DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2003/17

Evaluation of GEUS' research activities within programme area 4 "Mineral resources and Greenland mapping"

James Franklin, Simon Harley and Jesper Sand Damtoft

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MINISTRY OF THE ENVIRONMENT

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The Department of Economic Geology

Summary
The Economic Geology Group is Greenland-oriented, with some projects in Eastern Europe and in the Third World. Its primary purpose is the development of knowledge and data bases to enable regional mineral resource assessment. It does this through seven major activity areas. Project highlights include a long-standing programme of resource-oriented studies in Isua, and topical studies of Greenland's large igneous provinces, as well as for other base and precious metals. The group has gained high acclaim internationally for its excellence, and thus has attracted numerous foreign research teams that complement the GEUS effort. The Economic Geology group also undertakes and interprets a variety of surficial geochemical and geophysical surveys. These are also done to the highest international standards, and are undertaken primarily to attract exploration investment in Greenland.

The current programme is a mix of regionally oriented and commodity (or deposit-type) oriented projects. While recognising that the group is small in comparison to many other surveys, its focus on attracting resource exploration to Greenland fits well with its mandate. Some change in the organisation and delivery of the programme, outlined as a series of recommendations, are meant to improve the breadth and responsiveness of the programme to ever-changing needs.

Recommendations
In order to ensure coverage of all of the major ore deposit types that might be present in Greenland:

- Consider assigning formal mineral deposit type portfolios to each research scientist in the mineral deposits research group.

- Consider expanding the Annual Review to incorporate all papers describing mineral deposits occurrences and attributes of these deposits or the regional geology that might be useful for exploration purposes. Some of these papers thus might not be published in the conventional literature. It is important to ensure that as much credit is given to the author(s) for "in house" publication as is currently given for publication in the peer-reviewed journals.

To improve the usability of the geochemical and geophysical surveys, and to attract a broader spectrum of industry participants in Greenland exploration:

- All past and future geochemical data should be made available digitally as it is produced, at a cost that is comparable to that charged by surveys elsewhere.

- Final reports on each release of a stream sediment geochemical survey should be accompanied by a thorough review of the metallogenic attributes of the region. Potential ore deposit types should be described in the context of occurrences and observed anomalous elemental combinations.
- The systematic potential fields surveys (magnetic, with targeted gamma ray surveys) should be continued until all of the ice-free parts of Greenland are surveyed.
- In-house seminars and short courses should be organised in GEUS to demonstrate the methods and limitations of interpretation of magnetic and other potential fields data.
- The interpretation of the results of hyperspectral surveys should be published in journals that are commonly read by the mining industry. More surveys should be undertaken in areas of high prospectivity, using the advice of mineral deposits specialists to establish the size and spectral characteristics of likely alteration types.

A much greater degree of integration between the Mapping and Economic Geology groups should be attained, as part of a strategy to make the GEUS products even more useful (and thereby attractive) to industry:

- All geological reports should include a section on regional metallogeny. This should contain summaries of types of mineral deposits present in the area, with a list of key geological, geochemical and geophysical signatures that could, be used by exploration teams. Regional metallogeny (or a summary of resource potential) should be undertaken by economic geologists, working in consort with mapping g and other colleagues, and should involve a field component as well as laboratory analysis.
- On a five-year cycle, an assessment of the resource potential of Greenland should be prepared or revised. This will be used as a planning tool for prioritising future mapping and other programmes, and as an advertising document to attract industry to Greenland.
- All future geological maps should be made available in a variety of commonly used GIS formats. These should be priced competitively with similar data sets available in Canada and Australia.

The international activities of the Economic Geology group prove an opportunity to broaden the experience base of its staff members, as well as to gain some new sources of revenue for GEUS. International work should continue to be a component of the GEUS programme, but should not expand beyond its present scope. Otherwise the focus on attracting economic investment to Greenland might be lost.

- International projects should not exceed 10% of the overall effort of GEUS.

The Department of Geological Mapping

Summary
The Mapping Group is essentially Greenland-oriented, though it also conducts some projects in Eastern Europe and in the Third World. Its primary purpose is the mapping of the pre-Quaternary and non-basinal geology of Greenland, with the aim of producing both geological maps and research publications contributing to the understanding of the geological evolution of Greenland. This is accomplished through an impressive portfolio of publications in international journals in addition to the published maps and annual reports. The mapping is organised thematically, with the current principal focus areas being the East Greenland Caledonides, the West Greenland Tertiary large igneous province, the Nagssugtoquidian belt and the Ketilidian Belt. Much of this work is internationally recognised as excellent, enabling GEUS to attract numerous international co-investigators to complement its excellent, well-motivated and highly skilled research team.

Recommendations
In order to ensure that the mapping programme is carried out to the highest standard and continues to be internationally competitive:

- Following the appointment of a metamorphic geologist, consider making resources available for the appointment of a structural geologist with expertise in brittle (faults, veins, joints, pseudotachylites) structures as well as ductile regime structures.

In order to ensure that greater and more directed integration is established both within the Department and across to other Departments:

- Develop a strategy of producing explanatory map sheet notes as soon as possible, along with digital maps. Consider including economic resource assessments to a greater depth than is currently the case, and integrate the available geophysical and geochemical spatial data with geological interpretations.
- Consider adding value to existing maps by producing thematic maps that depict specific aspects of the geology and promote these as targets for economic appraisal as well as further geological mapping.

In order to ensure the best utilisation of staff resource, generate greater and more co-ordinated integration within the Department, and ensure continuity of experience and knowledge:

- Consider developing a description of each research staff member in the department (and each department in the programme) and a link-o-gram to the projects they work on and with whom they work and liaise. This information should be placed on the GEUS website.
- Consider putting in place a mentoring / understudy programme for new staff and an assignment programme for experienced staff who would in time take over mapping programmes from retiring personnel.

In order to maximise the gains to Greenland geology of conducting external work:

- The extent of commercial activities should be kept under constant review to ensure that the balance is correct.

The Department of Quaternary Geology

Summary
The Department of Quaternary Geology is engaged in several Programme Areas. The activities in Programme Area 4 deals with providing a framework for exploitation of raw materials in Denmark by advising authorities and companies, investigating raw materials deposits, and collecting, storing and communicating data from mapping, drilling and other investigations.

Responsibility for raw materials investigations on land falls under the individual counties. This means that GEUS activities are limited to special materials and nationwide thematic investigations of selected raw materials. This is carried out by a small team of experienced geologists who also are engaged in geological mapping (Programme Area 5). Raw materials investigations of the Danish sea bottom falls more directly under GEUS. This is a strategic effort by GEUS carried out in a competent and effective manner. The results are a general map and resource assessment of the "Inland Sea" between Jutland, the islands and Sweden, and a raw materials map of the sea bed west of Jutland.

Recommendations
The raw materials investigations at sea are of national importance and impetus should be maintained. A total overview and a database of the resources and reserves of raw materials in Denmark should be created. It is noted that the department emphasises cooperating with other institutes and agencies. This multidisciplinary approach should be pursued further.

- GEUS is conducting a pilot study of a data centre for Danish raw materials ("Fagdatacenter for Råstofgeologi"). This should be brought forward to a nationwide database in close co-operation with the relevant private companies. Furthermore, this database should be compatible with assessments of recyclable waste materials. Factors such as land use, impact on protected areas, groundwater etc. should be included.
- It is advised that the geological habitat mapping approach is developed further, if possible taking other factors of importance to the environment into consideration.
- The relevance of the heavy minerals activities in Denmark should be assessed. Sufficient staff should be allocated to conclude the project quickly and establish a basis for deciding whether to commence exploitation in Denmark.
- It should considered to what degree materials research is in accordance with the GEUS mission. If this is judged to be the case, more formal co-operation structures should be created with other materials research groups at the Geocentre, other institutes or in industry in order to created a "critical mass" of materials research scientists.

There is little interaction between the activities under Programme Area 4 in the Department of Quaternary Geology and the Mapping and Economic Geology Departments. Quaternary activities in Greenland and geological mapping in Denmark are dealt with under Programme Area 5 (Nature and Environment).

- The programme areas should be modified so that Quaternary activities in Greenland and Denmark were covered in one programme area. Mapping and economic geology of Denmark should also be carried out in the same programme area - most naturally Programme Area 5 in order to put emphasis on sustainable exploitation of Danish resources.

Publications and Publication Strategy

Recommendation

The balance between digital provision and paper provision needs to be assessed carefully over the next year or so, based on an analysis of the actual and probable client/user base. The objective of promoting excellence in research requires that output to international journals is enhanced in either mode.

Critical Issues

There is a range of over-arching issues that affect all programme areas. The committee grouped its recommendations for these as follows:

Planning

Setting and evaluating priorities, including developing an appropriate balance between home and international activities, could be improved. Using government priorities as a basis for programme planning should assist in assessing the impacts of programmes, and thus provide a results-based analysis on which future funding might be obtained. A more formal procedure for evaluating the impacts of all aspects of the programme is needed. Accordingly, we recommend the following:

- A formal priority-setting procedure should be developed. Priorities should be set on the basis of government policies, an analysis of resource potential and the quality of scientific problems.
- The present strategies for decision-making on provision of assistance to third world countries within the broad area of mineral resources and institutional capacity building are continued, but that a well-defined limit is placed on the proportion of resource and activity directed to this end. We recommend a limit of 10% of activity, measured in terms of expenditure.
- A formal attempt should be made to develop a method for assessing the economic impact of the GEUS programmes. This should be divided into impacts for exploration, and impacts for risk reduction and social well being. Consideration should be given to models developed by the USGS and the Geological Survey of Canada for this type of

analysis. Additional criteria for measuring the success or otherwise of research activities may include:

- Invitations to present keynote talks at international conferences
- Numbers of overseas research partnerships fostered and developed
- Citations of flagged 'key papers'
- Invitations to act as editors on international journals and other measures of international recognition

Staffing

GEUS and its predecessors have been remarkably successful in attracting first-class scientists to its staff. In order to ensure the continuation of excellent research under rapidly changing external conditions, the following are suggested:

- Implement a Mentoring system for knowledge transfer.
- The overseas development component of the programme should be carefully monitored so that it does not divert staff resource from the principal mission. We suggest that it occupy no more than 10% of overall staff commitment and no more than 20% of any individual scientific staff member's time over an evaluation period (i.e. 1 year in 5).

Communicating

Although GEUS does an excellent job of communicating its results, through publications and displays at major exploration-oriented meetings, a few relatively inexpensive modifications to its present communications activities might reap greater benefits in terms of attracting industry to invest in Denmark and Greenland:

- GEUS should develop a strategy to visit senior managers of the major mining companies that either have had programmes in arctic regions, or have worldwide exploration strategies. Promotional material, including a metallogenic map of Greenland and metadata descriptions of various products should be provided to industry at these visits. A long-term communications strategy directed towards the mining industry should also be developed.
- GEUS resources the development and maintenance of public-oriented, dynamic and highlight-focussed web pages to complement the existing material on its website and present some of the content of what is being accomplished.
- The GEUS web managers adopt and adapt the good features of sister websites such as those of the British Antarctic Survey and Australian Antarctic Division, organisations that use their sites for promotion / public awareness and professional communication.

