GEOLOGINEN TUTKIMUSLAITOS
GEOLOGICAL SURVEY OF FINLAND

TUTKIMUSRAPORTTI N:o 7
REPORT OF INVESTIGATION No. 7

M. Ketola, E. Piiroinen and R. Sarikkola:

On feasibility of airborne radiometric surveys for uranium exploration in Finland

Tiivistelmä: Aeroradiometristen mittausten käyttömahdollisuuksista uraaninetsinnässä Suomessa

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Ketola, M., Piiroinen, E. and Sarikkola, R. 1975: On the feasibility of airborne radiometric surveys for uranium exploration in Finland. Tiivistelmä: Aeroradiometristen mittausten käyttömahdollisuuksista uraaninetsinnässä Suomessa. *Geological Survey of Finland, Report of Investigation No. 7.* 43 pages, 5 figures, 1 table, 31 plates.

The aim of this paper is to estimate, on the basis of the results of a helicopter-borne test survey made in 1972, the feasibility of airborne radiometric surveys for uranium exploration in Finland. The survey covered two separate areas, of which the smaller (225 km^2) is located in southern Finland, north of Porvoo, and the larger (600 km^2) in western Lapland, in the frontier area comprising the communes of Kittilä, Kolari and Muonio. The results prove that airborne radiometric surveys made with advanced instrumentation can give useful information for uranium exploration as well as geological mapping in Finland. For the successful accomplishment of an airborne radiometric survey, even in favourable conditions, it is essential that the parameters of the survey system be correctly calculated. Dominant factors in determining the final result are a sufficient detector volume and high-quality data processing. In prospecting for uranium, an investigation of the survey area should be made to work out the local geomorphology and Quaternary geology and the results should be taken into consideration also when the bounds of the flight area are drawn.

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ISBN 951-690-032-1

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1. INTRODUCTION

Radiometric surveys by airplane or helicopter are mainly used for geological mapping and uranium exploration. The γ-radiation recorded during these surveys is mainly due to radioactive materials, such as uranium, thorium and potassium, contained in the upper layers of the ground close to the surface. Airborne radiometry is often carried out in connection with aeromagnetic and electromagnetic surveys. As for the feasibility of the airborne radiometric method in Finland, some restrictions are imposed by the vegetation, the waterway conditions, the northern location of the country and, most of all, the deposits overlying the bedrock. The conditions affecting radiometric operations in Finland have been described by, among others, Ketola and Sarikkola (1973).

In Finland, interest in airborne radiometric surveys has not been so great as in airborne magnetic and electromagnetic surveys, which have been frequently undertaken. The Geological Survey of Finland started systematic airborne magnetic surveys at a flight altitude of 150 m as early as 1951, and three years later the airborne system was supplemented with electromagnetic equipment. The national airborne geophysical general mapping project, about which information has been given in publications by, among others, Puranen (1959) and Marmo and Puranen (1966), was completed in 1972. Airborne magnetic and electromagnetic low-altitude surveys on a large scale at altitudes of 30-80 m for exploration for sulfide and iron ores have been carried out by, for example, the Outokumpu Co., the Rautaruukki Co. and, in recent years, the Finnprospecting Co., which does contract work. The Geological Survey of Finland started airborne magnetic, electromagnetic and radiometric surveys in 1972. In these measurements, the crystal volume of the spectrometer detector is approximately 27 l.

The aim of this report is to estimate the feasibility of airborne radiometric surveys for uranium exploration in Finland on the basis of the results gained through the air-

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borne test survey carried out by Prakla-Seismos GmbH, Federal Republic of Germany, in the summer of 1972. The previous results had not been positive. Airborne radiometric surveying has been used to some extent as an auxiliary means of geological mapping by, for example, the Geological Survey of Finland, the Rautaruukki Co. and the Outokumpu Co. In connection with its aerogeophysical general mapping program, the Geological Survey of Finland has since 1956 carried out measurements of total radiation, using a crystal detector with a small volume. These measurements have given some information on the radioactivity of the ground surface. The Rautaruukki Co., which in 1968 acquired an airborne γ-spectrometer, has benefited greatly from the data obtained by the method in the surveys, for example, of the Sokli carbonatite massif located in eastern Finland, at Savukoski. Also earlier efforts had been made to determine the feasibility of low-altitude airborne radiometric surveying in uranium exploration in Finland through test surveys carried out by, among others, the Geological Survey of Finland, the Outokumpu Co. and the Atomienergia Co. In 1968 the Swedish Terratest Ab carried out an airborne spectrometric test survey for the Outokumpu Co. over the Koli area, but the results from the standpoint of uranium exploration remained rather insignificant. The survey was made with a Jet-Ranger helicopter at a flight speed of approximately 100 km/h at an altitude of 30 m. The spectrometer had one 5 x 6" NaJ(Tl)-crystal detector. The survey data were recorded on magnetic tape, but the data processing and the drawing of the contour maps were partly done manually.

The idea of a new test survey came after thorough study of the literature at the beginning of 1971. In the low-altitude spectrometric surveys made in Finland, no tests had yet been carried out involving the use of a large detector and the digital recording of data, a method that had become generally adopted towards the end of the 1960s. In practice, it had also proved difficult to satisfy the needs of regional exploration for uranium by means of reconnaissance ground measurements, especially in Lapland. The test survey was regarded as justified, since it would lead to better knowledge of the feasibility of the expensive equipment under the conditions prevailing in Finland, especially, since the results yielded by previous tests from the standpoint of uranium exploration had been close to negative. The spectrometric method was preferred, whereby, according to the available literature, a large-volume crystal detector was required. Digital recording of the survey data and processing as well as contouring by computer were favoured - in addition to the previously published information - by the positive results obtained in Finland since 1968 in the digital recording of airborne magnetic and electromagnetic survey data and their processing by computer. These results have been examined in the paper published by Ketola, Laurila and Suokonautio (1972). Since it proved impossible to find a contractor able to carry out an airborne test survey in accordance with the specification in the summer of 1971, the project was postponed till the summer of 1972. The German company Prakla-Seismos GmbH was commissioned to do the survey.

The airborne survey, the costs of which were borne jointly by the Ministry of Commerce and Industry and the Outokumpu Co., was carried out by helicopter between July 1 and August 30, 1972, and the contractor handed over to the Outokumpu Co. the measurement results in the form of contour maps together with the data-processing reports in February of 1973. The survey was directed by Dr. D. Boie and Mr. H. Wecker, M.Sc. (Eng.), as representatives of Prakla-Seismos GmbH. Mr. Wecker headed the flight group in Finland.

2. SURVEY AREAS

The airborne test survey was made over two separate areas, the locations of which are shown in Fig. 1. One of the areas, measuring 225 km^2 (15 x 15 km), is located in southern Finland, north of Porvoo. The larger area, 600 km^2 (20 x 30 km), was selected from northern Finland, in the frontier zone

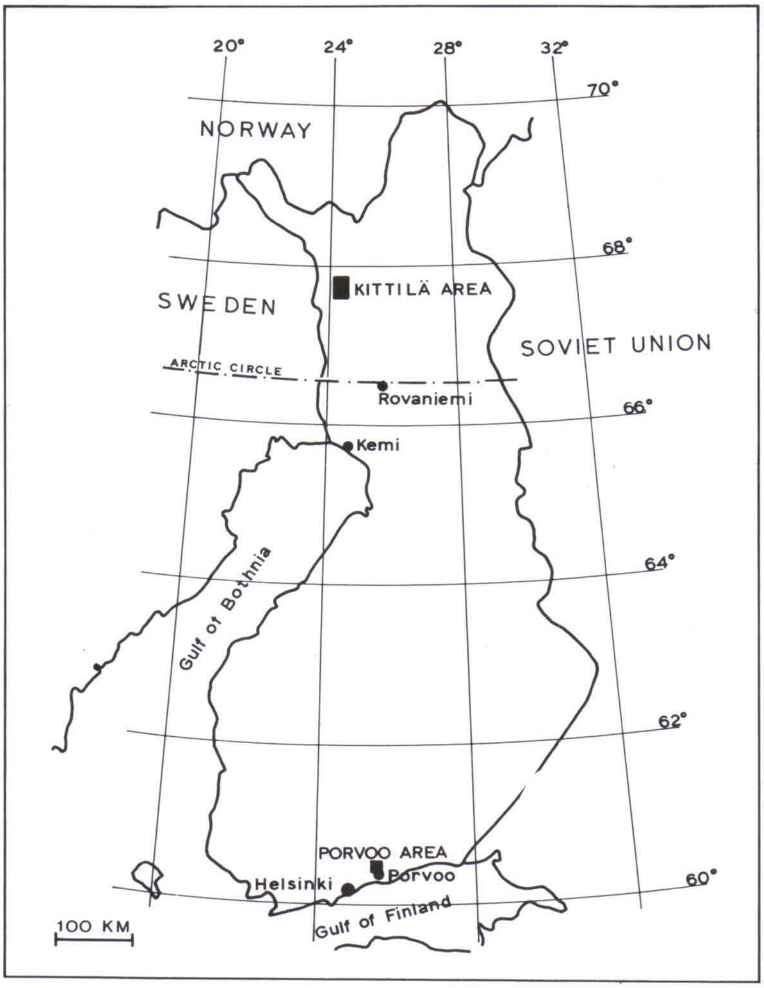
20°
24°
28°
32°
70°
NORWAY
68°
KITTILÄ AREA
SWEDEN
SOVIET UNION
ARCTIC CIRCLE
Rovaniemi
66°
Kemi
64°
Gulf of Bothnia
62°
PORVOO AREA
Porvoo
Helsinki
60°
Gulf of Finland
100 KM

Fig. 1

comprising the communes of Kittilä, Kolari and Muonio. In the following the southern area is called the Porvoo area (Area II) and the northern one, the Kittilä area (Area I). In the Porvoo area, where 1 850 line-km were flown, the survey was carried out in a north-south direction. Over Kittilä ca. 5 000 line-km were flown in an east-west direction.

Several small uranium deposits are known in both areas, as are some uranium-bearing boulders and boulder trains too. In these areas also several radiometric ground surveys had been made before the airborne surveys were started. In the Porvoo area these ground surveys, which were carried out by, for instance, the Imatran Voima Co. and the Outokumpu Co., were mainly in the nature of reconnaissance. From the Kittilä area, where the Outokumpu Co. has been carrying on systematic exploration in recent years for uranium, ample material for comparison has been available, including radiometric contour maps drawn after the results of ground surveys made in summer and winter at different line intervals. In the southern part of the Kittilä survey region, there are the fells known as Aakenus-, Pyhä-, Lainio- and Kesänkitunturit which rise about 500-600 m above sea level. The biggest relative differences in elevation in the area are ca. 300 m.

3. TECHNICAL SPECIFICATIONS FOR THE AIRBORNE TEST SURVEY AND THE PRINCIPLES OF THEIR SELECTION

The results of the aerospectrometric surveys made by the Geological Survey of Canada, the Atomic Energy of Canada Ltd. and the Geofoto Services, Inc., (Texas Instruments) in 1967-1971 using large detectors have had a particular influence on the planning of the airborne test survey described in this report. In the planning work, profitable use was made of the information given in the following articles: Darnley, Bristow and Donhoffer (1969), Foote (1969), Darnley (1970, 1971), Duval and Cook (1970), Denham (1970), Darnley and Grasty (1971) and Gregory (McPhar). Furthermore, the selection

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of the equipment and the measuring techniques applied was decisively influenced by the correspondence and personal discussions between the authors and Dr. D. Boie, representing Prakla-Seismos GmbH, and Vice President G. Denham, of the Exploranium Corporation of Canada (Geometrics).

The most important technical specifications for the spectrometric helicopter-borne test survey were the following:

1. Helicopter: Alouette III.
2. Gamma spectrometer: The DGRS-1000 spectrometer made by Exploranium, to which the digital ADVG-recording system constructed by Prakla-Seismos GmbH was attached.
3. Volume of the crystal detector: 16.6 l, i.e., 9 pcs of 6 x 4" NaJ(Tl)-crystals. Additionally, a crystal detector, volume 5.54 l (3 pcs of 6 x 4" NaJ(Tl)-crystals), shielded against ground radiation by a lead disk, was installed for recording of the bismuth (Bi 214) radiation in the air (atmospheric channel).
4. Flight altitude: 50 m.
5. Flight speed: 100 km/h.
6. Line separation: 125 m.
7. Measuring channels: potassium (K40), uranium (214), thorium (Tl208), the atmospheric channel and the total radiation.
8. Recording of radiometric survey data: digital recording at 1/3 s intervals. Analogue recording using 2 s integration time constant.
9. Analogue and digital recording of flight altitude. Altimeter Honeywell, HG 9050.

10. The data processing and contouring were carried out by computer. In connection with the data processing, a correction for altitude variations, Compton scatter and atmospheric radiation was made. Later, to reduce random fluctuations, the corrected data have been smoothed by parabolic application. By means of a comparison of the corrected, non-smoothed data with the smoothed data through the application of an experimentally selected threshold value, the statistically reliable local anomalies have been separated. The contour maps have been drawn on a scale of 1 : 10 000 from values obtained by adding up the smoothed data and local anomalies.

11. Photomosaics on a scale of 1 : 10 000 were used in the navigation. Before starting the flight lines had been marked on the photos. Since the navigation proved to be more difficult than had been expected, a compensated gyro compass was installed into the helicopter to facilitate flight over forested areas.

12. The flight line was photographed at 5/3 s intervals on 35 mm film with a single-frame camera. A Robot camera with a 24-mm wide-angle objective was used, the scale being 1 : 2 100. At intervals of 20 s (every 12th photo), the time, the number of the photo as well as the number of the profile were recorded on the rim of the film to synchronize the positioning and measurement results. In practice, a 5/3 s photo density corresponds to a 100 per cent coverage on the flight path.

The flight speed, altitude and crystal detector volume have an essential effect on the results of airborne radiometric surveying. On the basis of previous ground surveys, many uranium-bearing boulders and small uranium deposits, i.e., "almost point-like" radiation sources, were known to exist in the survey areas; and since their localization was the primary aim of the test survey, efforts were made in selecting the parameters to make the instrumentation effective in detecting such radiation sources. Thus it was natural to fly the survey at a low altitude and, within the limits permitted by the cost estimates, with a small line separation, at a low flight speed and using a large detector. To cut down the costs, it would have been natural to use an airplane for the test survey. In the southern part of the Kittilä survey area, there are marked differences in elevation, which during flights cause climb angles of up to 20-25^{o}. From previous experience gained under equivalent circumstances in airborne magnetic and electromagnetic surveys, it was known that these elevation differences make it difficult to carry out surveys with an airplane. When big differences in elevation occur, it is difficult to maintain a constant flight speed and terrain clearance during the flight. Despite the fact that, in connection with data processing, a correction for altitude is made in the results of the radiation measurements, it is not sensible to make an excessive correction on account of its approximate nature. In view of these factors, a decision was made to carry out the test flight with a helicopter. However, a helicopter with suitable space inside and the required payload capacity was not available in this country, so the Alouette III used in the test flight had to be brought from Germany, where the instrumentation was also mainly installed.

