

anomalies were subsequently used as input for the MagB_Inv inversion modeling. Following RTP correction, the Radially Averaged Power Spectrum (RAPS) method was applied to estimate

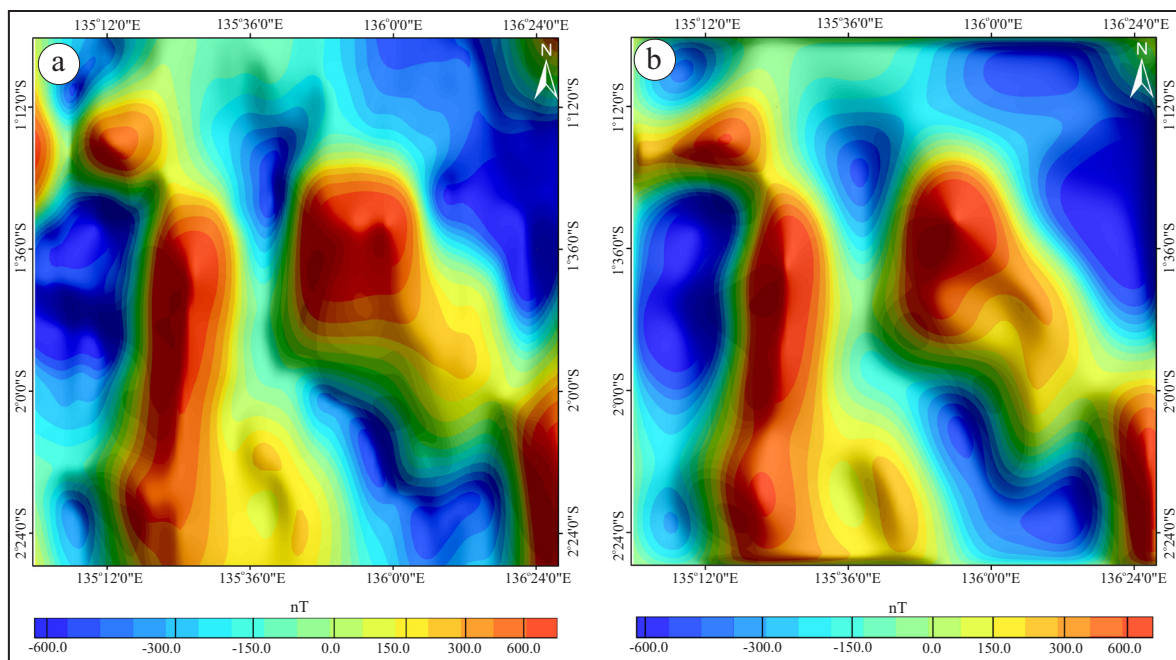


Figure 3. Inversion process from the RTP anomaly data in Cendrawasih Bay and its surroundings Observed magnetic anomaly map after RTP transformation, enhancing anomaly symmetry and centering responses over causative bodies, and (b) Calculated magnetic anomaly derived from the 2D MagB_Inv inversion model.

the average depth of magnetic sources (Spector and Grant, 1970). This spectral analysis allows for the separation of regional and local anomalies by identifying depth-related frequency components in the magnetic signal. This step provides the initial average depth Z_0 , which serves as an essential input for subsequent magnetic inversion modeling using MagB_Inv.

RESULT AND ANALYSIS

Basement Depth Estimation

To further refine the interpretation of magnetic source depths, a RAPS analysis was conducted on the RTP-corrected magnetic anomaly data. As shown in Figure 4a, the RAPS curve was segmented into three linear regions corresponding to

