An integrated approach to mineral exploration and environmental assessment in southern and eastern Africa - a pilot study in Tanzania

Report on the project supported by the Danish Council for Development Research (RUF project number 90953)


Village in the Mpanda area, West Tanzania
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Summary

The pilot project An integrated approach to mineral exploration and environmental assessment in southern and eastern Africa, has been very successful scientifically and has furthermore developed good, durable co-working relationships with partners in Tanzania, University of Dar es Salaam and Geological Survey of Tanzania. An international network of researchers has been focused on the Ubendian Mobile Belt in Tanzania.

During the project all existing geoscience data from the Ubendian mobile belt of South-West Tanzania were compiled and evaluated. The results are compiled in GIS ArcView 3.2, and will be made available on CD-ROM.

Fieldwork was carried out in two areas, Lupa goldfield and Mpanda Mineral Field in South-West Tanzania. The fieldwork focused on regional and detailed geologic studies especially concerning the origin of the gold-bearing quartz reefs, which are exploited extensively by small-scale (artisanal) miners. A better understanding of the origin of the gold in the quartz-reefs will help find new reefs, which will be of benefit to the community and local enterprise.

The other part of the fieldwork was concerned with environmental aspects and sought to localise and deliniate the extent of heavy metal pollution in the drainage system from previous copper-lead mining and from the extensive use of mercury to extract gold by amalgamation. Heavy metals were traced downstream from an old copper-lead mine. Several of the ‘amalgamists’ had very high contents of mercury in their hair, and the mercury was also detected in the drainage system. The amalgamation process is, however, not the only source for the mercury pollution; imported soaps with up to 2% mercury also contribute to the pollution of humans and the drainage systems. A special report on ‘Mercury in soap in Tanzania’ has been published.

Future projects are listed in the recommendations of this report. Two joint research projects have already started within the pilot project:

1. A joint project between University of Dar es Salaam, GEUS, and University of Oulu concerning an investigation of an eclogite, depicted by garnet composition and zonation, is well under preparation and will be presented at a conference in Austria in April 2000.

2. Lead isotope studies carried out in Copenhagen in co-operation with Professor R. Frey (Geological Institute, University of Copenhagen) on samples collected by the field team in the Mpanda area have yielded important new information concerning the timing and the origin of the gold mineralisations. In the Lupa Goldfield area the gold mineralisation is related to the granitoid c. 1960 Ma, but Pb-Pb-isotope data indicate a younger age of the granitoids than anticipated. In the Mpanda Mineral Field the mineralisations are all related to younger processes, contemporaneous with the intrusion of the carbonatite (722±43 Ma). These results have significant implications for future gold exploration.
Interlaboratory comparison has been carried out by analysing the same samples at two laboratories in Tanzania and a commercial laboratory in Canada. This study revealed that the two laboratories in Tanzania found gold in samples, which are believed to be barren.

Based on the success of the pilot project it has been decided to apply for funding for two projects and one pilot project to be co-ordinated and carried out within the same project area:

1. A four year research project, which will be sought financed by RUF, Danish Ministry of Foreign Affairs, within geological and environmental sciences carried out jointly by geologists and biologists from University of Dar es Salaam, Geological Survey of Tanzania, Geological Survey of Denmark and Greenland (GEUS), and National Environmental Research Institute (NERI).

2. An educational programme, which will be sought financed by ENRECA, Danish Ministry of Foreign Affairs, initially for a period of three years. It is intended to up-grade eighteen Bachelors of Science to Masters of Science and three to four Masters to Ph. D. within geological and environmental sciences. The student training projects will be integrated into the science project.

3. A pilot project within socio-economic sciences will be carried out, provided RUF funding can be obtained. This pilot project will investigate economic, cultural, demographic and socio-environmental relations which have been identified as relevant themes to explore: organisation of mining activities, labour force and its origin, as well as relations to alternative land use, livelihoods, and tenure arrangements are examples of issues in question.
Introduction

About this report

This report is the final report for the Danish Council for Development Research (RUF) project no 90953, handed in to RUF at the successful conclusion of the pilot project in Tanzania in February – March 2000.

The report must serve as part of the required documentation for the activities and results of the pilot project. For that reason rather detailed information has been included in the twelve appendices. The main part of the report, the first 45 pages, contains similar information, but in an abbreviated form, which will give a good overview of the pilot project, its objectives, activities and results. However, for a full and detailed understanding, it may in some cases be necessary to consult the appendices.

Figures and tables of the main text and the first eleven appendices have been numbered consecutively. The ‘References’ section includes all references in the main text and in the appendices.

The content of the report reflects the situation as it was at the time of printing mid February. Some activities will, however, continue until final publication has taken place. The continuation of some of the activities will depend on funding being achieved.

The pilot project

The pilot project: An integrated approach to mineral exploration and environmental assessment in southern and eastern Africa - a pilot study in Tanzania, hereafter named the pilot project, was initiated by the Geological Survey of Denmark and Greenland (GEUS) early 1999. It is a joint project involving co-operation between GEUS, lead agency, the National Environmental Research Institute (NERI), the Geological Survey of Tanzania (GST) and the Department of Geology, University of Dar es Salaam (DGUDES). The Danish Council for Development Research (RUF) finances the pilot project for the period 1st June 1999 to 15th March 2000 under the Danish Ministry of Foreign Affairs.

The initial one-year pilot project reported here encompassed the following activities:

- The compilation and integrated evaluation of existing geoscience and environmental data from a study area suggested by Tanzanian collaborators, in co-operation with partners in Tanzania.

- Four weeks of fieldwork in the study area to follow-up on conclusions from the initial evaluation and to investigate general geology, mineralisation patterns, and environ
Figure 1. *Field area, South-West Tanzania, indicated by red rectangle*
mental indicators. Personnel from GEUS and NERI were involved in the fieldwork in close co-operation with participants from the Geological Survey of Tanzania and the University of Dar es Salaam.

- The compilation and interpretation of results from the fieldwork, again in co-operation with contacts in Tanzania. Production of prototypes of GIS databases with data relevant for use of authorities in Tanzania, of interest for mining companies and for further research. Publication of new data and results of the work will be undertaken. Preparations for incorporation of socio-economical issues in the main project.

- The formulation of research plans for a main project, subject to a successful outcome of the pilot project.

- The development of good, durable co-working relationships with partners in Tanzania and internationally.

During 11 to 14 June 1999 a planning seminar was held in Copenhagen with the following participants:

Peter Appel (PA), GEUS Geological Survey of Denmark and Greenland
Gert Asmund (GA) NERI National Environmental Research Institute
Christian Glahder (CG) NERI
Sospeter Muhongo (SM) DGUDES Department of Geology, University of Dar es Salaam
Faustin Petro (FP) GST Geological Survey of Tanzania
Henrik Stendal (HS) GEUS
Leif Thorning (LT) GEUS
Tapani Tukiainen (TT) GEUS

During the planning seminar it was discussed where in Tanzania the activities of the pilot project should take place. Two areas were discussed, the area south of Lake Victoria and the Ubendian Mobile Belt along the east shore of Lake Tanganyika. Based on recommendations from SM and FP it was decided that the Ubendian of Soth-West Tanzania was the best area for the project (Fig. 1). The broad geological picture of the Ubendian is known, but not in any detail. The area also hosts numerous auriferous quartz reefs as well as a significant copper-lead deposit. The area thus offers ample opportunities for joint research projects within various fields of geology ranging from regional geology to detailed ore geology and isotope geochemistry.

In the area extensive small-scale mining for gold takes place. The small-scale miners use mercury to extract the gold. The mercury is not recycled and is therefore a major hazard to the environment and to the health of the local population. There are thus important fields within environmental sciences for joint research projects between Danish and Tanzanian scientists.

During the planning seminar it was also decided that TT should travel to Tanzania to gather as much digital data and information as possible. Appendix 1 contains a full summary of the issues discussed at the planning seminar.
Compilation and evaluation of existing data

(T. Tukiainen & T. M. Rasmussen)

Tapani Tukiainen from GEUS visited GST in Dodoma and various offices, including SEAMIC in Dar es Salaam during one week in early July. During the visit he collected all available satellite data and topographic maps from the Ubendian region, especially the Chunya and Mpanda areas. The acquired data have been compiled in a project GIS database and will be presented on a CD-ROM. The compiled spatial data are formatted for use in ArcView 3.2. The data set consists of GeoTiff, ArcView grid and shape files. Additional details are given in Appendix 5.

The data is in the UTM projection now typically used in the area; the following projection parameters have been used:

- UTM Zone: 36
- Spheroid: Clarke 1880
- Unit: Metre
- Meridian of Origin: 33° East of Greenwich
- Latitude of Origin: Equator
- Scale Factor at origin: 0.9996
- False Easting: 500 000 m
- False Northing: 10 000 000 m

Georeferencing of the data sets is based on the scanned unstable hardcopies of the topographic base maps. Consequently the positional accuracy is of reconnaissance character.

Topographic data

The cartographic base for the project consists of 37 topographic maps at scale 1:50 000 (Published by the Surveys and Mapping Division, Ministry of Lands, Housing and Urban Development, Government of the United Republic of Tanzania). The maps were scanned (B/W) and georeferenced and resampled to conform the original map projection using the method of ‘nearest neighbour’. The scanning of paper hardcopies typically introduces a registration error, and the order of magnitude appears in this case to be ±10-20 meters. This can be observed along some map sheet boundaries.

Satellite image data

The Landsat TM image data are compiled from four standard Landsat TM scenes made available by the Geological Survey of Tanzania. The Landsat TM image data was geomet-
rically corrected to conform to the project map projection; registration control points were selected from the topographic base maps.

The GIS database furthermore contains the Landsat TM bands 1,2,3,4,5 and 7, false colour composite of TM-bands 4(R), 3(G), 2(B) and Normalised Difference Vegetation Index NDVI calculated from the Landsat TM data. Processing details can be found in Appendix 5.

**Geological maps**

Six published 1: 125 000 scale geological maps (Quater Degree Sheets) three from the Mpanda area (Karema 169W, Mpanda 153, and Sitalike 170) and three from the Chunya area (Makongolosi 228, Shoga 229, and Mbeya 244 – former 70S.W.) covering the field areas of the project, were scanned (in colour) and georeferenced and resampled to conform to the project map projection. The map sheet Nkamba, which is available only as a poor hand coloured copy, was not scanned. Because of the poor quality and accuracy of the older topographic maps used as base of the published geology, vectorisation of the geological maps was considered of marginal value and it was decided not to do this in the pilot project. The geological maps are published by the Government of Tanzania but through time by various groups such as 1) The Geological Survey of Tanganyika, 2) Mineral Resources Division, Tanzania, and 3) V/O Technoexport Moscow, Geological Survey of Tanzania.

**Mineral occurrences**

This data set originates from GST and contains selected mineral occurrences based on the compilations by the Soviet/Russian investigators (V/O Technoexport, Moscow) and the published geological maps. The positional accuracy of data seems to be of poor and variable quality.

**Sample Locations**

The positions of the rock samples collected for this project have been included in the GIS database (Table 6 and Figs. 15-18).

**Airborne magnetic data**

Magnetic data are available from an airborne survey that was carried out by Geosurvey International G.m.b.h. in the mid 1970-ies. The survey includes a complete coverage of the continental part of Tanzania and an offshore part in the vicinity of Zanzibar. Nominal line spacing for this survey was 1000 m and a flight altitude of 120 m above ground level was
used. The measurements were carried out using a Geometrics G803 precession magnetometer and the sampling distance was 50 m (Full country package of grids and line data available on CD-ROM e.g. by agreement with African Geoscience of Verona Holdings Ltd).

Apart from map sheets 169W and 187, data from the project area were available in digital form as point data from the area covered in the present project. Therefore, maps with contours of the magnetic field from map sheets 169W and 187 have been digitised. The contour interval of the original maps is 10 nT and the data are referred to the magnetic Epoch of January 1 1977.

Data ordered in a regular grid has been made from the digitised magnetic contours from all map sheets of the project area by Thorkild Mack Rasmussen. A minimum curvature algorithm was used for the interpolation to produce 500 metres by 500 metres grid of total magnetic intensity.
Fieldwork in the Ubendian Mobile Belt, South-West Tanzania

(P. W. U. Appel)

On 8th September CG and HS flew to Tanzania, PA arrived a few days later on 13th September. CG spent some days in Dar es Salaam visiting departments at the University of Dar es Salaam, ministries, the Danish embassy, NGO-organisations, travel agencies etc. (Appendix 11). HS worked at the Geological Survey of Tanzania (GST) in Dodoma and presented the project to the Assistant Commissioner for Mineral Resources P. M. Kenyunko (Director of GST). HS handed in six test samples for analyses at GST and SEAMIC. These tests resulted in a positive dialogue with the two analytical laboratories and lead to some changes in the analytical procedure for our field samples.

The field team consisted of Sospeter Muhongo, Said Mnali, Faustin Petro, E. Brian Temu, Peter Appel, Christian Glahder, Henrik Stendal and four drivers (Figure 2).

Field work started mid-September in the Chunya area North of Mbeya, in the literature called the Lupa Goldfield, where the field team was introduced to District Commissioner Clemence F. Mbwali who was very interested in the pilot project, and asked to receive a copy of the final report. A more detailed description of the fieldwork is presented in Appendix 2. A day by day account of the geological observations has also been prepared by HS, but is not included in this report (Diary – Tanzania – September/October 1999).

Figure 2. Field team in Chunya
The fieldwork comprised studies and sampling of a number of gold reefs and their host rocks. Several small-scale (artisanal) mining sites were investigated. The small-scale gold miners use mercury to extract gold from the ore (amalgamation) by a method described in Appendix 3. The mercury used in extracting the gold is usually not recycled, but evaporates during the amalgamation process. According to the District Commissioner in Chunya, an estimated 60 kg mercury is "lost" to the environment per month in the Lupa Goldfield during the peak gold mining season! For further details see section 7 and Appendix 7.

On the 24th September fieldwork started in the Mpanda Mineral Field. The work in this field area was carried out similarly to the work in the Lupa Goldfield and a more detailed account is included in Appendix 2. Furthermore, one day was spent on a site with an eclogite showing between Mpanda and Karema. The eclogite was sampled and a research programme directed towards a detailed understanding of the eclogite has been carried out at the University of Dar es Salaam, University of Oulo, Finland, and GEUS. Appendix 12 contains the GEUS part of the preliminary manuscript on the eclogite study.

Finally, EBT, FP, and HS carried out limited fieldwork in the Karema-Ikola-Kipili area at the shore of Lake Tanganyika.

The field team members held a meeting in Mpanda on the 27th September to discuss the continuation of the main project. During this meeting it was also discussed and in general terms decided, how the present report should be written. At the meeting it was decided that all participants of the fieldwork should be listed as authors of the final report, and that the principle author(s) should be shown at the beginning of each chapter when appropriate. Suggestions for the future continuation of the joint project were outlined. A full summary of the meeting is enclosed in Appendix 4.

PA presented a lecture (9th October) entitled: Geology and Mineral Resources of Greenland, at the Department of Geology, University of Dar es Salaam. Before departure from Dar es Salaam PA, CG and SM had meetings with vice-chancellor Professor Mathew Luhanga and with Professor Idris S. Kikula, Director of Research and Publications at the University of Dar es Salaam. Prof. I. S. Kikula wrote a letter of support for future research and educational programmes carried out by Danish and Tanzanian research institutes and Universities in the manner suggested for the continuation of the project (Appendix 10).

HS stayed at GST in Dodoma from the 9th – 14th of October and took care of the samples for thin sections and analyses. In addition, meetings with the GST staff concerning preparation and discussion of the future co-operation. In Dar es Salaam (14th-19th of October) HS took care of the samples for thin sections made by the Department of Geology, University of Dar es Salaam and the discussion of the preparation of samples for analyses with SEAMIC.
Geology of the Ubendian belt

(S. Muhongo, S. Mnali, F. Petro, E. B. Temu)

Introduction
The NW-SE trending Palaeoproterozoic Ubendian belt of east and central Africa (Fig.3) was first recognized and defined by McConnel (1950). It is over 600 km long and up to 200 km wide, extending from eastern Congo to northern Malawi via SW Tanzania (Fig.3). On its north, the Ubendian belt separates the Archaean Tanzania and Congo cratons. Thus, it is possible that this belt developed on Archaean crust that connected these two cratons. It is, in its north, overlain with an angular unconformity by Mesoproterozoic rocks of the Karagwe - Ankolean (Kibaran) Supergroup and nonconformably by the Neoproterozoic rocks of the Bukoban Supergroup of western Tanzania. The Ubendian belt merges with the NE-SW trending Palaeoproterozoic Usagaran belt on its southern margin producing E-W trending tectonic fabrics (Fig. 3). These two belts are considered to be equivalent in age and are thus coeval (Priem et al., 1979).

McConnell (1950, 1972), Sutton et al. (1954) and subsequent workers recognised the high-grade metamorphism (reaching granulite grade) and intense deformation within the belt. The belt is made up of distinct structural blocks or terrains persistently trending NW-SE; each separated by a ductile shear zone up to 600 km in length. Most shear zones show a NW-dextral strike - slip displacement. The parallelism of the Ubendian structures and the Phanerozoic rift faults (McConnell, 1972; 1980) suggest that the Ubendian belt was intensely reactivated during the Phanerozoic taphrogenesis and in the subsequent formation of the Cenozoic East African Rift System.

Geological Setting
The high grade Palaeoproterozoic Ubendian belt defines the W and SW margin of the Archaean Tanzania craton (Fig. 4). McConnell (1950) and Sutton et al. (1954) recognised that the high grade Ubendian belt is made up of several lithologically and structurally distinct blocks or terrains which are strongly elongated in a NW-SE direction and laterally persistent up to 200 km. Sutton et al. (1954) argued that the persistent NW-SE trending structural pattern shown by the blocks making up the Ubendian belt suggest a single evolution scheme for all of them. Smirnov et al. (1973), UNESCO (1983), Daly et al. (1985) and Daly (1988) have defined eight lithotectonic terrains with the belt (Fig. 4). The salient geological characteristics of the eight blocks are summarised in Table 1 below.
Table 1.  *Salient geological characteristics of the Ubendian terrains (modified after Daly, 1988)*

<table>
<thead>
<tr>
<th>TERRAIN</th>
<th>DOMINANT LITHOLOGY</th>
<th>LINEATION TREND</th>
</tr>
</thead>
<tbody>
<tr>
<td>KATUMA (MBOZI)</td>
<td>gneiss, migmatites, quartzites ± granulite, ± metabasite.</td>
<td>NE - SW</td>
</tr>
<tr>
<td>IKULU</td>
<td>gneiss, granulite, ± eclogite</td>
<td>NW - SE</td>
</tr>
<tr>
<td>UBENDE</td>
<td>amphibolite, gneiss, meta-basites</td>
<td>ENE - WSW</td>
</tr>
<tr>
<td>WAKOLE (WANSISI)</td>
<td>schists rich in aluminosilicates</td>
<td>NW - SE</td>
</tr>
<tr>
<td>UFIPA</td>
<td>granitic gneiss</td>
<td>NW - SE</td>
</tr>
<tr>
<td>NYIKA</td>
<td>granulite (cordierite - bearing)</td>
<td>E - W</td>
</tr>
<tr>
<td>UPANGWA</td>
<td>meta-anorthosite</td>
<td>NW - SE</td>
</tr>
<tr>
<td>LUPA</td>
<td>meta-volcanics, granite, granitic gneiss</td>
<td>NW - SE</td>
</tr>
</tbody>
</table>

In the southern part of the Ubendian belt (i.e. south of 07° 30’ S and east of 30° 35’ E, Fig. 5), a late Palaeoproterozoic plutono - volcanic (Kate - Kipili) complex are ubiquitous. These volcanics which are discordantly overlying the Ubendian gneisses are intruded by granites (UNESCO, 1983). The effect of the NW - SE trending Ubendian shears can be traced in this plutono - volcanic complex. Neoproterozoic granites and syenites are also found in the ductile - brittle shear zones in this part of the belt (Theunnissen et al., 1992; Lenoir et al., 1994).

**Tectonometamorphic evolution**

The Ubendian belt is characterized by the persistent NW and NNW - trending fabrics and long shear zones marking the boundaries between the terrains that make up the orogen. It is also characterized by the ubiquitous S - L and S - C fabrics that can be traced in all of its eight lithotectonic terrains. These terrains are bounded by steep shear zones or faults that are parallel to the strike of the orogen. Another evidence for intense deformation in the orogen is the presence of abundant mylonites, especially within the contact zone between adjacent terrains. These mylonites show different degrees of deformation within and at the margins of the terrains, e.g. occurrences of blastomylonites and ultramylonites. Thus, the Ubendian terrains are heterogeneously deformed, and this is in part due to the different rheologies of the constituting rocks and variations in strain patterns within the orogen. Sutton et al. (1954) considered the Ubendian belt to be a deep-seated zone of strike - slip displacement.