Taking into consideration the topography and the vegetation in both test survey areas, it would have been possible to use a slightly smaller terrain clearance than 50 m. Since, in radiometric measurements, the flight altitude must be in proportion to the used line separation, at a low flight altitude a dense line separation should be used to enable one to record to the greatest possible extent the radiation from the areas falling between the lines. On the other hand, a higher flight altitude contributes to better navigation accuracy and flight safety. It was known in advance that navigation by means of photomosaics would be rather inaccurate, so when the line separation was selected, attention had to be paid also to the restrictions set by the accuracy in positioning; in other words, the line separation had to be wide enough to ensure that the deviations in navigation and the uncertainty in the flight path recovery would not be unreasonable with respect to the network of lines used. Since the survey costs per unit area on the network of lines used and the price of each line-km during the test survey is high, it was necessary to take the cost level into consideration when determining the line intervals. The experiences gained from the airborne magnetic low-altitude surveys carried out by the Outokumpu Co. showed that when navigating with photomosaics, the smallest possible line interval is 125 m in making airborne low-altitude surveys in Finland.

It is advisable to use a low-flight speed in airborne radiometric measurements, where the number of counts to be recorded increases per unit distance. With a helicopter, somewhat better than with an airplane, it is possible to carry out the survey at a low speed and to maintain a constant speed, even in difficult topographic conditions. With an Alouette III helicopter, the test survey could have been accomplished also with a slightly lower flight speed than 100 km/h. A lower flight speed would, however, have led to increased flight time and thus to higher costs.

Radon emanated from earth decays in the air into bismuth. To record Bi 214-radiation, a 5.54 l crystal detector, which was shielded against ground radiation by a lead disk, was installed into the helicopter (atmospheric channel). On the basis of the information in the literature the experiment was regarded as necessary since Foote (1969), Darnley and Grasty (1971) as well as Darnley (1971), among others, lay stress in their articles on the importance of recording the Bi 214-radiation in the air and regard it as a correction to the measurement results of the uranium channel.

Darnley (1971) has compared the airborne spectrometric survey systems used by the Geological Survey of Canada (GSC)

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by calculating the relative counts per distance unit, that is, the so-called figures of merit for the various survey systems. For each airborne spectrometric system, two figures of merit are given, and in this way the ability of the survey system to localize radiation sources of large and small area is visualized. A figure of merit of 100 has been applied to GSC´s Skyvan-mounted spectrometer system with a crystal volume of 50.1 l (12 pcs of 9 x 4" NaJ(Tl)-crystals), flight speed of 193 km/h and flight altitude of 122 m. The figures of merit for the airborne spectrometric systems used in test flights ordered by Outokumpu Co. from Prakla-Seismos GmbH and Terratest Ab are given in the table on this page together with the figures of merit for the GSC´s systems.

T a b l e 1.

Flight System	Detector		Flight	Flight	Fig. of Merit	
	Size	Volume	Alt.	Speed	Large Area	Small Area
GSC-mapping	12(9x4)	50.1	122	193	100	100
" -recon.	6(9x4)	25.0	152	225	36	28
" -helicopter	3(5x5)	4.83	76	48	51	99
Prakla-Seismos	9(6x4)	16.6	50	100	98	382
Terratest	1(5x6)	1.93	30	100	13	123

As the table shows, when the figure of merit was estimated, attention was paid only to the crystal volume (l), flight altitude (m) and flight speed (km/h). The dead time of the spectrometers included in the comparison was so short that it had no effect on the number of recorded counts. The quality of the data processing was naturally not measurable so that it could have been regarded as a parameter when the figure of merit for the whole system was calculated. The figures of merit reveal that the test survey system of Prakla-Seismos GmbH is sensitive to radiation sources with small areas.

Towards the end of the surveys in the Kittilä area, a sub-area of 5 x 5 km was flown over with a smaller detector of 5.54 l being used to investigate the effect of the crystal volume on the measurement results (additional program). The other parameters of the survey system, the flight path recovery and the data processing were in this supplementary survey the same as in the regular test survey, when the crystal volume was 16.6 l.

The results of the test survey have been presented on a scale of 1 : 10 000 in the form of contour maps. But the results of the atmospheric channel are drawn up in profile form. As an experiment, U/Th, U/K and Th/K ratios were determined from the results yielded by certain sub-areas to make it possible to estimate whether the ratios with respect to uranium exploration reveal information not to be drawn directly from the channel maps. The results arrived at through the test survey and the information obtained have been examined in the concluding part of the report in the light of certain contour maps of both the Porvoo and Kittilä survey areas.

4. ON THE GEOLOGY OF THE SURVEY AREAS

4.1 General

In the survey areas, the Precambrian bedrock is better exposed than on the average in Finland. In northern Finland, the rocks are frequently broken by frost into extensive fields of rubble, i.e. accumulations of rocks. The fell tracts are to a large extent covered by these accumulations, which in this report have also been regarded as exposures. The topographic differences observed in the survey areas are mainly caused by the bedrock. The southern flight area represents a typical clearly bounded Finnish landscape, where the variations in elevation vary between 30 and 60 m, whereas the fells in Lapland rise to an elevation of 400-600 m above sea level and the variations in elevation in the Kittilä area are as much as 300-400 m. The relief of the bedrock is levelled by the overburden, which consists mainly of various tills, but also of glaciofluvial formations and, especially in southern Finland, of glacial clay deposits.

The radiation to be recorded in airborne radiometric measurements comes mainly from the layer consisting of the few uppermost decimeters of the overburden or bedrock exposures. Therefore, the conditions for successful application of radiometric measurements in uranium exploration include a sufficient occurrence of exposures in the survey areas as well as the existence of possible residual sediments and an almost local type of moraine.

4.2 Porvoo Survey Area

Characteristic of the Porvoo survey area are clay soils brought under cultivation, which account for 40 per cent of the area. The relatively flat landscape is broken up by forested moraine or esker formations and patches of rock, which in many places rise above the fields. Rock exposures take up 10 per cent and till beds 35 per cent of the area. The thickness of the till layer is 2-3 m. The surface layer has been washed and the pebbly fraction mainly carried relatively short distances (1-2 km). The eskers are low in the area and do not completely level the topographic differences in the bedrock; but there are plenty of exposures also in the esker area. The map of the bedrock in the survey area is shown in Fig. 2. To a variable extent, the area belongs to the zone of migmatitic rocks of sedimentary and volcanic origin. On the average, the grade of migmatization is high. The granite penetrating into the schists and the metavolcanic rocks is, in most cases, coarse, even pegmatitic. Even in large granite

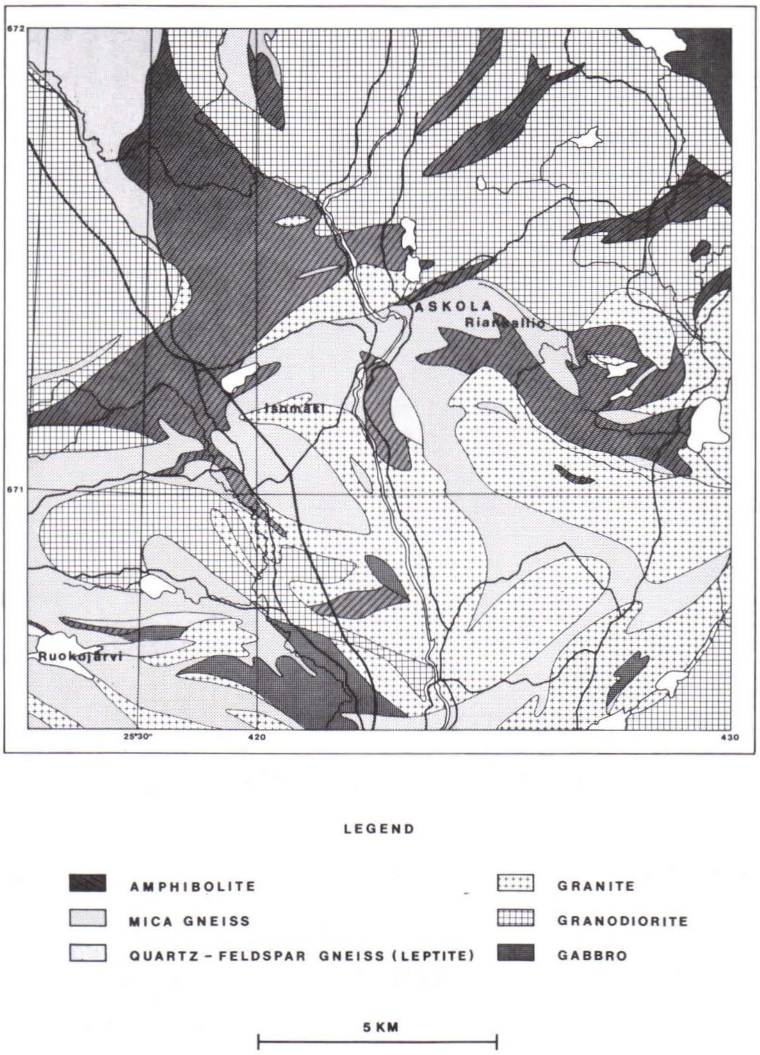
672
671
ASKOLA
Ruokojärvi
25°30'
420
430
LEGEND
AMPHIBOLITE
MICA GNEISS
QUARTZ - FELDSPAR GNEISS (LEPTITE)
GRANITE
GRANODIORITE
GABBRO
5 KM

Fig. 2

areas, relics of schists are always to be found. The colour of the granite often varies according to the paleosome, that is, the schist material. In basic schist surroundings, the granite is pale; in leptitic surroundings, reddish. The migmatite zones of the Askola area have been depicted in plate 1 and the exposures in the area have been classified into three groups in accordance with the dominating material. The effect of the paleosome material can be observed, not only in the colour but also in the mineral composition of the granite. For example, the granite intruding certain schist horizons has assimilated aluminium, which comes up in the form of high garnet contents.

Uranium and/or thorium appear in the Porvoo area mainly in connection with the granite or schist relics and accumulations of mica in the granite. The schist material connected with the deposits is in general highly variable. Both amphibolitic and aluminous schists occur in connection with uranium deposits, the most common of them are lump-like concentrations with small surface areas ($< 1\ m^2$). Small pegmatite veins have been met with where uranium and/or thorium appear as highly homogenous disseminations. In connection with the ground surveys, boulders have also been found that indicate the existence of pitchblende veins. In the 1950s, small uranium deposits were experimentally hoisted in Askola.

4.3 Kittilä Survey Area

The Kittilä area is divided into two different types of landscape, the peneplain and the fell zone. The peneplain area, which is typical of Central Lapland, as a whole, with elevations of cs. 200-250 m above sea level, is gently sloping landscape. The ground is covered with glacial drift and bogs[1)] cover over 20 per cent of the total area. Exposures

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[1)] The term swamp is used in the plates.

with accumulations of rocks account for only about 1.5 per cent. Residual sediments (weathered rock) occur, but covering only 1-3 per cent of the area. Some 70 per cent of the peneplain surface is sandy till 2-4 m thick on the average.

The fell zone rises steeply 200-400 m above the plain. The timber line is 350-400 m above sea level, and above the timber line the fell rubble weathered by frost is only partly covered by a thin moss layer.

The geological map of the flight area is shown in Fig. 3. The bedrock is divided into three stratigraphical groups: the granites and granitic gneisses, the schist area and the quartzites, and the so-called Kumpu-quartzite, which composes the youngest part. In the west and southeast, the bedrock consists of granites and migmatitic gneisses, which are well exposed. The most characteristic rocks of the peneplain area are the basic volcanic rocks, the greenstones; but in the southeastern part of the area, there are also acidic volcanic rocks. Rocks of sedimentary origin are mica schist and phyllite. The fells are made up of quartzite, the layers of which are inclined $40-80^{o}$. The lowest part of the ca. 1.5-2 km thick quartzite is a typical basal conglomerate. The degree of weathering of the material gradually increases upwards in the horizons deposited on top of the conglomerate. The topmost horizons are made up of orthoquartzite or intercalating ortho- and sericite-quartzite.

Uranium has been found in the area in conformable lenses in the sericite-quartzite horizon. The most important deposits are on the Kesänki fell. In the peneplain area, uranium appears in the form of patches in connection with albitite veins or narrow carbonate pitchblende veins in the phyllite. It has been established in the radiometric ground measurements that in the peripheral granites, the background values of the uranium and thorium radiation are relatively high. Both uranium and thorium have been found also in patchy concentrations.