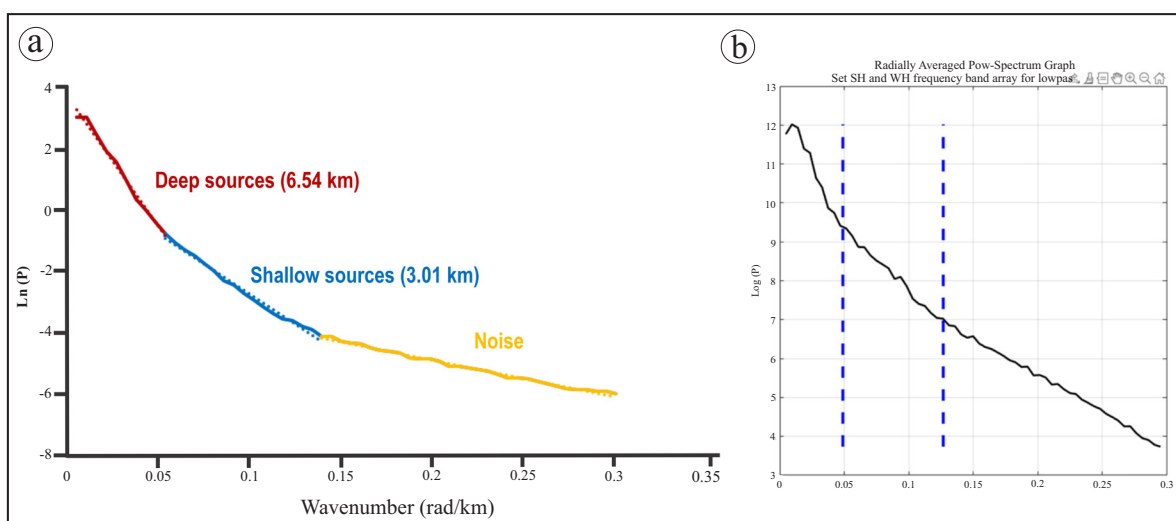


Figure 4. Estimated depth of RAPS based on several sources of anomaly, and (b) Cut-off frequency of RAPS using the MagB_Inv programme on magnetic anomaly data.

deep sources (interpreted as regional anomalies), shallow sources (local anomalies), and high-frequency noise. Depths were calculated from the slope of each segment following the method of Spector and Grant (1970). The deepest segment indicated a maximum source depth of 6.54 km, while the shallow segment revealed an average depth of approximately 3.01 km. These values were used to determine the initial $\text{Avg}Z_0$ for inversion, and to guide the selection of spectral cutoff values in the filtering stage.

The SH and WH parameters used in the MagB_Inv inversion algorithm define the roll-off frequency band for a low-pass filter that stabilizes the iterative solution. As illustrated in Figure 4b, these filter parameters were applied during inversion to suppress noise and enhance model convergence. While both the RAPS-based segmentation and the SH/WH filtering operated in the frequency domain, they served distinct purposes: the former was a preprocessing tool for interpreting source depth distributions, while the latter was an inversion-internal filter to ensure spectral regularization (Pham *et al.*, 2020).

The inclination and declination values used in the modeling were obtained from The British Geological Survey geomagnetic field calculator, yielding an inclination of -20° and a declination of 1.66° for the studied area. A magnetization contrast of 5 A/m was adopted based on iterative testing, where a higher contrast produced inversion results that better matched the expected geological depths. The SH and WH parameters were set at 0.0776 and 0.0434, respectively. These values were chosen based on the dominant spectral wavelengths identified in the RAPS analysis (see Figure 3b), with the aim of minimizing high-frequency noise during the inversion process. The inversion was performed in divergence mode, with a maximum of 100 iterations, and was terminated once the RMS error increased between successive iterations. This implementation follows the approach described by Pham *et al.* (2020). Figure 3b depicts the Z_0 of 4 km. This finding was further corroborated by well data in Cendrawasih Bay provided by Tonny and Bagiyo (1993), where

the depth of The Auwewa Formation, identified as a volcanic rock basement (Gold *et al.*, 2017), was also reported as 4 km. Noble *et al.* (2016) provided this depth information, suggesting that the volcanic basement can reach up to 7 km.

The magnetization contrast of 5 A/m was selected to reflect the magnetic properties of mafic to ultramafic igneous rocks underlying the studied area, such as basalt, gabbro, and serpentinite (McAdoo and Haebig, 1999; Babault *et al.*, 2018). These lithologies are known to exhibit relatively high magnetic intensities. In particular, Fuji *et al.* (2016) reported that serpentinized peridotites with a serpentinization degree of 96 % can reach magnetization values of up to 11 A/m, which supports the interpretation of a high-magnetization basement such as The Yapen Highland Fault Zone. Sensitivity testing during inversion also confirmed that lower values (*e.g.* 1-2 A/m) resulted in unrealistically shallow basement depths, whereas 5 A/m provided inversion results consistent with prior geological and seismic data in the region (Sapiie and Hadiana, 2007; Gold *et al.*, 2017).

