Tectonophysics 585 (2013) 48–67

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Magnetic susceptibilities of rocks of the Antarctic Peninsula: Implications for the redox state of the batholith and the extent of metamorphic zones

Anke S. Wendt [a,1,2], Alan P.M. Vaughan [a,*], Fausto Ferraccioli [a,1], Anne M. Grunow [b,3]

[a] British Antarctic Survey, ECE, High Cross, Madingley Road, Cambridge, CB3 0ET, UK
[b] Byrd Polar Research Center at Ohio State University, 108 Scott Hall, 1090 Carmack Rd, Columbus, OH 43210, United States

ARTICLE INFO

Article history:
Received 12 September 2011
Received in revised form 11 July 2012
Accepted 18 July 2012
Available online 28 July 2012

Keywords:
Magnetite–ilmenite series
Circum-Pacific
fO_2
Terrane tectonics
Magmatic arc
Raw data

ABSTRACT

A combination of 1555 magnetic susceptibility measurements from the Antarctic Peninsula between 65°S to 72°S (for which the raw data are made available), and petrological, structural and metamorphic data, has been used to improve understanding of: (1) magma sources for the Antarctic Peninsula batholith; (2) genetic relationships between granitoids and metamorphic rocks, and; (3) to provide a semi-quantitative measure of the extent and grade of metamorphic zones. The redox state of Jurassic plutonic rocks indicates that these had continental magma sources in the tectonostratigraphic terranes of the Central and Eastern domains. Triassic and Cretaceous plutons, on the other hand, had subduction-related sources in the Central Domain of the western Antarctic Peninsula and continental sources in the Gondwana-margin Eastern Domain. Circum-Pacific comparisons of magnetite–ilmenite belt geometries identify the Antarctic Peninsula belt as a natural continuation of comparable South American belts. Susceptibility trends are generally retained by orthogneisses, suggesting that they formed by deformation of plutonic rocks mostly at or below upper amphibolite-facies conditions. Metasedimentary rocks are weakly magnetic across the peninsula, and are spatially associated with continentally derived or crustally contaminated plutons (ilmenite-series). Orthogneisses and metabasites from strongly magnetic plutonic environments show areas of very low magnetic susceptibilities that may be linked to fluid-enhanced, tectonometamorphism-induced reduction of magnetic susceptibility. The distribution of reduced magnetic susceptibility areas follows the surface traces of major shear and fault zones in Palmer Land. Our results are consistent with tectonic interpretations of oblique compression and uplift of an arc block on the Pacific margin of Gondwana during the Palmer Land Event.

1. Introduction

Magnetic susceptibility in rocks is a direct indicator of the amount of magnetite (a strongly magnetic metastable mineral) and thus provides a useful measure of the redox state of magmatic arcs and associated metamorphic domains (e.g. Clark, 1997; Frost, 1991b, 1991c). Combined with interpretation of aeromagnetic data, magnetic susceptibility has revealed much about the magmatic arcs of the circum-Pacific region. These include the Phanerozoic granitoids of Japan (e.g. Ishihara, 1979) and South Korea (Ishihara, 1981; Jin et al., 2001), South China (Ishihara and Wang, 1999), the Malay Peninsula (Ishihara et al., 1979), the Lachlan Fold Belt of Australia (Chappell, 1994; Tainosho et al., 1988), the Sierra Nevada (Bateman et al., 1991), the Northern Cordillera (Hart et al., 2004) and Peninsular Range batholith of North America (e.g. Gastil et al., 1990) as well as in the Andean granitoids of Northern Chile (Ishihara, 1981) and Peru (Ishihara et al., 2000), and also over part of the Antarctic Peninsula batholith (Vaughan et al., 1998). Studies indicate important variations in the processes of granitoid formation and deformation during arc evolution (e.g. Hart et al., 2004; Ishihara, 1998; Takagi, 2004) and that magnetic susceptibilities can be used to identify economic mineralization provinces (e.g. Ishihara and Murakami, 2004).

