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Locating the Cambrian Suture in Wilkes Land, East Antarctica, Based on Russian Geophysical Data

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Abstract: Interpretation of modern aeromagnetic and radar data, primarily from Russian surveys in East Antarctica between 88°–102°E, has resulted in a tectonic map of Precambrian provinces, including two protocratonic domains and two orogens of different ages. The crust of the Charcot Province is presumably composed of Mesoarchean tonalite-gneisses of Cape Charcot (3003 ± 8 Ma), which underwent metamorphism at ~2890 Ma and a zircon-forming episode at ~550 Ma. The West Mawson protocraton province is identified based on magnetic data and is represented by terranes that may have accreted to the western edge of the East Mawson craton in the Mesoproterozoic. The Wilkes Orogen correlates with metamorphic and intrusive rocks of the Bunger Hills, Highjump Archipelago, Obruchev Hills, and exposures in the lower reaches of the Denman Glacier, mostly associated with positive magnetic anomalies forming an elongated, segmented magnetic belt. The Rayner Orogen has a heterogeneous geological structure and can be subdivided into several tectonic zones with specific lithological compositions and slightly different geological histories. All previously proposed fault locations (sutures) between Indo-Antarctica and Australo-Antarctica are not reflected in either modern aeromagnetic data or bedrock topography. Most likely, it is located along the boundary between the Charcot craton and the Wilkes Orogen and corresponds to the Northcliffe Glacier. ADMAP-2 data allow tracing its continuation towards the southern Prince Charles Mountains and/or the subglacial Gamburtsev Mountains.

Keywords: magnetic anomalies, radar data, magnetic properties, craton, province, fault, Kuunga suture

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Research Article

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1. Introduction

The study of the geological structure of the Denman Glacier (DG) area and adjacent Wilkes Land territories began in 1956–1957 during the 1st Soviet Antarctic Expedition (SAE). Coastal and inland rock outcrops were investigated and a 1:100,000 scale geological survey of the Bunger oasis (BO) was completed. The results of these works were published in the monograph by [*Ravich et al.*, 1965], which provides a detailed petrographic description, chemical and mineral composition of rocks, tectonic structure, characteristics of rock complexes, and tectonomagmatic events. Currently, geologists from the Polar Marine Geosurvey Expedition (PMGE) and VNIIOkeangeologia continue active studies of the geological structure of the BO.

Australian geologists have also made significant contributions to the study of the region's geology. For example, geologists R. Tingey and J. Sheraton visited the main rock outcrops in the BO, Obruchev Hills (OH), and most of the small outcrops located on the western side of the DG in 1986. These field observations were accompanied by the first detailed geochemical and geochronological studies of the region's rocks.

The first aerogeophysical surveys were carried out during the 1st SAE in 1956–1957 at a scale of 1:100,000 over the BO and the OH, and at a scale of 1:1,000,000 over the remaining coastal territory of Queen Mary Land (QML, see Figure 1; [*Glebovsky*, 1959]). For a long time, the results of these surveys, understandably of low quality due to the limitations of that time, served as the only source of geophysical information for a vast area of East Antarctica [*Golynsky et al.*, 2002].

The next stage of research in this region is associated with the implementation of the international projects ICECAP and ICECAP II/EAGLE in 2009–2011 and 2015–2016, respectively [*Aitken et al.*, 2014; *Roberts et al.*, 2018]. As a result of these regional surveys, new information on potential fields and subglacial relief became available for Wilkes Land and QML, where it was previously almost entirely absent. This data were acquired using a varied observation system – from 5–10 km between flight lines over the DG, to 50 km over the remaining territory, where flights were carried out using a fan-shaped flight line system.

During the 62nd–65th, 67th, and 69th Russian Antarctic Expeditions (RAE), the area of the DG, OH, and adjacent territories up to 88°E in the west of the region was surveyed by PMGE researchers using an An-2 aircraft (Figure 1). During the survey operations, more than 41,500 km of magnetic and radar line data were acquired along a network of meridional flight lines spaced 5 km apart. Tie lines were flown orthogonally to the primary lines every 15 km. This made it possible to significantly refine the information and approach the interpretation of the obtained data more objectively.

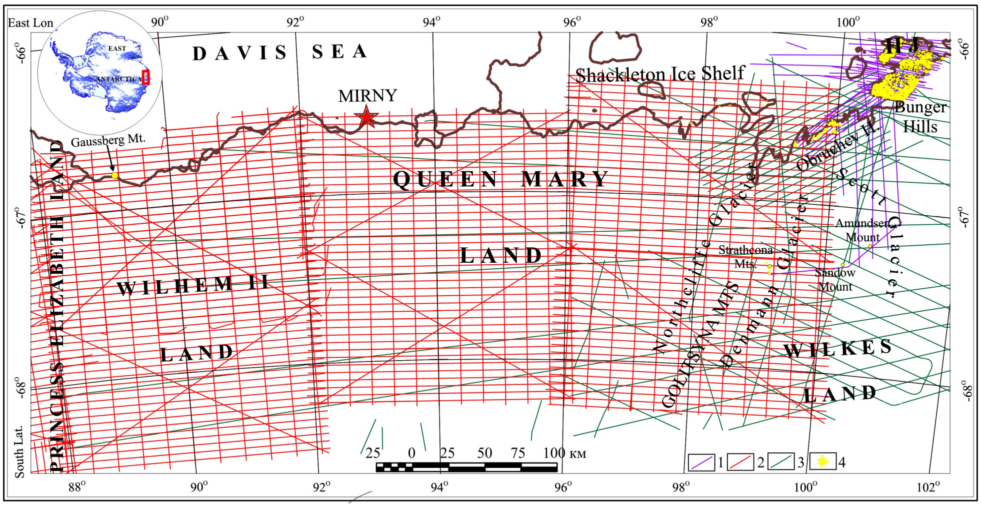

Figure 1. Aeromagnetic flight-line network collected by the RAE, ICECAP and ICECAP II/EAGLE projects. 1 – flight-lines by SAE-1; 2 – flight-lines by RAE62-69; 3 – flight-lines by ICECAP and ICECAP II/EAGLE projects; 4 – rock outcrops. HJ – Highjump Archipelago.

2. Geological Framework of the Denman Glacier Area

The study area plays a crucial role in understanding the tectonic relationship between India, Australia, and Antarctica within the supercontinents Rodinia and Gondwana (Figure 2). This area preserves evidence of Australo-Antarctica's Mesoproterozoic assembly during Rodinia's formation, marked by a widespread orogenic event (1300–1150 Ma) spanning from Southwest Australia's Albany-Fraser Orogen to various locations in Wilkes Land, Antarctica [*Boger*, 2011; *Boger et al.*, 2001; *Daczko et al.*, 2018; *Fitzsimons*, 2000; *Morrissey et al.*, 2017; *Tucker et al.*, 2017]. While this Mesoproterozoic history is relatively well-documented, the impact of Gondwana's amalgamation in the Neoproterozoic-Cambrian remains ambiguous. New aeromagnetic data help define tectonic units, terrains, and structural features, and, combined with existing geological data, can illuminate the region's development within this broader orogenic context, including its connection to similar structures in Australia.

