NGU Report 93.045

The distribution of ^{137}Cs in the Meråker and Grong/Snåsavatnet Areas

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REPORT

Report no. 93.045 | ISSN 0800-3416 | Grading: Open

Title:
The distribution of ^{137}Cs in the Meråker and Grong/Snåsavatnet Areas

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Client:
NGU

County:
Nord-Trøndelag

Commune:
Meråker, Grong, Snåsa

Map-sheet name (M=1:250.000)
Østersund, Namsos, Grong, Trondheim

Map-sheet no. and name (M=1:50.000)
Several

Deposit name and grid-reference:

Number of pages: 44 Price: kr 190,-

Map enclosures: 4

Fieldwork carried out:	Date of report:	Project no.:	Person responsible:
1988-1991	12.08.93	61.1889.70	Jan S. Rønning

Summary:

Helicopter radiometric data collected over parts of Nord-Trøndelag between 1988 and 1991 have been reprocessed to produce maps of ^{137}Cs fallout resulting from the reactor accident in Chernobyl. Backcalculated data indicate that some parts of Nord-Trøndelag received ^{137}Cs levels in 1986 were one sixth of levels published for certain areas in the 30 mile exclusion zone around Chernobyl.

Four maps at 1:100,000 scale have been produced. Two cover the municipality of Meråker and 2 cover the map sheets Grong and parts of Harran, Overhalla, Snåsa and Snåsavatnet. Each area is covered by a map of cesium counts at helicopter level and a map showing apparent ground concentration back calculated to 1986.

The Meråker cesium map is compared to topographic and quaternary geological maps. The distributions of radio-cesium are found to be consistent with the behavior as documented in the literature. We demonstrate that airborne mapping is a rapid and cost effective technique for mapping contaminated areas, and that it has potential for monitoring the movement of cesium in the environment following a nuclear accident.

Keywords:	Radiometri	
Geofysikk	Forurensing	
Helikoptermåling		Fagrapport

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2 SUMMARY

Following the nuclear accident at Chernobyl in 1986, parts of Nord-Trøndelag received large amounts of radioactive fallout. We have reprocessed helicopter geophysical data over parts of the regions affected, and have produced separate ^{137}Cs fallout maps for the Grong/Snåsavatnet area and for the Meråker area. Results indicate that concentrations of ^{137}Cs alone in the Snåsavatnet area are higher than 100 KBq/m^2 and in the Meråker area over 50 KBq/m^2 over areas of a few square kilometers.

The values we measured are for ^{137}Cs only. However, if the initial activity of *all radionuclides are included* we infer an initial activity that was six times higher (Grønlie et al, 1990), or 600 KBq/m^2 in Snåsavatnet. For cesium 137, these concentrations are approximately one fifth to one sixth of the 15 curie/km^2 (550 KBq/m^2) level (Rich, 1989) in the Chernobyl area immediately following the accident in 1986. However, unlike the area around Chernobyl, the affected areas we have identified in Norway are small, patchy and isolated. We show helicopter mapping is an effective way to do identify such areas.

We compare the cesium maps with quaternary geological and topographic maps in the Meråker area and note that the extent of deposition is controlled be such factors as slope, (both its direction and steepness), drainage patterns and quaternary geology. Patterns of distribution indicate the cesium is moving downslope and concentrating in upland peat bogs and swampy regions. These concentrations could form a reservoir which could be the source of continued environmental radioactivity over the next 50 years. However, further work is required to determine if this cesium, and related radionuclides, will be released slowly into the environment, or whether it will be held benignly in upland areas.

3 INTRODUCTION

In the early morning hours of April 26, 1986, a steam pipe in one of the RBMK type reactors at Chernobyl broke, allowing the stream to come in contact with the graphite moderator. The steam then reacted with the graphite to produce hydrogen, which then mixed with the air in the reactor and exploded, blowing through the cement and steel shielding covering the reactor. Thus exposed to air, the graphite ignited and the resulting fire sent a radioactive fallout plume to a level of a few hundred meters. Convective motions the following day sent the cloud to a level of several kilometers and then even higher by cumulus cloud activity (Apsimon et al, 1988) where it then became incorporated into a storm front headed for Scandanavia. Thus blown over the Baltic Sea and Sweden, the fallout reached Norway two to three days later.

Figure 1 shows the locations of the RBMK type reactors which are currently either planned or under operation. Note that all are as close *or closer* to Norway than Chernobyl is. In the past year, there have been accidents at the St. Petersburg complex and another fire again at the Chernobyl complex. Since the states in the former Soviet Union are dependent on nuclear energy, RBMK type reactors continue in operation so the threat of another Chernobyl type accident persists. There also exist pressurized light water reactors in the former Soviet Union which do not use a graphite moderator, and so are considerably less dangerous than the RBMK design. The RBMK reactor is particularly dangerous because of the possibility that the graphite moderator can catch fire.

The cloud of fallout reached Norway on April 29, approximately four days after the fire began following the path shown in figure 2. Scattered rainshower activity that day in Nord-Trøndelag washed parts of the fallout cloud to the ground, forming highly radioactive patchy distributions. NGU was involved in airborne and vehicle-based reconnaissance surveys (Lindahl and Håbrekke, 1986), and results of the airborne reconnaissance mapping activity are presented in figures 3 and 4. In those figures, data are presented both orthognostically (along the flight lines) and as a smoothed gridded data set. Because of the extremely patchy nature of the anomalies, it is unlikely that the griding accurately represents the distribution of fallout on the ground. One important result of this initial airborne reconnaissance activity was to demonstrate that the fallout was often quite intense, and concentrated in small areas.

Fig 1. Location of Soviet designed nuclear reactors in Europe. Numbers indicate the total number of reactors in operation, and those in brackets, the total number under construction. RBMK (Chernobyl) type reactors are plotted with a ★, with the corresponding place name. The total number of non-RBMK type reactors in a country are indicated in italics. Data are taken from the IAEA, 1992.

Table 1 lists the major radionuclides contained in the fallout. Of those, only appreciable amounts of ^{137}Cs remain, the remainder having decayed away. Strontium was bound to large particles, and although the amount released is reported to have been one third of the cesium released (NLVF, 1992), in Scandanavia levels are much lower than that. In Sweden, ^{90}Sr levels were determined to be between 1 and 2 percent of the cesium levels, and traces of transuranium elements appeared at approximately 0.01% of cesium levels (Mascanzoni, 1987). ^{90}Sr levels in Norway were reported at 1% of cesium levels (NLVF, 1992). The consensus in the literature is that initial levels of ^{134}Cs activity were between 0.5 and 0.6 of ^{137}Cs levels (eg. Walling and Quine, 1991, Santschi et al, 1990).

Cesium fallout has been documented to have extensively entered the food chain. Animals concentrate it in muscle tissues, and predators tend to have higher concentrations of cesium in their bodies than do the prey. Zach et al (1989) found for example, that where soil concentrations ranged from 0.03 to 0.21 Bq/g, moose and deer had concentrations in the flesh of approximately 0.3 Bq/g and wolf 1.8 Bq/g. Mascanzoni (1987) measured the amount of ^{137}Cs in farm animals, game, fish and food products in Sweden. Most food was found to be within acceptable limits, but no correlation between soil activity and uptake was attempted. Uptake of ^{137}Cs into the food chain is dependent on many factors, including the levels of potassium and other nutrients, pH, the amount of organic matter and so is difficult to predict. Such considerations are beyond the scope of this report, and the reader is referred to Zach et al (1989), Mascanzoni (1987) and Taylor et al (1987) for further details.

Table 1: Major Radionuclides Released from Chernobyl

Element	Half Life (days)
^{137}Cs	11,000 (30 yr)
^{134}Cs	730 (2 yr)
^{106}Ru	368
^{103}Ru	40
^{140}Ba	13
^{131}I	8
^{99}Mo	3
^{132}Te	3

Initial Activity Ratio (April 1986): $^{134}Cs/^{137}Cs = 0.6$ Half-life data are taken from IAEA (1991), and major elements from Santschi et al (1990).

There are a number of epidemiological studies in the literature reporting on the health effects of fallout from Chernobyl. Certainly, the effect on health in areas near Chernobyl were quite extensive (eg. Kazakov, 1992). In that report for example, thyroid cases in the city of Gomel just north of Chernobyl rose from one case per year just before the accident to 38 cases per year after it, while in Brest approximately 500 kilometers to the west, the increase was 5 cases per year from 0 prior to the accident. As previously discussed, the relative proportions of radionuclides that reached Scandanavia are different than those affecting the Chernobyl region, so the implications on public health may not be the same. In fact, the may be no statistical evidence on a national level, that Chernobyl fallout had any effect on the Swedish population (Moberg and Reizenstein, 1993). We show however, that the fallout patterns in two areas of Norway are both local and intense, so statistical fluctuations in the national data may mask the consequences on health to the populations living in the affected areas.

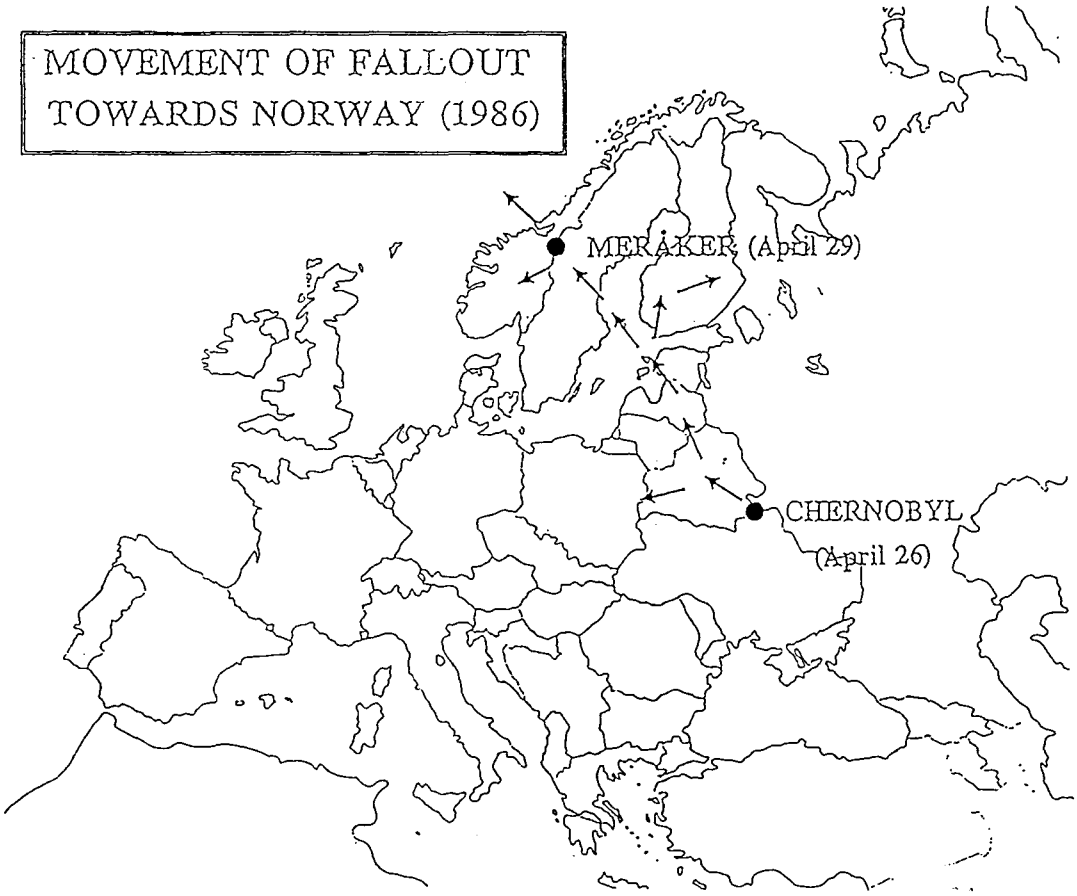


Fig. 2. Map of Europe showing the path taken by the fallout from Chernobyl to Meråker (after Gould, 1990).