Magnetic properties of rocks reflect, above all else, the partitioning of iron between strongly magnetic oxides and weakly magnetic material such as silicates and carbonates. This partitioning depends on chemical composition, oxidation ratio of iron and the conditions of petrogenesis (e.g. Clark, 1997). It is now widely accepted that from all Fe–Ti oxides, spinel magnetite (Fe_3O_4) is the most important mineral in determining magnetic susceptibility (the degree of magnetization κ, specifically volume susceptibility, which is dimensionless, in response to an applied magnetic field) (e.g. Bannerjee, 1991; Clark, 1997; Telford et al., 1990). Consequently, κ measurements are a direct indicator of the average magnetite volume in rock (Clark, 1997).

Oxides in rocks form two distinct groups: the very weakly magnetic (diamagnetic and paramagnetic) oxides, comprising corundum, spinel, chromite, green spinels, rutile, ulvospinel, low-Fe^{3+} ilmenite

* Corresponding author. Tel.: +44 1223 221400.
E-mail addresses: awendt@slb.com (A.S. Wendt), apmva@bas.ac.uk (A.P.M. Vaughan), ffe@bas.ac.uk (F. Ferraccioli), grunow.1@osu.edu (A.M. Grunow).
[1] Tel.: +44 1223 221400.
[2] Current address: Schlumberger, Data & Consulting Services (DCS), Geomechanics, Risabergveien 3, 4068 Stavanger, Norway.
[3] Tel.: +1 614 292 5348.

0040-1951/$ – see front matter. Crown Copyright © 2012 Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2012.07.011

etc., and oxides broadly classed as ferromagnetic, which includes magnetite, titanomagnetite, ferric iron-rich ilmenite and hematite. Although there is complete solid solution between magnetite and the other common spinels, magnetite (Fe_3O_4) plays a special role because it is the most magnetic oxide (e.g. Bannerjee, 1991; Clark, 1997; Frost, 1991b) and because it has, together with ilmenite ($FeTiO_3$), a distinct mode of crystallization that depends mainly on oxygen and sulfur fugacity and hence monitors the oxidation or reduction state of a rock (e.g. Carmichael, 1991; Frost, 1991b; Takagi, 2004; Takagi and Tsukimura, 1997). Under metamorphic conditions and for a given rock composition, the stability, crystallization or break-down of magnetite and ilmenite depends on oxygen and sulfur fugacities, which are controlled by temperature and/or fluid circulation (e.g. Frost, 1991c; Ishihara, 1981).

In this paper, we present the first regional-scale magnetic susceptibility study of the Antarctic Peninsula, from 65°S to 72°S and 61°W to 68°W, expanding on the work of Vaughan et al. (1998). Magnetic susceptibility data have been combined with quantitative oxygen fugacity analyses from magnetite–ilmenite geothermobarometry, and interpreted in the light of recent metamorphic, structural, geophysical and tectonic observations. The combined datasets provide insights into the tectonic history and metamorphism of the peninsula. Using them, we seek to: (1) define the limits of magnetite–ilmenite series granitoid regions; (2) identify genetic relationships between granitoids and metamorphic rocks and; (3) quantify the extent and grade of metamorphic zones. We discuss our results both within the framework of large-scale circum-Pacific distribution of magnetite–ilmenite belts and, on a smaller scale, in the context of the terrane accretion model for the Antarctic Peninsula (Fig. 1) (Ferraccioli et al., 2006; Vaughan and Storey, 2000; Vaughan et al., 2012a).

2. Geological setting

The Antarctic Peninsula is one of five crustal blocks in West Gondwana (Storey, 1991) The Antarctic Peninsula is composed of at least two suspect terranes in fault contact with para-autochthonous rocks of the continental Gondwana margin (Vaughan and Storey, 2000; Vaughan et al., 2012a). George VI Sound separates the farthest outboard subduction complex of the Western Domain (Fig. 1) from the Central Domain. The Central Domain is a composite magmatic arc terrane largely equivalent to the Antarctic Peninsula batholith of Leat et al. (1995) in Palmer Land. It has been subdivided using aerogeophysical data into a felsic western zone and a mafic eastern zone (Ferraccioli et al., 2006). The Central Domain Eastern Zone (CDEZ) (Fig. 1) has been interpreted as a Permo-Triassic primitive magmatic arc, the Dyer Arc (Vaughan et al., 2012b). The Eastern Palmer Land Shear Zone (EPLSZ) (Fig. 1) is a major dextral-oblique (strike–slip to reverse slip) zone of convergence between the Central Domain and Eastern Domain (Fig. 1). The Eastern Domain (Fig. 1) appears to represent the deformed Gondwana continental margin.