Decision making

GEUS must first and foremost develop excellent rapport with the decision makers in the Danish government. Once parliamentarians and senior government officials recognise the excellent value-for-money that GEUS provides, "selling" future programmes should be facilitated. Several improvements in this form of communication include:

- Develop a strategy for communicating with legislators and senior managers in both the Danish and Greenland Home Rule governments. This should include a plan for direct

contact, as well as well-illustrated promotional literature and reports on the impacts of the various programme activities.
- Institute an industrial advisory committee. This committee should answer to the Minister of the Environment, thereby ensuring access to the most senior government managers.

Programme Delivery

As part of improved communications, we encourage a GEUS-wide georeference metadata system be developed, which will facilitate client access to all forms of GEUS data.

- The policy and methodology currently in use by the Economic Geology Department should be employed throughout GEUS in database development, and that a procedure is established for ensuring consistency of approach to metadata referencing and database management across the whole Programme and indeed GEUS. This procedure and code of good practice should be supported by training days, explanatory manuals, and seminars.

Programme Evaluation and Strengthening

Programme responsiveness and the quality of future projects might be better ensured by developing improved project management protocols, streamlining the organisation, and more closely integrating the various GEUS programme activities at both the planning and delivery stages. Such integration should occur both within major programme elements (e.g. within the economic geology teams) and between the three major programme areas under consideration in this review. Consideration should be given to better integration, particularly at the planning stages with programme activities outside of Programme Area 4. Such better integration might include the Greenland Home Rule, the Danish Lithosphere Centre and the universities, as well.

Strategy and organisation

- The Panel recommends that each department prepare an annual departmental strategy paper, describing aims, staffing situation, resource allocation and action plans.
- GEUS management should consider a revision of the departmental structure better reflecting the GEUS strategies and work being carried out.
- Improve project management by improving the already existing formal project structure, e.g. by applying Coopers “stage-gate” method combined with an improved project management “on-the-job” training and motivation
- Create a new programme area dealing with sustainable use of natural resources and geo-environmental matters in Denmark (including basic geological mapping). This could be done by merging the Denmark activities in Programme Area 4 with Programme Area 5, perhaps including elements from Programme Area 2 (see also Department of Quaternary Geology).

Project planning and execution

- Introduce regular monthly Research in Progress seminars and annual / semi-annual Thematic and Skills workshops within the Programme Area and open, attendance to all groups within the new Geocentre.
- All field project proposals submitted to the management team should include clear evidence that consultation with other groups in the Programme Area has taken place during planning, and specific statements as to how existing data sets will be used and/or enhanced.
- The modes of operation and structures of the field programmes are modified to include a significant period (up to one year?) of reflection and synthesis, pooling together geological, geophysical and geochemical data, prior to any final field season.
- This may require adoption of a 2 year on - one year off - one year on field model. This reflection / synthesis / evaluation phase should involve, at the very least, collaborative assessment of geology plus geophysics plus geochemistry; each of these aspects should have been covered for the area under study in one or both of the early field seasons. The final season in a four-year cycle would include targeted mapping / sampling that uses and tests the synthesised data sets.
- (See also Department of Economic Geology, (5) Integrated science, above). As part of the project planning process, as well as in the project interpretation and publication stage, multi-disciplinary input should be obtained on all geochemical and geophysical programmes. Regional mapping and mineral deposits specialists should be asked to review the data and make recommendations for potential ore deposit types in the area. Also, these specialists should provide succinct reviews of the various occurrences and their geological attributes

Interaction with external stakeholders

- Greenland Home Rule geologists should be formally mentored by GEUS regional and mineral; deposits geologists, and should be encouraged to prepare high-quality reports on discoveries and prospects in their respective regions.
- A 2 season lead-in period (e.g. advertise in 2002 for field projects running in 2004) should be adopted for attracting students to projects involving GEUS.
- GEUS Programme Area 4 should implement a summer scholarship / prize / bursary programme for mid-term students to provide them with insight into GEUS activities, and then advertise ‘forthcoming projects’ at least a year before they are due to begin. This would enable students to plan ahead, take time to consider the opportunity, and approach it with some inside knowledge of GEUS (through short-term holiday bursaries). The Panel notes that the Programme Area has already taken action on this recommendation.
- A two-season lead time in advertising and soliciting expressions of interest is provided by GEUS in order to involve the highest calibre external collaborators. This is compatible with the timescale needed in order to obtain and place funds, attract students, and gain leave from research institutes.

1 Mandate - The Terms of Reference

The Evaluating Panel was set the objectives of evaluating the Programme Area 4 “Mineral Resources and Greenland Mapping”, comprising the following fields of research:

1. Geological mapping of Greenland and geology of Greenland, excluding petroleum geology
2. Mineral resources of Greenland
3. Mineral resources of Denmark

These areas, involving the Departments of Geological Mapping, Economic Geology and Quaternary Geology, were to be evaluated on the basis of

- Published reports, maps, articles and other relevant material produced over the period 1996-2001, and
- Interviews with GEUS management and staff, coupled with visits to laboratories and facilities in Copenhagen

The purpose of the evaluation was to:

1. Identify areas of high-quality research;
2. Identify areas where the research undertaken by GEUS should be strengthened;
3. Identify areas, which should be strengthened in order for GEUS to expand its ability to be involved in assistance to third world countries, with an emphasis on mineral resource evaluation and institutional capacity building;
4. Provide comments and proposals as to strategic changes, amendments and improvements to GEUS’ work in the programme area in order for GEUS to improve its ability to fulfil its stated mission in the programme area.

2 Evaluation process

Meeting One
The evaluation team of Dr James Franklin, Professor Simon Harley and Jesper Sand Damtoft met with staff of GEUS in their first visit on 25-27 March 2002. The general organisation and schedule of this visit was as follows:

Monday: Introduction to the Programme area and to its constituent parts - the Departments of Mapping, Economic Geology, and Quaternary Geology. A series of presentations by the heads of departments and by Kai Sørensen set the scene for future questions and issues.

- Presentation by Peter Dawes on the publication policy and strategy of GEUS, and in particular the level of international and local / in house publication.
- Interviews and talks with scientists from the individual departments, with the evaluators in turn seeing various workers individually.
- Visit to the new Geocentre facility, and the existing facilities run by the Mapping Department (thin sections, XRF, ICP-MS) and by the Danish Lithosphere Centre (Sector ICP-MS).
- Reading and selection of scientific papers / literature that would provide insight into the level and quality of work and allow selection of material to be examined by the Evaluators prior to the next meeting.

Meeting Two
The evaluation team met with staff of GEUS, and prepared their final report, in their second visit on 3 June - 5 June 2002. The general organisation and schedule of this visit was as follows:
- Organisational meeting with Kai Sørensen and the heads of the Departments of Mapping, Economic Geology, and Quaternary Geology. This was followed by a series of discussions between the Evaluators focussed on the key questions posed by their observations together with potential recommendations. A further meeting with Kai Sørensen was held in order to clarify the questions.
- Further development of their presentation by the Evaluators, and presentation of this to the staff of Programme 4 of GEUS at 1500.
- Finalisation of the draft report.

3 Background: GEUS' purpose, structure and context

3.1 Purpose

The Geological Survey of Denmark and Greenland (GEUS) is a "sectorial research institute" under the Ministry of the Environment. The overall framework for GEUS is laid down by a Danish Government Order that defines the purpose of GEUS as follows:

To create, apply and disseminate knowledge about the materials, processes and their interplay, which are relevant for the exploitation and protection of the geological values in Denmark and Greenland.

According to the Order, GEUS' tasks are:

- To carry out geological mapping, data collection and data storage concerning Denmark and Greenland
- To perform research, advisory service, monitoring and communication of knowledge to the public and other defined user groups within the field of earth sciences and related branches of knowledge.

The vision of GEUS is to maintain and expand its ability to serve as the main advisor to the Danish Government and the Greenland Home Rule within the fields of environment, energy and resources, and increasingly to engage in assistance to Third World and Eastern European countries. The GEUS mission is also to a lesser extent to contribute to the informed administration and legal framework related to resource management in Greenland.
The following strategies for the development of GEUS have been proposed:

- GEUS' research shall be project-oriented and conducted in an open dialogue with stakeholders and other research institutes in Denmark and internationally.
- GEUS shall be a central partner concerning earth sciences research, education and advice, crossing sectorial boundaries and traditional disciplinary boundaries.

3.2 Organisation of GEUS

The GEUS management consists of a managing director and two vice directors.

The scientific goals and objectives for the 4-year period 2000-2003 are laid down by a contract between the then Minister of Environment and Energy and the Board of GEUS. The contract is based on the previous 4-year period contract.

The Survey is divided into 9 scientific departments (fig. 1). The Department of Quaternary Geology was recently formed by a merger of the Department of Quaternary and Marine Geology and the Department of Environmental History and Climate. EDP, Public Relations and Administrative Secretariat are staff functions to the Management.

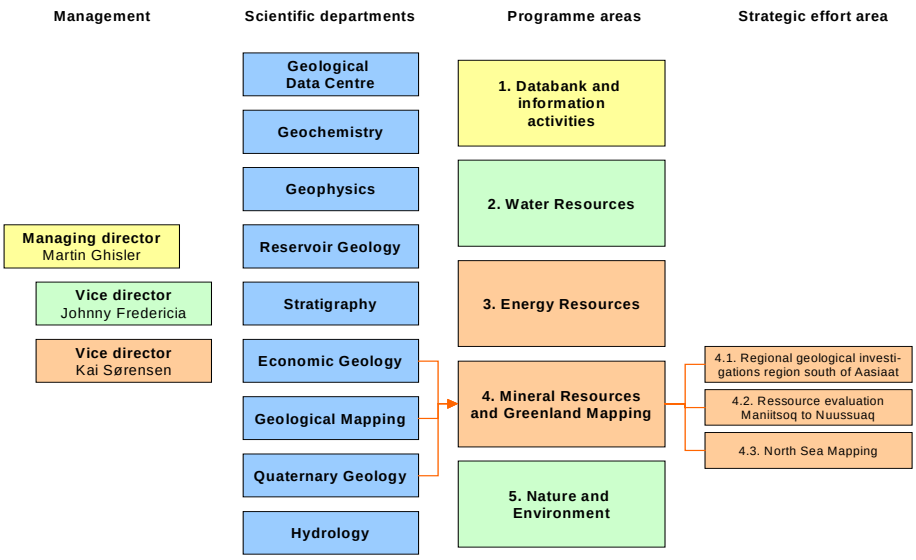

Figure 1. *Organisation structure of GEUS*

The scientific work is organised in 5 programme areas, each managed by a member of the Management. The organisation of the programme areas aims to increase multidisciplinary and interdepartmental co-operation (fig. 1)

Forty per cent of the total resources are earmarked for 27 strategic effort areas, of which 19 are concerned with research and development.

3.3 Context: Budgetary constraints

The “Contract of Results” assumes a stable, but slightly decreasing basic grant from the national finance law. The average grant is assumed to be 125 mio. DKK/year and the reduction to be 10% in the period 1999-2003. In addition to this, external funding of 70 mio. DKK/year is assumed, resulting in a *total turnover of ca. 200 mio. DKK*.

According to the Finance Law 2002, the GEUS basic grant will be reduced further over the coming years. The basic grant is by 2005 to be reduced to 104 mio. DKK, a reduction of 25% compared to 2001 (fig. 2). As the external funding is not expected to increase, this could lead to a significant reduction in the range of activities and/or quality of work. As a consequence, a reconsideration of GEUS strategy and ways of working to accommodate the reduced economic framework is advisable.

