Report on Loan 813

Lithospheric structure of West Greenland

Richard England (*University of Leicester*), Peter Voss, (*Geological Survey of Denmark and Greenland*)

On behalf of :
Formation and evolution of the continents: The North Atlantic Craton Experiment consortium.
Participants: *University of Durham* – Lead Institution (D.G. Pearson, K.W. McCaffrey, R.W. Hobbs & J.P. Davidson – Earth Sciences); *University of Bristol* (C.J. Hawkesworth, M.J. Kendall, G. Helffrich, M. Walter, Earth Sciences); *University of Leeds* (G. Stuart, G. Lloyd); *University of Leicester* (R.W. England); *University of London* (M.A. Menzies; A.J. Hurford; M. Batt); *University of Cambridge* (N. White);
Other Partners: *Geological Survey of Denmark and Greenland* (GEUS: Trine Dahl Jensen, P. Voss, P. Jaspen).

Abstract 5 broadband seismometers were deployed along a profile as a pilot project in west Greenland between July 2006 and September 2007. 78% data recovery was achieved. The data have been converted to miniSEED and are of good quality owing to the lack of ambient noise. The instruments detected local and teleseismic earthquake events. Initial work at the Geological Survey of Denmark and Greenland has concentrated on calculating receiver functions for crustal thickness and velocity and on local earthquake tomography. There is considerable scope for further work on this good but small dataset which has been archived with IRIS and GFZ Potsdam.

Introduction This loan application was made on behalf of the Crustal Evolution Consortium (listed above) for 5 broadband seismometers to undertake a pilot study supported by the Greenland Bureau of Minerals and Petroleum to investigate variations in lithospheric and crustal structure across the exposed Archean - Proterozoic boundary in West Greenland. The original intention was that the Crustal Evolution Consortium would submit an application to the NERC for a consortium grant which would follow this pilot study with more comprehensive work but this was rejected at the pre-proposal stage. The initial results presented here were produced by Peter Voss at the Geological Survey of Greenland and Denmark for the Greenland Bureau of Mineral and Petroleum. A subsequent application for further work (by Geoff Lloyd at Leeds) was also unsuccessful. As a consequence this work lost its initial momentum and the participants have concentrated on other funded projects, although the data will be worked up by the Greenland Survey. The data will shortly be publicly available through IRIS.

Geological background A question that is key to our understanding of the evolution of the Earth as a planet is how the continental crust and underlying sub-continental mantle lithosphere stabilises and evolves over time. In particular, comparatively little is known about the structure and physical properties of the sub-continental mantle lithosphere. By coupling seismology with geochemistry it is possible to compare the present structure, obtained from seismology, to the structure at intervals in the past, obtained from petrological and geochemical studies of xenolith suites. In addition, recent advances in these fields mean that it is possible to resolve details with increasing accuracy and precision.

West Greenland provides an ideal natural laboratory to study the evolution of some of the Earth's oldest lithosphere. Its crustal structure and evolution has been well studied and shown to comprise Archean and Proterozoic terranes separated by approximately E-W trending boundaries (Fig. 1.). These terranes have then suffered E-W directed Mesozoic extension resulting in the formation of the Labrador Sea. Recent seismic work [1] has produced the first 3-D tomographic models for the crust and upper mantle which suggest a seismically thin crust and mantle root, compared with other well studied cratonic regions (e.g. Kaapvaal [2,3,4]). Because of its great age the region has been the focus of petrological, geochemical and isotopic studies since the 1960's. What is now exciting interest is the recent discovery in West Greenland of extensive suites of mantle derived xenoliths within Kimberlite pipes which erupted between 600 and 55 Ma. Extensive and detailed study of these kimberlites and xenoliths (Pearson in progress) can be used to obtain estimates of the thermal gradient, composition and seismic anisotropy of the lithosphere at the time of eruption. These results can be compared with the present information from seismic studies and used to describe the evolution of the lithosphere over time.