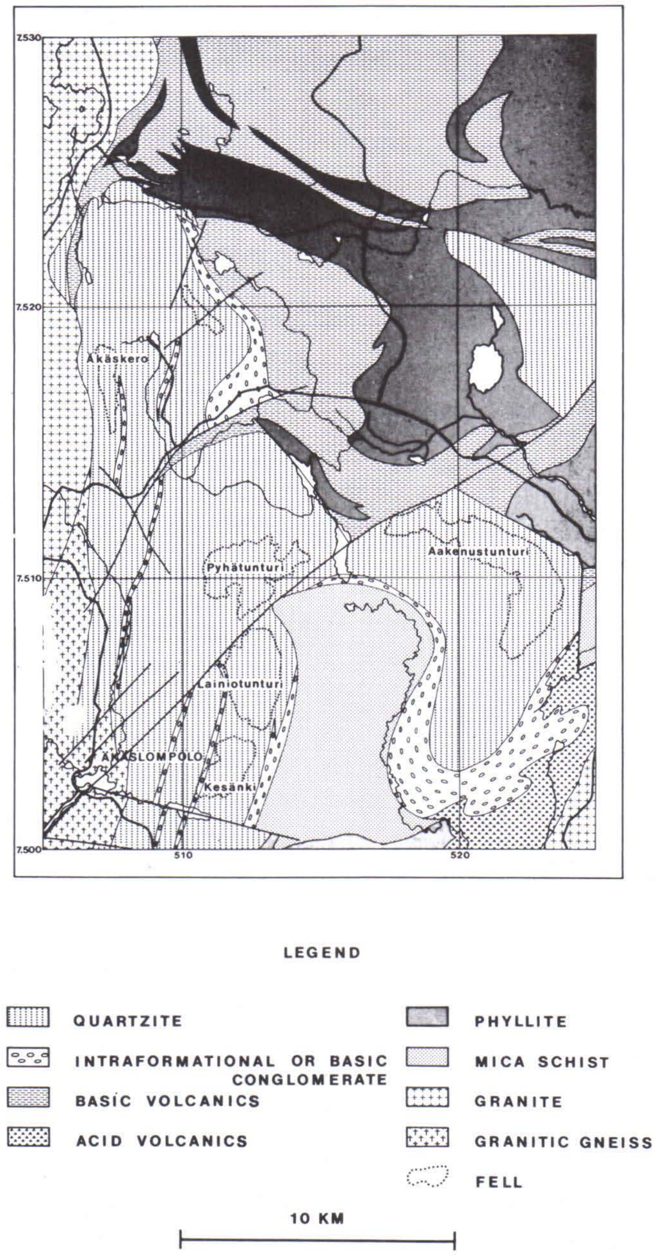
7.530
7.520
7.510
7.500
510
520
Äkäskero
Pyhätunturi
Aakenustunturi
Lainiotunturi
ÄKÄSLOMPOLO
Kesänki
LEGEND
QUARTZITE
INTRAFORMATIONAL OR BASIC CONGLOMERATE
BASIC VOLCANICS
ACID VOLCANICS
PHYLLITE
MICA SCHIST
GRANITE
GRANITIC GNEISS
FELL
10 KM

Fig. 3

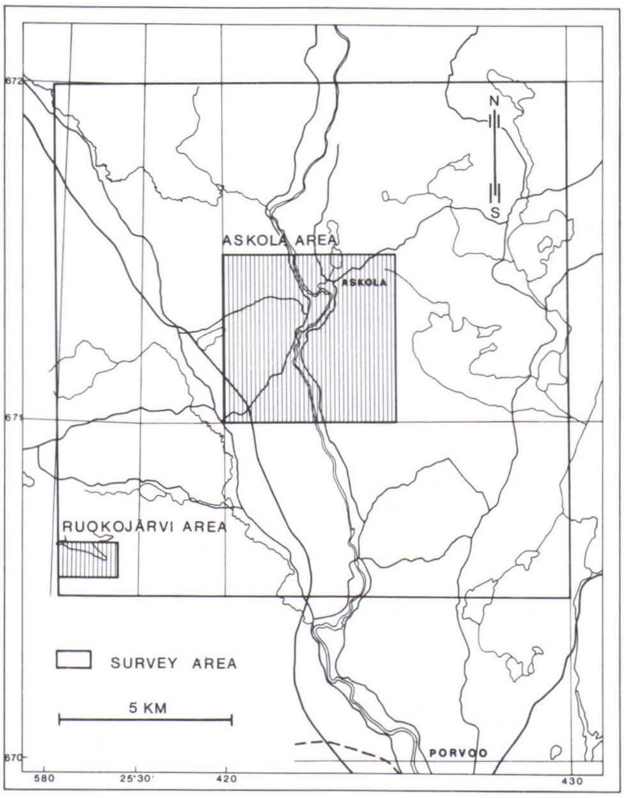
ASKOLA AREA
ASKOLA
RUOKOJÄRVI AREA
SURVEY AREA
5 KM
PORVOO
N
S
672
671
670
580
25°30'
420
430

Fig. 4

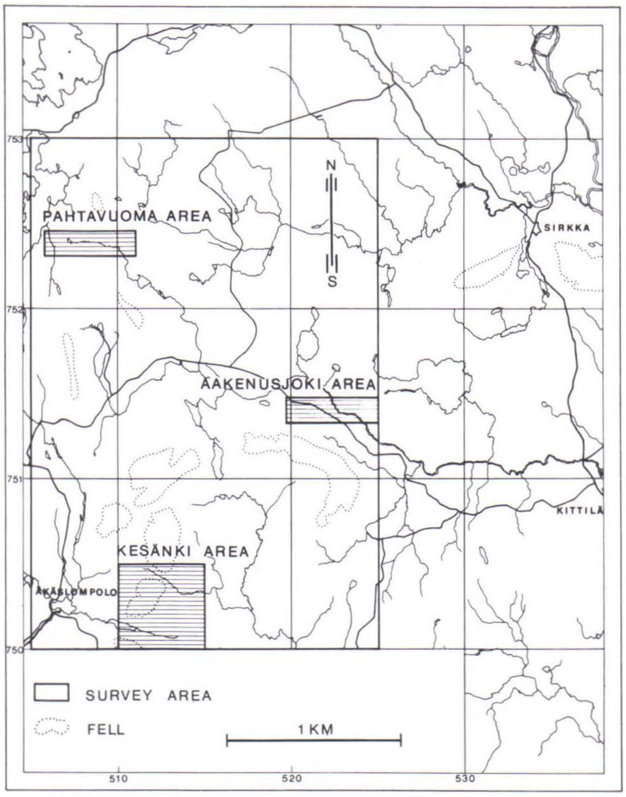
PAHTAVUOMA AREA
ÄAKENUSJOKI AREA
KESÄNKI AREA
SIRKKA
KITTILÄ
ÄKÄSLOMPOLO
SURVEY AREA
FELL
1 KM
N
S
753
752
751
750
510
520
530

Fig. 5

5. ON THE RESULTS OF THE AIRBORNE TEST SURVEY

5.1 General

To illustrate the feasibility of the airborne spectrometric method, examples have been selected from the results of the airborne test survey over the Porvoo and Kittilä areas. The Askola and Ruokojärvi localities serve as examples of the Porvoo survey area and the Kesänki, Pahtavuoma and Aakenusjoki areas as examples of the Kittilä survey area. They are marked on the index maps in Figs. 4 and 5. In these survey areas, which differ considerably in their geology from each other, also the causes of the anomalies differ. The average radiation level in the Porvoo area is much higher than in the Kittilä area. Besides the total radiation and channel maps, a topographic map of the sample areas has been generally presented, since it has been established that the results of airborne radiometric low-altitude surveys are in distinct correlation to the variations in the types of geomorphology and vegetation. In addition to the foregoing, there have been marked on the topographic maps the exposures, the most important radioactive boulders, the radioactive wells, etc. Since in the Kittilä area and, to some extent, in the Porvoo area as well, considerable differences in elevation occur, the elevation contour lines have also been marked on the topographic maps of these areas. On the basis of the airborne test survey results, ground surveys were undertaken in both of the survey areas in the summer of 1973. These survey data and the radiometric material on the ground surface available from earlier years have been used to draw some sample maps which have been compared with the results of the airborne test survey. An attempt has been made to describe the limited scope of the airborne spectrometric method in the light of the uranium occurrence of Pahtavuoma, which does not appear on the aeroradiometric maps. On the other hand, an example has been chosen of the geochemical anomaly in the Aakenusjoki area, where no uranium occurrence is known. The sample areas represent, however, fairly typical Finnish conditions, which, from the standpoint of adopting the airborne spectrometric method, are in general relatively unfavourable. The total radiation and channel maps measured on the Kesänki area by a 5.54 l detector as well as the ratio maps of the Askola area prepared as an experiment are included in the report. The intention has been to present the sample maps selected to represent each sub-area on the same scale to make it easier for the reader to compare them.

5.2 Porvoo Survey Area

5.2.1 Askola Area

In the total radiation and channel maps of the Askola area presented in plates 3-6, a large number of anomalies can be seen. When the contour maps are compared with the topographic map in plate 1, it can be observed that the anomaly variations are in correlation with, for example, the forest, field, bog and lake areas. In the patches of woods, which rise above the fields, there are many rock exposures or the bedrock is covered by till of almost local origin. In the fields, the thickness of the glacial drift varies considerably probably from a few meters to several dozen meters. The bogs and lakes are visible on the contour maps as distinct minimum points. The radiation of the fields, especially as shown by the total radiation and potassium map, is considerably stronger than that of the forested areas. This may be due to the circumstance of clays occurring in the fields or to the shielding effect of the forest, which has been studies by Kogan, Nazarov and Fridman (1971). When the contour maps are analyzed, it would seem important, from the standpoint of uranium exploration, to separate the forested tracts from the fields in the Askola area, since the radioactive axposures are located in the forests. The exposures marked on the topographic map, which appear abundantly in the Askola area, are in general visible as points denoting total radiation maxima. The necks of fields between the woods cause, however, maximum anomaly values, which may not be easily distinquishable from the exposure anomalies without topographic comparison.

Comparison of the channel maps reveals that the sources of radiation are different by nature. The Askola quarry and tailing area, which was in experimental operation in the 1950s and the location of which is presented in plate 1, appears as a strong anomaly in the total radiation, uranium and thorium maps. The uranium mineralization of Askola is combined with the schist relic, bearing abundant garnet in granite and pegmatite. In the Riankallio area, located north of Askola, the anomaly can be seen on the total radiation and uranium map. On the thorium map, no distinct anomaly appears, and on the potassium map, only a weak correlation is to be observed. The exposures in the Isomäki area cause a strong anomaly on the total radiation and uranium map. In general, it can be said that most of the anomalies appearing on the total radiation map can also be found on the uranium map; so the Askola area must be regarded as uranium-critical.

The bedrock in the Askola area is conspicuously migmatitic. An attempt has been made to classify the types of migmatites in plate 1 according to the contents of granite material and the types of granites observed in the exposures. On the basis of the findings of the airborne survey, reconnaissance scintillometric measurements have been carried out on certain exposures in the area, and the results are given in plate 2. The exposures with the strongest radiation are located in the areas of granite and veined gneiss. In the exposures in the areas of amphibolite and mica gneiss, the radiation level of the migmatizing granite material is relatively low. Between the radiation observations in plate 2 and the total radiation map in plate 3, there is a good correlation when the variations of terrain and vegetation are regarded in the examination with reference to plate 1. The exposures with the strongest radiation seem to occur in areas with a highly variable schist part and this variation also crops up as a variation in the granite types.

The ratio maps of UOTh, Th/K and U/K were drawn experimentally from the results of the airborne test survey. The ratio maps of the Askola area were prepared on the basis of both corrected and uncorrected results. The maps prepared from corrected results are reproduced in plates 7-9. A correction for altitude variations, Compton scatter and atmospheric radiation has been made in the results, the random fluctuations have been smoothed by parabolic application, and the statistical reliability of the results has been tested with a threshold value. The ratio maps shown in plates 10-12 were prepared on the basis of uncorrected values, the random fluctuations of which were smoothed by parabolic application and the statistical reliability of which was tested with a threshold value. The values 70 x U/Th, 500 x Th/K and 300 x U/K were used in drawing the contour maps. A comparison of the maps shows that a better result is arrived at by calculation of the ratios from the corrected than from the uncorrected values. Defects have appeared in the computer program. The count rate of the channels remains, e.g., as to lakes and bogs, so small that the result is not statistically reliable. These points give unreliable ratio values, since the ratio is computed by the program irrespective of the count rate, so when the ratio maps are examined, they should be compared with the topographic map in plate 1.

The ratio maps facilitate classification of the anomalies. The Askola quarry and tailing area can be localized by means of a strong anomaly on the U/K and Th/K maps. On the U/Th map, there appears no anomaly, since uranium-thorium ore is involved. In the Riankallio and Isomäki areas, the anomaly appears only on the U/Th and U/K maps. The fields come up distinctly anomalous on the U/K and Th/K maps, especially on the Th/K map. It is easier to utilize the U/Th results even without a topographic map, since the background radiation in the woods and fields is almost the same in plate 7. The ratio maps clarify in some cases the information obtained from the channel maps. The anomaly zone in the north-south direction, situated x = 6710-6713, y = 423.2, appears more distinctly on the U/K map than on the channel maps. There are several exposures in the anomaly zone. The eskers depicted in the topographic map of plate 1 cause on the U/Th map wide and shallow anomalies, which are, however, "disturbed" by the anomaly variations caused by the radioactive exposures and the different types of terrain. On the other hand, the errors are also accentuated on the ratio maps. Evidence of this is given by the long anomaly zones parallel with the flight lines on profiles y = 420.250, 420.625 and 420.700. The incorrect anomalies are probably due to the fact that tieing the results of the lines to the general radiation level has not turned out successfully enough.

In plate 13, there is a profile map showing the results from the atmospheric channel in the Askola area. Between the uranium map in plate 5 and the anomalies of the map in plate 13, a distinct correlation is to be observed. A correlation can also be seen when the anomalies of the thorium map are examined in plate 6. The Askola quarry and tailing area and the Riankallio and Isomäki areas appear anomalous on the map in plate 13. As to lakes and bogs, there are distinct minima on the map of the atmospheric channel. The result shows that a part of the radiation obtained with the shielded detector comes from the ground. It is possible that, as regards the uranium, what is involved is a primary radiation that comes from below in an oblique direction and passes by the lead shield; and, as regards the thorium, it is the Compton scattering in the air and the detector crystals (ca. 7 per cent of the radiation penetrates the lead shield beneath the detector). So the method of measuring the radiation of bismuth in the air during the test survey can not be regarded therefore as satisfactory when airborne radiometric low-altitude surveys are made at a flight altitude of 50 m. The daily variations in the Bi 214-radiation in the air would seem to be slight during the survey.

5.2.2 Ruokojärvi Area

In the Ruokojärvi area, which is located in the south-western part of the Porvoo survey area, a strong anomaly was established by the survey. The contour maps of the Ruokojärvi area, which prove that the anomaly was caused by a source of uranium-thorium, have been depicted in plates 14 and 15. To the north from the anomaly, a minimum can be seen in the contour maps at the point of Ruokojärvi, the location of which appears in the topographic map in plate 16. On this map, elevation contour lines have been drawn showing that the anomaly is located on top of a hill, which rises some 30 m above the level of the lake and is fairly well exposed. It was established in the ground surveys that the Ruokojärvi area is a strongly granitized mica-gneiss-amphibolite zone, where the proportion of granitic material is more than 60 per cent. The granite contains uranium and thorium in bodies of various sizes. The outcrops of the largest bodies, which in general are poorer in their contents, are about 20 m^2 wide. The location of the uranium-thorium bodies and rock exposures have been marked on the topographic map in plate 16.

