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European Project for Ice Coring in Antarctica (EPICA)

An international research effort with participation of Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Sweden, Switzerland and the United Kingdom of Great Britain and Northern Ireland

Comprehensive Environmental Impact Evaluation for Recovering a Deep Ice Core in Dronning Maud Land, Antarctica

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1. Summary

The present study assesses the logistical and scientific activities planned for the EPICA deep ice core drilling project in Dronning Maud Land (DML) in respect of their potential impacts on the Antarctic environment. It takes the form of an environmental impact assessment in accordance with the Protocol on Environmental Protection to the Antarctic Treaty. The description of the project and the planned activities also refers to alternative methods, including the factors on which the final decision was based. This is followed by an assessment of impacts on the Antarctic environment.

During the European ice core project entitled 'European Project for Ice Coring in Antarctica' (EPICA), deep cores will be recovered from inland ice in the Antarctic. The project as a whole is jointly supported by Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Sweden, Switzerland and the United Kingdom of Great Britain and Northern Ireland. The scientific objective is to obtain high-resolution records of the climatic and atmospheric conditions across several glacial-interglacial cycles as a contribution to the international climate research effort. EPICA is organised in two phases: a) a core from Dome Concordiaoncordia (Dome Concordia), recovery of which is organised by France and Italy, will allow conclusions to be drawn about major climate changes across several glacial-interglacial cycles; b) a core from a site in Dronning Maud Land (DML) will focus on rapid climate oscillations during the last glaciation. The body responsible for planning and executing this work is the Alfred Wegener Institute Foundation for Polar and Marine Research in Bremerhaven, Germany.

In the search for a suitable site for the core, a pre-site survey has been carried out over the last four years, during which the ice thicknesses, accumulation rates, distributions of stable isotopes and trace substances as well as the flow velocity of ice were determined. On the basis of these results, a suitable site for recovery of a deep ice core was identified at 75°0′S, 0°0′E (DML 05). The ice profile at that location exhibited the requisite profile characteristics for successful ice analysis, namely uniform stratification, flat bedrock and an ice thickness of 2750 ± 50m.

The site is located on the back of a firn-ice transition characterised by predominantly vertical ice movements and a low horizontal flow velocity, on the plateau of the inland ice sheet (Amundsenisen). The transition there between porous firn and compact, impermeable ice is located at an ice depth of approx. 80 m. The distance to the ocean is around 560 km. An automatic weather station operated by the University of Utrecht is situated on the site and has recorded meteorological data since 1998. The wind speed is prevailingly low, while annual mean temperatures are approx. –46°C. Meltwater does not form at any time of the year. No birds, other fauna or flora are found on the inland ice of the Amundsenisen ice sheet.

Planned activities during the deep ice core recovery project involve setting up a temporary drilling camp, including trenches for drilling and for processing the ice core (the 'Drill and Science Trench'). All materials required (with a total mass of approx. 650 t) will be transported to the Antarctic by sea, unloaded at the ice shelf edge near the German overwintering station, 'Neumayer Station', then transported overland from there over the inland ice (in 'traverses') to the chosen drilling site. A depot for supplies and in case of emergency is situated in the Kottas mountains, Heimefrontfjella. Passenger transport and return transport of the ice core segments to the edge of the ice shelf will mainly be by aircraft. Work at the drilling camp will be confined to the three summer months (December to February) of each season. Three seasons are planned for the actual core recovery, with one season each for follow-up measurements and dismantling work (total duration: five years). The Neumayer Station Station will be the logistics base during this period.

The drilling camp is designed for approx. 20 scientists and technicians involved in carrying out and supporting the ice core project. It will be used exclusively as a summer camp and, when drilling has been completed, will be dismantled and transported overland to ships that will take everything back to Germany. The camp consists of 20-foot container units and will be erected as a platform on steel supports. Besides the platform, the camp will also include further container units for accommodation, storage tanks and supplies. An alternative would be a temporary drilling camp on sleds.

Power is supplied by a generator whose waste heat is used to provide a supply of water (snowmelt). Alternatives would be wind turbines or solar energy arrays.

In order to operate the various vehicles and generators, Arctic diesel is required for generators and traverse vehicles, kerosine for aircraft and small quantities of petrol for Ski-Doos. Combustion of these fuels results in emissions that are calculated on the basis of the total supply volumes. The wastes produced will be collected and brought back from the Antarctic. Grey and black water will be discharged into the ice via a drainage pit. Alternative wastewater disposal methods would be gas incineration, microfiltration or return transportation. The camp will be closed down and secured for the winter months. When the ice core has been recovered, the drilling equipment will be dismantled and brought back. Some parts (steel, wood, cables) will be left in the ice. An alternative would be to dig out these parts from an extensive area.

The overland transport route from Neumayer Station to the drilling site runs exclusively across shelf and inland ice. The ascent to the inland ice plateau is made to the east of the Kottas mountains, Heimefrontfjella. There is no alternative, shorter route. Transportation is effected by sled convoys. Two traverses per season are planned for supplies to the camp, whereby a single traverse takes about 25 days. The bulk of operating supplies will be transported in tank containers. An alternative would be transportation in drums. Ten to fifteen return flights per season are planned for transporting people and materials.

Ice coring begins by fore-boring into the permeable firn. Casing pipe will be installed in this section to prevent seepage of drilling fluid. The deep core itself will be recovered using electromechanical drilling equipment. The borehole will have a diameter of 130 mm at a maximum depth of 2750 ± 50 m. In order to compensate for the hydrostatic pressure of the surrounding ice and to prevent any plastic deformation of the borehole, it will be necessary to use a drilling fluid. For the envisaged core depth, there is no alternative to drilling with drilling fluid. Losses of drilling fluid will occur through evaporation, incomplete recovery of fluid from the ice chips created by drilling, and any leaks in the casing. The drilling fluid is Exxol D40 (pure petroleum), with a densifier for adjusting the fluid to the required density. The densifiers used will be HCFC 123 or HCFC 141b chlorinated hydrocarbons. Alternative drilling fluids are alcohol, ethyl glycol, silicone oils and n-butyl acetate, combined with perchloroethylene/trichloroethylene as densifiers. There are no alternatives to leaving the drilling fluid in the borehole. During ice core recovery, it is possible that unforeseen delays may occur. In such a case, appropriate measures will be taken to ensure the success of the ice core recovery operation. In the future, horizontal flow of the ice will lead to the borehole being displaced and deformed.

For assessing the impacts of the planned ice core project on the Antarctic environment, data on the environmental conditions in the area affected, on the planned activities and on the properties and fate of the materials used were taken into consideration and reference made to the relevant literature. The extent to which the protected environmental resources referred to in the Protocol on Environmental Protection to the Antarctic Treaty and the Act Implementing the Protocol on Environmental Protection to the Antarctic Treaty (AUG), respectively, are affected is being examined, potential impacts are described, and criteria are applied for assessing the type, extent, duration and intensity of direct impacts on such environmental assets. These impacts are shown in the form of a matrix.

Impacts on the glacial environment may occur due to changes in the structure of snow and firn, in snow drift, to particle deposits as a result of fuel consumption, and to materials being left behind. Impacts are likely as a result of camp operations, the traverses and the drilling operations. Ambient air quality is affected by gaseous immissions as a result of fuel consumption and the evaporation of drilling fluid. Impacts can be expected at the camp during traverses and drilling operations. Climate and weather patterns might be affected by immissions of climate forcing and ozone-depleting gases. Impacts due to the planned activities might occur as a result of fuel consumption and the use of densifiers with environmentally relevant properties. Water quality, the aquatic environment as well as the marine environment may be affected by loading and unloading operations at the edge of the ice shelf. Direct impacts of the planned activities might result from accidents involving the release of pollutants. Effects on flora and fauna could be caused by noise or pollutant loads. The planned activities are not expected to have any impacts on penguins at the ice shelf edge or on other bird species, provided that no pollutants are released.

The planned project will cause an increase in the amount of transportation to the Antarctic and in the level of activities emanating from the Neumayer Station Station (indirect impacts). During the preliminary investigations and the project itself, emissions and particle deposits recur along the traverses and at the drilling site (cumulative impacts).

The camp will be transported and set up in accordance with previously used methods. In order to minimise environmental impacts, materials will be monitored in respect of stock levels, consumption and returning of waste. Preventive and safety measures are in place for conceivable accidents (especially leakage of fuel). Steps are being taken to ensure that a sufficient distance is kept from where any birds in the area tend to rest. On the basis of current fuel consumption, it is possible using shallow coring to assess the level of actual immissions and the depth of snow layer affected by particle deposits.

Unavoidable impacts of the planned ice core project include the drilling fluid remaining in the borehole, immissions caused by the consumption of fuel and other operating supplies, and temporary changes in the snow and ice surface as a result of setting up the camp and using vehicles to access it. If the ice coring is not carried out (the 'no action' alternative), no changes can be expected in relation to the current status quo in Dronning Maud Land. If the ice coring is successful, international climate researchers will be rewarded with high-resolution archives of palaeoclimatic conditions from the Atlantic sector of the Antarctic. Potential uncertainties in conducting the environmental impact assessment derive from unforeseeable characteristics of the ice sheet, changes in the logistical requirements for transportation and scheduling, as well as unforeseeable changes during the actual drilling work.

Having taken all the above factors into consideration, the applicants have come to the conclusion that the unavoidable strains imposed on Dronning Maud Land by the EPICA deep ice core recovery project can be confined to a level at which the impacts on the Antarctic environment are minimal on the whole.

2. Research objectives and general description of the project

The polar ice caps are an unique archive containing information not only about climate changes, but also about the past composition of the atmosphere. Ice core analyses therefore play a major role in climate research. Deep ice cores recovered on Greenland (GRIP, GISP2) and in the Antarctic (Vostok, Dome Fuji) have already made substantial contributions to our understanding of the interactions between atmospheric concentrations of greenhouse gases and changes in climate during recent glacial-interglacial cycles. Detailed predictions of future climate will depend on close collaboration between climate modelling and detailed analysis of past climate changes.

The 'European Project for Ice Coring in Antarctica' (EPICA) is a long-term European ice core project, jointly supported by Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Sweden, Switzerland and the United Kingdom of Great Britain and Northern Ireland. In the course of this project, deep ice cores will be recovered from the inland ice of the Antarctic. The expected results will be high-resolution records of climatic and atmospheric conditions over several glacial-interglacial cycles. The project is so designed that the results will permit a comparison to be made with the successful ice core projects on Greenland, thus enabling conclusions to be drawn on climatological trends in the northern and southern hemispheres. Furthermore, comprehensive documentation will be obtained of climate processes in the Antarctic, documentation that has been mainly confined so far to analysis of the ice cores recovered at Vostok and on Dome Fuji. In order to achieve these aims, it is essential that ice cores be recovered from two sites featuring different accumulation rates, so that the required resolution is obtained on different time scales, on the one hand, and that continent-wide differences be identified with special reference to the complex structure of the Antarctic atmosphere.

The EPICA as a whole will be conducted in two phases:

1. Ice core recovery on Dome Concordia (Dome C)

The ice core from Dome Concordiaoncordia (Fig. 1) will enable conclusions to be drawn about major climate changes across several glacial-interglacial cycles. An ice core from this site is viewed as an ideal basis for setting events in the Antarctic within a global context, especially by comparing them to ocean sediment cores, continental archives and Greenland ice cores. The ice core drilling programme is being carried out with Italy and France responsible for logistics operations.

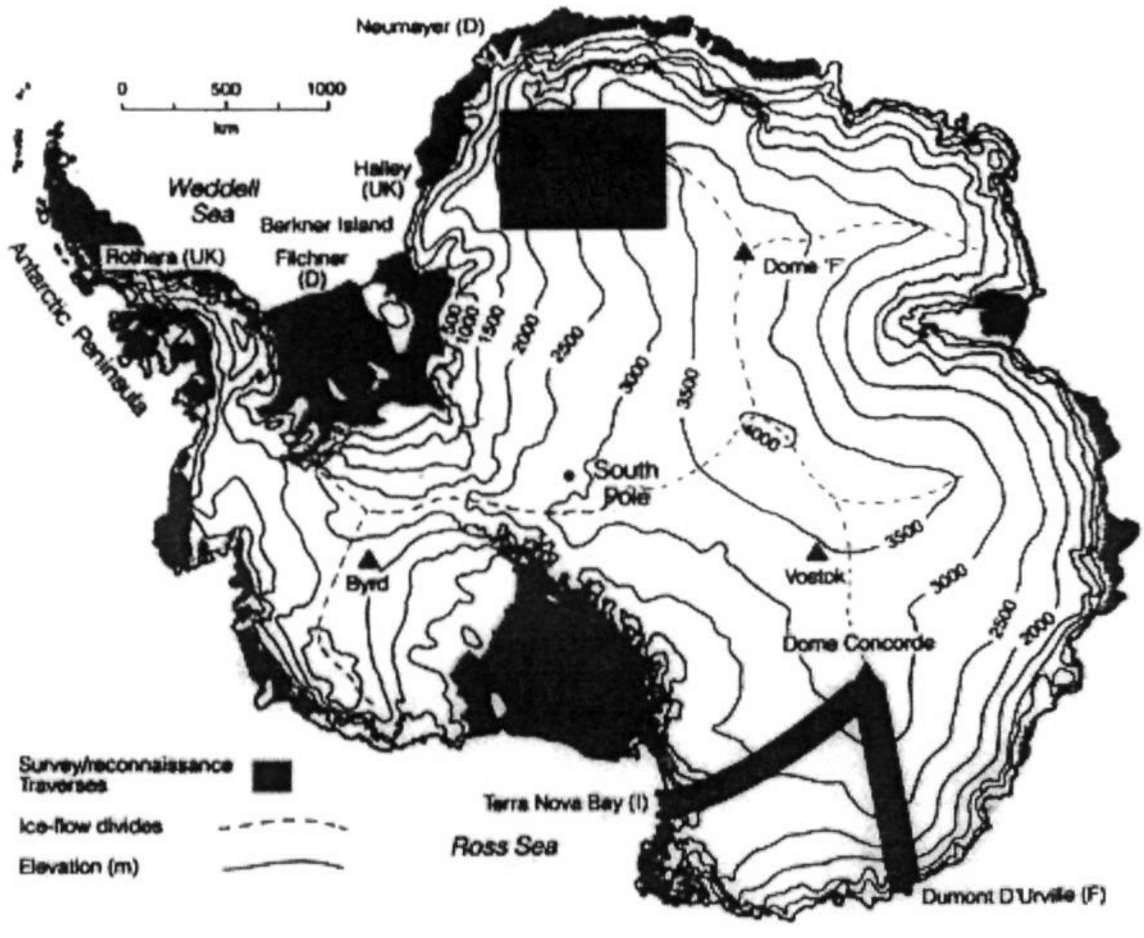

Fig. 1 Map of Antarctica showing the two areas under investigation in the frame of EPICA: Dome Concordia and Dronning Maud Land (source: EPICA/ESF)

2. Ice core recovery in Dronning Maud Land (DML)

Dronning Maud Land (Fig. 1) is characterised, relative to Dome Concordia, by the greater influence of the Atlantic Ocean, one and a half times the annual snowfall rate, and thinner ice cover. An ice core at this site will concentrate on rapid climate oscillations that were identified on Greenland for the last glaciation period. In order to identify a suitable site, the EPICA DML pre-site survey has been carried out since 1995/96 within the international framework provided by EPICA. The area around 'DML05', on the Greenwich meridian at 75°S, appeared to be a suitable location at which to commence drilling.

The planning and execution of logistical operations for the DML ice core will be managed by the Alfred Wegener Institute Foundation for Polar and Marine Research in Bremerhaven, Germany.

There can be no excluding at the outset that the drilling activities themselves may be classified under the Protocol Implementation Act as having "more than a minor or transitory impact" on the Antarctic environment and/or its original state. This classification requires that an environmental impact assessment be conducted in respect of the planned activities. In consultation with the EPICA Steering Committee, the Alfred Wegener Institute Foundation for Polar and Marine Research, as the institution responsible for logistics, has taken over the task of preparing the environmental impact assessment.

3. Description of the planned activities

3.1 General description and scheduling of the planned activities

In order to prepare and execute the deep core recovery, a drilling camp will be set up, including a Drill and Science Trench (trenches for recovering and processing of the cores). For this purpose, all materials required for erecting accommodation for scientists and technicians, for recovering the ice cores and for supplying the camp will be unloaded at the ice shelf edge (Ekströmisen) and transported from there across the ice shelf and the adjacent inland ice to the envisaged site on the inland ice plateau (Amundsenisen) of Dronning Maud Land (Fig.1). The linear distance from the ice shelf edge, near Neumayer Station Station, to the planned drilling site is approx. 560 km, increasing to approx. 750 km due to the terrain along the transportation route. Passengers will mainly be transported by air from the Neumayer Station Station.

The total mass of goods required for the project amounts to around 650 t. Further details on this point are provided in Sections 3.5.2 (Traverses) and 3.3 (Drilling camp).

Work at the drilling camp, including the traverses, will be limited each season to the three summer months, December to February, on account of the restricted accessibility of the Antarctic for supply ships. This corresponds to approx. 75 days' operation time for the camp and 60 – 65 drilling days. At the end of each season, the camp will be closed down and secured for the winter (see Section 3.3.7).

Three summer seasons are planned for the actual core recovery, with one season each for building up the camp and dismantling work including follow-up measurements. This means that a total of 5 years must be assumed for the ice core recovery programme as a whole (Table 1). The final schedule will depend on the actual progress of core recovery, since at least 2500 m must be drilled at the planned location, where the ice thickness is 2750 ± 50 m, in order to record a complete glacial cycle (approx. 110,000 years). When the ice core project has ended, the camp will be dismantled and transported overland to the ships.

A total of 25 – 30 scientists and technicians will be involved in the drilling work and the traverses.

For deep core recovery, a drilling fluid must be used that counteracts the hydrostatic pressure of the surrounding ice. This prevents the borehole from being deformed and the ice from splintering during drilling operations.