The MagB_Inv inversion process involves inversion parameters in estimating the depth of the magnetic basement of the studied area, as presented in Figure 3. Figure 3a shows that the observed magnetic anomaly is consistent with the calculated magnetic anomaly (Figure 3b). Figure 5a depicts the determination of the magnetic basement depth distribution after 25 iterations. The representation of basement topography within The Cendrawasih Bay Basin and its surrounding small islands further illustrates the results of the magnetic basement modeling. Figure 5b shows the results of the 3D inversion, displaying an irregular and undulating basement topography with varying depths ranging from 0.4 km to 7 km (average depth 3.5 km). The delineation results, which consist of three subbasins, are shown in Figure 5b.

The 3D model shows the magnetic basement eastern Bird Head region, Papua waters, forming a basin and ridge structure. In general, some areas are shallower, namely in the northern part, to be precise, of The Yapen Islands, which have

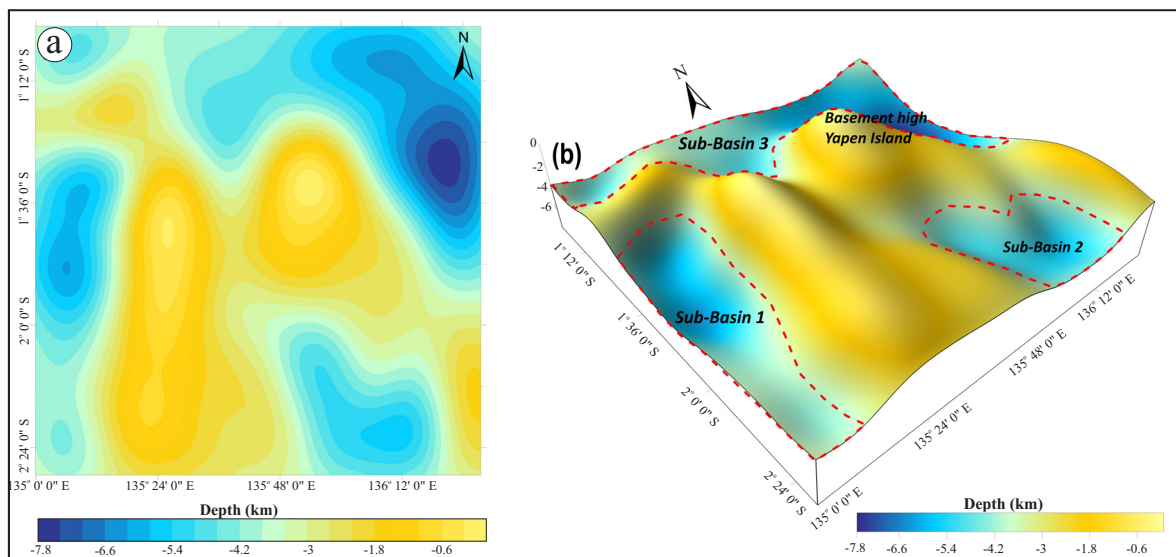


Figure 5. The estimated depth of magnetic basement: (a) Depth of the inverted magnetic basement, and (b) 3D topographic of the magnetic basement of Cendrawasih Bay and its surroundings.

ridge relief in response to intrusive rocks with a depth of <1 km. On the other hand, in the northern and southern parts of The Yapen Islands, there is basement subsidence, indicating basin relief. The magnetic basement is deepest in the western part of the studied area, as shown in Figure 5b.

Comparison of The Magnetic Basement Model

The comparison of the magnetic basement model with a seismic section trending northwest–

southeast (Figure 6) indicates a good agreement of consistency between the two independent datasets. Figure 6a presents the basement structure interpreted from marine magnetic data inversion, while Figure 6b shows the subsurface structural relief derived from a seismic cross-section published by Sapiie and Hadiana (2007). Furthermore, the interpreted basement trend is also consistent with regional tectonic features and fault alignments observed in earthquake