In the Ruokojärvi area, a ground survey was carried out by scintillometer with a point density of 20 m and a line separation of 100 m to clarify the details of the airborne radiometric anomaly. The survey data have been presented in the form of a profile map in plate 16. In connection with the data processing, the continuous weighted averages of three sequential points have been calculated from the original data. The profile map has been drawn on the basis of the weighted averages. In the smoothed scintillometric data, plenty of anomaly maxima can be established that also indicate that the airborne radiometric anomaly is caused by several radiation sources of variable size. A detailed survey was carried out in the exposed area to clarify the mode in which the uranium and thorium occur by taking samples from a small test area with a point density of 10 x 10 m and having them analyzed in the laboratory. In the sampling area, which has been marked on the topographic map, a ground survey was also carried out with a point density of 10 x 10 m using a DISA 400-spectrometer. The results of the spectrometric ground survey and the contents analyzed from the samples, between which a clear correlation exists, are given in plate 17. The results of the spectrometric ground survey confirm the picture obtained by geological mapping and sampling, according to which uranium and thorium are present in the Ruokojärvi area in the granitic neosome as bodies varying in content and size. The way uranium and thorium occur in the Ruokojärvi area can probably be generalized to apply also to the largest part of the anomaly areas found in the Porvoo survey area.

5.3 Kittilä Survey Area

5.3.1 Kesänki Area

The Kesänki area represents a typical fell district in western Lapland. The Kesänki fell, as marked on the topographic map in plate 18, is located in the middle of the area. The northern edge of Ylläs fell and the southern part of Lainio fell belong to the area. The highest summits of the fells rise approximately 500-600 m above sea level, so the biggest differences in elevation in the Kesänki area are roughly 300 m. The fells are bare of trees and covered with rubble produced by frost; the rubble is of almost local origin. There are not many actual exposures, and they are marked on plates 18 and 19. The uranium bodies in the area are found in thick formations in combination with arcose-, sericite- and ortho-quartzites. The most remarkable of there uranium bodies is the uranium mineralization of Kesänki fell, which occurs in association with sericite-quartzite. Vertical strata bound uranium lenses are rather clearly indicated by the covering block accumulations. The locations of the uranium-bearing boulders met with in the Kesänki area, which are mainly concentrated on the eastern edge of Kesänki fell, close to the timber line, appear in plate 18. The thickness of the rubble varies between 3 and 30 m. The average U-content of the uranium-bearing boulders lying close to outcrops is about 0.05 per cent, and the boulder density is ca. 0.2 boulders/m^2. The size of the radioactive blocks varies, but is in general < 0.1 m^3. The radiometric and geophysical measurements carried out in the Kesänki fell area have been dealt with by Ketola and Sarikkola (1973).

In connection with the regional uranium surveys, a reconnaissance scintillometric ground survey was also carried out in the Kesänki area with a point density of 20 m and line intervals of 500 m. In the results of this survey, which are presented in the form of a profile map in plate 19, a strong anomaly is established in the northwestern corner of Kesänki fell on profile x = 7504. The anomaly is mainly caused by block accumulations, indicating the outcrops of uranium mineralization. In connection with the data processing, the continuous weighted averages of three sequential pints were computed from the results of the ground survey, on the basis of which the profile map in plate 19 was drawn. In the profile map, other positive anomalies can also be observed, as on the northern edge of Ylläs fell, at the point where the uranium-bearing exposure is located, and at certain points on the exposures and block accumulations found along the eastern and western edges of Kesänki fell. A reconnaissance scintillometry carried out at broad line intervals gives a fairly good preliminary idea of the radiation variations in the area. Under the conditions prevailing in Lapland, however, this kind of systematic survey, as combined with exploration for boulders, is an inconvenient and expensive method. One of the purposes of the test survey was to explore the possibilities of replacing such surveys with airborne measurements.

The contour maps drawn on the basis of the results of the test survey, in which a detector of 16.6 l was used, are reproduced in plates 20-23. The radioactive block accumulations, which indicate outcrops of the Kesänki uranium mineralization, cause a strong anomaly in the total radiation and uranium maps. On the thorium map in plate 23, no anomalies appear at the point of the large block accumulations. The analyses carried out with the blocks covering the Kesänki uranium mineralization and outcrops show that the mineralization and outcrops show that the mineralization does not contain thorium. Neither does any anomaly appear on the potassium map in plate 21; therefore the discriminative ability of the spectrometry must be regarded as good. The correlation between the scintillometric ground survey in plate 19 and the map on total radiation in plate 20 is close; hence at least in this case, information was obtained by the airborne survey comparable with the reconnaissance profile measurements. In the total radiation and channel maps, the lakes and bogs marked on the topographic map are visible as minimum points. In the eastern part of the area, which is geologically the basement quartzite formation, the effect of the wide boggy district comes clearly to the fore in the maps. The uranium map, where there are fewer anomalies, may be regarded as somewhat more distinctly delineated than the total radiation map. For example, the afore-mentioned anomaly caused by the Kesänki accumulations of uranium-bearing blocks is most clearly to be seen on the uranium map. On the eastern edge of Kesänki fell, in the total radiation, potassium and thorium maps, an anomaly zone is to be seen, one caused by a coarse arcosite quartzite. The arcosite does not come up in the uranium map, owing to the good discriminative ability of the spectrometry.

Towards the end of the surveys, the Kesänki area was overflown with a smaller crystal detector of 5.5 l being used to investigate the influence of the crystal volume on the survey results. The other parameters of the system, flight path recovery and data processing, were the same in this supplementary survey as in the actual test survey, when the crystal volume was 16.6 l. The maps measured with the smaller detector are show in plates 24-27. The intensity of the anomalies in the maps measured with a detector of 16.6 is in general approximately 2.5-3.5 times higher than the values in the maps measured by a detector of 5.54 l. The correlation between the total radiation maps measured with a larger and smaller detector in plates 20 and 24 is fairly close. The uranium and thorium maps in plates 26 and 27 are considerably more "restless" than the corresponding maps in plates 22 and 23, which were measured with a larger detector. Several point-like uranium and thorium anomalies were registered with a smaller detector, but they have no correlation to the results measured with a larger one. The influence of the boggy tract in the eastern part of the area becomes rather weakly evident from the maps in plates 26 and 27.

5.3.2 Pahtavuoma Area

The maps showing the total radiation, the uranium and the thorium in the Pahtavuoma area are presented together with the topographic map in plates 28 and 29. The eastern part of the maps is geologically a greenstone-phyllite area while the western part consists of syenitic granite. The western part of the Pahtavuoma copper deposit, in connection with which uranium-bearing carbonate veins have been found, is only partly visible in the maps of the area described. Before the test survey, one uranium-bearing group of veins had been exposed underneath a till layer about 1-1.5 m thick. The location of the exposed point becomes evident from the topographic map in plate 28. Corresponding veins were met with in the drilling also in the area located somewhat to the west. In the excavations carried out after the test survey, such veins were found also on the surface of the bedrock.

In the ground surveys no clear hints of uranium in, e.g. boulders, were found in the neighbourhood of the outcrops of the veins. A clear anomaly, though a small one, was localized by radon measurements in the western part of the area with vein occurrences.

An anomaly registered in the airborne spectrometric survey appears on the total radiation and uranium maps at the uranium pit exposed through excavations. The excavation, which measures about 20 x 50 m, causes a very strong anomaly on the uranium map. The nearest flight line in an east-west direction touches the exposed area directly on the southern edge. The anomaly can be seen on the total radiation map, but it might not be easy to recognize its significance exclusively on the basis of the total radiation results, in which the variations caused by dry and moist ground are marked. The western uranium veins, which were buried during the survey under an overburden 2-5 m thick, do not come to light at all in the airborne spectrometric results. There are granite exposures in the western part of the Pahtavuoma area. In the westernmost exposure, there is a narrow, breaking vein of pitchblende, which causes a clear anomaly on the uranium map. The total radiation of the granite exposures in the western part of the area, as measured on the ground, is roughly double compared with the other dry parts of the area.

5.3.3 Aakenusjoki Area

The Aakenusjoki area is boggy and the bedrock is mainly covered by drift. The eastern part of the area consists of sandy esker material. The results of the survey are given in plates 30 and 31. On the total radiation map and, especially, in the eastern part on the uranium map, a strong anomaly appears, and it has been established that the anomaly is caused by a radioactive well, with the surrounding uranium-bearing soil and peak located along the riverside of Aakenusjoki. The location of this radioactive area, which is about 50 m^2 wide, has been marked on the topographic map. The ground measurements carried out with a scintillometer prove that the average intensity of the total radiation in the surroundings of the well on the radioactive area is ca. 10 x the background of the dry area and the maximum intensity ca. 40 x the background. The bedrock in the area is phyllitic, and no uranium bodies are known in the close vicinity of the anomaly.

Two patches of pegmatite-granite boulders have been marked on the topographic map, on the points of which the intensity of the total radiation is about 5-10 x the background. These boulders and, obviously, also the surrounding till beds cause clear anomalies on the uranium map of plate 31. The boulders cannot be localized by reference to, for instance, the total radiation map. In the Aakenusjoki area, the uranium map gives considerably better information than the total radiation and other channel maps do.

6. CONCLUSIONS

On the basis of the airborne spectrometric results, ground surveys were carried out in both areas in the summer of 1973. These survey data as well as the geological and ground-radiometric comparative material obtained from the exploration areas in previous years and the experiences gained through the test survey justify, in the authors´ opinion, the following estimations and conclusions:

1. The results of the airborne surveys prove that airborne radiometric measurements made with advanced instrumentation can yield useful information for uranium exploration and geological mapping in Finland. The anomalies appearing on different channels have made it possible to localize a large part of the known radiation sources, which are significant from the standpoint of uranium exploration. A condition for the successful execution of the measurements is that the parameters of the survey system be correctly decided and that the processing of the data meets with sufficient quality requirements. Successful execution of an airborne radiometric survey intended for uranium exploration calls for a clarifying survey of the geomorphology and Quaternary geology, the results of which should

be taken into account also when limiting the flight area.

2. The advantages of spectrometry become clear when the results are examined. Channel maps have made it possible to classify anomalies. Several examples can be found to prove the discriminative ability of spectrometry. In the Kittilä area, the uranium and thorium maps have proved important from the standpoint of uranium exploration. When examining airborne spectrometric maps on low-altitude surveys, it is advisable to pay special attention to the variations in the terrain and vegetation in the survey area. Most of the anomalies marked on the uranium maps appear, however, also on the total radiation maps. The measurement of total radiation with a sufficiently large detector could be regarded as a preliminary method of uranium exploration in Finland. The equipment and data processing are cheaper and simpler than in spectrometric measurement.

3. When estimating in the light of the airborne radiometric results the influence of crystal volume, flight altitude, flight speed and line separation on the obtained data, it should be kept in mind that the purpose of the test survey was primarily to determine the feasibility of the advanced instrumentation for airborne radiometric measurements in uranium exploration in Finland. To achieve the best possible survey system, efforts were made to select the parameters within the expenditure limits so that the line intervals would be sufficiently dense and the figure of merit profitable for small radiation sources.

   It proved in practice to be the right decision to select the helicopter. The experience gained throught the test survey, especially over the southern part of the Kittilä area, where steep fell sides appear, proved that in these conditions it would not have been possible to maintain with an airplane a constant flight speed and altitude as could be done with a helicopter. Even the Alouette III helicopter was forced to operate over the steepest fell slopes within the utmost limits of its rate of ascent, because on warm summer days there is strong turbulence of the air over the slopes. In the Porvoo survey area it would obviously not have been necessary to use a helicopter; in a great part of Finland it would therefore, for financial reasons, be more economical to carry out airborne radiometric surveys with airplane.

In the Kittilä survey area, where the average radiation intensity generally is small, "point-like" anomalies appear, especially on uranium maps, having been established by observation values of only one or two flight lines. Ground surveys have in many cases established that such point-like anomalies are significant from the standpoint of uranium exploration; a dence network of lines in the low-altitude airborne radiometric surveys would therefore seem to be of importance.

A low flight altitude and reduced flight speed do not alone guarantee a useful result, not even if the minimum values permitted by the practice were used. As regards the final result, the most dominant factors are the detector volume and the quality of the data processing. A reliable result on the uranium and thorium channels seems to require a large crystal detector. In case the standard of the data processing is insignificant, the large detector is even more important.

4. The high quality of the data processing has had a decisive influence on the positive result obtained

with the test survey. The processing time required for computing the results and the costs thus arising were high, though only the results of four channels were to be converted into contour maps. The required data processing time is naturally dependent on various factors, most of all on the computer used, the programs, the number of corrections made in the results, the method of smoothing out the random fluctuations, the interpolating method, etc. The costs of data processing are in proportion to the information to be computed: in other words, the greater the number of channels computed, the higher the costs. Hence it would be advisable to optimize the computer costs and the amount of information obtained from the material to be processed.

5. One of the most difficult problems to crop up during the survey involved navigation. The photomosaics used in the navigation were partly too old, especially on the Kittilä survey area. Several aerial photos had to be combined to draw the navigation maps. On account of the defectiveness of the photomosaics and the monotone terrain, very few reliable fiducial points are to be found in certain places. Especially in the beginning, navigation over forested and boggy streches caused enormous difficulties; but in the course of the flights, the compensated gyro compass mounted in the helicopter facilitated to some extent the work of the pilot and the navigator.

   Since it is aimed to carry on low-altitude airborne surveys by various geophysical methods on a fairly large scale in Finland, it would be advisable to start an investigation of the possibilities to improve navigation and positioning. Automatization of navigation and improvements of positioning accuracy are important not only in facilitating the localization of aero-anomalies in the ground, but they also have a decisive significance from the standpoint of data processing.

6. In connection with the processing of airborne survey data, ratio maps have been calculated only experimentally. Defects have appeared in the computer program. The ratio maps facilitate the classification of anomalies, and these maps can be used to clarify the information obtained from the channel maps. The possibilities of using ratio maps should be investigated further.

   Though airborne radiometric surveys in the future will probably be of great importance for regional uranium exploration in Finland, they should be regarded as only one method of regional exploration, owing to the deposits overlying the bedrock and to the waterway conditions, as has been pointed out in the summaries by, for example, Ketola (1972) and Ketola and Sarikkola (1973). In the areas, where airborne radiometric surveys have been made, geochemical methods applicable also to regional surveys should be used. For use of these supplementary methods, Finnish waterway conditions provide good possibilities in several cases.

7. ACKNOWLEDGMENTS

The authors are pleased to acknowledge their debt to Mr. Pauli Isokangas, director of the Exploration Department of the Outokumpu Co., and Dr. D. Boie and Mr. H. Wecker, M.Sc. (Eng.), of Prakla-Seismos GmbH, for their valuable cooperation in the investigations described in this paper. Besides the authors, Mr. V. Suokonautio, M.A., of theExploration Department of the Outokumpu Co., participated in the planning of the test survey. He served as an expert in preparing the ADP-questions for data processing. Mr. M. Tenhola, B.A., carried out the field investigations for the Askola map sheet. Our thanks are also due to Professor H. Stigzelius, director of the Geological Survey in Finland, for accepting this paper for publication in the series of Reports of Investigations. The financial support granted by the Ministry of Commerce and Industry upon the recommendation of the Atomic Energy Council of Finland made it possible to realize this eventful and comparatively expensive project.