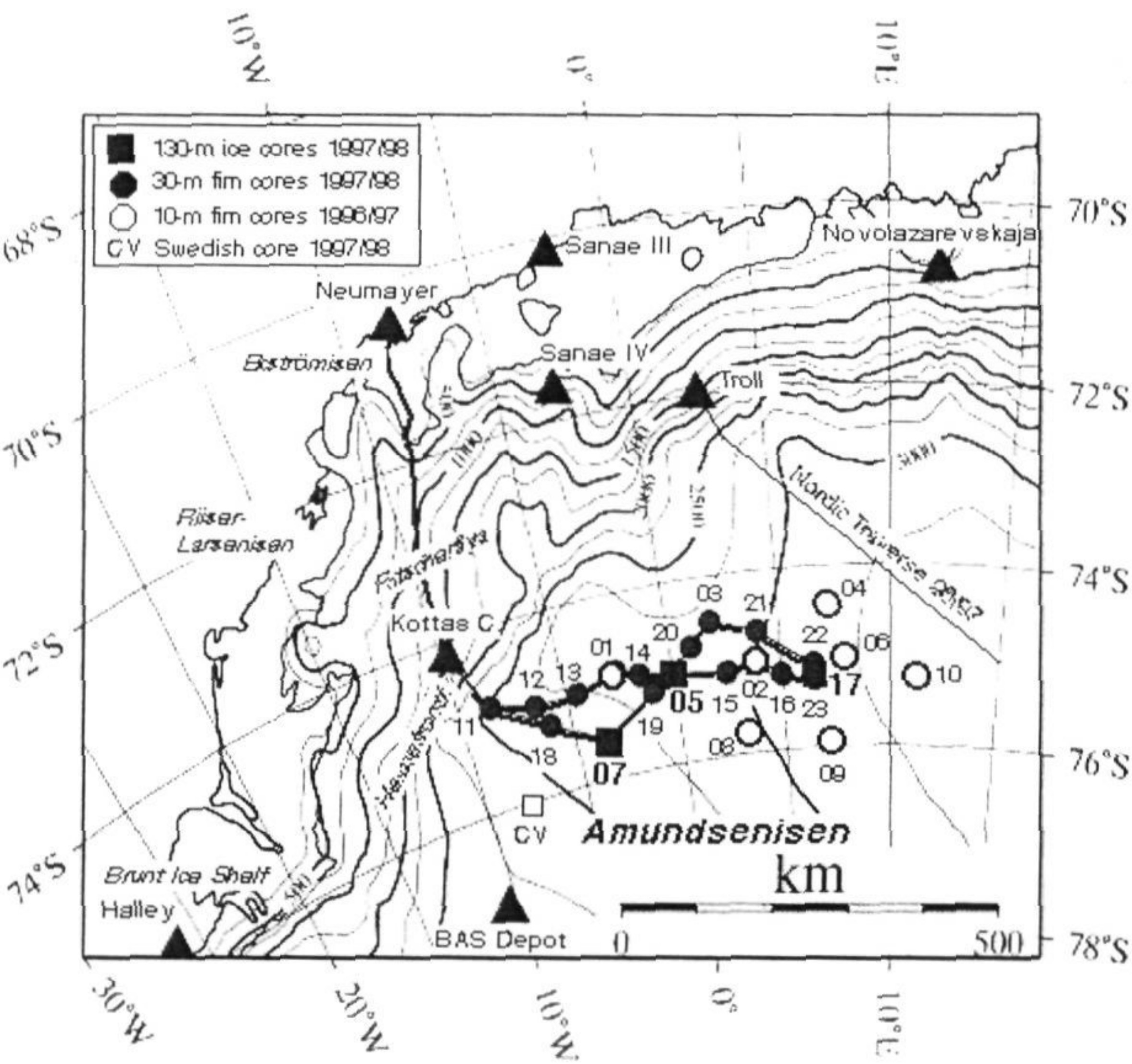

Fig. 2 Map of Dronning Maud Land showing locations visited during the EPICA pre-site survey and supply routes. The proposed EPICA drilling point is DML 05 at 75° S, 0° E. (see also the attached map)

Table 1 Timetable for tasks and logistics

	Season 1	Season 2	Season 3	Season 4	Season 5
Logistics tasks:	Erection and commissioning of the drilling camp	Completion and commissioning of the camp Installation of deep coring equipment	Camp operation	Camp operation	Shut-down and dismantling of the drilli equipment and the camp
Scientific tasks:	Fore-boring and borehole casing	Drilling to depth of approx. 1000 m	Drilling to depth of approx. 2000 m	Drilling to final depth	Scientific measurements in the borehole
Transport of materials for erecting camp	X	X			
Transport of operating supplies to the drilling camp	X	X	X	X	X
Commissioning of the camp	X	X	X	X	X
Measurement work, packing, transportation of the ice cores back to Europe		X	X	X	
Depot storage of operating supplies for the coming season	X	X	X	X	
Conservation of the camp for the winter	X	X	X	X	
Transport of all waste back to Europe	X	X	X	X	X
Transport of all materials and equipment back to Europe					X
Transport:					
Traverses	2 traverses = 5 traction vehicles	2 traverses < 5 traction vehicles	1 traverse = 5 traction vehicles	1 traverse = 5 traction vehicles	2 traverses = 5 traction vehicles
Fuel requirement (m^3 Arctic diesel)	67.2	44.8	33.6	33.6	67.2
Fuel requirement for camp (m^3 Arctic diesel)	20 (1/2 x 80 d x 500 l)	40 (80 d x 500 l)	40 (80 d x 500 l)	40 (80 d x 500 l)	20 (1/2 x 80 d x 500 l)
Fuel requirement for aircraft (m^3 JP8)	21	35	35	35	21

3.2 Selection and description of the site

3.2.1 Pre-site survey in Dronning Maud Land and selection of the site

The aims of the four-year EPICA pre-site survey in Dronning Maud Land were as follows:

- The ice thicknesses in the survey area were to be measured and mapped with the help of surface and airborne ice radar systems. The objective was to measure not only the total ice thickness, but also the internal stratification of the ice sheet. The measuring method is described in Nixdorf et al. (1999), the result in Steinhage et al. (1999). These measurements provided the first opportunity ever to generate a relief map of the highly structured bedrock and in this way to select a site with flat bedrock appropriate for recovering a deep ice core. This work was carried out in a partnership of German and British workgroups.

- The second key objective of the survey was to determine the geographical distribution of accumulation rates. This was done with the help of firn cores (core length 10 – 150 m). The results of the surveys carried out by the Norwegian, Swedish, British and German workgroups are published in Isaksson et al. (1999) and Oerter et al. (1999a, b).

- The firn cores can be analysed to determine not only the accumulation rates, but also to identify the component substances in snow that are to be analysed at a later stage when the deep ice cores have been recovered. Data is now available on the present-day distribution of stable isotope concentrations (^{18}O and ^{2}H) and selected trace substances (e.g. sulphate, nitrate, MSA, chloride), thus offering an opportunity to interpret changes that occurred in the past. Initial output from these studies can be found in Isaksson et al. (1999) and Oerter et al. (1999a, b).

- A further objective of the survey was to specify the location of survey sites and to ascertain the flow velocity of the ice. Here, the field measurements were also supported by numerical modelling, from which the balance velocity can be estimated (Huybrechts et al. 1999).

- As part of the survey programme, a new satellite image map (included in the Annex) was produced for Dronning Maud Land.

Early in the year, an EPICA Science Group Workshop was held at which the results obtained to date were discussed. The conclusion was that an area suitable for deep core drilling existed at 75° 0′S 0° 0′E, in a radius of 50 km around the DML05 site. The ice profile at this location has

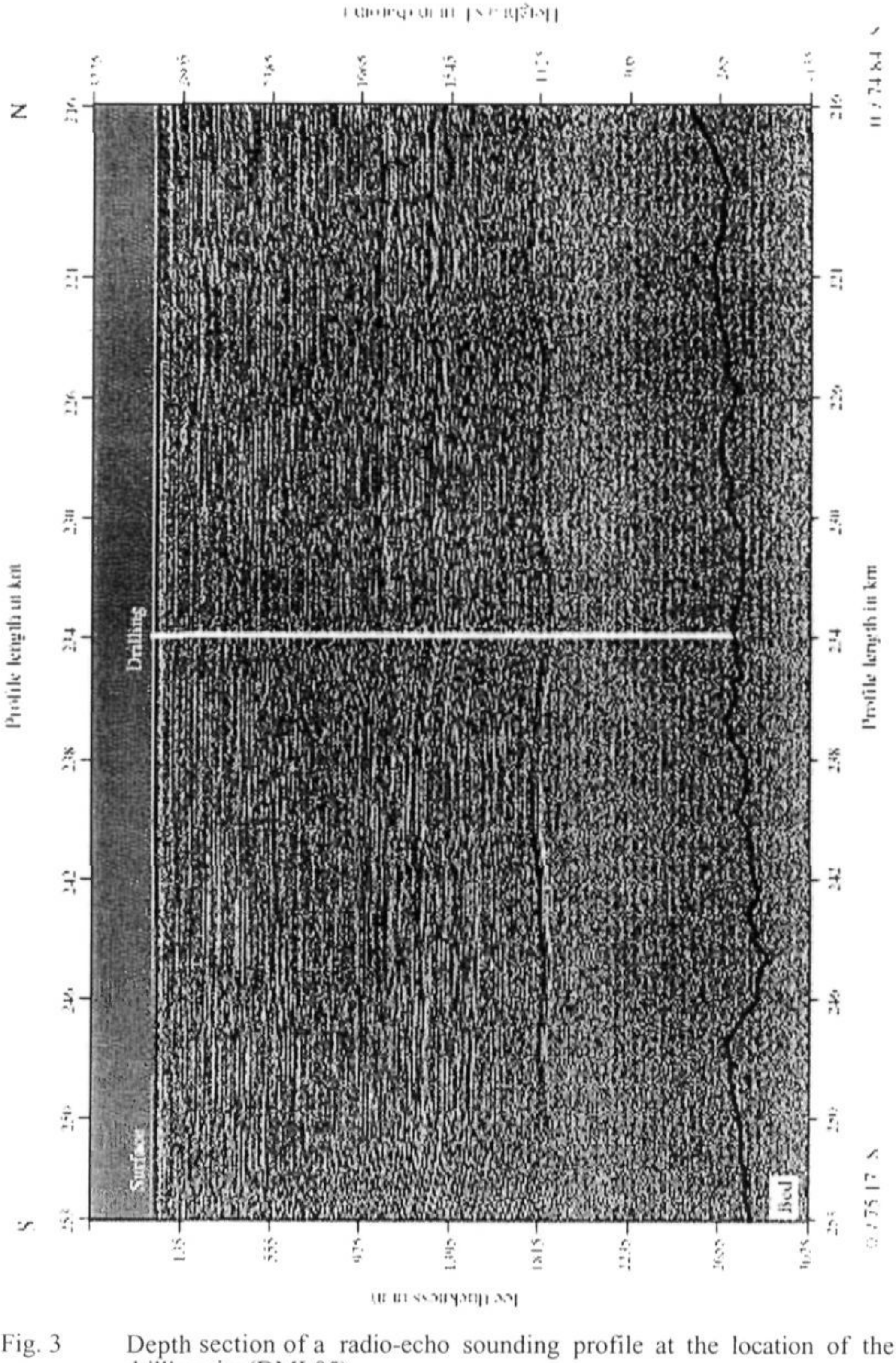

Fig. 3 Depth section of a radio-echo sounding profile at the location of the proposed drilling site (DML05)

the characteristics necessary for successful ice analysis, namely uniform internal layering over flat bedrock, and an ice thickness of 2750 ± 50 m (Fig. 3). The multiannual mean accumulation rate is around 62 kg m^{-2} a^{-1}. One further criterion relates to the position of the site on an ice divide characterised by predominantly vertical ice movements and low horizontal flow velocities. As early as the 1997/98 season, a 150 m-long ice core was recovered at point DML05, providing the first data on the structuring of the ice layer and how it has changed over time.

3.2.2 Alternative choice of site

From the studies carried out during the pre-site survey, it was established that the combination of the required ice properties in DML at this position offered the greatest prospects of success for deep ice core recovery. No site with similarly good conditions was identified in DML.

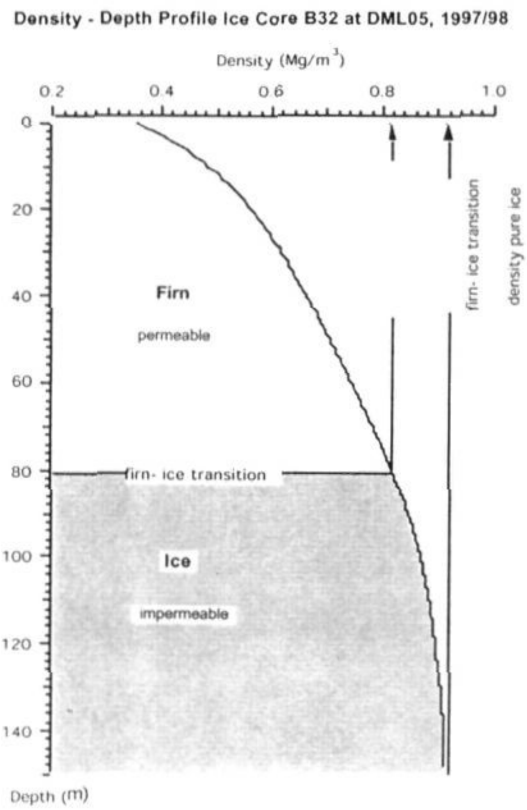

Fig. 4 Density-depth profile of the ice sheet at the DML05 drilling site

3.2.3 Description of the site chosen for the ice core

3.2.3.1 Geographical position, meteorological and glaciological conditions

The chosen site for the drilling camp at 75°S, 0°E is on the plateau of the inland ice sheet (Amundsenisen), approx. 300 km eastwards of the Heimefrontfjella region (see Fig. 2). The distance to the ocean is approx. 560 km. There is no ice-free ground in the immediate vicinity or at any medium distance away. There are no inland (freshwater) lakes within a radius of at least 300 km.

A mean annual snowfall of 70 kg m^{-2} a^{-1} was derived for the DML05 site. The surveys revealed high interannual variability (approx. 35 %, Oerter et al. 1999b). In addition, a slight increase in the accumulation rate in the course of this century can be identified (cf. values in Table 2).

An ice sheet is composed of porous firn layers and the ice mass underneath them. The density-depth profile determined at DML05 shows the transition from firn that is still porous to compact ice at approx. 80 m (Fig. 4). The flow velocity of the ice is <9 m a^{-1}, the main directions of flow being SW and NW from the area chosen for the camp (outflow from a firn-ice transition).

Table 2 Geographical position, weather conditions and ice properties at the DML05 drilling site chosen for the core

Geographical position	75° 0.15´S, 0° 0.42´E Amundsenisen/Dronning Maud Land
Elevation above sea level	2882 m (corresponding to approx. 700 mbar air pressure)
Distance to the coast (ice shelf edge at Neumayer Station) Linear distance Overland	 approx. 560 km approx. 750 km
distance to the next Nunatak (Heimefrontfjella)	approx. 300 km
Air temperature during the polar summer (Dec. – mid Feb.)	- 20°C - -35°C
Mean annual temperature (1998)	-46.0° C
Wind speed (1998)	Max. approx. 15 m s^{-1}
Prevailing wind direction (1998)	NE – E (approx. 65°)
Cumulative increase in snow depth in 1998	approx. 30 cm (mean increase in snow approx. 20 cm)
Ice thickness	2750 ± 50m
Mean accumulation rate	62 kg m^{-2} a^{-1} (mean for 1810-1997) 71 kg m^{-2} a^{-1} (mean for 1930-1996)
Flow velocity of the ice	approx. 2 – 9 m a^{-1}

(Data taken from Oerter et al. 1999b; Steinhage et al. 1999; weather data: Oerlemans, pers. comm.)

There is an automatic weather station operated by the University of Utrecht at the DML05 site. Meteorological data (temperature profile, precipitation, wind speeds and direction) have been available since 1.1.98. Daily mean values recorded since 1998 are shown in Fig. 5, and the mean values are listed in Table 2.

The wind speeds at the site are low and only rarely reach 10 m/s (especially in summer). This accords with the lack of roughness in the snow surface. The prevailing wind direction is NE to E.

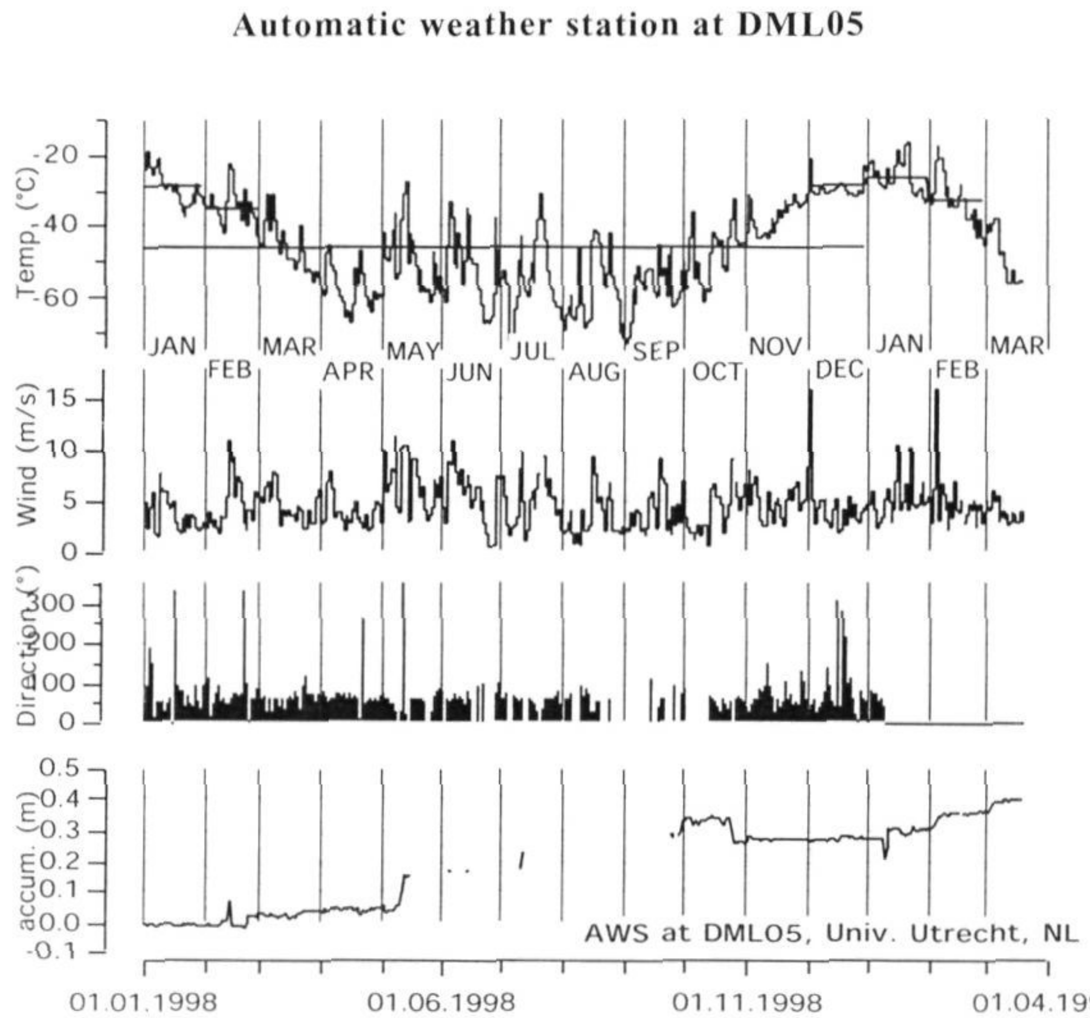

Fig. 5 Mean daily values for air temperature, wind speed, wind direction and graph of increasing snow depth at the automatic weather station operated by the University of Utrecht in 1998 (Oerlemans, pers. comm.)

3.2.3.2 Biota in the vicinity of the drilling site

The site is located on an inland ice plateau characterised by very low temperatures (annual mean in 1998: –46°C). Meltwater does not arise during any season. The entire transport route is over shelf ice and inland ice.