The Denman Glacier area, lithologically heterogeneous, is divided into two parts. The eastern part stretches 220 km from Mount Borzov southward to the Highjump Archipelago, encompassing the archipelago itself, the BH oasis, the OH, and other minor outcrops on the mountains southwestern flank. The western part consists of small outcrops on the glacier's western side [*Ravich et al.*, 1965; *Sheraton et al.*, 1995]. The eastern part is composed of rocks of primarily igneous, sedimentary, and volcanogenic-sedimentary origin, deformed and metamorphosed under granulite to amphibolite facies conditions, and a series of plutonic rocks ranging in composition from gabbro to granite [*Ravich et al.*, 1965; *Sheraton et al.*, 1995].

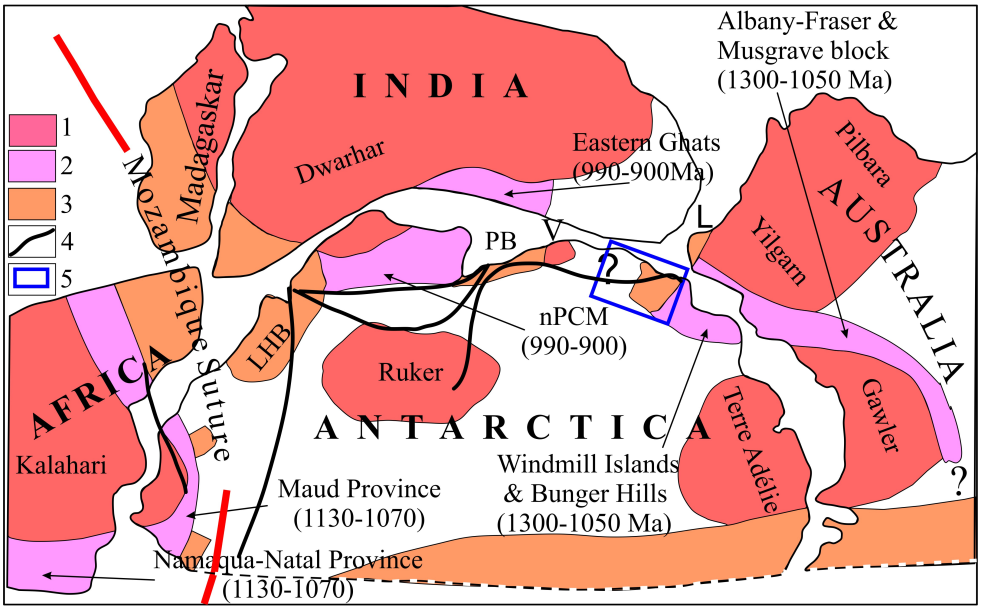

Figure 2. Reconstruction of Gondwana centered on Antarctica at ca. 500 Ma (modified after [*Boger*, 2011]). East Antarctica and margins of adjacent continents showing Archean-Paleoproterozoic cratonic blocks (1) and Mesoproterozoic-Neoproterozoic (2) and Paleozoic orogenic belts (3). Mozambique suture represents proposed boundary between east and west Gondwana. 4 – sutures [*Boger*, 2011, and references therein]; 5 – study area. L – Leewin Complex, LHB – Lützov-Holm Bay, nPCM – northern Prince Charles Mountains, PB – Prydz Bay, V – Vestfold Hills.

The western part of the territory is designated as the Charcot Province [*Aitken et al.*, 2014]. The crust of this province is presumably composed of Paleo- to Mesoarchean (3400–3000 Ma) tonalite-gneisses that underwent metamorphism at ~2890 Ma and a zircon-forming episode at ~550 Ma [*Black et al.*, 1992]. The southwestern part of the area is intruded by granitoids with ages of around 500 Ma.

The BO comprises rocks of three (may be four) main structural-lithological complexes: 1) an Archean basement mapped in the eastern and southeastern parts of the oasis; 2) a Paleo- to Mesoproterozoic volcano-sedimentary complex; and 3) a Mesoproterozoic intrusive complex of gabbro-monzonite-granite composition [*Tucker et al.*, 2017]. Mesoproterozoic mafic dikes (1130 Ma) are also present in the oasis [*Stark et al.*, 2018]. Archean orthogneisses with ages ranging from 2800 to 2600 Ma are interpreted as part of a Mesoproterozoic reworked Archean basement underlying Proterozoic metamorphosed volcano-sedimentary sequences [*Tucker et al.*, 2017].

The OH are mainly composed of schistose orthogneisses with interlayers of mafic crystalline schists. They are underlain by Neoarchean metamorphic rocks dated at 2650 Ma [*Sheraton and Black*, 1992] and 2692 ± 12 Ma [*Daczko et al.*, 2018]. Massive pyroxene-quartz-feldspar gneisses of predominantly felsic composition form most of the bedrock outcrops of the OH and Cape Jones. They are intruded by charnockites dated at 1200–1170 Ma [*Sheraton and Black*, 1992; *Tucker et al.*, 2017] and 1142 ± 4 Ma [*Alexeev et al.*, 2011]. The data obtained indicate a nearly synchronous Proterozoic evolution of the continental crustal blocks of the OH and BO areas. Orthopyroxene-biotite granites and two-pyroxene tonalites from the headwaters of the DG in the Strathcona Mountains can be correlated with the metamorphic sequences of the BO [*Mikhalsky et al.*, 2015a].

One of the problems attracting the attention of the researchers in this area is determining the location of the Neoproterozoic-Cambrian Kuunga suture (orogen), along which East Gondwana was assembled by the amalgamation of Indo-Antarctica and Australo-Antarctica [*Boger*, 2011; *Boger et al.*, 2001; *Fitzsimons*, 2003]. This orogen is largely hidden beneath the East Antarctic Ice Sheet, and the various interpretations of its trace between scattered rock outcrops remain controversial, often with conflicting trends. Overall, several hypotheses have been proposed, but there is currently no consensus on the location of this suture zone in Antarctica [*Aitken et al.*, 2014; *Boger et al.*, 2001; *Daczko et al.*, 2018; *Fitzsimons*, 2003; *Gardner et al.*, 2015; *Mulder et al.*, 2019].

Within the framework of this study, maps of the magnetic anomalies (Figures 3; 4) and subglacial relief (Figure 5; 6) of the region were compiled, which allowed to propose the existence of a suture in the area of the Northcliffe Glacier. These maps incorporate modern data from six aeromagnetic and radar surveys conducted by PMGE in areas located to the west and east of Mirny Station. In addition, materials from the international projects ADMAP-2 [*Golynsky et al.*, 2018] and BEDMAP-2 [*Fretwell et al.*, 2013] were used.

3. Petromagnetic Property of Rocks

To study the petrophysical properties of rocks from the OH, outcrops on the western flank of the Denman Glacier, and nunataks located in the lower reaches of the glacier, 56 samples from the collection of V.A. Maslov and N.V. Borovkov of VNIIOkeangeologia, as well as from earlier Russian expeditions, were used.

The magnetic susceptibility of the rocks from the OH, measured using KT-5 and KM-7 kappameters, varies widely from (0.02–0.06) × 10^{-3} SI units for pegmatites, metapsammites, and garnet gneisses, to (70–84) × 10^{-3} SI units for crystalline schists. The magnetic susceptibility of orthogneisses ranges from 3.19 to 89.7 × 10^{-3} SI units, with an average of 11.7 × 10^{-3} SI units, while for crystalline schists it varies from 1.55 to 84 × 10^{-3} SI units.