T i i v i s t e l m ä :

AERORADIOMETRISTEN MITTAUSTEN KÄYTTÖMAHDOLLISUUKSISTA URAANINETSINNÄSSÄ SUOMESSA

Aeroradiometrisia mittauksia, joita suoritetaan lentokoneella tai helikopterilla, käytetään hyväksi etupäässä uraaninetsinnässä ja geologisessa kartoituksessa laajoja alueita tutkittaessa. Näissä lentomittauksissa rekisteröitävä γ-säteily aiheutuu pääasiassa maan ylimpien pintakerrosten sisältämistä radioaktiivisista aineista. Aeroradiometrinen mittaus suoritetaan joko skintillometrilla tai spektrometrilla, joissa säteilyn rekisteröinti tapahtuu tallium-aktivoidulla natriumjodidikidedetektorilla. Totaalisäteilyä mittaavalla skintillometrilla ei eri aineista lähtevää γ-säteilyä voida erottaa toisistaan. Spektrometrisilla laitteilla on mahdollista analysoida säteilyn laatua ja tehdä päätelmiä säteilylähteen uraani-, torium- ja kaliumpitoisuudesta.

Aeroradiometrisen menetelmän käytölle Suomessa asettavat rajoituksensa kasvillisuus, vesistöolosuhteet, maan pohjoinen sijainti sekä ennen kaikkea kallioperän päällä oleva irtomaakerros. Kallioperästä tuleva γ-säteily absorboituu

jo alle 0.5 m matkalla irtomaakerroksessa. Suomessa kiinnostus aeroradiometrisiin tutkimuksiin on ollut laimeampaa kuin magneettisiin ja sähköisiin aeromittauksiin, jotka antavat käyttökelpoisia tuloksia suoraan kallioperästä myös järvien kohdalla ja irtomaakerroksen peittämillä alueilla. Geologinen tutkimuslaitos on tehnyt vuodesta 1956 lähtien 150 m lentokorkeudesta aerogeofysikaalisen yleiskartoituksen yhteydessä totaalisäteilymittauksia, jotka antavat jonkin verran tietoa maankuoren radioaktiivisuudesta. Matalalla lentokorkeudella (30-50 m) suoritettavien aeroradiometristen mittausten soveltuvuutta uraaninetsintään on pyritty 1950- ja 1960-luvuilla selvittämään eri yhtiöiden toimesta. Kokemukset eivät kuitenkaan ole olleet positiivisia.

Aeroradiometrisen mittauksen antamiin tuloksiin vaikuttavat olennaisesti mm. lentonopeus, lentokorkeus ja detektoritilavuus. 1950- ja 1960-luvuilla tehdyissä koelennoissa käytettiin pieniä, alle 2 litran detektoreja. Tämän vuosikymmenen alussa oli etenkin Kanadassa, jossa maa- ja kallioperä ovat lähes samanlaiset kuin Suomessa, alettu aerospektrometrisissa korkealentotutkimuksissa kokeilla suuren detektoritilavuuden käyttöä. Koska suurta detektoria sekä 1960-luvun loppupuolella yleistynyttä digitaalista mittaustulosten rekisteröintiä ja tulosten tietokonekäsittelyä ei kirjallisuustiedoista päätellen oltu vielä kokeiltu aerospektrometrisissa matalalentotutkimuksissa, päätti Outokumpu Oy tilata saksalaiselta Prakla-Seismos GmbH-yhtiöltä tällaisen koelennon kahdelle tutkimusalueelle. Lentomittaus, jonka kustannuksista vastasi kauppa- ja teollisuusministeriö Outokumpu Oy:n kanssa, tehtiin kesällä 1972.

Tutkimusalueista pienempi (225 km^2) sijaitsi Etelä-Suomessa Porvoon pohjoispuolella ja suurempi (600 km^2) Länsi-Lapissa Kittilän, Kolarin ja Muonion kuntien alueella. Molemmat koelentoalueet olivat geologialtaan aikaisempien tutkimusten perusteella melko hyvin tunnettuja ja niiltä oli löydetty useita pieniä uraaniesiintymiä sekä uraanipitoisia lohkareikkoja. Pohjoisen lentoalueen eteläosassa sijaitsevat mm. Aakenus-, Pyhä-, Lainio- ja Kesänkitunturit, jotka kohoavat

n. 500-600 m merenpinnan yläpuolelle. Suurimmat suhteelliset korkeuserot alueella ovat n. 300 m. Korkeuserojen ollessa suuret on säteilymittauksen kannalta tärkeiden tasaisen lentonopeuden ja vakiolentokorkeuden säilyttäminen lentokoneella hankalaa, joten koelento päätettiin tehdä helikopterilla. Suomesta ei kuitenkaan ollut saatavissa sisätiloiltaan ja kantokyvyltään sopivaa helikopteria, joten koelennolla käytetty Alouette III jouduttiin tuomaan Saksasta, missä mittauslaitteiden asennus myös pääosiltaan tapahtui. Mittauslentokorkeus oli 50 m ja -nopeus n. 100 km/t. Linjaväli oli 125 m ja detektoritilavuus 16.6 l. Lennolla rekisteröitiin totaalisäteily sekä säteily uraani-, torium- ja kaliumkanavilla. Kokeiluluontoisesti oli helikopteriin asennettu alta lyijysuojattu detektori, jonka tilavuus oli 5.54 l, radonin hajoamisesta ilmassa muodostuvan vismutin (Bi214) aiheuttaman säteilyn rekisteröimiseksi. Suunnistus ja lentoreitin paikannus suoritettiin ilmakuvien avulla. Tuloskäsittely korjauslaskuineen tapahtui tietokoneella sama-arvokäyräkartoiksi.

Koelentoalueilla saadut tulokset osoittavat, että Suomen olosuhteissa aeroradiometriset tutkimukset uusimmilla mittauslaitteistoilla antavat käyttökelpoista tietoa uraaninetsintää ja geologista kartoitusta varten. Suuri osa koelentoalueilla tunnetuista uraaniesiintymistä ja lohkareikoista voitiin paikallistaa lentomittaustulosten perusteella. Mittausten onnistumisen edellytyksenä on, että ne suoritetaan oikein mitoitetulla lentosysteemillä ja mittaustulosten käsittely täyttää riittävät laatuvaatimukset. Uraaninetsintään tarkoitetun mittauksen kannalta on tarkoituksenmukaista, että lentoalueilla on suoritettu pinnanmuodostusta ja kvartäärigeologiaa selvittävä tutkimus, jonka tulos otetaan huomioon myös lentoalueita rajattaessa.

Spektrometrisen mittauksen käyttökelpoisuuden uraaninetsinnässä on koelentotulos selvästi osoittanut. Kanavakarttojen avulla voidaan suorittaa anomalioiden luokittelua ja tehdä päätelmiä säteilylähteiden uraani-, torium- ja kaliumpitoisuudesta. Suurin osa uraanikartoilla todetuista anomalioista esiintyy kuitenkin myös totaalisäteilykartoilla.

Preliminäärisenä uraaninetsintämenetelmänä voitaisiin Suomessa ajatella totaalisäteilymittausta riittävän suurella detektorilla. Laitteisto ja tuloskäsittely on totaalisäteilymittauksessa halvempi ja yksinkertaisempi kuin spektrometrisessa mittauksessa.

Matala lentokorkeus ja alhainen lentonopeus eivät yksinomaan takaa aerospektrometrisissa mittauksissa käyttökelpoista tulosta, vaikka käytettäisiin käytännön sallimia miniarvoja. Erittäin määrääviä tekijöitä lopullisen tuloksen kannalta ovat detektoritilavuus ja tuloskäsittelyn laatu. Tiheän linjavälin käyttö näyttäisi olevan tärkeätä. Mittaustulosten rekisteröinti on suoritettava digitaalisesti ja tuloskäsittely tietokoneella. Tuloskäsittelyn kustannukset ovat verrannolliset käsiteltävän tiedon määrään, ts. mitä useamman kanavan tulokset käsitellään, sitä korkeammat ovat kustannukset. Näin ollen tietokonekustannukset ja käsiteltävästä materiaalista saatavan informaation määrä on pyrittävä optimoimaan. Kokeiluluontoisesti on lentoalueiden eräiden karttalehtien mittaustuloksista laskettu U/Th, U/K ja Th/K suhdekartat. Suhdekartat helpottavat anomalioiden luokittelua ja niiden avulla voidaan selventää mittauksen antamaa informaatiota. Suhdekarttojen käyttömahdollisuuksia olisi edelleen tutkittava.

Helikopterin käyttö mittauksissa on tarkoituksenmukaista vain silloin, kun tutkimusalueella esiintyy suuria korkeusvaihteluita. Suuressa osassa maatamme aeroradiometriset mittaukset on kustannussyistä edullisinta suorittaa lentokoneella. Geologinen tutkimuslaitos on aloittanut v. 1972 magneettiset, sähköiset ja radiometriset matalalentotutkimukset. Spektrometrin detektorin tilavuus näissä mittauksissa, jotka nykyisin tehdään DC-3 lentokoneella, on 27 l.

Ilmakuvien avulla tapahtuva suunnistus ja paikannus on melko epätarkka menetelmä. Paikannuksessa olisi pyrittävä automaattiseen järjestelmään, joka parantaa paikannustarkkuutta, helpottaa tulosten tietokonekäsittelyä ja sallii suuremman mittaustehon.

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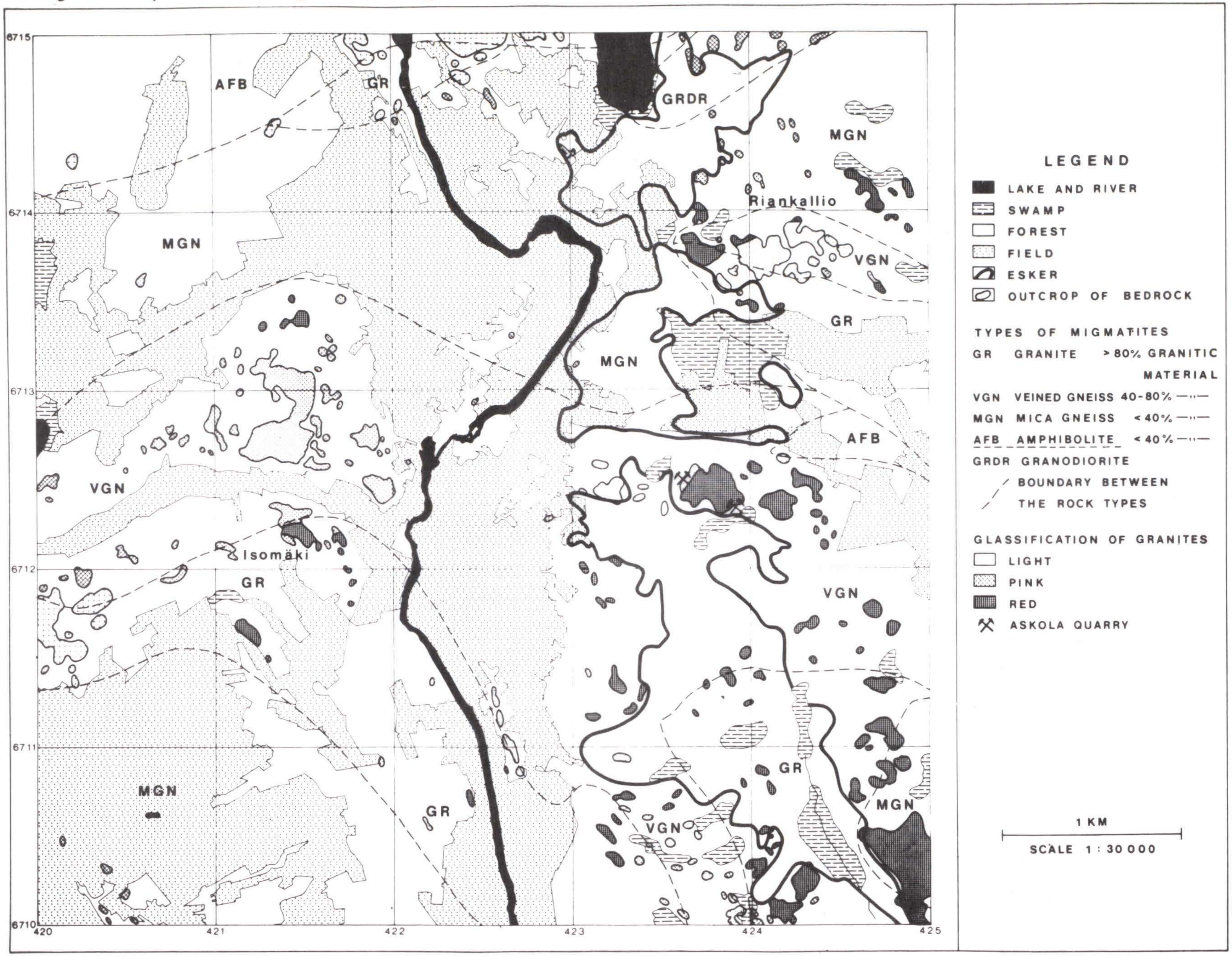
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420
421
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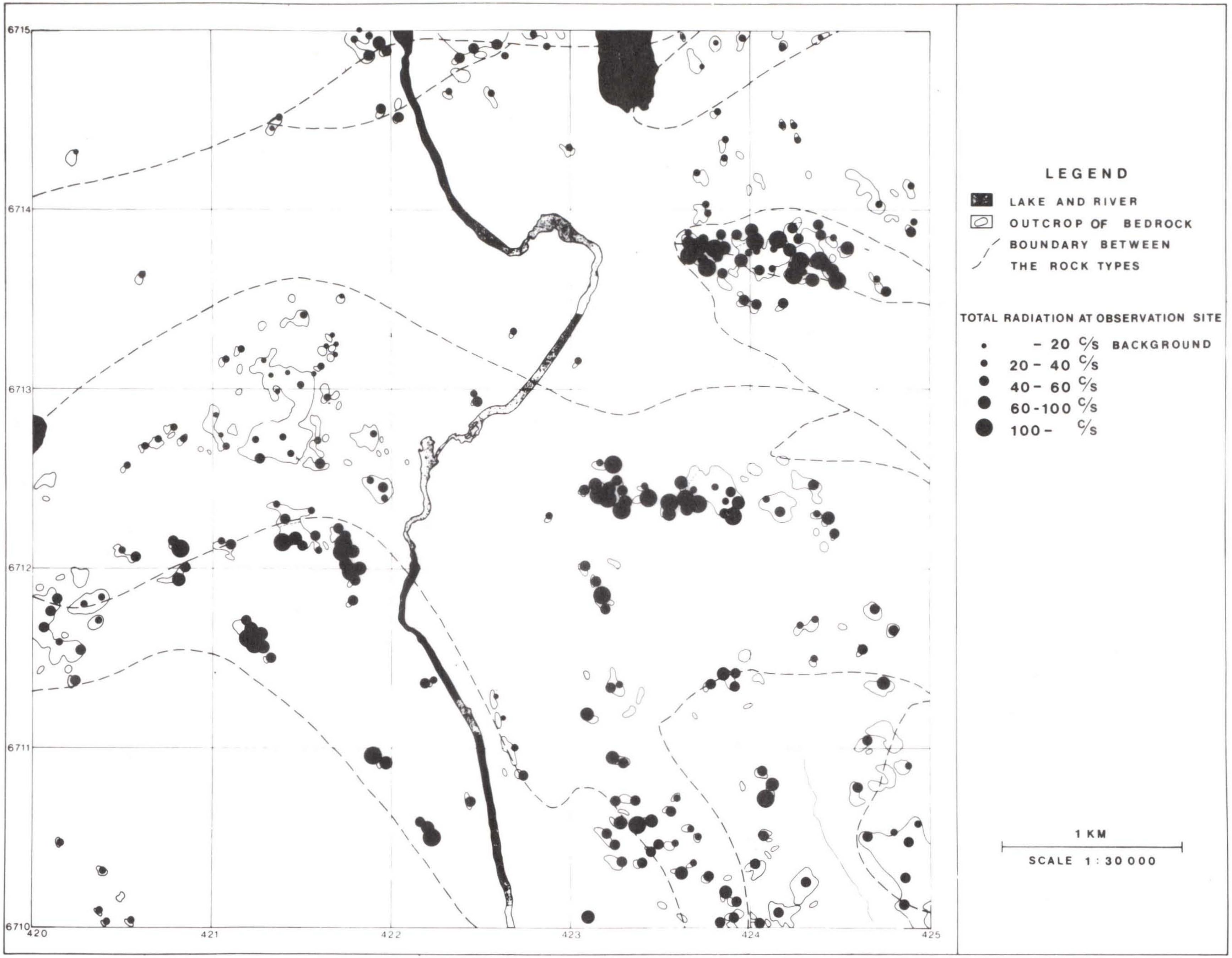
424
425
AFB
GR
GRDR
MGN
Riankallio
VGN
GR
MGN
AFB
VGN
Isomäki
GR
VGN
MGN
GR
GR
VGN
MGN
LEGEND
LAKE AND RIVER
SWAMP
FOREST
FIELD
ESKER
OUTCROP OF BEDROCK
TYPES OF MIGMATITES
GR GRANITE > 80% GRANITIC MATERIAL
VGN VEINED GNEISS 40-80% —"—
MGN MICA GNEISS < 40% —"—
AFB AMPHIBOLITE < 40% —"—
GRDR GRANODIORITE
BOUNDARY BETWEEN THE ROCK TYPES
GLASSIFICATION OF GRANITES
LIGHT
PINK
RED
ASKOLA QUARRY
1 KM
SCALE 1 : 30 000