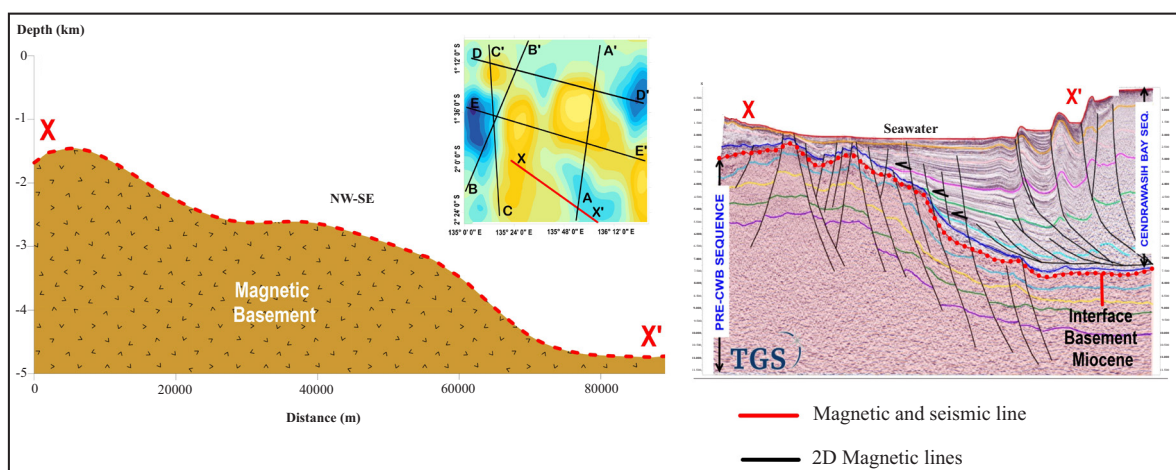


Figure 6. Comparison between magnetic basement model and interpreted seismic section along the NW–SE trending profile X–X'. (a) Magnetic basement geometry derived from 2D inversion of marine magnetic data, showing a gradual deepening trend toward the southeast, and (b) Seismic stratigraphic interpretation along the same profile, illustrating fault structures and the interface between Miocene volcanic rocks and basement (highlighted by red dotted line). The correlation supports the reliability of the magnetic inversion result. The inset map shows the spatial location of the profile relative to the studied area. Modified from Sapiie and Hadiana (2007).

epicentre distributions and geological maps of the area. Both models reveal structural lowering of the basement in the southeastern part of Cendrawasih Bay during The Miocene, associated with the Cendrawasih thrust-fold system. Given the similarity in basement geometry, magnetic basement modeling can be extended to areas without seismic coverage to explore structural controls and hydrocarbon potential in the region.

Depth Characteristics of Magnetic Basement

To analyze the basement morphology and subbasin distribution in the studied area, five profiles (A-A' to E-E') were extracted from the magnetic basement depth model (Figure 7a). These profiles traverse key structural zones

across Cendrawasih Bay and its surrounding islands. Profile A-A' (Figure 7b), oriented south-east–northwest, crosses Subbasin 2 and Subbasin 3. It shows a shallow basement high near The Yapen Island (~0.5 km deep), interpreted as a basement ridge associated with Miocene volcanic and ultramafic exposures. Toward both flanks, the basement deepens to over 3 km, outlining two structurally bound subbasins. Profile B-B' (Figure 7c), trending southwest-northeast, intersects Subbasin 1 and Subbasin 3. It highlights a broad synclinal depression in the west with depths reaching ~6 km, suggesting significant sediment accumulation. The basement shallows near Yapen Island, consistent with a basement ridge feature.