Out of a total finance law grant of 130.2 mio. DKK in 2002, 32,4 mio. DKK will be spent on Greenland activities, most of which are carried out in Programme Area 4.

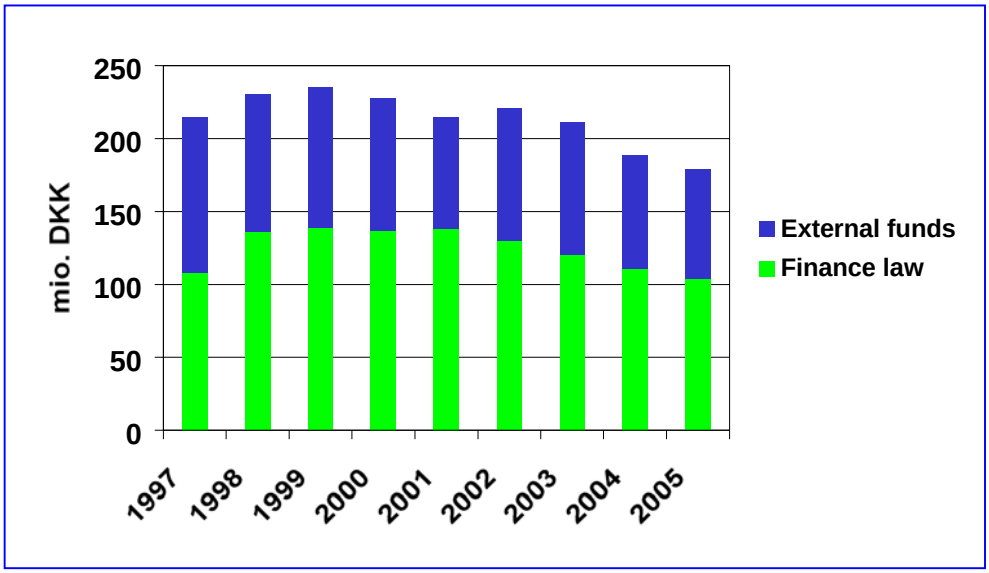

Figure 2. *GEUS' budget*

3.4 Staff profile

GEUS' staff consists presently of 354 persons of whom 49% are scientists and further 6% are managers. The budget reduction in the 2002 finance law will result in a significant staff reduction, as the number of man-years will be reduced from 350 in 2001 to 302 in 2005.

The average age of GEUS' scientific personnel is 43.4 years, but significantly higher in certain departments (e.g. Greenland Mapping: 55 years). GEUS faces a problem in the coming years, as the financial situation prevents new hires and hence will push the average age up further.

4 Programme Area 4 - Mineral resources and Greenland mapping

The overall purpose of Programme Area 4 is to provide the basis for a focused exploration for and environmentally sustainable exploitation of mineral resources in Greenland and Denmark. Vice Director Kai Sørensen is responsible for the programme area (in addition to Programme Area 3: Energy Resources).

Three departments are involved in the Programme Area:

- Department of Greenland Mapping (Head: Christian Knudsen)
- Department of Economic Geology (Head: Leif Thorning)
- Department of Quaternary Geology (Head: Peter Gravesen)

The programme area covers the 3 fields, which include one strategic effort area each:

- Geological mapping of Greenland/geology of Greenland (petroleum geology not included)
  4.1 - Regional geological investigations of the region south of Aasiaat
- Mineral resources of Greenland
  4.2 - Resource evaluation from Maniitsoq to Nuussuaq
- Mineral resources of Denmark
  4.3 - North Sea mapping

According to its 9-point “Geology for a Changing Society” statement the key goals in relation to the Programme Area 4 are:

- GEUS should be internationally recognised and in some areas a leader in research;
- GEUS should be the central (and lead) institution for advising the government authorities of Denmark and Greenland on geoscience;
- GEUS shall be the national repository for geological data, particularly on Greenland;
- GEUS shall play a visible role in aiding the development of geological / geoscience activities and sound resource policies in developing countries;
- GEUS shall be strongly involved in developing networks and attracting partner researchers / research groups to carry out mutually advantageous work, both in the national and international spheres;
- GEUS shall be visible in society and seek to communicate knowledge about geoscience to the public.

The total resource consumption is found in Tables 1 and 2. Compare realised figures for 2001 (table 1) with budget 2001 (table 2).

Table 1. *Resource consumption*

	R1998	R1999	R2000	R2001	B2002	B2003
Man-years	67	71	65	66	57	57
Annual turnover (mio. DKK)	53	54	38	43	39	39
Finance law	*30*	*30*	*24*	*28*	*25*	*25*
External funding	*23*	*24*	*15*	*15*	*14*	*14*

Table 2. *Budget 2001 for Programme Area 4*

	Man-years	**Finance law** (mio. DKK)	**External funding** (mio. DKK)	**Total** (mio. DKK)
Greenland mapping	16	9,9	0,7	10,6
4.1 - Regional geological investigations of the region south of Aasiaat	*5,3*	*4,3*	*0,0*	*4,3*
Mineral resources of Greenland	22	11,2	4,7	15,9
4.2 - Resource evaluation from Maniitsoq to Nuus-suaq	*7,6*	*5,1*	*0,8*	*5,9*
Mineral resources of Denmark	9	4,4	1,9	6,3
4.3 - North Sea mapping	*4,3*	*3,0*	*0,0*	*3,0*
TOTAL	**55**	**24,7**	**13,4**	**38,1**

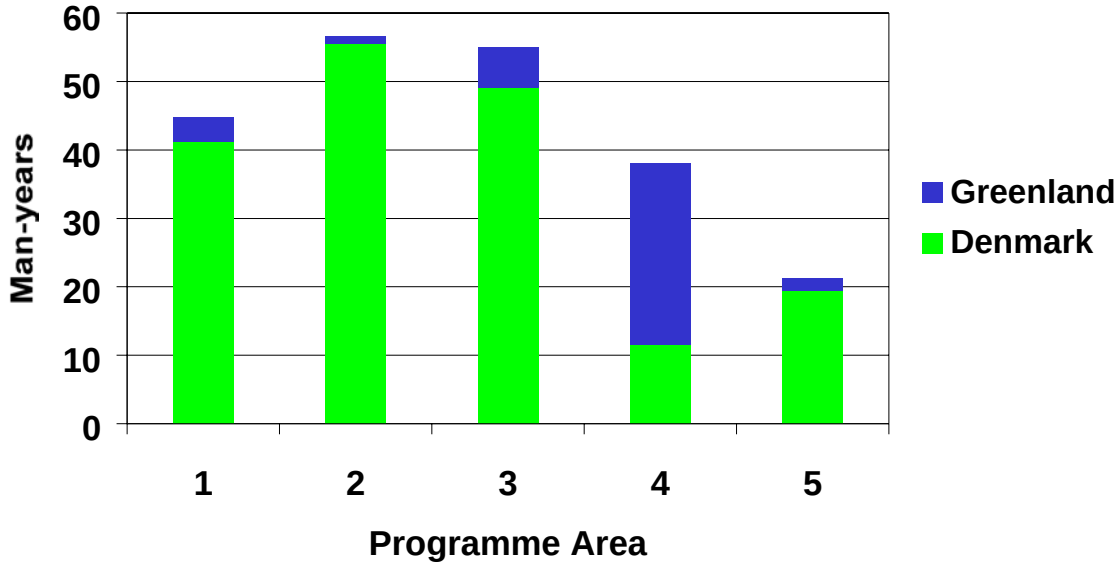

Figure 3. *Programme area budgets 2001*

5 Analysis of departments

5.1 The Department of Economic Geology

Background
Most of the work in the Economic Geology Group is Greenland oriented, as the Greenland Home Rule government supports GEUS both financially and politically. This group also leads projects in Eastern Europe and in the Third World. The department has 20 employees, including 15 academics and 5 support staff. The group includes scientists involved in airborne geophysics, mapping and focused mineral deposits studies, as well as specific geochemical surveys.

Mission
The primary purpose of the Department of Economic Geology is development of knowledge and data bases to enable regional mineral resource assessment, primarily in Greenland. These assessments will be used to underpin resource development strategies and encourage mineral exploration in Greenland.

Activities
The major activity areas are:

- Mineral deposits research
- Regional geochemical surveys
- Regional geophysical surveys (potential fields)
- Remote sensing research
- Integrated interpretation
- Database and GIS development
- International activities

Mineral deposits studies
The new integrated Isua project includes a new map, integrated paleobiology, astrophysics, volcanology, with fluid inclusion studies. This builds on an extensive history of research on various aspects of the metallogeny of this most ancient Archean crustal segment. This project has been a model of international cooperative involvement, with scientists from many institutions contributing to it over a 20 year period. The present focus is on establishing the evolutionary history of this granite-greenstone complex, and fitting the various types of mineral occurrences into an all-encompassing metallogenic framework. Much of the previous work has examined very specific problems: for example, several recent publications describe detailed mineralogical relationships and alteration of ultramafic rocks. These are nicely balanced, however, by papers of a more summary nature, including descriptions of recent gold discoveries, as well as descriptions of primary sedimentological and volcanic features in relatively low-strain segments of Isua. Largely through the efforts of the project

leader, Isua has been reinstated as one of the best known natural laboratories for the study of the earth's earliest crust.

Greenland is well known for its classic large igneous complexes, foremost amongst them, the Skaergaard. A recent excellent overview of the geology of the Skaergaard intrusion includes some new geophysically - based models that provide a three-dimensional view of the volumes of the various units, and illustrates the distribution of the units with the best potential for PGE mineralisation. This study provides new chemical data and discusses technical aspects of the recovery of the PGE mineralisation. Again, through the outstanding work of geologists in GEUS (and its predecessor, GGU) studies of these large igneous provinces have set the standard for comparison with similar intrusions world-wide. These studies include both front-line petrology, such as the high-profile published papers on natrocarbonatite and liquid immiscibility, and topical economic geology. Lessons learned from them have been exported for both academic and exploration purposes to many other areas. With the recent interest in PGM deposits, they once again have been highlighted, and the current project exemplifies the value of returning to a well-studied area with new technology, and new concepts, with the result that our knowledge of the processes attendant on forming such deposits is much better known. This information will be applied elsewhere in Greenland, with a reasonable expectation of discovery of an economic resource. Studies like this and particularly reports like 2001/23 should be undertaken on other forms of mineralisation in Greenland.

There are numerous other topical studies on mineralisation in Greenland that has been prepared by members of the Department, as well as non-GEUS scientists. For example, a new carbonate hosted zinc - lead - silver occurrence in Washington Land in western Greenland (report 1998 -3) consists of stratabound mineralisation in a dolomite unit. It is compared to the Polaris Mine in the Eastern Canadian Arctic islands. This study provides a useful database of sulphide compositions with locations. Another paper describes the occurrence of gahnite in the Isua Greenstone Belt. This is an important discovery, as it may indicate the potential presence of Broken Hill - type or VMS deposits. This latter paper, as well as many others, might better have been published as part of the annual review, where industry would have easier access to it. Also, these studies would have additional value if the linkage to ore deposit potential were strengthened. Numerous other topical papers, such as a description of recent gold discoveries in West Greenland, studies of lead isotope signatures of sedimentary rocks as a tool for tracing ore lead sources, and a description of gold occurrences and lead isotopes in the Ketilidian Mobile Belt South Greenland are published in the conventional literature. Again, the quality of the work is excellent, but these papers are somewhat "lost" in the academic literature, and would benefit from at least a reference in MINEX, or publication in the Annual Review.