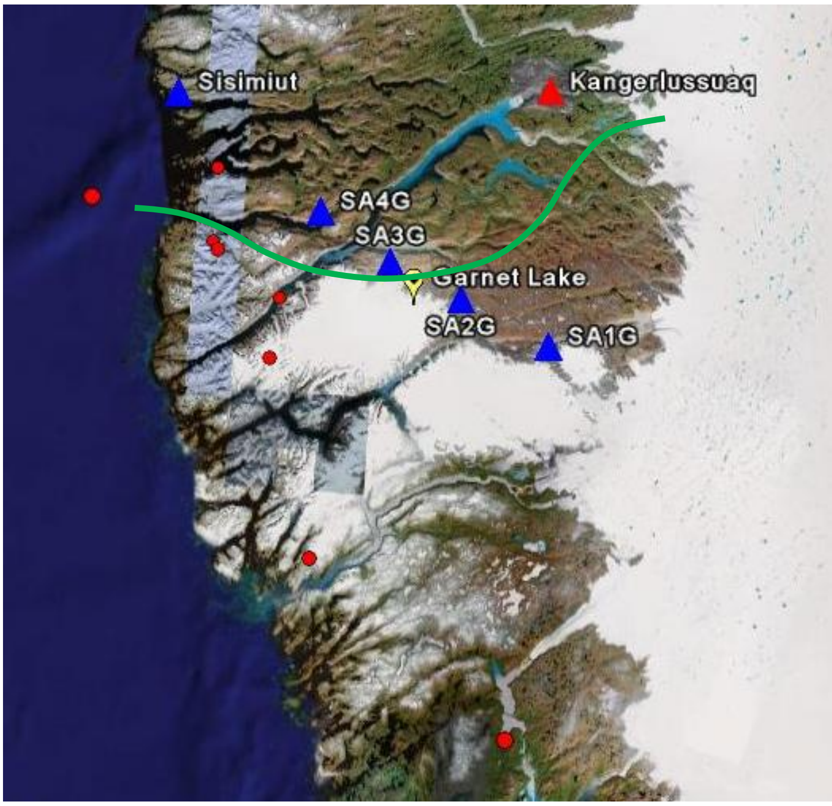

Figure 1. Google Earth image showing the positions of the seismometers (Blue triangles);the permanent seismic station at Kangerlussuaq; approximate location of the Archean – Proterozoic terrane boundary (green line, Proterozoic crust lies to the North) and local earthquake hypocentres (red dots).

Data acquisition, primary processing and archiving 5 Guralp broadband instruments were deployed by the Geological Survey of Denmark and Greenland on a NW-SE oriented profile from the coast to the edge of the ice sheet in West Greenland across the Archean – Palaeozoic terrane boundary (Fig. 1). The instrument at Sisimiut (SISG), nearest the coast, was installed in the basement of the Greenland Survey's permanent store and supplied with mains power. The other instruments were deployed in the field and powered by solar panels. These instruments shut down during the winter months owing to the lack of sunlight but 2 (SA1G and SA2G) out of the 4 successfully rebooted in March when sufficient light was available to recharge the batteries (Fig. 2). Recording was to SAM data loggers at a sample rate of 50 Hz. Data recovery is 78%, excluding the winter months for which 4 of the 5 instruments could not have been powered up. Unfortunately, the data lost due to the failures is from two adjacent stations on the north (Proterozoic) side of the Archean – Proterozoic terrane boundary. This limits the scope of studies involving the analysis from simultaneous recording of events (e.g. delay time analysis, tomography and surface wave studies). The data were reformatted from GCF to miniSEED records and these have been archived at IRIS and at GFZ-Potsdam together with other data (including the GLATIS data) from the Geological Survey of Denmark and Greenland. The data will be publicly released by IRIS in September 2010.

The seismic data are of very good quality. The Greenland Survey have considerable experience of deploying instruments in Greenland and there is very little ambient noise. 452 teleseismic events recorded were recorded from a range of back azimuths (although the majority lie to the north and SW of the array) (Fig. 3). In addition to the teleseismic events, the instruments detected 72 local earthquakes (the epicentral locations of some of these are shown on Fig. 1). Owing to the linear nature of the array and the lost recordings these can only be located with limited confidence. Examples of the teleseismic and local earthquake data are shown in Figs 4 and 5 respectively.

