Twenty Sixth Indian Antarctic Expedition 2006-2008
Ministry of Earth Sciences, Technical Publication No. 24, pp 279-287

Magnetic Fabric Studies in Larsemann Hills, Prydz Bay Region, East Antarctica

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ABSTRACT

Larsemann Hills region, East Antarctica was studied for directional magnetic properties of magnetic susceptibility, known as the Anisotropy of Magnetic Susceptibility with the objective to obtain further constraints on Precambrian geological evolutionary history of the region. This independent approach provides supportive data for evaluating deformation history with the advantage that even weak fabric anisotropies can be recognized and documented, therefore useful in discriminating initial deformation or overprint of sedimentary fabrics. Rock units, various pelites and granite gneisses in the Larsemann Hills region document a diachronous geological evolutionary history which includes a Paleoproterozoic felsic/mafic gneiss basement over which younger supracrustal sequence of pelitic, psammitic and felsic para-gneisses were deposited. The region has undergone two major phases of metamorphism at ca ~1Ga and during Early Palaeozoic (~500 Ma), the latter a medium- to low-pressure granulite-facies metamorphism at ~7 kbar pressure and 800 – 850 ºC temperature. Several episodes of deformation and intrusions of granities and pegmatites are reported from this region. During field studies the NE – SW trending and moderately dipping S2 foliation was observed as the most prominent deformation phase. The foliations have been associated with tight isoclinal F1 folds while the S2 foliation itself has been folded along moderately tight to open F2 folds with fold axes varying from 35º to 57º towards 30º to 125º. The terminal deformation phase has resulted in broad open warps.

A total of 53 on-site oriented samples were selected and studied for AMS using standard techniques. The data were plotted on Schmidt Net to identify AMS principal axes. The magnetic fabrics reflect preferred-orientation of all the constituents of a rock viz. the ferromagnetic, paramagnetic and diamagnetic minerals. Magnetic fabric studies carried out on quartzo-feldspathic gneiss (ortho-gneiss) and amphibolite from the Schirmacher Oasis, Magnetic fabric analysis has identified magnetic susceptibilities in the range of paramagnetic to mixed-type (paramagnetic + ferromagnetic), related to biotite and hornblende subfabrics. The magnetic fabric anisotropies allow two possible groupings characterized by prolate (linear) and oblate (planar) geometries.

Keywords: Larsemann Hills, East Antarctica, Magnetic Fabric, Pelitic rocks, Granite gneiss

INTRODUCTION

Directional magnetic susceptibility, the Anisotropy of Magnetic Susceptibility (AMS), an important rock magnetic property, has been established as a suitable tool for qualitative and quantitative characterization of rock fabrics (for details see Hrouda, 1994; Borradaile and Henry, 1997; Martin-Hernandez et al., 2004). AMS can offer a wealth of applications in conjunction with geological and structural data for evaluating deformation history of the terrane. Besides providing supportive data for evaluating deformation history of the region the advantage of the AMS method is its high sensitivity for detection of even weak fabric anisotropies. Therefore it is especially useful in discriminating initial deformation or overprint of sedimentary fabrics (Parés et al., 1999, de Wall & Warr 2004). In addition, the directional fabric can be recognized in magmatic rocks where no visible fabric is seen, especially in case of apparently undeformed magmatic rocks. AMS studies in the Larsemann Hills region, East Antarctica, were undertaken with this background as a parallel study to complement the efforts of the Antarctic Division of Geological Survey of India for a better understanding of the geological evolution of this region. Field work was carried out in team with the geoscientists of Geological Survey of India during as part of the 26th Indian Scientific Expedition to Antarctica (January – April 2007).