ASKOLA AREA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BOUNDARY BETWEEN
THE ROCK TYPES
TOTAL RADIATION AT OBSERVATION SITE
- 20 c/s BACKGROUND
20 - 40 c/s
40 - 60 c/s
60 - 100 c/s
100 - c/s
1 KM
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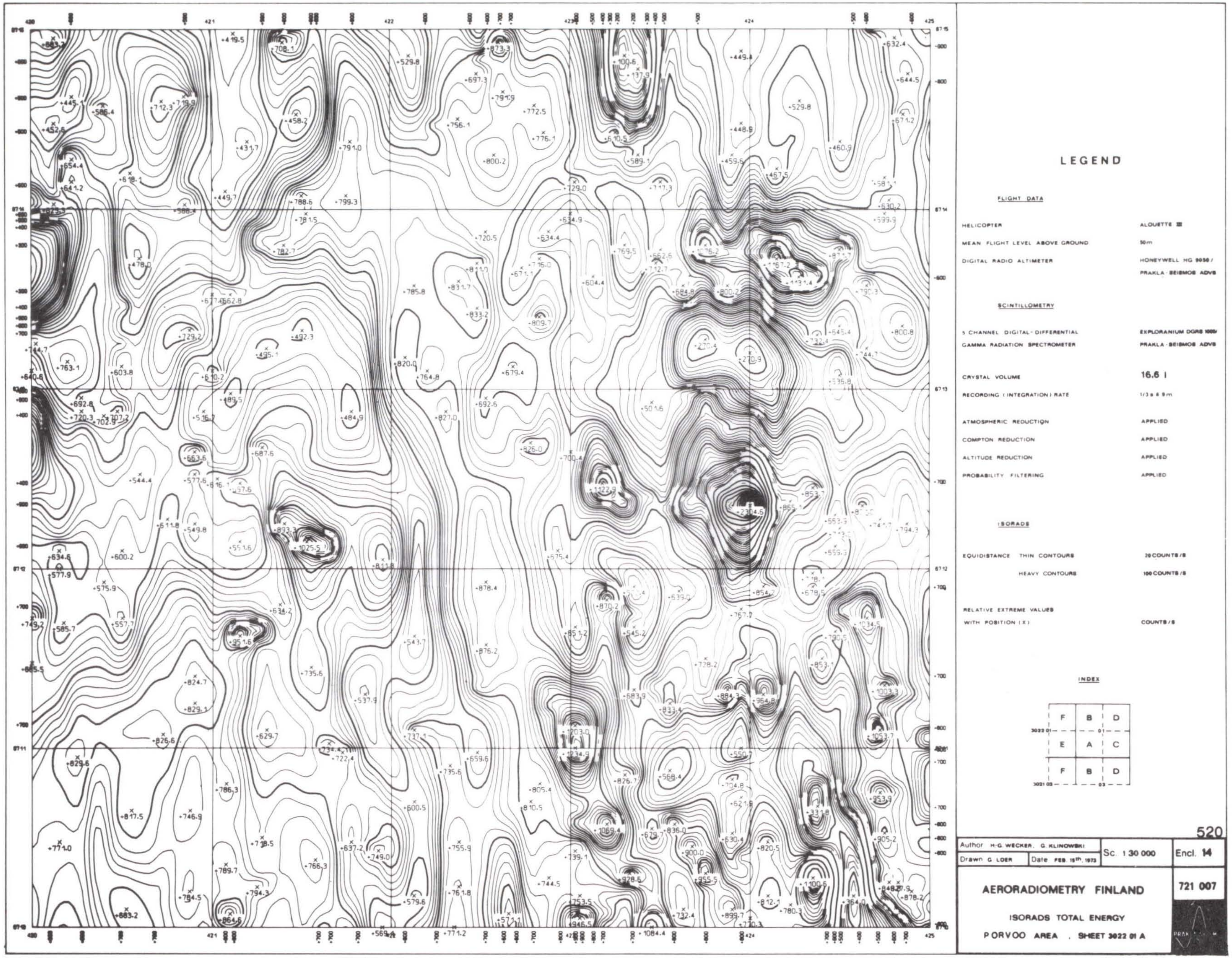
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MEAN FLIGHT LEVEL ABOVE GROUND
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SCINTILLOMETRY
5 CHANNEL DIGITAL-DIFFERENTIAL GAMMA RADIATION SPECTROMETER
EXPLORANIUM DGRS 1000/ PRAKLA-SEISMOS ADVS
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16.6 l
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COMPTON REDUCTION
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EQUIDISTANCE THIN CONTOURS
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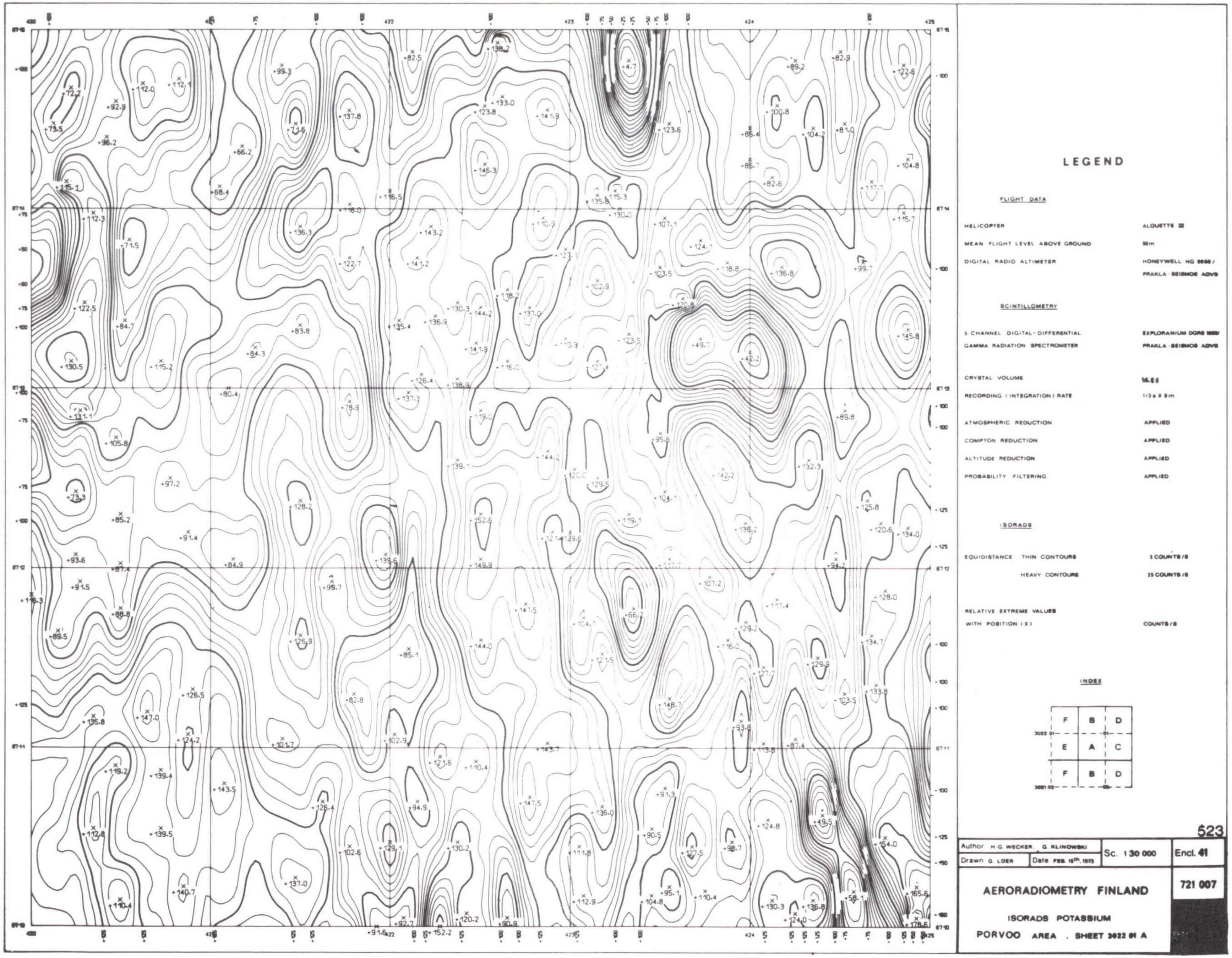
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5 COUNTS / S
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25 COUNTS / S
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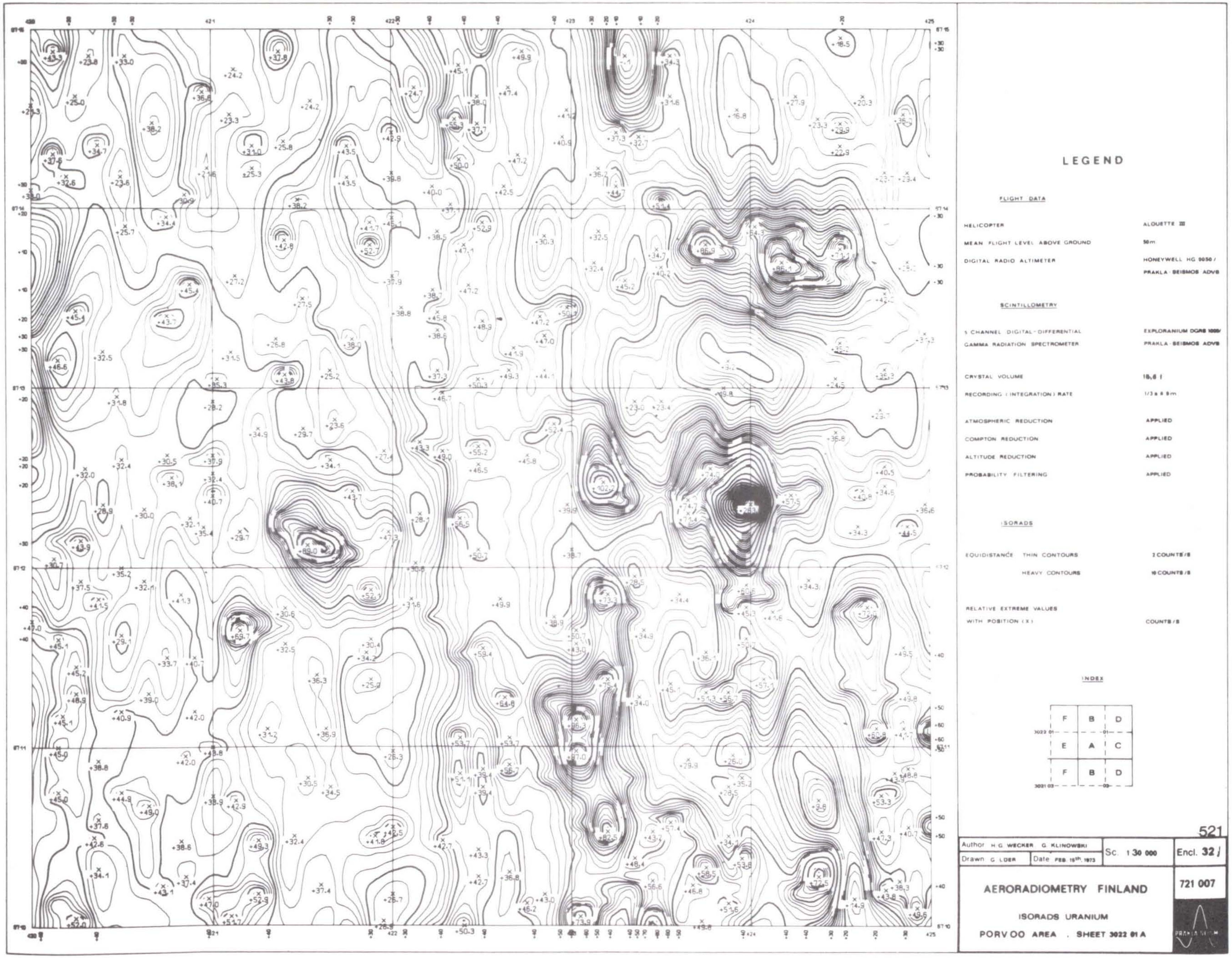