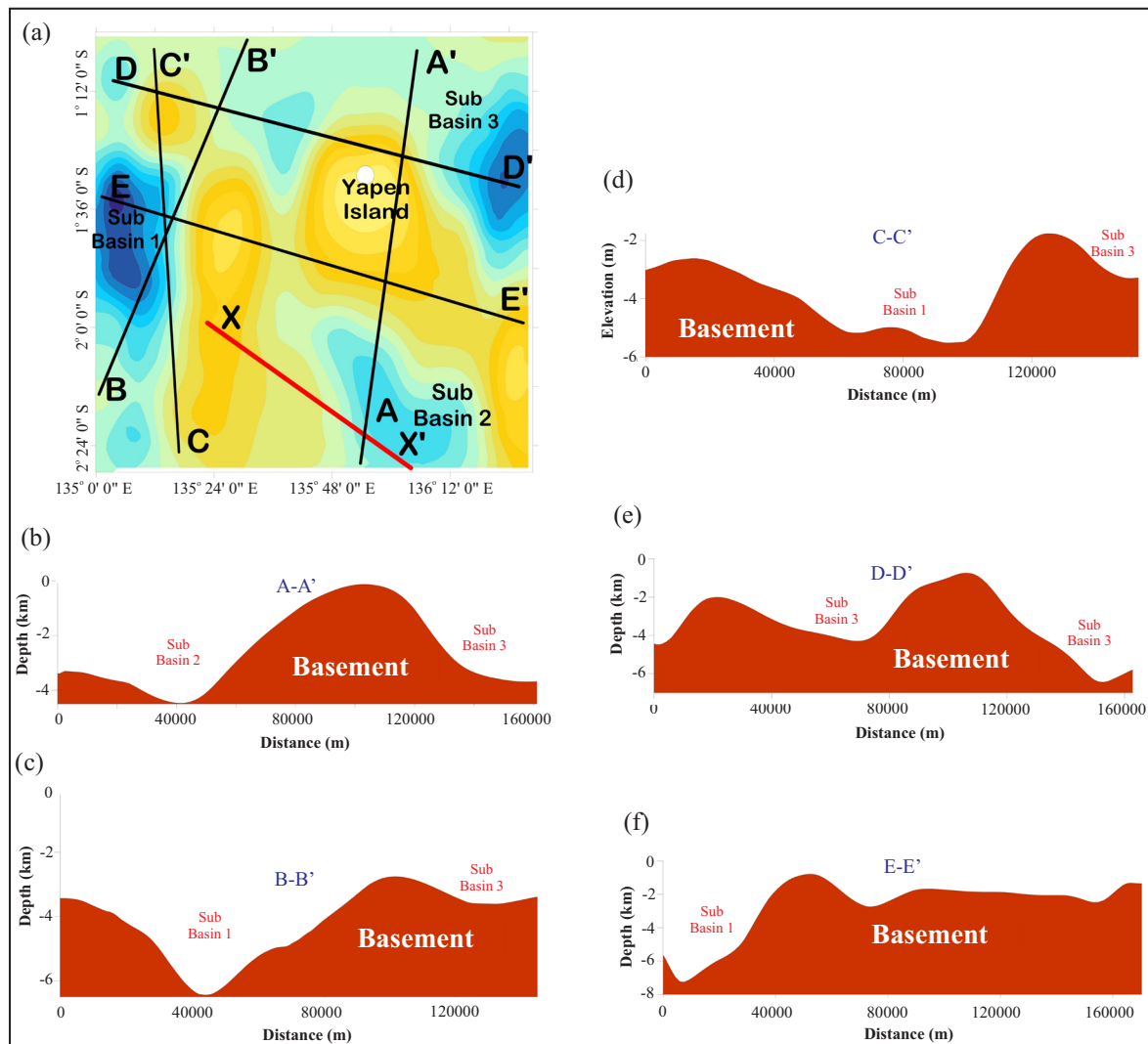


Figure 7. Magnetic basement depth profiles across five selected transects in the studied area (a) Slicing profile, (b) Profile A-A', (c) Profile B-B', (d) Profile C-C', (e) Profile D-D', and (f) Profile E-E'.

Profile C-C' (Figure 7d), oriented southwest–northeast, shows significant basement undulation in the southwestern segment (2.2–6.5 km), while the northeastern part appears structurally stagnant. This profile emphasizes the asymmetric geometry of Subbasin 1. Meanwhile, Profile D-D' (Figure 7e), crossing Subbasin 3, shows complex undulating basement topography with depth variations from ~1 km to 6 km. The eastern segment hosts the deepest part, corresponding to a structurally confined sediment accumulation zone. Lastly, Profile E-E' (Figure 7f), oriented west-east, intersects Subbasin 1 and the Yapen basement high. The profile captures a deep basin to the west (>6 km), transitioning to a relatively stagnant basement in the east, aligned with uplifted crustal blocks.

The magnetic basement depth model reveals significant variability, ranging from approximately 0.5 km to 7 km. This depth variation defines three major subbasins, each bounded by prominent basement highs. Notably, elevated basement features around Yapen Island correspond spatially with the YFZ, suggesting a strong structural control. Overall, the inversion results demonstrate that marine magnetic data can reliably delineate subbasin geometry in geologically complex and data-scarce offshore regions.

DISCUSSION

The resulting anomalies represent rocks exhibiting various magnetism. Pham *et al.* (2020) magnetic inversion technique was employed to generate a subsurface model in Cendrawasih Bay, including its surrounding small islands, to delineate the characteristics of the magnetic basement rocks. Magnetic inversion has proven effective in delineating basin structures and identifying previously undocumented geological features relevant to hydrocarbon exploration. The studied area comprises strongly magnetized crystalline basement overlain by low-magnetization sedimentary sequences (Dong *et al.*, 2023), and the magnetic method provides essential insights into their spatial distribution and depth.