Geological Background of Larsemann Hills

Larsemann Hills in the Prydz Bay region in East Antarctica documents a diachronous geological evolutionary history which includes a Paleoproterozoic felsic/mafic gneiss ensemble as the basement overlain by a younger supracrustal sequence of pelitic, psammitic and felsic para-gneisses. The depositional age of the younger rocks is still uncertain, however, some isotopic data trace their lineage to the older gneisses. The region has a well documented record of two metamorphic events at ca ~1Ga and during Early Palaeozoic (~500 Ma). The region experienced medium to low pressure granulite-facies metamorphism during the early

Palaeozoic, characterized by peak metamorphic conditions at ~7 kbar pressure and 800 – 850 ^{o}C followed by decompression with 2-3 kbar pressure and 650 ^{o}C temperature with exhumation largely driven by crustal extension (for details see Stüwe et al., 1995). The region records various episodes of deformation and late stage intrusions of granities and pegmatites. Mafic dykes are generally absent and are seen mainly in the Vestfold Hill region. Tectonic models generally argue for a continental-continental collisional scenario, with thermal input derived from a thinned mantle lithosphere.

Field Observations and Lithology

Field work along with other team members from Geological Survey of India was undertaken through foot traverses for observation of megascopic features, structural data and sampling in the Bharati Promontory and nearby islands such as Stornes peninsula, Fisher Island, McLeod Island etc.

The dominant rock types in the Larsemann Hills are metapelitic cordierite- and Fe-Ti oxide-rich gneisses and a variety of leucogneisses. Felsic, garnet-bearing, variably foliated ‘yellow gneiss’ (60% of outcrop) and cordierite-rich ‘blue gneiss’ (10% of outcrop) constitute the two major metasedimentary units. These lithologies also host a variety of enclaves of variable size, which include metapellite, meta-arenites, metapyroxenite, amphibolites, etc. The terrane is intruded by quartz, aplite and pegmatite veins belonging to different generations.

The main rock types exposed in the area are leuco-migmatitic gneiss, mafic rich migmatitic gneiss with rafts and enclaves of mafic rocks, some quartzitic (arenite) patches, granite gneiss and granite. There are evidence of multiple episodes of deformation and the fold interference patterns are well-documented in the McLeod Island and in other parts of Larsemann Hills. Geological map of Bharati promontory was prepared on the basis of field observations (please see the report submitted by Antarctic Division, Geological Survey of India published elsewhere in this volume). About 75 representative rock samples were collected in all for AMS and petrochemical studies.

Garnetiferous orthogneiss, the predominant lithology that forms the basement, is a medium grained rock primarily consisting of quartz, plagioclase, orthoclase, biotite and garnet as major minerals and apatite, zircon, magnetite, spinel, and monazite as accessory phases. Garnetiferous paragneiss is a medium grained, light grey to grey, magnetite bearing highly deformed rock which occurs as disseminated bodies within the orthogneiss country. Main minerals include quartz, plagioclase, K – feldspar, sillimanite/andalusite and garnet. Large size (visible to naked eye) magnetite crystals are quite conspicuous in these rocks. Cordierite gneiss also occurs as patches within the orthogneiss country. Purple blue cordierite crystals aggregates can be observed on exposed surfaces of the outcrop. The minerals include quartz, plagioclase, orthoclase, biotite, cordierite, opaque (magnetite), spinel, apatite, zircon and monazite. Medium to fine grained, light grey coloured migmatite shows a characteristic mineral assemblage comprising quartz, plagioclase, orthoclase, biotite and garnet with minor apatite and magnetite.

A pink coloured granitoid body the Progress Granite was also studied and sampled at the southwestern corner of the Stornes Peninsula where it is well exposed. It is medium to coarse grained rock and shows a crude fabric. The granitoid also hosts a number of amphibolitic enclaves whch show well-developed foliation and imprint of multiple deformation episodes. The granite mainly consists of quartz, plagioclase, K-feldspar and biotite – muscovite. Monazite is the most abundant accessory phase along with magnetite, spinel, zircon, fibrolite, etc. while secondary chlorite as alteration product of biotite can also be observed in thin sections. The amphibolitic rafts comprise plagioclase, quartz, biotite, hornblende and opaque minerals. Metapelite and meta-arenite bands can be traced for long distances within the ortho-gneiss country. Metapelite and meta-arenite mineralogy includes quartz, plagioclase, sillimanite, biotite, spinel, zircon ± garnet.