In general the mineral deposits research programme seems to be largely curiosity driven, with little evidence of a long-term systematic plan. Members of the research team have developed a high level of expertise for specific important ore deposits types, but there are apparent gaps in covering the range of ore deposit types that might be present in Greenland. Consideration should be given to assigning "portfolios" to individual scientists, For example, a portfolio might include ore deposits of magmatic affiliation. This specialist would cover large mafic igneous suites including Ni-Cu-PGE and Ti-V deposit types, and also

granite-related mineralisation including porphyry-type, copper-gold-oxide, epithermal and possibly skarn deposits. Another portfolio might include “syngenetic” mineralisation styles, including VMS, Sedex, and BHT types, and yet another might cover sediment-associated deposits (MVT, red bed copper-cobalt). These assignments could be reviewed on a regular basis. An alternative might be to define portfolios on the basis of regional tectonic domains. This has the advantage of providing an extensive metallogenic assessment of resource potential for each region, but the disadvantage of requiring redundancy of expertise. One suitable compromise would be to follow the model of the Geological Survey of Canada, whereby individual researchers are hired on the basis of their specialisation of a specific portfolio of ore deposit types, but from time to time all of the experts are asked to assess the regional metallogeny of a specific tectonic domain.

Recommendations

Consider assigning formal mineral deposit type portfolios to each research scientist in the mineral deposits research group.

Consider expanding the Annual Review to incorporate all papers describing mineral deposits occurrences and attributes of these deposits or the regional geology that might be useful for exploration purposes. Some of these papers thus might not be published in the conventional literature. It is important to ensure that as much credit is given to the author(s) for “in house” publication as is currently given for publication in the peer-reviewed journals.

Surficial (Stream Sediment) Geochemistry

This programme has undertaken to provide stream sediment geochemical surveys of virtually all of Greenland. The work is very systematic, and done to the highest geological and analytical standards. Analytical quality control and quality assurance is done to international standards. This type of information is highly attractive for exploration companies, and should create high immediate economic impact through enhanced expenditures in exploration.

An excellent example is the Northwest Greenland geochemical survey, which covers the Thule area stream sediments with one sample per 20 km^2. Remapping to upgrade geological database accompanied this work, and all showings were prospected. A second example is the report detailing geochemical mapping of the Upernavik-Kap Seddon region Northwest Greenland (Report 1999 – 43). This example of a regional geochemical programme of GEUS demonstrates an excellent programme that is targeted to the exploration industry. It consists of well-illustrated and very robust data sets. Hopefully these data are available digitally, as most mining companies want to plot their own data, and undertake their own metallogenic evaluation. These surveys would benefit form a more robust review of the potential deposit types in the area, which could be provided by an economic geologist. This would enhance the usefulness of this data sent by directing the industry to specific types of targets. The report notes high values for a large number of elements, indicates that they may be related to granitic deposits in the area, but only spends two pages on the types of mineralisation that might be present. Descriptions of the types of deposits in the area would augment this.

Recommendations
All past and future geochemical data should be made available digitally as it is produced, at a cost that is comparable to that charged by surveys elsewhere.

Final reports on each release of a stream sediment geochemical survey should be accompanied by a thorough review of the metallogenic attributes of the surveyed region. Potential ore deposit types should be described in the context of occurrences and observed anomalous elemental combinations.

Geophysics
Geophysical airborne surveys are flown in the summer, with processing in the fall for a March release. Modern surveys started in 1992, with annual surveys (1994-98) targeted to specific areas around Greenland to obtain both magnetic and Geotem data (400 m line spacing). These surveys were targeted to areas of high mineral potential, and were considered experimental. One, a helicopter survey, covered 5 small areas in SW Greenland, included radiometric, frequency domain, VLF and magnetic survey data. From 1995 to 1999 a magnetic survey programme for Southwest Greenland was flown with 500 m line spacing, 300 meters above the ground. All surveys are levelled to a consistent set of standards. The data are interpreted, with some follow-up in the next year on the most important anomalies.

Aeromagnetic data have become the standard tool for enhancing geological interpretation of complexly deformed terrains. GEUS maintains a complete database of magnetic measurements, and sells these data “on demand”. The price covers the cost of data preparation and transmittal. This policy is consistent with all other geological surveys. Data releases generally instigate rapid response by industry, and the costs of these surveys are quickly recaptured in data sales and expenditures by the private sector.

Regional gravity data are also available for all of Greenland. These surveys are completed by the Danish geodetic programme, but made available to customers on the same basis as aeromagnetic data.

The magnetic interpretation maps are not used as extensively as they could by the regional mappers in GEUS. Interdepartmental seminars should be fostered in order to facilitate more exchange of ideas and approaches.

Recommendations
The systematic potential fields surveys (magnetic, with targeted gamma ray surveys) should be continued until all of the ice-free parts of Greenland are surveyed.

In-house seminars and short courses are organised in GEUS to demonstrate the methods and limitations of interpretation of magnetic and other potential fields data.

Remote sensing research
Experimental spectral reflectance surveys have been flown in a few areas of East Greenland. These were funded jointly by the EU, GEUS and the Greenland Home Rule authority. The primary purpose was to try to detect environmental contamination sites, but in the case of Greenland, a more important result is the possibility of detecting alteration associated

with economic mineralisation. Hyperspectral data have been used successfully in arid terrains to detect ore bodies; use of this technique in Greenland might have similar applications. This research is innovative and potentially useful.

Recommendation

The interpretation of the results of hyperspectral surveys should be published in journals that are commonly read by the mining industry. More surveys should be undertaken in areas of high prospectivity, using the advice of mineral deposits specialists to establish the size and spectral characteristics of likely alteration types.

Integrated science (Regional metallogeny)

The quality of the regional mapping and mineral deposits research is excellent. An integrated approach (geology + geophysics + geochemistry + remote sensing, all digitised into GIS databases accessed via Arc View) would allow for a variety of scales and depths of observation - from reconnaissance and basic data analysis and presentation to in-depth detailed research. The product would be an assessment of the regional metallogeny of a region. A key question regarding integration of data and its interpretation is the mechanism for facilitating such integration (e.g. by project leaders?) Do the scientists in the individual areas of study (e.g. mineral deposits, geochemistry, and geophysics) interact with each other, and with regional mappers?

Few projects have taken advantage of the stream sediment and potential field's data that are available for some areas. For example the study of geology of East Greenland on the Caledonian is a preliminary report to that gives a good overview of the geology, but gives only minor reference to the mineral potential. It seems that areas are mapped, and a series of papers produced on each area, most of which relate to the fundamental geological attributes of the region such as its sedimentary geology, volcanic petrochemistry and intrusive and structural history. However although types of mineralisation are noted by the mappers, there does not seem to be much follow-up that would explain the style, potential size and key indicators of each type of mineralisation. What could be improved and better defined is the link each between the regional programmes, the geochemical and geophysical programmes and the economic geology programmes. Funds should be set aside for a visitation by an economic geology department expert, preferably in the last year of each mapping project. By that stage most of the occurrences should have been noted, and the basic geological information gathered, so that the economic geology specialist could efficiently review the types of mineralisation, add some specialised studies, and write a section of the regional report that might attract industry to the area.

The end product of integrated science projects should include a thorough assessment of the mineral potential of the region: a metallogenic assessment. From time to time, and primarily for planning purposes, a summary paper assessing the resource potential of all of Greenland should be prepared. This should be a succinct document, accompanied by a map, and provided by an integrated team of regional mappers, or deposits geologists, geochemists and geophysicists.

Recommendations
All geological reports should include a section on regional metallogeny. This should contain summaries of types of mineral deposits present in the area, with a list of key geological, geochemical and geophysical signatures that could, be used by exploration teams. Regional metallogeny (or a summary of resource potential) should be undertaken by economic geologists, working in consort with mapping g and other colleagues, and should involve a field component as well as laboratory analysis.

On a five year cycle, an assessment of the resource potential of Greenland should be prepared or revised. This will be used as a planning tool for prioritising future mapping and other programmes, and as an advertising document to attract industry to Greenland.

Database/GIS
Much of this is covered elsewhere in this report. All 500,000 scale maps are digitised, and the southern Greenland sheet has been compiled, together with geological and geochemical databases. All new maps should be made available digitally. All regional geophysical and geochemical data are available digitally, as well. GEUS uses Arc View as its principal platform; this is one of the two industry standards. It should consider making its files available in other formats; this requires little effort during the preparation stage, but is more work of done later.

Recommendation
All future geological maps should be made available in a variety of commonly-used GIS formats. These should be priced competitively with similar data sets available in Canada and Australia.

International projects
Economic geology programmes have been initiated in several countries, generally to generate revenue, but also to provide exposure for GEUS scientists to ore deposit types elsewhere. Most of these projects are providing institutional guidance to third-world nations, and a few have science components. For example, the Tanzania programme is examining growth in a Paleoproterozoic belt in of Southwest Tanzania. There is a major laboratory programme looking for high-grade ilmenite in Vietnam and in Africa. This is a specialised programme, and is targeted as a specific market area for GEUS. A specialised analytical approach has been adopted for this, which runs overnight on the SEM. This seems to accomplish the object of all for obtaining some revenue for the survey, while at the same time not holding up the access to the facilities for in-house work.

Recommendation
These projects should not exceed 10% of the overall effort of GEUS.

5.2 The Department of Geological Mapping

Mission and current situation

This Department has as its mission the geological mapping of Greenland, coupled with the description and understanding of the major geological environments in Greenland apart from Phanerozoic sedimentary basins. It therefore is responsible for geological mapping principally in the Precambrian basement and in the younger (Tertiary) large igneous provinces (LIPs). It is also primarily for the development and maintenance of a geological map data base for Greenland, available to the public. This mapping is carried out on both regional scales (1:500,000 and 1:100,000) and on finer scales where warranted. At the present time GEUS has produced 13 or the 14 possible 1:500,000 maps of Greenland and the last one is nearly complete (in compilation). It has also produced 56 of the possible 244 1:100,000 maps.

The Mapping Department contains 23-24 people, including 5 technicians. From a peak of 12-14 mappers in the 1980s the GEUS Mapping Department has seen its numbers, in terms of active mappers, fall to 8-9 in the 1990s and now to only 4. With these staff limitations it is simply not possible to facilitate all the mapping that needs to be carried out if a systematic, map-by-map, strategy is to be continued. However, the international flavour of the mapping work is very important - most projects have half of the involved scientists originating from outside of GEUS, providing both field personnel and complementary expertise.

Priorities and targets

There is a wealth of existing work and laboratory follow-up to be published, but new mapping will have to be confined to a few definite and clearly defined targets. The key problem is how to prioritise what to do next, given that at best only one new 1:100,000 map can be compiled and produced each year. The priorities now established in directing the mapping strategy appear to include the following:

- choose areas with some mineral potential
- carry out both strategic research and mapping aimed at data base provision for potential user groups
- conduct applied research that utilises the classical tools available in the Department and used to carry out Greenland mapping, branching out to use these in other areas and countries. The tools include petrology/petrography, geochemistry, mineral chemistry, isotope geochemistry and structural geology.