Granulite - facies metamorphism in the Ubendian belt was first described by Sutton et al. (1954). Subsequent workers, e.g. Smirnov et al. (1973) and UNESCO (1983) have also documented granulite facies rocks in the orogen. Boven et al. (1999) have recently reported on the P-T data of the high grade rocks, including eclogites, from the Ubendian belt. UNESCO (1983) found out that the granulite - facies metamorphism in the Ikulu and Wakole/Wansisi is associated with the E - W trending recumbent folds. The intense deformation that brought about NW- and a NNW- trending fabric is associated with the amphibolite
Figure 3. Major Precambrian geotectonic units and structural trends in eastern and central Africa. TC = Archaean Tanzania Craton, UB = Ubendian Belt, US = Usagaran Belt, Bb = Bangweulu Block, Kb = Kibaran Belt, Ir = Irumide Belt, MB = Mozambique Belt, LA = Lufilian Arc, LT = Lake Tanganyika, LV = Lake Victoria, LR = Lake Rukwa, LM = Lake Malawi, L = Other Lakes (Modified after Lenoir et al., 1994).
Fig. 4: Sketch map of the Ubendian terranes and their bounding shear zones.

Figure 4. Sketch map of the Ubendian terrains and their bounding shear zones.
- facies metamorphism. Thus, this metamorphic event which is dominant in the Ubendian belt, was associated with thrusting and shearing, and accretion of the terrains. It was during this event that the older recumbent and isoclinal folds and concomitant S-L fabrics were refolded into upright and reclined folds generating new S-L and S-C fabrics that superimposed onto the older ones. Most of the S-L fabrics were oriented parallel to the terrain elongation (NW-SE). In a few terrains (i.e. Ubende, Mbozi, Nyika), traverse fabrics (e.g. NE-SW, E-W; Table 1), at a high angle to the terrain elongation (NW-SE) have been reported (UNESCO, 1983; Daly, 1988). Stretching lineations (Table 1) in the Ubendian terrains indicate different displacement directions, thus, some rotation might have taken place during the emplacement of these terrains (Daly, 1988). Stretching lineation in the amphibolite-facies rocks in the Ufipa terrain indicates dextral strike-slip displacement to have taken place in that part of the orogen (Boven et al., 1999). Retrogression down to the greenschist-facies was associated with the prolonged shearing deformation that affected the high-grade rocks in the different Ubendian terrains. Retrograded greenschist facies mylonites in the Ufipa terrains show that sinistral strike-slip movement was associated with this prolonged shearing deformation which affected the whole of the Ubendian belt and was confined to the terrain boundaries (Boven et al., 1999).

P-T data of eclogites and mafic granulites from the Ubendian belt have been used to constrain its metamorphic evolution. A kyanite-bearing eclogite revealed temperature (T) averaging at about 720°C and pressure (P) at about 17 kbar (Boven et al., 1999 and references therein). These authors interpreted these P-T conditions to reflect a high P metamorphic event that occurred during subduction. Exhumation history can be traced in the retrograded eclogites that have lower P values (12 - 15 kbar) but slightly higher T values (800° - 850°C) (Boven et al., 1999). These authors might have overlooked isothermal decompressional textures to explain the slightly higher temperatures that are recorded in the retrograded eclogites. Mafic granulites have also lower P-T values (6-9 kbar, 600° - 650°C). Metapelitic blastomylonites in shear zones gave the lowest P-T values (5-10 kbar, 550° - 600°C) indicating intense retrogression of the exhumed Ubendian rocks within the shear zones.

The Palaeoproterozoic Ubendian belt is now regarded as a product of the collision between the Archaean Tanzania and Congo cratons (Lenoir, et al., 1994; Boven, et al., 1999 and references therein). This collision took place at about 2100 - 2025 Ma (Lenoir, et al., 1994). It was during this collisional event that the E-W trending granulites and perhaps the eclogites were formed. A similar geological scenario is reported from the Usagaran belt (Priem et al., 1979). The lithotectonic blocks or terrains making up the Ubendian belt were accreted or juxtaposed adjacent to the Archaean Tanzania Craton at about 1860 Ma (Lenoir et al., 1994). It was during this accretional event that the persistent penetrative NW-trending shear fabrics developed and became a characteristic tectonic fabric of the Ubendian belt. Reactivation of these late Palaeoproterozoic NW-SE shear zones is in continuum to present times, and controlled the formation of the Karoo rift faults and the associated sediments; and the Cenozoic Western East African Rift System.
Economic Geology of the Ubendian belt

The Ubendian belt hosts a number of economic mineral deposits which include precious metals (Au and Ag), base metals (e.g. Cu, Pb, Zn), gemstones (e.g. emerald, tourmaline), industrial minerals (e.g. Fe, Cr, Ni, PGE, mica, feldspar) and construction materials (e.g. marbles, granites). Detailed account on the economic geology of the Ubendian belt may be found in Harris (1981) and Smirnov et al. (1973).

Metaquartzites in the Ubende terrain have horizons bearing Fe - Mn ores. This type of mineralisation is interpreted as a volcano - siliceous sedimentary type that evolved in an arc system (Tamain et al., 1988). The Ikulu terrain has mafic rocks hosting disseminated Cu and Au ores. Mafic and ultramafic complexes (i.e. peridotite - norite - gabbro - diorite) are mineralised with Cr, Ni - Fe, Cr - Ni - Fe, Ni - Cu, Ti - Fe and this type of mineralisation is considered to be characteristic of volcanic arc system; and the abundancy of chromites pinpoints to the presence of ophiolites (Tamain et al., 1988) in this part of the belt. The Lupa terrain has pronounced Au - base metal mineralisation whereas the Upangwa terrain has enormous Fe - Ti deposits in its anorthosites. Pegmatites, mostly post - kinematic, in the Ubendian belt have a variety of minerals of economic importance. These include mica (i.e. muscovite) and gemstones (i.e. beryl, emerald). The mafic layers of the Sangu - Ikola carbonatite complexes, N and NE of the Karema town, in the Katuma terrain (Fig. 5), are enriched with Cu - Pb - Nb.

Mpanda Mineral Field

The argument that the Ubendian belt terrains have minerals of economic importance may be substantiated by giving brief accounts of some well known mineral deposits such as the Mpanda Mineral Field (MMF).

The MMF lies within the Katuma, Ikulu and Ufipa terrains (Fig. 5) It is underlain by Palaeoproterozoic gneisses, migmatites and schists. Mafic and ultramafic rocks are ubiquitous whereas granites intrude the basement in the southern part (e.g. in the Sikitiko area) of MMF. Nanyaro (1989) dated the MMF granites using the Rb - Sr method and obtained an age of 1846 ± 37 Ma that was interpreted as an emplacement age for the granites. Conjugate set of NW - and NE - trending shears and faults cut across the MMF rocks. Three types of mineralised veins can be found in the MMF: (i) Au - rich veins, (ii) Au - base metal rich veins and (iii) base metal rich veins. Au, Ag, Cu, Pb and occasionally W and Fe mineralisations are characteristic of these three types of veins. These veins were emplaced in shear zones and fissure which cut - high-grade rocks and the post - kinematic granites. The sulphide mineralisation in the MMF is dated at about 1580 Ma (Nanyaro, 1989). This age looks equivocal when interpreted in the framework of the whole Ubendian orogenesis. Pb and Cu mining in the MMF at the Mkwamba Mine began in 1946 (Harris, 1981) and Au was recovered as a by - product of this mining operation. Ore grades in the abandoned Mkwamba mine are in the order of: 1-3% Pb, 0.1 - 1% Cu, 50 - 200g/t Ag and 1-5g / ton Au (Nanyaro, 1989).
Manyoro Deposit

Manyoro deposit is within the Katuma terrain and lies between Sumbawanga and Mpanda towns. The volcano - sedimentary sequence in the Manyoro area was subjected to amphibolite - facies metamorphism and deformation at approximately the same time as the Fe - Mn oxides were crystallising (syngenetic). 18 million tons of magnetite and Mn - oxide with ore grades in the order of 21.63% Fe, 11% Mn, 0.58% TiO₂ are reported from this deposit (Tamain et al. 1988). Malachite, pyrite and chalcopyrite are the prominent sulphides and are concentrated in shear zones. Au is found to be associated with these sulphides and are concentrated in shear zones.

Lupa Goldfield

The Lupa Goldfields (LGF) is located at about 100 km north of the Mbeya town (Fig. 6). It occupies a triangular area totalling about 2600 km² (Fig. 6). The LGF is underlain by Palaeoproterozoic gneisses, migmatites and amphibolites that are intruded by granodiorite, diorite (Saza - Chunya) and granites (Ilunga) (Fig. 6), that range in age between 1960 Ma and 1920 Ma (Mnali, 1999). The peak metamorphism in the LGF reached the lower amphibolite grade.

Gold deposits in the LGF are both primary (lode) and secondary (placers). The former occurs in quartz veins in shear zones e.g. in the ENE - WSW trending Saza Shear Zone. The placer Au occurs in stream and riverbeds, hillside eluvial deposits and weathered rubble zones on top or adjacent to the quartz veins.
Geological results and interpretation

(H. Stendal)

The areas visited during the fieldwork included the Lupa Goldfield, the Mpanda Mineral Field, and Kaream-Ikola-Kipili area. The Lupa Goldfield and Mpanda Mineral Field (Figs. 5-6, 16-18) are both well known for their gold production (e.g. van Straaten 1984). The Karema-Ikola-Kipili area does not have a significant gold production, but some known copper occurrences were located and confirmed during the fieldwork. The following comments and results are based on observations carried out during the fieldwork and the subsequent chemical analyses of the collected samples. The pilot project has also evaluated the quality of the analytical methods used by comparing commercial neutron activation analyses (INNA) and induced coupled plasma analyses (ICP) with the results obtained by the SEAMIC laboratory and the Madini (Geological Survey of Tanzania) laboratory. The various analytical results have been exchanged between the involved laboratories. The Pb-Pb isotopes were analysed by the Geological Institute, University of Copenhagen by Professor R. Frei.

Lupa Goldfield

The Lupa Goldfield is the second largest gold area in Tanzania (van Straaten 1984). Some 600 000 oz. (18 662 kg) of fine gold have officially been produced from this area since 1935. The largest gold mine, the new Saza Mine, produced approximately 250 000 oz. (7 776 kg) between 1939 and 1956 (van Straaten 1984). The average recovery grade was 7.6 g/t. Mnali (1999) refers to other production figures than van Straaten (1984). The estimates of Mnali (1999) is 30 t of Au and about 8 t of Ag produced from the placer and reef mining in the Lupa Goldfield since its discovery in 1922. This is a good illustration of the difficulties obtaining reliable production figures from Tanzania. Part of the reason is probably the uncertainties around the quantities of gold mined by small-scale miners.

Gold in the Lupa Goldfield is found in quartz reefs associated with shear zones such as the extensive Saza zone (Fig. 6), which contains several occurrences (Kuehn et al. 1990; Sango 1988). Sango (1988) defines two styles of gold mineralisation: 1) auriferous quartz reefs and 2) banded iron-formations (BIF). The fieldwork was mostly concentrated on the quartz reef type. The mineralisation in the reefs consists of quartz veins with small amounts of carbonate, sericite, chlorite, tourmaline, and pyrite. Most of these minerals occur due to hydrothermal alteration processes. Native gold occurs in quartz, often associated with sulphides such as pyrite, chalcopyrite, galena, molybdenite, and rarely sphalerite. Pyrite is the most abundant alteration mineral and is found as wall-rock alteration surrounding the quartz veins.

The gold mineralisation in the Lupa Goldfield is both structurally related and host rock related (Fig. 6). The gold mineralised fluids may be magmatic, coming from the huge masses of granodiorites and diorites of the Saza-Chunya granitoids (a batholith?) or from the
slightly younger Ilunga granite. According to Mnali (1999) the ages of these granitoids are 1960 Ma and 1920 Ma, respectively. The preliminary conclusions based on the fieldwork are:

- gold reefs are controlled by the fault systems in the Lupa Block;
- many of the gold occurrences are hosted in diorite;
- there is no evidence of younger intrusions, which could be the sources for the mineralising fluids;
- it is suggested that the gold formation is of Palaeoproterozoic age.

**Mpanda Mineral Field**

In the Mpanda Mineral Field some 69 574 oz. (2 164 kg) of gold was produced as a by-product of base metal mining, and only 962 oz. (30 kg) from alluvial sources (van Straaten 1984). Mineralisation in the Mpanda Mineral Field is aligned along two main structures: 1) base metal deposits along a WNW-ESE trending fault zone and 2) a gold-bearing NNW-SSE trending linear belt within two successions known as the Katuma and Ikulu series (Fig. 5, Kuehn et al. 1990).

The largest base metal deposit is Mkwamba, where the mineralisation consists of quartz-siderite veins with galena, chalcopyrite, pyrite, silver and gold. Wall-rock alteration is common and comprises mainly quartz-sericite-chlorite schists. The gold-bearing occurrences are confined along the Katuma Series (migmatites) and Ikulu series (quartz-mica schist). The Katuma Series has a large amount of mafic rocks. About 50 veins are known in an area of c. 80 km² (Kuehn et al. 1990). The veins are quartz-siderite veins associated with similar quartz-sericite-chlorite alteration as mentioned above. The preliminary conclusions based on the fieldwork are:

- base metal and gold mineralisations are widespread and controlled by structures and to a certain extend by the host rocks;
- copper is only present if basic rocks occur in the vicinity of the mineralised veins;
- the mineralised fluids are younger than the host rocks, as evidenced in the Sangu carbonatite area where quartz-copper-hematite must be younger than the carbonatite;
- the veins from the Sangu carbonatite have the same appearance as the veins in the Mpanda area.

**Karema - Ikola - Kipili area**

Most of the mineralisations visited (Fig. 5) are found in connection with quartz veins in shear and/or breccia zones. The Karema-Ikola area has many basic to ultrabasic rocks, whereas the Kipili area mostly is associated with granitic rocks (Kate granite). Small copper occurrences are recorded in several places, which all are structurally controlled by the same type of veins as found in the Mpanda area.
Analytical results

During the field work rock-, sediment-, and tailing samples were collected. The purpose of the sampling was three-fold:

- to get an indication of the gold grade in the gold occurrences;
- to investigate the secondary dispersion of the metals (e.g. Au, Cu, Pb, Hg) in the sediment- and tailing samples;
- to compare analytical results from different laboratories.

The analytical methods used are Neutron Activation analyses (INNA, Actlabs, Table 7), Induced Coupled Plasma analyses (ICP, Actlabs, Table 8), and fire assay with AAS determination (Madini (=GST), Table 9 and SEAMIC, Table 10). The sample descriptions are given in Table 11 and the geographical coordinates of the sample sites linked to the sample numbers are listed in Table 12.

From the analytical results it is obvious that the contents of gold, copper, and lead vary considerably. The results confirm most of the gold and base metal occurrences visited. The highest INNA gold value is 69.5 ppm Au (461416) from a sediment sample taken from the gold washing pool in Shoga village. The best rock sample is a quartz vein from the Izumbi occurrence with 49.2 ppm (461411). Many of the visited occurrences have gold contents ranging from 1 to 10 ppm gold. This level is the gold grade, from which the small-scale miners are capable to exploit gold. Preliminary investigations by Scanning electron microscopy equipped with EDS showed that the visible gold with a grain size up to 1.5 mm in a sample from Kapanda contained no silver but about 0.15 % copper.

Copper (ICP-results) is common both in the Lupa Goldfield and in the Mpanda Mineral Field. Only a few samples in the Lupa area are rich in lead, whereas lead is very common in the Mpanda area. The Mpanda area is also very rich in Ag and Bi compared to the Lupa region. The silver contents are up to 696 ppm and bismuth up to 2 168 ppm from the Mkwamba mine. The only site, where the zinc contents are significant, is at Ibindi "A" (up to 1.1%). Arsenic is found in both areas but is most common in the Mpanda area. Molybdenum is more common in the Lupa area than in the Mpanda area. The element association for the Lupa Goldfield is Au-Cu-(Pb- Mo) and for the Mpanda Mineral Field the most common association is Au-Cu-Pb-Ag-Bi.

Sediment and tailing samples from around Mkwamba yield 0.5-1.2 ppm gold (461478-461482) which is one tenth of a sample of galena-chalcopyrite ore with 11 ppm gold taken on the mining site (Sample 461428, Table 7). Similarly, the Pb (ICP) and Cu (ICP) contents of the sediment samples are high, with maximum values of 7 657 ppm and 1 416 ppm, respectively. The samples have also unusual high Ag, As, and Bi contents, 18.9 ppm, 131 ppm and 45 ppm, respectively. Sediment samples from the Katavi National Park are not anomalous in any metals. This means that pollution from the Mkwamba mine is not dispersed into the Katavi National Park.

The comparison of the analyses carried out in different laboratories is illustrated for the gold analyses in Fig. 7.
From the analytical results it can be concluded that the fire assay analytical method by Madini shows lower gold values than the INAA method for the same samples. By experience based on similar analyses from Greenland this is quite common and not to be worried about. There are also a few outliers that can be explained by the nugget effect. The most serious problem is when the samples have low gold values. Based on the test results, both SEAMIC and Madini have problems, because their analyses in such cases sometime show the presence of gold in samples which are known to be barren (Fig. 7).

**Pb-isotopes**

Pb-Pb isotope analyses of some of the mineralised rocks have just been finished at the time of writing and the results are preliminary (Table 13). Some interesting conclusions can, however, be drawn already at this early stage:

- In the Lupa Goldfield the Izumi-mineralisation are likely to be related to the intrusive granitoids. The Pb-Pb isotopes indicate a juvenile origin of the lead but that creates an interpretation problem. The problem is the age of the granitoids, which based on the isotope data look to be younger than the anticipated age (1960 Ma). The outlined trend of an age reference line suggests an age of 1500-1400 Ma. The meaning of the data is, therefore, not fully understood at the present. More data are needed for a better understanding of the Pb-Pb ratios.

- In the Mpanda Mineral Field the Pb-Pb data are more consistent and more reliable conclusions can be drawn. All the analysed mineralisations are related to ore processes, which are younger than the host rocks. The mineralising processes are timewise related to the intrusion of the carbonatite. An isochron consisting of galena from Mkwaamba, magnetite from the carbonatite, and the red carbonatite phase yields $722 \pm 43$ Ma with a MSWD 0.71. Most of the other mineralisations in the area cluster around the galena sample from the Mkwamba mine. The source of the Pb is to be found within the Palaeoproterozoic rocks themselves.

**Geophysical data compared to geology and mineralisation**

The total magnetic field reflects the major divisions of the Ubendian mobile belt. The highest nT values are obtained over granitoids (e.g. Kate granitoids) and over the basic to ultrabasic rocks in the Ikola area (Fig. 8). Low magnetic responses are mirrored over the Rukwa basin and the Sangu carbonatite. A close-up of the Mpanda Mineral Field shows that the NNW-SSE trend follows a magnetic escarpment, but the WNW-ESE direction is not obvious on the total magnetic field map (Fig. 9). It is concluded that the total magnetic field map is certainly helpful in defining the boundaries between the individual structural blocks of the Ubendian mobile belt. Concerning the reflectance of the gold mineralisation it is possible to trace the NNW-SSE trend in the Mpanda area and it strongly suggests following this trend in NNW direction north of Mpanda.
Environmental aspects

(C. M. Glaheer)

The environmental work was concentrated on:

- the use of mercury in small-scale gold mining,
- the possible environmental contamination from lead, copper and other metals at the abandoned Mkwamba lead-copper mine,
- the physical impact on the environment from the mining activities such as forest clearings, digging of pits, road constructions etc.

More detailed information is given in Appendix 7.

Mercury in the environment

Small-scale gold miners use mercury to extract the gold from the ore (Appendix 3). Gold is mined as placer mining and gold reef mining, and mercury is used only in gold reef mining. A total of 11 gold reef mines were visited in the Lupa Goldfield and the Mpanda Mineral Field, and six gold extraction places, mostly in villages in the vicinity of the mines, were visited in the area. At the gold reef mines and in the gold extraction places samples were collected of human hair, corn porridge (Ugali), corn, soil and sediment (Tables 14-17).

The ‘amalgamists’ and ‘burners’ had on average a total mercury content in the hair of 2.86 ppm (SD=3.69, n=9) and the miners and panners had on average 1.79 ppm (SD=1.87, n=4). The farmers and the teacher living in the mining villages had on average a mercury content in their hair of 0.20 ppm (SD=0.10, n=6), and the three persons working in a restaurant in Mpanda 0.10 ppm (SD=0.07, n=3). So, individuals working intensively with the mercury have about 30 times more mercury in their hair than control persons. A mercury content in ‘amalgamists’ of 2.9 ppm is comparable to the 3.3 ppm in hair of small-scale gold miners at Lake Victoria (Kahatano et al 1998).

The average mercury concentration in the sediment of the amalgamation pools was on average 46.50 ppm, and the mercury content in the soil 2-50 m from the amalgamation and burning activities was on average 9.79 ppm. This average soil content is 20 times higher than the average mercury content in Earth’s crust of 0.5 ppm. About 200 m from the amalgamation activities the mercury concentration in soil was only 0.1 ppm. Crops like corn and cassava were grown in the villages nearby the gold extraction, but the mercury content in only one collected corn sample was low (0.04 ppm). Porridge (Ugali) made from corn had in two samples an average mercury concentration of 0.11 ppm, and this somewhat higher content could perhaps stem from the water. Drinking water was in most villages taken from or near the dried out riverbeds, and in one case the mercury content in the well sediment was 0.61 ppm. This well, however, was situated only 10 m from an amalgamation pool. Sediment samples from two other wells situated 500-1,000 m from gold extraction were on average only 0.01 ppm.
The mercury content in the amalgamation pool may be dispersed to the environment when the sediment is removed from the pool. The dry sediment is transported to a nearby river to recover more gold by a second amalgamation. Amalgamation also takes place at or directly in the river. The mercury content in the river sediment 10-25 m downstream the amalgamation pool was on average 1.13 ppm, while the concentration 500-1,000 m downstream was on average 0.06 ppm. This value is about three times higher than the average mercury content of 0.02 ppm in river sediment upstream from the amalgamation pools. Mercury in sediments from the washing pools used by placer gold miners yielded 0.02 ppm. This is in accordance with the information obtained in the field that the placer gold miners were not using mercury in their process.

