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Magnetic Properties of Rocks from the South-Eastern Part of the Weddell Sea Region, Antarctica

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Summary: The major objective of this paper is to summarize the available data on magnetic properties of rocks outcropping in the south-eastern part of the Weddell Sea region. From north to south: western Dronning Maud Land, the coastal nunataks of north-western Coats Land, the Theron Mountains, the Shackleton Range, the Whichaway Nunataks and the Pensacola Mountains. Although the quality of data from the different areas varies, such a summary allows to identify the main lithological units responsible for the magnetic anomalies. Predominantly, they represent sequences of Precambrian felsic gneisses and Jurassic intrusives of different composition.

Zusammenfassung: Das Hauptziel dieses Artikels ist die Zusammenfassung der verfügbaren Daten der magnetischen Eigenschaften von Gesteinen, die im südöstlichen Abschnitt der Weddellsee-Region aufgeschlossen sind. Von Norden nach Süden: westliches Dronning Maud Land, die küstennahen Nunataks vom nordwestlichen Coats Land, die Theron Mountains, die Shackleton Range, die Whichaway Nunataks und die Pensacola Mountains. Obwohl die Datenqualität gebietsweise sehr unterschiedlich ist, erlaubt solch eine Zusammenfassung die Identifikation der wichtigsten lithologischen Einheiten, die ursächlich sind für die magnetischen Anomalien. Sie repräsentieren hauptsächlich Sequenzen von präkambrischen felsischen Gneisen und jurassischen Intrusiva verschiedener Zusammensetzung.

INTRODUCTION

Though the region of the Weddell Sea and its mountainous frame is difficult to access it is in some aspects a comparatively well investigated part of Antarctica. It was covered by several aeromagnetic surveys carried out mainly by Russian and British expeditions (MASOLOV 1980, JOHNSON et al. 1992, GOLYNSKY et al. 2000) and the geology of the mountainous areas free from ice was studied by numerous field parties (e.g. WOLMARANS & KENT 1982, CLARKSON et al. 1995). However, systematic studies of magnetic properties of rocks outcropping in this region were almost not conducted. Measurements of rock magnetization either were sporadic or were carried out in the context of paleomagnetic studies. Exceptions were the investigations of ORLENKO (1982) and MASLANYJ et al. (1991). The former was the first comprehensive petromagnetic study of rock samples from Antarctica including only a few areas of the south-western part of the Weddell Sea region, the Pensacola Mountains and the Shackleton Range. The latter was a study devoted mainly to the western part of the Weddell Sea region including some data from the Dufek intrusion located in the southernmost part of the region. The only systematic petromagnetic field study were carried out more recently in the Shackleton Range (SERGEYEV et al. 1999).

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The aim of this paper is to summarize all available petromagnetic data from the south-eastern part of the Weddell Sea region, from western Dronning Maud Land in the north-east to the Pensacola Mountains in the south-west (Fig. 1) and to identify which lithological units may cause the magnetic anomalies in this area.

WESTERN DRONNING MAUD LAND

The preliminary study of magnetic properties of the rocks of western Dronning Maud Land (Fig. 2) was carried out on samples collected by Russian geologists during the 1987/88 austral summer season. Most of the available samples were collected in Borgmassivet and Ahlmannryggen, whereas other areas were sampled only sporadically.

Western Dronning Maud Land consists of two tectonic provinces, the Grunehogna and Maudheim provinces (WOLMARANS & KENT 1982), that are very different in geology and lithology. The Grunehogna province situated to the north-west of the Jutulstraumen and Pencksökket is built up of a subhorizontal cover of Early-Mid Proterozoic low-grade metasediments and metavolcanics (Ahlmannryggen and Jutulstraumen Groups) intruded by sills of Mid Proterozoic dolerites (Borgmassivet intrusives). The highly-magnetic nature is characteristic only for Mid Proterozoic dolerites (Tab. 1), whereas all other units are generally low-magnetic. Only the magnetization of the andesitic basalts of the Straumsnutane Formation (main member of Jutulstraumen Group) remains an open question: ten samples from this unit collected by Russian geologists were low-magnetic (Tab. 1), whereas three samples collected by South African geologists for paleomagnetic studies (WOLMARANS & KENT 1982) were highly-magnetic (mean magnetic susceptibility X = 9.97 10^{-3} in SI units). In any case, the total volume of highly-magnetic rocks within the outcrops of Grunehogna province can not be large, because the anomaly pattern is "quiet" and the amplitudes are small: from -100 to +250 nT (GOLYNSKY et al. 2000).