The major geological areas of interest in the past decade or so have been problem-led, reflecting geological issues that are important both in Greenland and in the wider international context. These include:

- Specialist geological mapping of alkaline intrusions
- The Ketilidian and Nagssugtoquidian Belts

- The Tertiary basalt province (E and W Greenland), with high-precision 1:100000 maps and detailed cross sections produced.
- The Caledonian fold belt of E Greenland, now traced for 1200 km and reinterpreted as containing a westerly thin-skinned foreland fold and thrust belt and an easterly deep-seated deformed belt (with eclogites).

Areas of high quality research in the Mapping Department
It is clear that a number of the scientists are well published, with excellent papers in top class journals as well as the more traditional published products (maps, internal reports).

It is clear that the programme has staff who are receptive to change and who show great enthusiasm for their work. This is a real positive for GEUS, and helps it achieve excellent output and quality of product even though there are some important areas in which performance can be enhanced through enabling mechanisms.

Oblique collision and deformation / magmatism relations in the Ketilidian Orogen
GEUS provides high-quality input to the highly collaborative and successful Ketilidian mapping programme that also involves UK and USA workers. This work on the record of oblique collision coupled with syn-collisional melting in the Ketilidian is in our view front-rank innovative geoscience in its contribution to continental tectonics. The work embodies an excellent integration of geology, structural analysis, petrology, geochronology and modelling, and has led to exciting new ideas regarding the relations between steep and shallow structures (inverse flowers etc, detachments between steep zones) and the presence / absence of extension. This work is published in a series of excellent papers in high-profile journals, is widely cited, and influential.

East Greenland Caledonides and their correlations with other areas
The demonstration of a western zone of thin-skinned tectonics, with thrusting of at least 80 km to the west, that changes eastward to a region of thick-skinned and deep crustal compression in which eclogites have been produced locally is of international quality, and provides important links with the Caledonides in other regions. Complementary U-Pb isotopic studies of the provenance and age of Neoproterozoic metasediments in E Greenland, collaborative work underpinned by GEUS, has led to exciting and testable hypotheses as to the role of the Grenville Orogeny and the positions of Laurentia and Baltica, again high quality science with international impact.

Terrane amalgamation in the Nagssugtoquidian
The documentation of deep-seated thrust stacking on flat lying structures with intervening shears is high-quality fieldwork at the forefront of current research on deformation in the deep crust. The inference of collision between two crustal blocks (with windows of less overprinted material preserved) that telescoped an intervening zone of calcalkaline magmatics, sediments and perhaps oceanic crust (ultramafics and mafics) is very important too. Closure / collision occurred at 1870-1840 Ma - an event that could correlate closely with those in Scotland, specifically in South Harris. The multidisciplinary project on the Nagssugtoquidian has involved workers from the DLC, the US, Australia and elsewhere,

and has been a major success with very good papers in highly cited and reputable journals.

Tertiary Magmatic Province of West Greenland
The research on the detailed chemical / lithostratigraphy of the lavas of Disko has combined in quite a unique way superb geochemistry and precise photogrammetry to produce a facies variation map of the lavas. This has major implications for understanding the process of basin development and evolution offshore of west Greenland. When completed, the major memoir / report / volume on the Disko mapping and palaeoenvironmental / volcanological intepretations will be a unique and world-class contribution to understanding past volcanic successions and magma petrogenesis. The published papers on this work and previous related work on the Tertiary Magmatic Province have very high international impact and continue to attract top class collaborators to GEUS, which is seen as a major contributor to modern igneous geology, especially with respect to plumes, LIPs and opening of the Atlantic.

Additional positive aspects

Documentation of the GEUS mapping archive
This includes compilation a glossary of stratigraphic names (with spatial information), and placing all of the information into a digital archive is a major ongoing task. This is clearly necessary if GEUS is to fulfil its role as custodian and source of geodata on Greenland. Geoinformatics developments will need to be taken into account in the construction and implementation of the database as it develops.

Photogrammetry Development
The Mapping department has embraced new technology in photogrammetry, using digital processes to generate DEMs and produce topographic maps / information for both general (mapping) and specific (e.g. landslip and tsunami) purposes. This is still in early stages, with the main user in the process of learning the capabilities of the software and its applications, but is already a very progressive and valuable development.

Commercialisation
The Department has adopted the strategy of using its instrumental (and some intellectual) resources to attract commercial jobs (e.g. SEM mineral chemistry, Pb/Pb on detrital zircons for provenance studies, institution development in Ghana). It is clear that these provide funds to help support the staffing, and are an important resource so long as they create capacity (see next section).

Areas in which research should be strengthened or action considered
A longer lead-in time is required in order to involve the highest calibre external collaborators - the timescale is that required in order to obtain and place funds, attract students, and gain leave from research institutes.

There is a strong need to define (on the basis of collected data) what the likely and present clients / users will need from GEUS in the future. This must be taken into account when

deciding, for example, the balance of targeted versus regional mapping, the balance between digitising older work and producing new work on areas only looked at in reconnaissance previously, and the balance of rapidly produced reports versus international standard papers.

There is a priority to appoint and retain a scientist in the general field of Metamorphic Geology and Petrology, with a strong field capability and research-level petrology. This is clear, given that one priority area is in unravelling the accretion / growth history in West Greenland to southern Greenland (basement / metamorphic project). There is a growing need to appoint a structural geologist with expertise in brittle phenomena, to work on post-accretion crustal development and link with geological studies of faulting in offshore regions.

Recommendations

Following the employment of a metamorphic geologist, provide resources for the appointment of a structural geologist to the Mapping Department.

The progressive development of an integrated approach (geology + geophysics + geochemistry + remote sensing, all digitised into GIS databases accessed via ArcView) allows for a variety of scales and depths of observation - from reconnaissance and basic data analysis and presentation to in-depth detailed research.

Integration as noted above should be promoted as part of the research culture across the Programme area in general, and should form an important component of future mapping activity.

Only some of the published maps are complemented by explanatory notes. This situation needs to be improved and priority should be given to developing a strategy of producing such notes as soon as possible, along with digital maps. Future notes should include economic resource assessments to a greater depth than is currently the case, and integrate or include the available geophysical and geochemical spatial data with geological interpretations.

Add value to existing maps by producing thematic maps that, for example, depict specific aspects of the geology and promote these as targets for economic appraisal as well as further geological mapping.

Within a few years the older staff will have left, taking with them their stored (but unpublishable) expertise and inside knowledge. There is a real danger that accumulated expertise and intellectual capital will not be able to be passed on, to complement the necessary but never fully encompassing digital data: person to person contact is necessary to pass on the intellectual resource.

Put in place a mentoring / understudy programme for the new staff.

It will be useful to develop and provide a description of each research staff member in the department (and each department in the programme) and a link-o-gram to the projects they work on and with whom they work and liaise, both within and between the departments.

There are dangers in the outside research and commercialisation activities referred to in the previous section causing a loss of focus on the principal mission of the group - to map in and develop a geological understanding of Greenland.

The extent of commercial activities should be kept under constant review to ensure that the balance is correct.

5.3 The Department of Quaternary Geology

Mission and current situation

The purpose of the Denmark-centred activities in Programme Area 4 is twofolded:

Contribute to establish and provide the geological and administrative basis for production/exploitation of raw materials (stone, gravel, sand, clay, limestone etc.) on land and at sea, by:
- advising authorities (governmental and local),
- collecting, storing and communicating data from raw materials mapping and investigations,
- researching processes which produce and locate raw materials,

Assist private raw material extraction companies and advise authorities and private advisors in “special” cases that demand a level of knowledge or special equipment.

The activities are related to exploration on the land area or on the sea bottom. In addition, expertise on clay mineralogy is used for concrete development and other materials science related to the construction sector.

The administrative settings of mineral exploration on land and sea are very different, which has important implications for GEUS activities:

- Land: The 14 counties are individually responsible for raw materials mapping on land. It is the counties, which grant private companies permission to exploit onshore mineral resources. The counties employ their own geologists. Raw materials mapping has, however, a very low priority at the counties. GEUS performs background work and exploration of more special minerals (e.g. moler and heavy minerals).

- Sea: The National Forest and Nature Agency under the Ministry of the Environment are responsible for raw material mapping of the sea bottom. The agency awards sand and gravel exploitation permits to private companies. In practise, GEUS conducts the sea-bed mapping.

The Department of Quaternary Geology does not conduct any investigations in Greenland under the banner of Programme Area 4. The department has mapping obligations for Greenland in other programme areas, e.g. Programme Area 5: “Nature and Environment”.

Apart from the heavy mineral characterisation work carried out by the Department of Geological Mapping, the two other departments are not involved in Programme Area 4's Denmark-related activities.

Nine man-years were allocated to Denmark activities in the Work Programme 2001. Presently, the effort is:

- Exploitation on land: 2 part time scientists (also engaged in Programme Area 5, Denmark mapping)
- Exploitation at sea: 4-5 scientists, 2 technicians
- Materials science: 1 scientist (part time)

Priorities and targets

Land
A thematic investigation strategy is followed whereby a thematic examination is carried out for a new type of raw material on a 3-4 year rolling cycle. The order of the thematic investigations is agreed following discussion with the raw material industry, represented by the Confederation of Danish Industry. The thematic investigation has two phases:

Phase A: A general description of the raw material. The description is used to produce a detailed plan for investigations and projects. General descriptions have been prepared for:

- Limestone and chalk
- Clay
- Heavy mineral sand
- Next material to be described: Sand and gravel (in 2003)

Phase B: Research projects carried out in co-operation with the National Forest and Nature Agency, local counties and industry. Examples are:

- Heavy mineral exploration
- Clay for clay bricks
- Diatomite and bentonite

Sea
GEUS has compiled the results of 20 years of mapping and calculated the sand and gravel resources in the Baltic Sea, the Belts and Kattegat.

The strategy of the last four years has been to map the sea bed, the sand and gravel distribution, and sand transport in parts of the North Sea. It is the intention to:

- Continue the mapping in the North Sea
- Establish geological habitat mapping in the North Sea and the Baltic.
- Establish a connection between mapping at sea with raw material demand on land.

Data bases
GEUS maintains a borehole data archive (JUPITER) and a database of geophysical investigations on land (GERDA). It is the intention to establish a new report system for quality data, and a new marine geological database.

Areas of high quality research in the Quaternary Department

Raw material mapping at sea
GEUS possess a dedicated and very competent group of scientists engaged in mapping and resource assessment at sea. A general map of the "Inland Sea" between Jutland, the islands and Sweden has been completed, and the mineral resource has been calculated. More detailed mapping is done at specific areas or in connection with large public works. As a priority area, the west coast of Jutland is presently being mapped. The mapping covers the beach from the top of the dunes to the sea bed at a depth of 25 m. The mapping is done both from a raw materials point of view but also from a more scientific geological standpoint. The work aims to improve the models for coastal development. Deliverables are maps, reports and scientific papers. The "geology" is needed in order to get the result accepted for publishing. Mapping at sea is very expensive. High quality and expensive equipment is needed, e.g. a boat and several types of seismic equipment. Drilling is needed. The mapping is done in co-operation with the Danish Marine, which supplies the ship.

A highlight of the ongoing research is the development of integrated underwater resource identification and management, "Geological Habitat Mapping", which links the seabed geo-resources (aggregate / sand / mud) to fish and benthic habitat: the geology - biology link.

Recommendation
It is advised that the geological habitat mapping approach is developed further, if possible taking other factors of importance to the environment into consideration.