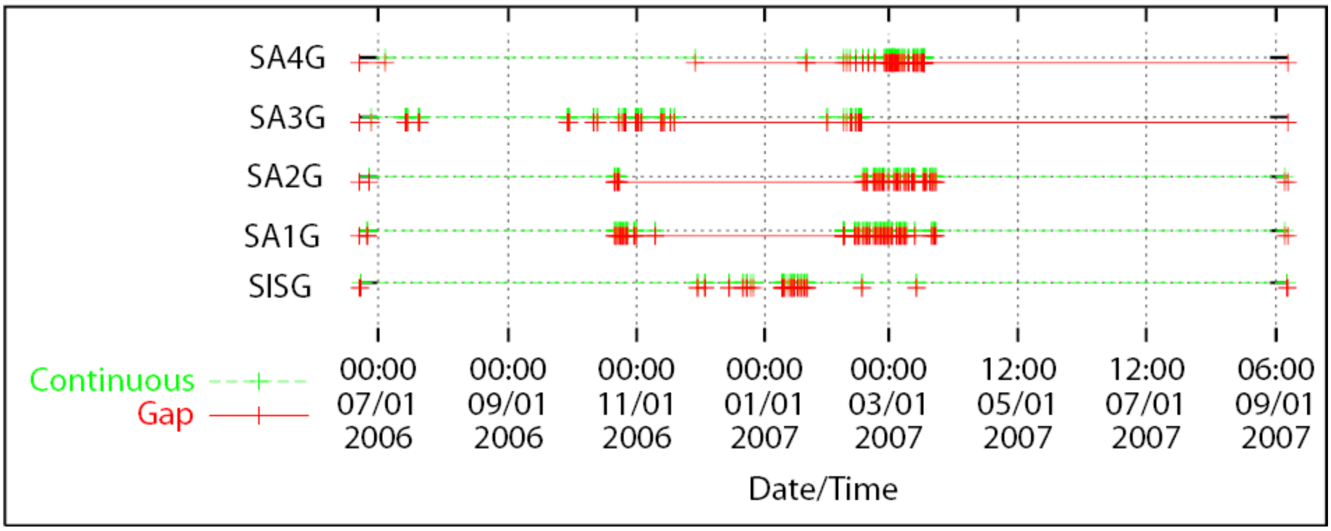

Figure 2. Display using IRIS' GOAT software showing recording availability from the instruments deployed in West Greenland.

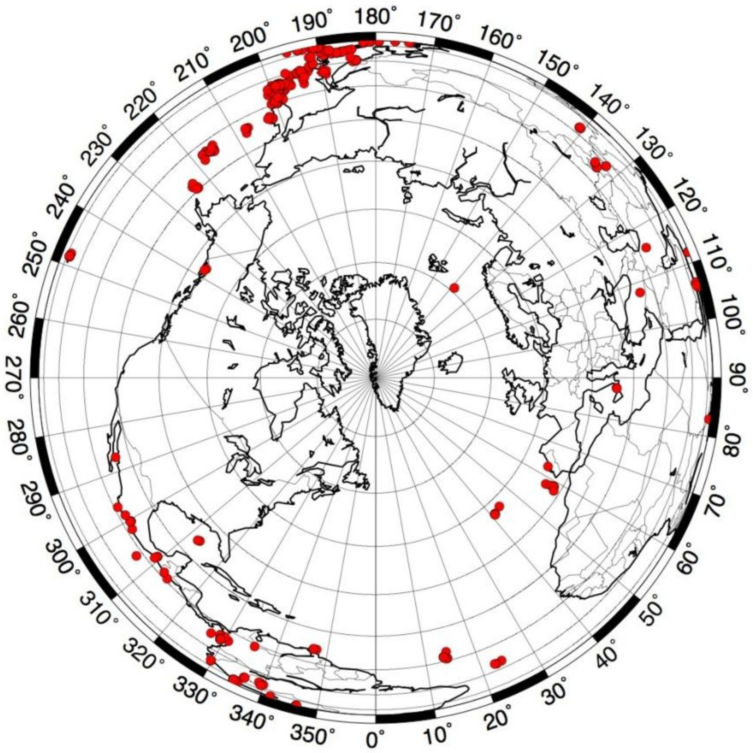

Fig. 3. Distribution of Earthquakes $M_b > 6.0$ within 90° of the array (red dots) which occurred during the deployment of instruments.

Interpretation Only a limited amount of work has been done on the data to date given the failure to attract additional funding which would enable the seismic results to be combined with the proposed studies of the xenoliths. It had originally been intended that SKS and SKKS splitting analysis would be performed on the data which would be compared with anisotropy measurements made on the mantle xenoliths. This would have enabled the group to examine the history and extent of mantle deformation.