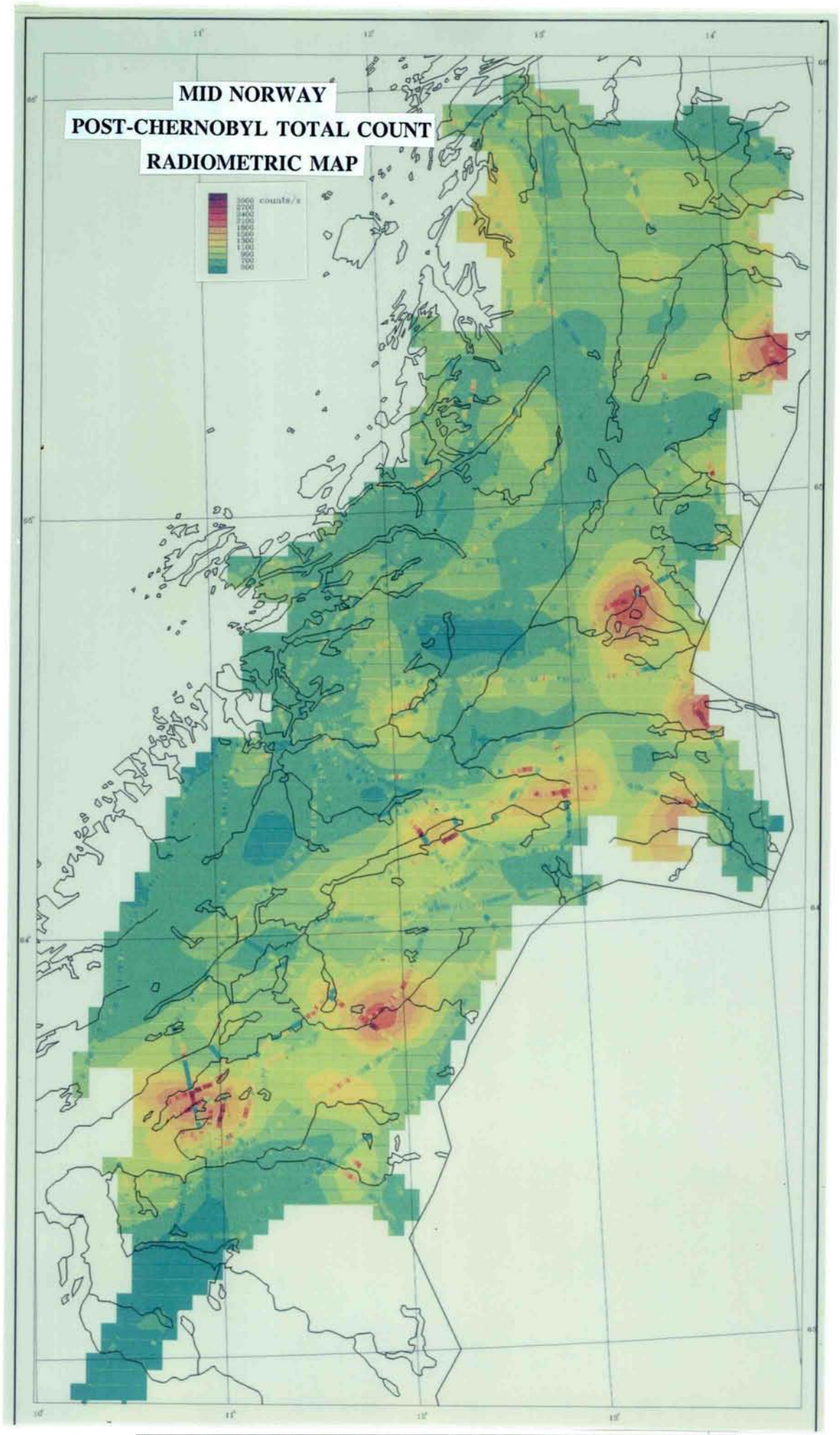


Fig. 3. 1986 total count radiometrics over central Norway

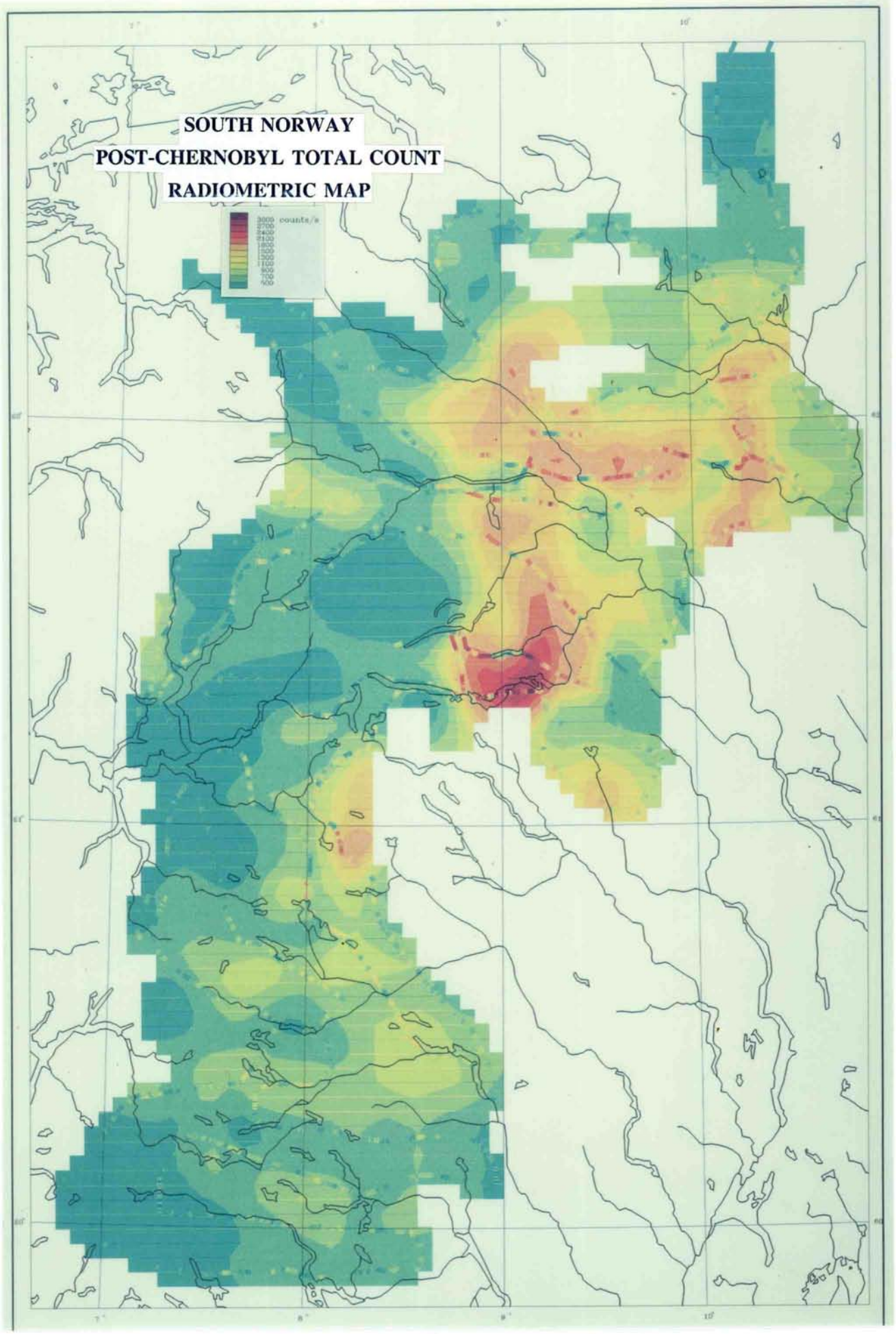


Fig. 4. 1986 total count radiometrics over southern Norway

4 THE SURVEYS

Data were collected with the helicopter geophysical package owned and operated by NGU. Part of this package included a 1024 cubic inch (16.8 liter) sodium iodide detector containing four crystals mounted in a single pack between the skids of the helicopter. Photon emission from the crystals was detected using photomultiplier tubes, which produced high voltage output that was processed by a pulse shaping signal processor and 256 channel spectrometer (Geometrics models GR-800 and GR-900). The full 256 channel spectrum was recorded once per second on magnetic tape.

Nominal flight elevation was 60 meters, but this varied to over 120 meters in very hilly terrain. Initial surveys were flown with manual navigation and supplemented in later surveys with a GPS (Global Positioning System) navigation unit. Given a nominal altitude of 60 meters, a sampling period of one second, and a speed of 30 m/s, samples are taken from overlapping strips extending approximately 150 meters along profile and 60 meters to each side.

The surveys from which our data comes were flown between 1988 and 1991. Descriptions of each survey can be found in the following: Grong and Harran (Rønning et al, 1990) Overhalla, (Rønning, 1990), Andorsjøen (Rønning, 1991), Snåsa, (Rønning, 1992), Snåsavatnet (Rønning, 1992), and Meråker (Mogaard, 1992).

5 PROCESSING

Data from the surveys listed above have been reprocessed to make ^{137}Cs maps over two areas. The Grong-Harran survey flown in 1988, and the Andersjøen, Snåsa, Overhalla and Snåsavatnet surveys flown in 1990 have been compiled into a single mapsheet. The Meråker survey flown in 1991 is plotted separately. In each area, maps of ^{137}Cs concentrations at flight altitude and at ground level have been produced.

The cesium data could not be processed in the same manner as the uranium, thorium and potassium channels. To process those channels, count rates in predefined windows shown in figure 5 are used. There is no such channel defined for ^{137}Cs, so one had to be defined from the 256 channel spectrum.

The lower 255 channels in the spectrum each have an energy range of 11.86 keV. Cesium was processed by extracting channels 48 to 62 inclusively and then adding them together to produce a single cesium channel. This channel was then merged with previously processed navigation, altimeter data and unprocessed radioisotope channels. These data were then corrected for deadtime of the spectrometer to produce a true rate in counts/sec. A further explanation of data processing is given in NGU report 92.315 (Walker, 1992).

Some counts attributed to ^{137}Cs may be due to other radioelements not included in the stripping calculations. Given the half-lives of those elements relative to when the surveys were flown, their relative proportions to ^{137}Cs in Norway, and the emission energies, errors introduced by not accounting for such radioelements will be under 10% for the earliest surveys and smaller for the later ones. We expect the dominant source of error to be from the 795 KeV peak emitted by ^{134}Cs, which has a half-life of approximately four years and an initial concentration ratio of 0.6 relative to ^{137}Cs.

Background corrections were time consuming, because it had not been the practice at NGU to fly special spectrometer background lines over lakes. Background levels were determined after plotting the dead-time corrected data, and extracting and averaging sections of line that passed over large lakes. Average levels determined on a flight-by-flight basis, and background rates were then subtracted from all radioelement windows. Channels were then

stripped using the stripping coefficients determined in Appendix B. Following this, the cesium channel was then corrected for atmospheric scattering using the radar altimeter to give a cesium count rate at ground level. Since this correction is an amplification, it is unstable, and corrections over 120 meters in elevation were not made. Conversion of the ground cesium count rate to Bq/m^2 was done using the concentration coefficient determined in the lab at NGU (see Appendix A). Ground count rate data were then converted to apparent 1986 levels to account for level differences to due radioactive decay from year to year.

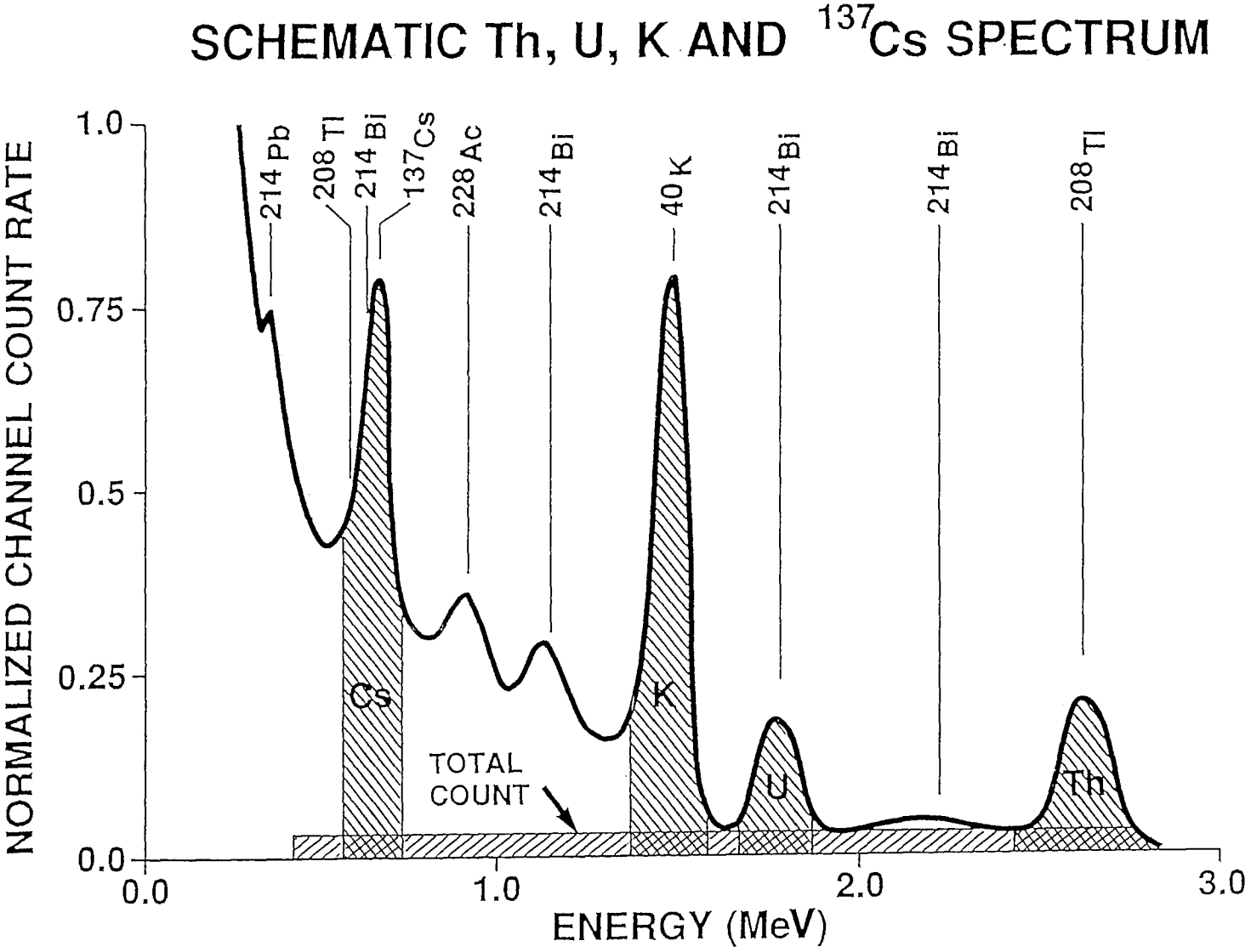


Fig. 5. Schematic spectrum of uranium, potassium, thorium and cesium-137 sources, showing windows locations and gamma-ray energies of daughter elements of the decay series.