Mineral assessment at land
Land raw materials are the responsibility of the counties, but 2 scientists work part time with "special" or "difficult" materials, which fall outside the expertise of the county geologists. The activities are concentrated on diatomite, bentonite and limestone. The scientists involved are very experienced and the results produced are of high quality but limited by the narrow scope of the activities.

Additional positive aspects
GEUS has been able to create good working relationships with other institutions or advisors, some of which could be perceived as competitors. The cooperation enables valuable research synergies to be established with other professions such as hydraulic engineers etc.

Cooperation has been established with the geomorphologists at the Geographical Institute. This is of major importance for understanding the coastal processes shaping the offshore

raw material deposits. It is expected that this co-operation will be further strengthened in the future as the Geographical Institute is part of the Geocentre.

The department has acquired geophysical equipment (Slingram, Georadar), which, however, mainly will be used for the "pesticide project" under Programme Area 5.

Areas in which research should be strengthened/action considered

Mineral resources of Denmark
Presently, there is no total overview of the resources and reserves of raw materials in Denmark. 16-17% of Denmark has not been mapped as yet. Among the reasons are the low priority given by the counties and that there is no central database of the information already collected. It has been suggested that existing information should be compiled and a set of common norms for the classification of raw material deposits developed. This could be done at the new "Fagdatacenter for Råstofgeologi" at GEUS. This work is presently in its initial phase, as GEUS together with the Forest and Nature Agency and 3 counties are conducting a pilot study.

Recommendation
GEUS should bring this forward to a nation-wide database in close co-operation with the relevant private companies. Furthermore, this database should be compatible with assessments of recyclable waste materials. Factors such as land use, impact on protected areas, groundwater etc. should be included.

Heavy minerals
The heavy mineral exploration project is temporarily on hold as its driving force, Christian Knudsen, has moved to head the Mapping Department. The project, which is financed by Du Pont, is continued at the Mapping Department with other staff. The activities are supported by the SEM/EDS quantification method developed and operated at the Mapping Department. This method has a high commercial interest (significant income is generated by selling analyses) and might have other applications. There is presently no possibility of funding for applying the heavy mineral expertise for third world assistance.

Recommendation
The relevance of the heavy mineral activities in Denmark should be assessed. Sufficient staff should be allocated to conclude the project quickly and establish a basis for deciding whether to commence exploitation in Denmark.

Materials research
GEUS is involved in building materials research (concrete technology) in Programme Area 4. The AFM (Atomic Force Microscope) and the other clay mineralogical skills are applied to an artificial sedimentary rock: concrete. Various natural pozzolanic materials have been evaluated as cement supplementing materials in concrete, and palygorskite investigated as a mineral addition to concrete. The relation to the GEUS mission is that the activities deal with aspects of clay mineralogy (interaction with cement and other components of concrete). It is noted, however, that the AFM is used in co-operation with other institutes to

study the interaction between silica fume, fly ash and cement in hydrated cement paste - i.e. a very indirect link to clay mineralogy.

The research carried out is undoubtedly of high interest and good quality, but the effort is limited, as the scientists engaged have obligations in other programme areas. However, it is evident that GEUS has high-level expertise centred on the laboratories (i.e. the AFM and ICP-MS) which could be applicable in materials research. Attention is drawn to the government's nanotechnology effort. Nanotechnology Centres are being created at e.g. Copenhagen and Aalborg Universities. Inorganic materials research is also of interest to the building materials sector, but funding is limited.

Recommendations

It should be considered to what degree materials research is in accordance with the GEUS mission. If this is judged to be the case, more formal co-operation structures should be created with other materials research groups at the Geocentre, other institutes or in industry in order to create a "critical mass" of materials research scientists.

The Department of Quaternary Geology is involved in studying the Quaternary of Greenland but not in mapping the Quaternary; the glacial and post-glacial features of Greenland are essentially under the remit of the Nature and Environment programme area (Programme Area 5), rather than within this programme area. Similarly, geological mapping in Denmark is located in Programme Area 5. This unusual organisational structure, probably a historical relic, does not appear to be sustainable: the most productive nearest-neighbour interactions involving this Department would appear instead to be those with Quaternary groups in Greenland and Denmark. The aim of supporting an environmentally sustainable exploitation of natural resources in Denmark needs input from mapping, hydrology, environmental sciences and other disciplines.

The programme areas should be modified so that Quaternary activities in Greenland and Denmark were covered in one programme area. Mapping and economic geology of Denmark should also be carried out in the same programme area - most naturally Programme Area 5 in order to put emphasis on sustainable exploitation of Danish resources.

6 Publications and publication strategy

The three-fold GEUS publications strategy appears well founded and thought out, with a clear commitment by the relevant staff (e.g. Dawes) to maintain high standards across the board. The Scientific Series, which includes the Bulletins and Annual Reviews, is particularly valuable and will become more so when available on-line and fully indexed. The adoption of a peer-review model for this series is very commendable and ensures quality. The Open File series is important in order to maintain records and have information available in-house, but would be of greater use outside once full catalogue and meta-data facilities are implemented. The Newsletters, which have recently been revamped and reformatted as well as made available for on-line viewing, are a very useful resource for promoting the interest of mining and petroleum companies.
Many of the Programme Area 4 scientists also publish in the international literature, with an average of 14.6 publications per annum in international peer-reviewed journals. In addition the scientists produce a large number of in-house reports. With a strong move to web-based access it is likely that the overall research effort will become more 'visible' to a wide range of geoscientists.

Recommendation
The balance between digital provision and paper provision needs to be assessed carefully over the next year or so, based on an analysis of the actual and probable client/user base. The objective of promoting excellence in research requires that output to international journals is enhanced in either mode.

7 Critical issues and recommendations

7.1 Changing conditions

Fundamental changes in the context within which GEUS operates, which have to be considered in the development of future overarching strategies, include:

- reducing basic grant
- high average age (e.g. 55 in Mapping)
- possible changes in national strategies regarding resources, energy, foreign aid, environment and changes in structure of Danish research organisations

However, whilst recognising these changes, GEUS Programme Area 4 still has to fulfil its essential mission:

To create, apply and disseminate knowledge about the materials, processes and their interplay, which are relevant for the exploitation and protection of the geological values in Denmark and Greenland.

The sections below detail a number of important questions that arose through the investigations carried out by this Evaluation Panel, organised under three broad headings: planning, communication and integration and co-ordination. Each question is followed by an explanation of the view of the Panel and relevant recommendations for action in order to strengthen the research of GEUS.

7.2 Planning

"How are priorities set and then re-evaluated within the period of the Contract of Results?"

Currently this is based on existing information and science-based directions. New programme activities should be ranked first on the basis of governments priorities. For example, if government has a priority to make Greenland more self-sufficient through economic development strategies, then programmes should be designed to assist with this, by enhancing the opportunities for discovery of new resources. Secondly, new activities should be prioritised on the basis of exploration and development needs in Greenland. The basis for this would be a Greenland-wide resources assessment, as described above see Dept of Economic Geology section *). Finally, some programme activities should be science-driven. This three-fold approach would lead to enhanced geoscience databases, including geochemical surveys, geophysical data, new maps and reports and more refined metallogenic analyses.

Recommendation
A formal priority-setting procedure should be developed. Priorities should be set on the basis of government policies, an analysis of resource potential and the quality of scientific problems.

"How do you evaluate the amount of international work relative to national, and what areas should be strengthened in order to facilitate both?"

The Panel recognises that Programme Area 4 is involved in overseas development work and scientific investigations primarily in order to maintain its own staff capacity, and is impressed at the care with which decisions are made as to what overseas activities are taken on. The skills developed and applied to Greenland, and Denmark, activity should be looked upon as the commodities to be 'sold', but not at the cost of dilution of effort in Denmark and Greenland.

Work carried out in the international sphere, including foreign aid and infrastructure building, should capitalise on the existing strengths and research profiles in GEUS, applying these to other old shield areas, basalt provinces and rift zones, for example.

The Programme Area as a first priority needs to appoint staff in the general field of metamorphic geology, in economic geology, and in structural geology in the brittle domains in order to underpin its primary activity and allow it to cover the range of skills required both in Greenland and in overseas work.

Recommendation
The present strategies for decision-making on provision of assistance to third world countries within the broad area of mineral resources and institutional capacity building are continued, but that a well-defined limit is placed on the proportion of resource and activity directed to this end. We recommend a limit of 10% of activity, measured in terms of expenditure.

"How do you evaluate and assess the value of the work done relative to attracting industry or creating enhanced social value?"

Evaluation of past programme results may be a key factor in promoting the value of future work to funding agencies. The fundamental purpose of the Greenland programmes is to underpin economic development and social well being. The first is primarily to attract the mining industry to invest in exploration in Greenland, with the expected results of discovery and eventual production of base and precious metal deposits. Direct revenue through employment, and indirect through royalties, will provide a greater degree of self-sustainability for the local population. The second is to ensure the health and well being of the inhabitants, through avoidance of natural contaminants (generally heavy metals) in water and food supplies, for example.

Measuring the effect of economic development is relatively easy. Direct measures include the number of exploration leases granted the funds expended on exploration activities. In other constituencies, such as northern Canada, it has been found that at least twice as

much money is spent on exploration activities by the private sector as was spent by government on providing an enhanced geoscience data package to attract industry. Thus the expenditures are repaid to government through taxes and expenditures in the local communities. Over the longer term, the measures are less certain. Development of resources is a capital-intensive activity that generally involves investments of several orders of magnitude greater than the cost of geoscience surveys. Over the long term, about 90% of the gross value of the resource are returned to the community.

Measuring risk-reduction through geoscience work is more difficult. In a landmark study for the USGS, economic models were developed to assess the cost savings due to risk avoidance. However, such measures are specific for local conditions, and such an economic study would be required in both Greenland and Denmark, in order to accommodate local conditions. For example, in the US study, proper location of waste disposal sites ensured avoidance of groundwater contamination; this might be of significance to Denmark. In northern Canada, lake or stream geochemical studies enabled local residents to avoid consuming fish or using groundwater from lakes associated with high mercury sources (greenstone belts).

In general, the cost-benefit analysis of geoscience expenditures has always shown that the returns to government are, at a minimum, several times the expenditure. It is recommended that a system of measuring exploration expenditures be put in place following the release of each new major geoscientific study. Models for such studies are available for geological surveys in Canada and the US.

Recommendation
A formal attempt should be made to develop a method for assessing the economic impact of the GEUS programmes. This should be divided into impacts for exploration, and impacts for risk reduction and social well being. Consideration should be given to models developed by the USGS and the Geological Survey of Canada for this type of analysis.

Additional criteria for measuring the success or otherwise of research activities may include:

- Invitations to present keynote talks at international conferences
- Numbers of overseas research partnerships fostered and developed
- Citations of flagged ‘key’ papers
- Invitations to act as editors on international journals and other measures of international recognition

7.3 Staffing

"How can a staffing strategy be developed to cope with the changing conditions?"

The Panel recognises that the existing staff age profile poses problems for the retention of expertise and knowledge on the one hand, and for the effective fulfilment of the key goals of the Programme Area on the other.
Losses of retiring staff that will not be replaced with an overlap period allowed will potentially mean that a great deal of personal knowledge and intellectual capital may be lost. This can be alleviated by continuing the practice of re-appointing such staff on a part-time basis specifically for the task of documenting their knowledge in comprehensive reports coupled with metadata sets. A further step to ensure continuity of knowledge and maximise knowledge transfer would be to strategically assign staff to work with and learn from retiring staff over the final year of their service, a time when outstanding information and material should be collated and documented i.e. a form of Mentoring. It is recognised that this does happen within the Programme Area, but it occurs usually on the initiative of individuals rather than as a result of forward planning.