Orthogneisses of the OH, represented by pyroxene-feldspar orthogneisses of tonalitic, granodioritic, and granitic composition [*Ravich et al.*, 1965], are the most widespread. It is logical to assume that these rocks are responsible for the observed magnetic anomaly pattern in the region and are the source of the extensive positive magnetic anomaly with an intensity of up to 450 nT (Figure 3). Sillimanite-biotite and garnet-biotite paragneisses, present in subordinate amounts, have low magnetic susceptibility, not exceeding 0.4 × 10^{-3} SI units, and therefore cannot be considered as a source of the mapped anomalies.

In the Strathcona Mountains, located in the gradient zone of positive magnetic anomalies, rocks with low magnetic susceptibility are predominantly exposed (Figure 3). For plagiogneisses the magnetic susceptibility does not exceed (1–1.2) × 10^{-3} SI units, for porphyritic granitoids it varies from 0.3 to 1.9 × 10^{-3} SI units, and for granite-gneisses, it reaches 4.3 × 10^{-3} SI units. High values (17–20) × 10^{-3} SI units are observed in the intrusive body of granite-charnockites of Mount Gist (1190 Ma; [*Mikhalsky et al.*, 2015a]). Mafic xenoliths and metamorphic biotite-pyroxene gneisses and biotite schists are present at the contacts with the intrusive rocks, for which the magnetic susceptibility can reach 115 × 10^{-3} SI units.

Metamorphic rocks of Archean age from Cape Charcot [*Sheraton et al.*, 1995] are represented by weakly magnetic paragneisses with (4–5) × 10^{-3} SI units and practically non-magnetic orthogneisses with ~0.3 × 10^{-3} SI units. On the Davis Peninsula, the basement rocks, represented by amphibole-biotite orthogneisses and banded gneisses, are characterized by predominantly low magnetic susceptibility values (0.05–9) × 10^{-3} SI units. A local minimum in the magnetic field, not exceeding −200 nT in amplitude, corresponds to them.

Felsic orthogneisses are the most common rock type in the Jones Rocks, and they also outcrop on Hippo Island, Cape Gerlache, and Cape Charcot. Their composition varies from tonalites to granites [*Ravich et al.*, 1965]. Samples of (±pyroxene)-amphibole-biotite orthogneisses from Cape Jones, according to the measurements, have magnetic susceptibility values ranging from (40–70) × 10^{-3} SI units. The positive magnetic anomaly with an intensity of up to 800 nT is most likely caused by these orthogneisses (Figure 3; 4). Its linear shape is due to crustal-scale faults located on both sides of the horst-like uplift of Cape Jones, corresponding to the strike of the Obruchev and Denman Glaciers (Figure 5; 6). The magnetic susceptibility values for sillimanite-biotite and garnet-biotite paragneisses here, as in the OH, do not exceed 0.4 × 10^{-3} SI units.

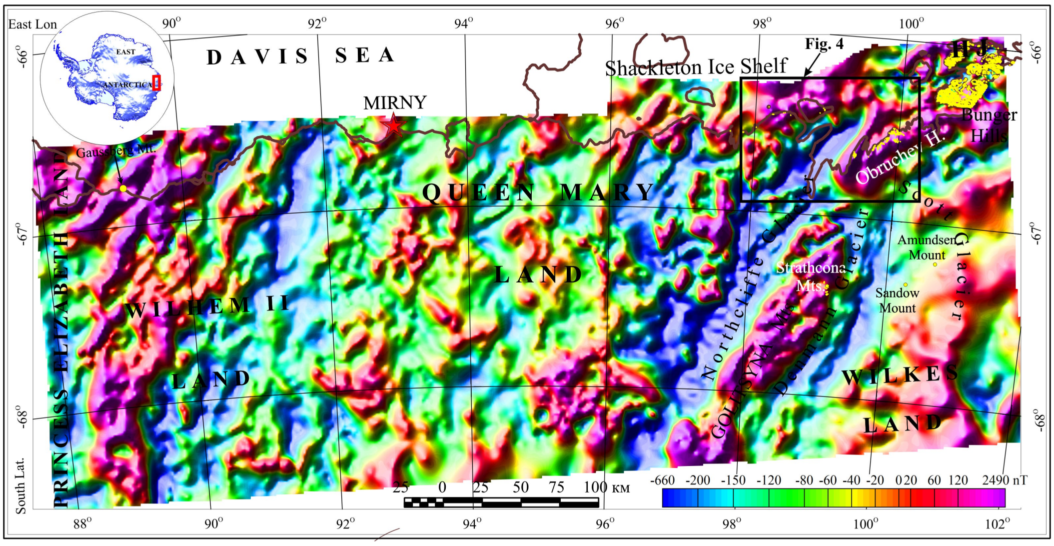

Figure 3. Magnetic anomaly map of Princess Elizabeth, Wilhelm II, Queen Mary and Wilkes Lands. Rock outcrops are highlighted in yellow. The inset (red square) shows the study area within Antarctica.

The Possession Rocks and Cape Harrison are composed of garnet-biotite orthogneisses with low magnetic susceptibility values (0.1–0.3) × 10^{-3} SI units and (0.4–2.7) × 10^{-3} SI units, respectively. These bedrock outcrops fall within the area of a negative magnetic field (about −100 to −250 nT). Gabbrodiorites, granite aplites, and biotite granites of the 500 Ma batholith, outcropping at Cape Delay Point, are characterized by high magnetic susceptibility values, (13–22) × 10^{-3} SI units, whereas biotite gabbro has low values 1 × 10^{-3} SI units.

The dike complex of the batholith in the Cape Kennedy area is mainly represented by non-magnetic rocks, with the exception of a biotite leucogranite sample, whose magnetic susceptibility reaches 64 × 10^{-3} SI units. Granosyenites and granodiorites of Hippo Island generally have high magnetic susceptibility values, (40–50) × 10^{-3} SI units, while porphyritic granosyenite exhibits values in the range of (2–7) × 10^{-3} SI units. Biotite granosyenites of Watson Bluff on the David Island ice dome, where the main outcrops of the batholith are concentrated, are characterized by similar values (1.5–8) × 10^{-3} SI units. The northern part of David Island is associated with an isometric anomaly with an intensity of 250–280 nT, which extends beneath the Shackleton Ice Shelf (Figure 3). Thus, the diverse rocks of the batholith create a distinctly different magnetic anomaly pattern from the OH, with positive anomalies of the order of 200–400 nT, which, to a first approximation, form a linear belt of sublatitudinal strike with a predominantly isometric anomaly development.

The magnetic properties of the rocks in the BO vary significantly. Metagabbroids (up to 165 × 10^{-3} SI units) and dolerites show high susceptibility. Neoarchean orthogneisses range from moderately magnetic (granodiorite-tonalite, 13.9 × 10^{-3} SI units) to weakly magnetic (granite-plagiogranite, 3.9 × 10^{-3} SI units), with alkaline orthogneisses (26.9 × 10^{-3} SI units) being the most homogenous. Migmatized pyroxene schists and melanogneisses have average susceptibility around 34.8×10^{-3} SI units. Neoarchean-Paleoproterozoic paragneisses exhibit heterogeneous magnetism, controlled by ore mineral distribution, not lithology, with susceptibilities ranging from 1.8 to 87×10^{-3} SI units [*Golynsky et al.*, 2024].