3.2.3.2.1 Mammals and birds

There are no colonies or accumulations of mammals and penguins, and no breeding grounds of birds in the vicinity of intended drilling site.

The nearest known penguin rookery is found at a distance of approx. 560 km, at the coast. During the summer months, Adelie penguins (*Pygoscelis adeliae*) are found there, in addition to Emperor penguins (*Aptenodytes forsteri*). In the area around the Neumayer Station Station, there is a breeding rookery of Emperor penguins with approx. 5000 pairs (Fig. 6, cargo handling facility at Neumayer Station, Atka Bay). By January, when most supply activities for Neumayer Station begin, the breeding rookery of Emperor penguins has already disbanded. At that time, there are only some residual stocks of moulting chicks on the remaining ice. Weddell seals (*Leptonychotes weddellii*), Antarctic petrels (*Thalassoica antarctica*) and two species of skua birds, the south polar skua (*Catharacta maccormicki*) and the brown skua (*C. lonnbergi*), are found on the sea ice, in the inlets and around the edge of the ice shelf.

The inland mountain ridges and the ice-free outcrops or mountain peaks (nunataks) projecting from the inland ice are populated by snow petrels (*Pagodroma nivea*) and kleptoparasitic south polar skuas (*Catharacta maccormicki*). Unlike most of the other Antarctic petrels, snow petrels breed far inland. To search for food, they move into the pack ice areas and may have to fly long distances before they reach the coast (summarised in Warham 1990). Descriptions have been given of breeding grounds in Dronning Maud Land up to 300 km inland from the coast, and at heights of up to 2100 m (Lovenskiold 1960, Somme 1977, Amundsen 1995).

Snow petrels are spring and summer breeders, and can be found in the breeding areas from October to March. The chicks are hatched on the Svarthamaren nunatak, Mühlig-Hofmann-Gebirge, Dronning Maud Land, around mid-January (Amundsen 1995). Nests are built on rocky, snow-free ledges, preferably where there are deep recesses and cracks that provide good protection against the wind. Volcanic rock is generally avoided, since it does not have such features.

On the flight and traverse route through the Kottas mountains, no petrels were observed there in a radius of around 100 km during the pre-site surveys (Oerter, pers. comm.). Snow petrels were seen in the Heimefrontfjella, at a distance of approx. 100 km from the traverse route (SVEA). If relevant, a distance of about 500 m must be kept from any breeding grounds. Skuas can be attracted by human activities.

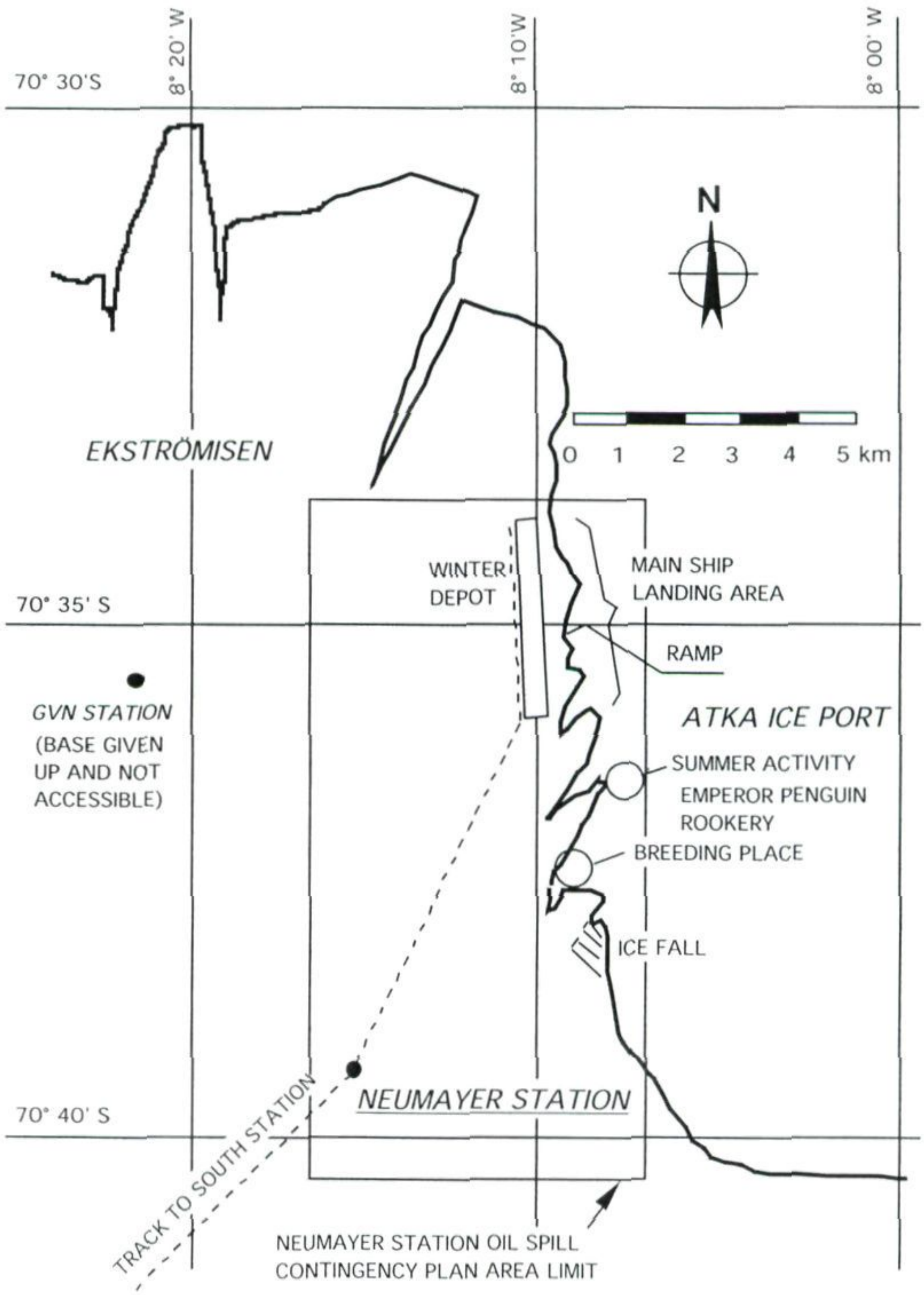

Fig. 6 Map of the ice shelf-edge adjacent to the Neumayer Station showing the main ship landing area and the location of the emperor penguin rookery (from Emergency Manual Antarctica, AWI (1999))

3.2.3.2.2 Cryptogamic and higher plants

The substratum under the drilling camp and the overland transport route is the inland ice sheet. There is no vegetation there. Similarly, none of the invertebrates occurring elsewhere in moss and lichen swards (nematodes, rotatoria, tardigrades, collemboles, acari), are found in this area.

3.2.3.2.3 Microflora

According to the current state of knowledge, some snow algae (e.g. *Chloromonas sp.*, *Chlamydomonas sp.*) are reliant on the saturation of snow with meltwater during the summer months and have been observed near the coast, often in the vicinity of bird or seal colonies (Akiyama 1979, Hoham 1992, Ling & Seppelt 1998). Colorations of the snow caused by snow algae were not identified during the pre-site surveys on the Amundsenisen.

3.2.3.3 Specially protected areas

There are no specially protected areas (SPAs) or sites of special scientific interest (SSSIs) within the range of influence of the transportation routes or the drilling camp (cf. Fig. 2).

The nearest SPA is the ice-free region of the Svarthamaren nunatak (SSSI No. 23), which is situated about 400 km from the DML 05 drilling site, in the Mühlig-Hofmann-Gebirge area of Dronning Maud Land (71°53´S, 5°10´E). This is the location of the largest known seabird rookery (Antarctic petrels) situated inland on the Antarctic continent.

3.2.3.4 Past and future use of the area

In the 1960s, the USA created a major traverse, the 'South Pole Queen Maud land traverse' (SPQMLT), the most northerly point of which is at the southernmost boundary of the area covered by the EPICA pre-site surveys.

From the 1995/1996 season onwards, pre-site surveys were carried out for EPICA on the Amundsenisen, southeast of the Kottas mountains, by Germany, the United Kingdom of Great Britain and Northern Ireland, Sweden, Norway and the Netherlands (Fig. 2). These studies involved an extensive glaciological programme of radio-echo sounding surveys to determine the thickness and internal stratification of the ice, (Steinhage et al. 1999), snow sampling and shallow firn cores for accumulation studies (Oerter et al. 1999 a, b).

As part of the EPICA programme, an automatic weather station operated by the University of Utrecht was installed at the DML05 site (cf. Fig. 5).

On completion of the ice core recovery programme forming the subject of the application, ice temperature and ice deformation at the drilling site will be monitored as long as possible by taking measurements in the borehole.

3.3. Erection and operation of the drilling camp

3.3.1 Logistical support

It is planned to set up a temporary drilling camp on the inland ice, in the immediate vicinity of the borehole. The latter camp is intended to accommodate a maximum of 20 scientists and technicians working on and supporting the ice core project (for the required staffing level, see Section 3.3.2.1). The camp will be used during the summer months only.

Logistical support for the drilling camp will be provided through the German overwintering station, Neumayer Station, which is situated on the Ekströmisen at Akta Bay (70°39´S, 08°15´W). The station is located on an ice shelf of around 200 m thickness, and is moving at a speed of approx. 166 m y^{-1} in a NNE direction. The shortest distance to the ice shelf edge is approx. 8 km.

3.3.2 Description of the camp

3.3.2.1 Planned activity

The temporary drilling camp comprises pre-fabricated, 20-foot container units and will be installed for the duration of the ice core project (estimated at 5 years). It is designed to accommodate 20 persons.

During the ice core recovery, scientists, technicians and operating personnel for the drilling camp will be deployed there. The personnel involved are grouped as follows:

Scientists and drilling technicians	14
Drilling camp operators:	
Technicians:	4
Cook	1
Doctor	1

During the drilling season, the station will thus be staffed by about 20 people in all.

During the installation and dismantling seasons (the first and last season), a construction crew comprising three fitters will be responsible for erecting and dismantling the camp.

Five technicians will be deployed on the traverses and will spend only short periods of time in the camp (see below).

The camp comprises a total of 14 containers (excluding the fuel dump), which will function as dormitories, sanitary areas, mess, kitchen as well as radio and computing rooms. They also contain a generator, snowmelting equipment, workshops and storage rooms (Fig. 7). Most of

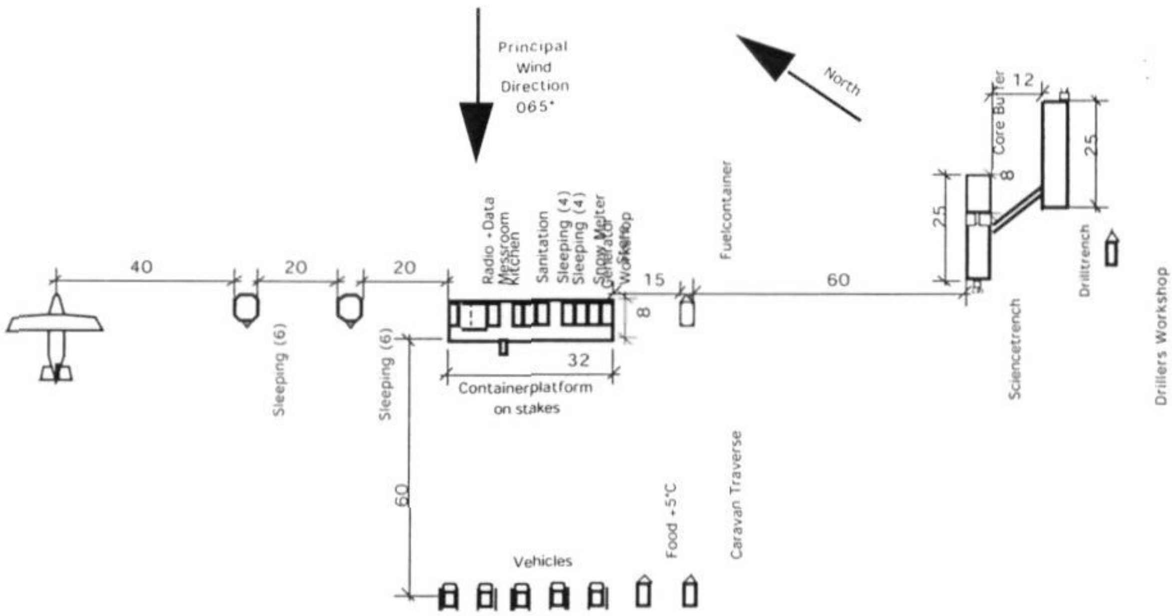

Fig. 7 Planned arrangement of the drill camp (measures in m)

the container units stand on a platform made of steel elements (11 containers in all). In addition, there will be 2 folding containers (each covering an area equivalent to 3 20-foot containers), providing an additional 12 beds. Drivers for the traverses will use their own mobile container as living quarters for the duration of their stay (3-5 days in each case).

Tank containers will be located at a distance of approx. 15 m from the platform. Parking areas for the camp vehicles and the food containers are envisaged at a distance of around 60 m from the platform. Those containers not situated on the platform will be on sleds, some of them being replaced each year (e.g. containers with food).

The container platform will be erected on steel supports (2 m ground clearance) and can be raised as required using winches, depending on the accumulation of snow (Fig. 8). At the drilling site, this will be necessary at most once in five years. The steel supports ensure that snow can drift through under the platform and that the containers are not covered by drifts. The steel supports rest on timber boards of different areas so that uniform pressure is exerted on the ice. Steel grids around the container units.serve as paths.

All container units will be fully fitted in Germany, thus reducing the time required for erection of the camp at the drilling site.

At a distance of approx. 70 m to the container platform, drill and science trenches will be dug. Each of these trenches will be 25 m long, 4 m wide and 4.50 m deep. Both trenches will be covered over with a timber roof. The actual drilling will be carried out in the driil trench, whereas measuring and packing work, as well as storage of the ice core segments in the 'core

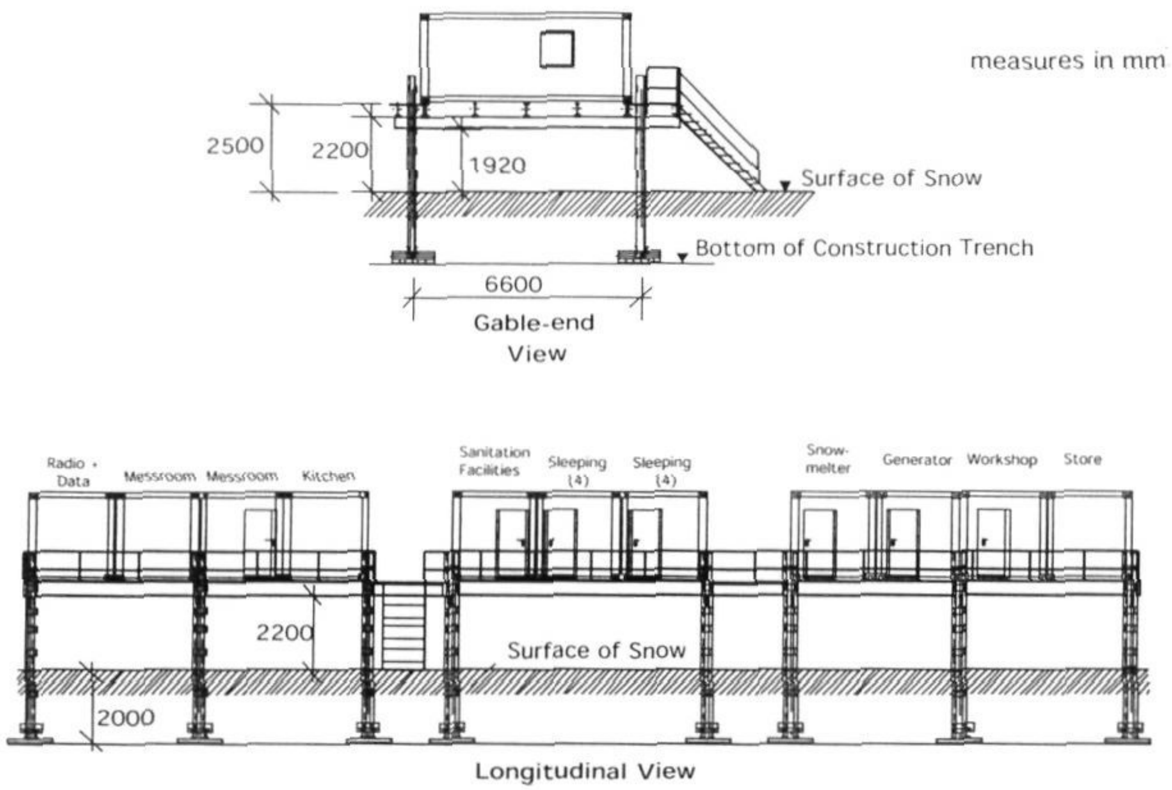

Fig. 8 Gable and longitudinal view of the planned container platform. The use of the single containers is shown as well.

buffer' will be done in the science trench. The trenches are situated 12 m apart and are connected by a further trench (Figs. 7, 9b). The drill trench will be equipped with a ramp of approx. 10 m length, so that heavy drilling gear can be moved into the trench.

Each of the two trenches has a lift for material transport. The lifts are simple roofers' lifts that run along ladders. These ladders also provide an emergency exit from the trenches. A good ventilation system is essential for providing a sufficient inflow of fresh air.

Power supply cables are laid in the snow between the container platform, the trenches and the vehicle pool. Plywood and timber supports are laminated withstanding seawater.