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ISORADS
EQUIDISTANCE THIN CONTOURS
2 COUNTS/S
HEAVY CONTOURS
10 COUNTS/S
RELATIVE EXTREME VALUES WITH POSITION (X)
COUNTS/S
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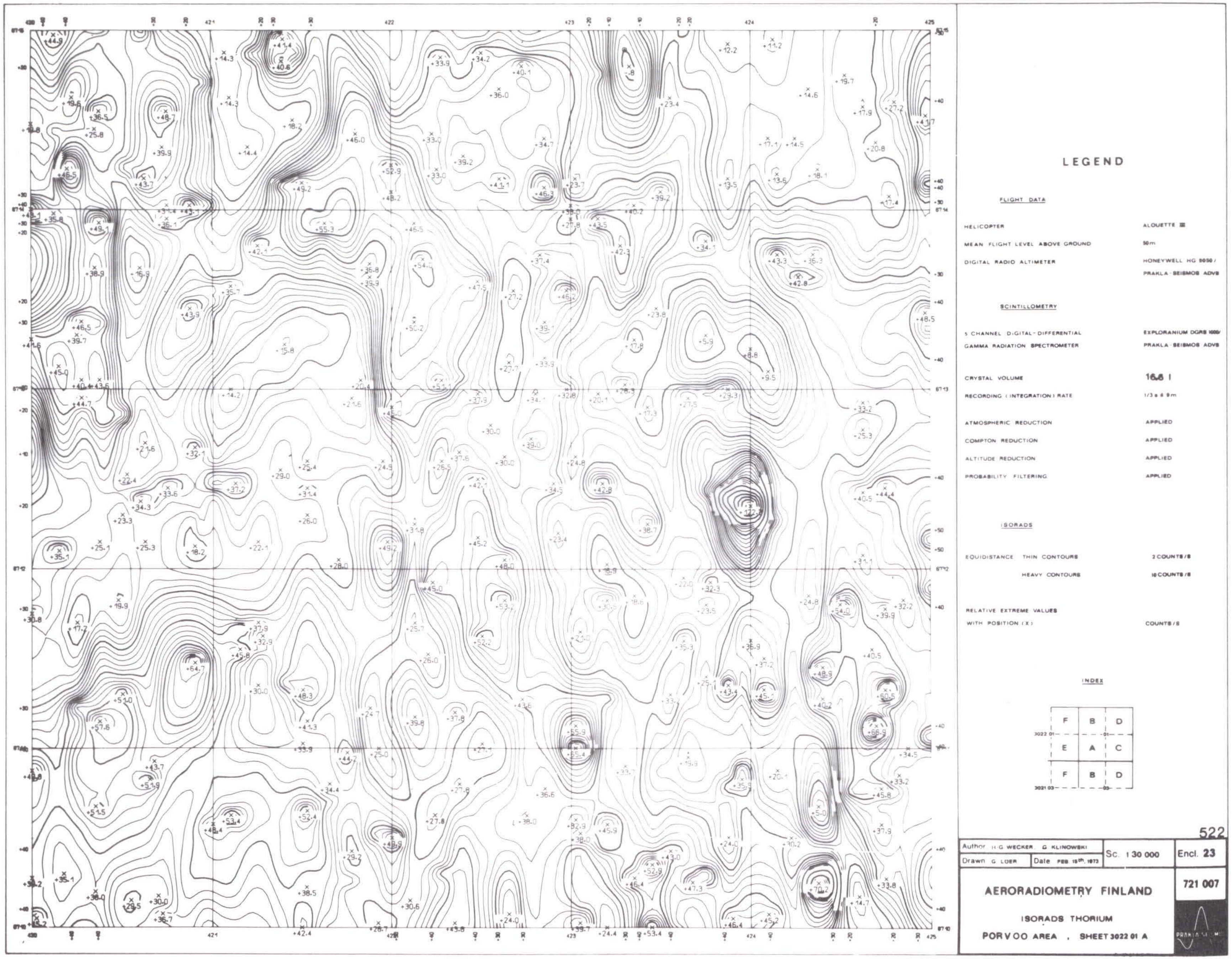
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RECORDING (INTEGRATION) RATE 1/3 s 4 9m
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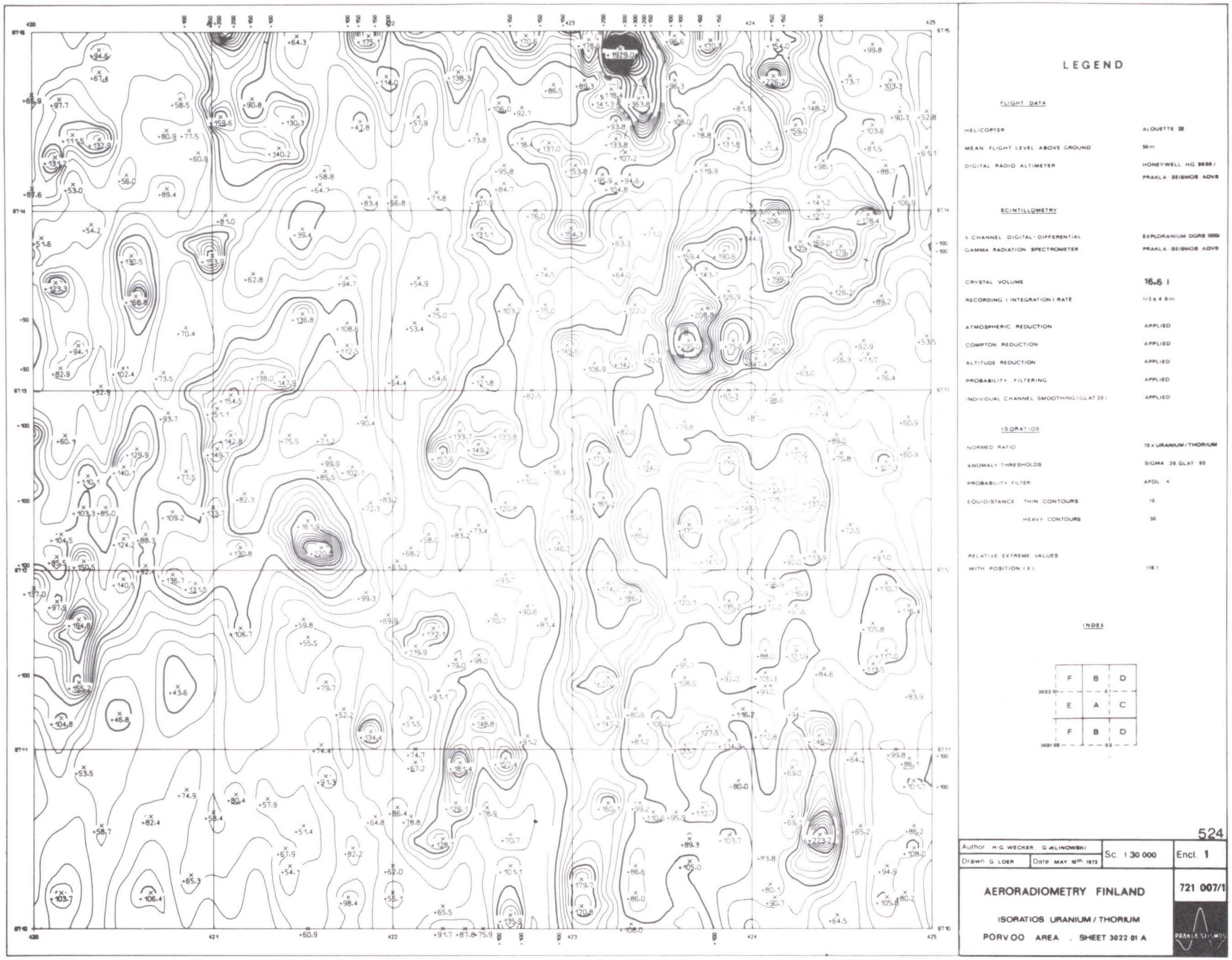
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EQUIDISTANCE THIN CONTOURS 10
HEAVY CONTOURS 50
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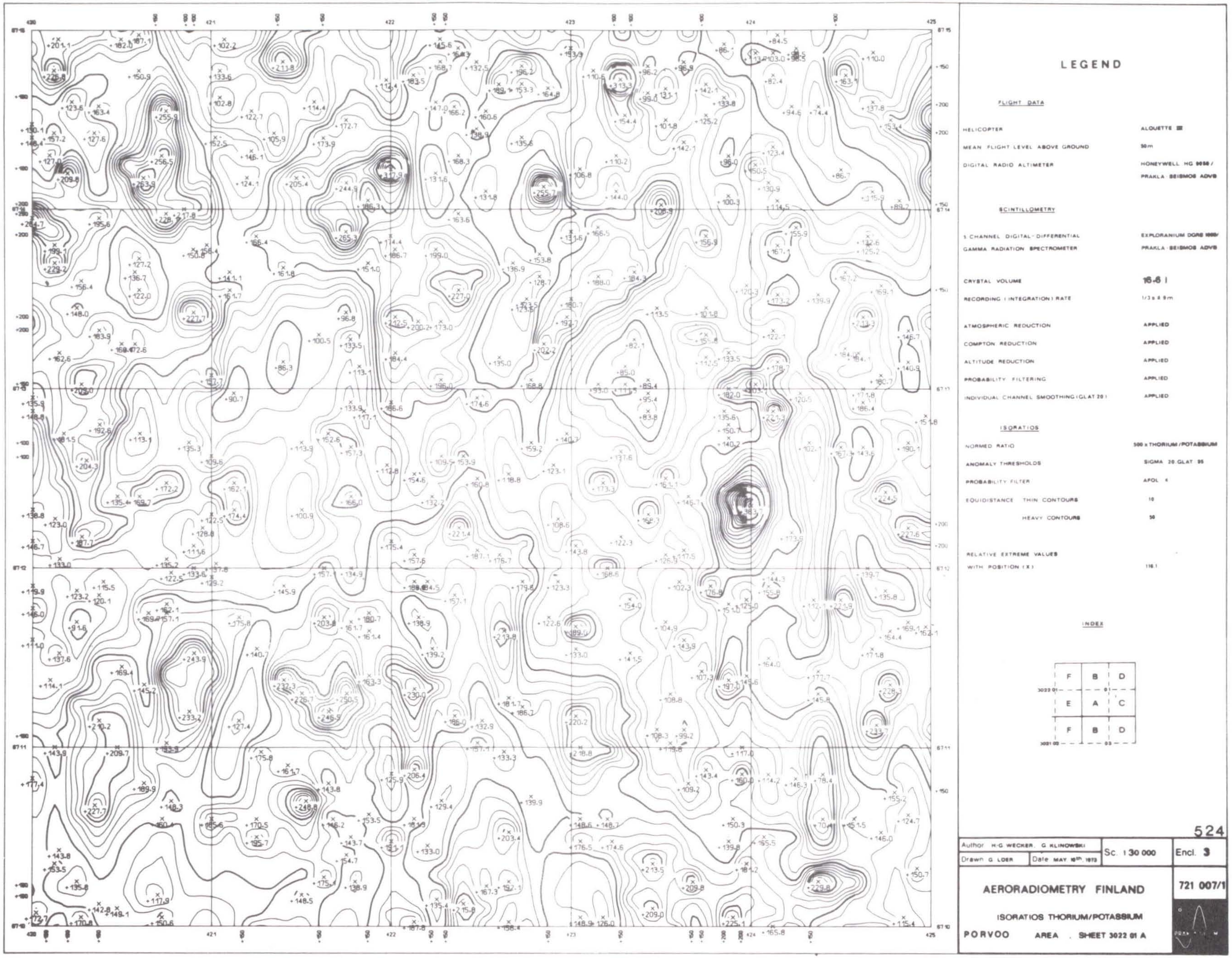
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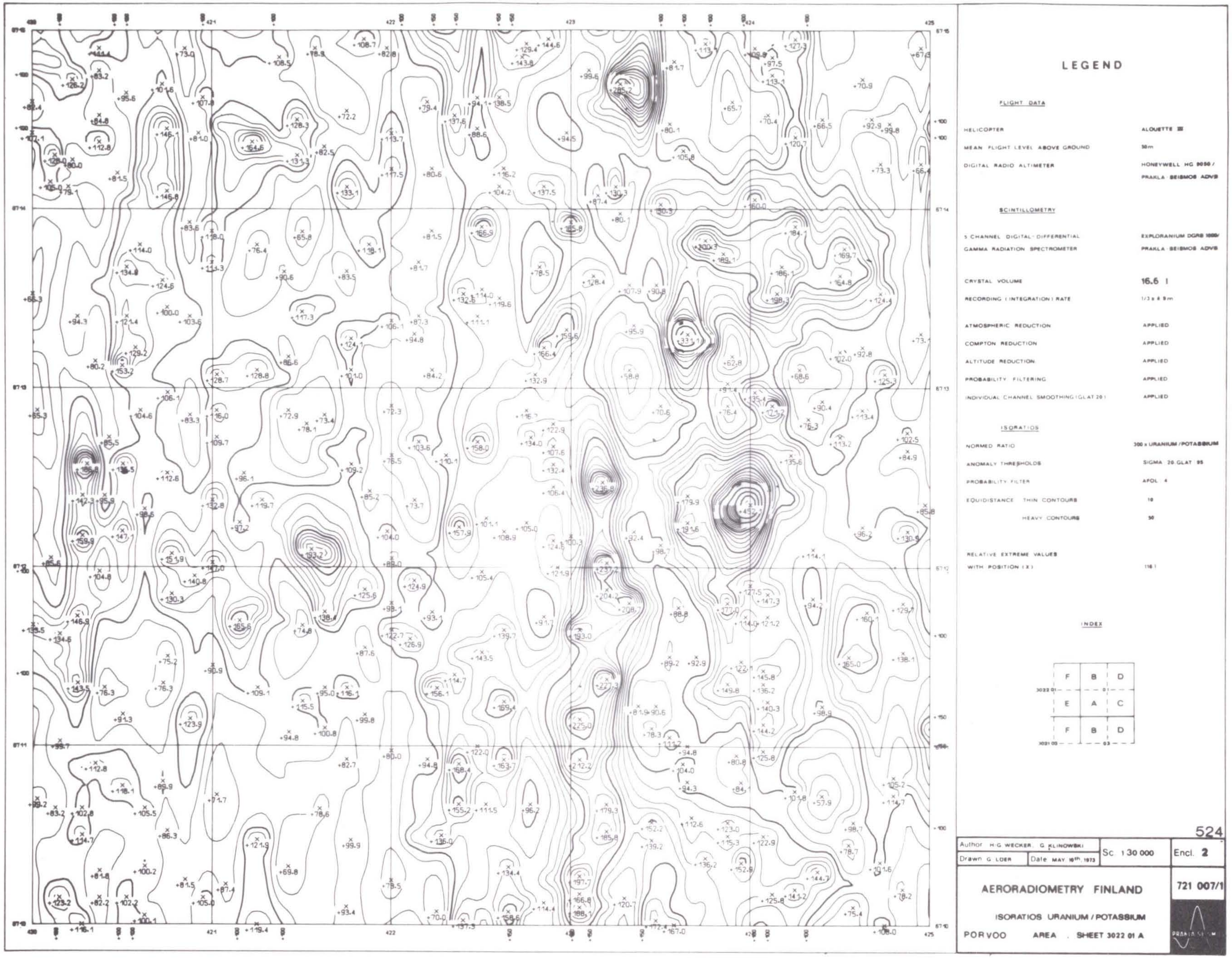
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HEAVY CONTOURS 50
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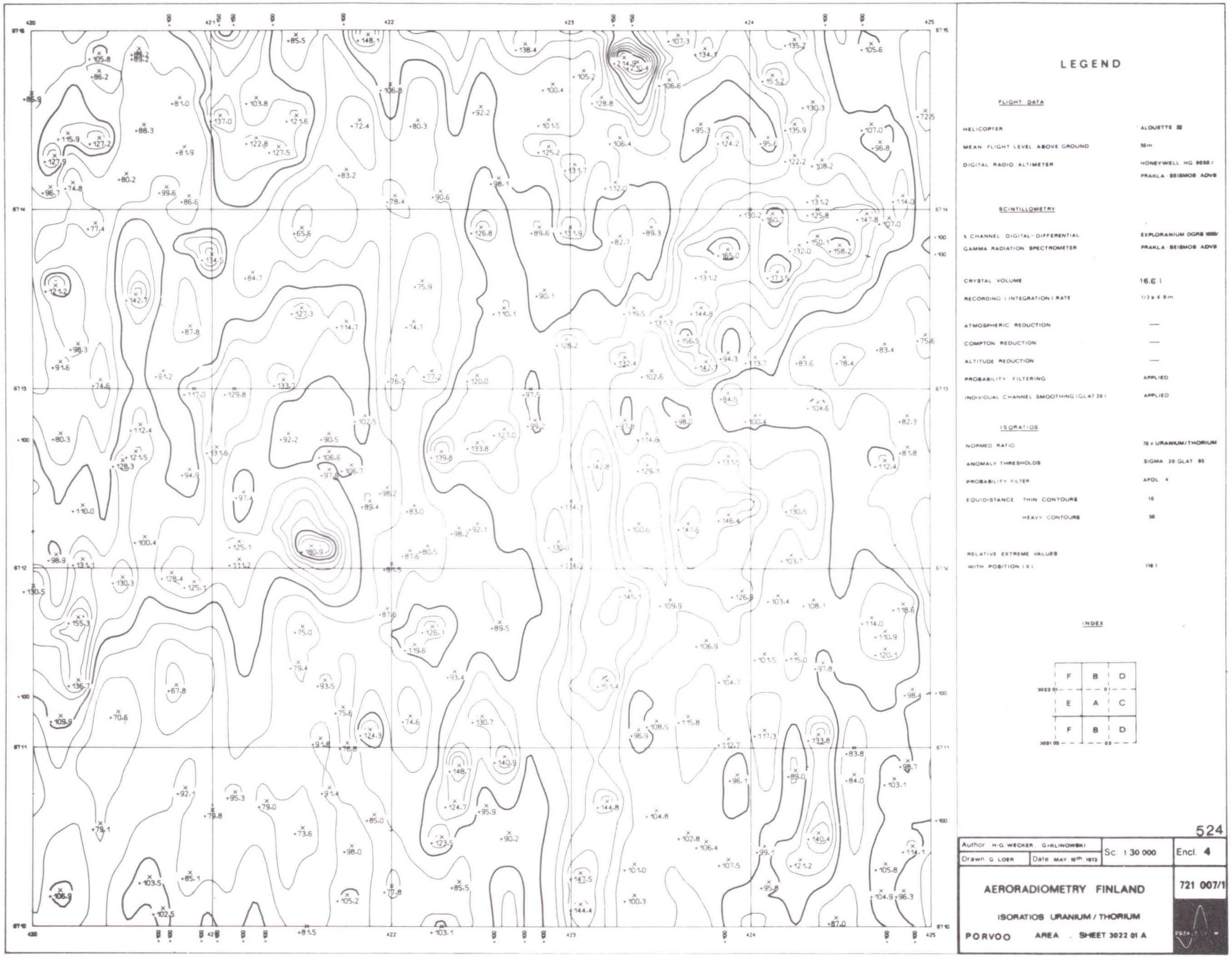
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PRAKLA SEISMOS ADVS
SCINTILLOMETRY
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SIGMA 20 GLAT 95
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LEGEND