The Maudheim province, south-east of the Jutulstraumen and Pencksökket, is an area built up by polycyclically deformed Mid Proterozoic high-grade metamorphics (Sverdrupfjella Group) represented predominantly by granitized and migmatized gneisses. These sequences are intruded by Phanerozoic felsic plutons of different composition and Jurassic mafic magmatic rocks that are covered by Palaeozoic sedimentary rocks (Early (?) Palaeozoic Urfjell Group and Late Palaeozoic Amelang Formation) and Jurassic basalts.

During this study the highly-magnetic nature was revealed within the Maudheim province only for Mesozoic nepheline syenites of Gburekspitzen and Jurassic basalts of Kirwanveggen (Tab. 1). Both units are not very widespread, and, it is assumed that neither can be responsible for the so-called Kirwan anomalies, which are the brightest and most important features of the magnetic field in this area. Phanerozoic felsic plutons of different composition (one of them is the pluton of nepheline syenites of Gburekspitzen) are not very extensive and, hence, can be responsible only for some comparatively small anomalies in this area. The Jurassic basalt bodies in western Dronning Maud Land are also not large enough to cause the Kirwan anomalies. Even in areas where these rocks crop out, not any high-amplitude anomaly occurs.

HUNTER et al. (1991) and CORNER et al. (1991) propose that a causative body of the Kirwan anomalies correlates with the granite-gneisses. LEITCHENKOV & KHLYUPIN (1993) also suggest that the Kirwan anomalies correlate with the old Precambrian complexes and emphasize that the magnetic causative body most likely is not connected with mafic rocks, because it has no gravity expression. Highly-magnetic felsic gneiss formations are quite usual members of Precambrian high-grade terrains. In particular, they are found in other parts of the Weddell Sea region: in the Haag Nunatak (MASLANYJ et al. 1991) and the Shackleton Range (see below). Unfortunately, the rocks of the Sverdrupfjella Group are almost not represented in the available Russian sample collections, therefore respective petromagnetic data are absent.

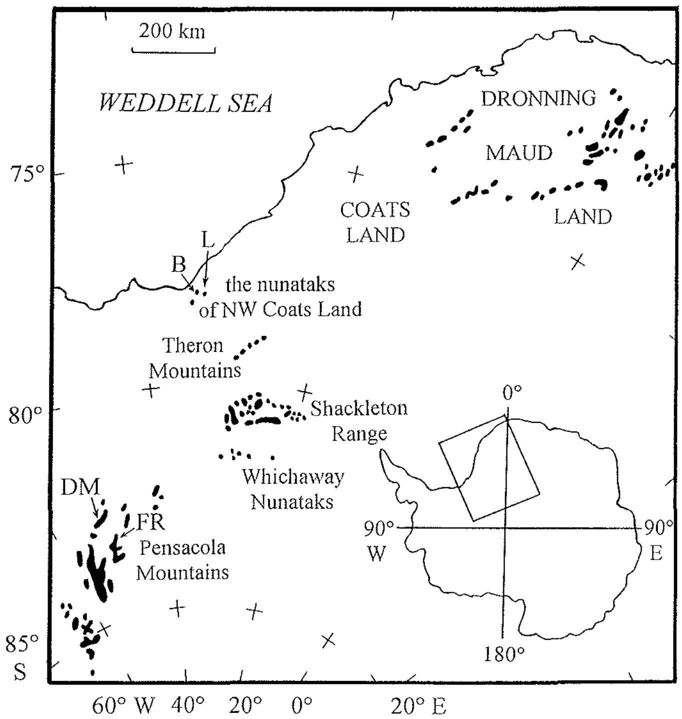


Fig. 1: Location of outcrops in the south-eastern part of the Weddell Sea region. L = Littlewood Nunatak; B = Bertrab Nunatak; DM = Dufek Massif; FR = Forrestal Range.

Abb. 1: Lokation der Aufschlüsse im südöstlichen Abschnitt der Weddellmeer-Region. L = Littlewood Nunatak; B = Bertrab Nunatak; DM = Dufek Massiv; FR = Forrestal Range.