6 DISCUSSION OF THE MAPS

On the Grong-Snåsavatnet compilation, level shifts between the different data sets are evident, which could be due to several factors: 1) incorrectly determined backgrounds, 2) physical movement of cesium, either down into the soil, or from place to place on the surface, 3) different weather or ground moisture conditions from year to year 4) the 1988 (Grong) data include more counts from ^{134}Cs spectral line at 795 KeV than the 1990 data from Andersjøen or Snåsavatnet. The Grong-Harran map data tend to be higher than adjacent areas in either Andersjøen or Snåsavatnet, arguing for one of points 2 or 4.

Ground concentrations in the Grong mapsheet are typically low relative to concentrations measured in Andersjøen and Snåsavatnet mapsheets. The maximum concentration is seen in map sheet Snåsavatnet, where the ground concentration is computed to have reached 120 KBq/m^2 (1986 equivalent ^{137}Cs), or approximately 200 KBq/m^2 total Cs (1986 equivalent). In the Meråker area, maximum concentrations are somewhat lower, approximately 90 KBq/m^2 total Cs (1986 equivalent).

These backprojected values are amongst the highest in Europe. Ground concentrations in the Severn catchment area in western England reached 3 KBq/m^2 of ^{134}Cs (8 KBq/m^2 total cesium) (Waling and Quine, 1991). Filipovic-Vincekovic et al (1991) reported combined ^{134}Cs, ^{137}Cs and ^{103}Ru levels in central Croatia at over 20 KBq/m^2. Total activity in Munich was measured in places at 315 KBq/m^2 and 252 KBq/m^2 was recorded in the French Alps (Gould, 1990). The backprojected activity we have calculated from cesium alone in Nord-Trøndelag is thus comparable to the highest values recorded in Europe. Measurements in Trondheim (Grønlie et al, 1990) indicated a correction factor of 6 can be used to account for the total change in activity between 1986 and 1990. Furthermore, cesium 137 activity backcorrected to 1986 indicates that cesium 137 activity in certain areas of Nord-Trøndelag is approximately one fifth to one sixth of that in the 1986 15 curie/km^2 contour recorded within the 30 kilometer exclusion zone now centered on Chernobyl (Rich, 1989).

Studies following the Chernobyl accident concentrated on ^{134}Cs measurements because of previously existing ^{137}Cs in the environment due to atmospheric testing, so it is conceivable

that some of the activity we have measured predates Chernobyl. However reported concentrations are low. ^{137}Cs in Montana measured in 1982 (pre-Chernobyl) ranged from 1 to 7 KBq/m^2 (Arnalds et al, 1989) and a level of 0.050 KBq/m^2 were reported as background in Croatia (Filipovic-Vincekovic et al, 1991). Given these results, the low background levels measured over much of the Grong mapsheet, and the extremely patchy nature and high intensity of the radiation, it is unlikely that atmospheric testing is a significant source of the cesium we have measured. Bomb test cesium would be expected to be more uniformly distributed and at much lower levels.

In Meråker, cesium occurs on eastward facing slopes: Slopes facing towards the direction from which the fallout came, tend to have more cesium activity than slopes facing the west. A full analysis of the Grong-Snåsavatnet data set has not yet been done. In both areas anomalies can be quite patchy but to the north and east of Snåsavatnet however, deposition is quite extensive.

7 COMPARISON WITH QUATERNARY GEOLOGY AND TOPOGRAPHIC DATA

Anomaly patterns we have seen are clearly related to quaternary geology, topography and hydrology. Considerable information about the behaviour of cesium in the environment is present in the literature, and the discussion we present here is by no means comprehensive. It does, however, touch on the major points we have encountered. Patterns of distribution we have interpreted correlate well with that expected from the literature.

To date our interpretation is limited to the Meråker area, using the 1:100,000 scale cesium maps (figure 6), a simplified quaternary geological map at 1:100,000 scale (figure 7) and superpositions of the two on topography (figures 8 and 9). Selected profiles shown in figure 10 which compare cesium, topography and quaternary geology are presented in figures 11, 12 and 13 using data extracted from gridded data sets. No interpretation work has yet been attempted on the Grong-Snåsavatnet data set.

Considerable documentation exists in the literature on how cesium is retained in soils. Retention is a strong function of soil parameters, and is in some situations reported to mimic potassium. In western Europe, the major retentive mineral in soils is illite, and recent work reported in Cremers et al (1988) indicates certain sites in illite select cesium in preference to potassium, supporting observations made by Zach et al (1989). Cremers et al further contend that the organic fraction in podzols play no role in cesium retention, although Filipovic-Vincekovic (1991) imply that in certain soils the organic fraction may be more important than clays in supplying sites where cesium can be bound.

Cesium fallout tends to concentrate in the near surface layers of soils. Both Filipovic-Vincekovic et al (1991) and Birattari et al (1991) found exponential drops in cesium concentration with depth; consistent with a uniform binding capacity with depth and a surficial source. The diffusion distance of cesium in soil correlates strongly with the amount of infiltrating rainfall and inversely with the clay and carbonate fraction. High rainfall in Norway may thus promote the migration of cesium. Where soils are thin, slopes are steep and rocks impregnable, migration may be downslope rather than vertical. Studies indicate that

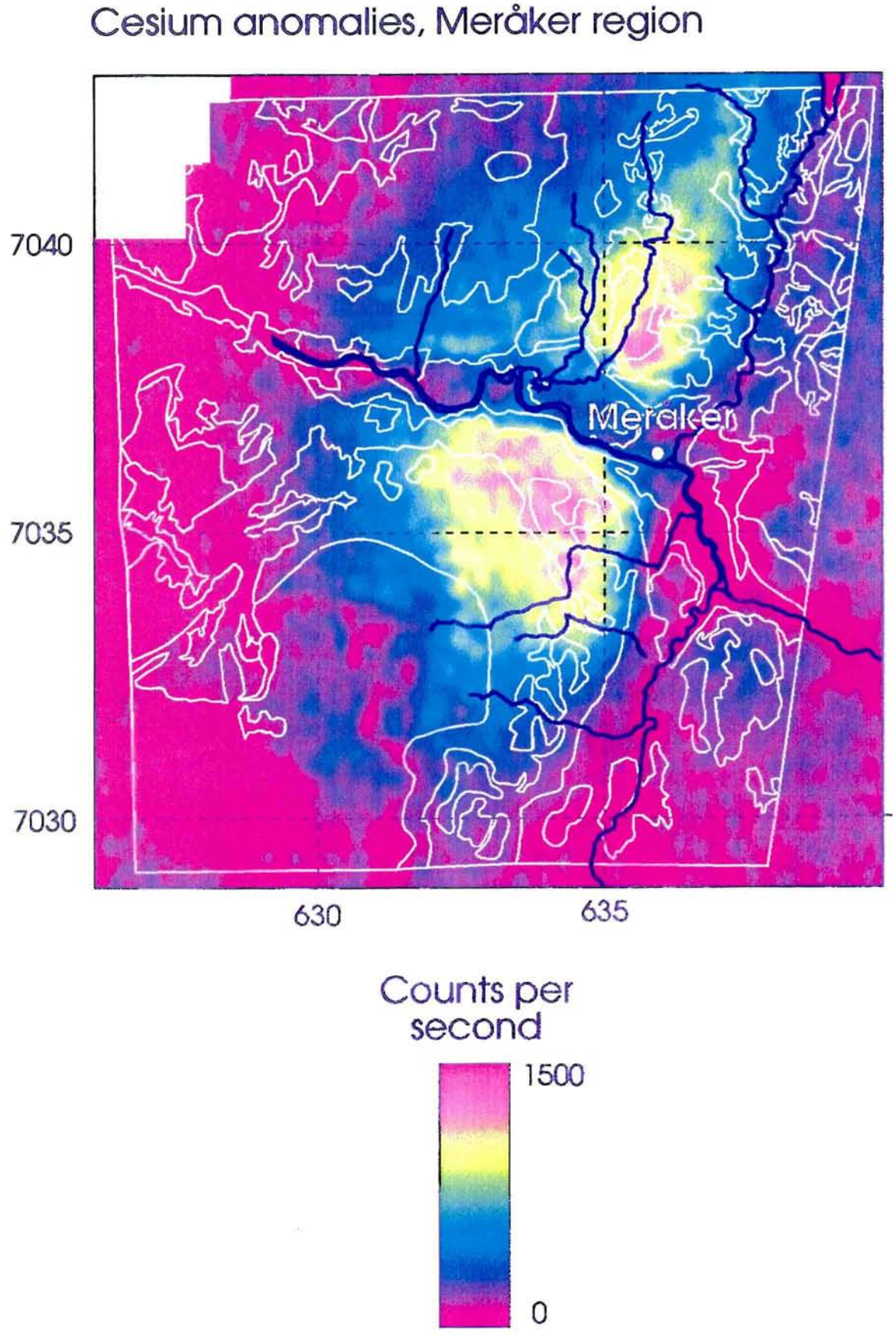


Fig. 6. Cesium counts at sensor elevation in the Meråker region at 1:100,000 scale