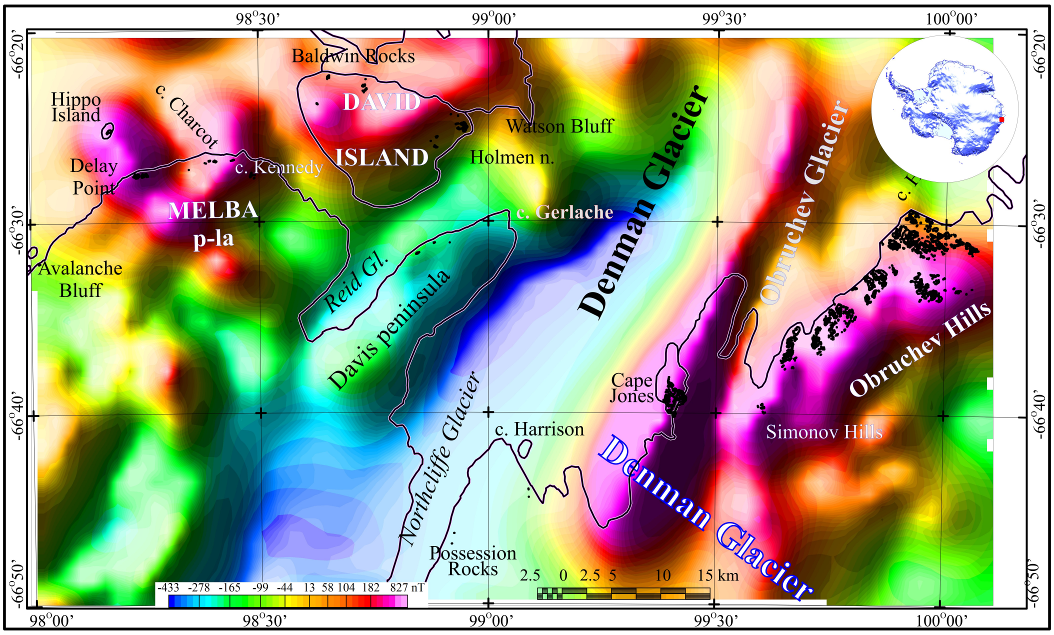

Figure 4. Magnetic anomaly map at the upper reaches of the Denman Glacier. Rock outcrops are highlighted in black. The red outline on the inset shows the location of the study area within East Antarctica.

Metapelitic rocks (max. sedimentation age 1490 ± 27 Ma) including orthopyroxene, cordierite, and biotite-garnet varieties, are magnetic. Modal susceptibility is typically 34×10^{-3} SI units, reaching 131×10^{-3} SI units (magnetite-bearing) and 159×10^{-3} SI units (titanomagnetite-rich with hemo-ilmenite). The area of relatively large-scale outcrops of rocks from this unit along the boundary with the Paz Cove intrusion is controlled by an intense positive magnetic anomaly [*Golynsky et al.*, 2019]. Paz Cove intrusion rocks are moderately magnetic, with gabbrodiorite and diorite porphyries having higher susceptibility (24.2×10^{-3} SI units) than leucocratic gabbro porphyries (14.6×10^{-3} SI units) and gabbro/microgabbro porphyries (4×10^{-3} SI units). The area of negative magnetic anomalies development over the Paz Cove intrusion, composed mainly of meta-intrusive rocks with moderate magnetic susceptibility, indicates magnetization oriented opposite to the present-day Earth's magnetic field [*Golynsky et al.*, 2019].

Migmatized garnet and sillimanite-garnet gneisses, quartzite gneisses, and quartzites are consistently weakly magnetic (modal value 0.28×10^{-3} SI units), dominated by metapsammites. Pyroxene crystalline schists (leucocratic to melanocratic) have a polymodal magnetic susceptibility distribution, peaking at 19.3×10^{-3} SI units. Amphibolitized varieties in shear zones show lower susceptibility (0.73×10^{-3} and 3.85×10^{-3} SI units). Orthogneisses (1700–1600 Ma) are moderately magnetic (12.3×10^{-3} SI units), similar to Neoarchean granite-tonalite orthogneisses. Rocks in shear zones are very weakly magnetic (0.2×10^{-3} SI units). Algae Lake intrusion rocks are moderately magnetic, with gabbros at 9.1×10^{-3} SI units and diorite-quartz monzodiorites at 28.9×10^{-3} SI units.

4. Schematic Tectonic Map

The schematic tectonic map (Figure 7) of Princess Elizabeth Land (PEL), Wilhelm II Land, Queen Mary Land, and Wilkes Land is based on geophysical data from the 62nd–69th RAEs and surveys conducted under the international projects ICECAP [*Aitken et al.*, 2014] and EAGLE [*Roberts et al.*, 2018]. Additionally, data on the BO from the 1st SAE [*Golynsky et al.*, 2002] were integrated with data from adjacent territories (Figure 3).

The most contrasting subglacial relief forms are found in the east of the region, where the valleys of the graben-like Denman and Scott Glaciers represent deep bedrock depressions, clearly indicating their tectonic nature (Figure 5). The Northcliffe outlet glacier is also distinctly expressed in the bedrock relief as a narrow (3–5 km) linear structure traced southwestward for about 270 km.

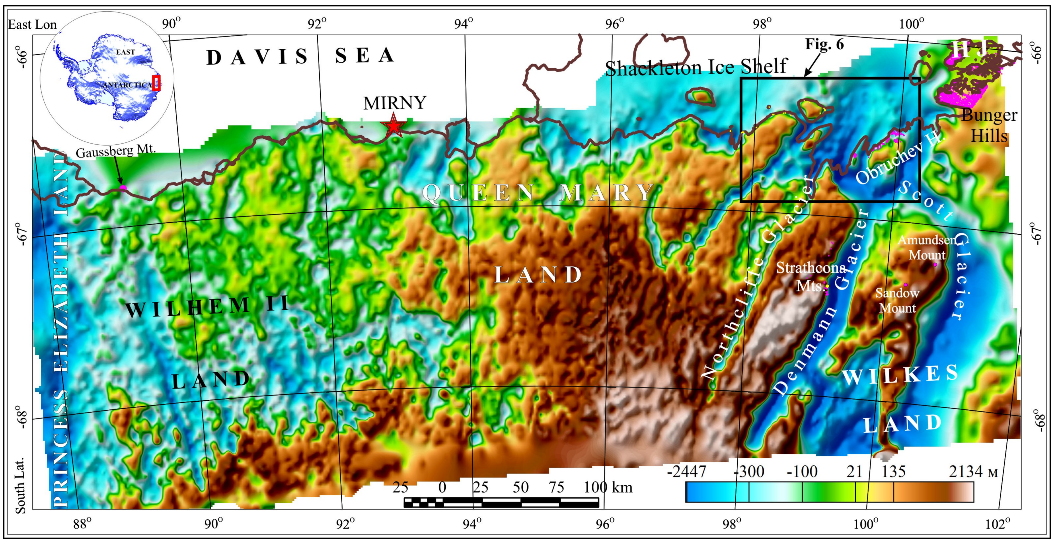

Figure 5. Bedrock topography map of Princess Elizabeth, Wilhelm II, Queen Mary and Wilkes Lands. HJ – Highjump Archipelago.