As the magnetic basement depths ranging from 0.4 to 7 km delineate sedimentary thickness variations that are relevant for assessing structural trapping configurations in hydrocarbon exploration (Figure 7). The suspected presence of an anticline axis may further indicate prospective hydrocarbon traps. Comparable observations have been reported in stratigraphic records, where the intrusion of igneous rocks into sedimentary basins is recurrent (Dow *et al.*, 1986; McAdoo and Haebig, 1999). These intrusive features influence basement surface topography and contribute to hydrocarbon migration and accumulation (Gold *et al.*, 2017).

In line with this, similar structural configurations have been found in other basins. For instance, in The Benue Trough of Nigeria, Abdullahi *et al.* (2019) reported magnetic basement depths of 1–9 km associated with anticlinal structures and igneous intrusions, which are indicative of mature petroleum systems. Likewise, Abdelmaksoud *et al.* (2023) showed that in the northern Oman-UAE Mountains, gravity and magnetic inversion data revealed a correlation between basement uplifts and shallow anticlinal features. A comparable approach was applied in The Gharb Basin, NW Morocco (Masror *et al.*, 2025), where magnetic data successfully revealed fault-controlled basin structure and basement segmentation. Although those regions are dominated by compressional regimes, the studied area is influenced by YFZ and transtensional tectonics. Both contexts emphasize the significance of basement morphology in controlling basin structure (McAdoo and Haebig, 1999; Kusnida *et al.*, 2023).

From the inversion model, three structurally bounded subbasins were identified located Cendrawasih Bay, including its surrounding small islands. Subbasin 1 lies between Cendrawasih Bay and Num Island, subbasin 2 is located between Cendrawasih Bay and Yapen Island, and subbasin 3 occupies the region between Yapen and Biak Islands. Block-1 and Block-2 are situated within Cendrawasih Bay, while Block-1 also extends into The Yapen Strait, forming The Yapen-Biak Basin (Figure 5b). All three subbasins exhibit sediment thicknesses exceeding 3

km, delineated by magnetic basement lows and bounded by structural highs such as ridges and fault zones. Comparable thicknesses were also found to be hydrocarbon-favourable in The Benue Trough (Abdullahi *et al.*, 2019) and The Red Sea Rift (Eldosouky *et al.*, 2022). To further explore this potential, two cross-sections-Profiles A-A' and C-C'-were selected from five slicing lines to generate conceptual models integrating magnetic basement and bathymetry (Figures 8 and 9).

The A-A' profile (Figure 8), spanning subbasins 2 and 3, reveals greater basement depth to the south. Positive magnetic anomalies cluster near Yapen Island, where shallow magnetic basement, and thin sediment cover are likely contributors (Alrefaee and Soliman, 2023). This is consistent with Zhu *et al.* (2022), who reported high magnetic susceptibility in mafic intrusive rocks-features, also present on Yapen Island. The ridge interpreted in this section likely consists of Miocene volcanic and ultramafic intrusions (Gold *et al.*, 2017). Ac-

cording to ESDM (2022), the basin block between Yapen and Biak remains underexplored. Basement structure maps also indicate strike-slip fault control, and the occurrence of the 7.9 MW Yapen earthquake with a hypocentre at 4 km deep supports this segmentation. These tectonic structures shape sediment distribution, and may regulate hydrocarbon migration and trap formation.

The C-C' profile similarly outlines basement highs and adjacent basins (Figure 9). Combined, both profiles illustrate the topographic variation of the magnetic basement, influenced by igneous intrusions and fault systems. This interpretation is supported by island basement geology (McAdoo and Haebig, 1999; Sapiie and Hadiana, 2007; Gold *et al.*, 2017; Babault *et al.*, 2018), which reveals a crustal affinity with The Pacific Ocean-Caroline Plate. This structural pattern influences sediment thickness variation across the three subbasins, with sediment thickness increasing gradually from west to east. This trend implies