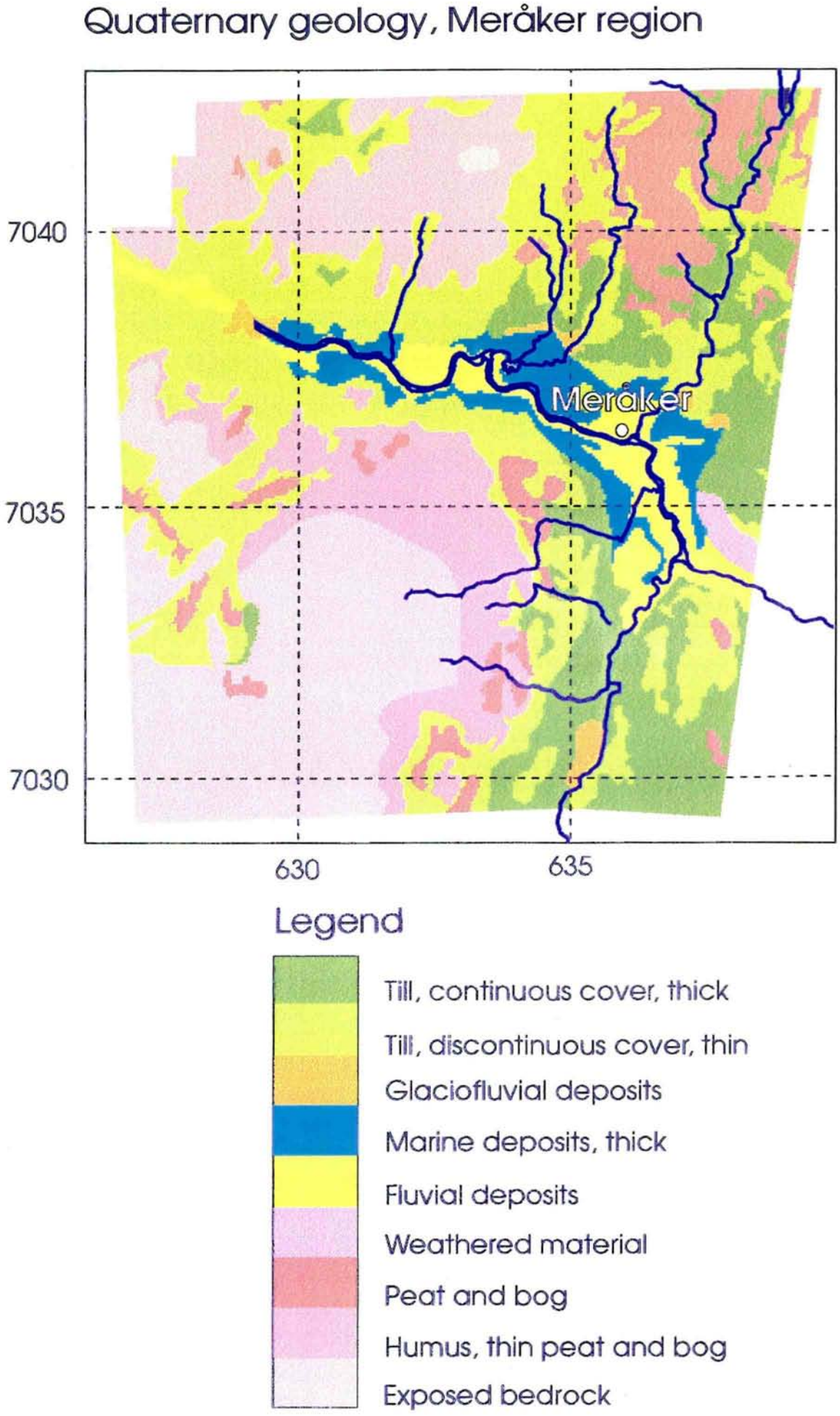
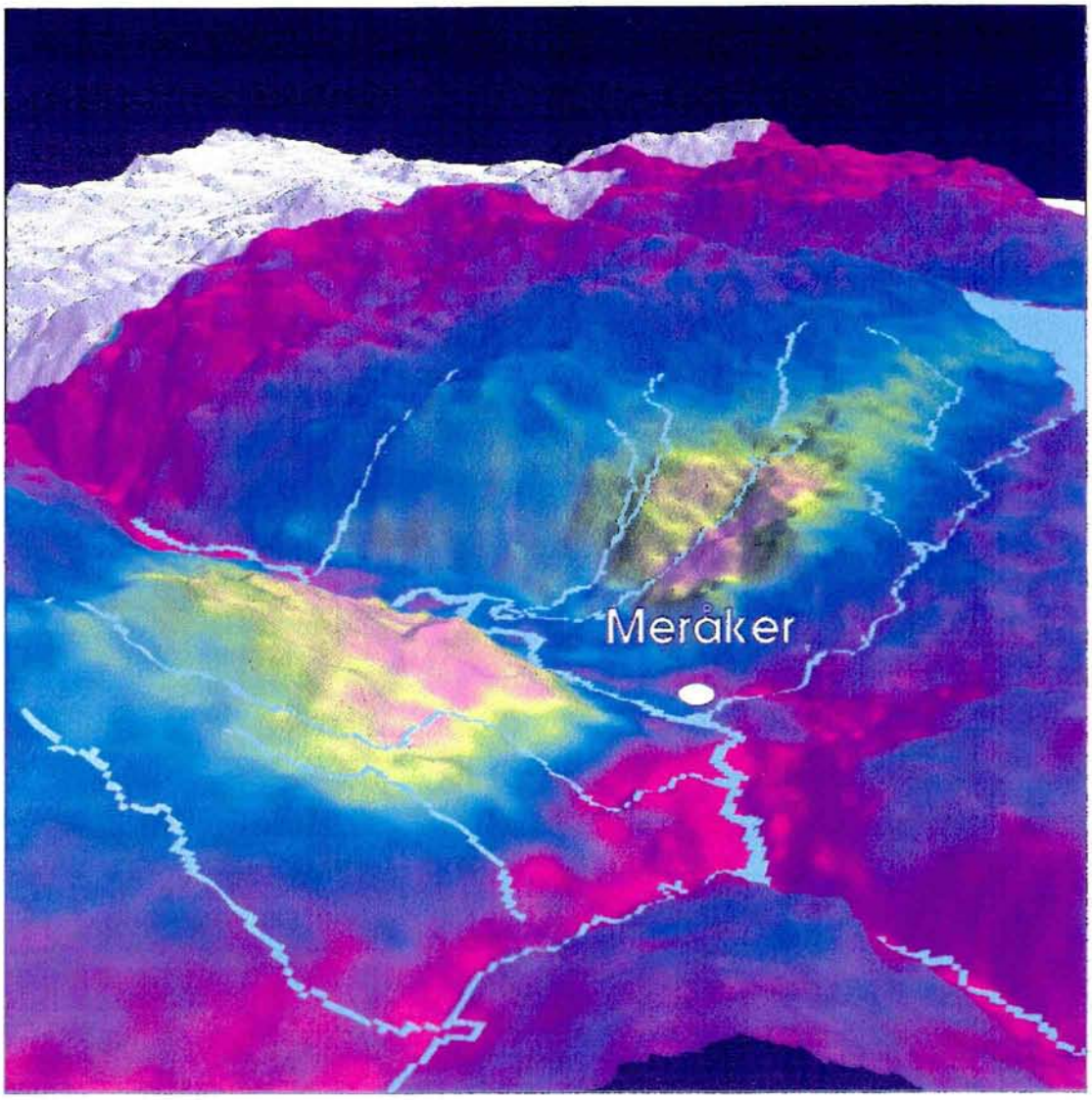


Fig. 7. Simplified quaternary geology of the Meråker region at 1:100,000 scale

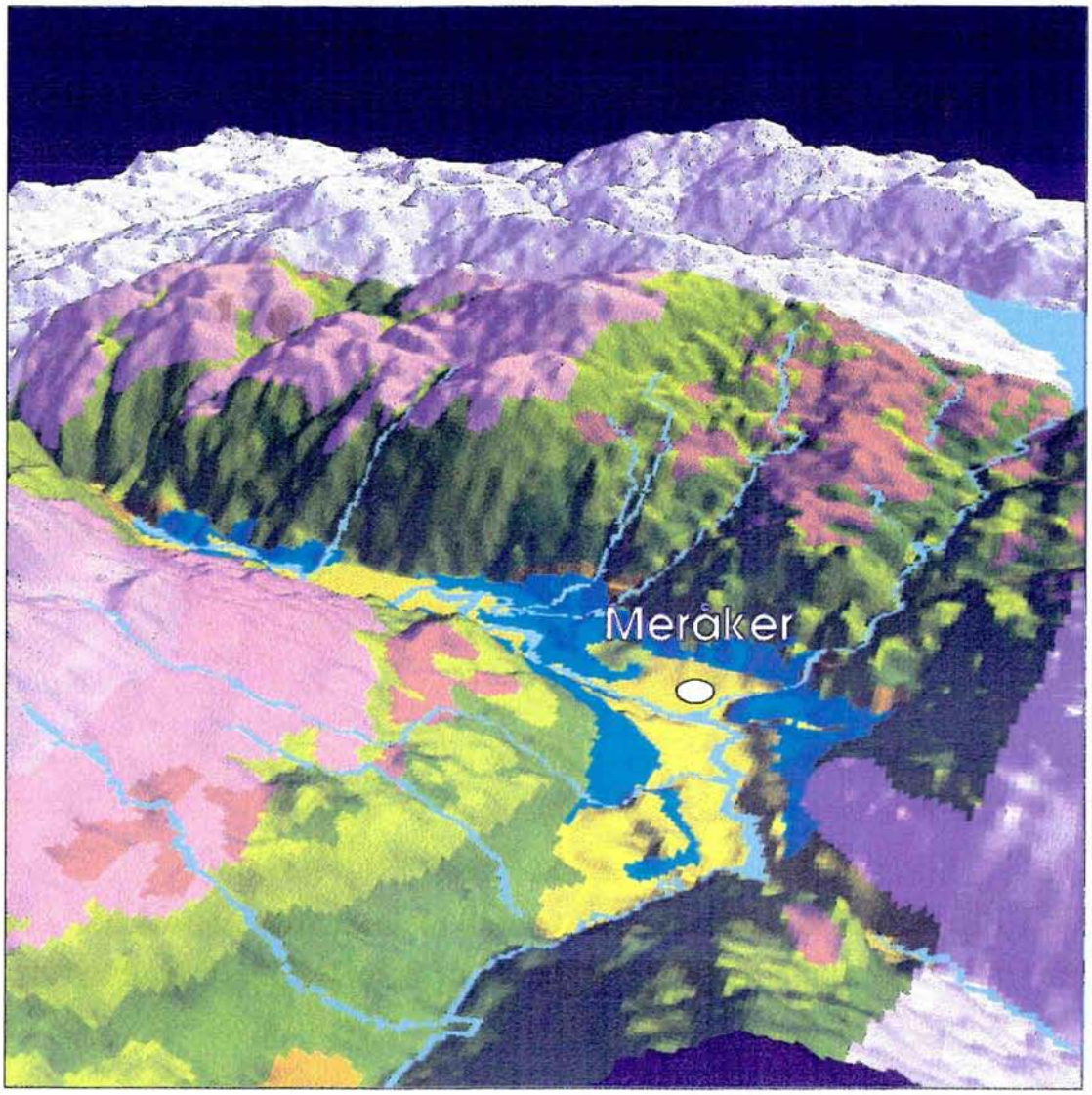
Cesium anomalies, Meråker region



Counts per second

Fig. 8. Cesium count rate in the Meråker region (from Fig. 6) and shaded relief superimposed on a topographic underlay. View is perspective from the southeast looking to the northwest. Vertical exaggeration is 4 times

Quaternary geology, Meråker region



Legend

Till, continuous cover, thick

Till, discontinuous cover, thin

Glaciofluvial deposits

Marine deposits, thick

Fluvial deposits

Weathered material

Peat and bog

Humus, thin peat and bog

Exposed bedrock

Fig. 9. Quaternary geology of the Meråker region (from Fig. 7) and shaded relief superimposed on a topographic underlay. View is perspective from the southeast looking to the northwest. Vertical exaggeration is 4 times.

the retention of ^{137}Cs in soil is high. Santschi et al (1990), in their study in Switzerland, for example, only a 1% fraction of total cesium in soils was subject to washing out with an exponential decay constant of 0.125/day, so more than one half of the cesium available to be washed out would have been released within the first week. Studies by Carlsson (1978) and Walling and Quine (1991) confirm this immobility. Carlsson found transport rates of 0.56%/year of cesium in the drainage area he studied, so that loss is dominated by nuclear decay. Walling and Quine found removal rates in the Severn catchment of 0.2%/year, in rough agreement with Carlsson. Removal rates however, are strongly dependent on such factors as erosion rates and soil types, so these figures may not be directly transferrable to the Norwegian scenario.

Evidence also exists that cesium concentrations are controlled by drainage on scales of just a few tens of meters. In a report by NLVF (1992) cesium concentrations mapped on a 1 meter grid was found to be approximately twice on the bottom a valley 2 meters deep by 30 meters wide than on the shoulders (150-250 KBq/m^2 vs. 50-100 KBq/m^2). Whether this pattern reflects the a "frozen" deposition pattern due to surface runoff when the fallout was deposited, or a slow creep of cesium downslope is unclear.

One major difference between our study and those cited is that snow covers upland areas in the study area during May, and so was likely still present there just after the accident at Chernobyl. Hence fallout radionuclides in Nord Trøndelag could have fallen on snow and could have been redistributed in the melting snow in the months following the accident.