The magnetic anomaly map clearly demonstrates the morphological heterogeneity and amplitude variability characteristic of deeply metamorphosed complexes of ancient platforms (Figure 3). Here, alongside relatively quiet areas, there are zones with sharply differentiated fields. For example, the Golitsyn Mountains, a horst-like uplift between the Northcliffe and Denman Glaciers, exhibit intense, near-continuous magnetic anomalies, suggesting the presence of the Wilkes Land orogen, an analog of southwestern Australia's Albany-Fraser Orogen. Since the rocks comprising the Obruchev Hills and Strathcona Mountains also record evidence for Mesoproterozoic metamorphic zircon and monazite growth and recrystallization (c. 1190–1140 Ma; [*Daczko et al.*, 2018]) and charnockite emplacement in the Obruchev Hills (1142.0 ± 3.6 Ma; [*Alexeev et al.*, 2011]).

A notable feature of the region's magnetic anomaly pattern is the strike of the anomalies, which has a NE trend, both for most isolated anomalies and for extended anomaly systems. The composite magnetic anomaly map allows tracing the continuation of previously identified structural-tectonic subdivisions into the adjacent territory of PEL and identifying previously unknown structures [*Golynsky et al.*, 2020, 2006].

4.1. Charcot Protocraton Province

The Charcot Protocraton Province (CPP) exhibits a characteristic magnetic signature consisting of a broad magnetic low punctuated by localized anomalies of variable intensity (Figure 3; Figure 4). The western boundary of the province is marked by a linear arc-shaped anomaly of low intensity, interpreted as a fault structure (Charcot fault). To the north of the province, positive anomalies dominate, caused by rocks of Pan-African age batholith. The eastern boundary of the province corresponds to an extensive zone of negative anomalies and coincides with the depression of the Northcliffe glacier (Figure 5).

The area of Early Precambrian consolidation of the Charcot protocraton (Charcot Province; [*Aitken et al.*, 2014]) is located west of the DG, where bedrock outcrops are represented by isolated nunataks sporadically scattered in the David Island area in the north and extending to the Jones Rocks in the west (Figure 6). This region, as well as the southeastern part of the BO and the OH, represents preserved blocks of Archean cratons that underwent reworking and orogeny during the Meso- to Neoproterozoic [*Fitzsimons*, 2000]. Granulite-facies metamorphic rocks intruded by plutonic rocks of widely varying composition predominate here [*Sheraton et al.*, 1995].

Presumably, the crust of this province is composed of Mesoarchean tonalite-gneisses of Cape Charcot (3003 ± 8 Ma), which underwent metamorphism around 2890 Ma and a zircon formation episode around 550 Ma [*Black et al.*, 1992]. The crystallization age of the igneous protolith of tonalitic orthogneisses on the Davis Peninsula is 3355.0 ± 5.4 Ma, which experienced polymetamorphism in the intervals ~3100–3000 and 2900–2800 Ma [*Maslov et al.*, 2023].

Evidence for high-grade Mesoproterozoic metamorphism and swarms of dolerite dikes, characteristic of the BO, is absent here. However, the available data are sufficient to consider the upper reaches of the DG as a single tectonic province. Neoarchean formations are intruded by rocks of widely varying composition (from mafic to felsic), including a large batholith of syenites and granites on David Island with an age of about 500 Ma [*Black et al.*, 1992]. For example, the Gillies Islands are composed of granitoids with an age of 516 ± 5 Ma, orthopyroxene tonalites with an age of about 511 ± 6 Ma occur at Delay Point [*Sheraton et al.*, 1995].

In the middle reaches of the Denman Glacier, near Cape Harrison, a single sample of granite gneiss has been dated. Slightly discordant zircon analyses with magmatic oscillatory zoning yield an upper intercept age of 1192 ± 83 Ma and a lower intercept age (nearly concordant analyses of metamorphic rims) of 533 ± 21 Ma [*Daczko et al.*, 2018]. This result for the Cape Harrison granite gneiss should be considered as the easternmost of all existing Cambrian metamorphic age determinations for the DG region.

4.2. Western Mawson Protocraton Province

Based on the analysis of geophysical data from the ICECAP international project, the Mawson Craton in East Antarctica can be divided into eastern and western parts [*Aitken et al.*, 2014]. The Eastern Mawson Craton (EMC) is identified in Adélie Land and George V Land, where Neoarchean and early Paleoproterozoic rocks occur, showing similarities to rocks of the Gawler Craton in South Australia [*Payne et al.*, 2008]. The Western Mawson Craton (WMC) includes Wilkes Land with a few outcrops along the Sabrina Coast and terranes that may have accreted to the western margin of the EMC in the Mesoproterozoic.

The WMC is associated with extensive arcuate magnetic anomalies trending east-west [*Golynsky et al.*, 2018]. The northern part of the WMC borders the Wilkes Orogen [*Zhang et al.*, 2012], which is correlated with the accretionary-collisional Albany-Fraser Orogen (AFO) in southwestern Australia. The Antarctic branch of the AFO is recorded at Law Dome and is characterized by high-amplitude magnetic anomalies, including strong remanent components [*Golynsky et al.*, 2018].

Platform structures of the craton, composed of a volcano-sedimentary complex, are developed here, as evidenced by the presence of weakly metamorphosed and gently folded supracrustal formations of Mount Amundsen and Mount Sandow, and sheet-like dolerite bodies [*Ravich et al.*, 1965]. U–Pb ages of detrital zircons from the supracrustal sequences mainly fall into two groups: ~1350–900 Ma and ~1800–1500 Ma, corresponding to the ages of crystalline rocks in western Australo-Antarctica [*Mikhalsky et al.*, 2020]. The youngest zircons with magmatic zoning give a maximum depositional age of about 950–900 Ma for the rocks in a continental basin that formed in the Neoproterozoic in connection with the activity of the proto-Darling Fault system in Western Australia, where the Sandow Group may have its correlatives (Moora and Badgeradda Groups; [*Mikhalsky et al.*, 2020, and references therein]).

4.3. Wilkes Orogen

According to the proposed interpretation the metamorphic and intrusive rocks of the BO, HA, OH, and outcrops in the lower reaches of the DG, which are mainly associated with positive anomalies in the form of an extended, segmented magnetic belt, define the extent of the Wilkes Orogen. The most complex pattern of anomaly distribution is observed in the HA area, where positive anomalies dominate in the northern part, and an alternating field is observed in the south. A similar pattern is characteristic of the BO, with the only difference being that the mosaic field is concentrated in the northern part of the oasis, and the main belt of positive anomalies is concentrated along the southern boundary of the oasis.