Vestfjella is predominantly made up of Jurassic basalts, basement rocks are unknown, and it is unclear whether this area is part of Grunehogna province or part of Maudheim province. Notably, Jurassic basalts from Vestfjella are low-magnetic (Tab. 1). Obviously, the number of basalt samples from here (N = 4) do not give a reliable value. However, KRISTOFFERSEN & AALERUD (1988) with reference to personal communication of R. Lovlie also noted the low magnetization of basalts in Vestfjella. Hence, the characteristic magnetic anomaly known in the southern part of the Vestfjella area can not be caused by basalts. Possibly, it is caused by a body of Jurassic olivine gabbro known from the southern part of Vestfjella. Unfortunately, this massif was not visited by Russian geologists, and, hence, there are no petromagnetic data

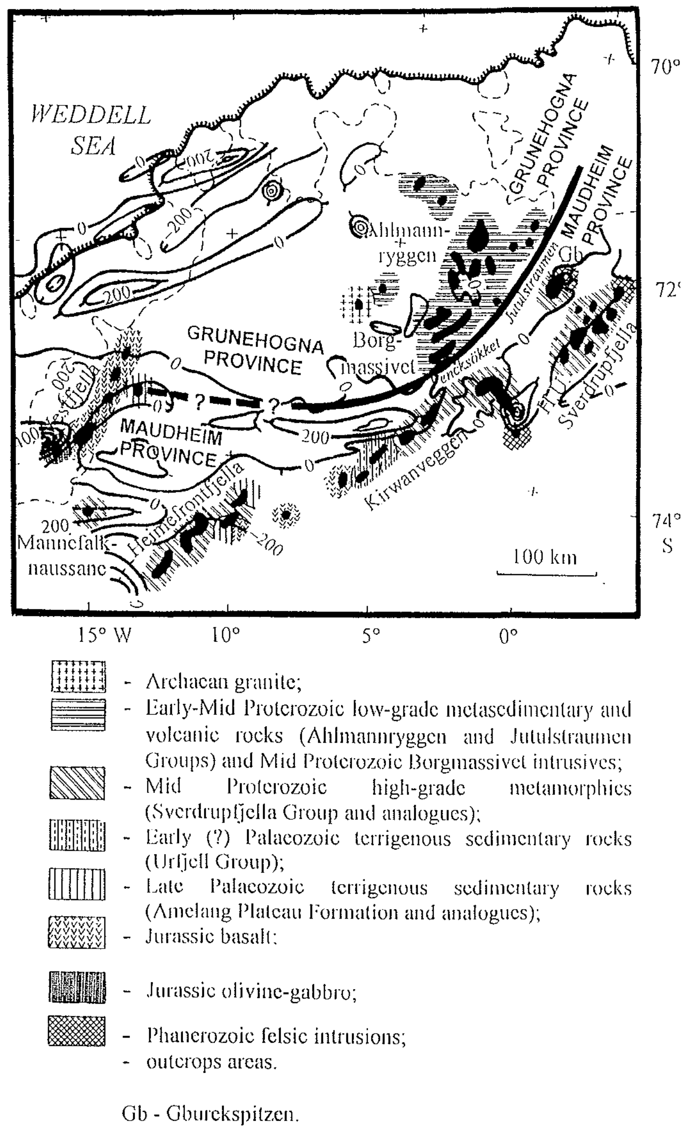


Fig. 2: Geological sketch map of western Dronning Maud Land (modified after WOLMARANS & KENT 1982, HJELLE & WINSNES 1972, TINGEY 1991). General simplified pattern of magnetic anomalies is shown in accordance with data of KHLYUPIN et al. (1987) and SPIRIDONOV et al. (1987). Contour interval at 200 nT.

Abb. 2: Skizzierte geologische Karte des westlichen Dronning Maud Land (verändert nach WOLMARANS & KENT 1982, HJELLE & WINSNES 1972, TINGEY 1991). Das vereinfachte allgemeine Muster der Magnetfeldanomalien ist in Übereinstimmung mit Daten von KHLYUPIN et al. (1987) und SPIRIDONOV et al. (1987) gezeigt. Das Konturenintervall beträgt 200 nT.