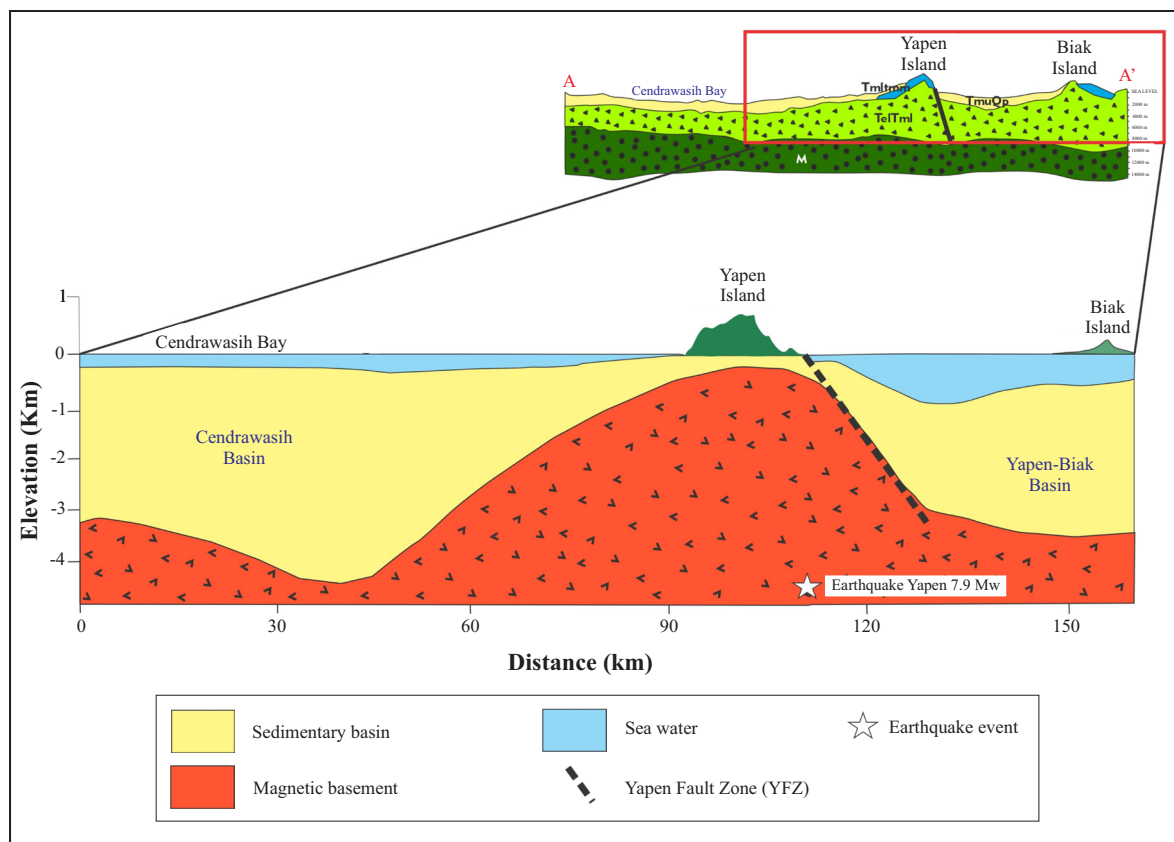


Figure 8. The magnetic basement model tied to the geological cross-section: (a) The geological cross-section of the Profile A-A', and (b) The magnetic basement model on the Profile A-A'.