Peter Voss is currently performing a receiver function analysis of crustal thickness and structure which will form the basis of a report to the Greenland Bureau of Minerals and Petroleum. The Receiver Functions suggest considerable azimuthal heterogeneity of the crustal structure beneath the stations (Fig. 6). An initial interpretation of the data from stations on the Palaeozoic basement suggests a crustal thickness of c. 52 km, which is typical for crust of this tectonothermal age.

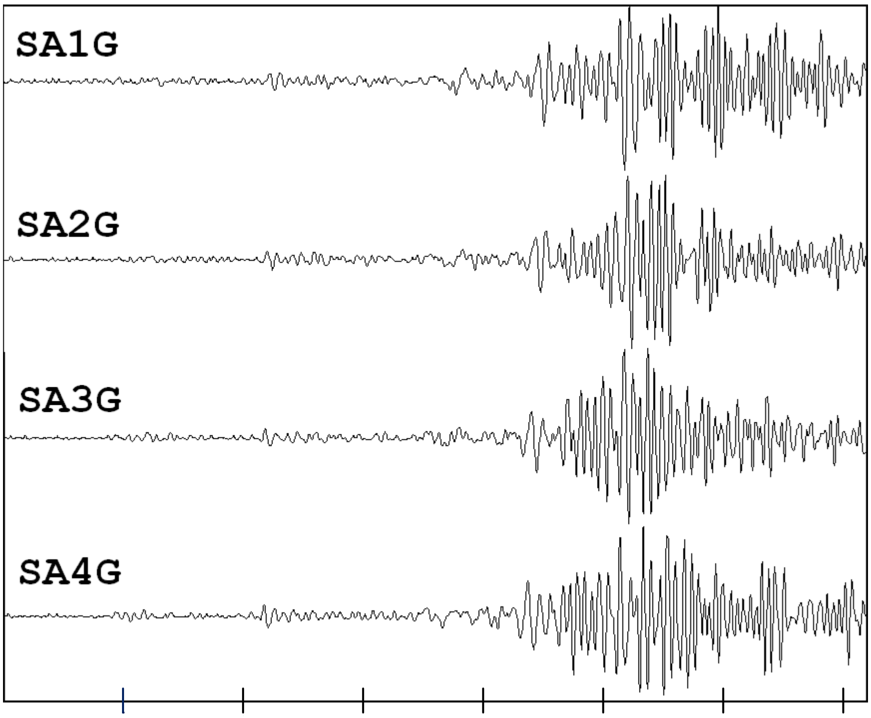

Figure 4. Seismograms from a teleseismic earthquake in Gulf of California, (M_b 5.9) showing clear P, S and surface wave arrivals. Ticks are at 5 min intervals, starting 5 minutes following the event.

The Receiver Functions will be modelled to produce a series of 2D models of the crustal velocity structure which will then form the starting point for analysis of the crustal structure in 3D using the local earthquake data. In addition is it proposed to calculate S Receiver functions to attempt to constrain and contrast the thickness of the lithosphere beneath the Archean and Proterozoic crust.