Recommendations
Implement a Mentoring system for knowledge transfer.

Of perhaps greater concern is the potential conflict between the need for experienced staff to facilitate institution building in the international component of the programme (e.g. in Ghana) and the need to appoint and train new, young staff to carry on and develop the field activities. Working overseas and Greenland/Denmark field programmes require people at different stages of their careers. There is a danger that as more senior staff members are diverted into overseas operations their expertise will not be as readily transferable to new staff. Given this caveat, we also recognise that experience gained in working internationally is both stimulating and enlightening and hence can add value to the Greenland programme.

The overseas development component of the programme should be carefully monitored so that it does not divert staff resource from the principal mission. We suggest that it occupies no more than 10% of overall staff commitment and no more than 20% of any individual scientific staff member's time over an evaluation period (i.e. 1 year in 5).

7.4 Communication

"How can GEUS improve communication with industry to attract investment in mineral prospecting?"

GEUS already does an outstanding job of informing industry about its work, primarily through the MINEX newsletter. This well-illustrated and informative publication provides descriptions of the highlights of new programmes, complete with pictures and diagrams of new data sets, publications and scientific discoveries. MINEX is comparable to AUSGeo, AGSO's publication of a similar type, and far exceeds anything provided by other geological surveys. So what can be done to enhance "market penetration" of GEUS results? Contin

ued presence with display booths at major industry meetings, such as the Prospectors and Developers meeting in Toronto, and the Roundup in Vancouver, is essential. Direct contact with exploration managers is probably the best remaining approach. This can be done in two ways. Direct e-mailing of MINEX to mining companies will ensure that it is available to the exploration decision makers. Also, organised visits to senior exploration managers by GEUS staff are encouraged. Such visits could be organised to coincide with the Roundup, for example, as Vancouver is the home of offices of most of the world's major mining companies. Companies with a history of arctic exploration should be the primary targets. Well illustrated presentations, with a handout including recent MINEX newsletters, data sheets describing recent geochemical and geophysical releases, descriptions of the regulatory framework in Greenland, contact numbers for offices and senior officials should be included. Consideration might be given to developing a CD with metadata, such as is done by AGSO sand the USGS.

Recommendation

GEUS should develop a strategy to visit senior managers of the major mining companies that either have had programmes in arctic regions, or have worldwide exploration strategies. Promotional material, including a metallogenic map of Greenland, and metadata descriptions of various products should be provided to industry at these visits. A long-term communications strategy directed towards the mining industry should also be developed.

What mechanisms need to be put in place to ensure that the highlights are transmitted to as wide an audience as possible as fast as possible?

The Panel recognises that measures have been put in place to advertise economic highlights to potential industry clients (e.g. MINEX), and also recognise that the excellent series of Reviews of Greenland Activities provide valuable insights into the main areas of research in Greenland. However, in the latter case the time lag between work being accomplished and new problems and exciting possibilities recognised, and publication of the Reviews may be more than a year.

In order to continue to attract collaborating researchers, improve the attractiveness of the Greenland activity to students, and further promote Greenland geoscience it is important to use as many avenues as possible to advertise these highlights more rapidly. A dynamic web page with updates on a regular basis, bringing news from the field essentially as it happens (as in Antarctic research programmes) and highlighting new discoveries within days or weeks of them being made would be a useful addition to the range of advertising / information distribution methods currently employed. Such public-oriented web-based information is often picked up by the more popular science magazines (e.g. New Scientist) and newspapers, to be used in broader articles that disseminate science messages worldwide. This mechanism would complement the superb public awareness programmes and leaflets produced by GEUS largely for Danish audiences.

Recommendations

GEUS resources the development and maintenance of public-oriented, dynamic and highlight-focussed web pages to complement the existing material on its website and present some of the content of what is being accomplished.

The GEUS web managers adopt and adapt the good features of sister websites such as those of the British Antarctic Survey and Australian Antarctic Division, organisations that use their sites for promotion / public awareness and professional communication.

7.5 Decision making

"How can links to decision makers at all levels of government be improved?"

Probably the most important "clients" for GEUS' work are its funding agencies. The Ministry of the Environment is its principal source of funds (National finance bill), with most of the remainder obtained from the Greenland Home Rule, with smaller amounts from the Research Councils. GEUS is administered by a board, and the day to day management is in the hands of a managing director and two deputy managing directors. The obligations of the Board and the directors are laid down in a constitution. The Board must ensure that the programme is relevant to Danish society and carried out at a high professional quality level.

For Greenland, GEUS' tasks are based on "Legislative governmental notice No. 368 dated 18 June 1998 on mineral resources in Greenland" and in the "Agreement between the Greenland Home Rule Government and the Danish Government on the administration of mineral resources in Greenland as of July 1, 1998" dated 8 January 1998. The director of the Bureau of Minerals and Petroleum represents the Greenland Home Rule Government in the board of GEUS. Besides mapping and research tasks GEUS operates the data-bank of Greenland, and supports the Bureau of Minerals and Petroleum under the Greenland Home Rule Government.

The programme is delivered under the "Contract of Results 2000-2003", a four year plan. GEUS tasks range from advising the minister, governmental institutions and other public authorities, to operative tasks as specified in legislation that are characteristic for national geological surveys, to professional tasks for private enterprises, and to carry out long-term research and development tasks. GEUS uses a contractual guidance concept, which is a combination of goals and economic framework. Specifics, outlined earlier in this report, are given for Programme 4.1 (regional mapping), 4.2 (mineral resources) and 4.3 (North Sea mapping). Some of the resources are reserved for long-term development of knowledge, while the remaining resources are used to discharge tasks outlined as a series of goals in the annual work plan described in "Contract of Results 2000-2003".

The plan is the basis for eventual programme evaluation. Accountability presently is measured largely in the publication output of GEUS (see "Contract of Results" Enclosure 1). The value of these published outputs is easily recognised by science managers and stakeholders, but less easily evaluated by non-technical administrators and politicians. The missing part of the current evaluation mechanism is a measure of impact of the result. As noted above Funding agencies, particularly those directly related to Parliament are usually impressed by information that measures the impact (or potential) impact of programme results. The problem with such measures of geoscience data is that the impacts must be

measured over many years following the release of results. Consequently, impacts are usually anecdotal and semi-quantitative at best. From time to time, GEUS might consider providing a succinct overview of the economic and societal benefits of its programmes, in an informative, well illustrated narrative. Frequent contacts with members of Parliament, field visits by local authorities such as members of the Greenland Home Rule Committee, invitations to senior managers of the funding agencies to visit the field operation all usually provide an opportunity to show the "value for money", and develop a culture of continuing (or even expanded) support for GEUS' work.

Recommendation
Develop a strategy for communicating with legislators and senior managers in both the Danish and Greenland Home Rule governments. This should include a plan for direct contact, as well as well-illustrated promotional literature and reports on the impacts of the various programme activities.

"How to mobilise industry stakeholders to develop and support your programmes objectives?"

External evaluation of GEUS work by stakeholders is usually valued by funding agencies, as it provides an independent, critical assessment of the value of past work, as well as guidance for future directions. For much of the Greenland work, and some of the Denmark programme, the target stakeholders are the resource development agencies; mining companies for Greenland, oil and gas industries for marine geoscience programmes, and industrial minerals companies. One mechanism that has been successfully used by other geological surveys, particularly in Canada and Australia, is to form an Industrial Advisory Committee. Its members typically serve a three year term, and are drawn from those industries that are active in the country, either presently or in the past. For Greenland, it might be useful to have a board drawn from mining companies with a tradition of Arctic exploration. While most of these are based in Canada, they all work internationally, and senior members (Vice Presidents or Chief Geologists) commonly serve on such boards in other countries. For the marine mapping and industrial minerals programmes, companies that use aggregates should be involved. In addition, stakeholders for Programme 3 (Energy Resources), drawn from the oil and gas industries should also be included.

The advantages to having such a committee include:

- The committee provides an independent review on an ongoing basis of the value of programme results
- The committee members would meet with the Minister of the Environment, to deliver a brief "report card", which usually would raise the profile of its work to the political level
- The committee could provide advice on future programme directions that would help encourage exploration activities, or underpin sustainable development of aggregates, for example.
- The members of the committee would become more aware of the valuable work done by GEUS. These people in turn could become informal 'ambassadors" for the programme, hopefully attracting more industrial investment in Greenland, in particular.

The committee could meet twice a year, usually for a two-day period, when it would receive presentations on current activities, and interact with staff in planning future projects.

Recommendation
Institute an industrial advisory committee. This committee should answer to the Minister of the Environment, thereby ensuring access to the most senior government managers.

7.6 Programme delivery

"Is there a plan to create a complete metadata referencing system for Greenland and Denmark?"

We recognise that digitised databases are available, being developed and/or being considered for geophysical data (aeromagnetics, gravity), and geochemical data (e.g. stream sediment, lithogeochemistry), and applaud the efforts and imagination of the Economic Geology department in initiating and developing this approach to a high level.
It is also apparent that digital databases are being built in the Mapping Department, including the database on the glossary of Greenland stratigraphy and literature, digitised map series, digital structural and geological information in current mapping work, and (potentially?) with isotopic data. It is not clear to the evaluators whether all these activities are being effectively coordinated and whether a common and shared knowledge base is being developed by strategy or by chance.

Recommendation
The policy and methodology currently in use by the Economic Geology Department should be employed throughout GEUS in database development, and that a procedure is established for ensuring consistency of approach to metadata referencing and database management across the whole Programme and indeed GEUS. This procedure and code of good practice should be supported by training days, explanatory manuals, and seminars.

7.7 Programme evaluation and strengthening

Strategy and organisation

"Is the present structure of departments and programmes optimal?"

Relation between departments and matrix structure
A matrix organisation is used in the daily work by the management. Budgets and priorities are set according to the individual programme area, but resource management is carried out by the individual departments. The individual department managers decide how each department shall perform, according to the work programme for the project area. The departments do not have individual planning and performance strategies.

Some (e.g. Greenland Mapping) prepare a departmental strategy on their own initiative.

Recommendation
The Panel recommends that each department prepare an annual departmental strategy paper, describing aims, staffing situation, resource allocation and action plans.

Co-ordination between departments across the matrix structure are not perfect, some examples are:

- Geophysics Dept: does not co-ordinate activities with the geophysics carried out at the Dept. of Economic Geology
- Geochemistry Dept: does not co-ordinate with the Dept. of Economic Geology
- Greenland activities at the Dept. of Stratigraphy: these are not co-ordinated with Programme Area 4, as these deal with oil/gas
- Geophysics in the Dept. of Quaternary Geology is not co-ordinated with the Geophysical Dept.

The Department of Geological Mapping has identified a number of areas, which may generate income to support the department's main mission. These seem; however, to be more related to other departments:

- Heavy minerals analyses (Economic Geology, Quaternary Geology)
- Dimension stone and industrial minerals in Greenland (Economic Geology, Quaternary Geology)
- Provenance studies for oil companies
- Environment (Quaternary Geology, Hydrology)

The Department of Quaternary deals with raw materials which, of course, are not of Quaternary origin. Other departments work with the same rock, but in other settings (e.g. chalk as oil reservoir).