In order to follow a possible long distance dispersion of mercury from the small-scale gold mining sites, sediment samples were collected from rivers and lakes in the Katavi National Park situated 25 km or more from the mining sites. The mercury concentration in the sediments seems to decrease from the place where the river enters the national park (0.06 ppm), to where it leaves Lake Katavi (0.03 ppm). The mercury concentration increased to 0.21 ppm in another river entering the national park, indicating that this river carries mercury from gold mining sites.

The possible mercury content of fish species eaten by people in the gold mining areas was studied in the Chunya area at Lake Rukwa (Fig. 1). The mercury content in five different fish species varied between 0.3-1.4 ppm, with highest concentrations in bottom dwelling and predatory fish. In Denmark, freshwater fish with a mercury concentration above 1.0 ppm are banned for consumption. According to this threshold value two of the Lake Rukwa fish species analysed exceeds this value.

In conclusion:

- gold miners have a mercury content that is 30 times higher than persons not involved in gold mining,
- soils and sediments near the amalgamation places are 20-60 times higher than the background values,
- the mercury content of fish used for consumption are above or the same as the acceptable threshold value,
- a major decrease of the mercury content in humans and in the environment would be obtained by the introduction of retorts.

Other metals in the environment.

The possible metals contamination of the environment from the abandoned Mkwamba copper and lead mine in the Mpanda area was studied. Two big waste rock deposits and two big tailings are situated in the mine area and adjacent to the Mpanda river. This river flows to the Katavi National Park. The mercury concentration in the tailing samples (0.06 ppm) was low and not much higher the upstream content of 0.02 ppm. The tailings contained
about 0.3 % copper, 0.3 % lead, 1.2 % manganese and 21% iron. The waste rock deposit contains 0.08 % copper, 0.7% lead, 0.3% manganese and 5% iron.

In order to follow a possible long distance dispersion of metals from the Mkwamba mine, sediment samples were collected from rivers and lakes in the Katavi National Park and analysed for different metals (Cu, Mn, Fe, Zn, Pb, Ag and Au). The copper concentration in the sediment decreases through the national park from 126 ppm to 25 ppm, but increased to 82 ppm where a new river entered the national park. The lead concentration in the sediments is almost the same throughout the Katavi National Park with concentrations of 25-48 ppm.

In conclusion, copper and lead concentrations in the sediments of the rivers flowing into the Katavi National Park are enhanced compared to the Earth’s crust, but the metal content of sediment samples are comparable with stream sediments in general. Sediment samples from the rivers upstream of the mining areas are needed to establish the local background concentrations. Also, samples of sediments and wildlife from the rivers between the mining areas and the national park are needed, before any final conclusions can be drawn.

**Mining, land use and environmental protection.**

The natural vegetation of the Chunya and Mpanda areas is the deciduous Miombo forest rich in hardwood species. People in the area are living of extensive agriculture, tobacco, timber, charcoal, fish, bee-products and small-scale gold mining. The physical impact on the environment of the gold mining will be described in the following.

**Small-scale gold mining.**

Placer gold mining takes place in or at rivers in the area, resulting in many smaller holes in such areas. In the rainy season these holes can increase the turbidity of the rivers, change the course of the rivers, and damage the roads. At the gold reefs, pits of 20-40 m of depth are constructed, and the waste rock is dumped on the sides of the pits. There seemed to be no back-filling in any of the gold reefs that we visited.

**Larger mining activities.**

The two largest former mining activities in the area are the abandoned copper-lead Mkwamba mine in Mpanda and the Demco Processing Plant in Saza. At the Mkwamba mine nothing seems to have been done to re-establish the environment: two big waste rock deposits, two huge tailings, as well as houses and railway tracks are visible in the area. The two tailings are uncovered by vegetation, and they are situated down to the Mpanda River, so that wind and water easily disperse the metals in the tailings. At the Demco Processing Plant a huge tailing, and two smaller ones, are visible in the area. The tailings have 0.15 ppm Au and up to 500 ppm Pb. The main threats to the environment are, as described
above with the tailings from the Mkwamba mine, the metals dispersed in the environment by water and wind. The Lake Rukwa is only 15 km downstream of the Demco plant.

At the Demco site it was demonstrated that the amalgamation could take place in a closed system. The mercury-gold amalgam is burned with the use of a retort so both gold and mercury are recovered. The retorts are produced by the Institute of Production and Industry (IPI), Tanzania, and the prize for a retort is about 30 US$. A major improvement of the mercury content in humans and in the environment would be obtained by the introduction of retorts. This has been proven in Brazil, where the use of retorts decreased the mercury contamination of the environment to 1% (Ikingura & Mutakyahwa 1997).

In conclusion:

- there seems to be not major physical impact on the environment, such as soil erosion, due to the different mining activities in the area.
- smaller impacts, such as turbidity of rivers and damages to roads can be mitigated by backfilling of abandoned mining sites
- major concern must be due to the dispersal of metals from tailings and waste rock deposits left at the Mkwamba mine and the Demco Processing Plant,
- the number of sediment samples are too low to define numbers for background values in the respective areas sufficiently accurate.
Socio-economical issues:

The socio-economic issues related to the pilot project were discussed at the planning seminar and have been addressed repeatedly during the fieldwork, though not in a systematic and strictly professional manner. During the time in Tanzania, suitable contacts for further co-operation on the subject were sought. Institute of Resource Assessment, University of Dar es Salaam was identified as the best contact in Tanzania. Socio-economical issues like 'conceptual framework for livelihood strategies and environmental change' has been further discussed with NERI and researchers from Roskilde University Centre (RUC) at a series of meetings during the autumn 1999.

Based on the activities so far, a more elaborate proposal for a co-ordinated pilot project is now being prepared by GEUS, NERI and RUC; a brief version is included in the recommendation. Initiation of the socio-economical pilot project will also ensure that relevant data and experiences can be accumulated and taken into account for actions in the main project. GEUS and NERI will keep in close contact for the preparations of the pilot project. Established contacts to partners in Tanzania will be evolved to ensure their participation.
Mercury in soap in Tanzania

(P. W. U. Appel & C. M. Glahder)

During the pilot project the Danish participants learned that mercury-bearing soaps and creams manufactured in the United Kingdom were illegally smuggled into Tanzania and sold on the markets in towns and villages. The purpose of mercury in these products is to make black skin and hair lighter coloured. The distribution of soaps and creams containing mercury is, according to WHO, banned in many African countries, in the EU and in North America. Several brands of soaps with high contents of mercury were found on the markets in the field area e.g. the market in Mpanda, and samples were purchased for analysis.

The content of mercury compounds in the soaps turned out to be approximately two percent. Such levels pose a serious health hazard, and may cause kidney- and brain damage in people using the products. Mercury poisoning can cause diseases connected with the nervous system, the kidneys and the skin. The mercury from the products enters the body by penetrating the skin and also via inhalation. Water used for washing becomes highly contaminated with mercury. In the environment, this discarded mercury is converted into the highly toxic methylmercury by bacterial action. Methylmercury and other organic mercury compounds then enter the food chain and eventually end up in humans, for example, through fish consumption.

A separate report on these problems has been written and delivered to the Danish Minister of Environment and Energy (Appendix 8). The report suggests that the manufacturing and export of soaps, or similar products containing mercury should be banned.
Conclusions

- The goals defined for the pilot project have been fully achieved and many important aspects and issues have been identified for continued co-operation between institutions in Tanzania and Denmark. The scientific outcome of the pilot project has and will in the future benefit both the Tanzanian and the Danish group.
- Existing geoscience data from the Ubendian mobile belt of West Tanzania have been compiled and evaluated. This started at GST with T. Tukiainen’s co-operation with F. Petro and E. B. Temu during the visit to Tanzania. Further data processing was carried out at GEUS together with T. M. Rasmussen. The results are compiled in ArcView 3.2 and as Geosoft grid files, and will be made available on CD-ROM. New data obtained in the pilot project will be added as they become available.
- The fieldwork and the subsequent analytical work in Tanzania and Denmark indicated several important research areas within structural geology, mineralisations, isotopes, and environmental sciences. Several joint research projects have been formulated.
- Two co-operative research projects have already started with planned publication of results during the spring 2000:
  - A joint research project between University of Dar es Salaam, GST, GEUS and University of Oulu, Finland has investigated eclogites (deep seated high grade metamorphic rocks).
  - Lead isotope studies carried out in Copenhagen in co-operation with R. Frei (Geological Institute, University of Copenhagen) on samples collected by the field team in the Mpanda and Lupa areas have yielded important new information as to the origin of the gold mineralisations. In the Lupa Goldfield, the gold mineralisation is probably related to the granitoid c. 1960 Ma of age, but Pb-Pb-isotope data indicate a younger age of the granitoids than anticipated. In the Mpanda Mineral Field the mineralisations are all related to younger processes, contemporaneous with the intrusion of the carbonatite (722±43 Ma). This has significant implications as to where more gold mineralisations may occur.
- Six test samples have been analysed at different laboratories in order to check the analytical quality.
- The fire assay analytical method used by GST shows lower gold values than the INAA methods. By experience from similar analyses from Greenland this is quite common and not to be worried about. There are also a few outliers that can be explained by the nugget effect. A most serious problem, however, are the low values. Both SEAMIC and GST have obtained gold contents in some samples which by other analytical methods are seen to be barren.
- Within environmental sciences the pilot project revealed that several small-scale miners have very high mercury contents in their hair, results which are comparable with similar investigations carried out previously by other groups in the lake Victoria region. The high mercury contents are ascribed to amalgamation. At DEMCO in the Chunya area a so-called retort was demonstrated. By using this retort amalgamist can recover virtually all the mercury, thus avoiding poisoning of himself and polluting the environment. It is suggested that a future research project should try to introduce retorts in the villages. This would have two obvious effects. Firstly, the small-scale miners save money on buying mercury and secondly much less mercury is spread to the environment.
- The stream sediment programme showed that further work is needed, such as determination of regional metal background levels, mapping of the dispersion of mercury and base metal pollution in the river systems.
- The pilot project investigation of mercury in soap in Tanzania has caused considerable interest and wide attention from the Danish Ministry of Environment and Energy and the press.

Based on these results, the project group must conclude that the foundation has been laid for a successful continuation in terms of the scientific objectives, local support, and international interest. During the course of the pilot project the form, content and goals of the main project were discussed repeatedly internally in the project group and with a number of external contacts. During the fieldwork the Danish and Tanzanian researcher obtained very good scientific and personal relationships. The resultant outline of the future main project is described in the following section of this report.
Recommendations

The following recommendations were agreed upon during the fieldwork and have subsequently been developed in more detail through correspondence between the Danish and Tanzanian participants, and meetings among Danish participants. It is intended to establish two co-ordinated joint projects:

A joint research project

An educational programme

The research project and the educational programme will start at the same time, preferably mid 2000. The research project should last for four years and the educational programme initially last for three years. GEUS will hand-in co-ordinated applications towards financing of these activities to RUF and ENRECA, respectively, before the 15th March deadline.

The joint research project

The project involves fieldwork in the Ubendian of South-West Tanzania and laboratory work in Tanzania as well as in Denmark. The research will include three disciplines:

- Geological Research
- Environmental Research
- Socio-economical Research

Geological Research

The geological investigations will comprise mapping and sampling in the Mpanda Mineral Field and Lupa Goldfield. The projects will be carried out by Tanzanian and Danish researchers together with M.Sc. and Ph. D. students. The senior researchers from GEUS, University of Dar es Salaam, and the Geological Survey of Tanzania will take care of the supervision of the students. It is the aim to use Tanzanian preparation and analytical laboratories as long as they fulfil international standards.

Geological research projects can be summarised to the following headlines:

- The genesis of gold mineralisation and the related hydrothermal alteration pattern.
- The prediction and localisation of new gold-quartz reefs; disciplines like structural geology, fluid inclusions, isotopes, and geophysics will be applied.
- The geochemistry of the mafic rocks in the Palaeoproterozoic Ubendian with the aim to understand the geotectonic setting of the mobile belt.
- The study of provenance and age of the granitoids by means of isotopes related to the geotectonic setting.
If the project succeeds in finding new gold reefs, it will provide a significant contribution towards more mining activity, which may result in increasing sources of income to the private and public sectors.

The geological projects already ongoing based on the samples collected during the fieldwork in 1999 will be continued in the main project:

- Chemistry of garnets in eclogites in the Ubendian exemplified by samples from localities T28-T30. This project involves GEUS, University of Dar es Salaam, and the University of Oulu, Finland.
- Lead isotopes in gold mineralisation of the Mpanda area; involves the field participating institutions and the University of Copenhagen.

**Environmental Research**

The aim of the environmental research work in the Mpanda and Chunya areas will be:

- To study the impact of mercury from the small-scale gold extraction on humans and the environment in order to mitigate this contamination.
- To study the dispersion of metals and the impact of metals, mainly copper and lead, from Mkwamba mine in the Mpanda area on the environment, in order to suggest mitigating measures.

Masters and Ph.D.s from the University of Dar es Salaam together with biologists and geologist from NERI, GEUS and DGUDES will carry out the studies. Both the DGUDES and the NERI laboratories will undertake laboratory work. Knowledge has been gained from the pilot project on the total mercury contamination of human beings, fish, sediments etc. More detailed knowledge is necessary on the inorganic/organic mercury fraction, the dispersion of mercury downstream rivers and the concentrations in humans (urine/blood), fish (lakes and rivers), crops, soil etc. Mercury contamination after the use of retorts and different extraction techniques and localities will be investigated. Studies of how to reduce the dispersion of metals from waste dumps and tailings in to the environment by water and wind. Based on such work, suggestions can be offered how to reduce contamination from these deposits.

The DGUDES laboratory will be supported so that international standards and subsequent intercalibration can be achieved by bringing the equipment up to date and introducing a restoration program. Chemists and technicians will be exchanged for visits at the institutions involved.
**Socio-economical Research**

Based on the discussions between GEUS, NERI, and RUC, Pia Frederiksen (NERI), who participated in the original planning seminar and who has obtained background information from PA, CG and HS has suggested the following cause of action. The plan is to arrange for a socio-economical pilot project under the umbrella of the four year project.

Gold mining in Tanzania – as well as in other countries - are to a large extent undertaken by small-scale miners (artisanal miners). This have formerly been seen as constituting a problem for the sector as it is related to informal and even illegal activities, including smuggling out the products, as well as to environmental problems. Increasingly, however, it is acknowledged that it also involves development opportunities through the creation of labour and through the economic impact on the local communities, and programs are being developed, which departs in this view. (One example is a program underway under UNDP: Artisanal Mining and Sustainable livelihoods). This perspective is also recognised in the Tanzanian mining policy, which talks about formalisation and support to this sector.

Any initiatives towards the sector call for knowledge of the sector and its relations to the local population and community, but until now artisanal activities in general and certainly for Tanzania are poorly described.

Economic, cultural, demographic and socio-environmental relations would be relevant themes to explore: organisation of mining activities, labour force and its origin, as well as relations to alternative land use, livelihoods, and tenure arrangements are examples of issues in question.

It is thus advisable to include in a future research project a preliminary exploration of research questions on to the socio-economic issues related to the artisanal mining activities in the study area.

**The academic educational programme**

The educational programme aims at upgrading a number of B. Sc. to M.Sc. level and some from M. Sc. to Ph. D. level. The plans have been carefully discussed with the Tanzanian participants, who placed much emphasis on the importance of such a programme.

The plan calls for four M. Sc. students within geology, one to two within environmental sciences each year and maybe one or two M. Sc. students within socio-economic sciences. Furthermore one or two Ph. D. students from Tanzania, and possibly one or two from Denmark should start in year one of the project and participate during the three years of project time. The research fields for the Ph. D. students depend on which candidates will apply.

If successful, the educational programme will graduate the following candidates during a three-year period:
12 M. Sc. in Geology  
6 M. Sc. in Environmental Sciences  
2 M. Sc. in Socio-economical Sciences  
3 to 4 Ph. D. in Geology and Environmental Sciences

Field areas will coincide with areas investigated in the research project. The first year, fieldwork will mainly be carried out in the Mpanda area. The second year the Chunya area will be investigated. The location for the third year has not yet been decided. The decision depends on the results from the first two field seasons.

During the fieldwork the students will carry out fieldwork comprising detailed mapping and sample collection for a period of about two months starting for the first time early September 2000. Each student will have a Tanzanian and Danish supervisor, and both supervisors will guide the student during the first three weeks of their field season. Towards the end of the field season the Tanzanian supervisors will revisit the field area and guide the student for the remaining part of the field season. A similar procedure will be used within environmental and socio-economical sciences.

**Additional objectives**

During the joint research project some students, laboratory technicians and researchers from Tanzania is expected to visit research institutes in Denmark (GEUS, NERI), and researchers from Denmark will visit and help supervise and quality control laboratories at the University of Dar es Salaam and the Geological Survey of Tanzania.

Ideally the research programme will also require purchase of a limited number of PC's with appropriate software, books and scientific journals for the University of Dar es Salaam and the Geological Survey of Tanzania.

It is the intention also to include other research groups in the joint research project. Several contacts have already been established. One group around Kent Condie from New Mexico has a major interest in carrying out field and laboratory work in the field area, see Kent Condie's suggested research programme in Appendix 9. Contacts with research groups from neighbouring countries especially Zambia and Congo will be strengthened. These countries have similar geology and are very interested in joint research.

It may be possible within the project to demonstrate the beneficial effects of a recovery system for mercury. Mercury can be bottled again by introducing the retort, a closed system for amalgamation, in the project area. Funding will be sought for activities towards that goal, such as the purchase of equipment and on the job training of the artisanal miners.
Acknowledgements

The authors would like to acknowledge the financial support from the Danish Council for Development Research to the pilot project (RUF project 90953). The involved institutions DGUDES, GEUS, GST, and NERI are thanked for their support, their general interest in the pilot project, and for their financial contributions. DGUDES and GST kindly provided cars and drivers, without which the fieldwork could not have been carried out. The field team also wants to thank the regional and district commissioners for permission to do fieldwork in the different areas. The help from local wardens, field guides, and the various contact persons in Tanzania, including the Danish Embassy in Dar es Salaam, is highly appreciated.
References

(Includes references from the appendices).


Kawanabe, H., & Kwetuenda, M. K. e. 1988: Ecological and limnological study on Lake Tanganyika and its adjacent regions. (No further information!).


Appendix 1

(L. Thorning)

**Summary of main conclusions and agreements reached at Planning Seminar**

Enclosure 1: Summary of project dates
Enclosure 2: Christian M. Glahder’s stay in Dar Es Salaam during c. 7 - 13 September 1999.
An integrated approach to mineral exploration and environmental assessment in southern and eastern Africa - a pilot project in Tanzania.

Summary of main conclusions and agreements reached at Planning Seminar

GEUS, Copenhagen, 11 – 14 June 1999.
Leif Thorning, 14 June 1999
Final Edition 18 June 1999

Principal participants in the Planning Seminar:

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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<tr>
<td>Peter Appel (PA)</td>
<td>GEUS</td>
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<tr>
<td>Geert Asmund (GA)</td>
<td>NERI</td>
</tr>
<tr>
<td>Christian Glahder (CG)</td>
<td>NERI</td>
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<tr>
<td>Sospeter Muhongo (SM)</td>
<td>DGUDES</td>
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<tr>
<td>Faustino Petro (FP)</td>
<td>GST</td>
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<tr>
<td>Henrik Stendal (HS)</td>
<td>GEUS</td>
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<tr>
<td>Leif Thorning (LTH)</td>
<td>GEUS</td>
</tr>
<tr>
<td>Tapani Tukiainen (TT)</td>
<td>GEUS</td>
</tr>
</tbody>
</table>

Geological background:
Sospeter Muhongo gave two talks on the geology of Tanzania; One on the Archean for a general audience and one on the Ubendian for the project group. In the latter he included suggestions for places of fieldwork. B/W copies of Muhongo’s overheads are available.

Faustino Petro brought a large number of maps and other information from GST as basis for the discussion. A number of maps were purchased by the project.

Sospeter Muhongo will provide a good bibliography sometime in July after his participation in an International Geological meeting in South Africa, maybe soon enough to give to Tapani Tukiainen, when he is in Dar es Salaam early July?

It is very important to keep the main objectives and goals in mind during all phases of the project, and to make sure that the geological and the environmental issues address the same region of Tanzania.

Trip to Tanzania for the gathering of digital data and information:
The project provides the necessary funds for a trip to Tanzania, Dar es Salaam and Dodoma, early July with the purpose to acquire any existing data from the intended field area. Senior Computer Geoscientist Tapani Tukiainen will arrive with Swissair flight at 8:35 on Sunday 4 July and stay in Tanzania for about one week. Faustino Petro will make arrangements for immediate further transport to Dodoma (and back). While in Dodoma, TT will discuss and arrange the transfer of as much data as possible, digital, reports, maps etc. When back in Dar es Salaam, Sospeter Muhongo will assist with arrangements. Tapani Tukiainen will bring a list of priority items to get hold of for the project. This will include literature, maps (digital preferred or paper), geoscience data and environmental data.
A suggested schedule with required contacts will be forwarded prior to TTs arrival to Dar and Dodoma.