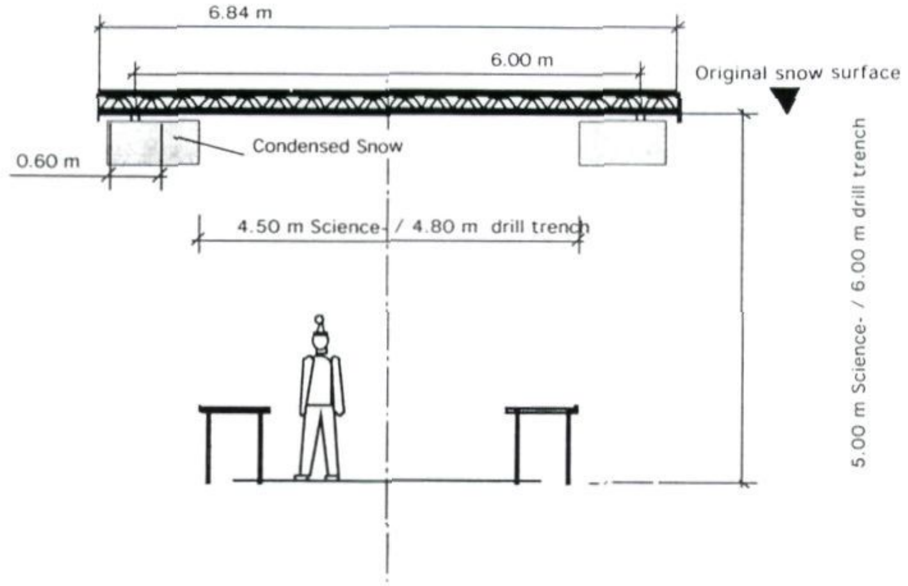

Fig. 9a Cross section through drill and science trench, respectively (measures in m)

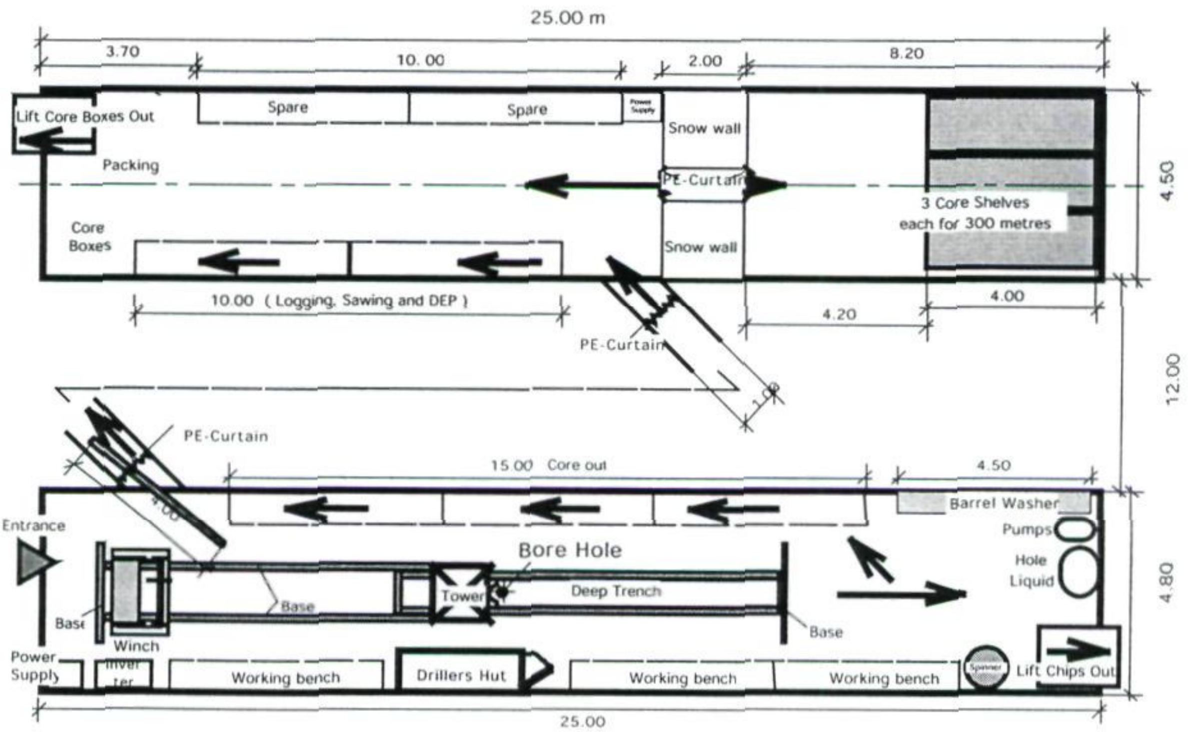

Fig. 9b Ground plan of drill an d science trench (measures in m). the arrows mark the way of ice core processing

Table 3 Drilling camp elements and materials

Element	Material	Specifications	Volume (m^3)
Supports and framework in total			39
Supports, frame Grids Grid supports	steel, ungalvanised steel, galvanised Steel, ungalvanised	St 37-2 St E 26	
Footboards, approx. 20 m^2	Squared timber, 10/10 cm		2
14 containers (without permanent/removable fittings)	Steel		315
Cables between camp areas	Copper cable, rubberised	H07RNF	2
Drill trench:			
Trench cover	Timber, plywood		32
Base/Floor	Timber		4
Science trench:			
Trench cover	Timber, plywood		20
Floor	Timber, plywood		3
Shelves for core buffer	Timber		15

3.3.2.2 Alternatives

A conceivable option would be to erect a temporary camp on sleds. However, this would be greatly impaired by snow drift and would have to be cleared of snow at regular intervals. This would necessitate seasonal transportation of the container sleds to and from the camp and thus a higher level of fuel consumption compared to a stationary camp for the duration of core recovery.

3.3.3 Energy and water supply

3.3.3.1 Planned activity

Power is supplied to the camp by a generator (diesel aggregate with turbo supercharger) with approx. 90 KVA output. This new generator will be specially procured for the ice core project and conform to the best available technology in terms of both power efficiency and environmental protection aspects (soot filter). An emergency generator will also be provided in addition to this main generator.

The water supply system (snowmelt) uses the waste heat of the generator. A burner will also be taken to the site as an emergency precaution, since the coolant system of the reserve generator is not connected to the heat exchanger for melting snow.

3.3.3.2 Alternatives

A wind turbine, like the one operating at the Neumayer Station Station, involves a considerable amount of construction work. Due to the low wind speeds and periods with no wind at all at the site on the inland ice plateau, such a turbine would be unable to provide an adequate power supply.

For this reason, a wind turbine is no alternative to a diesel generator for a temporary camp at this location.

In order to deliver a permanent output of 90 KVA, a solar energy array comprised of standard 0.86 m^2 elements would cover an area of approx. 1400 m^2. Before such an array could enter service, a considerable amount of construction and installation work would be necessary (installation of the solar cells, cabling work, energy storage systems). Because of the building work thus necessitated for annual operations at the camp for a two- to three-month period each year, a solar energy array would be an unrealistic alternative to a diesel generator.

Both a wind turbine and a solar energy array would have to be designed for double the required power output compared to a generator, since there is no waste heat, as in a diesel generator, that could be used to melt snow for water supply purposes. Both types of energy supply system would have to be completely dismantled at the end of the core recovery activities, and any pollutants (e.g. batteries) disposed of.

3.3.4 Fuels/Operating materials

3.3.4.1 Type and quantity

Arctic diesel is required for the generator and the PistenBully vehicles. This fuel is transported and stored in 14,500 l tank containers with built-in fuel pumps, mounted on sleds. The pumps are powered by electricity (24V DC/220 V AC) from the traverse vehicles (24 V) or the generator (24V / 220 V). They are fitted with fuel filters, fuel meters, a self-locking filling gun and a 16 m pipe suitable for all types of fuel. There is an oilpan under the pump. All openings for normal filling or pumping are located on the top. Draining outlets with double valves and protective caps are located on the underside. All tank containers comply with the standards for fuel transport containers and are inspected and approved by Germanische Lloyd. Inspections are carried out in Germany every five years.

Ski-Doos require minimal amounts of petrol in operation. The petrol is transported and stored in 200-litre steel drums. A maximum of 300 litres per season is required.

No kerosine (JP-8) is stored at the camp for regular use by aircraft. At Neumayer Station there are tank containers storing 120 t JP-8 for normal flights. However, a fuel reserve is provided

Table 4 Type, quantity, specification and storage of fuels and operating supplies for a project duration of 5 years

Type/use	Ignition temp. (°C)	Flash point (°C)	Toxicity	Water risk category (WRC)	Risk of explosion at volume %	Risk of static charge	Dangerous goods code	UN No.	Quantity (m^3)	Storage/Transport
Arctic diesel PistenBully (traverses)	240	>55	low	WRC 1; weak	low; at 1.1 - 6.5	-	Xn	1202	247	Tank containers, IMO
Arctic diesel for camp (80d x 350 l /season)	*ditto*	*ditto*	*ditto*	*ditto*	*ditto*	-	Xn	1202	160	Tank containers, IMO
JP-8 (aircraft fuel: kerosine) of which emergency reserve at camp	approx. 220	38	low	WRC 2; weak	low; at 0.6 - 6.5	yes	Xn, Xi IMDG/GGVSee: 3.3	1223	147	Tank containers, IMO approx. 10 - 20 200l drums
Unleaded normal petrol for Ski-Doo (91 octane)	approx. 220	< 21	toxic, carcino-genic	WRC 3; weak	high; at 0.6 - 8.0	-	T, F+ IMDG/GGVSee: 3.1	1203	1.5 max.	200 l drums
Shell Motor oil DG 1040 (or similar) for two-stroke engines (Ski-Doo)		210		WRC 2; weak	-					

to cover for emergency situations caused by sudden weather changes or technical problems (10-20 200-litre steel drums; see 3.5.3).

The 200-litre steel drums are the same as 55-gallon storage and transport drums. Their inner walls are coated and the outer surface painted according to a colour code (Arctic diesel: orange, petrol: grey, kerosine JP-8: red).

Lubricant requirements for all generators and vehicles (motor oil, two-stroke oil, gear oil) is approx. 300 kg per season.

It is not intended to have stationary tank depots with built-in fittings, because the activities at the camp and the drilling site are for a limited time only.

3.3.4.2 Estimated emissions from fuel and lubricant consumption

The total requirement for the entire ice core project amounts to 247 m^3 (205 t) of Arctic diesel for the traverse vehicles, 160 m^3 (112 t) of Arctic diesel for camp operation and 147 m^3 (120 t) of kerosine for transportation flights (see Table 1 for a list of seasonal requirements). Burning these fuels causes emissions.

The total quantity of gaseous emissions and particles released into the atmosphere are estimated for consumption of the entire fuel supply brought to the site. For camp operations (the generator), mean emission values for generators of 50 – 147 kW output were used as a basis (EU Report No. 1445-99).

Total estimated emissions as a result of camp operations (maximum values)

CO	0.5 t
CO_2	350 t
NOx	6.9 t
Particles	0.1 t

The amount of operating supplies required at the camp is approx. 12.5% of the total during the erection and dismantling phases (first and last season), and approx. 25% during the drilling season.

Diesel consumption during the traverses can be broken down to approx. 27% of the total for the erection and dismantling phases (2 traverses in each case) and approx. 14 – 18% of the total during the drilling season. Emissions are calculated on the basis of 2.63 kg CO_2 l^{-1}. The total amount of emissions generated will be distributed along a route of 5250 – 6000 km (simple traverse route), for 7 – 8 traverses.

Total estimated emissions as a result of traverses (traction vehicles; consumption 247 m^3):

CO	0.97 t
CO_2	650 t
NOx	12.7 t
Particles	0.18 t

In addition, fuel consumption during transportation flights will lead to airborne emissions of CO, CO_2, NO_x, SO_2. For estimated mean emissions of approx. 2.5 kg CO_2 l^{-1} kerosine, a maximum of 378 t CO_2 will be released to the atmosphere through the combustion of aircraft fuel (147 m^3).

3.3.4.3. Estimate of immissions

The use of vehicles and the operation of the camp cause immissions to the atmosphere and the snow surface. As described in the previous section CO, CO_2, NO_x and soot particles are emitted. The emission is continuously and the emitted compounds will be taken away from the place of emission by the moving air masses. Thus the gaseous compounds will be mixed in vertical and horizontal direction by turbulent diffusion and continuously become diluted. The residence time in the atmosphere of soot particles until complete deposition is approximately 5 – 7 days (R. Weller, pers. com.). To asses the emissions the contribution of the CO_2 emissions into the boundary layer of the troposphere above the Antarctic ice sheet (height of the temperature inversion approx. 800 – 1000 m) was estimated as well as the deposition of soot particles on the snow surface.

3.3.4.3.1 CO_2 immission at the camp

The hemispheric circulation continuously exchanges the tropospheric air masses above the Antarctic continent. The lower air masses are transported within 7 – 10 days over distances of a couple of thousands of kilometres as it was shown by trajectory models. The general flow direction points from the continental ice sheet to the ocean. Above the coastal regions this air movement overlaps with the general circulation pattern of the low-pressure systems. According to this air flows from the low latitudes to the interior of the Antarctic continent within the free troposphere. Said circulation causes a complete exchange of air masses within the troposphere above the Antarctic within a period of 1 – 2 weeks. Therefore, atmospheric compounds with long residence times will be measured at the same concentration as at lower latitudes. The gradients are small due to this exchange mechanism.

For a rough estimate it is assumed that a vertical turbulent mixing occurs only within the boundary layer, that means below the temperature inversion and up to a height of approx. 1000 m. If a lateral turbulent mixing is taken into account as well proportional to the distance from the source and a mean wind velocity of 2.5 m/s assumed, then the amount of daily emitted CO_2 will be diluted in an air volume of 23,000 km^3. This results in an increase of the CO_2 mixing ratio by 18 ppt (parts per trillion = 1 part CO_2 in 10^{12} parts of air). The natural CO_2 mixing ratio is appr. 350 ppm (parts per million = 1 part CO_2 in 10^6 parts of air), seven orders of magnitude larger.

This estimate is based on the simple condition that no dilution takes places into the free troposphere und it shows that the immissions of exhaust gases are negligible.

3.3.4.3.2 Deposition of soot particles

As already discussed the residence time of soot particles in air until complete deposition lasts appr. 5 – 7 days. The annual snowfall amounts for appr. 30 cm snow per year or 60 kg m^{-2} a^{-1}.

The estimate for the deposition of soot is based on the assumption that 50% of the soot particles will be deposited within the first day. This means that the deposition takes place across an area of appr. 23,000 km^2 based on a mean air movement of 2.5 m/s. The total amount of emitted soot particles sums up to 0.1 t soot during a 5-years operation period. Thus 0.02 t soot will be deposited during one season resulting in a mean deposition rate of 0.043 ng cm^{-2} a^{-1} and a soot concentration within an annual snow layer of 0.0072 ng/g_{firn}.

The background value measured at South Pole is 0.1 – 0.3 ng/gfirn (Warren & Clarke 1990). Therefore one can expect the deposition rates of soot in the wider surroundings of the drill camp to be remarkable lower than this background value.

3.3.5 Wastes and sewage disposal

3.3.5.1 Planned activities

Wastes will be separated and collected according to substance type (glass, paper, plastics, metals, organic waste). All wastes will be separated and brought back, then properly disposed of once it has returned from the Antarctic. Appropriate waste containers will be taken to the site for subsequent transportation purposes. Accounts will be kept of all materials brought back to Germany.

The water consumption in the drilling camp will amount to approx. 100 l per day and person. For a maximum of 20 people, this equals 2000 l per day. This estimate includes grey and black water, including water for sanitary and washing purposes.

Grey and black water will be discharged into the ice through a plastic pipe. Liquid wastes may be disposed of in this way on condition that this is the only possible means of disposal, pursuant to § 24 (2) AUG and Article 4 Annex III, Protocol of Envirnonmental Protection to the Antarctic Treaty, respectiviely. The feasibility of alternatives is examined in the following.

3.3.5.2 Alternatives

At other summer camps, e.g. at Dome Concordia, faeces were disposed of by gas incineration ('incinerator toilets'). Gas is required, in addition, for this type of disposal. However, incineration was beset by technical problems. Furthermore, there were substantial safety problems (oral reports by participants on the expedition) that exposed the field camp staff to enhanced risks. At the current state of technical development, the shortcomings and safety aspects of such incineration methods mean that they are not an acceptable alternative.

Alternative wastewater purification plants (microfiltration systems) are currently being tested for use on board ships. These systems are smaller than conventional ones, and would therefore be conceivable alternatives for mobile use. Before they can be used in the Antarctic, it is necessary to wait until the test results have been obtained from the stationary experimental installations and subsequently checked for minimum operating temperature, energy consumption, susceptibility to breakdowns and overwintering capacity (storage at–70°C).

For a maximum water consumption of 2000 l per day and a maximum operating time of approx. 75 days, total water requirements will run to approx. 150,000 l per season. This means that transporting the grey and black water in frozen form back to Europe would involve a substantial volume if the camp is operated to capacity. Due to the incoming solar radiation and the higher temperatures near the coast, there is every likelihood that the frozen blocks might melt or disintegrate, with the consequence that they would have to be transported in suitable containers. Given that the 15 scheduled flights are reserved for ice core transportation and that there are no 'empty' flights, this would involve a considerable increase in transport capacities (traverses or flights), and hence a higher level of fuel consumption. The maximum 150,000 l (150 t) corresponds, for a payload capacity per flight of 800 kg, to approx. 190 flights or 5 sled convoys.

3.3.6 Camp vehicles

Various vehicles will remain at the camp for the duration of the drilling activities, namely a snow blower, a PistenBully vehicle with hydraulic crane, and two Ski-Doos.

Heavy lifting that requires more than one crane (e.g. during erection and dismantling of the platform, or when transporting the drilling gear) will be carried out jointly with the traverse vehicles. This is mainly the case during the erection and dismantling stages.

3.3.7 Closing down the camp and securing it for the winter months

The drilling camp will be vacant for about nine months of each year.

In order to secure the camp and its facilities until the next operating season, the following action will be taken:

- The mobile container units will be removed from the immediate camp area and relocated several hundreds of metres away, in order to prevent a greater increase in snow around the platform and the trenches.
- All water discharge systems will be emptied to prevent freezing and subsequent bursting. These include the entire freshwater system, sanitary and washing facilities, and the snow melting plant. There are no antifreeze liquids in these systems.
- All container units and the trenches, including ventilation and cable shafts, lifts, etc., will be locked and sealed so that no snow can enter. This is done by boarding them up with plywood and sealing with cotton wool. If necessary, snow blocks can be used to protect the containers against further drifts.
- The generator will be shut down with a full day tank (for the first day of the following season).

There is every likelihood that tank containers and fuel drums will remain on site during the winter months. This will depend on the current consumption/requirements and the transport conditions in each year of operation.

3.4 Dismantling the drilling camp

3.4.1 Planned activities

When ice core recovery has been completed, the drilling camp will be totally dismantled and brought back via Neumayer Station. The following parts are exceptions:

- - steel supports of the container platform
- - timber covers for the trenches
- - rubberised electrical cables that were buried in the snow
- - GFK pipes in the borehole (firn)

3.4.2 Alternatives

Removal of the abandoned parts is not feasible unless large volumes of snow are shifted. The natural increase in snow is approx. 70 kg m^{-2} yr^{-1} (cf. Table 2). In the camp area, this amount is further increased by snow drift, with the result that after five years there will be an additional 1.5 m of snow, approximately.

In order to remove the steel supports of the platform, they would first have to be completely exposed, since they were screwed onto timber boards (measuring approx. 1.6 m x 1.6 m x 0.1 m; cf. Section 3.3.2) to ensure uniform distribution of pressure. These footboards act as anchors in the snow and prevent the supports from being pulled out with ease. The timber boards were originally about 2 m under the snow surface, but after five years they will be approx. 3.5 m below the surface. What this means is that the entire support construction would have to be exposed over a considerable area, involving 1.75 times as much excavated snow as was the case when first erecting the platform. The volume of snow that would have to be moved in order to lay bare the supports and refill the trenches could amount to as much as 900 m^3 or 360 t.

Over the 5-year period of operations, the timber covers over the trenches will also have been covered by 1 – 1.5 m of snow. The roof construction is so designed that it can carry the weight of snow, but not the weight of heavy vehicles driving over it. Approx. 250 m^3 of snow would have to be cleared away manually. This would mean additional staff and prolonged operation of the camp.

The electrical cables laid between the generator and the drill and science trenches will also be covered by up to 1.5 m of snow, and would have to be shovelled or ploughed clear.