The present matrix organisation links the GEUS overall strategy to the departments in a cross-functional and interdisciplinary manner. This seems logical, but not totally optimal as the responsibilities of the departments themselves may be ambiguous.

Recommendation
GEUS management should consider a revision of the departmental structure better reflecting the GEUS strategies and work being carried out.

Project management
The department managers are project owners, and are responsible for overseeing the projects, including milestones. Day-to-day project administration is carried out by the department secretaries in co-operation with project managers. GEUS carries out a project manager education scheme. It is the intention that 30% of all employees shall have passed a project manager course by 2003. There are mixed opinions on the value of these courses. GEUS also uses a number of project management tools. In spite of the management scheme and use of these tools, it seems that some projects are not completed on

time. The workloads of the GEUS employees are however, high. The reason for this apparently low project efficiency is, according to one interview that project managers perform more work than is asked for and paid for. Increasing the project efficiency by avoiding "overkill" may be one way of maintaining or increasing GEUS activity level in spite of the reduced funding.

Recommendation
Improve project management by improving the already existing project structure, e.g. by applying Coopers "stage-gate" method combined with an improved project management "on-the-job" training and motivation.

"Do the Danish activities fit into Programme Area 4 - are there any interactions?"

The Programme Area 4 has somewhat successfully linked the departments of Economic Geology and Mapping. However there is little synergy between the Greenland and Denmark work (except heavy minerals in Denmark, presently is on hold). The Danish activities in Programme Area 4 is strongly related not only to Programme Area 5 (mapping, groundwater, environmental impacts), but also to other disciplines such as coastal engineering, biology (geological habitat mapping), geography (geomorphology), agricultural science, hydraulic engineering, environment and social science. For example, the effects of sea-level change may become an important research area in the future where geologists must interact with other disciplines.

Recommendation
Create a new programme area dealing with sustainable use of natural resources and geo-environmental matters in Denmark (including basic geological mapping). This could be done by merging the Denmark activities in Programme Area 4 with Programme Area 5; perhaps including elements from Programme Area 2 (see also the section on the Department of Quaternary Geology).

Project planning and execution

"How can integration and co-ordination between Mapping and Economic Geology Departments at GEUS be improved?"

Whilst the Panel recognises that important steps have been taken to achieve integration and co-ordination between the Mapping and Economic Geology departments, it is also apparent that there still scope for improvement in the ways in which the two departments interact and integrate on research projects. Firstly, workers who should liaise more on areas of common interest do not appear to do so in a systematic fashion. Secondly, there does not appear to be a managed 'loop' in the mapping cycle that actively promotes the consideration and integration of economic perspectives and data. This gap needs to be addressed, and future products actively assessed for their 'value added' in terms of not only providing excellent geological data and syntheses but also in-depth analysis of resource potential. Thirdly, there also appear to be cases where the Economic Geology workers do not fully or effectively utilise existing geological knowledge.

Within GEUS

The Panel recognises that interdepartmental seminars and workshops do occur, generally on an occasional basis. We consider that these should be fostered and that an agreed programme of monthly seminars and annual or semi-annual workshops, with compulsory attendance, be instituted within Programme Area 4 in order to facilitate more exchange of ideas and approaches on areas / regions of common interest.

Thematic workshops, such as the recent Ketilidian workshop, should become a regular feature of the research environment. Staff development and education in each other's techniques and approaches should be fostered through annual or semi-annual Skills workshops that complement Thematic workshops (e.g. Principles and applications of aeromagnetics, geochemical sampling, and structural analysis).

Recommendation

Introduce regular monthly Research in Progress seminars and annual / semi-annual Thematic and Skills workshops within the Programme Area and open, attendance to all groups within the new Geocentre.

Within the timescale and operation of individual field mapping activities

All field programmes should obtain advice and input in the planning stage from the economic geology group as to what contribution geochemistry and geophysics might make; conversely, all targeted economic geology programmes should consider how mapping might help at the initial planning stage. Whilst this process has been happening in some recent field activities, largely on the initiative of individual scientists, a more formalised consultation process is necessary to ensure optimised use of the vast data resource that GEUS has available.

Recommendations

All field project proposals submitted to the management team should include clear evidence that consultation with other groups in the Programme Area has taken place during planning and specific statements as to how existing data sets will be used and/or enhanced.

The modes of operation and structures of the field programmes are modified to include a significant period (up to one year?) of reflection and synthesis, pooling together geological, geophysical and geochemical data, prior to any final field season.

This may require adoption of a 2 year on - one year off - one year on field model. This reflection/synthesis/evaluation phase should involve, at the very least, collaborative assessment of geology plus geophysics plus geochemistry; each of these aspects should have been covered for the area under study in one or both of the early field seasons. The final season in a four-year cycle would include targeted mapping / sampling that uses and tests the synthesised data sets.

"Within the "Greenland Minerals Programme", how can integration and co-ordination between the geochemistry, geophysics and mineral deposit modelling components be improved?"

Just as there is room for improvement in co-ordination and reporting between the mapping and economic geology groups, discussed above, there is a need to more tightly integrate the projects undertaken by the geophysics and geochemical surveys with those of the mineral deposits research group. The work carried out in Greenland has been summarised as "Regional Mineral Resource Assessment", and in general, it has accomplished this well. There appears to be a very robust effort to collect information, but the follow-up could be improved. The metallogenic work is done somewhat in isolation of the other parts of the mineral exploration - related programmes. For example, there is an opportunity for much better integration of the geochemical programme with the metallogenic (as well as regional mapping) projects. Interpretation of the extensive stream sediment and geophysical surveys (including some of the more "experimental" geophysical work using hyperspectral reflectance) would be more robust if it involved more input from the mineral deposits specialists. When interpreting the remote sensing and geochemical results, there is a need to consider a broad range of geological models, applying geochemical results in the more innovative way, combining geophysics and geology tools to asses the potential for non-traditional (in the Greenland context) or unexpected ore deposit types, as well as for established deposit types.

For example combinations of elements specific to certain ore deposit types, such as copper – gold – cobalt– rare earth – uranium anomalies may indicate the presence of copper-gold-oxide (Olympic Dam) type deposits. The geochemical surveys might look for indirect indicators of PGE mineralisation, to identify possible magmatic- PGE-Ni-Cu potential. This could best be don e by obtaining advice from the mineral deposits specialist for magmatic Ni-Cu-PGE deposits. Heavy mineral data might work well for other deposit types. For example, gahnite may indicate the potential for BHT or VMS deposits; both are common in similar geological settings in the Canadian arctic.

In future, project planning and interpretation should be undertaken by multi-disciplinary teams, drawn from the metallogenists as well as the geochemical and geophysical specialists. As part of the summary of results of these projects, an assessment of resource potential should consider a broad range of ore deposit types. These summaries could then be published in MINEX to attract industry to spend exploration resources in Greenland.

Recommendation

(See also Department of Economic Geology, (5) Integrated science, above). As part of the project planning process, as well as in the project interpretation and publication stage, multi-disciplinary input should be obtained on all geochemical and geophysical programmes. Regional mapping and mineral deposits specialists should be asked to review the data and make recommendations for potential ore deposit types in the area. Also, these specialists should provide succinct reviews of the various occurrences and their geological attributes.

Interaction with external stakeholders

"Is there a need for better co-ordination with the Greenland home rule Bureau of Minerals and Petroleum - who is responsible for prospect level documentation versus metallogenic research?"

While the administrative framework for GEUS' programme delivery in Greenland is clear, the level of interaction at the working level is less so. The Greenland Home Rule Office maintains a staff of geologists in Nuuk, whose responsibility it is to advise on land use, permitting, and to maintain an overview of exploration-related activities in Greenland. These geologists do site visits and collect information on mineral occurrences. The GEUS research scientists, and in particular, the mineral deposits specialists, undertake process-related research on specific aspects of the metallogeny of Greenland. The level of interaction between the Home Rule geologists and the GEUS research scientists is not clear. The formers are, in many ways, similar to the district geologists in the regional offices of various Provinces in Canada or States in Australia. These geologists give advice to prospectors and exploration companies, undertake site visits from which a permanent record of the geology of occurrences, as well as the exploration results, are obtained, and can be the "promoters" for exploration activity in Greenland. They also provide input into planning of future activities. The researchers, by ensuring good communication with the Home Rule Office geologists, could benefit by being drawn to new opportunities for research that would have immediate relevancy. Such targeted research results might be of more use to industry on the short term, compared with the present activities, which although are of top quality, may lack immediate relevancy for exploration companies.

Recommendation

Greenland Home Rule geologists should be formally mentored by GEUS regional and mineral; deposits geologists, and should be encouraged to prepare high-quality reports on discoveries and prospects in their respective regions.

"What is the nature of the relationship between GEUS and DLC, and how will this evolve over the next 5 years?"

The DLC is running out of funding in the next 3-4 years. GEUS will not take over all staff and the DLC wholesale, but staff will be able to apply for advertised posts and projects. DLC has not had a uniformly positive record of collaboration with the Geology Department of the University or with GEUS, although former DLC staff members are now employed in GEUS.

"How can the relationship between GEUS and the higher education sector in Denmark be improved and how should the roles be defined?"

19 PhD students at Danish Universities are GEUS-related, and GEUS operates a Masters' programme for 45 students. The main fields of interest for these students are climate research, groundwater and pesticides, biology; students in lithosphere / mapping are rare. There is considerable room for improvement - GEUS has data but needs people to work on it and conduct new research. Cohabitation at the new Geocentre will improve this situation.

GEUS is involved in several graduate research schools, but hard rock did not obtain funding in this regard.

Recommendations
A 2 season lead-in period (e.g. advertise in 2002 for field projects running in 2004) should be adopted for attracting students to projects involving GEUS.

GEUS Programme Area 4 should implement a summer scholarship / prize / bursary programme for mid-term students to provide them with insight into GEUS activities, and then advertise 'forthcoming projects' at least a year before they are due to begin. This would enable students to plan ahead, take time to consider the opportunity, and approach it with some inside knowledge of GEUS (through short-term holiday bursaries). The Panel notes that the Programme Area has already taken action on this recommendation.

A two-season lead time in advertising and soliciting expressions of interest is provided by GEUS in order to involve the highest calibre external collaborators. This is compatible with the timescale needed in order to obtain and place funds, attract students, and gain leave from research institutes.

"How can co-ordination between GEUS, the Counties and the Forest and Nature Directorate be improved - does it require a change in legislation?"

It is the impression of the panel that there is good co-ordination between the Forest and Nature Directorate and GEUS. Co-ordination with counties is more difficult, as responsibility for raw materials at land are assigned to the individual counties. It is hardly realistic to expect that this responsibility will be transferred to another government body in the present situation.

"Can there be better integration of the laboratories between and within GEUS, DLC and the University?"

There is an agreement as to which items are joint and which belong solely to GEUS. Joint laboratories and equipment can be accessed by all staff and members of the Geocentre, with operational cost payments being made where appropriate.

The laboratories are organised in different departments, but the reason for this is not always clear, as the skills are used in other departments. The panel has considered whether it would be advantageous to created a "material characterisation centre" and create a larger critical mass of competent staff? The panel considers, however, that the move to the Geocentre will achieve much improved integration between the laboratories.