**Compilation of existing data:**
Starting immediately after the planning seminar, the compilation of existing data will commence. For the rest of June efforts will be directed towards getting a good overview of data in sufficiently good shape to be incorporated. There was general agreement that only the main field area should be compiled in GIS (see later). The main area of interest for the compilation is defined as follows:

- Northern boundary: 6° S
- Southern boundary: 7° 30 S
- Western boundary: 30° E
- Eastern boundary: 32° E

The following data items have been discussed at the planning seminar:

*Topographic base maps:*

May not be easily available in digital form. Most likely they will have to be produced from paper maps or satellite data. SM and FP do not feel there will be any copyright problems. There is a defined standard national grid for Tanzania (Petro will provide details later). Most, but not all have 20 metre contours. Datum used is ARC 1960 and update of ARC 1964. The maps are in UTM projections:

- From 25° E to 30° E: Zone 35 is used
- From 30° E to 36° E: Zone 36 is used
- From 36° E to 41° E: Zone 37 is used

For the project compilation the following should be used:

- Projection: UTM
- Zone: 36
- Datum: WGS 84, if the corrections from the ARC 1969 and 1964 can be established

It may be feasible to produce base maps from either Landsat data or radar data. Tapani Tukiainen will examine these options.

*Existing geological maps:*

Scanning and vectorisation of acquired maps are probably the most realistic option. Satellite based map may also be considered. SM and FP assure that there will be no problems with copyrights here, as this is a co-operative effort. No discrepancies are expected at the boundaries of existing maps. The existing legends will be used as the basis for a data model.
Landsat TM data:

The project will buy Landsat TM scenes covering the field area. GEUS will attempt to get scenes from the new Landsat TM 7, if those data are being released now or soon. Pan-chromatic (15 by 15 metres) from same source may be suitable as base map (alternative to digitised map), if available. Otherwise Landsat TM data from previous satellites (5) will be used.

All participants in the project can use the scenes acquired for both geological and environmental issues. TT will investigate which scenes to buy and which types of processing can be included before the fieldwork.

TT will look into the use of Radarsat data for imaging (most likely) and a proper DEM (Digital Terrain Model, less likely).

Geophysical data:

It is important to get existing aeromagnetic and EM data from field area into the project database in digital form. Petro and Muhongo uncertain if these data can be obtained easily. The Ministry owns them. A letter to the Ministry will be drafted asking for the data to be released for use in this project. Petro will try to help getting the data released. The project can pay a reasonable price for use of the data and their incorporation into the project database.

Gravity data are probably available, but it is uncertain at what terms. The ideal would be digital position, height, measurement and calculated anomaly. FP will check this. Final decision when TT is in Dodoma.

There are no petrophysical data available.

Geosoft formats are desirable for the geophysical data.

Mineralisation data

Localised Information on economic geology is available in the GST database, and a subset for the field area can be transferred to the project database. This will be arranged, while TT is in Dodoma.

Mining companies may have data or be interested in sharing information. However, the Ministry/GST must handle any and all contacts to the mining industry.

GIS compilation platform:

The spatial information is to be compiled in ArcView GIS, and as a rule data-basing of attribute information will be done in dbf files. Crystal Reporter will be used for reporting. The version of ArcView to use should be the same for all participants (version 3.1).
Once the correct parameters for the spatial data and maps have been decided upon (while TT is in Dodoma, at the latest), GEUS will provide a standard ArcView project file with the correct definitions etc. for the use of all participants. This will ensure compatibility between various compilers.

**Geochemistry:**
As far as is known, only scattered and scarce information exists. The Russians carried out some geochemical work, but reports only show interpreted maps, not the geochemical data. Probably it will not be possible to include geochemical data in the pre-field compilation.

**Age determinations:**
No age determinations of mineralisations exist, as far as SM and FP know. Getting new ages of mineralisations (first priority) and host rocks (second priority) is important.

**Mercury pollution:**
SM will contact two researchers on his own institute, Dr. C. Kinabo and Dr. S. Mnali, who are interested in and work with mercury pollution and mine processing. Other sources may be available.

**Animals, vegetation and other environmental indicators:**
Christian Glahder has compiled a wish list of contacts and subjects, which is enclosed with this summary (Enclosure 2).

**Socio-economical issues:**
Hanne Bach and Pia Frederiksen, both from NERI, gave a very interesting introduction to possible socio-economic issues, which could be related to the project, with the starting point in a ‘conceptual framework for livelihood strategies and environmental change’ used by Pia in a previous project near Iringa in Tanzania. This could be adapted to family-, group- or village level. The subsequent discussion, especially the input from SM and FP, made it clear that there are many issues to work with. To make a start, Pia gave some suggestions (overheads will be included with the final summary), and it was decided that Hanne and Pia should produce a questionnaire (in English, Swahili translation will be considered), which could be used in Tanzania for interviews during the pilot project. This will ensure that some data, opinions and facts can be accumulated and used as part of the basis for actions to be included in the main project. GEUS and NERI will keep in close contact for the preparations for the pilot project. Institute of Resource Assessment, University of Dar es Salaam was identified as the best contact in Tanzania. SM will contact them.

**Fieldwork September - October 1999:**
The agreed starting date for the fieldwork operations is 6 September 1999.

**Area and schedule:**
Principal field area will be a cross-section of the Ubendian terrains between Karema and Mpanda, where most of the time should be spend. Secondary field area is the Lupa gold field, where maximum one week should be spent.
Christan Glahder departs from Copenhagen with Swissair 6 September 1999 at 17\textsuperscript{30}, arrives Dar es Salaam early on 7 September. CG spends a week in Dar contacting environmental groups, and obtains Research Permit. Muhongo assists with contacts.

Henrik Stendal departs from Copenhagen with Swissair 8 September 1999 at 17\textsuperscript{30}, arrives Dar es Salaam early 9 September. HS obtains Research Permit with assistance from Muhongo and on the 9\textsuperscript{th} or 10\textsuperscript{th} is taken to Dodoma by GST, where he assists preparations for fieldwork.

Peter Appel departs from Copenhagen with Swissair 13 September at 17\textsuperscript{30}, arrives Dar es Salaam early 14 September. PA obtains Research Permit and presents a talk at the University on the early Archaean of West Greenland.

On 15 September, Sospeter Muhongo, Saidi Mnali, Christian Glahder, and Peter Appel depart Dar in two four-wheel drive cars with drivers, to go to Morogoro to meet group from Dodoma. Faustino Petro, Temu, and Henrik Stendal depart Dodoma to go to Morogoro with two cars and drivers. Together all four vehicles and the entire project group drive to Mbeya and stay there overnight.

The following day the group drives to Chunya, which will be the base for a week of fieldwork in the Lupa district. Christian takes samples at the small-scale mines and perhaps at Lake Rukwa. After about one week the base is shifted to Mpanda, for another week of fieldwork, and finally to Karema, also for a week of fieldwork.

The remaining time may be used as a buffer, or to add additional localities e.g. further south along the coast of Lake Tanganyika near Kipili.

The fieldwork ends not later than 15 October 1999. Around that time, PA will return to Dar es Salaam and immediately continue to Copenhagen. CG will return to Dar, stay there for a few days to organise/discuss analysis in relation to the environmental programme and then continue to Copenhagen. HS will go to Dodoma to help arrange the analysis programme perhaps to be carried out there and at the same time instruct personnel. HS will then proceed to Dar to do similarly there, before he returns to Copenhagen. Details in the travel arrangements around the end of the fieldwork will be finally arranged on site. All tickets Dar – Copenhagen will be open.

Samples will be taken to Dar, cut and crushed, separated and split at the Geology Department under the supervision of Sospeter Muhongo. HS will decide upon the final analysis programme after discussions in Dodoma and Dar. HS will bring suitable sliced slabs of the rock samples to Copenhagen for the production of polished sections and thin-sections.

Field party:

The total field party will consist of 11+ persons; a plan for the aiming has been summarised in Enclosure 1.

- Peter Appel
Henrik Stendal
Christian Glahder
Sospeter Muhongo
Saidi Mnali
Faustino Petro
E. B. Temu
Four drivers
Occasionally, different local village guides and/or Wardens/scouts from regional Mines Offices of the Ministry

Additional participants in scientific work:
The project cannot support further participants in the fieldwork. However, international co-operation with other groups interested in the same area is desirable and very welcome. The following interested parties have been discussed and may be contacted later in the process; some of them will be involved in the pilot project during the phase subsequent to the fieldwork; others may be valuable contacts for the main project:

- Dr. Francis Tembo, University of Zambia
- Professor A. B. Kampunzu, University of Botswana
- Dr. R. Mapeo, University of Botswana
- Mr. Bulambo, Postgraduate)
- Professor M. Kabengele, University of Lubumbashi
- Professor K. Tshimanga, University of Lubumbashi
- Dr. Pekka Tusk, University of Oulo, Finland
- Drs. Mike Hamilton or Uri Amalin, GSC, Canada
- Dr. K. C. Condie, Technical University of New Mexico, USA
- Professor Robert Frei, Copenhagen University, Denmark
- Professor Hugh Rollinson, Cheltenham College, UK

Accommodation and food:
Overnights will in most cases be in huts/small guesthouses; GST will provide tents and other necessary equipment for emergencies. No food needs to be brought from Denmark, unless a participant suffers from specific cravings. All food and lodging are paid on an individual basis out of the allowances given to participants.

Vehicles:
GST will provide one pickup and one four-wheel drive car (Toyota or Nissan) running on diesel, with drivers.

Muhongo will provide two four-wheel drive cars (Toyota Land Cruisers) running on diesel, with drivers from the University car pool.

Personal items, medicine:
Danish participants should bring malaria pills (Danish authorities presently recommend ‘Malarone’). SM will bring a small supply of basic medicine from the University clinic. There
is a hospital in Mbeya. Sun-screens and ointment for heat-rash or the like, is considered personal items and should be brought individually.

**Other equipment:**
- GST will provide hammers
- Computers will be brought on an individual basis as needed. Probably, 220 V will be available at most guesthouses, but not all and not all the time. The possibility of using solar cells will be considered
- GPS will be used for positioning. It will not be attempted to use DGPS
- Cameras will be brought on an individual basis
- Rock samples will be wrapped in newspapers or similar, local material
- HS will bring some small, zip-closed plastic bags
- CG will bring small plastic bottles and sample medium (alcohol).

**Daily allowances and payment for use of vehicles:**
The present budget for the fieldwork, assumed to have been accepted by RUF, is based on RUF rules and figures quoted from Tanzania participants at the time of budgeting. The meeting here in Copenhagen showed that some of the original quotations are no longer valid. This is a surprise and a problem, which it was decided to try to solve. The new prices are still reasonable, c. half the commercial rates. Basically, the fieldwork budget must be recalculated to accommodate the following changes, which has taken place since the budgeting took place:

- Change in exchange rate for US $ from 6.80 DKK to 7.15 DKK
- Use of vehicles at 50 US $ per day per vehicle, not 25 US $
- Four vehicles, not three
- 3600 litres of diesel fuel at 1 US $ per litre, not 1500 litres (Estimate: 1200 km to field area, 2400 return, 100 km/day in 20 days in field area, four vehicles, but less driving in pickup, 5 km on one litre of diesel.)
- The actual schedule and duration for each participant
- The addition of local guides (2000 shilling per day) and Wardens (25 US $ per day) for some of the field period. For budget estimates will be used 21 Warden days.

Leif Thorning will do the re-calculation when all figures are available. Alternative ways of financing will be looked into and tried, but it is not guaranteed that the additional funding will be forthcoming. However, for now the project planning will proceed assuming this can be done.

Payment of daily allowances will be arranged as follows if possible: Daily allowances to Tanzanian participants, in US $ at the beginning of the fieldwork. Payment of use of vehicles will be according to invoice from the two organisations before the commencement of the drive to the field area. The project cashier will on an ad hoc basis pay for the fuel directly to local suppliers.

**Post fieldwork activities:**
This subject will be dealt with in greater detail later, not the least during the fieldwork period.
The programme of analysis should be concluded in time for all data to be available before Christmas. Reporting of other aspects of fieldwork should commence immediately after the conclusion of the fieldwork. Digital reporting should be used whenever possible. Details to be agreed upon later.

The first draft for quality control at the various institutes should be ready end of January.

The final report should be a part of the application for the following main project.

The writing of joint, internationally published papers will be put aside until after the 15 March deadline. Plans or preliminary manuscripts can be mentioned as products of the project in the final report, but such manuscripts will probably not be part of the final report. Joint publications are desirable.

The application for the main project must be ready for the 15 March RUF deadline.

Co-operation agreements:
The co-operative agreements were signed by the GEUS director general Martin Ghisler and Professor Sospeter Muhongo. Faustino Petro will bring two copies for GST to Tanzania and arrange for their signing. One copy will be returned to GEUS via TT when he visits Dodoma.

Enclosure 1: Summary of project dates:

11 – 14 June: Planning Meeting, GEUS, Copenhagen
3 July: Tapani Tukiainen departs Copenhagen; Flight Swissair at 1730.
4 July: TT arrives Dar es Salaam at 835 a.m. and continues to Dodoma with the assistance of Petro.
7 July: TT returns to Dar es Salaam
11 July: TT returns to Copenhagen
6 September: Christian Glahder departs Copenhagen; Flight Swissair at 1730
7 September: CG arrives Dar es Salaam at 835
8 September: Henrik Stendal departs Copenhagen; Flight Swissair at 1730
9 September: HS arrives Dar es Salaam at 835
? September: HS goes to Dodoma with the assistance from GST
13 September: Peter Appel departs Copenhagen; Flight Swissair at 1730
14 September: PA arrives Dar es Salaam at 835
15 September: All participants leave Dar/Dodoma and meet in Morogoro and continue to Mbyea; by car (altogether four vehicles)
16 September: Continue to Chunya and stay there app a week for fieldwork in Lupa district
23 September(?): Continue to Mpanda; work based here for approximately one week
30 September(?): Continue to Karema; work based here for approximately one week
15 October: End of fieldwork
15 - 25 October: Winding down and return of all Danish participants to Denmark. Organising of analysis programme
24 December: All chemical analysis data available and distributed
1 February 2000: Deadline for manuscript to final project report ready for quality control
15 March 2000: Deadline for application to RUF for main project and for completion of final report.

Enclosure 2:

Christian M. Glahder’s stay in Dar Es Salaam during c. 7 - 13 September 1999.

During my stay I wish to visit the following institutions, departments etc. Written material (reports, scientific papers, documents, acts, maps) would be most welcome, either sent to me prior to the visit in September (best) or handed to me in Dar Es Salaam. The material is primarily related to the Ubendian area, but also material covering the hole of Tanzania is of interest.

National Environmental Management Council (NEMC)
Rules and regulations of mineral exploration and exploitation, with special emphasis on environment.

University of Dar Es Salaam, Dept. of Wildlife
Knowledge of important wildlife areas, e.g., bird colonies and wetlands. Both National Parks, Game Reserves etc. and wildlife areas of importance outside the reserves, with other protection (e.g., Ramsar sites) or no protection. Any protection of Lake Rukwa. Hunting regulations with species and periods. Hunting acts.

University of Dar Es Salaam, Dept. of National Parks and Game Reserves
Especially the reserves in or close to the Ubendian area. Wildlife (mammals, birds, reptiles) and vegetation in the reserves, seasonal migrations of mammals, endangered and/or vulnerable species, research and monitoring in the reserves, restrictions in the reserves to geological surveys and mineral exploration and exploitation.

University of Dar Es Salaam, Dept. of Fisheries
General knowledge of fish populations in the Ubendian area, the importance of fish populations in the rivers of the area, migration of any of the fish populations (e.g., to and from Lake Tanganyika), the importance of Lake Rukwa, local or national use of different fish populations. The importance in terms of number of people dependant of fisheries and export to other parts of Tanzania. Is the Department or other institutions performing monitoring and research of possible contamination of fish population, e.g., from mercury.

University of Dar Es Salaam, Analytical Laboratories
Which elements (metals, organics) are analysed for, and which species, types of analysis, equipment, detection limits, intercalibration programs.

University of Dar Es Salaam, Dept. of Geology/hydrology or Geological Survey
Water catchment areas in the Ubendian area.
Meteorological Institute
Weather data for the Ubendian area, rainfall with monthly variations, prevailing wind directions in different periods.

University of Dar Es Salaam, Dept. of Social Affairs
Number of people in the Ubendian area, small-scale mines and no. of people dependant on these, area farmed, no. of people dependant on fisheries, hunting. Any active large scale mines in the area, industrial plants. Tourism.
Appendix 2

(H. Stendal and C.M. Glauder)

Extractions from field diaries: Geological record (HS) and Environmental record (CG)

Lupa Goldfield
Mpanda Mineral Field
Karema – Ikola – Kipili area
Extractions from field diaries: Geological record (HS) and Environmental record (CG).

Sample numbers in the format #xx are geological samples and are listed in Table 11. Sample numbers in *italics* are environmental samples listed in Table 14-16. Full field diaries are available.

**Locality T1 – Kikugwe**
The metasediments in Kikugwe consists of various clastic sediments such as conglomerates, sandstones, and shales. The sedimentary sequence belongs to the Buanji Series of the Bukoban sediments.

Malachite staining was seen in the grey to black shales. The copper mineralisation followed the banding in the metasediments. It looked like a typical strata-bound sedimentary copper occurrence.

**Lupa Goldfield**

**Locality T2 – Kasanga Bridge**
Exposures in the riverbed were mainly light sheared gneisses with intrusions of diorites and basic dikes. The intrusions looked undeformed and the diorite had magmatic layering. The gneiss’s were in many places hydrothermally altered – the feldspars were altered and the gneiss clearly bleached. Prominent shear zones were crossing the riverbed striking 20°. These zones were intensely sheared and altered up to one m in thickness. Patches of milky white quartz veins were seen in and around the shear zones, but we were told, that this milky quartz never contains gold.

There are a few “artisanal” operations for alluvial gold at the site. Gold is searched for with the use of traditional panning methods and a home made washboard. According to two panners meet at the site, no mercury is used for concentrating the gold. Two samples of human material and two sediment samples from the gold washing pool were taken. The two panners do not use mercury at Kasanga Bridge.

**Locality T3 and T4 – Kasanga Village (“Iron Hill”)**
The “Iron Hill” consists of Banded Iron Formation (BIF) comprising magnetite, hematite, and quartz. The contents are roughly 30% iron oxide minerals and 70% quartz.

The area contained a lot of the milky white quartz veins. The quartz veins were brecciated and at a later stage hematite stained. Sample # 1 and 2 (=461401 and 461402).

**Locality T5 – Ifumbo**
This is an open pit where active mining takes place. The mined part is an E-W striking and steeply north dipping quartz vein.

The host rock is granite but the hydrothermal alteration was extensive especially on the north wall. The feldspars were kaolinized and later silicified. Along the quartz veins the host rock was strongly sheared. The quartz was gold bearing and the sheared rocks contained a
few percentages of disseminated pyrite. The assumed gold-bearing samples were hand-picked on the spot. Sample # 3-6.

**Locality – Njiwa Village**
The ore from Ifumbo is processed in the village Njiwa. The handpicked samples are ground by manpower by hammering an iron rod into a wooden bowl where the sample is placed. The fine-grained rock powder is amalgamated in a gold pan by the hand and a stone for crushing the powder to an even more fine-grained sample. The gold is liberated from the gold-mercury pearl by heating the pearl up, so that the mercury vaporises.

In the middle of the village the ore was crushed, ground and washed with mercury in one house and yard, while the gold-mercury amalgam was burned in another house facing the yard. Many of the village’s inhabitants, both adults and children, took part in the work. The skin on their hands, arms, feet, and legs were exposed to the solution of mercury in water. The water was kept in a concrete pool basin and water normally evaporated from the pool. The sediment from the pool was placed in a pile inside the yard. Mercury evaporated from the burning of amalgam and could be inhaled by the burners and the people in the village, and also be disposed on the soil, crops etc. Five samples were taken of human hair (# 3-7), one sediment sample was taken from the gold washing pool (27), and one soil sample (28) from between the two houses with crushing and burning.

**Locality T6 – Izumbi**
A 30-40 m long open pit strikes more or less NE parallel to an undulating sinistral shearing. The host rock is granodiorite but close by a lot of basic rocks (amphibolites) occurs. The most intense hydrothermal alteration is in a two-m wide zone with heavily argillization, but where amphibolites occur, the alteration is chloritization. In the shear zone crosscutting quartz veins occur (up to 10 cm thick) and on the northern side of the pit aplite veins intrude. These intrusions seem to take place at the same time as the shearing, to judge from lamination in the aplite veins parallel to the shearing. In the silicified parts the rocks are mineralised with copper and gold. Sulphides are found in small amounts such as pyrite, chalcopyrite, and galena. A late manganese staining occur. Visible gold is recorded and one sample was purchased. Samples # 7-12.

**Locality T7 – Twiga**
The geology at this site is similar to the Izumbi, but at this place a lot more pyrite is present. Sample # 13.