The GFK pipes remaining in the borehole prevent the drilling fluid from seeping into the permeable firn. Furthermore, it is planned to keep the borehole open by extending the GFK pipes beyond the upper edge of the drill trench for later follow-up measurements (e.g. recording of temperature profiles) in the borehole.

3.5 Means and routes of transport

3.5.1 Transportation into the Antarctic

In the first season, and due to the volume of material involved, a large proportion of the equipment will be transported in containers to Neumayer Station, in partnership with South Africa (SANAP/ R/V 'S.A. Agulhas'). The remaining supplies will be transported aboard the 'Polarstern' research vessel.

The total mass of goods to be transported to the Antarctic amounts to about 650 t. Fuel accounts for approx. 440 t of that total. Approx. 142 t will be brought back when drilling has been completed. Approx. 68 t will remain in the Antarctic (40 t drilling fluid, steel supports for the camp, timber covers over the trenches)

Neumayer Station will be given basic responsibility for unloading the heavy equipment. Sanae IV will probably serve as the base for smaller payloads of people and spare parts transported by helicopter (Oryx). Depending on weather conditions, regular supplies will generally be provided from Neumayer Station during the December to January period.

The crossing from South Africa to Neumayer Station (in the case of materials transportation via South Africa) takes about 10 days. Protected environmental resources that might be affected by ship transportation are listed for the sake of completeness in Table 10. The transportation requirements of the deep core recovery project will be met by ship expeditions that are mainly carried out for other research projects and supply operations.

Loading and unloading of the supply ships at Neumayer Station will be carried out at the ice shelf edge using the ship's crane. Empty fuel tanks with a capacity of 14,500 l, such as those used in this project, can be refilled via connecting pipe directly from the ship. The ship's captain bears responsibility for such refilling and for all cargo discharging operations (in the case of freight, until it has been landed on the ice shelf).

Transportation of people and smaller consignments of materials will also be carried out by helicopter, weather conditions permitting. Only in exceptional cases will fuel drums be transported by helicopter. Such freight will be flown as shig load.

The loading and unloading site at the ice shelf edge is several kilometres away from the nearest rookery of Emperor penguins. When supplies are delivered by 'Polarstern' (usually from January onwards), the penguins are no longer breeding and most if not all of the breeding rookery will already have disbanded.

3.5.2 Overland transportation to the drilling site / traverses

3.5.2.1 Planned route

The overland transport route from Neumayer Station to the drilling site runs exclusively across shelf and inland ice. This means that no ice-free areas with a substratum of sand, pebbles or rock will be driven on. The ascent to the inland ice plateau is made to the east of the Kottas mountains, Heimefrontfjella. There are no visible crevasses along the route from Neumayer Station over the Kottas mountains to the DML 05 site.

3.5.2.2 Alternative route

There is no alternative, shorter route to the drilling site. The route is determined by the possible points of ascent from the ice shelf to the inland ice, and by the possibility to cross the mountains onto the high plateau of the inland ice.

The shortest route (linear distance) from Neumayer Station to the drilling site is criss-crossed by crevasses in the glacier that cannot be crossed by the vehicles. Land vehicles with heavy loads would also fail to climb the steep ascents (e.g. Kirvanveggen).

The route described above was already tested in the context of the pre-site surveys and can be managed by traverse vehicles. Another possible ascent would be to the west of the Heimefrontfjella. The latter route is used by Swedish traverses, for example, but would mean a detour of more than 100 km.

3.5.2.3 Executing the traverses

3.5.2.3.1 Planned execution

All components of the camp as well as the entire supply system are based on 20-foot (standard) containers, use of which can vary according to requirements. The containers are transported on sleds pulled by PistenBullies (tracked vehicles) (1 container per sled). This method of overland transport is used for the bulk of materials and for transporting materials back to Neumayer Station. The total volume of building materials, equipment and operating supplies for the drilling camp is approx. 325 t. Fuel accounts for 112 t of that total.

Fuel for camp operations and for ice coring will be transported in 20-foot tank containers conforming to the ISO standard (14,500 litres capacity) and, to a lesser extent, in 200-litre fuel drums. Since each tank container has its own pump system, the vehicles can be easily refilled with fuel from the container during the traverses.

To supply the drilling camp, it is planned to carry out two traverses per season from Neumayer Station. Five Kaessbohrer snow cats will serve as traction vehicles.

A supply traverse will take about 25 days, with the following itinerary in the case of favourable weather conditions:

Neumayer Station: vehicle maintenance and loading	3 days
Travel across the inland ice	10 days
Camp: Unloading and vehicle maintenance	3 days
Return to Neumayer Station	9 days

The drivers have a mobile container with them as living quarters. Any waste produced is collected according to type of substance and brought back to Europe via Neumayer Station. Wastewater and faeces are discharged into the ice, whereby water consumption during the traverse will amount to about 10 litres per person and day.

It is possible for Do-228 and Twinotter aircraft to land at the former Kottas Depot (74° 12.3´S, 9° 44.2´W), 400 km from Neumayer Station. A fuel depot (Arctic diesel for traverse vehicles, kerosine, petrol) has been set up there for return journeys and as an emergency reserve; emergency supplies are also stored there. The maximum amount of fuel stored at the Kottas Depot is around 30,000 l.

3.5.2.3.1 Alternative execution

One alternative would be to transport fuel in drums containing smaller quantities. The problematic aspect with drums, however, is that they can be damaged during transportation and relocation, as well as leakages when filling vehicles with fuel. Drums kept outdoors are soon covered by snow as a result of snow drift and must be cleared of snow on a regular basis using machinery, whereby unintentional damage may occur. The risk of smaller leakages and damage to the drums is probably higher than is the case with fuel containers.

3.5.3 Airborne supplies

Small Dornier Do 228 (Polar 4) and Twinotter aircraft are used for transporting people and smaller consignments of supplies from the coast and/or from Neumayer Station to the drilling site. These aircraft can take off and land on level snow. By agreement with SANAP, there are also helicopter (Oryx) flights for passenger transportation so that scientific and technical staff can be replaced during a particular season. Passengers are transported by air and not on traverses, in order to avoid any unnecessary loss of time during the short season.

It is not planned to build any fixed landing strips at or in the vicinity of the camp. The landing strips on the snow are marked using short bamboo poles bearing flags, for example. No permanent fixtures will be installed.

A small amount of JP-8 aircraft fuel (10 – 20 drums) will be stored at the camp as an emergency reserve. This is equivalent to 2000 – 4000 litres, or 6 – 11 hours' flying time at a consumption rate of 350 litres per hour.

Supply flights go directly from Neumayer Station to the drilling site.

Ten return flights from Neumayer Station are planned for the erection and dismantling phase (40 flights in all) and 15 return flights during each drilling season (90 flights in all). These flights include transportation of the ice cores to Neumayer Station. Thus, a total of 130 flights is planned for the entire period of operations.

During the pre-site surveys, no snow petrels were spotted within an 80 – 100 km radius of the flight and traverse route.

Air and overland supply routes are shown in Fig. 2.

3.6. Implementation of the ice cores drilling programme

3.6.1 Description of ice core drilling activities

3.6.1.1 Preparatory work / preliminary cores

To begin with, a dry borehole approx. 120 m deep and with a diameter of 255 mm will be sunk into the permeable firn. To prevent any drilling fluid from leaking, casing pipe will be installed in this first section (4.4% of the total ice thickness of 2750 m). Glass fibre pipes (GFK) will be used for this purpose.

An estimated four days will be required for this fore-bore. Installing the casing pipe will take about two days. If possible, the fore-boring should be done a season before the main boring, in order to achieve the best possible seal between the pipe and the surrounding ice, and hence to minimise any losses of drilling fluid through leakage. The borehole is sealed primarily by gradual closure of the borehole around the casing, in addition to constructional measures at the bottom end of the casing. In the process, the surrounding ice is pressed against the casing in the borehole. This must be achieved before escaping drilling fluid can penetrate between the borehole walls and the inner casing. Given that deformation is a very slow process under the prevailingly cold temperatures, the interval between installation of the casing pipe and addition of drilling fluid should be as long as possible.

3.6.1.2 Technical schedule for deep core recovery

3.6.1.2.1 Planned activity

Once the casing has been installed in the borehole, it will then be possible to commence with the actual deep core recovery. This is done using an electromechanical drill and drilling fluid. Depending on the properties of the ice, dry drilling is possible to depths of approx. 200 m (max. approx. 350 m). Greater core depths require the use of a stabilising fluid that compensates the hydrostatic pressure of the surrounding ice, thus preventing the plastic deformation of the borehole and constriction of its diameter.

The drilling bit is suspended on a cable (Fig. 10). The drilling fluid is fed into the borehole through tubes. The surface of the drilling fluid is some metres down the borehole.

The drilling bit has a diameter of 128 mm, the borehole a diameter of 130 mm and the recovered ice core a diameter of 100 mm. In each drilling cycle, ice cores of 2 – 4 m length as well as the resultant ice chips are extracted. A total of about 800 drilling cycles must be reckoned with.

At the surface, the ice core is removed from the core barrel, and the chamber is emptied of the ice chips and drilling fluid mixture. The amount of ice chips produced results from the

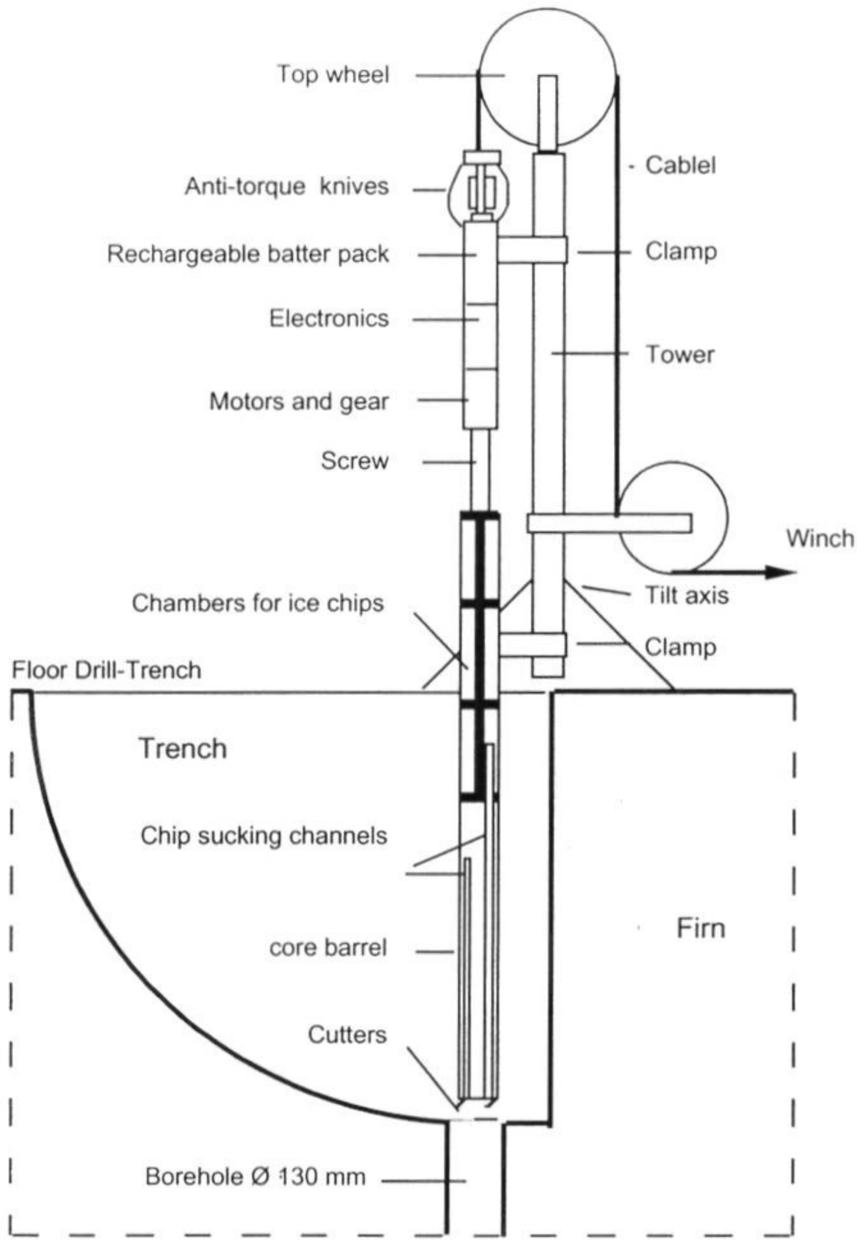

Fig.10 Design of the deep core drill

difference in volume between the recovered core (21.587 m^3) and the borehole (36.482 m^3), i.e. approx. 14.895 m^3 or approx. 13.4 t in the unconfined state. The impregnated drillings are separated from the drilling fluid in a centrifuge. The drilling fluid is recovered with an efficiency of 92 – 95 % and can subsequently be fed back into the borehole. The ice chips dry out further by subsequent evaporation, such that they can be tipped into a shaft in the snow. Since the density of the centrifuged chips is only about 0.55 g cm^{-3}, a shaft of about 26 m^3 or approx. 3 m edge length and 3 m depth will be needed.

When drilling has been completed, the borehole is to remain open so that sensors can be lowered for follow-up measurements. Since the trenches will not be kept open, it will be necessary to extend the GFK piping to the upper snow surface.

Drilling will be done in two shifts by 4 men in each case. About five people will be required for processing the cores.

Table 5 Drilling bit components, materials required, accessories

Component/Material	Material
Deep core drilling bit, consisting of:	Steel, aluminium
outer pipe for the deep core drilling bit	
drilling bit	
driving motor	
winch Slush pan for catching ice chips on core extraction	
Casing	Glass fibre / GFK
O-rings, steel cable, spare parts	

3.6.1.2.2 Alternatives

For a borehole of the depth envisaged there is no alternative to drilling with drilling fluid.

It would be possible to fill the ice chips into containers and transport them out of the Antarctic. The empty drilling fluid drums could be used for this purpose. To transport the amount produced, at least 17 additional flights would be necessary on the basis of 800 kg payload per flight, or one additional sled convoy for the overland transport.

3.6.2 Drilling fluid

3.6.2.1 Planned composition of the drilling fluid

A total 36.5 m^3 of drilling fluid is required to drill a borehole to a depth of 2750 m, with a borehole diameter of 130 mm. The drilling fluid remains in the borehole when drilling has been completed.

Specification to be met by the drilling fluid:

- The hydrostatic pressure of the fluid should be identical to that of the surrounding ice. Since the surface level of drilling fluid in the borehole does not reach the surface, the density of the drilling fluid must be adjusted to approx. 0.935 Mg m^{-3}, i.e. slightly greater than the ice density.

- The viscosity of the fluid must not hinder the hoisting and lowering of the drilling bit too much.
- The melting point must be lower than the lowest temperature in the surrounding ice (approx. – 50°C).
- The fluid must not cause any modifications to the surface of the recovered core.
- It must not corrode the drilling bit or the cable.
- It must not be toxic.
- It must not be explosive.

It is planned to use Exxol® D40 (pure petroleum) as the drilling fluid, with a densifier for adjusting the required density. The ratio of D40 to densifier will be about 80 parts to 20.

With regard to its environmental impacts, petroleum of the Exxol D type is preferable to other types of petroleum, because the proportion of aromatic compounds is only 0.5% (the maximum concentration in turbine fuels is 20-25%).

Possible densifiers are Solkane® 123 or Solkane® 141b (HCFC 141b). At Dome Concordia, D40 is used with Forane® 141b. Both HCFCs (chlorinated hydrocarbons) are used as substitutes for fully halogenated CFCs. The most recent experience gained with the two densifiers is that from the ice core drilling programme at NGRIP, Greenland, in summer 1999. Experience on the latter ice core programme showed that Solkane® 123 was not suitable. The physical properties of Solkane® 123 are heavily dependent on the ambient pressure. In the absence of particles with a size of about 2 µm, a colloidal suspension may be formed that then causes problems when pumping the fluid (N. Gundestrup, pers. comm). Forane® 141b (HCFC 141b) apparently leads to better drilling progress, and plans are to continue using this densifier (specifications, volumes and toxicity: see Tables 6, 7).

Solkane® 123 (HCFC 123; 1,1-dichloro-2,2,2-trifluoroethane) is non-combustible and has much smaller impacts on the ozone layer than CFCs.

Solkane® 141b (Solvey Flour) is identical to Forane® 141 b (Elf Atochem) and Freon (Du Pont) (1,1-dichloro-1-fluoroethane; $CCl_2F\text{-}CH_3$) and has similar properties.

Properties of environmental relevance are summarised in Table 8.

The calculation of the total required volume of drilling fluid is based on the experience gained at the Dome Concordia and NGRIP ice cores. Both of these ice core projects consumed 22.5 l per meter depth, ascertained from the amounts that had to be filled into the borehole. The maximum amount needed can therefore be calculated, for a maximum depth of 2800 m (2750 ± 50 m), as 61.6 m³.

Table 6 Type, specification, quantity transported and storage of the drilling fluid at a core depth of 2800 m
*: non-inflammable; CAS: Chemical Abstract Service.
Sources: 1) Talalay & Gundestrup 1999; 2) Manufacturer's product information

	Drilling fluid	Densifier		Source
Name	Exxol®D40	HCFC 123	HCFC 141	
Chemical formula	(pure petroleum)	$CHCl_2CF_3$	$CCl_2F\text{-}CH_3$	2)
Flash point (°C)	40	- *	- *	1)
Spontaneous ignition temperature (°C)	> 200	> 650	532	1)
Solubility in water (%)	< 0.1/20°C	0.39/25°C	0.4/20°C	1)
Boiling point (°C) (1 atm)		27.6	31.7	2)
Evaporation (22.5°C): V ($g\ h^{-1}\ m^{-2}$)	110 (for 0-30% material consumption)	8133 (for 0-93% material consumption)	5268 (for 0-87% material consumption)	1)
Toxicity		Short-term tox. low Long-term effic. can be proved	Not toxic under the Dangerous Goods Decree	2)
Hazardous Goods code		III B MAK		2)
CAS No.		354-25-6	430-57-9	1)
Volume (m^3)	49/43	13	20	
Storage/transport	in drums	in drums	in drums	

Table 7 Borehole volume and composition of the drilling fluid for the intended mixtures (Density values at 0 °C after Talalay & Gundestrup, 1999)

Borehole volume:					
Depth (m)	2800				
Diameter (m)	0.13				
Volume (m^3)	37.165				
Drilling fluid	Density (g/cm^3)	Mixing ratios (m^3)	(to)	Mixing ratios (m^3)	(to)
Exxol®D40	0.778	*48.670*	**37.865**	*42.335*	**32.937**
Solkane®123	*1.526*	*12.930*	**19.731**		
Solkane®141	**1.28**			*19.265*	**24.659**
Mixture	0.935				
Drilling fluid: Consumption per metre of borehole (m^3)	0.022				
Volume (m^3) / weight (t)		61.600	57.596	61.600	57.597

Table 8 Densifier properties of relevance for the environment. ODP: ozone depletion potential according to UNEP/WMO; GWP: global warming potential according to UNEP; reference level is CFC 11 ($ODP_{CFC\ 11} = 1$; $GWP_{CFC\ 11} = 1$)

	Retention time in the atmosphere (y)	ODP	GWP
CFC 11 ¯	100	1	1
HCFC 123 (123)	1.7	0.02	0.022
HCFC 141b (Forane®141b)	9.4	0.11	0.09

Losses arise from the following factors:

- Evaporation: The drilling fluid evaporates at the surface of the drilling bit and the ice core (wetting by the drilling fluid) at a low ambient pressure low of 0.7 atm. and a temperature of approx. –20°C - -30°C (max. – 15°C) in the drill trench. The critical factor for evaporation in this case is the surface temperature, not the ice temperature of –50°C that occurs in deeper ice layers. The evaporation rate of the D40/densifier mixture lies between the values for the specific components (e.g. 37.6 g h^{-1} m^2 for D60/HCFC141b and 34.1 g h^{-1} m^2 for D60 at 22.5°C, 1 atm.). Estimating the amount of evaporation loss is a problematic exercise, since losses depend on the thickness of the fluid film, which is difficult to ascertain. Evaporation at the surface of the borehole itself is negligibly small due to the small surface involved.