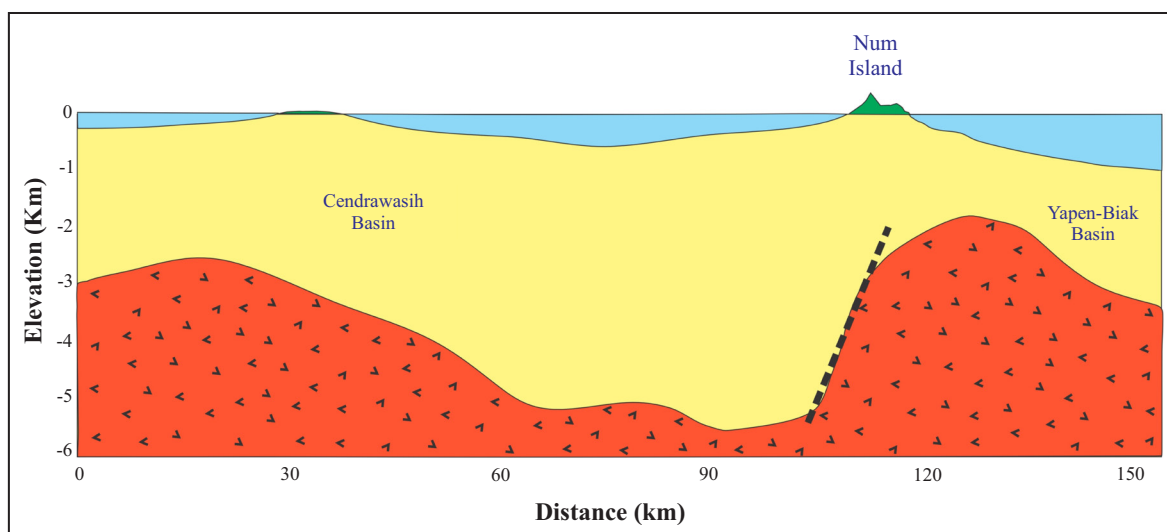


Figure 9. Magnetic basement model and hydrocarbon potential in the Cendrawasih and Yapen-Biak Basin Subbasins on the Profile C-C'. The black dotted lines represent possible faults that cross the magnetic basement.

lateral variation in source rock maturation and potential migration pathways, which may affect hydrocarbon accumulation zones.

Sediment thickening in the western part of Cendrawasih Bay is indicative of potential hydrocarbon reserves (see Figure 9). The complex basin configuration around Cendrawasih Bay, including its surrounding small islands, results from fault deformation adjacent to the Yapen strike-slip fault, which cuts through these thick sediments (depicted by the black dotted line in Figure 9). This deformation, which was active until recently, influenced basement and topographic relief, shaping the surrounding islands (Dow and Sukanto, 1984; Atmawinata and Ratman, 1982; Atmawinata *et al.*, 1989; Gold *et al.*, 2017; Babault *et al.*, 2018).

In addition to the subbasin structure, another significant finding is the correlation between Yapen Island Miocene volcanic and ultramafic exposures, and one of the highest magnetic anomalies in the area. This suggests a shallow, high-magnetization oceanic crust. Furthermore, the Bird Head of Papua full tectonic cycle, including regional compressive tectonic processes, sedimentation, magmatism, and metamorphism, may be associated with these intrusive bodies (Pieters *et al.*, 1983; Dow and Sukanto, 1984; McAdoo

and Haebig, 1999; Charlton, 2000; Decker *et al.*, 2009; Gold *et al.*, 2014; Babault *et al.*, 2018). Future work should prioritize integrating well data from Tonny and Bagiyo (1993). Coupled with seismic attributes, this may refine lithological interpretation and maturation assessments.

Despite these strengths, several limitations remain. Magnetic inversion methods are inherently non-unique, and their outcomes depend on input assumptions and model constraints (Xu *et al.*, 2023). Moreover, while the magnetic basement model was compared with regional seismic data, validation was restricted by the limited spatial coverage. The profiles presented (Figures 8 and 9) should thus be seen as conceptual, reflecting the magnetic basement and bathymetric configuration of eastern Cendrawasih Bay. In summary, despite the insights provided by magnetic inversion, this study is limited by the absence of seismic attribute data and the lack of direct well control in two of the three subbasins. Future investigations should reduce these uncertainties through the acquisition of high-resolution seismic data and broader well coverage. A domain-based magnetic basement classification, as applied in The Barents Sea by Marello *et al.* (2010), could also be adopted to distinguish tectonically distinct crustal blocks in Cendrawasih Bay.

CONCLUSION

This study employed marine magnetic data and inversion modeling to investigate the basement morphology beneath eastern Cendrawasih Bay, Papua. The results reveal three subbasins: (1) between Cendrawasih Bay and Num Island, (2) between Cendrawasih Bay and Yapen Island, and (3) between Yapen and Biak Islands. These subbasins are characterized by sediment thicknesses exceeding 3 km, and are bounded by structural highs associated with intrusive igneous bodies and fault zones, including the Yapen strike-slip fault and fold-thrust systems.

Magnetic basement depths derived from 2D inversion range from 0.4 to 7 km, delineating subsurface structural segmentation that corresponds with known tectonic features, and aligns with regional seismic data. The presence of magnetic highs around Yapen Island and the spatial correlation with Miocene volcanic and ultramafic outcrops further support the interpretation of shallow intrusive basement features. These structural elements influence sediment distribution, and may define subbasin geometries that are favourable for initial hydrocarbon assessment. The application of marine magnetic data proves effective in early-stage basin delineation, particularly in tectonically complex and seismically sparse regions.

Marine magnetic methods offer a practical and efficient approach to delineate prospective subbasin areas prior to high-resolution seismic surveys, especially in data-limited offshore regions. While current findings contribute valuable regional insights, further studies should incorporate gravity data and additional seismic acquisition to reduce ambiguity in basement geometry and improve subsurface characterization.

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