Rock Units	mean magnetic susceptibility (10^{-3} SI units)	number of representative samples
GRUNEHOGNA PROVINCE		
- Early Proterozoic metasedimentary rocks of Ahlmannryggen Group	0.45	67
- Early-Mid Proterozoic sandstones of Jutulstraumen Group	0.12	16
- Early-Mid Proterozoic andesites-basalts of Jutulstraumen Group (Straumsnutane Formation)	0.72	10
- Mid Proterozoic dolerites (Borgmassivet intrusives)	14.20	23
MAUDHEIM PROVINCE		
- Early (?) Palaeozoic sandstones of Urfjell Group	0.06	15
- Mesozoic nepheline syenites of Gburekspitzen	28.20	5
- Jurassic basalts of Kirwanveggen	15.90	4
VESTFJELLA		
- Permian sandstones	0.12	10
- Jurassic basalts	0.79	4

Tab. 1: Magnetic susceptibility of some widespread rocks of western Dronning Maud Land.

Tab. 1: Magnetische Suszeptibilität einiger häufiger Gesteine im westlichen Königin Maud-Land.

available for these rocks. Nevertheless, HJELLE & WINSNES (1972) mentioned a concentration of about 2 % of ore mineral in these rocks. Possibly, it is magnetite, and in this case the rocks should be highly-magnetic. As for the low-magnetic nature of basalts from Vestfjella, it is thought, that it is a specific feature of these rocks and not characteristic for other Jurassic basalts of the region. The Vestfjella basalts underwent intense secondary alterations (HJELLE & WINSNES 1972) which probably caused destruction of primary magnetite and decrease of magnetic susceptibility.

COASTAL NUNATAKS OF NORTH-WESTERN COATS LAND

The coastal nunataks of north-western Coats Land are composed of Mid Proterozoic felsic subvolcanic rocks (MARSH & THOMSON 1984). Two nunataks were visited by German geologists during 1994/95 austral summer season (EuroShack expedition) and the magnetic susceptibility of 12 rock samples was measured in this study. The samples from Bertrab Nunatak were highly-magnetic ($X = 17.3\ 10^{-3}$ SI, $N = 9$), whereas the samples from Littlewood Nunatak were low-magnetic ($X = 0.25\ 10^{-3}$ SI, $N = 3$). The results of these measurements are in a good accordance with data of GOSE et al. (1997), who report that ore minerals in the granophyres from Bertrab Nunatak are represented by magnetite, whereas ore minerals in the rhyolites from Littlewood Nunatak consist of haematite. The magnetic anomalies near the coastal nunataks of north-western Coats Land are of low-amplitude nature (GOLYNSKY et al. 2000, GOLYNSKY & ALESHKOVA 2000), therefore the occurrence of "Bertrab rocks" should be minor in this area.