- Losses due to 92-95% recovery of the drilling fluid when extracting the ice chips

- Loss due to indeterminable leakages at joins in the casing, at the transition between firn and impermeable ice.

A quantitative breakdown of these losses is not possible, because the various processes cannot be determined or measured by direct means.

Small amounts of isopropanol are required for cleaning the bit and the core catcher. Glycol is used whenever necessary in order to loosen a drilling bit that has become jammed in the dry hole (the volume transported to the site is approx. 0.650 m^3).

3.6.2.2 Alternatives

3.6.2.2.1 Drilling fluid

It would be conceivable to use other drilling fluids having different characteristics and impacts on the environment. The properties, advantages and drawbacks of drilling fluids commonly used up to now have been described in detail in Talalay & Gundestrup (1999).

Fluids such as alcohol or ethyl glycol modify the surface of the ice core and for that reason are unsuitable as drilling fluids on this project. Furthermore, ethyl glycol is highly toxic.

100% silicone oils (dimethyl siloxane oils) exhibit good environmental and toxicological properties. However, they are highly viscous at low temperatures and greatly reduce the speed of the drilling bit in the borehole. The deeper the borehole, the more the hoisting and lowering times for the drill become a crucial factor affecting progress. A considerable increase in the project duration would therefore result. Silicone oils exhibit a low rate of evaporation. This leads to persistent wetting of the materials and the ice core, which then become greasy on the surface and make operations more difficult.

Silicone oils are very expensive compared to other drilling fluids.

From the scientific viewpoint, the only alternative to pure petroleum (D40, D60) is n-butylacetate. The latter is biodegradeable, but corrodes the materials of the drill (e.g. electrical cables). It is also a health hazard and requires that work be carried out with gas masks and breathing equipment, and that additional safety precautions be taken. Furthermore, this particular drilling fluid entails a risk of the borehole deforming or the drill becoming stuck, because the deeper the depth being drilled the more difficult it becomes to adjust the density of the fluid.

Given the requirements described in the foregoing, there are no alternatives to the chosen drilling fluid, among the various drilling fluids currently available, that would provide for a similar quality of core recovery results with less severe impacts on the environment.

3.6.2.2.2 Petroleum-based densifier for drilling fluids

There are no alternatives at present to the densifiers chosen for the project. However, a new densifier (HFC-365) is tested that also exhibits a lower ODP value than HCFC 141b, for example. It is expected that this densifier will replace HCFC 141b in about four years.

In the borehole filled with drilling fluid, it is technically feasible to replace the fluids if drilling (the core depth) has progressed only part or half the way, by feeding the new fluid through a pipe to the base of the borehole so that the fluid to be replaced is pushed back upwards. Experience has been acquired with this technique at NGRIP.

Perchlorethylene and trichlorethylene have a relatively high toxicity and would therefore make strict safety precautions necessary.

CFCs commonly used up to now, such as CFC 11, may no longer be used in the European Union from 2000 onwards due to their damaging impacts on the ozone layer.

3.6.2.2.3 Alternative means of dumping the drilling fluid

The borehole is to remain open so that measurements can be taken in future. This means that the drilling fluid must remain in the borehole in order to prevent the hole from closing up.

The fluid is prevented by the borehole depth from being pumped away. It would theoretically be possible to pump the fluid from greater depths using a cascade of pumps. For a core depth of 2700 m and a borehole diameter of only 130 mm, this is technically almost impossible; another consequence would also be that the hole would close in while the fluid is being pumped out, and that the pumps would remain stuck in the borehole if there were any deformation of the ice.

3.6.3 Measuring and processing of the ice core

The length, diameter and weight of the core segments will be logged. Electrical properties (DEP – Dielectric Profiling for dating) will be measured by non-destructive means along 2-metre segments. All other analyses will be carried out in laboratories back home. No chemicals will be used during the field work.

The core will then be cut into one-metre units, sealed in PE foil and packed in PP boxes. PP boxes serve as transport packaging for the trip back to Bremerhaven. Depending on drilling progress and the properties of the ice core (internal stresses and strains due to the alleviation of pressure and changes in temperature), interim storage may be necessary in the core buffer of the science trench.

To ensure that the ice cores are transported from the drilling site to the coast as gently as possible, it is planned to fly the filled ice core boxes by plane (Dornier; Do 228) to Neumayer Station. Until such time as the supply ship departs, the boxes will be stored at the station in refridgerated containers (-20°C). Six metres of the ice core can be transported in each box, with each flight taking approx. 15 boxes.

3.7 Potential outcomes

3.7.1 Failure to recover core

It is conceivable that unexpected delays or disruptions may occur during the core recovery operations (e.g. the drilling bit becomes stuck, changes occur in the ice characteristics and prevent the borehole from being extended, technical failures). In such a case, suitable measures are to be taken to ensure that the ice core is successfully recovered. These measures include:

- if the drilling bit becomes stuck: releasing it using available means (within a season, at the latest in the following season)
- if the characteristics of the ice change, and/or the borehole is deformed: a second borehole is attempted
- in the event of unforeseeable technical breakdowns: repair or procurement of a replacement via Neumayer Station

Should it not be possible to solve these problems within an acceptable and financeable time frame, the drilling camp will be dismantled and transported back via Neumayer Station.

The likelihood of technical breakdowns leading to a complete standstill of coring operations must be classified as minimal on the basis of the tried and tested organisation of the camp and the drilling equipment (e.g. at NGRIP). When a drilling bit gets stuck, as has happened on other ice core projects, this is partly attributable to non-optimal properties of the drilling fluids (cf. Section 3.6.2.1 and Talalay & Gundestrup 1999). Delays lasting up to a full season have already occurred on other ice core recovery sites (for example at Vostok or GISP), but were subsequently overcome. However, what cannot be foreseen are the characteristics of the ice layers, and thus the progress of drilling at greater core depths.

3.7.2 Future development of the borehole in the event of successful recovery

The horizontal flow of the ice will lead to the borehole being displaced and deformed. Since the deeper ice layers remain stationary at first, the borehole will be pulled apart and constricted. The area surrounding the former opening, which will then be located in deeper layers of the ice sheet, will reach the ice shelf zone in approximately 100,000 or more years. There, the drilling fluid will be released to the marine environment in small absolute concentrations over an extended period.

4. Methods and data for assessing the impacts of the planned ice core project

4.1 Sources of data and information

In order to assess the impacts of the planned activities, relevant information was collected and evaluated on the environmental conditions in the affected area, the variability of those conditions, the type and duration of activities, the properties and fate of materials used (Section 3) and about potential impacts on the relevant environmental resources (Section 5.1). Other sources of information included previous environmental impact assessments of activities in the Antarctic, which provide an insight into and a knowledge base on potential environmental impacts, on procedures for assessing those impacts and ways of minimising them (see References section). Wesnigk (1999) and Carstens et al. (at press) give suggestions on methods, procedures and evaluation criteria in respect of activities in the Antarctic.

Experience gained by scientists and technicians from similar ice core projects and logistical activities in the Antarctic were also taken into consideration.

4.2 Methods

Potential impacts of the planned ice core project on the environment are analysed in the following way:

The potential impact on the protected environmental resources as specified in § 3 (4) AUG and Article 3 (2b) Protocol of Environmental Protection to the Antarctic Treaty, respectively, are examined. This analysis is based on the descriptions in Section 3 above of the activities themselves and the initial environmental reference state at the site.

A description is provided of the possible impacts on the relevant environmental resources that may result from each particular activity.

To enable a description of the direct impacts of the proposed activities on the affected environmental resources in respect of type, extent, duration and intensity, the possible direct environmental impacts are evaluated using a matrix. This method complies with the recommendations and methodologies for previous environmental impact assessments of activities in the Antarctic (ATCM 1999). As far as layout and applied criteria are concerned, the present study is based on the procedure recommended by Wesnigk (1999).

The criteria used for assessing impacts on protected environmental resources are:

- extent of the affected area
- duration of environmental impact
- intensity of environmental impact

Potential impacts of transportation, erection of the drilling camp and of the borehole itself relate primarily to the glacial environment and ambient air quality. Definitions of the criteria applied are provided in Table 9.

Within the matrix the term 'glacial environment' embraces ice shelf and inland ice.

Table 9 Criteria for evaluating the impacts of the proposed ice core project on the glacial environment and ambient air quality (definition based on Wesnigk 1999)

	Low (L)	**Medium (M)**	**High (H)**	**Very high (VH)**
Spread, extent	Local, confined area	certain part of an area/formation is affected, >local	A certain entire area / formation is affected	Large-scale impacts, causing further impacts
Duration	Weeks to 1 season; Short in relation to natural processes	Several seasons, a number of years; impacts are reversible	Decades; impacts are reversible	Irreversible or chronic changes
Intensity	Natural functions and processes are not affected	natural functions or processes are influenced for a short period, but are not changed over a long period or permanently	Natural functions or processes are influenced or changed over the long term	Permanent disruption of natural functions or processes

The only impacts on organisms that are liable to occur along the transport route concern birds. The following criteria are applied in this context:

Table 10 Criteria for evaluating the impacts of the planned ice core project on flora and fauna

-	Low (L)	Medium (M)	High (H)	Very high (VH)
Spread, extent	No disturbance/ impairment of fauna	Disturbance/ impairment is possible	Major impairment of individuals, reduced breeding success	Impairment at population level
Duration	Short compared to growth period / breeding season	Recovery likely within a single growth period / season	Recovery within a single growth period / season is uncertain	Recovery within a single growth period / season is unlikely
Intensity	Natural functions and processes are not affected	natural functions or processes are influenced for a short period, but are not changed over a long period or permanently	Natural functions or processes are temporarily influenced or changed	Permanent disruption of natural functions or processes

If the marine / aquatic environment is affected, then each separate ecosystem component must be considered. For marine birds and seals, the criteria specified in Table 10 are applied at the level of individuals. For possible impacts on marine flora and fauna (plankton communities, benthos, fish), the population and/or community level and its ecological niches (environmental requirements) are the scale at which assessment is carried out (Carstens et al., at press).

Table 11 Criteria for evaluating the impacts of planned ice core project on the marine environment

	Low (L)	Medium (M)	High (H)	Very high (VH)
Spread, extent	No disruptive impacts on populations, communities or their environment	Disturbance/ impairment of populations, communities or their environment are possible	Impairment of populations or changes in their environment are beyond the scale of natural fluctuations	Substantial impairment of populations or communities
Duration	Short (days to weeks)	Temporary changes; reversible within weeks to months	Long-term changes impairment of populations or communities	Long-term or permanent changes
Intensity	Natural functions and processes are not affected	natural functions or processes are influenced for a short period, but are not changed over a long period or permanently	Natural functions or processes are temporarily influenced or changed	Permanent change in populations or communities

Consideration was also given to the likelihood of potential impacts or environmental strains actually occurring. A forecast is made on the basis of the planned activities and their known characteristics and risks (cf. Section 3). A distinction is made between impacts that are certain to occur (accepted or known impacts), probable impacts (impacts that are likely to occur given experience to date) and impacts that are unlikely to occur of all precautionary measures are implemented.

Direct impacts of separate activities during the ice core project are described in text and in tabular (matrix) form. Indirect and cumulative impacts are dealt with in the form of text.

5. Direct impacts of the planned activity

5.1 Potential impacts on protected environmental resources pursuant to Section 3 (4) AUG and the Protocol of Environmental Protection to the Antarctic Treaty

The ice core recovery activities, including erection of the camp and provision of transport, will be carried out in an area of the Antarctic in which scientific activities have been carried out in the form of pre-site surveys in recent years (see Section 3.2.1).

The planned activities can be expected to have direct impacts along the transport route from the discharge point at the ice shelf edge to the drilling camp, and at the actual site of the camp itself. Along the traverse route and at the drilling site itself, impacts on the glacial environment and the inland ice sheet must be taken into account. Immissions caused by the combustion of fuels and the use of drilling fluid must be included in the evaluation with regard to their effects of air quality, climate and weather. It is necessary to examine whether any flora and fauna in the area might be affected by the planned activities. Water quality, the aquatic environment and the marine environment could be affected while loading and unloading at the ice shelf edge.

The following environmental resources, as listed in § 3 (4) AUG and Article 3 (2b) Protocol of Environmental Protection to the Antarctic Treaty, respectively, must therefore be included in the evaluation:

- glacial environment,
- air quality,
- climate and weather patterns,
- flora and fauna (in the vicinity of the transport route)
- water quality and the aquatic environment (in marine areas)
- marine environment

5. 2 Impacts on protected environmental resources

5.2.1 Glacial environment

The use of vehicles, the erection of the camp and actions associated with these will cause localised changes to the surface structure of snow and ice.

The duration of such changes will depend on their dimensions (e.g. size and depth of trenches) and on local glaciological conditions (characteristics of ice, deposition of snow).

If parts of the camp extend above the surface, they will influence drifting snow and hence the local deposition patterns. The influence of these changes on the glacial environment is dependent on the construction design and size of the camp, as well as the length of time it exists.

If liquid matter (grey and black water) is discharged into the ice, their subsequent fate will depend on temperatures at the site. At negative temperatures, they will freeze after being discharged into the ice. If there is no seasonal melting of snow and ice, the deposited matter will remain in frozen form at the site and will be transported over the long term by glacial movement.

Substances that are liquid at the ambient temperatures (see drilling fluids) will also remain in impermeable ice layers at the site location. In permeable firn layers, they will leach to lower layers and may spread further unless appropriate steps are taken to prevent this happening (see Sections 3.6.1 and 8.1.2).

Fuel consumption will cause gaseous and particulate products of combustion to be released into the atmosphere, where they are then transported. Depositions of gaseous and particulate substances on snow and ice surfaces can occur as deposits of the substances themselves (dry deposition) and as deposition via snow crystals or fog (wet deposition) (Davidson et al. 1996, summarised in Gregor et al. 1998). Due to their large surface area, snow crystals provide an efficient filtering mechanism, whereby that efficiency is dependent on the structure of the ice crystals.

Particulate components (e.g. soot particles) are released to the atmosphere, transported and subsequently deposited on the snow surface. Once deposited, they are not released again to the atmosphere ('one-hop pathway'; Gregor et al. 1998). For carbon particles, a 'scavenging ratio' (concentration in snow / concentration in air) of approx. 150 has been determined.

Snow, and substances deposited with it, may be transported close to the ground level by the action of winds (saltation and resuspension; Gregor 1998). Typical threshold values for surface transport range between wind speeds of 6 and 9 m s^{-1}, depending on the characteristics of the snow surface (saltation; Pomeroy and Jones 1996). Depositions may cause changes in surface albedo.

At the Amundsen-Scott Station (South Pole Station), soot particles from diesel generators were identified on the snow in a well-defined area on the leeward side of the station. The mean wind speed there is approx. 5 m s^{-1}, with winter maxima of 15 m s^{-1}. Higher concentrations of the next order of magnitude (up to 3 ng/g_{firn} compared to a background concentration of 0.1 –0.3 ng/g_{firn}) were found in a 'plume' at distances up to 1 km from the station, although these concentrations had no effect on the surface albedo of snow, even in the centre of the plume

(Warren & Clarke 1990). To estimate the immissions for the EPICA drill camp the assumption was made that 50% of the soot will be deposited during the first day (Section 3.3.4.3) This is a maximum guess. It might be less. Even with this conservative guess the estimated soot concentrations are smaller than the natural background values in the interior of Antarctica. The investigations carried out by Warren & Clark (1990) had shown that soot concentration as high as the threefold natural background value do not cause measurable changes of snow albedo. It would be an interesting task to measure the accumulated soot concentration in the vicinity of the camp after the drilling project is finished. The gaseous compounds will influence the firn quality not at all.

5.2.2 Air quality

The ambient air quality at specific locations is influenced by immissions depending on their level, distribution, duration and intensity. Fuel consumption by vehicles, aircraft and generators leads to emissions and hence to depositions in the atmosphere. Gaseous components (CO_2, CO, SO_2, NO_x) are released to the atmosphere, where they are distributed over the Antarctic by the circulation of air masses.

The air quality will not be changed adversely due to the emissions of the camp. The emissions of the traverse vehicles are completely negligible with respect to air quality changes as they take place over a one-way travel distance of 750 km. The natural CO_2 mixing ration is 350 ppm seven orders of magnitude larger then the expected change by 18 ppt due to the CO_2 immissions.

Evaporation of liquids (drilling fluid) causes immissions as well. The level of immissions and their impact on air quality depend on the volume and properties of the fluids used (evaporation rates) and on the intensity of drilling (Sections 3.6.1, 3.6.2). These emissions will influence only the air quality within the drill and science trenches, but will have no adverse impacts on the ambient air in the surroundings of the camp site.

5.2.3 Climate and weather patterns

Pollutant loads of climate-forcing substances to the atmosphere are caused by the combustion of fuels and the evaporation of drilling fluid.

A direct impact on climate and weather patterns by substances released to the atmosphere through emission or evaporation cannot be proved, but merely evaluated on the basis of the quantities released. The immission of gases generated by fuel combustion (mainly CO_2) adds to the total concentration of CO_2 in the atmosphere (cf. Fabian 1984).

Evaporation engenders release to the atmosphere of the substances proposed as densifiers, namely Forane® (HCFC) 141b and Solkane® (HCFC) 123, which have potential impacts in connection with ozone layer depletion and the greenhouse effect (Section 3.6.2). The atmospheric retention times of these substances are 1.7 and 9.4 years for HCFC 123 and HCFC 141b, respectively (Talalay & Gundestrup 1999).

5.2.4 Water quality and the aquatic environment

Water quality and the aquatic environment could be affected during the planned activities by loading and unloading operations at the edge of the ice shelf. Impacts on water quality must be expected when chemical or physical properties of the seawater near the ice shelf edge are changed. This could occur if contaminants (e.g. fuels) are released to the marine environment.