Despite this possible difference between our study area and studies cited, our results fit well with the literature. We find, for example, that in the river valley west of Meråker which is dominated by fluvially deposited sands and gravels, virtually no cesium was measured. Presumably, the reason for this that soils in this area are relatively clay poor, so the cesium is not bound to the surface and has either penetrated too deeply into the soil to be seen or has disappeared altogether. We also find low concentrations over the marine deposits (these exclude shore deposits) which also lie on the valley floor. These are mapped as a combination of silt (0.063 mm - 0.002 mm) and clay (under 0.002 mm) particles. These silts and clays are likely glacially derived, and so may represent finely ground rock and not cesium

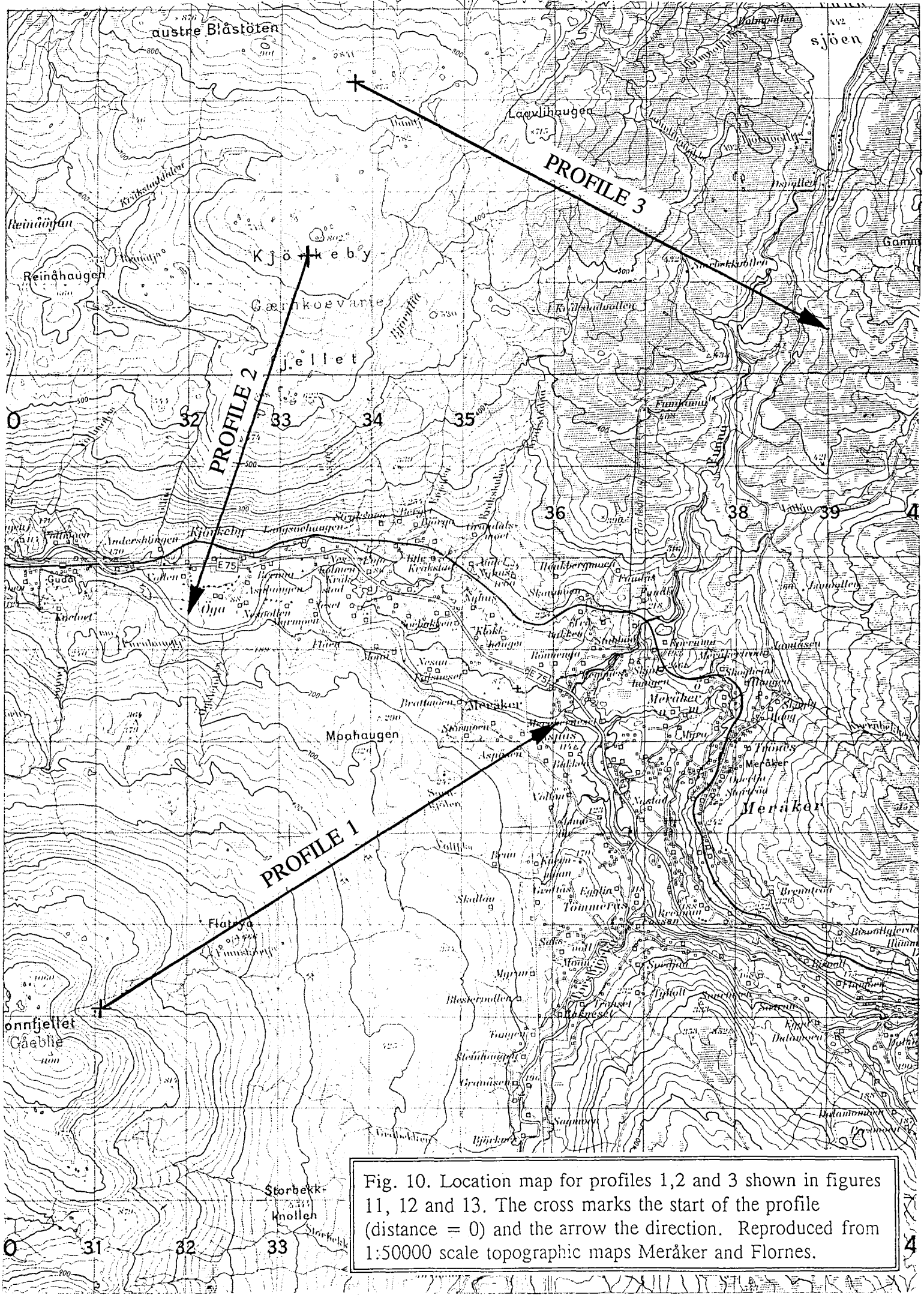


Fig. 10. Location map for profiles 1,2 and 3 shown in figures 11, 12 and 13. The cross marks the start of the profile (distance = 0) and the arrow the direction. Reproduced from 1:50000 scale topographic maps Meråker and Flornes.

PROFILE 1: HEIGHT, CESIUM AND QUATERNARY GEOLOGY

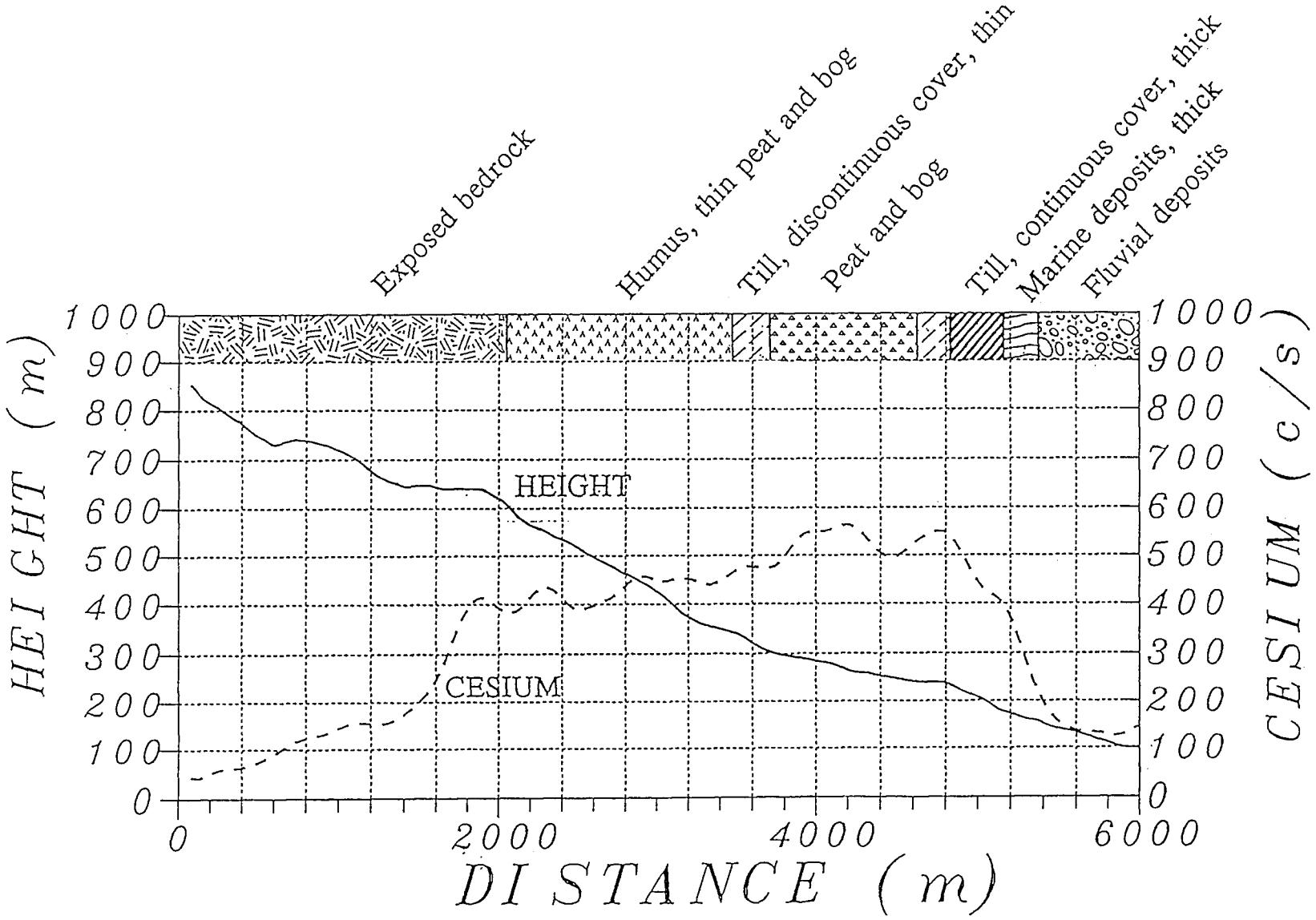


Fig. 11. Profile 1, figure 10 showing height above sealevel, cesium counts/second and quaternary geology.

PROFILE 2: HEIGHT, CESIUM AND QUATERNARY GEOLOGY

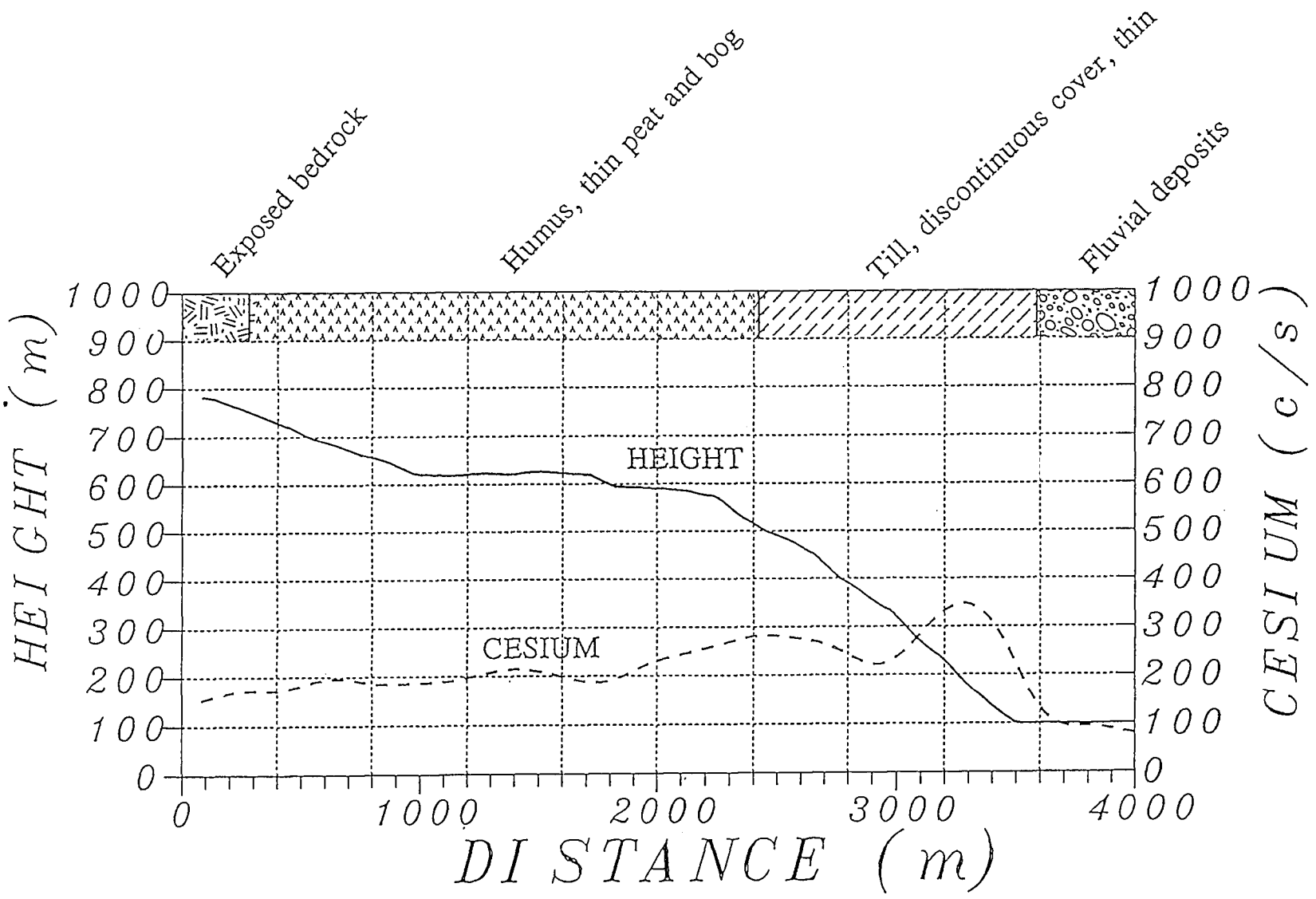


Fig. 12. Profile 2, figure 10 showing height above sealevel, cesium counts/second and quaternary geology.