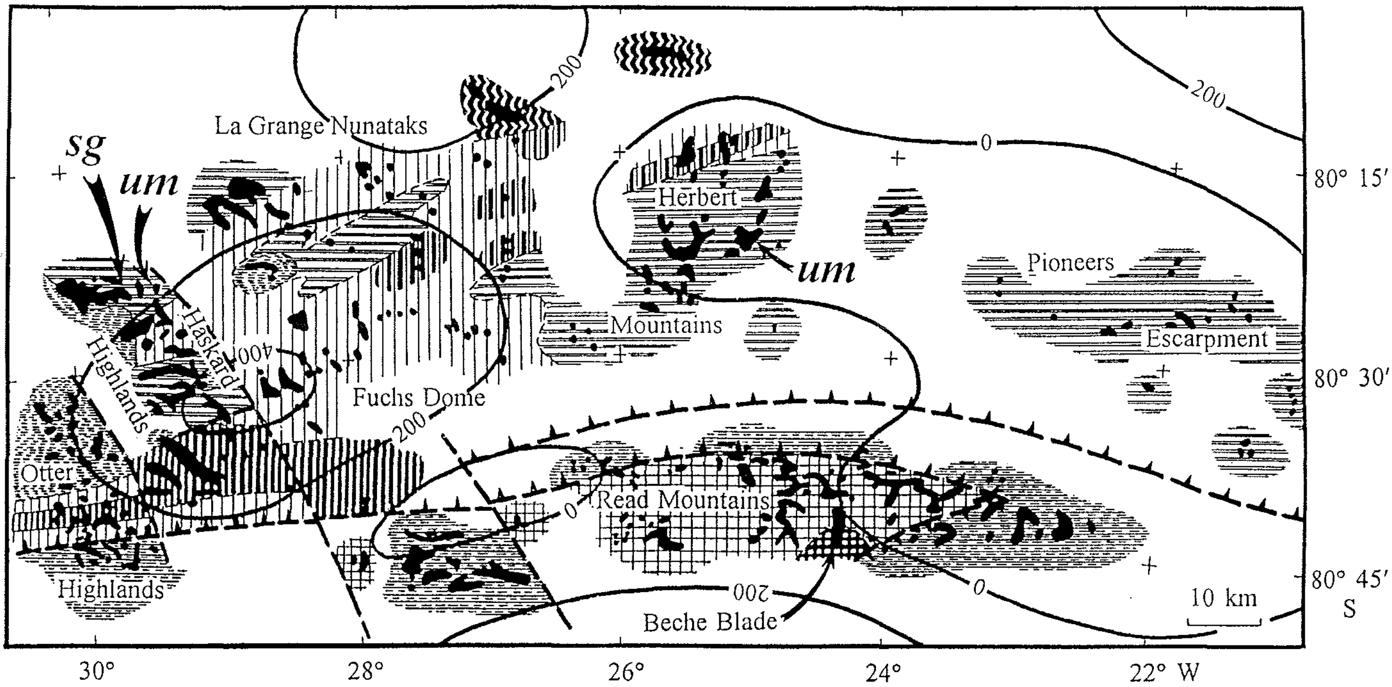
SHACKLETON RANGE

Intensive investigations on magnetic rock properties of the Shackleton Range was carried out during the work of the EuroShack expedition in 1994/95 austral summer season (SERGEYEV et al. 1999). Detailed field petromagnetic studies were carried out on 76 nunataks. Furthermore, magnetic susceptibility was measured on additional samples collected on 73 other nunataks.

The outcrops in the Shackleton Range (Fig. 3) are represented mainly by rocks of Precambrian metamorphic basement, of Early Proterozoic high- to medium-grade gneisses of the Stratton Group and Late Proterozoic medium-grade supracrustals of the Pioneers Group in the northern part of the Range, and Mid Proterozoic high-grade gneisses of the Read Group in the southern part. The Read Group is overthrusted by Late Precambrian to Early Palaeozoic low-grade metasedimentary rocks forming the Mount Wegener Nappe, whereas the Stratton and Pioneers Groups are covered in the western part of the Range by Early Palaeozoic terrigenous sedimentary rocks of the Blaiklock Glacier Group.

Highly-magnetic nature was revealed for five felsic gneiss units (Tab. 2). The "Pointer Nunatak Gneiss", "Morris Hills Gneiss" and "Beche Blade Gneiss" were distinguished (SERGEYEV et al. 1999). The "Wiggans Blastomylonites" (MARSH 1984) and "Stratton Gneiss" (MARSH 1983) (or "unit a" by GREW & HALPERN 1979) were described before, but their highly-magnetic nature was unknown ("Stratton Gneiss" is not to be confused with Stratton Group). It is notable, that all above-mentioned highly-magnetic units are represented mainly by felsic gneisses, whereas the other highly-magnetic rocks are noted in the Shackleton Range very rarely and form only small bodies (dykes, zones of alterations, sporadical thin layers, etc.). The only exception is the large (about 1 x 2 km) recently discovered body of the ultramafic rocks in the south-east of the Herbert Mountains (TALARICO et al. 1999). The mean magnetic susceptibility of these rocks is $59.0\ 10^{-3}$ SI ($N = 118$).

The most widespread highly-magnetic unit in the Shackleton Range is the "Pointer Nunatak Gneiss". It forms a large body (of about 9 km thickness) situated in the south-western Shackleton Range, and is responsible for the large magnetic anomaly in the area of Haskard Highlands and Fuchs Dome (SERGEYEV et al. 1999). Possibly, the "Beche Blade Gneiss" is



Southern part of the Range:

- Read Group (Mid Proterozoic high-grade metamorphic rocks), undifferentiated;
- Read Group, "Beche Blade Gneiss";
- Stephenson Bastion, Wyeth Height and Mount Wegener Formations (Late Precambrian - Early Palaeozoic low-grade metasedimentary rocks).

Northern part of the Range:

- Stratton Group (Early Proterozoic high- to medium-grade metamorphic rocks), undifferentiated;
- Stratton Group, "Pointer Nunatak Gneiss";
- Stratton Gneiss, "Morris Hills Gneiss";
- Pioneers Group (Late Precambrian medium-grade supracrustal gneisses);
- "Wiggans Blastomylonites";
- Blaiklock Glacier Group (Cambro-Ordovician terrigenous sedimentary rocks).