5.2.5 Marine environment

During the planned activities, the marine environment could be affected by loading and unloading operations at the edge of the ice shelf. This would be the case if pollutants were released to the marine environment, or if the environmental conditions for marine flora and fauna were changed in any other way. Different human-induced impacts on separate components of the marine ecosystem, including sea birds and sea mammals, are described in detail in Carstens et al. (at press).

5.2.6 Flora and fauna

Overflying aircraft and traverse vehicles cause noise, which may have impacts on birds and mammals if any are present in the vicinity. Besides the intensity of noise, the duration and/or frequency of recurrent disturbances are among the factors that could have impacts on breeding success, for example. Particular reference is made in this connection to the presence of breeding colonies in the vicinity of human activities (see Wesnigk 1999, Carstens et al., at press).

Any release of contaminants (e.g. leakage of fuel) can cause damage to birds or mammals through direct contact, or indirectly as a result of damage to their environment. Microorganisms (bacteria, snow algae) may be similarly affected by contaminants and by human-induced changes in their environment (changes to the snow surface, relocation). Possible impacts at the level of populations are of crucial significance in respect of these organisms (cf. Sections 4.2, 5.2.5)

5.3. Impacts of the proposed activity on protected environmental resources

5.3.1 Glacial environment

5.3.1.1 Camp operation

Direct impacts on the glacial environment can be expected within a corridor along the traverse (see below) and at the site of the drilling camp. These impacts include: changes caused to the surface structure of snow by vehicles and activities in the drilling camp area; immissions due to fuel combustion, and the discharge of grey and black water into the ice.

Within a period of one season to a few years, structures in the snow and firn at the site of the camp will no longer be visible due to snow accumulation (cf. Section 3.2.3.1, increasing depth of snow).

During drilling operations, the slipstream effect of the camp itself may lead to slight changes in the deposition of snow within a radius of a few hundred metres. This effect is reduced by the platform design, which allows snow to drift through the supports, and by relocating mobile containers when closing up the camp for winter (cf. Sections 3.3.2, 3.3.7).

Camp operations and the concomitant emissions are confined to the summer months (December to February). During those months, the wind speed is low most of the time (cf. Section 3.2.3.1). The prevailing wind direction is NE – E. At local level, operation of the generator will lead to the deposition of aerosols and contaminants on the ice. It can be expected that aerosols resulting from generator and vehicle operation will be deposited on the snow surface on the leeward side of the camp (Fig.11), as was described for the Amundsen-Scott Station. Any change in surface albedo in and around the drilling area as a result of vehicle movements and soot emissions can be neglected on account of its local confinement and temporary duration. Local depositions of aerosols and contaminants on the snow and ice surface are gradually loaded to firn layers under the surface by the accumulation of snow.

Grey and black water discharged into the ice freezes in the drainage pit. Given that temperatures at the site do not normally exceed–20°C (Fig. 5), the water remains there in frozen form. The impact on the surrounding glacial environment is therefore considered to be low.

Certain components (ungalvanised steel, timber) will remain in the inland ice on a long-term basis after the camp has been dismantled. This group of components is very limited (see Section 3.3.2) and neither the release of pollutants nor influences on natural processes are expected. Their impact on the surrounding glacial environment is therefore considered to be low.

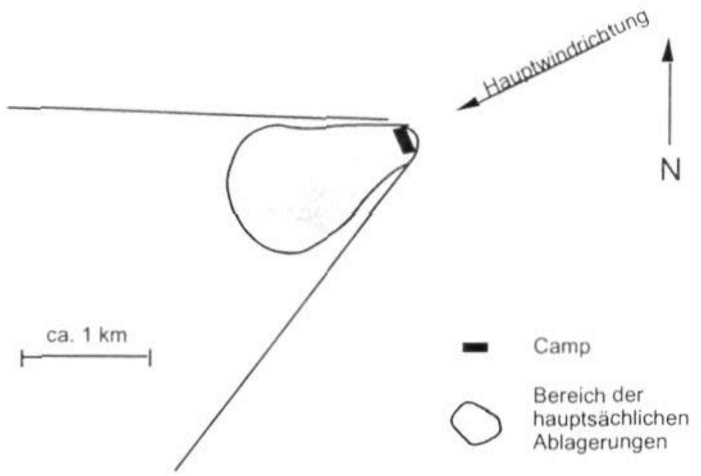

Fig. 11 Estimated deposition of particulate matter on the snow surface in and around the drilling camp

Impacts due to accidents, with concomitant release of substantial fuel quantities, would be confined on shelf or inland ice to the immediate vicinity of such leakages (15 m^3 correspond, for example, to 2 m x 2 m x 6.25 m depth for a snow density of 0.6, or: 10 m x 10 m x 0.25 cm depth). If such an accident were to occur, pollutants could be recovered and disposed of in a suitable manner (see Section 8.1.2). If fluids are not discharged into the marine environment and no bird colonies are affected, the potential impact on the glacial environment is considered to be low.

5.3.1.2 Traverse

Along the traverse route, there will again be changes to the surface structure of snow and ice as a result of vehicles, immissions from fuel combustion (Section 3.3.4) and particle deposits on the snow surface. Grey and black water will be disposed of in the ice at points along the traverse route. Waste will be collected and brought back from the Antarctic.

Direct impacts on the glacial environment are confined to a corridor along the traverse. Vehicle tracks and water disposal affect a strip some metres wide. Particle deposits resulting from the fuel consumption of traverse vehicles are likely to occur at distances up to several hundreds of metres (cf. 5.3.1.2), depending on the respective wind speed and wind direction.

Two traverses per season are planned for the first and last season, when the site is erected and dismantled, whereas one traverse is planned for each drilling season. Trips across snow and ice, as well as emissions, relate to the route from Neumayer Station to the drilling site, but are of short duration and intensity from a local perspective. Structures in the snow and ice, as well as particle deposits, will no longer be visible or will be displaced to deeper snow layers within a period of one season due to the increase in snow depth. The volume of wastewater discharged into the ice is low and will remain on the inland ice in frozen form. The impacts on the glacial environment of actions related to the traverses are therefore considered to be low.

5.3.1.3 Drilling

The maximum drilling depth is 2750 ± 50 m; the ice at the drilling site will therefore be affected over its entire vertical extent.

The drilling fluid fills the borehole up to the maximum core depth and remains in the ice for the long term; however, it is confined to the borehole and in the distant future will be integrated into the ice matrix of the immediate surroundings when the borehole gradually closes. No impacts on natural processes in the glacial environment are expected as a consequence of these substances and the borehole itself being left behind. Any evaluation of impacts ensuing from a geographical displacement of the borehole as a result of ice movements would be somewhat speculative on account of the long timeframes involved (> 10.000 years).

The casing components (GFK pipes) will remain in the firn after drilling activities have been completed. They prevent the drilling fluid from seeping into the surrounding firn in the upper portion of the borehole. The casing itself is not expected to cause even minimal impacts on the glacial environment.

5.3.2 Air quality

5.3.2.1 Camp

Near-surface immissions resulting from the combustion of fuels by the generators are expected to be locally confined (see Section 3.3.4.2). Additional loads will be generated by camp vehicles and by aircraft taking off and landing. Gaseous and particulate combustion products will be released into the atmosphere and transported there, as well as being distributed by the circulation of air masses over the Antarctic. Camp operations will be limited in duration to three months a year over a total period of five years. The consumption of Arctic diesel at the camp and the concomitant loads to the atmosphere will amount during the erection and dismantling phase (first and last seasons) to an estimated 12.5%, in each drilling season to 25% of the total.

Impacts on air quality in the camp area are assessed as low due to the small total amounts of fuel and emissions involved (see Section 3.3.4) and to the limited duration of operations.

5.3.2.2 Traverse

Cargo discharges at the ice shelf edge, and the vehicle movements this entails, are limited in duration to a number of hours to a few days only, and occur once or maybe twice a season. Traverses (approx. 5 traction vehicles) are carried out once or twice a season (see Table 1).

Impacts of these activities on the air quality along the traverse route are of minimal geographical extent and intensity. From the local perspective, the emissions involved are of short duration (the total duration of the traverses is approximately 25 days; cf. Section 5.3.1.2). Impacts on air quality are assessed as slight.

5.3.2.3 Drilling

During drilling operations, part of the drilling fluid evaporates at the surface. The volume of evaporated fluid depends on the thickness of the fluid film on the surface of the drilling bit and the ice core as well as the intensity of drilling (hoisting/lowering). The estimated loss of fluid relative to the total requirement takes account of this evaporation (see Section 3.6.2), although it is not possible to quantify the exact amount.

Impacts on air quality can be expected in the geographically confined area of the drill trenches during intensive drilling operations. The drilling fluid evaporates as a consequence of hoisting and lowering the drill bit, removing the ice core and excavation of theice chips. At the surface, beyond the drill trenches, dilution and emission of volatile components to higher layers of the atmosphere are likely to occur (see 5.3.3).

Once the drilling work has been completed, no further evaporation is expected due to the small surface area of the drilling fluid (diameter of the borehole), since no further movements of the fluid occur (e.g. through hoisting and lowering the drilling bit), the surface of the fluid is a number of metres below the ice surface, and the opening is covered over.

5.3.3 Climate and weather patterns

Gaseous combustion products will remain in higher strata of the atmosphere for longer than the drilling activities continue, but due to atmospheric circulation can only be assessed in a global context. The CO_2 emissions resulting from the fuel combustion of transport means and drilling equipment will have negligible impacts on the global atmospheric concentration of CO_2.

The evaporation of drilling fluid will initially lead to effects on air quality in the drilling trench. The effect of the drilling fluid on weather and climate conditions (intensity) was classified as low, because the quantities used will not product a measurable or identifiable effect on climate. The densifiers have a potential, ozone-depleting effect, however. This impact is confined by using densifiers with a low ODP (ozone depletion potential) compared to the substances commonly used to date.

Compared to Forane® 141b, Solkane® 123 has a low OPD, contributes less to the greenhouse effect and exhibits a shorter retention time in the atmosphere. Recent experience on Greenland indicates, on the other hand, that if the preferred densifier, Forane® 141b, is used, drilling process is likely to be better and there is less risk of hold-ups (Section 3.6.2.1). This reduces, in turn, the probability of additional emissions being caused by a prolongation of drilling activities. As far as possible impacts of the drilling fluid are concerned, no distinction is made here between the potential densifiers.

5.3.4 Water quality and the aquatic environment

The material required for the proposed activities will be unloaded at the ice shelf edge from the ship onto the ice shelf (Section 3.5.1). Accidents during unloading could lead to the release of pollutants (e.g. fuels) that would impact on water quality, the aquatic environment, the marine environment and the ice shelf. The release of substantial quantities of fuel (more than a single barrel, content of a whole container) could impact on water quality, the aquatic environment and marine environment over a medium-sized area around the pollutant source.

The likelihood of such accidents occurring is minimal, given the many years of experience acquired at Neumayer Station in supply operations of this kind. In the event of accident, there are rules of conduct in place which enable a rapid response and minimisation of environmental impacts (Section 8.1.2).

In the distant future, drilling fluid encased in the ice matrix will reach the edge of the ice shelf. Assessing the potential impacts on water quality and on the aqueous and marine environment would be purely speculative at this juncture.

5.3.5 Marine environment

Impacts of the proposed activities on the marine environment could occur only during loading and unloading at the ice shelf edge (see 5.3.3). If contaminants are released to the marine environment, all compartments of the ecosystem may be affected due to interrelationships within the food chain (plankton, benthos, fish, birds, mammals; summarised in Carstens et al., at press). The duration and intensity of impacts in the case of substantial contaminant release can thus be assessed as medium to high if the contaminants affect a medium-sized area around the point of release. These impacts would recede as a result of evaporation and dilution, although organisms could be affected for a season or longer.

The likelihood of such impacts is minimal, provided the right precautions are taken to confine contamination quickly (see 5.3.4). No other impacts on the marine environment are likely to be caused by the proposed activities.

5.3.5 Flora and fauna

Emperor penguins are found in the vicinity of the cargo discharge site at the ice shelf edge close to the Neumayer Station Station. When the supply operations are being carried out, any breeding colonies will have already disbanded in large measure, the penguins then being a sufficient distance away (Section 3.3.2.3, 3.5.1). The activities in question take a relatively short amount of time (hours to days). For that reason, no animals are going to be affected by noise pollution.

Provided the traverses do not go near where petrels breed and/or live, and these sites are not flown over either, birds will not be disturbed by any noise created along the supply routes. A sufficient distance can be kept should this not be the case.

Areas of special biological interest are located at the coast at a distance of around 700 km (e.g. penguin colonies) or at approx. 400 km distance inland (Svarthamaren Nunatak) and are not affected by the proposed activities.

No direct impacts on biota are expected to be caused by operating and supplying the camp, or by the actual drilling operations.

Even though the presence of micro-organisms on the inland ice is not entirely excluded, no minor or transitory impacts on their populations or distribution are to be expected as a consequence of traverses, the erection and operation of the camp, or the drilling itself.

Table 12 Matrix showing possible environmental impacts of the proposed activities Dur.: Duration; Int.: Intensity; Prob.: Probability of impact occurring

		• Possible impacts on the environment	•	•	•	•	•	**Possible measures for avoidance/minimisation**	
Activities/ field of operation	**Duration of activity**	**Type**	**Environmental resources affected**	**Extent**	**Dur.**	**Int.**	**Prob.**	Yes / No	**Description**
Transport									
Ship transport	Weeks-Months	Emissions	Air quality					Yes	Suitable fuel, soot filters
		Wastewater, ship's paint	Marine environment water quality, aqueous environment, flora and fauna, possibly sea ice						Filtering/purification non-toxic paint finish
		Loss/leakage of fuel	ditto					Yes	Suitable precautions accident procedures
		Accidents	ditto					Yes	Suitable ice category, safety regulations, precautions
Loading/unloading at the ice shelf edge	Hours - days	Emissions from aircraft	Air quality	L	L	L	Certain	(Yes)	Suitable fuels, regular maintenance
		Noise	Fauna	L	L	L	Certain	Yes	Distance from bird colonies is sufficient
		Accidents involving release of greater quantities of fuel	Water quality, aqueous environment, marine environment	M	M-H	M-H	unlikely	Yes	Observance of safety regulations, suitable precautions, checks on fuel containers
		-N-	Glacial environment (ice sheet)	L	M-H	L	unlikely	Yes	ditto
Air transport	**10-15/season**								
Flights (Do 228)	hours	Emissions	Air quality	M	L	M	Certain	(Yes)	Suitable fuel, regular maintenance
		Noise	Fauna (birds)	L	L	L	Certain	Yes	If relevant, maintain distance from bird colonies

Table 12 (contd.) Matrix showing possible environmental impacts of the proposed activities **Dur.: Duration; Int.: Intensity; Prob.: Probability of impact occurring**

								Possible measures for avoidance/minimisation	
	1-2/season			Extent	Dur.	Int.	Prob.	Yes/No	Description
Snow runway	3 months year	Change in snow surface	Glacial environment	L	L	L	Certain	(No)	Runways are covered by snowfall during winter
Traverses									
Sled convoys (snow cats)	approx. 25 days in each case	Tracks left by vehicles	Glacial environment	L	L-M	L	Certain	(No)	Tracks are covered by snowfall during winter
		Emissions	Air quality Glacial environment	L-M	L	L	Certain	Yes	Suitable fuel, aircraft maintenance
		Noise	Fauna (birds)	M	L	L	Unlikely	Yes	If relevant, maintain distance from bird colonies
Accumulation of waste	more than 25 days in each case	Loss/release	Glacial environment	L	M	L	Unlikely	Yes	Collection and transport of all waste back to Europe
Wastewater discharge	more than 25 days in each case	Discharge into ice	Glacial environment	L point source	M	L	Certain	No	
Fuel storage (Kottas depot)	3 months/year (5 years)	Accidents involving release of substantial fuel quantities	Glacial environment	L	M-H	L	Unlikely	Yes	Compliance with safety regulations Checks on fuel containers
Tank filling, handling of fuel containers	3 months/year (5 years)	Leakages	Glacial environment	L	M	L	Probable	Yes	Suitable precautions when filling tanks
Drilling camp									
Erection of platform	1 season	Changes to surface	Glacial environment	L	M	L	Certain	Yes	Dismantling and transport of camp components back to Europe
Presence of the camp	5 years in total	Changes to surface; Increase in snow depth	Glacial environment	L	M	L	Certain/ Probable	Yes	Dismantling and transport of camp components back to Europe

Tab. 12 (contd.) Matrix showing possible environmental impacts of the proposed activities Dur.: Duration; Int.: Intensity; Prob.: Probability of impact occurring

								Possible measures for avoidance/minimisation	
				Extent	Dur.	Int.	Prob.	Yes/No	Description
Generator operation	3 months/year (5 years)	Emissions Deposition via snowfall	Air quality Glacial environment	L	M	M	Certain	Yes	Suitable fuel Maintenance
Operation of all camp vehicles + equipment, incl. generator, aircraft landing and taking off	3 months/year (5 years)	Emissions Deposition via snowfall	Air quality Glacial environment	L	M	M	Certain	Yes	Suitable fuel Maintenance No unnecessary excursions
Water supply	3 months/year (5 years)	Removal of snow for melting	Glacial environment	L	M	L	Certain	(No)	Snow accumulation during winter
Waste	3 months/year (5 years)	Release	Glacial environment	L	M	H	Unlikely	Yes	Transport of all waste back to Europe
Wastewater disposal	3 months/year (5 years)	Discharge	Glacial environment	L	M	L	Certain	No	
Fuel storage	5 years	Accidents	Glacial environment	L	M-H	M	Unlikely	Yes	Suitable precautions for handling fuels. Compliance with safety regulations
Tank filling, handling of fuel containers	3 months/year (5 years)	Leakages	Glacial environment	L	M	L	Unlikely	Yes	Suitable precautions for handling fuels. Compliance with safety regulations
Excavation of the science and drill trenches	5 years	Excavation; Changes to surface	Glacial environment	L	M	L	Certain	(No)	Trenches are levelled with surroundings by the accumulation of snow
Timber and steel components are left in the ice	Long-term	Alien materials left behind	Glacial environment	L	H	L	Certain	No	Removal would have greater impacts than abandonment

Tab. 12 (contd.) Matrix showing possible environmental impacts of the proposed activities Dur.: Duration; Int.: Intensity; Prob.: Probability of impact occurring

								Possible measures for avoidance/minimisation	
Drilling				**Extent**	**Dur.**	**Int.**	**Prob.**	**Yes/No**	**Description**
Borehole casing	Long-term	GFK pipes left in borehole	Glacial environment	L	H	L	Certain	No	Removal would have greater impacts than abandonment
Storage of drilling fluid	3 years	Accidents: leakage of fluid	Glacial environment	L	H	L	Unlikely	Yes	Suitable precautions for handling fuels. Compliance with safety regulations
		Evaporation	Air quality	L	M	L	ditto	ditto	see above
		Evaporation	Weather and climate		H	L	ditto	ditto	see above
Use of drilling fluid	3 seasons	Pumping into borehole	Glacial environment (max. drilling depth)	M	H	L	Certain	Yes	Careful handling
		Evaporation	Air quality (drill trench)	L	M	M	Certain	Yes	Densifiers with low ODP are chosen
		Evaporation	Weather and climate		H	L	Certain	ditto	see above
Drilling fluid left in ice	Long-term	Remains in the borehole	Glacial environment	M	H	L	Certain	No	Removal of the drilling fluid is not possible
		Release at ice shelf edge	Marine environment Water quality	? In > 100,000 years	?	?	Probable	No	Release in low concentrations over a period of decades?
Recovery and processing of ice core	3-4 seasons	Ice core recovery	Glacial environment	L	L	L	Certain	No	

6. Possible indirect impacts of the proposed activity

6.1. Possible indirect impacts on protected environmental resources

Indirect or second-order impacts may arise from the drilling project's requirement for materials and human resources. The latter involves more intensive transportation to the Antarctic and the possible risk of accidents. Thus, possible impacts relate primarily to the environmental resources in and around the ice shelf edge, as specified in Section 5.1.