PROFILE 3: HEIGHT, CESIUM AND QUATERNARY GEOLOGY

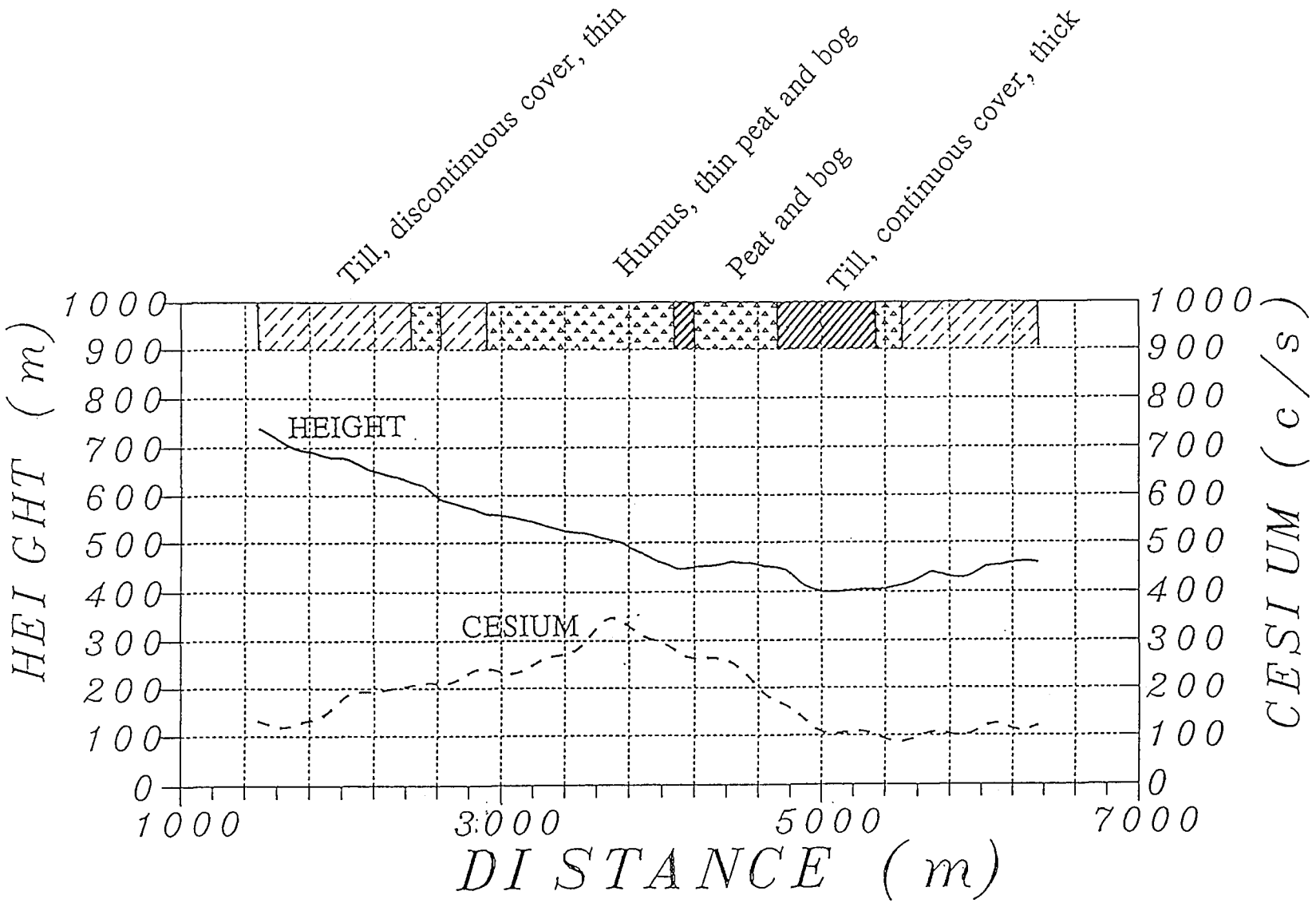


Fig. 13. Profile 3, figure 10 showing height above sealevel, cesium counts/second and quaternary geology.

sorbant fractions such as illite. Although it is conceivable that shower activity responsible for the cesium deposition missed the valley and hit the two adjacent hillsides, we present evidence which indicates this is unlikely. Similar results are observed at upper elevations where soils have not yet developed. At elevations above 600 meters on profile 1 and 800 meters on profile 2, the quaternary geology is mapped as exposed bedrock. Because of the lack of soil there, any cesium was probably not fixed and so was flushed down to lower levels. This being the case, the 1% fraction reported by Santschi et al for the initial mobile fraction is probably not applicable to regions with exposed bedrock. Evidence for this is seen on profile 1, where the cesium count rate steps suddenly on a plateau at approximately 640 meters elevation near the point where exposed bedrock meets the zone covered by humus, thin peat and bog. The linear increase of cesium with distance down slope in the exposed bedrock region may be indicative of greater soil development with distance downslope in the area mapped as exposed bedrock. Alternatively, the cesium could have been transported downslope by surface runoff. This could have occurred either as runoff during the initial rainshower activity, as transportation with the initial snow melt, or the profile could reflect a gradual migration of cesium downslope with time. The initial depositional profile was in fact more uniform.

The cesium count rate increases approximately linearly downslope on profile 1 through the area mapped as humus, thin peat and bog, again either reflecting greater average soil thickness down slope, downslope migration in the initial runoff, or subsequent movement. However, the large step in cesium argues for some form of down slope migration, either initially or from subsequent remobilization and sorbtion during the years subsequent to 1986.

The sudden falloff in cesium activity on profile 1 is associated with a change in slope and a shift in quaternary geology from peat and bog to till and marine deposits. Such behaviour is sensible since runoff tends to be greater on steeper slopes than on flat ones, and peat has been observed to have better sorption capacity than till in ground measurements (Mac Niocaill et al, 1992). Why the count rate should decrease linearly down slope in the till and marine deposit layers is not clear. This might be an artifact of the relationship of the flight line geometry to the slope: significant radiation may be impinging on the crystal from the side.

Profile 2 was chosen to illustrate the large peak in the cesium count rate near on the side of the valley near its bottom, and adjacent low values on the valley bottom itself. It is unlikely this profile reflects the initial deposition profile, and is taken as evidence of slow movement of cesium downslope and of washout in the fluvial deposits on the valley floor. This effect is dramatically illustrated in the perspective view (figure 8). The count rate changes sharply where the north slope of the valley to the west of Meråker meets the valley floor.

Profile 3 is included to show the dependence of cesium concentration on hydrology. The profile in intersected by two streams, one at 4100 meters and the other at 5000 meters. At 4100 meters, the cesium count rate profile flattens out, and at 5000 meters, the anomaly terminates. Both these effects support the argument that cesium either was or is being, washed down slope until it is intercepted by a stream. Again, whether this reflects ongoing downslope cesium migration, or just the initial distribution down slope from runoff is unclear.

8 DISCUSSION

Given our findings, we believe that helicopter measurements can dramatically improve the effectiveness of ground sampling programs in the event of a second nuclear disaster. Ground sampling of course, provides the ultimate ground-truth, because airborne radiometric measurements are influenced by such factors as soil moisture, the diffusion depth (burial shields radioactive sources), vegetation and source geometry/topography. However, a comprehensive picture of fallout patterns could be built-up if airborne measurements were used in conjunction with a limited soil sampling program.

A measurement program by Statens Strålevern based on four samples per municipality was the basis of a radiation map published by the Norwegian Mapping Authority (Radioactive Fallout Pattern in Norway, 1991 *in* NLVF, 1992). From our work, we know the distribution of fallout can be so locally variable that averages over entire municipalities (see the Meråker map) are not necessarily representative of many places in that municipality. We also know that airborne geophysics can only map *apparent* concentrations of radionuclides. If both methods were combined, a map could be made with the quantitative precision of soil measurements and the efficient coverage available from the air.

Since producing results from soil sampling is slower than producing results from airborne geophysical measurements, soil data would be only of limited use for rapid decision making in the event of another nuclear accident. However, NGU has the capability to provide extensive coverage with virtually immediate information should such an accident occur again. Such information could be used to define radioactive areas, for example protecting the needless destruction of livestock should they wander from uncontaminated areas into contaminated ones. Since we also know now that water supplies are quickly contaminated following an accident, quickly defining contaminated watersheds has important public health implications, and could significantly reduce medical costs resulting from the long term effects of exposure to radiation.

NGU's costs for such mapping are currently under NOK 300 per line kilometer: less than NOK 1500 per square kilometer using a 200 meter line separation. The cost of each point,

including acquisition and processing, is thus under NOK 10. Processing time for a map sheet the size of Meråker is currently under one week, but preliminary maps usable for civil defence could be available either the same day or one day after collecting the data. These maps could also be a guide for follow-up soil measurements, greatly enhancing the effectiveness of the ground program. More inter-agency cooperative work is needed.

One problem encountered in the course of our research is the diversity of institutions working on this problem: health, agricultural, environmental, meteorological and geological among others. Each naturally has their own set of problems to solve, agenda, method of reporting and preferred units to work in. Because of this, it is difficult to relate work done by one group to that done by another. Whether it be possible for health and agricultural authorities to use our data in their research is not clear, and the information we required or would have liked was often not present. Certainly, it was painful trying to incorporate their findings into ours. If multidisciplinary progress is to be made, and so understand how geological, environmental, agricultural and health issues related to nuclear accidents are linked, collaboration between research groups in different disciplines and institutions in Norway must be improved.

9 CONCLUSIONS

We have produced maps of ^{137}Cs fallout for two areas in Nord-Trøndelag, which show that fallout can be intensely concentrated in small areas. In certain areas we have calculated that the initial intensity of cesium 137 fallout is calculated to be upto one fifth of to the initial intensity within the 30 kilometer exclusion zone now surrounding Chernobyl.

Detailed airborne radiometric surveys with line spacings of 200 meters and a nominal sensor altitude of 60 meters are an effective tool for mapping fallout patterns associated with nuclear accidents. Because radio-cesium is held in the uppermost parts of the soil, airborne radiometric measurements provide a quick and economic method for monitoring cesium fallout in the years following a nuclear accident. Ground soil sampling is required to calibrate the airborne data, but in the event of a second nuclear accident, airborne measurements provide the only effective way to cover the vast areas quickly enough to minimize economic losses and solution for large tracts quickly, and are more representative, faster, and cheaper than ground sampling.

We have also shown fallout can be intensely concentrated in spotty and sparsely distributed patterns. Given such a distribution, *averaging ground samples based on 4 analyses per municipality,* can be misleading: *However, the sampling itself, is important!* Airborne reconnaissance mapping, using line spacing of a few kilometers, can identify locate areas where fallout is the most extensive. Subsequent detailed ground surveys can be used to define the nature of this contamination. The power of the combined data sets is much greater than the power of either individually.

Much of cesium distribution we have mapped in the Meråker region can be explained knowing the behaviour of cesium in soils and watersheds documented in the literature. Airborne geophysical mapping is therefore consistent with other techniques for mapping contamination following a nuclear accident. With further work, the effectiveness of airborne mapping will be improved.

10 RECOMMENDATIONS

The possibility of a quick response team should be investigated. Should one be established, it should be regularly tested to ensure that it is prepared. With two pilots, operators and navigators available, mapping could be done continuously during available daylight hours. Since the effect of fallout both on public safety and on the economy is so large, such an initiative would be cheap insurance. To do this, the spectrometer should be calibrated so that a number of radionuclide apparent concentration maps could be produced. This would involve purchasing a number of short lived radioactive sources so this calibration could be done.

We furthermore recommend that follow-up ground studies be done in the more contaminated areas with the goal of identifying elements such as neptunium and plutonium. It may well be that a major use of ^{137}Cs mapping is not in the identification of cesium itself, but in identifying areas containing more dangerous substances. The local distributions of cesium and other elements may not be identical due to variation is their geochemical properties, but the most important role of cesium mapping could be as a marker to other less detectable radionuclides. Many of the radionuclides contained in the Chernobyl fallout had decayed by the time the surveys were flown, and so have little chance of being identified in the data sets we processed for this report. However, transuranic elements have a long half-life and could be identified in our data set. Since reported concentrations are low, it will be necessary to accumulate counting statistics over a large area to reduce the statistical counting error. Procedures for analyzing spectra for transuranic elements are outlined by the IAEA (1991).

Additional fallout maps could be generated in other areas. NGU has flown surveys over the Steinkjer, Vuku, Fosen, Kautokeino and Pasvik areas for which fallout maps could be made. The Fosen area, for example, is known to have received considerable contamination after Chernobyl. The area covered by the Snåsavatnet-Grong should also be compared with quaternary geological, hydrographic and topographic data to test whether cesium there behaves similarly to fallout in the Meråker area.

A recalibration of the spectrometer for counts into KBq/m^2 is also required, as the calibration

described in appendix A was done under time constraints. Comparisons with laboratory derived calibration should be made with a calibration over a test strip.

Parts of the Meråker area should be resurveyed from the air to establish whether the patterns we have seen in the distribution of cesium reflect the initial movement in the surficial runoff (or conceivably the snow melt), or whether it is the result of continued flow down slope. If the latter is found to be the case, geochemical and hydrological work could be done so that the mechanisms governing migration could be better understood. Follow-up spectrometer work on the ground along permanently marked profiles or grids could also help establish migration rates and project lifetimes, and should be carried out over a period of several years. Also of interest is to determine whether the hills overlooking Meråker hold a reservoir of cesium which is slowly being released into the streams, rivers (and drinking water) in the valley below. This would require a multi-disciplinary effort, since important factors governing cesium distribution in soils and mobility in water are not within the realm of geophysics.

One problem with resurveying areas with an airborne gamma-ray spectrometer is that the count rate variations from survey to survey can be caused by variations introduced by ground moisture, aircraft altitude, changes in vegetative cover and other spurious effects not related to changes in the radionuclide distribution. One way to overcome this problem would be to use the potassium count rate to normalize the cesium count rate, plotting the cesium count rate as a ratio to the potassium counts. The potassium and cesium energy decay energies are relatively close, so the attenuation coefficients of both in the soil and the air should be similar. Thus, when areas are resurveyed, changes in the signal from radio-element concentration can be separated from other environmental effects.