**Locality T8 – Shoga**
A big open pit in basic rocks. A big discussion between participants was here concerned with some pillow-like structures, which some believed to be pillows while others did not. One view (HS) was that it is a diorite with a weathering pattern (exfoliation) formed because of the jointing in the area. The rock is a dark equigranular, middle-grained rock with no change in grain size. Ultra basic rocks also occur in the pit. In a shear zone, striking 140°, the chloritized basic rocks contain up to 5 vol% pyrite. Sample # 14-15. Two samples of human hair (8/9, 10) were also collected.
Locality T9 – Shoga Village
In the middle of the village the ore was crushed, grinded, amalgamated and burned. Many people in the village took part in the gold processing. Two samples of human hair (# 11, 12), one sediment sample from the gold washing pool (29 and sample #16), four sediment samples from the river (34-38), two soil samples (30, 31) and one Ugali (corn porridge) sample (32/33), were collected.

Locality T10 Lake Rukwa
At Lake Rukwa we bought five different fish species (40-53). All fish were caught in the Lake Rukwa, the pelagic species (Pelege, Kachinga and Gege) up to two kilometres km from the coast, the Kambale living at the bottom was probably caught near the coast. One sediment sample was taken on the beach close to the landing place (39). This place is about 15-km down-stream the Demco plant. The rivers Lupa and Zira drain the Lupa Goldfield area and run into Lake Rukwa close to this site.

Locality T11 – Rukwa mine
The old mine follows a 60° striking fault zone. The sheared basic rocks are brecciated and silicified. Copper is common and is found in chalcopyrite, bornite, and chalcocite together with pyrite. The gold is in the Russian report mentioned to be in the pyrite. Sample # 17-18.

Locality T12 – Luika
As in T11 again a sheared ore zone which the open pit follows. The host rock is again diorite, but granite also occurs. In the extensive altered shear zone quartz veining are common. The quartz veins (max. one-m thick) were jointed. It is claimed in the Russian report (Luena et al. 1974) that gold is only found in the shear zone cutting the diorite and not in the granite. This statement was not confirmed. Sample # 19.

Locality T13 – Demco plant
Sample # 20-22 are tailings. Detailed description of the Demco plant in Appendix 7.

Locality T14 – Razorback (Elizabeth mine)
The old working at Razorback strikes 140° and the mining target are quartz veins from a shear zone. The host rocks are extensive altered. Copper-bearing quartz veins and “box-work” ore were recorded. Sample # 23-24.

Locality T15 – Ilunga granite (N of Makongolosi)
The pronounced hills north of the Saza – Mpanda road comprise the Ilunga granite. It is a light coloured granite, but not completely fresh when the feldspars are altered and the granite is hematite stained in cracks. According to Professor Muhongo and Dr. Mnali the age of the Saza-Chunya granitoids are c. 1960 Ma and the Ilunga granites are 1920 Ma dated by U-Pb on zircons. Sample # 25.

Geological summary of the Lupa Goldfield
It seems that the gold mineralisation in the Lupa Goldfield is both structurally related and host rock related. The gold mineralised fluids might be magmatic coming from the huge masses of granodiorites and diorites of the Saza-Chunya granitoids (a batholith?) or from
the slightly younger Ilunga granite. The gold reefs are controlled by the fault systems in the Lupa Block and many of the gold occurrences are hosted in diorite. There is no evidence of younger intrusions, which could cause the mineralising fluids. Thus, it is suggested that the gold be of Palaeoproterozoic age.

**Locality T16 – Manyoro deposit**
This is a metamorphosed Fe-Mn deposit with spessartine. The ore body is elongated into a volcano-sedimentary series. It is a banded iron formation – see more in Tamain *et al.* (1988). Sample # 26.

**Mpanda Mineral Field**

**Locality T17 – Mkwamba mine**
The Mkwamba mine is an old copper, lead and gold mine situated a few km west of Mpanda town. Mkwamba is the biggest former operating mine in the Mpanda. The mine is placed on the pronounced E-W fault zone where smaller mines towards east also formerly were mined. “Artisanal miners” still go for gold within the old mines. The ore in situ is sitting in breccia and shear zones (N-S striking) in extensively altered host rocks. Galena is in some places massive and occurs both as a fine-grained type and a coarse-grained type. Next to galena, chalcopyrite and pyrite are the most abundant ore minerals. A late hematite veining (veinlets) has occurred. Sample # 27-30.

From an environmental point of view there is many signs showing that this big mine former was active such as:

1. a railway track leads to the mine,
2. many old stone buildings occur,
3. two big waste rock deposits are situated close to the ore,
4. two big tailing deposits are placed not far from the mine and adjacent to the Mpanda river.

One sample of tailings (55), and three samples of sediment from the Mpanda river (54, 56, 57), were collected for mercury analysis, four samples of the two tailing deposits (78, -79, -81, -82), and one sample of the waste rock deposit (80.)

**Locality T18 – One km east of Mpanda**
A good outcrop of metabasites which are common in the Mpanda area and which is part of the Katuma Series. The metabasite is middle-grained, deformed, and has a large proportion of plagioclase. Sample # 31.

**Locality T19 – Mnyakaliza**
At this locality both fresh and hydrothermal altered gneisses of the Katuma Series are common. The alteration intensity was followed towards the mineralised shear zones. Many types of alterations were observed such as argillization, sericitization, silicification, and epidotization. The mineralised veins carried galena, chalcopyrite, and a lot of siderite. These veins strike E-W. A later hydrothermal overprints the galena-chalcopyrite-siderite veins with a pronounced quartz and hematite veining. Sample # 32-33.
Locality T20-T23 – Msangama
The Msangama hill and the streams west of the hill has many rock exposures, where the Katuma Series was studied with its gneisses, amphibolites, and dikes. Exposures showed mylonites, breccias, hydrothermal altered rocks, and basic rocks with a variety of textures. The general strike of the rock pile is SE-NE with steep to vertical dipping. Also ultrabasic rocks were recorded. Sample # 34 (T20), #35 (T21), #36 (T22), #37 (T23).

Locality T24-T27 – Kasimba and Simbo
Kasimba and Simbo are located on the E-W fault zone east of Mkwamba mine. The western part of Kasimaba comprises a breccia zone with alterations of the host rocks such as silicification and epidotization. The host rocks are gneisses and amphibolites. The breccia zones are filled out with quartz and contain disseminated galena, pyrite, chalcopyrite, and siderite. A few kilometres further eastwards the breccia zone gets more silicified and contain fewer ore minerals. At Simbo the host rocks are very altered and it is hard to recognise the parent rock. Here hematite is a pronounced ore mineral in veinlets. Along the Kasimba-Simbo trend there are several small pits and trenches from former exploration and from artisanal mining. Sample #38 (T25).

Locality – T28-T30 – Kapalamsenga
The Ubende Series (?) contains a lot of basic rocks which are metamorphosed in high amphibolite to granulite facies and in some places the metamorphic grade may even reach the eclogite facies. Most of the rocks are garnet amphibolites. The possible eclogites have green minerals, garnet, and a considerable amount of quartz. The eclogitic rocks are pervasive micro-veined with dark veinlets. Sample #39-40 (T28), 41 (T30).

Locality T31 – D-reef
The investigation of the gold occurrences along the NW-SE fault zones close to the border between the Katuma Series and Ikulu Series started at this site. There are not many outcrops. The artisanal miners follow the old mine operations and work up to 20-m underground. From the ore boulders it appears that copper is abundant together with oxidised ore (goethite). The miners take the gold-bearing ore from the oxidised ore. They are not able to take gold out of the copper ore (chalcopyrite and bornite). The ore zone is clearly brecciated and has a late phase of hematite veining. The ore is processed at place in the D-reef village. Sample # 42-46.

The ore was crushed by hand at the mining site before it was transported to one of the two places where concentration, amalgamation and burning took place. The first place was in the outskirts of the D-Reef village and the second site was about one km from the D-Reef village at the Mpanda River. Many men of different age took part in the work, and their skin on hands, arms, feet and legs were exposed to the mercury in the water. In both places the water was kept in a pool dug in the ground. The burning of the amalgam was done over open fire at the site. At the village site the water from the gold washing pool will flow about half a km in a stream draining into the Mpanda River. This tributary was without running water at the time of our visit, but water was just below the surface of the riverbed, and drinking water is taken from here (60 and 61). At the Mpanda river site the gold washing pool was made on the shore of the Mpanda River, and often the pans were washed in the
river. The D-Reef site is situated downstream the Mkwamba mine. At or near the village site, one sediment sample from the gold washing pool (58), two sediment samples from the tributary (60, 61), one soil sample from a nearby Cassava field (59), one Ugali (corn porridge) sample (62/63), and one corn sample (64), were collected. At the Mpanda River site one sediment sample from the gold washing pool (67) and two sediment samples from the Mpanda River (65, 66), were collected.

Six samples of human hair (13-19) were taken, whereas three were amalgamists and burners, and three were farmer, panner, and teacher respectively.

**Locality T32 – Kapanda**

Both fluvial and hard rock mining took place here. In the old pit a new shaft is dug to a depth of nearly 20-m. The gneiss in the pit is extensively altered especially by sericitization. Aplite dikes (10 cm thick) intrude the gneiss. The reef with the ore is only 10-20 cm wide and strikes NE, dipping 60° SE. Amphibolites occur fairly fresh in the pit and contain pyrite. Chalcopyrite and hematite dominates the ore zone, but galena is also observed even if it is not so common here. Sample # 47-50.

The mining site was situated on a hill about one kilometre from the Kapanda River where the gold processing takes place. At the mining site artisan miners had dug a hole of c. 30-m in depth, 40-m in width and 2-300 m in length in about 12 years (since 1987). A new shaft of about 20-m was dug together with a ventilation shaft. Waste rocks were found downhill. The ore is transported down to the Kapanda River and amalgamated. Water was not flowing in the river, but occured in the riverbed just below the surface. The drinking water pool was placed in between two waterholes used for amalgamation within a distance of 10 m. Malachite-staining occurs at the walls of the pools. The Kapanda River runs from the amalgamation site to the Katuma River.

At the Kapanda River, one sediment sample from the gold washing pool (69) and one sediment sample from the drinking well (68), were collected. Two samples of human hair from amalgamists and burners (20 and 21) were obtained.

**Locality T33 – Magamba**

The shear-breccia zone is rich in pyrite and strikes N-S and dips steeply towards west. The gold is only processed from the oxidised ore. The mineralised reef is only 5-30 cm thick. The ore mineralised veins have pyrite and siderite and later veins of hematite. The mining shaft looked very dangerous with big loose blocks just over the shaft entrance. Sample # 51-54.

**Locality T34 – Ikulu veins**

Here are several trenches where quartz veins are exposed. The veins comprise chalcopyrite, pyrite, siderite and the typical overprinting of hematite veining. Sample # 55.

**Locality T35 – Ibindi “B”**

Great efforts by many workers were spent to reach the gold-bearing reefs in 6-8 m depth. But no real exposures were seen in this part. The reefs are only 10-20 cm wide. Some of the ore in the stockpiles were studied before they were processed. We were presented for
'the real stuff' – the gold in a rather coarse-grained form. The ores are quartz veins with chalcopyrite and hematite. Sample # 56-57.

**Locality T36 – Ibindi “A”**
Ores from an old pit were examined. These brecciated quartz specimens were rich in ore minerals such as galena, chalcopyrite, chalcocite, and siderite. Hematite was present, but not dominating at this site. From the hand specimens it was possible to describe a paragenetic evolution of the ore minerals: After the brecciation, chalcopyrite was interstitially precipitated between the breccia clasts. In the next step galena was introduced and small galena veinlets crosscutted the chalcopyrite and replaced the chalcopyrite as well. Siderite appeared as gangmineral and a final hematite veining occurred. Simultaneous with the introduction of the ore minerals, silicification occurred. The general strike between Ibindi “A” and “B” is 35°. Sample # 58-60.

**Locality T37-T38 - Mtukula**
Mtukula covers an area starting at the foot of a hill and going to the top of the hill. It is hard to judge if the Mtukala is an elongation of Ibindi “A” and “B” or not. The host rocks at the foot of the hill are strongly silicified and have chalcopyrite and siderite in the veins. At the top of the hill a new trench was in progress in a shear zone, but the reef with gold were only 2 cm wide (N-S striking). In the sheared and silicified gneisses occurs a 10 cm wide zone with a lot of graphite (striking E-W dipping 75°S). This was the first time during the fieldwork graphite was observed. Sample # 61 (T37), #62 (T38), and five tailing samples from the Mkwamba area collected by CG (# 101b-105b).

**Locality T39 – Singiliwia**
The gold reef belongs to an E-W fault system but a parallel system to the Mkwamba-Simbo one. The quartz reefs are 10-80 cm wide and dipping 60°S. Some of the reefs can locally be up to 1.4 m wide. The gold content is in general 5-8 g/t, but up to 16 g/t Au has been recorded. In the big pit, two reefs were joined together and yielded 10 g/t Au. The ore contains chalcopyrite, pyrite, barite, small amounts of galena, and coarse-grained siderite. It should be noted that the galena presented by the miners, were in actual fact hematite. The hematite occurs as late veins as usual. Sample # 63-64.

**Localities in Katavi National Park**
Sediment samples were collected in the northern part of the Katavi National Park with the assistance of an armed guide. Lake Katavi was almost dry and looked more like a swamp area. Big numbers of Hippopotamuses (c. 200), Buffaloes (c. 800), Zebras (c. 100) and antelope species (c. 300) were observed in the lake area. Sediment samples were taken at the following sites: Katuma river before Lake Katavi (#72; T 108.), southern part of Lake Katavi (#71; T 107), Katuma River after Lake Katavi (#70; T 106), Katuma River immediately after inlet of Kabenga River at Sitalike village (#74, T 110) and Katuma River in the National Park south of Sitalike (#73, T 109).

**Locality T-Mpanda town**
Three hair samples were collected from the owner and to employees from the Moon Light restaurant in Mpanda (# 22-24). These individuals will serve as controls, i.e. not involved in gold mining and not living in villages with such activities nearby.
Geological summary of the Mpanda Mineral Field

The base metal and gold mineralisations are widespread and controlled by structures and to a certain extent the host rocks. It looks, as it copper is only present if basic rocks occur in the vicinity of the mineralised veins. The gold occurrences north of Mpanda have not been visited, but should be planned to study in future projects. The mineralised fluids can be of Palaeoproterozoic age but also much younger. The young fluid system is evidenced in the Sangu carbonatite (see next paragraph) area where quartz-copper-hematite must be younger than the carbonatite veins, which have the same appearance as the veins in the Mpanda area.

Karema – Ikola – Kipili area

Kankulukulu T40 and T49
Along the Karema-road we tried to localise the Kankulukulu occurrence. The first outcrop was a matrix supported conglomerate (T40) of the Bukoban Series. The clasts were 1-10 cm in size and comprised all types of rocks seen in the Ubendian such as gneisses, granites, and amphibolites. Close by the Ufipa Series (?) is exposed, in which the copper occurrence of Kankulukulu should be. Here is a sequence of greenstones with intercalation of sericite schist and quartz layers (chert?). On the southern side of the road close to the foot of the Kankulukulu Hill there is a pronounced boundary between the greenstones and muscovite schist. The hill consists of the latter rock type. However, no copper was found. Samples # 73-74.

Localities T41-T44, Sangu carbonatite
Three phases of the carbonatite was recorded. The first two phases, which are a light grey and a red carbonatite, dominates. The grey phase contains apatite and the red phase has up to 5vol% of magnetite. The magnetite is disseminated but bigger patches up to 10 cm in thickness occur. The third carbonatite phase is more rare and is a fine-grained dark phase with disseminated pyrite. Fenitization occurs in this type. It is uncertain how much carbonate is present in the latter type, due to only a weak reaction with hydrochloric acid. Several trenches occur throughout the carbonatite. The trenches are all found in connection with brecciation and silification. Fluids have altered the carbonatite host rock so argillization, calc-silicate formation and silification are common. Most of the veins are either striking NNE-SSW or SE-NW and in general they are one m in thickness. The breccia zones are copper mineralised with chalcopyrite which are cut by a later hematite veining as seen several times in the Ubendian rocks. Graphite is also recorded in the veins. Sample # 65-67 (T41), 68 (T42), and 69-70 (T43).

Localities T45-T46, Njasa
Just outside the carbonatite, quartz veins occur in the metamorphosed basic rocks (Ukulu or Ubende Series?). The quartz veins are brecciated (up to 2 m in thickness) and the matrix consists of red carbonatite. The amphibolite clasts (up to 10 cm) in the breccia are heavily altered. The breccia zones strike SE-NW and are copper mineralised with chalcopyrite and bornite. The locality has at least 10 trenches within an area of 200 m x 300 m.
One of the hills deep in the forest consists of an ultrabasic body located in garnet amphibolites. According to Tamain (1988) and the Russian Geological map these ultrabasic bodies should contain chromite. This was, however, not found.

Sample # 71 (T45) and # 77 (T46).

Localities T47-T48, Shukula (N of Ikola)
The metabasites and ultrabasic rocks of the Ufipa Series are exposed at Shukula. The metabasites are garnet amphibolites and the ultra basicrocks are pyroxenites with a few specks of chalcopyrite and disseminated pyrite. A NW-SE fault zone constrains the extension of the basic rocks. On the eastern side of the fault zone quartzites dominate together with quartzitic gneisses. These gneisses had characteristic bluish quartz. According to the Russian map there should be a copper occurrence close to the fault zone, but this was not found. Sample # 72 (T48).

Locality T50, East of Kabwe
In the Ufipa segment containing a lot of gneisses, in many places mylonitised and heavily altered to sericite gneisses and subjected to extensive silicification. The silicification produces a lot of milky white quartz veins, sometimes with a sugary texture, up to several metres in thickness and up to several hundreds metres in length. The mylonitic zones strike 140° and dip vertical or steeply towards NE. No metal mineralisation was found. Sample # 75.

Locality T51, Namanyere – Kipili road
This site is in a new segment, the Kate Volcanics, which here consisted of the Kate granite. According to the Russian map there should be two phases of the Kate granite. The first phase are a porphyritic granite and the second one a biotite granite. The field observations, however, suggest that the two granites originally are the same. The coarse-grained porphyritic K-feldspar granite is sheared and the K-feldspars are altered and the quartz grains are elongated. The shearing strikes at site 30° and dips 45°SE. The field relations show gradual transition from one granite type to the other. In these granites copper is recorded but we did not find any. Sample # 76.

Geological summary of the Karema – Kipili area
Most of the mineralisations visited are found in connection with quartz veins in shear and/or breccia zones. The same types of veins are found both in the Palaeoproterozoic rock units and in the Neoproterozoic Sangu carbonatite and Bukoban sediments. The Karema-Ikola area has many basic to ultrabasic rocks with good exposures and with access to fresh rocks. The potential study area should be expanded northwards from Ikola where extensive areas of basic rocks occur.
Appendix 3

(P.W.U. Appel)

Gold mining and gold extraction by amalgamation

Figures 10 - 14
Gold mining and gold extraction by amalgamation

In the field area small-scale miners (artisanal miners) carry out extensive gold mining. Two types of small-scale gold mining take place: placer mining and gold reef mining. Placer mining is done in rivers and streams. This involves digging and panning of sands and gravel, and poses no significant environmental hazards. The small-scale mining of gold reefs is more widespread and results in serious mercury pollution. The size of the operation range from a few to a dozen persons digging pits in the order of a few tens to about 50 metres deep (Fig. 10). The gold reefs consist of quartz some carbonate and small amounts of sulphides and gold. The gold is generally fine-grained. The samples we investigated in the field contained visible gold up to about a millimetre in size. Microscopic investigations of the collected samples showed that the grain size of the gold is from about 5 µm to about one millimetre. The gold reefs exploited by the small-scale miners range from 4 cm to a few metres in widths. In some places, the deep tropical weathering has affected the country rock, which now often appears as soft red ground. This makes the digging quite easy, but the soft red soil lends little support to the walls in the pits, which means high risk for collapse.

Hand (Fig. 11) and then ground in wooden trunks crush the gold ore by old car axles (Fig. 12). After grinding the ore is panned and the light material discarded. The heavy material which contain the fine-grained gold is then treated with metallic mercury (bright spots in Fig. 13) in the pan. The ore-mercury mixture is stirred by bare hands in water and the overflowing water containing traces of mercury is spilled into the basin where the panners sit barefoot (Fig. 13). During the stirring of the ore-mercury mixture the gold forms an amalgam with the mercury. The amalgam is heated in an iron cup over open fire (Fig. 14) whereby the mercury evaporates and the gold is left in the cup. The evaporated mercury is partly inhaled by the amalgamists and the other inhabitants in the villages and partly condensed on the soil. The condensed mercury is washed into the drainage system during the wet season where it enters the food chain either directly as metallic mercury or as methyl-mercury, which is even more toxic than metallic mercury.