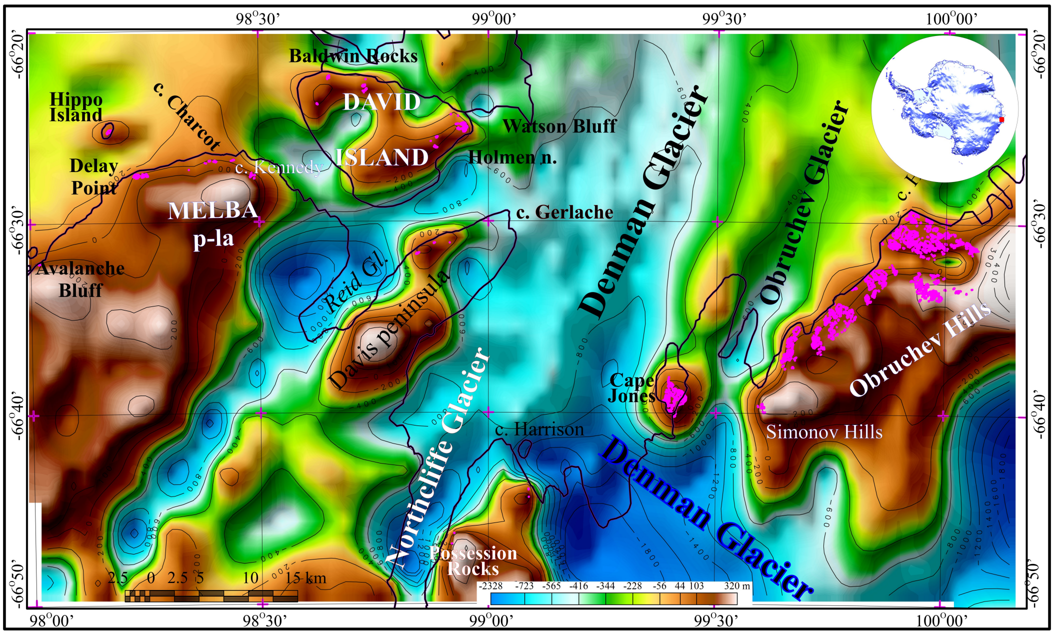

Figure 6. Bedrock topography map at the upper reaches of the Denman Glacier. Rock outcrops are highlighted in pink.

The OH are associated with a system of isometric and slightly elongated in the northeasterly direction positive anomalies, with intensities up to 300 nT. The width of the anomalies is about 25 km, and their length does not exceed 40 km. As they extend northward, the anomalies acquire a sublatitudinal orientation, forming an extended linear belt. This belt exhibits elements of an echeloned anomaly distribution and does not affect the BO, where an isometric anomaly of medium intensity is observed in the southern part.

South of the OH, on the western flank of the DG, a magnetic belt of similar width is recorded, but here the anomalies have an alternating character, and their intensity reaches 1030 nT. Despite the existing differences in the intensity and morphology of the magnetic anomaly field in the two regions separated by the DG, they represent a single entity and are caused by the rocks of the Wilkes Orogen, which can be traced southwestward for a considerable distance, according to the existing ADMAP-2 project data [*Golynsky et al.*, 2018].

Such an extended linear magnetic belt cannot correspond to a stable crustal block, like the Ruker Craton in the Prince Charles Mountains, even if fragments of ancient crustal consolidation nuclei may be present within it, which is characteristic of the OH and the BO [*Sheraton and Black*, 1992; *Tucker et al.*, 2017]. In the proposed interpretation, it corresponds to the Wilkes Land mobile belt, which, like the AFO in Australia, is considered a Mesoproterozoic granulite belt framing Archean cratons [*Fitzsimons*, 2000].

Its formation was preceded by crustal extension, sedimentation, and intense compression [*Clark et al.*, 2000; *Tucker et al.*, 2020]. Metamorphism developed during a single tectonic event and is characterized by multistage evolution and rapid changes in stages: granulite facies metamorphism, ultra-metamorphism, and syn-orogenic magmatism under amphibolite facies conditions. The Albany-Fraser Orogen, the central and northern parts of the BO, and the Windmill Islands area have similar rock complexes: a metamorphic sequence, charnockite intrusions, small bodies of porphyritic granites, and dolerite dikes [*Fitzsimons*, 2003; *Morrissey et al.*, 2017; *Zhang et al.*, 2012].

Geochronological data from the OH and the Strathcona Mountains [*Mikhalsky et al.*, 2015a] indicate that the Strathcona Mountains, the OH, and the BO, separated by the Denman and Scott Glaciers, experienced practically identical geological histories. Consequently, these territories could not have been separated by a Cambrian suture, as many authors suggest [*Boger*, 2011, and references therein]. Moreover, the rocks of the Strathcona Mountains were not affected by Pan-African events [*Mikhalsky et al.*, 2015a].

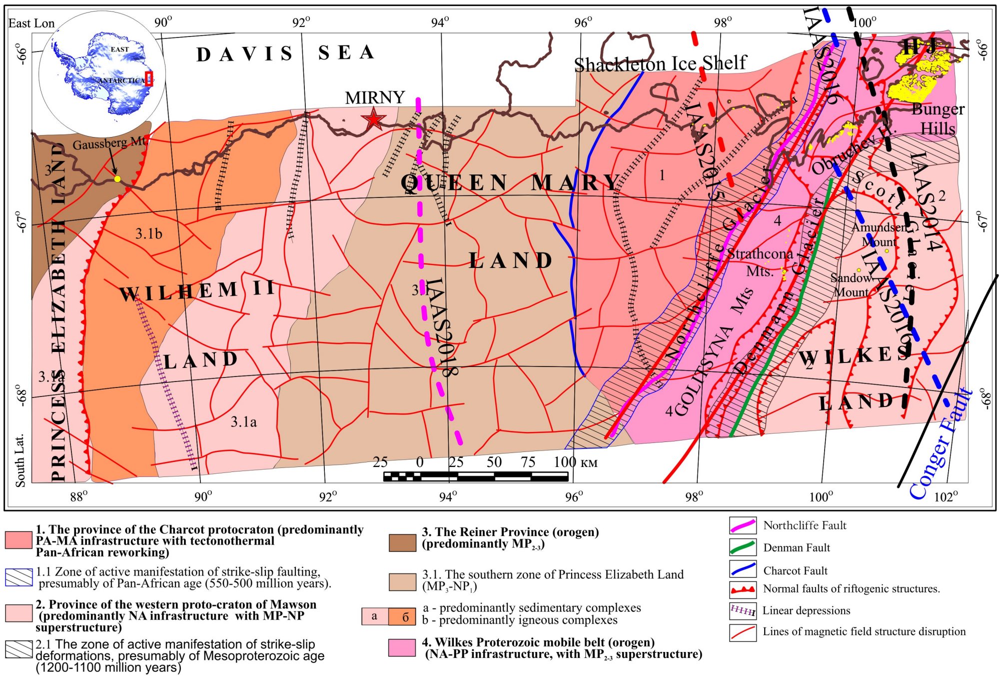

Figure 7. The schematic tectonic map of Princess Elizabeth Land (PEL), Wilhelm II Land, Queen Mary Land, and Wilkes Land. The locations of the previously proposed sutures (IAAS) are indicated by dashed lines of various colors.

4.4. The Rayner Province

A limited number of rock outcrops are found in the central and western parts of the region: the Gaussberg paleo-volcano, islands, and nunataks in the vicinity of Mirny Station. It is assumed that this area is composed predominantly of Meso- to Neoproterozoic geological formations of the Rayner orogen [*Fitzsimons*, 2000], typically characterized by t_{DM} values in the range of 1.6–2.4 Ga. It has a heterogeneous geological structure and can be subdivided into a number of tectonic belts with specific material compositions and slightly different geological histories [*Mikhalsky et al.*, 2013; *Mikhalsky et al.*, 2006]. Many of these belts possess individual anomaly magnetic field characteristics, which have been used to address the correlation between Archean cratons and Proterozoic mobile belts [*Golynsky*, 2007].

For the Prince Charles Mountains-Prydz Bay region, the Rayner orogen is subdivided into three belts (zones): the Rayner-Prydz belt located in the north, the Beaver-Prydz belt in the central and northern parts, and the southern PEL belt [*Mikhalsky and Leitchenkov*, 2018]. Geochronological data indicate that the Rayner orogen formed during three main Meso- to Neoproterozoic tectonothermal episodes: 1500–1100 Ma, 1000–950 Ma and 900–800 Ma, which are combined into the Rayner orogenic cycle [*Mikhalsky and Leitchenkov*, 2018].