Conversion factors from Bq/g to Bq/m^2 should be calculated. We have not come across a discussion of this in the literature, and a conversion would be useful for comparing our work with that reported in the literature. Clearly, such a conversion is dependent on such parameters such as the vertical distribution of cesium is the soil, ground moisture and shielding from vegetation. We furthermore suggest cooperative projects be established with other institutions working in different fields. Digital gridded data should be available to other

institutions, so that the comprehensive data sets NGU now has for Meråker and Grong/Snåsavatnet are not consigned to the bowels of obscurity.

11 ACKNOWLEDGEMENTS

The project was inspired by a visit to NGU by Bob Grasty, and then by later interpretative work by Conall MacNiocaill. Maps used in figure 2 and 3 were produced by Ola Kihle. The potassium used to calculate the stripping ratios was donated by Håvard Gautneb. The quaternary geological map was provided by Morten Thoresen and Arne Reite and digitized by Oddvar Blokkum. Per Ryghaug and Janne Grete Wesche kindly assisted with importing this map to the ArcInfo GIS system.

We would especially like to thank Ed Sharp, visiting professor at NTH from South Carolina State for and Dr. E. Steinnes (UNIT, AVH) for their critical review of this manuscript.

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APPENDIX A
CESIUM CALIBRATION

The GR-900 spectrometer was calibrated for cesium sensitivity on Feb 19, 1993 in the lab at NGU. For the calibration, the crystal pack was suspended 1.1 meters above the floor on its aluminum frame. The frame was supported above the floor on two 2 by 6 inch planks which sat on wood trestles approximately 2 meters apart. This gave a clear view directly under and to the side of the spectrometer, but the trestles partially obscured the view at each end of the spectrometer. The crystal pack was aligned so that the photomultipliers were parallel to the planks.

The calibration was done by moving a cesium point source about on a grid of 1 by 1 meter within the confines of the laboratory. Backgrounds were measured prior to and after the cesium source measurements, and were found to be 476 counts/second in the cesium channel. Measurement periods were approximately five minutes. Average background corrected count rates for each position are given in the table below. The rows of the table are aligned parallel to the photomultiplier tubes, with the third element in the first row being directly under the crystal pack.

171	**512**	**1211**	**645**	188
123	**212**	463	**281**	136
49	89	**135**	**98**	**54**

Bold entries denote data which were actually measured, and the remainder values that have been deduced. Note the bold values to the right (away from the high voltage supply) are approximately 10% higher than those on the left, so deduced values on the left were calculated from the corresponding value on the right by multiplying by 0.9. The two right most entries were calculated by ratioing the corresponding measured values in column 3: Eg. 188 = (135/463)*645; 136 = (98/463)*645.

Total counts from 5 by 5 meter square were determined by reflecting rows 2 and 3 through

row 1: sensitivity is assumed to be symmetric through the axis defined by the photomultiplier tubes. This results in a total of 6007 counts/sec.

The source used had a intensity of 298.5 KBq as of 21 march, 1988. The half-life of ^{137}Cs is approximately 30 years, giving an exponential decay constant of 0.0231/year. Since 1988 then, the source has decayed to approximately 0.89 of its original strength, or 266 KBq. Distributing the source on a 1 meter grid thus produced an effective surface source intensity of 266 Bq/m^2. so dividing 6007 by 266 yields the calibration constant of 23 $counts/sec/KBq/m^2$. For simplicity, and because the calibration is likely low since the area used for the calibration was not large enough to reach background at its perimeter, a value of 25 $counts/sec/KBq/m^2$ is being used provisionally until a better calibration can be effected.

APPENDIX B
THE GR-900 COMPTON STRIPPING RATIOS FROM PURE SOURCES

Pure radioactive sources were used to compute the Compton stripping ratios for the GR-900 in the lab. The experiment was done by placing the detector on a wooden shelf approximately 1 cm thick, with small uranium, thorium and cesium 137 sources placed on a shelf beneath. The potassium source consisted of a 5 kg. bag of K_2O used for agricultural experiments which was placed directly beneath the shelf the spectrometer was sitting on. The spectrometer was connected to NGU's RMS data acquisition system, and data were recorded on magnetic tape at a sampling rate of one second. The results tabulated below were measured Jan 13, 1993, and have been corrected for instrument deadtime to an effective sampling interval of one second.

Source	U	Th	K	Cs	Samples
Background	69.66	78.26	424.73	515.80	249
Cesium	72.75	81.18	427.07	4091.77	197
Potassium	74.54	80.20	499.60	522.53	582
Uranium	176.13	85.66	501.37	923.94	429
Thorium	160.77	369.01	547.70	1276.88	337
Background	67.84	79.16	422.64	512.66	261

Backgrounds were measured before and after the response of individual sources was measured.

Stripping ratios were calculated first by subtracting backgrounds from all data, and then dividing for example, the cesium response from uranium by the uranium response from uranium to yield the stripping ratio of uranium into cesium, eg:

Cs/U = (923.94 - 514)/(176.13 -69.66) = 3.85

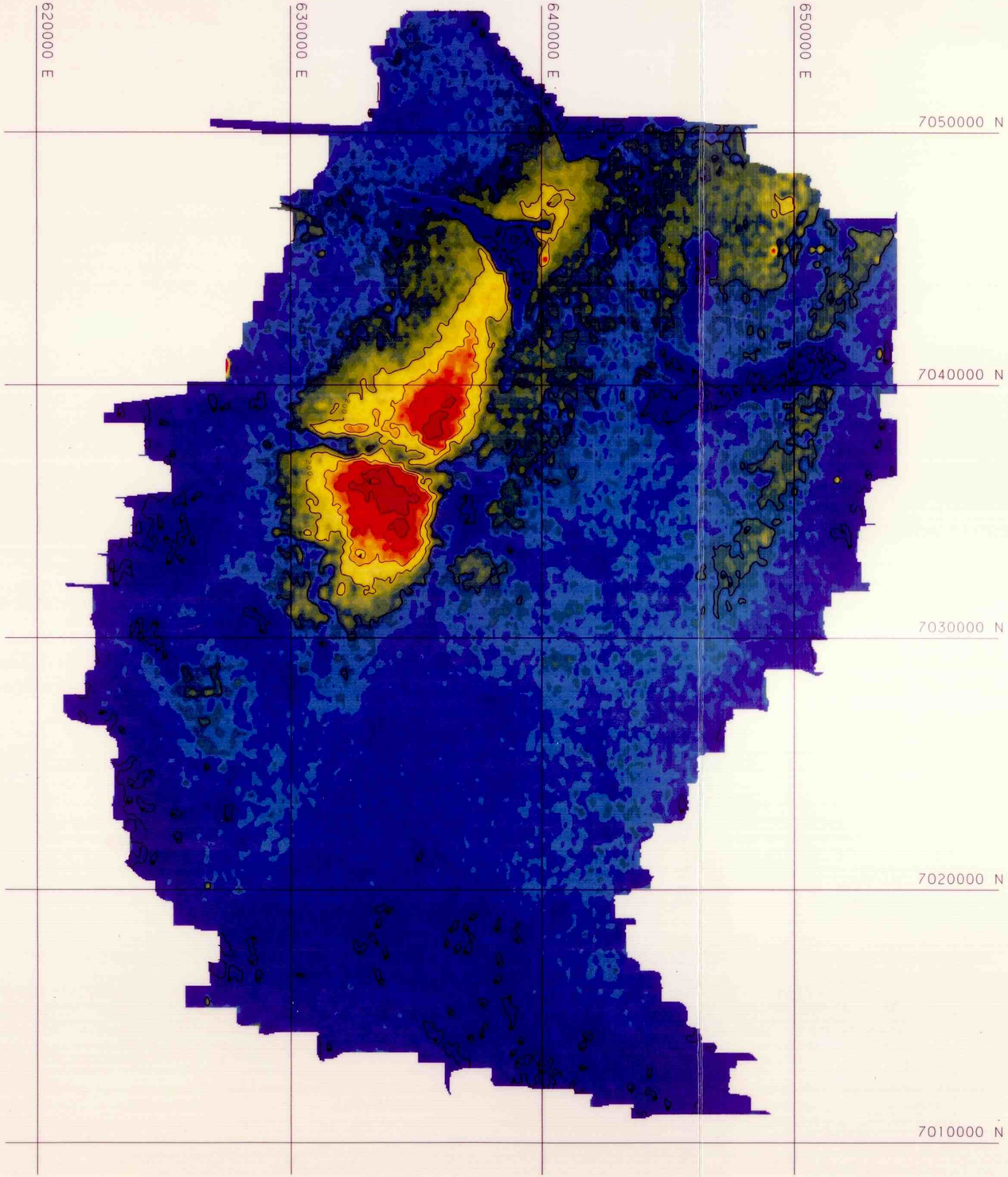
The stripping ratios are thus as follows:

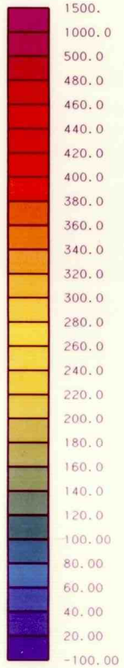
	U/Th = 0.31	U/K = 0.070	U/Cs = 0
Th/U = 0.070		Th/K = 0.02	Th/Cs = 0
K/U = 0.72	K/Th = 0.34		K/Cs = 0
Cs/U = 3.85	Cs/Th = 2.62	Cs/K = 0.52	

APPENDIX C
REDUCED COLOUR REPRODUCTIONS OF 1:100,000 SCALE MAPS

The following maps are copies reduced from the 1:10000 scale maps produced with this report.

Map 93.045-01	Meråker Cesium Counts
Map 93.045-02	Meråker Cesium Concentration
Map 93.045-03	Grong/Snåsavatnet Cesium Counts
Map 93.045-04	Grong/Snåsavatnet Cesium Concentration





NORGES GEOLOGISKE UNDERSØKELSE
Geological Survey of Norway

N

Cesium Tellinger

Cesium 137 kanalen
(i tellinger / sekund)

Kartkonturene er multiplum av
de som er listet nedenfor
100 t/s
500 t/s

Farger - distribuert etter en fargeskala
som vist til venstre

NORD TRØNDELAG PROGRAMMET

RADIOMETRI CESIUM KANALEN
KONTURER OG FARGER

MERAAKER

NORD TRØNDELAG

MÅLESTOKK 1 : 100.000

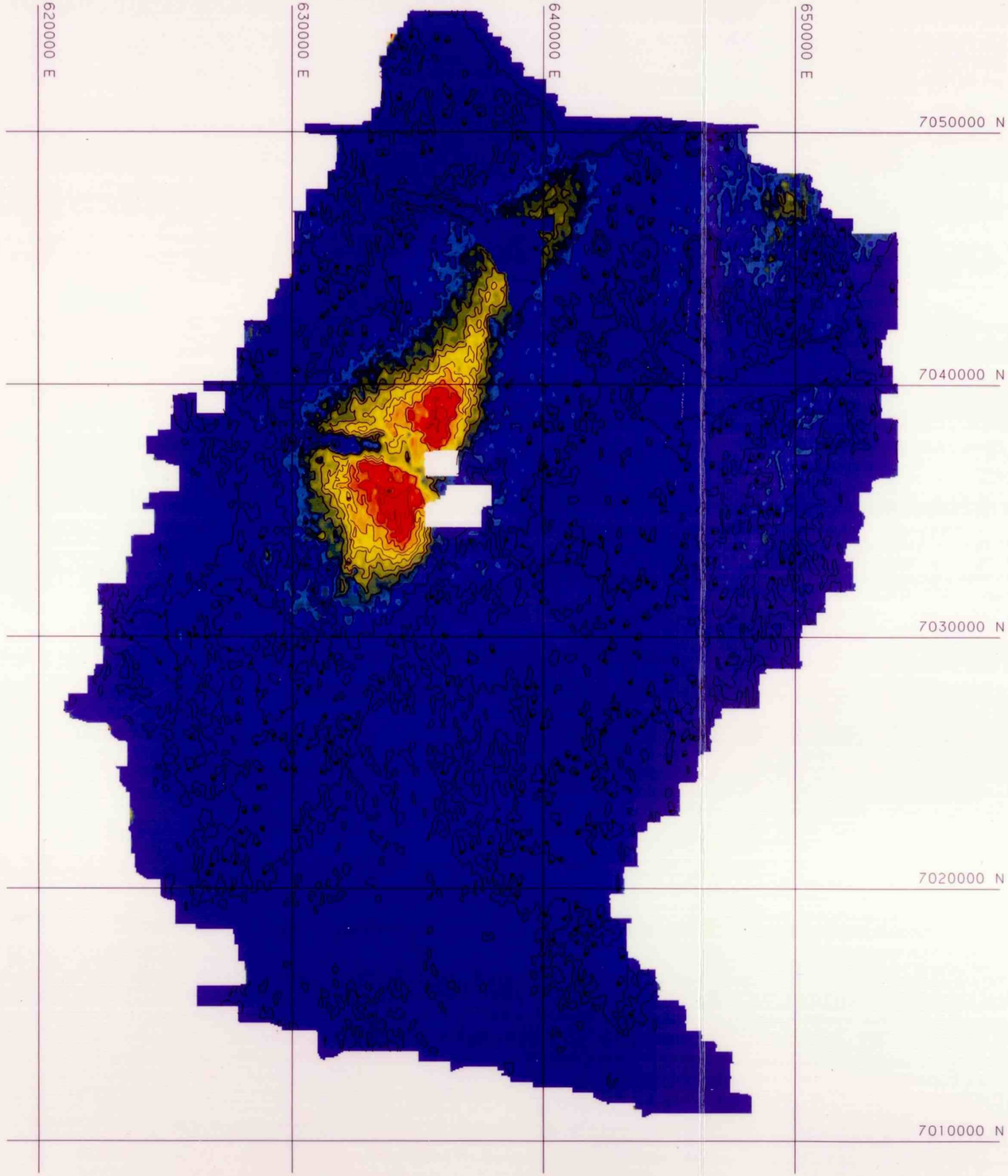
0 1000 2000 5000 10 KILOMETERS

NORGES GEOLOGISKE UNDERSØKELSE
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
TEL 07 - 90 40 11