At the DEMCO processing plant South of Lake Rukwa, a so-called retort was demonstrated. This is a very simple gadget constructed to recover mercury when the amalgam is heated over open fire. The iron cup with the amalgam is placed in the retort, which then is placed in the open fire. A cooling system with ribbons cooled by air or wet cloth leads to a flask which collect the condensed mercury. This retort is quite inexpensive and very efficient. If the amalgamists in the villages could be presented to use the retort they would save substantial amounts of money and save the environment for large quantities of mercury.
Figs. 10-14: For explanation, see text Appendix 3
Appendix 4

(Field Team Group)

Minutes of the meeting of the integrated research project on the Ubendian belt held in Mpanda town on 27.9.1999
Appendix 5

(L. Thorning and T. Tukiainen)

Details on the GIS compilation of existing data

Tables 2 - 6
Details on the GIS compilation of existing data

Apart from the geophysical and Landsat 5 TM data from the Geological Survey of Tanzania, the digital datasets were generated by GEUS by scanning the available topographic and geological maps covering the areas of interest. The GIS compilation was done using ArcView™ Ver. 3.2 software. In order to make the data sets usable for other GIS-software, the data is stored in formats exportable to the most common GIS-systems.

The UTM projection of the modern topographic 1: 50 000 scale base maps of Tanzania was used for the GIS-compilation of the datasets:

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<th>UTM</th>
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</tr>
<tr>
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</table>

The GIS compiled data sets of this study are listed in Table 1 – 5 of this Appendix. These data sets are available as ISO standard CD-ROM. The relevant data processing details are summarised in the following.

**Topographic maps 1: 50 000**

Only paper hardcopies of the topographic 1: 50 000 scale base maps were available for this study. The maps totaling 36 sheets were scanned with the resolution of 300 DPI and saved as B/W tiff files. The maps were georeferenced to conform to the appropriate UTM projection and converted to Geotiff format. The nature of the original material implies that the accuracy of georeferencing is limited, as can e.g. be seen along map sheet boundaries when mosaicing the georeferenced maps in GIS system. Future, more detailed use of the topographic base may necessitate a more detailed editing and vectorisation of the topographic features.

**Geological maps 1: 125 000**

The 1: 125 000 scale geological map of Tanzania published by the Geological Survey of Tanzania were scanned with the resolution of 300 DPI and saved as color (16 bit) tiff files. The map sheets were georeferenced and resampled to conform to the required UTM projection. The registration of the georeferenced geological maps with the topographic base maps is as a rule rather poor. This is due to the fact that the original topographic base for
the geological maps is of inferior quality and the scanning was based on the paper hard-
copies. Because of the overall poor cartographic quality, the vectorisation of the geological
maps was not considered viable in the pilot project, but will be necessary in the future main
project.

**Geophysical Data**

Most of the digital basis data (as Geosoft™ XYZ-files of digitised magnetic contours) for
the production of the aeromagnetic map was available from the Geological Survey of Tan-
zania. However, XYZ-data were missing for some map sheets and therefore these map
sheets were digitized by GEUS in the pilot project.

**Landsat TM Data**

Digital data for four full scenes of Landsat 5 TM data were available from the Geological
Survey of Tanzania providing an almost complete coverage for the area of interest:

<table>
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<td>171</td>
<td>065</td>
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<tr>
<td>172</td>
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</tbody>
</table>

The satellite image data was primarily used to a) improve the readability of the base maps,
and b) for vegetation studies by calculating the normalised vegetation indexes from the
Landsat data by using the following formula:

\[
\text{NVDI} = \frac{(\text{TM3} - \text{TM4})}{\text{TM3} + \text{TM4}}
\]

The NVDI data was calculated for all four Landsat 5 TM scenes and saved as tiff files: The
NVDI-values from −1 to + 1 were lineary mapped to the range 1 – 255. The calculation of
the NVDI indexes were based on the raw data from scenes with highly variable acquisition
dates.

The Landsat TM data for the Karema – Mpanda area was georeferenced and resampled
before being mosaiced to the UTM projection used. The atmospheric correction was done
done by using the black pixel extraction and the image was enhanced slightly by standard
methods. The colour composite of (TM4= red, TM3= green, TM2=blue) was converted to
a geotiff file for use as back drop in the GIS.

**Tabular data**

A list of selected mineral occurrences/mineral localities (mineral.db4/mineral.txt) with geo-
ographical coordinates was made available by the Geological Survey of Tanzania. The po-
positioning accuracy of this data is comparable to that of the geological maps.

The information with the geographical coordinates concerning the rock samples collected
during the fieldwork in the pilot project are contained in a special file, coordi-
A hand held GPS instrument was used for the positioning of the sample localities.

Table 2. Topographic maps at scale 1:50 000; 189 MB of data

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Surveys and Mapping Division, Ministry of Lands, Housing and Urban Development, Government of the United Republic of Tanzania)
### Table 3. Geological maps at scale 1:250 000, 398 MB of data

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The Geological Survey of Tanzania

### Table 4. Airborne Geophysical data; 23.2 MB of data

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</table>

The Geological Survey of Tanzania; digitised magnetic contour data by GST (Map sheets – 150-157, 169-174, 188-192,205-211, 224-229, 241-246, 257-262, 272-275) and GEUS (Map sheets - 169W, 187); processed by GEUS to 500 x 500 metres grid

### Table 5. Landsat TM data, 1040 MB of data

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Courtesy of GST; System corrected data

### Table 6. Tabular data

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GEUS & GST
Appendix 6

Geological sample sites and analytical data

Figure 15: Sample sites in the Lupa district, western part
Figure 16: Sample sites in the Lupa district, eastern part
Figure 17: Sample sites in the Mpanda district
Figure 18: Sample sites in the Karema – Ikola area

Table 7: INNA results: Actlabs
Table 8: ICP results: Actlabs
Table 9: Fire Assay and AAS results: Madini
Table 10: Fire Assay and AAS results: SEAMIC
Table 11: Geological sample description
Table 12: Geographical coordinates of the sample sites and the link to the sample numbers
Table 13: Pb-Pb isotope results
Appendix 7

Details on some environmental aspects

Mercury in the environment
Other metal in the environment
Mining, land use and environmental protection
**Details on some environmental aspects**

Much of the environmental work in the pilot project was concentrated on the use of mercury in small-scale gold mining and the possible mercury contamination of miners, inhabitants of the villages in the vicinity of the mines, and the environment. Also the possible contamination of the environment from lead, copper and other metals was studied in one area with an abandoned lead-copper mine. Finally, the physical impact on the environment derived from the mining activities such as forest clearings, digging of pits, road constructions etc. was studied. These three different aspects of mining activities in the South-West Tanzania are described in the following subsections.

**Mercury in the environment**

Small-scale gold miners heavily use inorganic mercury in order to extract the gold from the ore. The use of mercury in gold extraction is described in detail in Appendix 3. Gold is mined in two different ways: placer mining and gold reef mining. Mercury is probably only used in gold reef mining. One placer gold mining site (Kasanga Bridge) was visited and samples were collected of hair from two of the miners and sediments from the washing pools (Tables 14 & 15). All other mining sites visited were gold reef mines. A total of 11 such gold reef mines were visited in the Chunya (Ifumbo, Izumbi, Shoga and Rukwa) and Mpanda (D-reef, Kapanda, Magamba, Ikulu, Ibindi A, Ibindi B and Singiliwa) area. Moreover, six gold extraction places, mostly in villages in the vicinity of the mines, were visited in the Chunya (Njiwa/Mlimajine and Shoga villages) and Mpanda (D-Reef village, Kapanda river, Magamba-Ikulu and Demco processing plant (see detailed description below)) area. At the gold reef mines and in the gold extraction places samples were collected of human hair (miners, ‘amalgamists’, burners, farmers, panners and teachers), corn porridge (Ugali), corn, soil and sediment (amalgamation pool, rivers both upstream and downstream amalgamation, wells).

To compare the mercury content in humans in the mining areas with persons supposedly not in contact with gold mining, hair samples were collected of three men working in a restaurant in Mpanda town All 22 persons from whom hair samples were collected were men (Tables 14 & 15). The reason for this is the fact that women can be heavily contaminated with mercury from their use of mercury containing soaps meant to bleach their black hair and skin. The mercury contamination of the environment farther away from the gold mining areas was studied by analysing river and lake sediment samples from the Katavi National Park south of Mpanda, and fish species from Lake Rukwa (Fig. 19, Table 16).

Gold mining activities mainly take place in the dry season from May to December. In the Chunya area at least 3 000 individuals are directly involved in the activities and about 50-60 kg mercury are used per month (local Geological Survey of Tanzania mining engineer J. Mushi, pers. comm.). In the southern Mpanda area at least 1,000 persons are involved in mining activities (local Zonal Mines Office technician J. Mwakabbage, pers. comm.). So in these two areas at least 600-700 kg mercury are used and spread to the environment each year. According to Ikingura & Mutakyahwa (1997) 5 600 kg mercury per year were released from small-scale gold mining activities in Tanzania during 1991-1995, of which about 25% or 1 400 kg probably were released from the Chunya/Mpanda gold fields alone.
The ‘amalgamists’ and burners had on average a total mercury content in the hair of 2.86 ppm (SD=3.69, n=9) and the miners and panners had on average 1.79 ppm (SD=1.87, n=4). The farmers and the teacher living in the mining villages had on average a mercury content in their hair of 0.20 ppm (SD=0.10, n=6), and the three persons working in a restaurant 0.10 ppm (SD=0.07, n=3). So, individuals working intensively with the mercury have about 30 times more mercury in their hair than the control persons. Mercury content in ‘amalgamists’ of 2.9 ppm is comparable to the 3.3 ppm in hair of small-scale gold miners at Lake Victoria (Kahatano et al 1998, Table 17).

The mercury concentration in the sediments in the amalgamation pools was on average 46.50 ppm (SD=67.3, n=5, variation=5-165 ppm), and the mercury content in the soil 2-50 m from the amalgamation and burning activities was on average 9.79 ppm (SD=15.8, n=3). This average soil content is 20 times higher than the average mercury content in Earth’s crust of 0.5 ppm (Weast 1977). About 200 m from the amalgamation activities, the mercury concentration in soil was only 0.1 ppm. Crops like corn and cassava were grown in the villages nearby the gold extraction, but the mercury content in only one corn sample was low (0.04 ppm). Porridge (Ugali) made from corn had in two samples an average mercury concentration of 0.11 ppm, and this somewhat higher content could perhaps stem from the water. Drinking water were in most villages taken from or near the dried out river beds, and in one case the mercury content in the well sediment was 0.61 ppm. This well, however, was situated only 10 m from an amalgamation pool. Sediment samples from two other wells situated 500-1,000 m from gold extraction were on average only 0.01 ppm. No water samples were collected due to conservation difficulties and the necessity of large volumes.

The mercury content in the amalgamation pool can be spread to the environment in different ways. The sediment can be removed from the pool and placed in a deposit nearby. The wind will then gradually spread the fine-grained material. The dry sediment can also be transported to the nearby river to recover more gold by a second amalgamation. Also, amalgamation can take place at or directly in the river. The mercury content in the river sediment 10-25 m downstream the amalgamation pool was on average 1.13 ppm (n=2), while the concentration 500-1,000 m downstream was on average 0.06 ppm (SD=0.10, n=4). This value is about three times higher than the average mercury content of 0.02 ppm (SD=0.01, n=4) in river sediment upstream from the amalgamation pools. Mercury content of 0.02 ppm was found also in sediments from the washing pools used by placer gold miners indicating that no mercury is used in placer gold mining.

In order to follow a possible long distance transportation of mercury from the small-scale gold mining sites, sediment samples were collected from rivers and lakes in the Katavi National Park (Figure 20). The Katuma River enters the northern border of the park after it has passed through many gold mining sites; the nearest site is about 25 km from the national park. The Katuma river flows into Lake Katavi, and meets after the lake with the Kabenga river. The Kabenga river has further upstream passed other gold mining sites. The mercury concentration in the sediments seems to decrease from the place where the Katuma river enters Lake Katavi (0.06 ppm), to Lake Katavi (0.05 ppm) and to the place where Katuma river leaves Lake Katavi (0.03 ppm). Where the Katuma river meets with the Kabenga river, the mercury concentration increased to 0.21 ppm. About 20 km further downstream the mercury concentration in the Katuma river sediment had decreased to 0.13 ppm. There-
fore, it seems likely that most of the mercury contamination stems from the mining areas situated in the water catchment area of the Kabenga River.

The possible mercury contamination of different fish species eaten by people in the gold mining areas was studied in the Chunya area at Lake Rukwa (Figs. 1 & 19). In the southern part of the lake, situated downstream the Lupa Goldfield area, five different fish species were bought and their muscles subsequently analysed. The mercury content in the Kam-bale *Clarias gariepinus* (a catfish) was on average 0.6 ppm (SD=0.4, n=4). This mercury content was comparable to that of the one Pelege of 0.3 ppm and the five Gege with an average mercury concentration of 0.5 ppm (SD=0.2). The one Ningu *Labeo victorianus* had mercury content of 1.4 ppm, the highest of all fish analysed. The Kambale and the Ningu are bottom dwelling species, and they were expected to have a rather high mercury concentration, because inorganic mercury by bacterial activity is converted to organic mercury in the bottom sediment. This organic mercury, e.g. methylmercury is readily transferred to the fish through digestion and across the gills. The one Kachinga *Hydrocynus vittatus* (Tiger fish) analysed, had a mercury content of 1.1 ppm. This species is a predatory fish, so it was expected to have a higher mercury content than Pelege and Gege, because of bio-concentration of organic mercury in the food chain.

In Denmark, fish with a mercury concentration of above 1.0 ppm must not be sold or exported for consumption (Miljøministeriet 1985). According to this threshold value two of the Lake Rukwa fish species analysed exceeds this value.

In conclusion, gold miners have mercury content of c. 30 times higher than individuals not involved in gold mining. Soils and sediments in the vicinity of the amalgamation places are contaminated by a factor of at least 20-60 times that of the baseline values and the mercury content of fish used for consumption are above or close to the acceptable threshold value.

A major improvement of the mercury content in humans and in the environment would be obtained by the introduction of retorts. In Brazil the use of retorts decreased the mercury contamination of the environment to 1% (Ikingura & Mutakyahwa 1997).

**Other metals in the environment**

The possible metals contamination of the environment from the abandoned Mkwamba copper and lead mine was studied. The mine is situated in the Mpanda area. Two big waste rock deposits are situated close to the ore, and two big tailings are placed in the mine area and adjacent to the Mpanda River. This river flows into the Katuma river that enters the Katavi National Park. There was still some small-scale gold digging taking place in the area.

The mercury concentration in the tailing sample (0.06 ppm) was low compared to the average mercury content in Earth’s crust of 0.5 ppm (Weast 1977). There was no differences in mercury concentrations in the sediments from upstream and downstream the tailings deposit (average upstream: 0.02 ppm, and downstream: 0.03 ppm, Table 16).

The southern tailings deposit contains 0.3 % (or 3,000 ppm) copper, 0.2 % lead, 1.2 % manganese and 21% iron. The metals concentrations in the northern tailing are 0.1 % cop-
per, 0.3 % lead, 0.8 % manganese and 13 % iron. The gold concentration is on average 0.5 ppm in the tailings. There are differences in metals content when samples are taken ½ m and 1½ m from the tailing surface, respectively, but no trend is discernible. The waste rock deposit contains 0.08 % copper, 0.7% lead, 0.3% manganese and 5% iron. (Tables 7,8 & 18).

In order to follow a possible long distance transportation of metals from the Mkwamba mine, sediment samples were collected from rivers and lakes in the Katavi National Park (Figure 20) and analysed for different metals (Cu, Mn, Fe, Zn, Pb, Ag and Au). Because of the high copper and lead concentrations in waste and tailings deposits of the Mkwamba mine, it could be expected that relatively high concentrations of these two metals could be found in the Katuma river sediment inside the Katavi National Park, assuming no other natural sources in the area. The copper concentration in the sediments decreases through the Katuma lake from 126 ppm before to 25 ppm after the lake, increases to 82 ppm where the Katuma river after the lake meets with the Kabenga river and decreases to 53 ppm about 20 km further downstream. The lead concentration in the sediments is almost the same throughout the Katavi National Park with concentrations of 25-48 ppm. Copper and lead is not only confined to the Mkwamba ore, but is also found in many of the gold bearing ores. Therefore copper and lead can be exposed in the gold producing areas and thereby contribute to the elevated concentrations in the river sediments downstream the gold mining sites. The average copper and lead content in earth’s crust is 70 and 16 ppm, respectively (Weast 1977). According to these values the concentrations of both copper and lead seems to be slightly elevated.

In conclusion, copper and lead concentrations in the sediments of the rivers flowing into the Katavi National Park are elevated compared to the Earth’s crust, but more sediment samples from the rivers upstream of the mining areas are needed to establish the local baseline concentrations. Also, sediment samples from the rivers between the mining areas and the national park is needed, as well as biological samples.

**Mining, land use and environmental protection**

The natural vegetation of the Chunya and Mpanda area is the deciduous Miombo forest rich in hardwood species. People are in general living in small villages, with Chunya, Makongolosi and Mpanda as the only bigger towns in the area. People grow crops such as corn and cassava in an extensive agriculture, and holds few animals such as hens and goats. The most common way to grow crops is to clear an area in the forest by burning the trees, and after a few years start over again in a new place. Some tribes keep imported cattle and live like semi-nomads. Late in the dry season (September-October) they burn off the dry grass to stimulate the growth of fresh grass for their cattle. In some areas tobacco is grown, as shown on the land use map for Chunya (Fig. 19). Hardwood trees are cut to some extend, and in some areas the forest is totally cleared. The Miombo forests are used by bee-farmers that by extensive methods produce hundreds of tons of honey and bee-wax. Fish are caught in the Rukwa and Tanganyika lakes, and the fish are often transported over great distances to be sold on the markets in e.g. Mpanda. More recently, poison has been used to catch fish in the rivers in the area. Many people are dependent of small-scale gold mining in the area, and some work as farmers during the rainy season.
(December-May) and as miners in the dry season. The physical impact on the environment will be described in the following.

The Katavi National Park, rich in wildlife, is situated in the area. Outside of the national park rare mammal species like Chimpanzee *Pan troglodytes*, Wild dog *Lycaon pictus* and Puku *Kobus vardoni* (an antelope) can be observed in few numbers. Nile Crocodiles *Crocodylus niloticus*, on the other hand, are increasing in numbers in Lake Rukwa. Of bird species, Wattled crane *Bugeranus carrunculatus*, Denham’s bustard *Neotis denhami* and Shoebill *Balaeniceps rex* are decreasing in the area due to general human activities, while species like Long-tailed cormorant *Phalacrocorax africanus*, Great white egret *Egretta alba* and Open-billed stork *Anastomus lamelligerus* thrive in large populations.

**Small-scale gold mining**

Placer gold mining takes place in or at rivers in the area, resulting in many smaller holes in such areas. In the rainy season these holes can increase the turbidity of the rivers, and, to a smaller extent, change the course of the rivers. Also, roads can be damaged by these gold-digging activities. According to the Mining Act (1998) mining activities must not take place closer than 30 m from ordinary roads and 50 m from highways. When mining is finished the holes must be back-filled. When gold is dug from gold reefs, pits of 20-40 m of depth are constructed, and the waste rock is dumped on the sides of the pits. There seemed to be no back filling in any of the gold reefs that we visited. In one place, a major clearing in the forest was made to construct an open pit, a pool for water storage, buildings and a connecting road. Despite the many holes and pits dug in the area, we saw no signs of soil erosion. Also, there seemed to be rather few connecting roads in the area. In general, the impact on the environment of the small-scale gold mining seems to be small. This is mainly due to the very limited use of heavy equipment, and the relatively small amount of ore and waste produced over time.

**Larger mining activities**

The only two large-scale mining activities in the area are the abandoned copper-lead Mkwamba mine and the Demco Processing Plant. This Demco plant has, for the time being, reduced it’s gold extraction activities. At the Mkwamba mine nothing seems to have been done to re-establish the environment: two big waste rock deposits, two huge tailings deposits, as well as houses and railway tracks are visible in the area. The waste rock, rich in different metals as described above, is used for road construction, buildings etc., whereby the metals are widely spread in the area. The two tailings are uncovered by vegetation, and they are situated right down to theMpanda river, so that the metals in the tailings are easily dispersed by wind in the dry season and by water in the rainy season. At the Demco Processing Plant a huge tailings deposit, and two smaller ones, are visible in the area. The main threats to the environment are, as described above with the tailings from the Mkwamba mine, the metals dispersed in the environment by water and the wind. The Lake Rukwa is only 15 km downstream of the Demco plant.

In conclusion, there seems to be no major physical impact on the environment, such as soil erosion, due to the different mining activities in the area. Smaller impacts, such as turbidity of rivers and damages to roads can be mitigated by backfilling of abandoned mining sites.
Major concern must be expressed on the dispersal of metals from tailings and waste rock deposits left at the Mkwamba mine and the Demco Processing Plant.

Description of the Demco Processing Plant
The Demco plant is situated close to the Saza village. In the village a well was observed which in former days was a mineshaft. The Demco plant processes both gold bearing boulders taken by the plant itself at the Razorback/Elizabeth mine, and gold ore from the local small-scale miners. For the time being the plant is not in function because diesel is too expensive to buy. The Demco plant awaits a connection to the National Hydropower Plant which is able to deliver cheaper energy, but the cable connection is still pending due to financial problems.