Quantitative pressure–temperature (P–T) calculations for the Antarctic Peninsula (Wendt et al., 2008) indicate six metamorphic zones ranging from greenschist-facies conditions to granulite-facies conditions between 65°S and 72°S. The metamorphic zones are based on probable peak P–T conditions. The metamorphic zones are aligned with major compressive features, such as the EPLSZ, and geophysical features such as the Pacific Margin Anomaly (PMA) (Ferraccioli et al., 2006; Johnson, 1999; Maslanyj et al., 1990) (Fig. 2). In Palmer Land, metamorphic zones exposing the highest amphibolite-facies pressure and temperature conditions are oriented sub-parallel to the southern part of the PMA (Fig. 2) (Maslanyj et al., 1990). In the Central Domain Western Zone (CDWZ) (Ferraccioli et al., 2006) (Fig. 1),

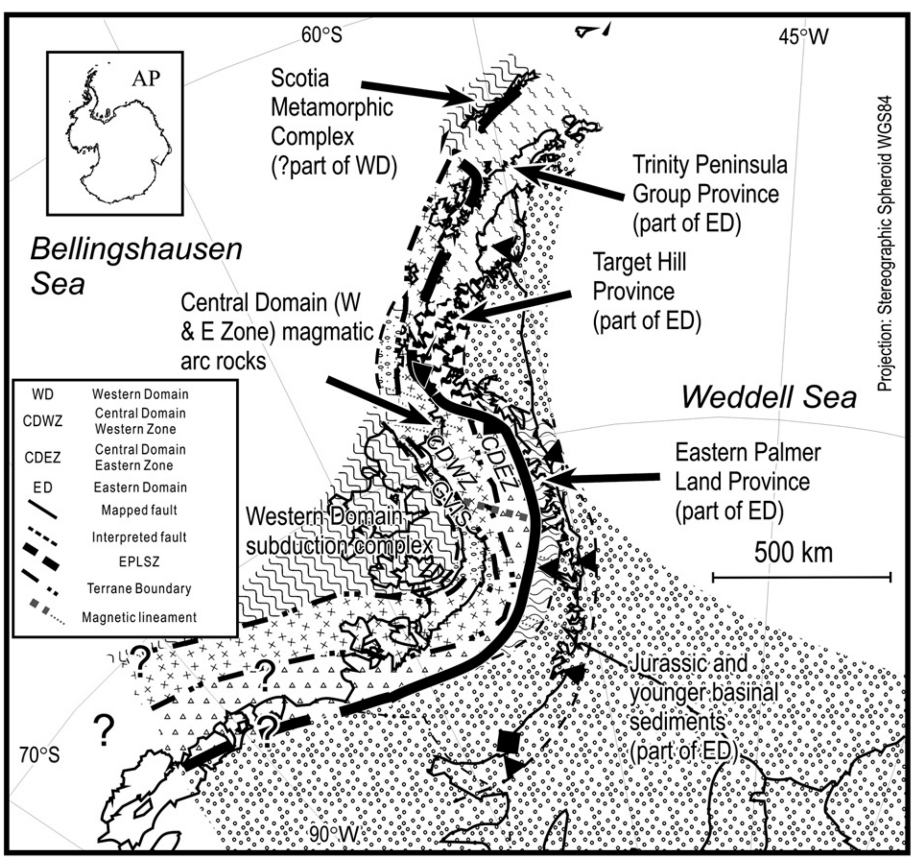

Fig. 1. Tectonostratigraphic terranes map of the Antarctic Peninsula. The Eastern Palmer Land Shear Zone (EPLSZ) separates subduction complex and magmatic arc terranes from Gondwana margin basinal sequences (modified after Ferraccioli et al., 2006; Riley et al., 2012; Vaughan and Storey, 2000; Vaughan et al., 2012a). Central Domain Western Zone (CDWZ); Central Domain Eastern Zone (CDEZ); Eastern Domain (ED); George VI Sound (GVIS).