Structure and Deformation History

The prominent foliation, the S2 foliation, is NE – SW (60º to 80º) with moderate to shallow (55º to 20º) easterly to southeasterly dips. The foliations are related to tight isoclinal F1 folds. The S2 foliation is further folded by moderately tight to open F2 folds. Axial planes of F2 folds trend from 210º to 240º with sub-vertical to 65º easterly dips. The plunge of F2 fold axes varies from 35º to 57º towards 30º to 125º. The terminal deformation phase has resulted in broad open warps of the F2 fold axial trace that can be designated as F3 folding with axial planes

Fig. 1: Field photographs showing development of folds related to various deformations events. (Field work carried out together with geoscientists from Geological Survey of India)

generally trending 335º to 30º with vertical dips (Fig. 1). The fold interference patterns (Hook-shaped) can be described as Type-II of Ramsay (1967).

AMS Analysis: Method and Results

A total of 53 on-site oriented samples were selected for AMS studies from which standard size cylinders (2.5 cm in diameter and 2.1 cm in height, with a sample volume of 10.8 cm^3) were drilled in the laboratory (University of Würzburg, Germany). The cylinders were measured for low-field magnetic susceptibility (MS) under ac-fields of 300 A/m and frequencies of 920 Hz with the AGICO-kappabridge KLY-4S at the Geological Institute in Würzburg. For characterization of the magnetic behaviour (paramagnetic or ferrimagnetic) and for discrimination of ferrimagnetic components the temperature-dependence of MS (Hrouda, 1994; Kontny & de Wall, 2000) has been measured in combination with a CS2-oven. Anisotropy of Magnetic Susceptibility (AMS) method uses the directional difference in induced magnetization for fabric characterization. The AMS tensor and the resulting magnitudes and orientation of the principal axes of the AMS-ellipsoids were calculated using the software package Anisoft. From the magnitudes of the AMS principal axes the mean susceptibility value, ($\kappa_{mean} = (\kappa_{max} + \kappa_{int} + \kappa_{min}) /3$ as volume susceptibility (in SI units) and shape and anisotropy factors were calculated using the standard software for the KLY-2 equipment. The shape of the AMS-ellipsoid is described by the T-factor ($2 (\ln \kappa_{int} – \ln \kappa_{min})/(\ln \kappa_{max} - \ln \kappa_{int}) -1$) which is > 0 to +1 for oblate, 0 for neutral and < 0 to -1 for prolate geometry (Jelinek, 1981). The anisotropy of the ellipsoid is expressed by the P´ value, also called as corrected anisotropy factor ($\exp (2(\ln \kappa_{max} – \ln \kappa)^2 +2(\ln \kappa_{int} – \ln \kappa)^2 + 2(\ln \kappa_{min} - \ln \kappa)^2)^{1/2}$ (Jelinek, 1981). Orientations of ellipsoid axes are displayed in Schmidt net projection in the lower hemisphere. Presentation of data in the standard Schmidt net and relationship between Shape factor and anisotropy are shown in the Figure 2 as an example (de Wall and Pandit, 2007).

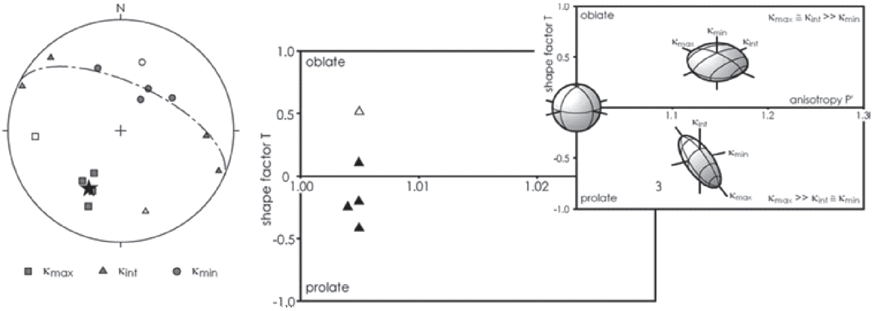

Fig. 2: Example of Schmidt Net projection of AMS principal axes. The prolate and oblate shapes of the ellipsoid are compared in the inset diagram while relationship between Shape Factor and Anisotropy are presented as x – y plot.