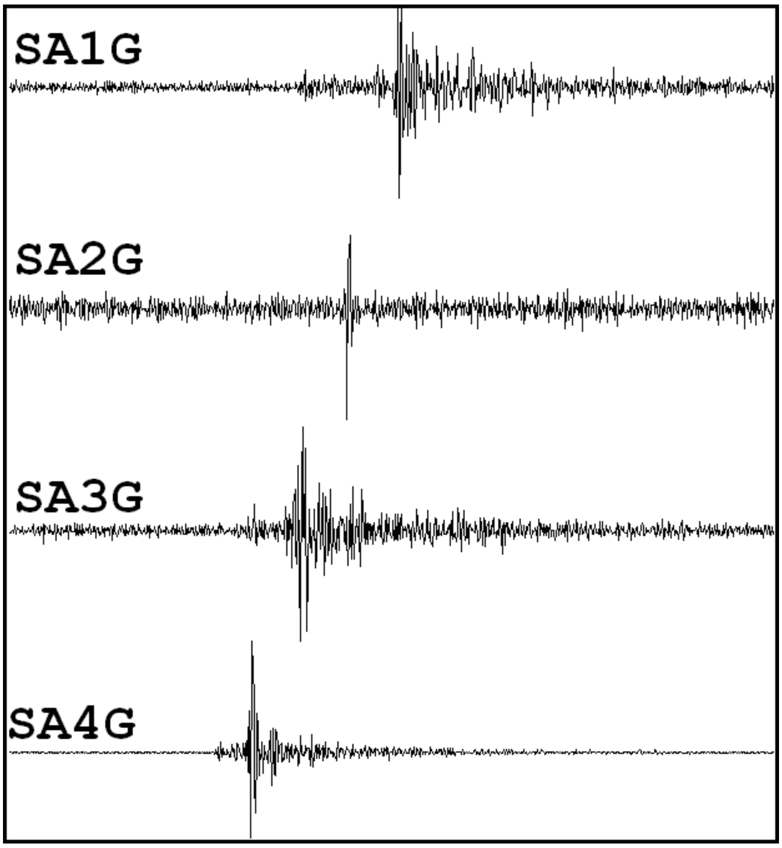

Figure 5. Seismograms from a local earthquake recorded during the summer of 2006 when the field array was operating.

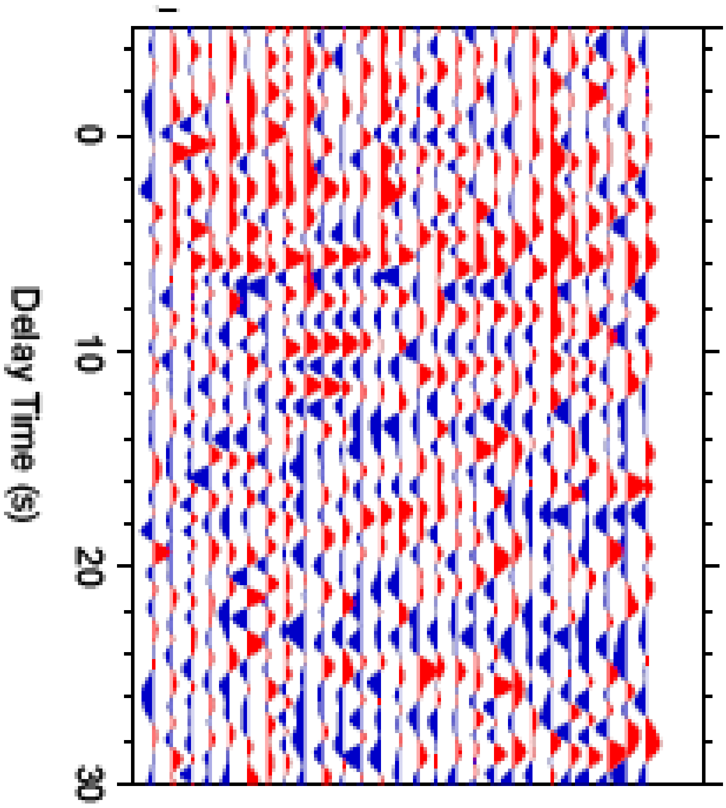

Figure 6. LQT Receiver functions calculated from teleseismic arrivals at the SISG station. Variability in the data suggest azimuthal heterogeneity in the subsurface beneath the station but a clear P_s arrival is visible for some events at c. 6 seconds, corresponding to a crustal thickness of c. 52 km.

Conclusions The 5 seismometers deployed as a pilot project in west Greenland recorded between July 2006 and September 2007. 78% data recovery was achieved. The data have been converted to miniSEED and have been archived at IRIS and GFZ Potsdam. Data quality is good and contains records of local and teleseismic earthquake events. Initial work at the Geological Survey of Denmark and Greenland has concentrated on calculating receiver functions for crustal thickness and velocity and on local earthquake tomography. There is considerable scope for further work on this good but small dataset. The majority of this will be undertaken by the Geological Survey of Denmark and Greenland following the UK groups failure to secure additional funding. RWE will maintain contact with colleagues at the Survey and ensure that any publications and further reports are communicated to the GEF.

References:

[1] Darbyshire FA, Larsen TB, Mosegaard K, Dahl-Jensen T, Gudmundsson O, Bach T, Gregersen S, Pedersen HA, Hanka W. 2004. A first detailed look at the Greenland lithosphere and upper mantle, using Rayleigh wave tomography Geophysical Journal International, 158, 267-286.

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