- outcrops; - faults; - thrusts.

sg - location of "Stratton Gneiss" ("unit a") outcrops;

um - location of the large bodies of ultramafic rocks.

Fig. 3: Geological sketch map of the Shackleton Range (simplified after Clarkson et al. 1995). General simplified pattern of magnetic anomalies is shown in accordance with JOHNSON et al. (1992). Contour interval at 200 nT.

Abb. 3: Skizzierte geologische Karte der Shackleton Range (vereinfacht nach Clarkson et al. 1995). Das vereinfachte allgemeine Muster der Magnetfeldanomalien ist in Übereinstimmung mit Daten von et al. (1992) gezeigt. Das Konturenintervall beträgt 200 nT.

Rock units	mean value of magnetic susceptibility (10^{-3} SI units)	number of studies nunataks	number of representative measurements
STRATTON GROUP			
„Pointer Nunatak Gneiss“	30.6	14	762
„Morris Hill Gneiss“	26.2	8	347
UNDIFFERENTIATED STRATTON AND PIONEERS GROUP			
„Wiggans Blastomylonites“ (Marsh 1984)	13.1	4	790
PIONEERS GROUP			
„Stratton Gneiss“ (Marsh 1983) or „unit a“ (Grew & Halpern 1979)	5.2	1	25
READ GROUP			
„Beche Blade Gneiss“	26.7	1	50

Tab. 2: Mean values of magnetic susceptibility of the highly-magnetic felsic gneiss units in the Shackleton Range.

Tab. 2: Mittlere magnetische Suszeptibilität der hoch-magnetischen felsischen Gneise der Shackleton Range.

also a widespread unit. Although the visible, outcropping thickness of it is only 0.4 km, there is a large positive magnetic anomaly over the ice-covered area immediately to the south of the outcrop of the "Beche Blade Gneiss". Probably, sequences of the "Beche Blade Gneiss" are responsible for this anomaly. Three other highly-magnetic units (the "Morris Hills Gneiss", "Wiggans Blastomylonites" and "Stratton Gneiss" (or "unit a")) form the sequences with visible thickness of hundreds of metres. Probably, their total intensity is not very large; at least they are not clearly related with magnetic anomalies registered by aeromagnetic surveys.

The high magnetization of the rocks of the above-mentioned highly-magnetic gneiss units is in a sharp contrast with a stable very low magnetization of the rocks of all other lithological units widespread in the Shackleton Range. The mean magnetic susceptibility of these lithological units is, as a rule, about 0.2-0.5 10^{-3} SI units.

THE THERON MOUNTAINS AND WHICHAWAY NUNATAKS

Both the Theron Mountains and the Whichaway Nunataks located to the north and to the south of the Shackleton Range, respectively, are composed of Permian terrigenous sedimentary rocks of the Beacon Supergroup intruded by sills of Jurassic dolerites (STEPHENSON 1966). In accordance with ORLENKO (1982) the Permian sediments from these areas show very low magnetic susceptibility (X = 0.1 10^{-3} SI, N = 8), whereas the Jurassic dolerites are highly-magnetic (X = 35 10^{-3} SI, N = 8).

PENSACOLA MOUNTAINS

The Pensacola Mountains are mainly composed of Late Proterozoic and Palaeozoic volcano-sedimentary and sedimentary sequences, partly affected by low-grade metamorphism (SCHMIDT & FORD 1969). The northern part of the Pensacola Mountains, the Dufek Massif and Forrestal Range, is made up of predominantly mafic rocks of the Jurassic Dufek Intrusion (FORD & HIMMELBERG 1991). These rocks are represented mainly by highly-magnetic varieties. In accordance with MASLANYJ et al. (1991), the mean value of magnetic susceptibility for gabbro from the Dufek intrusion is 49.1 10^{-3} SI (N = 71). At the same time all other lithological formations, including the volcanic ones, developed in the rest part of the Pensacola Mountains are of low-magnetic nature (ORLENKO 1982). The mean magnetic susceptibility of these rocks is less than 0.5 10^{-3} SI.

CONCLUSIONS

Most of the magnetic anomalies in the south-eastern part of the Weddell Sea region are caused by sequences of the Precambrian highly-magnetic felsic gneisses and Jurassic mafic intrusives (dolerites and gabbroes). Few anomalies can be caused by some Phanerozoic felsic plutons.

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