Garnetiferous quartzo-feldspathic (ortho-) gneiss showing banded nature

Amphibolite sill within banded orthogneiss showing displacement along fault planes

Fig. 3: Field photographs showing outcrop scale features in ortho-gneiss in Schirmacher Oasis

Magnetic fabrics reflect the bulk, preferred-orientation of all the constituents of a rock viz. the ferromagnetic, paramagnetic and diamagnetic minerals (Tarling and Hrouda 1993). For a reliable interpretation of AMS the magneto-mineralogy and magnetic behaviour were considered in concert with each other by performing thermomagnetic studies (Hrouda 1994, Kontny & de Wall 2000). For interpretation of the magnetic fabric anisotropies microstructural characteristics of the samples have also been investigated. Results of AMS studies and microfabric analysis are published elsewhere (Pandit and de Wall, 2014). In addition to Larsemann Hills area, amphibolites from the Schirmachar Oasis were also studied for AMS and the observations are given hereunder.

Schirmacher Oasis, a 35 km^2 coastal nunatak in the Dronning Maud Land (DML) in East Antarctica, is a predominantly amphibolite facies (quartzo-feldspathic and ortho-gneisses, amphibolite) terrane with remnants of high-grade metamorphites (charnockite – enderbite and mafic granulite). Geological evolution of this Neoproterozoic (~630 Ma) terrane can be related to three temporally distinct tectonothermal events. Structural evolution is complex and includes at least three deformation phases (folding during D1 and D2 and shearing during D3) under medium- to high-grade conditions. Magnetic fabric analysis was done on quartzo-feldspathic gneiss (ortho-gneiss) and amphibolite samples. This method provides three-dimensional information on rock fabric and offers a refinement of the field-based structural mapping. The magnetic susceptibilities are in the range of paramagnetic to mixed-type (paramagnetic + ferromagnetic) values and are therefore mainly related to biotite and hornblende subfabrics. The magnetic fabric anisotropies define two groups characterized by prolate (linear) and oblate (planar) geometries. Anisotropies are higher for the oblate fabrics (P’ 1.1 to 1.15) compared to the prolate ones (P’< 1.05). Oblate fabrics can be related to D1 and D2 fabrics while the prolate, lower-anisotropic geometries (SW-dipping magnetic lineations) are a result of D3 shear overprint.

ACKNOWLEDGEMENTS

The study was carried out as part of the 26th Indian Scientific Expedition to Antarctica and the success of the mission is the outcome of the effort of a number of organizations and individuals and it may not be possible to individually thank all of them. I would like to mention Sh. Rasik Ravindra, Director NCAOR, for being instrumental in introducing me to this wonderful aspect of global earth science. I am personally thankful to him for making it possible for me and also to the dedicated and hard working team at NCAOR who worked behind the curtain. I am thankful to Sh. Jayapaul D., the team leader, for his support during the expedition and a special word of thanks to Sh. Ajay Dhar who was a source of inspiration and a constant support all through. Geological field work under such harsh conditions was made bearable and enjoyable because of the wonderful company of fellow geoscientists, Amit Dharwadkar, Ashish Nath and Prakash Srivastava who also provided an ambient platform for useful academic discussion on regular basis. Magnetic Fabric analysis and interpretation were carriedout under guidance of Prof. H. de Wall. A special word of appreciation for the Helicopter crew who were professionals par-excellence and very cooperative. All the members of the team contributed in their own way to make my stay comfortable and studies useful. I wish to thank all of them; to mention some, Dr. C.D. Reddy, Dr. A. Bhattacharya, Dr. T. Meloth, Bhaskar Sharma, O.P. Saini, Chandrasekhar and all those young colleagues who kept the spirits high.

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