The Rayner-Prydz zone includes metamorphic and igneous formations of the eastern part of the Mawson Coast, the Larsemann Hills and adjacent islands, and the rock complex of the Rauer Islands [*Mikhalsky and Leitchenkov*, 2018]. In our interpretation, it is located west of Gaussberg volcano. The lamproite lavas of the volcano contain xenoliths of felsic gneisses and xenocrysts of zircon with $^{206}Pb / ^{238}U$ ages of about 320, 500, 980, and 2000–1800 Ma [*Mikhalsky et al.*, 2015b].

The southern PEL zone encompasses the eastern margin of the Amery Ice Shelf (AIS), the south of the central Prince Charles Mountains, the Grove Mountains, and extends to the Mirny Station area [*Golynsky et al.*, 2006; *Mikhalsky and Leitchenkov*, 2018]. Geochemical analysis of rocks from the eastern margin of the AIS indicates that they formed in island arc and volcanic arc settings over a long period (1347–1020 Ma; [*Liu et al.*, 2014]). Geochronological dating for the eastern margin of the AIS led [*Liu et al.*, 2014] to conclude that crustal formation began in the Paleoproterozoic (2.3–1.9 Ga). A somewhat different result was obtained by [*Mikhalsky et al.*, 2013]. The formation of igneous protoliths of the Pickering series is dated to 3.0–2.2 Ga, the Robertson series to 1.9–1.7 Ga, and the rocks of the eastern margin of the AIS to 2.5–2.2 Ga.

The geological structure of the Mirny Station area comprises four structural-lithological complexes [*Ravich et al.*, 1965]: 1) crystalline schists and plagiogneisses metamorphosed under granulite facies conditions; 2) dike-like gabbroid bodies emplaced after the regional metamorphism of the host rocks; 3) injection leucodiorites and plagiogranites; and 4) rheomorphic charnockites. The protolith of the metamorphic complex (1) formed around 1480 Ma and underwent high-temperature metamorphism between 980 and 920 Ma [*Mikhalsky et al.*, 2015b]. Repeated metamorphism likely occurred synchronously with the emplacement of charnockites (4) around 500 Ma. Dike-like gabbroid bodies (2) intruded the host rocks around 510 Ma [*Mikhalsky and Skublov*, 2020].

The southern PEL zone, identified based on magnetic data, includes the eastern margin of the AIS and the Grove Mountains [*Golynsky et al.*, 2006]. In the former, the sources of positive anomalies are orthometamorphic rocks of Proterozoic age (Pickering orthogneisses; [*Laiba and Kudriavtsev*, 2006; *Mikhalsky et al.*, 2013]). Negative anomalies predominantly correlate with areas of parametamorphic rock development (Manning paragneisses). A similar pattern is observed in the Grove Mountains: the main sources of positive anomalies are orthometamorphic rocks, while negative anomalies correlate with areas dominated by parametamorphic rocks [*Golynsky et al.*, 2006].

The intensity of magnetic anomalies of the southern PEL zone varies from −300 to 1850 nT (Figure 3). Over most of QML and eastern Wilhelm II Land, the magnetic anomaly pattern is relatively homogeneous, with predominantly positive values not exceeding 150 nT. Local positive and negative anomalies often have a conjugate character and are relatively evenly distributed over the area. Areas of positive anomalies are generally not combined into large-scale zones and are represented by isolated local anomalies. An exception to this rule is the southeastern part of the area, where positive anomalies with intensities above 150 nT are concentrated, likely due to their intrusive nature.

Extensive zones with negative magnetic anomalies with an average intensity of −100 to −150 nT are widespread in the central part of QML. Changes in magnetic anomaly intensity are generally monotonic, and horizontal gradients are small, indicating that the main volume of the Earth's crust in this area is composed of weakly magnetic rocks.

The western part of Wilhelm II Land is associated with an extended arcuate system of positive anomalies stretching in a submeridional direction from the southern map boundary to the coast (Figure 3). Starting at latitude −67.5°S, it forms two complex branches with anomalies varying in shape and amplitude. The western branch is characterized by the most intense magnetic anomalies (up to 1850 nT), while in the eastern branch their intensity is significantly lower, not exceeding 100 nT.

The intense linear anomaly, approximately 60 km long, in the Gaussberg volcano region, with two peaks of 900 and 1100 nT along its axis, might at first glance be attributed to a mantle plume and/or a feeder conduit (Figure 3). However, directly above the volcano, the intensity of the recorded anomalies does not exceed 175–200 nT. There are no noticeable changes in the magnetic field directly above the volcano, which recorded only local anomalies with amplitudes no greater than 30–50 nT. This suggests classifying Gaussberg as a non-magnetic formation, which is supported by magnetic susceptibility measurements of a collection of rock samples (lamproites) collected during the 2nd Soviet Antarctic Expedition. The magnetic susceptibility of 11 lamproite samples varies within the range of (0.28–0.46) $\times 10^{-3}$ SI units, and only one sample exhibits 15×10^{-3} SI units. The facts presented above do not allow the interpretation of the linear anomaly in the Gaussberg volcano area as the main feeder conduit and/or deep source of magmatic material. Therefore, the source of this linear anomaly is attributed to the magmatic formations of the Rayner-Prydz zone.

Analysis of geological and geophysical data allowed the division of the southern PEL zone into three subzones (Figure 7). The most extensive of these is located in the east and is presumably composed of Mesoproterozoic rocks of sedimentary and igneous origin in approximately equal proportions. In the west-central area lies a subzone dominated by rocks of igneous origin, flanked on both sides by predominantly parametamorphic formations.

Thus, Russian aeromagnetic surveys over the PEL and QML made it possible to map a Mesoproterozoic orogen that has preserved the geological characteristics of a long accretionary history [*Liu et al.*, 2014; *Mikhalsky et al.*, 2016]. This orogen can be traced continuously from the Clemens Massif to 96°E longitude, extending over 1200 km [*Golynsky et al.*, 2018]. This is one of the most extensive geological structures mapped using aeromagnetic surveys in East Antarctica. Its uniqueness also lies in the fact that the identification of similar structures within the Gondwanan continents, particularly in India, will allow for a more objective reconstruction of ancient continents.

5. Location of the Kuunga Suture

Aerogeophysical survey results from the ICECAP project identified an extensive fault east of the BO, interpreted as the suture between Indo-Antarctica and Australo-Antarctica (IAAS; [*Aitken et al.*, 2014]). This lineament crosscuts magnetic trends in some places and corresponds to a noticeable change in bedrock relief over more than 1500 km. However, its location is debatable from a geophysical standpoint, as the flight line spacing in several areas reaches 40–50 km, potentially leading to misinterpretation and inaccurate identification of geological structures.

According to the proposed interpretation, the suture intersects the East Antarctic coast near the Scott Glacier (~100.5°E), and its southern part continues towards subglacial Lake Vostok, where geophysical data also suggest a poorly dated subglacial boundary of ancient plates [*Studinger et al.*, 2003]. Subsequently, [*Gardner et al.*, 2015] concluded that the IAAS might have been displaced by later rifting processes to the DG area (~99.5°E), approximately 50 km west of the originally proposed position. [*Maritati et al.*, 2016] suggested that the IAAS also passes through the Chugunov Island area.