Mr. Christian Gregory, Demco, guided a tour through the plant. The ore is crushed in a big jaw-crusher and afterwards ground in ball mills. The ground material is then concentrated in spiral concentrators, and the heavy gold-bearing fraction is transferred to the amalgamation process. Amalgamation takes place in a closed system, and the process normally lasts for two hours. From a valve in the bottom of the amalgamation barrel the mercury-gold amalgam is poured into a bucket. The amalgam is afterwards burned with the use of a retort so that mercury is recovered. The retorts are produced by the Institute of Production and Industry (IPI), and the prize for a retort is about 30US$. The residue from the amalgamation is poured into a copper plate, mercury is added, and the residue is manually ground with a stone. The worker wears rubber gloves. The amalgam from this process is burnt. The amalgamation barrel is cleaned after the concentration of one batch of ore (60 tons), and the water is lead to the ground just beside the amalgamation process. The water from the processing of the residue is led to the same place. From 60 tons of ore a concentrate of 2-3 kg goes into the amalgamation barrel where 1 kg of mercury is added. About 100-200 g of gold is finally produced, equivalent to 2-3 mg gold per kg ore. The tailings are stored at the Demco site in a big tailing dam, which was dry at the time of our visit. The gold in the tailings is further concentrated in a cyanide heap-leaching process. By the two different concentration processes about 95% of the gold from the ore is recovered: 45% by amalgamation and 50% by heap-leaching.

24 tons of tailings is distributed in 8 heap-leaching concrete pools. In the bottom of each pool a layer of bricks is placed. The bricks are then covered with sacks, sand from the nearby river, tailings and 80 kg of lime. A cyanide-silver nitrate solution is then pumped into the eight pools, and the process lasts for only 5 minutes. The final solutions from the eight pools are then led to an end pool where the solution is filtered through a layer of bricks, sacks and sand, and led to the final gold recovery which takes place in a zinc-box system. Here a gold-zinc complex is formed, and gold is recovered after addition of sulphuric acid and hot water. About 25 g of gold is recovered from the 24 tons of tailings, or about 1 g gold per ton. The water used to clean the eight heap-leaching pools is led to a pool where the cyanide solution is prepared. In addition to the two areas with tailings from the concentration and amalgamation and from the cyanide heap-leaching, a third tailings deposit is situated on the Demco plant area. This tailings deposit is from the old mining activities, and contains about 200 mg mercury per kg (Kinabo et al. 1996).
As mentioned above also gold ore from the local small-scale miners are processed at the Demco plant, and a maximum of 3 tons of ore is processed per day. The prize for processing 1 ton of ore is 40US$. According to Mr. Gregory the small-scale miners are content with this agreement. The crushing and concentration of the ore is performed older installations at the Demco plant. This machinery was in function at the time we visited the plant. The concentrate is amalgamated by the small-scale miners themselves and burnt in the retort. The small-scale miners can bring their amalgam to the Demco plant and burn it in the retort, but only few of them use this arrangement. Outside of the Demco plant small-scale miners are allowed to search for gold in the tailings that slides outside the fence.
Figure 19. Land use map (timber and charcoal dealers, tobacco fields and forest reserves) covering the Chunya District, scale 1:500,00 (Kindly provided by the District Commissioner Mr. Mbwana)
Figure 20. Drainage system in the Mpanda area and the Katavi National Park in western Tanzania. Solid line with arrows: Rivers and flow direction; open circles: sediment sampling sites (no.’s 70-74 in Table 1); dot-and-dash line: Border of the Katavi National Park; dash line: Road; areas with vertical lines: towns and villages
Table 14. Total-mercury concentrations in human samples from the two mining areas Chunya and Mpanda

<table>
<thead>
<tr>
<th>No</th>
<th>Weight empty</th>
<th>Weight full</th>
<th>Total Hg mg/kg **</th>
<th>Description</th>
<th>Date</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6,1438</td>
<td>6,1928</td>
<td>4.554</td>
<td>Hair, male, 29 y</td>
<td>17.9.99</td>
<td>Kasanga Bridge 8°35.83S, 33°22.21 E</td>
</tr>
<tr>
<td>2</td>
<td>6,1866</td>
<td>6,2744</td>
<td>1.951 / 0.067</td>
<td>Hair, male, 25 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>6,0817</td>
<td>6,1308</td>
<td>1.947</td>
<td>Hair, male, 20 y</td>
<td>-</td>
<td>Milmajine, ca. 8° 39.62S, 33°19.64E (= Ifumbo)</td>
</tr>
<tr>
<td>4</td>
<td>6,1326</td>
<td>6,1845</td>
<td>3.434</td>
<td>Hair, male, 34 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>6,0728</td>
<td>6,2169</td>
<td>3.126</td>
<td>Hair, male, 33 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>6,0819</td>
<td>6,1700</td>
<td>0.382</td>
<td>Hair, male, 32 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>6,1678</td>
<td>6,3025</td>
<td>0.124</td>
<td>Hair, male, 42 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>6,1765</td>
<td>6,3126</td>
<td>0.435</td>
<td>Hair, male, 50 y</td>
<td>18.9.99</td>
<td>Shoga Mine, 8° 26.32S, 33°40.00E (see no. 9)</td>
</tr>
<tr>
<td>9</td>
<td>6,1245</td>
<td></td>
<td>0.413</td>
<td>Hair, male, 50 y</td>
<td>-</td>
<td>- Duplicate sample to Dept. of Geology (see no. 8)</td>
</tr>
<tr>
<td>10</td>
<td>6,1404</td>
<td>6,4077</td>
<td>1.200</td>
<td>Hair, male, 52 y</td>
<td>-</td>
<td>Shoga Mine, 8° 26.32S, 33°40.00E</td>
</tr>
<tr>
<td>11</td>
<td>6,1196</td>
<td>6,2220</td>
<td>2.150</td>
<td>Hair, male, 34 y</td>
<td>-</td>
<td>Shoga Village, 8° 25.71S, 33°39.69E</td>
</tr>
<tr>
<td>12</td>
<td>6,1464</td>
<td>6,1905</td>
<td>0.217</td>
<td>Hair, male, 40 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>6,1641</td>
<td>6,3307</td>
<td>12.261</td>
<td>Hair, male, 18 y</td>
<td>27.9.99</td>
<td>D-Reef Village, 6°24.54S, 31°02.57E</td>
</tr>
<tr>
<td>14</td>
<td>6,0968</td>
<td>6,3912</td>
<td>0.472</td>
<td>Hair, male, 42 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15</td>
<td>6,0874</td>
<td>6,4664</td>
<td>0.486</td>
<td>Hair, male, 21 y</td>
<td>-</td>
<td>D-Reef Village, 6°24.54S, 31°02.57E (see no. 19)</td>
</tr>
<tr>
<td>16</td>
<td>6,4341</td>
<td>6,5982</td>
<td>0.174</td>
<td>Hair, male, 37 y</td>
<td>-</td>
<td>near (~ 1 km) -</td>
</tr>
<tr>
<td>17</td>
<td>6,1294</td>
<td>6,2120</td>
<td>0.111</td>
<td>Hair, male, 41 y</td>
<td>-</td>
<td>D-Reef Village, -</td>
</tr>
<tr>
<td>18</td>
<td>6,1639</td>
<td>6,3893</td>
<td>0.185</td>
<td>Hair, male, 42 y</td>
<td>-</td>
<td>near (~ 1 km) -</td>
</tr>
<tr>
<td>19</td>
<td>6,1388</td>
<td>6,522</td>
<td>0.522</td>
<td>Hair, male, 21 y</td>
<td>-</td>
<td>- Duplicate sample to Dept. of Geology (see no. 15)</td>
</tr>
<tr>
<td>20</td>
<td>6,1133</td>
<td>6,2880</td>
<td>1.065</td>
<td>Hair, male, 64 y</td>
<td>28.9.99</td>
<td>Kapanda Village, 6°28.13S, 31°04.65E</td>
</tr>
<tr>
<td>21</td>
<td>6,1159</td>
<td>6,5379</td>
<td>0.801</td>
<td>Hair, male, 27 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>22</td>
<td>6,1699</td>
<td>6,3493</td>
<td>0.051</td>
<td>Hair, male, 17 y</td>
<td>29.9.99</td>
<td>Mpanda, 6°21.05S, 31°04.21E</td>
</tr>
<tr>
<td>23</td>
<td>6,2025</td>
<td>6,3261</td>
<td>0.071</td>
<td>Hair, male, 17 y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>6,1137</td>
<td>6,2056</td>
<td>0.182</td>
<td>Hair, male, 37 y</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* dry weight % not useful since it reflects the alcohol conservation.

** The hair samples are washed with detergent, acetone and demineralised water before analysis. For a more specific description consult (Petering et al. 1971). x Samples analysed at the National Institute of Minamata Disease (NIMD) of the Environment Agency of Japan, on behalf of Dr. J. Ikingura, Dept. of Geology, University of Dar es Salaam. See Table 15 for additional information on human samples.
Table 15. Additional information concerning human samples in Table 14

<table>
<thead>
<tr>
<th>No.</th>
<th>Present occupation</th>
<th>Years of gold mining</th>
<th>Previous occupation</th>
<th>No. Of months since last hair cut</th>
<th>Living in village</th>
<th>Predicted Hg contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>ad 1</td>
<td>Gold miner/panner</td>
<td>7</td>
<td>Study</td>
<td>1</td>
<td>Kasanga</td>
<td>+</td>
</tr>
<tr>
<td>ad 2</td>
<td>-</td>
<td>-</td>
<td>Cement worker</td>
<td>1</td>
<td>Kasanga</td>
<td>+</td>
</tr>
<tr>
<td>ad 3</td>
<td>Amalgamist/burner</td>
<td>Always</td>
<td>No</td>
<td>1</td>
<td>Mlimajine</td>
<td>+++</td>
</tr>
<tr>
<td>ad 4</td>
<td>-</td>
<td>-</td>
<td>? from Mbeya</td>
<td>3</td>
<td>Mlimajine</td>
<td>+++</td>
</tr>
<tr>
<td>ad 5</td>
<td>Farmer, office?</td>
<td>0</td>
<td>Same as now</td>
<td>1</td>
<td>Mlimajine</td>
<td>++</td>
</tr>
<tr>
<td>ad 7</td>
<td>Farmer</td>
<td>0</td>
<td>From Mbanda, when 5 years old</td>
<td>7</td>
<td>Mlimajine</td>
<td>++</td>
</tr>
<tr>
<td>Ad 8/9</td>
<td>Miner</td>
<td>11</td>
<td>Cement in Tanga</td>
<td>20 y, stopped growing</td>
<td>Shoga Village</td>
<td>++</td>
</tr>
<tr>
<td>ad 10</td>
<td>Miner</td>
<td>19</td>
<td>Amalgamist to 1997</td>
<td>10</td>
<td>Shoga Village</td>
<td>+++</td>
</tr>
<tr>
<td>ad 11</td>
<td>Amalgamist</td>
<td>14</td>
<td>Farmer</td>
<td>2</td>
<td>Shoga Village</td>
<td>+++</td>
</tr>
<tr>
<td>ad 12</td>
<td>Farmer</td>
<td>0</td>
<td>Same as now</td>
<td>½</td>
<td>Shoga Village</td>
<td>+</td>
</tr>
<tr>
<td>ad 13</td>
<td>Amalgamist/burner</td>
<td>5</td>
<td>Always this</td>
<td>1-2</td>
<td>D-Reef</td>
<td>+++</td>
</tr>
<tr>
<td>ad 14</td>
<td>-</td>
<td>-</td>
<td>No other</td>
<td>4</td>
<td>D-Reef</td>
<td>+++</td>
</tr>
<tr>
<td>Ad 15/19</td>
<td>-</td>
<td>-</td>
<td>No other</td>
<td>3</td>
<td>D-Reef</td>
<td>+++</td>
</tr>
<tr>
<td>ad 17</td>
<td>Teacher</td>
<td>0</td>
<td>Teacher in Magamba</td>
<td>1</td>
<td>D-Reef, last 4 years</td>
<td>+</td>
</tr>
<tr>
<td>Ad 16</td>
<td>Farmer (½)/panner (½)</td>
<td>0</td>
<td>Same as now</td>
<td>1 week</td>
<td>Near D-Reef</td>
<td>+</td>
</tr>
<tr>
<td>Ad 18</td>
<td>Farmer (½)/panner (½)</td>
<td>0</td>
<td>Same as now</td>
<td>2 weeks</td>
<td>Near D-Reef</td>
<td>+</td>
</tr>
<tr>
<td>ad 20</td>
<td>Amalgamist/burner</td>
<td>12</td>
<td>Fisherman, Lake Victoria</td>
<td>20</td>
<td>Kapanda</td>
<td>+++</td>
</tr>
<tr>
<td>ad 21</td>
<td>Amalgamist/burner</td>
<td>4</td>
<td>Farmer, Lake Victoria</td>
<td>4</td>
<td>Kapanda</td>
<td>+++</td>
</tr>
<tr>
<td>ad 22</td>
<td>Kitchen assistant</td>
<td>0</td>
<td>None</td>
<td>8</td>
<td>Mpanda</td>
<td>0</td>
</tr>
<tr>
<td>ad 23</td>
<td>-</td>
<td>-</td>
<td>None</td>
<td>1</td>
<td>Mpanda</td>
<td>0</td>
</tr>
<tr>
<td>ad 24</td>
<td>Restaurant owner</td>
<td>0</td>
<td>Mechanist, soap production</td>
<td>2 weeks</td>
<td>Mpanda</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 16. Total-mercury concentrations in non-human samples from the Chunya and Mpanda mining areas

<table>
<thead>
<tr>
<th>No</th>
<th>Wght. empty</th>
<th>Incl. Alcohol</th>
<th>Wght full</th>
<th>Dry wght % *</th>
<th>Total Hg mg/kg d.w.</th>
<th>Description</th>
<th>Date (99)</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>9,0941</td>
<td>11,9018</td>
<td>20,9877</td>
<td>89.95</td>
<td>0.0238</td>
<td>Sediment from gold washing pool, no Hg should have been used</td>
<td>17.9</td>
<td>8°35.83S, 33°22.21E</td>
</tr>
<tr>
<td>26</td>
<td>9,1184</td>
<td>11,4254</td>
<td>20,7643</td>
<td>82.93</td>
<td>0.0169</td>
<td>Sediment -</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>27</td>
<td>9,1304</td>
<td>12,3941</td>
<td>24,2106</td>
<td>84.53</td>
<td>0.0160</td>
<td>Sediment from pool with sediment sorted from amalgamating process</td>
<td>-</td>
<td>c. 8°39.62S, 33°19.64E (Ifumbo)</td>
</tr>
<tr>
<td>28</td>
<td>9,0687</td>
<td>12,7823</td>
<td>21,6063</td>
<td>81.23</td>
<td>28.0697</td>
<td>Soil just 2 m from amalgamating house and 2 m from Hg burning sediment. Pool with wastewater from amalgamation</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>29</td>
<td>9,1045</td>
<td>12,5452</td>
<td>24,0165</td>
<td>82.66</td>
<td>9.7189</td>
<td>Sediment. Pool with wastewater from amalgamation</td>
<td>18.9</td>
<td>8°25.71S, 33°39.69E (Shoga Village)</td>
</tr>
<tr>
<td>30</td>
<td>9,0025</td>
<td>12,4640</td>
<td>21,5309</td>
<td>76.6</td>
<td>0.3480</td>
<td>Soil. 10 m from amalgamation area in cornfield</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>31</td>
<td>9,0477</td>
<td>11,8908</td>
<td>18,1985</td>
<td>74.98</td>
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<td>Soil. ca. 200 m from amalgamation, downwind</td>
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<tr>
<td>32</td>
<td>9,0001</td>
<td>12,6021</td>
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<td>36.55</td>
<td>0.0741</td>
<td>Ugali (Porridge) corn pasta made from his own fields surrounding the village</td>
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<tr>
<td>33</td>
<td>9,2030</td>
<td>12,9785</td>
<td>0.0144</td>
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<td>-</td>
<td>Duplicate sample to Dept. of Geology (see no. 32)</td>
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<td>-</td>
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<td>34</td>
<td>9,1532</td>
<td>12,9226</td>
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<td>0.0131</td>
<td>Sediment from well (20 cm deep) c.1 km from the village downstream the tailings area</td>
<td>-</td>
<td>8°25.67S, 33°39.61E (Shoga Village)</td>
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<tr>
<td>35</td>
<td>9,1206</td>
<td>12,7546</td>
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<td>0.0103</td>
<td>Sediment river. Just upstream well and downstream the tailings area</td>
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<tr>
<td>36</td>
<td>9,1149</td>
<td>13,5510</td>
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<td>-</td>
<td>Sediment river. Just upstream well and downstream the tailings area</td>
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<td>37</td>
<td>9,1222</td>
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<td>23,5661</td>
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<td>Sediment, river. 50 m upstream tailings area</td>
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<td>38</td>
<td>9,0917</td>
<td>13,0498</td>
<td>19,3322</td>
<td>86.41</td>
<td>0.0468</td>
<td>Sediment, mud from tailings recovering</td>
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<td>8°25.81S, 33°39.73E</td>
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<td>13,3854</td>
<td>21,9652</td>
<td>77.8</td>
<td>-0.0046</td>
<td>Sediment, beach where fish were landed</td>
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<td>32°54.13E</td>
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<td>40</td>
<td>8,9382</td>
<td>12,2770</td>
<td>14,1154</td>
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<td>1.0472</td>
<td>Muscle. Kambale (Catfish)</td>
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<td>-</td>
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<td>12,8408</td>
<td>15,5165</td>
<td>23.38</td>
<td>0.0788</td>
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<td>42</td>
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<td>11,8289</td>
<td>15,2476</td>
<td>19.515</td>
<td>0.3437</td>
<td>Muscle, Pelege (Bigger Telapia) = 30 cm length</td>
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<td>12,4260</td>
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<td>18.12</td>
<td>0.9309</td>
<td>Muscle, Pelege (Bigger Telapia) = 25 cm length</td>
<td>-</td>
<td>8°23.89S, 32°54.13E (Lake Rukwa)</td>
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<td>45</td>
<td>9,0132</td>
<td>12,0590</td>
<td>15,0578</td>
<td>24.51</td>
<td>0.3086</td>
<td>Muscle, Kachinga (Tiger fish/predatory fish) = 30 cm length</td>
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<td>12,4257</td>
<td>15,4195</td>
<td>14.51</td>
<td>1.1090</td>
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<td>No</td>
<td>Wght. empty</td>
<td>Incl. Alcohol</td>
<td>Wght full</td>
<td>Dry wt % *</td>
<td>Total Hg mg/kg d.w.</td>
<td>Description</td>
<td>Date (99)</td>
<td>Position</td>
</tr>
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<td>47</td>
<td>9,1372</td>
<td>12,3721</td>
<td>15,0517</td>
<td>17.85</td>
<td>1.3568</td>
<td>Muscle, Ningu = 20 cm length</td>
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<td>-</td>
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<td>12,2531</td>
<td>14,4533</td>
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<td>0.6851</td>
<td>Muscle, Gege (Small Telapia)</td>
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<td>12,4227</td>
<td>15,3261</td>
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<td>0.4170</td>
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<td>-</td>
<td>-</td>
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<td>9,1027</td>
<td>12,3102</td>
<td>15,4053</td>
<td>11.31</td>
<td>0.5885</td>
<td>= 12 cm length</td>
<td>19.9</td>
<td>8°23.89S, 32°54.13E (Lake Rukwa)</td>
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<tr>
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<td>9,1908</td>
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<td>15,2270</td>
<td>19.06</td>
<td>0.3034</td>
<td>-</td>
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<td>-</td>
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<td>13,1856</td>
<td>15,9738</td>
<td>19.55</td>
<td>0.4342</td>
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<td>= 12 cm</td>
<td>-</td>
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<td>53x</td>
<td>9,0402</td>
<td>12,6444</td>
<td></td>
<td></td>
<td>0.0780</td>
<td>-</td>
<td>= 12 cm</td>
<td>-</td>
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<td>Sediment, Mpanda River, 200 m downstream tailings (Pb, Cu, Hg)</td>
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<td>55</td>
<td>9,2374</td>
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<td>24,9163</td>
<td>74.69</td>
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<td>Tailings, Bank out to Mpanda River, fresh 2 m from top. Sample from 15 cm</td>
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<td>9,1126</td>
<td>12,9367</td>
<td>21,9845</td>
<td>85.99</td>
<td>0.0112</td>
<td>Sediment, Mpanda River, Upstream tailings at washing area.</td>
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<td>57</td>
<td>9,1638</td>
<td>12,5321</td>
<td>21,7313</td>
<td>64.1</td>
<td>0.0262</td>
<td>Sediment, Mpanda River, 300 m upstream washing area.</td>
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<td>58</td>
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<td>12,4912</td>
<td>22,7567</td>
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<td>0.3567</td>
<td>Sediment, amalgamation pool</td>
<td>27.9</td>
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<td>9,1425</td>
<td>12,7710</td>
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<td>Soil, cassava field = 50 m West of amalgamation pool</td>
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<td>12,8035</td>
<td>26,2546</td>
<td>96.62</td>
<td>0.0154</td>
<td>Sediment, well, river bed, 500 m from village</td>
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<td>61</td>
<td>9,1126</td>
<td>12,8300</td>
<td>19,2718</td>
<td>85.34</td>
<td>0.2125</td>
<td>Sediment, river bed, 500 m from village</td>
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<td>-</td>
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<td>63x</td>
<td>9,1255</td>
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<td>0.1120</td>
<td>Ugali (porridge, Mr. S) made of corn/water</td>
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<td>12,5136</td>
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<td>Corn (Mr. S) from own fields</td>
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<td>93.53</td>
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<td>Sediment, Mpanda River, 25 m downstream amalgamation pool</td>
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<td>Sediment, Mpanda River, c. 100 m upstream amalgamation pool</td>
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<td>67</td>
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<td>28,9179</td>
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<td>16.9775</td>
<td>Sediment, amalgamation pool</td>
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<tr>
<td>68</td>
<td>9,1896</td>
<td>12,6841</td>
<td>20,6518</td>
<td>93.65</td>
<td>0.6141</td>
<td>Sediment, well, 10 m from amalgamation pool</td>
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<td>69</td>
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<td>5.0401</td>
<td>Sediment, amalgamation pool</td>
<td>27.9</td>
<td>-</td>
</tr>
<tr>
<td>70</td>
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<td>12,6769</td>
<td>20,3551</td>
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<td>Sediment, Katuma River, outflow from Katavi Lake</td>
<td>30.9</td>
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</tr>
<tr>
<td>No</td>
<td>Wght. empty</td>
<td>Incl. Alcohol</td>
<td>Wght full</td>
<td>Dry wght %</td>
<td>Total Hg mg/kg d.w.</td>
<td>Description</td>
<td>Date (99)</td>
<td>Position</td>
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<td>13,0658</td>
<td>17,9866</td>
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<td>0.0493</td>
<td>Sediment, Lake Katavi, south</td>
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<td>6°42.96S, 31°00.27E (Katavi Lake)</td>
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<td>13,0631</td>
<td>19,2639</td>
<td>68.27</td>
<td>0.0635</td>
<td>Sediment, Katuma River, tributary, inflow to Katavi River</td>
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<td>6°41.55S, 30°58.65E (Katuma River)</td>
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<td>0.1345</td>
<td>Sediment, Katuma River, in Katavi National Park</td>
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<td>6°43.09S, 31°08.93E</td>
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<td>74</td>
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<td>42.74</td>
<td>0.2095</td>
<td>Sediment, Katuma River, immediately after inflow of Kabenga River</td>
<td>-</td>
<td>6°37.81S, 31°08.66E</td>
</tr>
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</table>

* dry weight % not useful since it reflects the alcohol conservation.