6.2 Indirect impacts of the proposed activities (second-order impacts)

Execution of the planned ice core project involves a greater intensity of transportation in respect of materials and people to the Antarctic compared to the normal level of supply for the Neumayer Station. This means more unloading of materials at the ice shelf edge during the two seasons in which the site is erected and then dismantled.

Because Neumayer Station operates as the logistics base for supplying the camp, there will be a temporary increase during the summer season in the number of staff at, and the amount of transport activity from the Neumayer Station (traverses, flights).

Accidents involving substantial quantities of contaminants may have impacts at the ice shelf edge on flora and fauna, water quality and the aquatic environment, the marine environment and on the shelf ice. The glacial environment along the transport route to the drilling site would be affected. It is highly improbable that such accidents will occur (cf. Section 5.3.3, 5.3.4, 8.1).

7. Possible cumulative impacts

7.1. Possible cumulative impacts on protected environmental resources

Cumulative impacts may arise over time (recurrent impacts) as well as through the effects of different human activities at one particular location.

According to the current state of knowledge, no other research activities are planned in the area of ice core recovery in Dronning Maud Land during the proposed drilling period besides those conducted under the EPICA programme.

Possible cumulative impacts of the EPICA activities may be generated by seasonally recurrent transports and work carried out during the pre-site surveys, the ice core recovery operations and any follow-up studies that are conducted.

7.2 Cumulative impacts of the proposed activities

The combustion of fuels during transportation and at the drilling camp will cause the emission of gases (CO_2, CO, NO_x, SO_2) to the atmosphere (see Section 3.3.4.2, 5.3.2). The impacts on air quality will be transitory and non-cumulative due to the small amounts involved and to atmospheric circulation systems, even in the case of recurrent activities. Emissions will contain gases (CO_2, densifiers) that are potentially climate forcing and/or ozone depleting. Their impacts at higher strata of the atmosphere can only be viewed within a global context and are negligible in extent on account of the small total amounts concerned. It can be expected that other densifiers with more benign environmental properties will be available for future ice core recovery programmes.

When operating vehicles and generators, particulate matter may be deposited in the snow in the immediate surroundings of the traverses and the drilling camp. These depositions are gradually incorporated in the ice due to the accumulation of snow. Small amounts of such depositions will already be present from the traverses made during the pre-site surveys. During drilling operations, several transports will be made along the route to the drilling site. Depositions may therefore occur on repeated occasions in the areas concerned. Because of these depositions less than a minor impacts on the characteristics of and processes in the surrounding glacial environment can be expected.

When drilling operations have ended, the drilling camp is to be as fully dismantled as possible (Section 3.4). No cumulative impacts are expected as a result of particular components (ungalvanised steel, timber) remaining in the inland ice.

The vertical movement of ice and low horizontal flow velocity prevailing at the site mean that local contamination of the ice by drilling fluid will reach the ice shelf edge after about 100,000 or more years and once there will be released to the marine environment over an estimated period of several decades. By then, it is probable that the drilling fluid will no longer be existent as a discrete volume of fluid, but will be integrated in the surrounding ice matrix.

8. Minimisation and monitoring of environmental impacts

8.1 Minimisation of environmental impacts

8.1.1 Transportation and execution

Tried and tested procedures will be applied in respect of both the transportation required (traverses) and the erection of the camp. The people who are involved in planning and carrying out the project have experience in the Antarctic and have been instructed on environmental concerns as they relate to the Antarctic.

Project planning and execution are monitored by the environmental protection officer at AWI.

Stocks and consumption of materials are monitored by a technical operations manager. Precise bookkeeping is essential for the operational safety of the camp and for identifying possible disruptions. The calculation of requirements is specified in detail for each season on the basis of current consumption levels, in order to avoid unnecessary amounts of fuel and materials, on the one hand, and to prevent any problems for safety arising from a lack of fuel and materials, on the other hand.

All waste and equipment will be brought back to Germany once the ice core recovery work has been completed. The exceptions are the steel supports for the container platform, the timber covers of the trenches and the drilling fluid itself. Solid waste is separated according to type of material, collected, and properly disposed of after being brought back from the Antarctic. Liquid waste (grey and black water, including sanitary water) is discharged into a hole in the ice in accordance with the Protocol on Environmental Protection to the Antarctic Treaty.

If areas where birds live or breed are sighted in the areas traversed or flown over, steps will be taken to ensure that these are not flown over and/or that a sufficient distance is maintained from such areas.

8.1.2 Emergency plans

Appropriate precautionary and safety measures will be taken to cover against any conceivable disruptions or accidents.

As part of emergency planning for the region, cooperation is envisaged with South Africa (SANAP), involving the SANAE IV Station (71°41´S, 02°50´W) and with the United Kingdom (BAS), with participation by the Halley Station (75°35´S, 26°15´W). Current planning is coordinated before each respective season within the framework of SCALOP.

Table 13 Distances between the sites participating in regional emergency planning (linear distance)

	Neumayer Station	Drilling site DML 05
SANAE IV	230 km	380 km
Halley	800 km	740 km

All fuel containers comply with the international guidelines and are checked regularly for any damage. The persons responsible have guidelines for the responsible handling of fuels and for behaviour in emergencies. Technical and scientific personnel are informed about environmental aspects of working in the Antarctic. All such personnel must provide evidence of having participated in the seminar entitled "Environmental Protection in the Antarctic".

In the event of any fuel-related or other accidents occurring, there is a bilingual 'Emergency Manual Antarctica', drafted by the Alfred Wegener Institute (*Notfallfibel Antarktis*/Emergency Manual Antarctica; AWI 1999) for the responsible persons involved at Neumayer Station Station, the drilling camp, on the traverses and on airborne transport operations, as well as on all ship loading and unloading activities. Said manual contains all the required information regarding rescue action, minimisation of potential damage, responsibilities and reporting duties, and is prepared along the same lines as the COMNAP guidelines for emergency plans. The manual will also be given to the responsible bodies of those nations involved in logistics operations, namely the United Kingdom (BAS, Cambridge) and South Africa (Dept. of Environmental Affairs, Directorate Antarctica and Islands, Pretoria).

A written record must be kept of all details of an emergency and of the action taken.

8.1.2.1 Oil leakages and accidents

On snow-covered shelf ice and inland ice, fuels and oil leach into the snow and the firn ice underneath it. Horizontal spreading is dependent on the porosity and internal structure of the snow and ice, and on the viscosity of the fluid. Vertical spreading is greater than horizontal in the case of diesel oil and kerosine, at least in the upper layers. Lubricating oils have a higher viscosity at low ambient temperatures and therefore leach at a slower rate. The snow and oil temperatures as well as the intensity of the fluid leakage also influence the extent to which the contaminated volume expands (for detailed information and assessments, see the Emergency Manual).

Diesel oil and kerosine are of low viscosity and sink vertically into snow and ice without spreading in a horizontal direction. They seep quickly through the upper, less dense layers of ice. If the volumes involved are substantial and leakage continues, the fuels leach continuously to layers of higher density until an impermeable ice layer is reached. Once at this depth, the fluid spreads horizontally in an ever-widening circle until a state of equilibrium has been reached. At

Neumayer Station, such layers are found on the surface at regular intervals due to melting and freezing processes during the summer months (cf. Emergency Manual); at the drilling site, impermeable ice is not encountered until depths of 80 m and more (cf. Fig. 4).

Oil evaporates and is decomposed by bacteria, also under Antarctic conditions, although these processes are very slow. However, as a 'light' oil, diesel is decomposed faster than heavy fuel oil (HFO). The latter is not used.

8.1.2.2 Release of oil and/or fuel to snow, firn ice and at the ice shelf edge

In the event of fuel being released to the environment, depths of penetration and the quantities of fuel contained in snow and firn ice can be estimated on the basis of the pore volume and the increase in diameter of the contaminated area at increasing depth for areas without internal ice crusts. This is possible if the fluid is released relatively slowly and does not flow directly to deeper snow and ice layers via a hole at the surface.

Internal ice crusts occur in areas with occasional surface thawing phases in summer; because they are impermeable, they prevent further penetration in the vertical plane. Internal crusts can be anticipated in the surroundings of the Neumayer Station on the Ekströmisen, but not on the Amundsenisen on account of the lower temperatures there.

On the basis of the estimated depth of penetration and the volume involved, the contaminated areas are excavated in the case of fuel leakages. For safety reasons, the snow and ice surface is then levelled.

If fuel is released on the ice shelf during loading or unloading operations, or in the vicinity of Neumayer Station, there is no likelihood of any impacts on the areas, some kilometres away, where Emperor penguins are found, or on Adélie penguins, skuas or petrels. As soon as oil leakages are discovered, birds can be kept away from the polluted site and the contamination removed. In the worst conceivable case, there is a Plan of Action containing instructions on how to handle birds and mammals contaminated by oil, as well as general measures to be taken after oil or fuel has leaked.

Oil leakages to the marine environment during unloading could have impacts on marine organisms, as well as on penguins and seals in the inlets. In view of the general precautions applying to the unloading of fuels, the risk of more than a minimal amount (e.g. drips occurring for a short time when releasing the connecting tubes when filling the tanks) is considered to be very small.

8.1.2.3 Action to be taken in the event of accidents / leakages of fuel

In emergency situations, priority is attached to the health and safety of people. Once immediate risks to people and survival facilities are banished, the following measures are implemented:

- Elimination of the cause and collection of the fuel or polluting substances

- Any preventive measures that are necessary, if there is a possibility of pollutants spreading to sensitive areas (biota, area from which drinking water supplies are obtained)
- Decontamination of polluted areas
- ~~Seeu~~ring and return transport of contaminated material from the Antarctic

All substances contaminated with oil are classified as special waste and are transported in appropriate form back to Germany, where the waste is then disposed of (§ 22 (1) AUG and Article 2 (1) Annex III to the Protocol on Environmental Protection to the Antarctic Treaty, respectively).

As soon as possible, the Environmental Protection Officer at AWI should evaluate the situation, potential impacts in the future and measures to be implemented. In consultation with the Federal Environment Agency, the Environmental Protection Officer must provide his or her approval before monitoring operations at the site of the fuel leakage can be terminated.

8.1.2.4 Contamination by other substances

All waste whatsoever is taken back from the Antarctic in accordance with AUG and the Protocol of Environmental Protection to the Antarctic Treaty, respectively, (see 3.3.5). If waste or other contaminated substances are released to the environment, the measures to be taken are the same as for oil/fuel leakages. Any accidents in this connection must also be recorded in the waste book. If it is not possible to remove entirely the waste and/or the substances, or if flora and fauna are affected, the AWI Environmental Protection Officer must be called in.

If areas where birds live or breed are sighted in the areas traversed or flown over, steps will be taken to ensure that these are not flown over and/or that a sufficient distance is maintained from such areas.

8.2 Monitoring of environmental impacts within the meaning of AUG and the Protocol of Environmental Protection to the Antarctic Treaty, respectively

The pollutant emissions from combustion can be estimated from the consumption and composition of the fuels. This procedure is applied at the Neumayer Station as well. Direct deposition of particles is confined to the area around the camp and along the traverses.

On the basis of current fuel consumption and meteorological conditions at the site during the core recovery activities, the distribution of the particles and emission products deposited in the surrounding areas is assessed (cf. Section 5.2).

Snow samples taken in the course of drilling operations may provide dubious results under certain circumstances, because wind direction, wind speed and snow drift are subject to constant change, despite variances being known and wind speeds normally being low. In order to analyse the snow samples, it is necessary to have suitable reference locations, at sufficient distances from the source of emissions, with identical ice characteristics and accumulation rates (e.g. 13 km distant in Warren & Clarke 1990). An extensive monitoring programme would exceed the personnel and analytical capacities of the proposed project and would demand intensified activities (Ski-Doo trips) over a radius of some kilometres.

Records will be kept of the consumption and whereabouts of operating supplies and fluids, as well as waste brought back from the Antarctic.

Monitoring in respect of hydrocarbon depositions as a result of accidental leakages when operating machinery seems to make little sense, because fluids leach immediately to deeper layers in snow and permeable firn. Suitable precautions must be taken to prevent deposition in snow and firn.

There is no need for biological monitoring. At the drilling site on the inland ice, there are neither birds nor invertebrates, plants or identifiable populations of microorganisms (microalgae).

When drilling operations have been completed, 10-metre cores providing information about the accumulation rate at the site over the entire project duration will be covered. These cores can also be used to determine the thickness of the snow and firn layers in which particles and emission products were deposited during drilling operations.

9. Unavoidable impacts of the proposed activity

The drilling fluid fed into the borehole, as well as the GFK pipes in the top part of the borehole will remain in the ice and be transported with the ice in the direction of the coast.

The vertical movement of ice and low horizontal flow velocity prevailing at the site mean that local contamination of the ice by drilling fluid will reach the ice shelf edge after about 100,000 or more years and once there will be released to the marine environment over an estimated period of several decades. By then, it is probable that the drilling fluid will no longer be existent as a discrete volume of fluid, but will be integrated in the surrounding ice matrix. In the distant future, it will reach the ice shelf region, encapsulated in the ice matrix. The same applies to the steel supports for the platform and timber components of the trenches.

Combustion of fuels in connection with transportation and energy production at the camp will cause emissions, leading to the deposition of combustion residues. The direct impacts in snow and ice at the site will probably be confined to a radius of several hundred metres.

In the area around the drilling site and along the traverses, there will be temporally and geographically limited changes in the snow and ice surface due to vehicle movements, erection of the camp and excavation of the trenches.

10. Future development of the environment and other likely impacts if the proposed activity is not carried out (the 'no action' alternative)

10.1 Development of the environment

If the ice coring is not carried out, there will be no changes to the status quo at the drilling site and along the traverse route.

10.2 Other impacts

If the proposed ice core recovery in Dronning Maud Land is not implemented, the likely result is that no high-resolution archives of palaeoclimatic and atmospheric conditions from the Atlantic sector of the Antarctic will be available for the foreseeable future. The documentation of Antarctic climate processes aimed at within the EPICA framework will remain incomplete, because no comparative data to those from the Dome Concordia core drilling project will be available from an area with a higher accumulation rate and from an additional area of the Antarctic.

11. Possible impacts on scientific research and other uses

If ice coring in Dronning Maud Land is successfully carried out, valuable high-resolution archives of palaeoclimatic and atmospheric conditions from the Atlantic sector of the Antarctic will be available for international climate research.

Further measurements could be taken in the borehole itself. Besides the scientific activities described in the foregoing, including those performed by the weather station operated by the University of Utrecht, and a joint snow and aerosol sampling programme no other major scientific activities will be carried out in the vicinity of the drilling site.

Logistics operations and the scientific review of the project will be documented for subsequent use by scientists and institutions working in the Antarctic.

Impacts on other activities, e.g. tourist or logistics activities, will not arise, because no such activities occur at present on the inland ice in Dronning Maud Land.

12.Gaps and uncertainties affecting the EIA

Since all the described activities in connection with erection of the drilling camp and with the deep core-recovery itself must be assessed in advance for their impacts on the environment, various uncertainties arise. These may include:

- the discovery of other ice parameters or ice characteristics that require the drilling site to be relocated away from the area embracing a 50 km radius around DML 05
- changes in ice characteristics that require slight changes to the traverse route (e.g. crevasses)
- changes in logistical requirements, necessitating changes to the project schedule or procedural sequence (e.g. timetables of supply ships, weather conditions for mooring at the ice shelf edge and for traverses, failure of equipment and vehicles)
- changes in the conduct of the ice core recovery itself (e.g. drilling hold-ups due to the characteristics of ice at greater depths)

In such a case, an examination will be conducted as to whether the changed conditions will result in environmental impacts beyond those identified by the present Environmental Impact Assessment.

13.Conclusions

The activities will not cause more than minor impacts on organism populations on the inland ice.

Impacts on Antarctic flora and fauna and on water quality, the aquatic environment and the marine environment are only likely, if at all, during transport operations and/or near the coast. The risk of disruptive influences can be minimised by taking adequate precautions. Accidents involving the release of substantial amounts of fuel would possibly lead to significant impacts, although the likelihood of such an accident is assessed as minimal on account of the tried and tested procedures and safety measures.

Minor impacts of the proposed ice coring on the original state of the inland ice environment can be expected in the vicinity of the drilling site and the traverses due to deposition and abandonment of materials and alien substances, to vehicle movements to and from the trenches, to excavation of the trenches, and to immissions.

One impact that is more than minor or transitory is the drilling fluid that is left behind in the borehole and which will be released to the marine environment in the distant future. Until then, however, it will be encased in impermeable ice.

All in all, the unavoidable strains on the environment can be limited by suitable measures to such an extent that minimal impacts on the Antarctic environment can be expected.

Conducting the proposad research activities will result in a better understanding of the Antarctic and global environment and the changes in the past. EPICA is a highly recommended international project. In accordance with Article 3 of the Protocol of Environmental Protection to the Antarctic Treaty the value of the area under investigations as an area for further research, in particular research essential to understanding the global environment, will not be reduced.

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AUG	Gesetz zur Ausführung des Umweltschutzprotokolls vom 4. Oktober 1991 zum Antarktis-Vertrag (Umweltschutzprotokoll-Ausführungsgesetz) - Act Implementing the Protocol of Environmental Protection to the Antarctic Treaty
ATCM	Antarctic Treaty Consultative Meetings
AWI	Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung / Alfred Wegener Institute Foundation for Polar and Marine Research
BAS	British Antarctic Survey
CEE	Comprehensive Environmental Evaluation
COMNAP	Council of Managers of National Antarctic Programs
DEA&T	Department of Environmental Affairs and Tourism
DML	Dronning Maud Land
EIA	Environmental Impact Assessment
EPICA	European Project for Ice Coring in Antarctica
ESF	European Science Foundation
EU	European Union
GISP2	Greenland Ice Sheet Project 2
GRIP	Greenland Ice Core Project
GWP-Wert	global warming potential nach UNEP
IEE	Initial Environmental Evaluation
NGRIP	North Greenland Ice Core Project
ODP-Wert	ozone depletion potential
SANAE	South African National Antarctic Expedition
SANAP	South African National Antarctic Programme
SCALOP	Standing Committee on Antarctic Logistics and Operations
SCAR	Scientific Committee on Antarctic Research
UNEP/WMO	United Nations Educational Programme/World Meteorological Organisation