DATO: JUNI 1991

TEGNING NR: 93.045-01

KARTBLAD NR:
1722 II/III
1721 I/II/III/IV



NORGES GEOLOGISKE UNDERSØKELSE
Geological Survey of Norway

N

Cesium Konsentrasjon

Cesium 137 bakkekonsentrasjon beregnet i 1986 (KBq/m/m)

Kartkonturene er multiplum av de som er listet nedenfor

4 KBq/m/m
20 KBq/m/m

Farger - distribuert etter en fargeskala som vist til venstre

NORD TRØNDELAG PROGRAMMET

TILSYNLATENDE 1986 CESIUM KONSENTRASJON KONTURER OG FARGER

MERAAKER

NORD TRØNDELAG

MALESTOKK 1 : 100.000

0 1000 2000 5000 10 KILOMETERS

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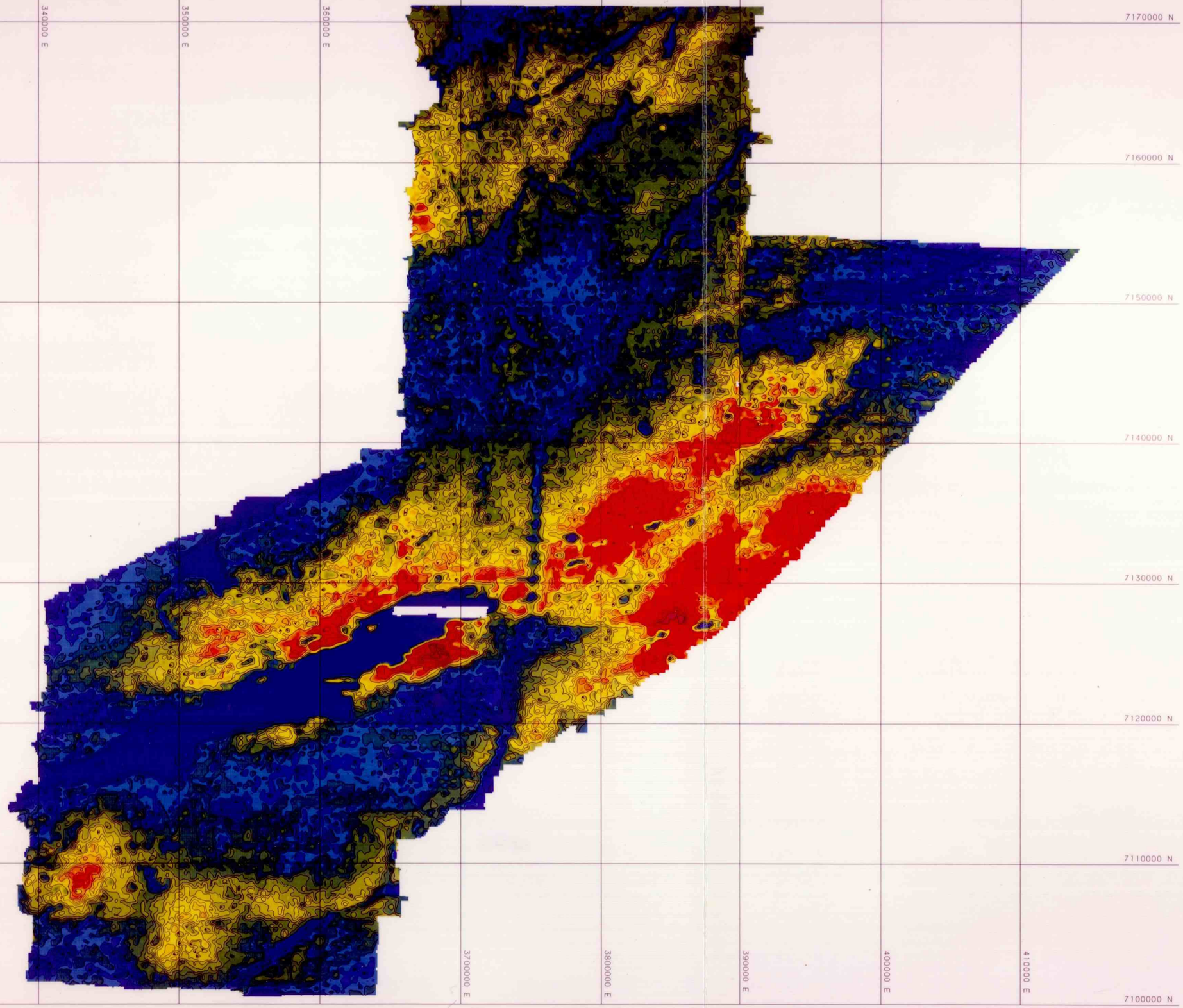
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
TEL 07 - 90 40 11

DATO: JUNI 1991

TEGNING NR: 93.045-02

KARTBLAD NR: 1722 I/III 1721 I/II/III/IV



NGU
NORGES GEOLOGISKE UNDERSØKELSE
Geological Survey of Norway

N

Cesium kanalen

Radiometri kaliumkanalen
i tellinger per sekund

Kartkonturene er multiplum av
de som er listet nedenfor

25 cps (1 KBq/m²eq)
100 cps (4 KBq/m²eq)
500 cps (20 KBq/m²eq)

Farger - distribuert etter en fargeskala
som vist nedenfor

1500.
1250.
1000.0
900.0
800.0
700.0
600.0
500.0
475.0
450.0
425.0
400.0
375.0
350.0
325.0
300.0
275.0
250.0
225.0
200.0
175.0
150.0
125.0
100.00
75.00
50.00
25.00
0.00

NORD TRØNDELAG PROGRAMMET

RADIOMETRI CESIUM KANALEN
KONTURER OG FARGER

SNAASAVATNET/GRONG/ANDERSJOEN

NORD TRØNDELAG

MALESTOKK 1 : 100.000

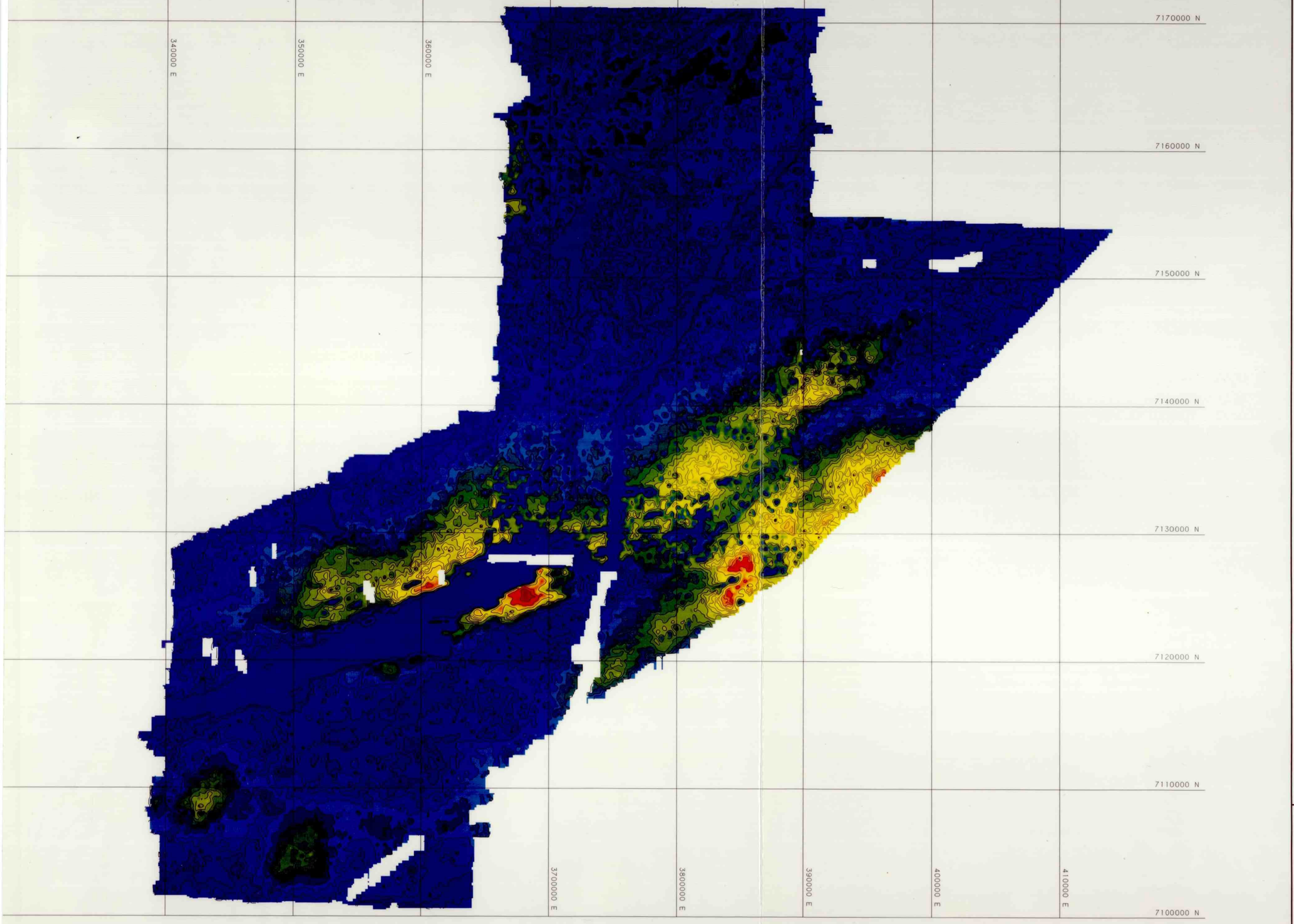
0 1000 2000 5000 10 KILOMETERS

NORGES GEOLOGISKE UNDERSØKELSE
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
TEL 07 - 90 40 11

DATO: FEB 1993

TEGNING NR: 93.045-03

KARTBLAD NR: 1823 I/II/III/IV 1723 I/II 1824 I/II



NGU
NORGES GEOLOGISKE UNDERSØKELSE
Geological Survey of Norway

N

Cesium Konsentrasjon

Cesium 137 bakkekonsentrasjon beregnet i 1986 (kBq/m/m)

Kartkonturene er multiplum av de som er listet nedenfor

100 cps (4 kBq/m/m)
500 cps (20 kBq/m/m)

Farger - distribuert etter en fargeskala som vist nedenfor

130.0
120.0
110.0
100.00
96.00
92.00
88.00
84.00
80.00
76.00
72.00
68.00
64.00
60.00
56.00
52.00
48.00
44.00
40.00
36.00
32.00
28.00
24.00
20.00
16.00
12.00
8.00
0.00

NORD TRØNDELAG PROGRAMMET

TILSYNLATENDE 1986 CESIUM KONSENTRASJON KONTURER OG FARGER

SNAASAVATNET/GRONG/ANDERSJOEN

NORD TRØNDELAG

MALESTOKK 1 : 100.000

0 1000 2000 5000 10 KILOMETERS

NORGES GEOLOGISKE UNDERSØKELSE
Leiv Eirikssons vei 39
N-7040 TRONDHEIM
TEL 07 - 90 40 11

DATO: FEB 1993

TEGNING NR: 93.045-04

KARTBLAD NR: 1823-I/II/III/IV 1723-I/II 1824-III