** The hair samples are washed with detergent, acetone and demineralised water before analysis. For more specific description consult (Petering et al. 1971). x Samples analysed at the National Institute of Minamata Disease (NIMD) of the Environment Agency of Japan, on behalf of Dr. J. Ikingura, Dept. of Geology, University of Dar es Salaam. See table 1 for additional information on human samples.

### Table 17. Total mercury in human hair. Data derived from the literature and this pilot study

<table>
<thead>
<tr>
<th>Place</th>
<th>Human group/no.</th>
<th>Hg, mg/kg</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>whole population</td>
<td>0.61</td>
<td>Bach (1980)</td>
</tr>
<tr>
<td>Aarhus (DK)</td>
<td>7 persons</td>
<td>2.0</td>
<td>Hansen (1981)</td>
</tr>
<tr>
<td>Upernavik (G)</td>
<td>14 persons</td>
<td>12.4</td>
<td>Hansen (1981)</td>
</tr>
<tr>
<td>Ummmannaq (G)</td>
<td>22 persons</td>
<td>12.8</td>
<td>Hansen (1981)</td>
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<tr>
<td>Nuuk (G)</td>
<td>50 persons</td>
<td>8.0</td>
<td>Hansen (1981)</td>
</tr>
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<td>Julianehåb (G)</td>
<td>25 persons</td>
<td>7.2</td>
<td>Hansen (1981)</td>
</tr>
<tr>
<td>Scoresbysund(G)</td>
<td>6 or more seal meals/week</td>
<td>15.5</td>
<td>Hansen (1981)</td>
</tr>
<tr>
<td>Scoresbysund(G)</td>
<td>3-6 seal meals/week</td>
<td>9.7</td>
<td>Hansen (1981)</td>
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<td>Scoresbysund(G)</td>
<td>3 or less seal meals/week</td>
<td>10.4</td>
<td>Hansen (1981)</td>
</tr>
<tr>
<td>Amazonas</td>
<td>Rio Urubaxi Acariquara 15 persons</td>
<td>69.2</td>
<td>Silva-Forsberg et al. (1999)</td>
</tr>
<tr>
<td>Amazonas (1999)</td>
<td>Rio Uneixi 17 persons</td>
<td>76.75</td>
<td>Silva-Forsberg et al.</td>
</tr>
<tr>
<td>Amazonas (1999)</td>
<td>Total 154 persons</td>
<td>75.46</td>
<td>Silva-Forsberg et al.</td>
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<tr>
<td>Bolivia (1999)</td>
<td>Asuncion,Amazonas m rarely eating fish</td>
<td>3.7</td>
<td>Maurice-B. et al.</td>
</tr>
<tr>
<td>Bolivia (1999)</td>
<td>Asuncion, Amazonas f rarely eating fish</td>
<td>5.5</td>
<td>Maurice-B. et al.</td>
</tr>
<tr>
<td>Bolivia (1999)</td>
<td>Carmen Florida m rarely eating fish</td>
<td>6.87</td>
<td>Maurice-B. et al.</td>
</tr>
<tr>
<td>Threshold</td>
<td>Poisoning risk (children, pregnant)</td>
<td>10</td>
<td>WHO (1976)</td>
</tr>
<tr>
<td>Threshold</td>
<td>Acute poisoning risk</td>
<td>50</td>
<td>WHO (1976)</td>
</tr>
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<td>Lake Victoria</td>
<td>Mwanza town 6 m non-miners</td>
<td>1.1</td>
<td>Kahatano et al. (1998)</td>
</tr>
<tr>
<td>Lake Victoria</td>
<td>Mwanza town 6 f non-miners</td>
<td>122</td>
<td>Kahatano et al. (1998)</td>
</tr>
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<td>Lake Victoria</td>
<td>Authors of ref. 6</td>
<td>3</td>
<td>Kahatano et al. (1998)</td>
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<td>Lake Victoria</td>
<td>Mwakito life mine-workers 8 m</td>
<td>3.3</td>
<td>Kahatano et al. (1998)</td>
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<tr>
<td>West Tanzania</td>
<td>Chunya/Mpanda amalgamists 9 m</td>
<td>2.9</td>
<td>This pilot study</td>
</tr>
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</table>

m = men, f = women, G=Greenland
### Table 18

Analytical numbers refer Table 9. * = Field number

<table>
<thead>
<tr>
<th>No</th>
<th>GEUS no</th>
<th>*</th>
<th>Comments</th>
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<tbody>
<tr>
<td>T 101b</td>
<td>461478</td>
<td></td>
<td>Tailings N, ½ m from top.</td>
</tr>
<tr>
<td>T 102b</td>
<td>461479</td>
<td></td>
<td>Tailings N, 1½ m from top.</td>
</tr>
<tr>
<td>T 103b</td>
<td>461480</td>
<td></td>
<td>Waste rock, used as road material etc.</td>
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<tr>
<td>T 104b</td>
<td>461481</td>
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<td>Tailings S, ½ m from top.</td>
</tr>
<tr>
<td>T 105b</td>
<td>461482</td>
<td></td>
<td>Tailings S, 1½ m from top.</td>
</tr>
<tr>
<td>T 106</td>
<td>461483</td>
<td>70</td>
<td>Sediment, Katuma river after Lake Katavi (6°41.87S, 31°01.34E).</td>
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<tr>
<td>T 107</td>
<td>461484</td>
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<td>Sediment, Lake Katavi S (6°42.96S, 31°00.27E)</td>
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<td>T 108</td>
<td>461485</td>
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<td>Sediment, Katuma river before Lake Katavi (6°41.55S, 30°58.65E)</td>
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<td>T 109</td>
<td>461486</td>
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<td>Sediment, Katuma river S of Sitalike village (6°43.09S, 31°08.93E)</td>
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<td>T 110</td>
<td>461487</td>
<td>74</td>
<td>Sediment, Katuma river/ Kabenga river, Sitalike (6°37.81S, 31°08.86E)</td>
</tr>
</tbody>
</table>
Appendix 8

Mercury in Soap in Tanzania

The enclosed part of the NERI Technical Report No. 306 1999 is published with permission by Department of Arctic Environment, Ministry of Environment and Energy
Appendix 9

Research proposal from Dr. Kent C. Condie

E-mail received November 1999
Appendix 10

Letter of support from Professor Idris S. Kikula, Director of Research and Publications, University of Dar es Salaam
Appendix 11

(C.M. Glauder)

Summary of meetings held in Dar es Salaam and Iringa, mostly on environmental issues
Summary of meetings held in Dar es Salaam and Iringa

Dar es Salaam was visited by biologist Christian Glahder during 9-15 September and 5-10 October 1999. The main purpose was to obtain general information on mining and the environment in Tanzania, and specific information on the Chunya and Mpanda areas. Therefore, departments at the University of Dar es Salaam, ministries, NGO-organisations, the Danish embassy, travel agencies etc. were visited in the course of the two stays. A biologist, working for the Wildlife Conservation Society, was visited in Iringa on 15 September. Below is a summary account of the meetings.

Zoology Department, University of Dar es Salaam

Dr. Simon Ndaro, bentic ecology, marine and freshwater biology, and environmental aspects. The main issue was freshwater fish population in the western Tanzania, i.e., in the rivers running to Lake Tanganyika and Lake Rukwa, including the fish in Lake Rukwa. Many fish species (e.g., Cladias mosambicas, Barbus ssp, Barlius ssp, Hydrocinas ssp and Arestes ssp) are caught by the local people and sold e.g., in Mpanda. The fish species use the rivers as spawning grounds and the larvae grow up in deltas and tributaries. The rainy seasons in November-December (light), and March-June (heavy) trigger their migrations from the lakes up in to the rivers. The rivers and the coastal areas of Lake Tanganyika are of great importance to the fish. Most of the Ciclids in Lake Tanganyika are endemic (c. 98%) and e.g. molluscs, contain many endemic species. Recently, poison has been used for fishing, and this method poses a danger to the fish populations. Lake Rukwa has seen an increase in numbers of crocodiles during the last decades. The Lake Rukwa catchment area is a “closed” system with no river running from the Lake Rukwa.

Addresses: - TAFIRI (Tanzania Fisheries Research Institute).
- African Museum of Fish, Dr. Tervuren, Belgium, SADC/GEF program in Lake Malawi, finished in 1999.
- Professor Hiroya Kawanabe, Dept. of Zoology, Faculty of Science, Kyoto University, Kyoto, 606, Japan.

References see Bernacsek (1980), Coulter (1991), Eccles (1992), Kawanabe & Kwetuenda (eds.) (1988), and Tanzania map 1:1,500,000.

Dr. Kabigumila, zoologist. Lake Rukwa is one of the two areas in Tanzania which hold the Puku Kobus vardoni, an antelope species. The Puku is also found in the Selous Game Reserve in southeastern Tanzania. The Puku is locally endangered and rare in Tanzania, refer to Kingdon (1997).

Addresses: Wildlife Division, att. Mr. Mugonja, the Ivory Room, Puku Road, Dar es Salaam.

References (see end of this appendix): Kingdon (1997).

Dr. Mlingwa, ornithologist, head of the Tanzanian IBA (Important Bird Areas) office. Bird species of specific interest in the Lake Rukwa-Katavi National Park area: The Wattled crane Bugeranus carunculatus (rare). Among the reasons for the decline are the destruction of marshes (breeding habitats) in the deciduous woodlands. The Long-tailed cormorant Phalacrocorax africans (large population in the area), Great white egret Eretta alba (large population in the area), Open-billed stork Anastomus lamelligerus (large population in the area), Shoebill Balaeniceps rex (rare), Long-toed flufftail Sarothrura lugens (rare), Grey crowned crane Balearica regulorum (decreasing), White-headed plover Vanellus albi-ceps (rare), and Great snipe Gallinago media (decreasing).
References see Baker (1996).

Department of Botany, University of Dar es Salaam
Professor Elia. The area east and north of Lake Rukwa contain most of its natural habitats. The hardwood of the Miombo forests is used to some extends, especially in the Lake Rukwa area. Some salt pans are situated along the lakeshore. Other persons in the department with knowledge of the Rukwa area were Frank Mbago, head of the herbarium, and Lennart Mwasumbi, a retired botanist.

Department of Geology, University of Dar es Salaam
Professor S. Muhongo, Dr. S. Mnali (both participants in the project and the field trip), Dr. J. Ikingura and chemist J. Mujumbo. S. Mnali and J. Ikingura had participated in a Swedish-Tanzanian project in the Lake Victoria area during 1992-1997 (see references). J. Ikingura and J. Mujumbo received seven duplicate samples of human hair, fish muscle, porridge and sediments for mercury analyses. J. Ikingura would have the samples analysed for methylmercury in Japan at the National Institute for Minamata Diseases by Dr. Akagi. Total mercury in the samples would be analysed at the department laboratory by J. Mujumbo. The laboratory was visited and the major analytical instruments were seen: The Atomic Absorption Spectrophotometer (AAS, Perkin Elmer 2380, c. 1985). The mercury analyser accessory for the AAS was a Perkin Elmer MHS-10 Mercury/Hydride System. The reaction chamber used for the mercury analyses had a crack, so the Central Science workshop at the University was trying to fabricate a similar reaction chamber. The Graphite furnace (As 40, HGA-300 programmer) had not been used for long. A Lambda 1 UV/VIS spectrophotometer for analysis of $P_2O_5$ was out of order because of mirror positions problems. It was the intention to send for a Perkin Elmer technician from Zambia, at an estimated cost of 2850 US$. The laboratory was equipped with 4-5 Instrument Cases, HACH, DREL/2010, for water quality analysis in the field. A Satorius Balance did not function satisfactory.


National Environmental Management Council, NEMC, Tancot house, Dar es Salaam
Ms. Esther J. C. Kerario. A new mining project follows a procedure where the mining company must fill in a registration form at the NEMC. On this basis the NEMC assesses the environmental aspects of the mineral exploration and exploitation, and dependant of the magnitude of the project the NEMC decides if an Environmental Impact Assessment (EIA) must be made by the company. Site inspections and evaluations of EIAs are performed at the NEMC. The approval of a mining project will among other rules and regulations include a monitoring plan and a closure plan; the latter must consist of a funding by the company for the closure. Not all of the above has yet been implemented. The normal practice of today seems to be that the mining companies contact the Ministry of Minerals and Energy. Here the companies have to fill in different forms before their permission is granted. It seems that the different ministries have their own environmental sectors.

Two new mining projects are on their way, the Ashanty mine and the Bulancaly mine. EIAs have been made on both projects.

Addresses: Kahama mining company, att. Bill Bali, Bulancaly mine, tlf.: 255 51 15 27 47/8, Fax: 255 51 15 13 53, e-mail: sutton@twiga.com.
Fisheries Division, Ministry of Natural Resources and Tourism, Ardi house, Dar es Salaam
Mr. Winfried V. Haule, Assistant Director. Received a copy of Field guide to the freshwater fishes of Tanzania (Eccles 1992) and the latest Annual Statistics Report for Lake Rukwa, 1995.

Wildlife Conservation Society of Tanzania, Dar es Salaam
Mr. Poul Y. Nnyiti, Senior Conservation Officer. The Miombo forest is a deciduous forest rich in hardwood species, e.g. Miombo Brachystegia sp, the most common tree in this type of forest and Mninga, the Black wood Pterocarpus angolensis. Many of the forested areas are Public Land with limited control from the local inspectors; the reason can be their lack of cars. Among the threats to the forests are the use of fire for clearing areas for farming and tobacco plantations. The Miombo forests are used by bee-farmers who produce honey and bee-wax. No major migration corridors for terrestrial mammals were known, but local knowledge could be obtained by the game officer Mr. Lukio Pallangyo in the Maliasili office, i.e., the Dept. of Natural Resources, in Mpanda. A few Chimpanzees Pan troglodytes were reported from western Mpanda, but their stronghold is the Mahale Mountains National Park. Wild dogs Lycaon pictus could be observed occasionally in western Mpanda, but packs of dogs have huge territories with breeding areas in e.g. the Rungwa Game Reserve or Ruaha National Park.

Addresses: Economic Research Bureau, att. Dr. Kulindwa, University of Dar es Salaam, P. O. Box 35096, tlf. 41 05 00/8; 41 01 53.
References e.g. MIOMBO (Newsletter of the Wildlife Conservation Society of Tanzania).

Wildlife Conservation Society (The New York Zoological Society), Iringa
Mr. David C. Moyer, biologist. He grew up in the Lake Rukwa area, and has seen many of the closed forests burnt open into farmland. Some areas like the Ufipa Plateau near Sumbawanga has probably not been covered by forest in recent time. Crops like corn and cassava are grown in areas in the forest cleared by burning the trees. A few years later the farmers move to new places. A tribe like the Wasukumas (dressed in blue) keeps cattle, often zebu-oksen, and lives like semi-nomads. The dry grass is burnt off to stimulate the growth of fresh grass. The Wattled crane Bugeranus carrunculatus population in the Lake Rukwa area is decreasing because marsh habitats have been destroyed in recent time. Also the Denham’s bustard Neotis denhami, living in more or less wooded habitats, are becoming rare in the area. There is probably some seasonal migration of terrestrial mammals between the northern parts of Lake Rukwa and the Katavi National Park, but no information is available. Few Chimpanzees Pan troglodytes in the area west of Lake Rukwa-Mpanda are confined to the head of the rivers. Wild dogs Lycaon pictus would probably use the area between Mpanda and Rungwa Game Reserve. A mountainous limestone area east of Mahale Mountains National Park contains many endemic butterfly species, but no thorough study has been performed. The Lake Rukwa area is probably important to all sorts of migrating birds (among these birds of prey and warblers) because the relatively narrow area of about 250 km between the lakes Tanganyika and Nyasa concentrates the birds. The Katavi National Park has been extended compared to the area shown on the map Tanzania, Rwanda-Burundi, Nelles Verlag, Germany. The extension is in eastern and southern direction so that it almost reaches the northern part of Lake Rukwa. The Uwanda
Game Reserve, which covers the north-eastern parts of Lake Rukwa according to the map, does not exist any more. This means that the Lake Rukwa is not formally protected. Reference see Backlund (1956).

The Danish embassy, Dar es Salaam

Mr. Mark Jensen, Minister Counsellor. Before and after our field trip we informed Mr. Jensen about our project, the field period and the areas visited. Talked about the possibilities of buying vehicles for the possible future project. Obtained copies of the report: Capacity building for the environmental management and pollution abatement, Mwanza region, Tanzania, 1996.-Ministry of Foreign Affairs, Danida, Denmark, 1997 (Annex 6A: Migro, C. L. C. Report on mercury pollution; Annex 6B: Olsen, H. & Bhatia, H. Environmental impact of gold mining on Lake Victoria).

Tanzania Natural Resources Information Centre, TANRIC, University of Dar es Salaam

Purchased five “Land Cover and Land Use” maps (1:250,000) covering the areas: Mbeya (SC-36-3), Mwimbi (SC-36-2), Sumbawanga (SB-36-14), Kipili (SB-36-13) and Mpanda (SB-36-9). The maps are printed in the UK on behalf of Surveys and Mapping Division, Ministry of Lands. Ministry of Natural Resources and Tourism, Tanzania. 1996 (18 US$ pr. map).

Published by the Surveys and Mapping Division, Ministry of Lands, Housing and Urban Development, Goverment of the United Republic of Tanzania.

Purchased 15 topographical maps, 1:50,000, covering the Mpanda and the Chunya areas (6 US$ pr. map).

The Commission for Science and Technology, Dar es Salaam

Received our one-year Research Permits. The prize per person was 300US$ and the prize for the project was 50US$.

Central Railway Station, Dar es Salaam

The train from Dar es Salaam to Mpanda leaves Dar es Salaam at 5:00 p.m. and arrives at Tabora next day at 7:30 p.m. Departure time from Tabora is 9:00 p.m. on the same day, and arrival time in Mpanda is 6:00 am the following day. Best connections from Dar es Salaam are Tuesdays and Sundays, with possible connection on Thursday as well. Arrival days in Mpanda are Thursdays, Tuesdays and Saturdays, respectively. A first class return ticket including sleeping coach is 43,300 TSh (about 54 US$), and a second class return ticket is 31,800 TSh (about 40 US$).

Travelling agency, Dar es Salaam

It is possible to reach Mpanda by a chartered aeroplane. The company Coastal Travels Ltd., managing director Anna Westh, 107 Upanga rd, P.O.Box 3052, Dar es Salaam, anna@coastal.cc, gave us the following total prizes: 3 persons (C 172, single engine plane): 3 080 US$; 5 persons (Seneca 5, two engines): 3 596 US$; 7 person: 5 580 US$; 11 persons: 5 084 US$; 13 persons: 5 332 US$. Waiting hour: 100US$, overnight pay: 150 US$, airpor tax 3 000TS per person.
Appendix 12

Danish contribution for an abstract for Eclogite paper

The abstract on Eclogite investigations carried out jointly between University of Dar es Salaam, GEUS and University of Oulu was not ready at the time of printing this report. Enclosed is therefore only the GEUS part of the joint work entitled:

A scanning electron microscopic study of garnets from eclogites from the Ubendian, West Tanzania, by C. C. Appel, GEUS.

Note, the figures in this copy have not been fitted to the other figures in the report.