One hypothesis, based on the analysis of detrital zircons from the East Antarctic shelf (60°–130°E), U–Pb geochronological data from the continent, and geophysical information from the ICECAP project, proposes a fundamental boundary between tectonic blocks within the Kuunga Orogen near Mirny Station [*Daczko et al.*, 2018; *Mulder et al.*, 2019]. In this interpretation, the boundary correlates with a previously identified unnamed fault near ~94°E based on ICECAP geophysical data [*Aitken et al.*, 2014].

Detailed maps compiled using modern airborne magnetic and radar surveys (Figures 3–6) unequivocally indicate the absence of a fault near 94°E, as suggested by the ICECAP data. Bedrock morphology data between Mirny Station and 94°E show only three local, linear, subparallel depressions trending NE-SW and located below sea level. These depressions are no longer than 50–70 km, with a maximum depth of about 765 m, and their origin is likely glacial erosion near the coast rather than tectonic activity. Magnetic anomalies above these depressions do not indicate the presence of a continuous tectonic structure in this area. Instead of the proposed fault, there is a segmented, curvilinear minimum with amplitudes up to 150–200 nT and a width of about 15–20 km. Therefore, the Mirny Station area, like all previously proposed locations that are not reflected in modern aeromagnetic data or bedrock relief information, is excluded from consideration for locating the IAAS suture.

In the east of the study area, two prominent morphostructures, the Denman and Scott glaciers, dominate, separating the subglacial Golitsyn Mountains located to the west from the deeper basins of Wilkes Land to the east. The bedrock beneath both glaciers is generally not well defined due to their substantial thickness. However, model calculations suggest that the DG may reach depths of more than 3500 m below sea level [*Morlighem et al.*, 2019].

On the interpretative map, most faults, with rare exceptions, do not coincide with magnetic highs but are more often associated with lows that contrast with the surrounding magnetic field. Their locations were determined by the displacement, bending, or termination of magnetic anomaly axes. Faults within rift structures are not considered in this work, as they have been addressed in publications by the authors [*Golynsky and Golynsky*, 2012], as well as the Knox Rift [*Aitken et al.*, 2014], whose configuration and location raise many questions.

Three fault structures deserve special attention: the Charcot Fault, the Denman Fault, and the Northcliffe Fault. The first is identified by an extended linear positive anomaly coinciding with the western boundary of the Charcot protocraton province. The Denman Fault is also associated with an extended segmented positive anomaly of low intensity (100–150 nT), spatially located along the eastern margin of the DG, most likely, this fault reflects a zone of dip-slip faulting or shear zone.

The Northcliffe Fault correlates with the most extensive system of linear magnetic lows, corresponding to the narrow trough of the Northcliffe Glacier. In all likelihood, it may represent the Cambrian Kuunga suture, along which eastern Gondwana was assembled through the amalgamation of Indo-Antarctica and Australo-Antarctica. An additional argument in favor of this interpretation is the absence of intrusive and metamorphic rocks ~500 Ma east of the Northcliffe Glacier, except for rare ultra-alkaline dikes in the BO [*Sheraton et al.*, 1995].

6. Conclusions

We improved knowledge of East Antarctica's subglacial geology by synthesizing geologic, magnetic and radar data sets that have been developed since [*Fretwell et al.*, 2013; *Golynsky et al.*, 2018]. This geophysically driven synthesis established a tectonic framework, clarifying the apparent extents of EA's geologic provinces located between PEL and Wilkes Land, characterized by different geological histories. An extensive subglacial valley network in the eastern part of the study area, comprising long, sub-parallel valleys suggests a stronger influence of tectonic inheritance on subglacial topography than previously recognized.

The Charcot Protocratonic Province has the long-term tectonic evolution history. It was formed and, consequently, stabilized at Paleo- to Mesoarchean. Afterwards, the CPP was reworked during the Pan-African tectonothermal event. The CPP is characterized by a broad magnetic low with scattered, variably intense anomalies. Its boundaries are defined by a low-intensity arc-shaped anomaly (Charcot fault) to the west, positive anomalies from Pan-African batholiths to the north and negative anomalies coinciding with the Northcliffe Glacier depression to the east. This data supports classifying the DG's upper reaches as a single tectonic province. The CPP basement rocks lack significant magnetic properties and generally correspond to areas with low magnetic field gradients and negative anomalies. The main sources of moderate-intensity positive anomalies in the north of the province are plutonic rocks of a batholith with an age of approximately 520 Ma.

According to our interpretation of the magnetic field data, the Western Mawson Craton is not bounded by the Aurora Fault to the east, as suggested in [*Aitken et al.*, 2014]. Instead, it extends as far as the Denman Fault zone, thus underlying the volcano-sedimentary complex of Mount Amundsen and Mount Sandow, which are traditionally interpreted as formations within an aulacogen-type structure deposited in a nearshore-continental facies.

The Wilkes Orogen is defined by a segmented, extended magnetic belt of positive anomalies associated with metamorphic and intrusive rocks in the BO, HA, OH, and lower DG outcrops. The HA and BO show complex anomaly patterns: the HA features predominantly positive anomalies in the north and alternating fields in the south, while the BO exhibits a mosaic field in the north and positive anomalies along its southern edge. The OH displays isometric and slightly elongated positive anomalies, transitioning northward into a sublatitudinal, echeloned linear belt. Despite differences in intensity and morphology, the magnetic anomalies across the DG represent a single entity linked to the Wilkes Orogen. This extensive belt, rather than being a stable craton, reflects a mobile belt analogous to Australia's Albany-Fraser Orogen, a Mesoproterozoic granulite belt surrounding Archean cratons.

Given the high magnetic susceptibility of the Archean and Proterozoic rocks within the Bunger Hills, the sources of observed magnetic anomalies are related with the pre-existing geological framework rather than being solely attributable to magmatic processes associated with the Knox Rift, as suggested [*Aitken et al.*, 2014]. The potential continuity with a similar feature over the Yallingup Shelf, offshore Western Australia, remains to be fully evaluated in light of these findings.

Aeromagnetic surveys conducted on the Prince Elizabeth Land, Wilhelm II Land and Queen Mary Land reveal a Mesoproterozoic orogen extending over 1200 km from the Clemens Massif to 96°E. The orogeny themselves exhibits a result of long-term accretion during the 1100–900 Ma orogeny. The orogen is divided into three subzones: an extensive eastern subzone, composed equally of Mesoproterozoic sedimentary and igneous rocks, and west-central subzones, dominated by igneous rocks flanked by parametamorphic formations. This extensive structure, mapped via aeromagnetic surveys, is crucial for Gondwanan reconstructions, particularly, with potential correlatives in India.

All previously proposed locations for the IAAS fault are not reflected in modern aeromagnetic data or bedrock relief information. It is most likely located along the boundary between the Charcot Craton and the Wilkes Orogen, corresponding to the Northcliffe Glacier, where an extended magnetic anomaly minimum may indicate the presence of normal-strike-slip faulting. ADMAP-2 project data [*Golynsky et al.*, 2018] allow tracing its continuation towards the southern Prince Charles Mountains and/or the subglacial Gamburtsev Mountains [*Kim et al.*, 2025]. The Denman Fault, identified by a linear anomaly of low intensity, is located in the boundary zone between the Wilkes Orogen and the WMC. The presence of conjugate negative minima on both sides of the Denman Fault suggests the existence of normal-strike-slip fault zones in this area. It is likely that the Late Paleoproterozoic-Mesoproterozoic suture passed through this area within present-day Antarctica.

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