FLIGHT DATA

HELICOPTER	ALOUETTE III
MEAN FLIGHT LEVEL ABOVE GROUND	50 m
DIGITAL RADIO ALTIMETER	HONEYWELL HG 9050 / PRAKLA - SEISMOS ADVS

SCINTILLOMETRY

5 CHANNEL DIGITAL - DIFFERENTIAL GAMMA RADIATION SPECTROMETER	EXPLORANIUM DGRS 1000/ PRAKLA - SEISMOS ADVS
CRYSTAL VOLUME	16.6 l
RECORDING (INTEGRATION) RATE	1/3 s ≙ 9 m
ATMOSPHERIC REDUCTION	—
COMPTON REDUCTION	—
ALTITUDE REDUCTION	—
PROBABILITY FILTERING	APPLIED
INDIVIDUAL CHANNEL SMOOTHING (GLAT 20)	APPLIED

ISORATIOS

NORMED RATIO	500 x THORIUM/POTASSIUM
ANOMALY THRESHOLDS	SIGMA 20 GLAT 95
PROBABILITY FILTER	APOL 4
EQUIDISTANCE THIN CONTOURS	10
HEAVY CONTOURS	50
RELATIVE EXTREME VALUES WITH POSITION (X)	116.1

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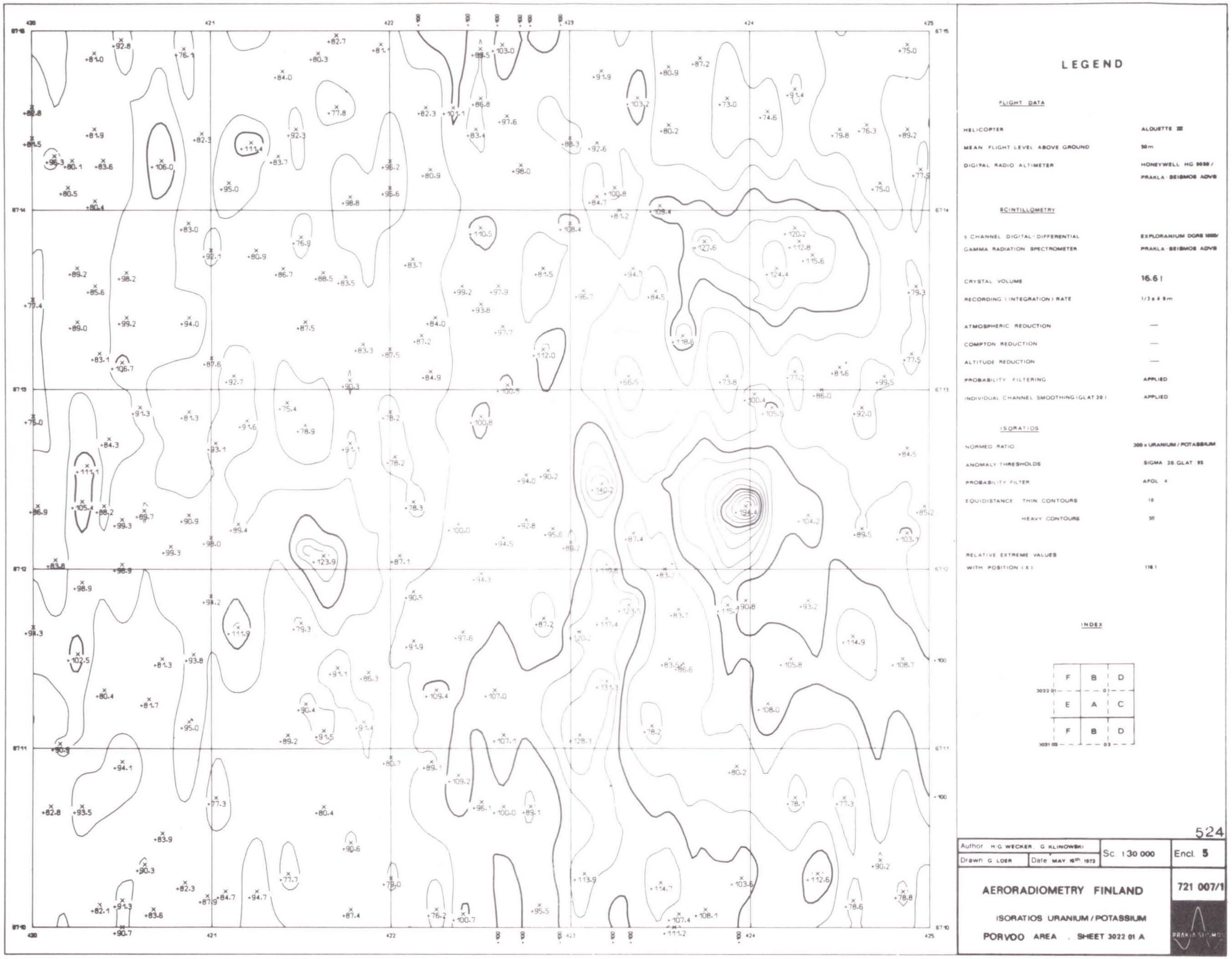
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SCINTILLOMETRY
5 CHANNEL DIGITAL · DIFFERENTIAL GAMMA RADIATION SPECTROMETER EXPLORANIUM DGRS 1000/ PRAKLA · SEISMOS ADVS
CRYSTAL VOLUME 16.6 l
RECORDING (INTEGRATION) RATE 1/3 s 4.9m
ATMOSPHERIC REDUCTION —
COMPTON REDUCTION —
ALTITUDE REDUCTION —
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ISORATIOS
NORMED RATIO 300 x URANIUM / POTASSIUM
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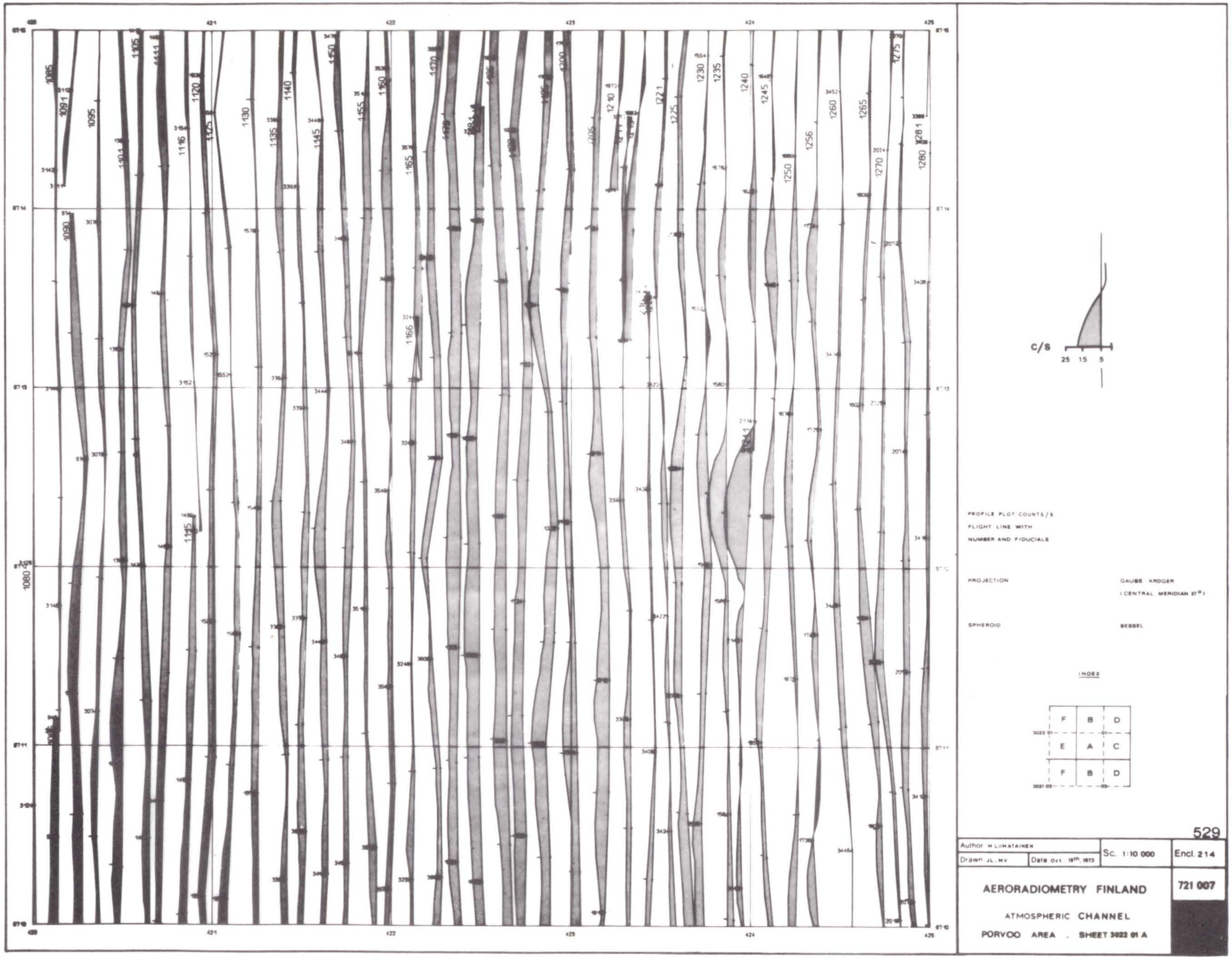
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GAUSS KRÜGER
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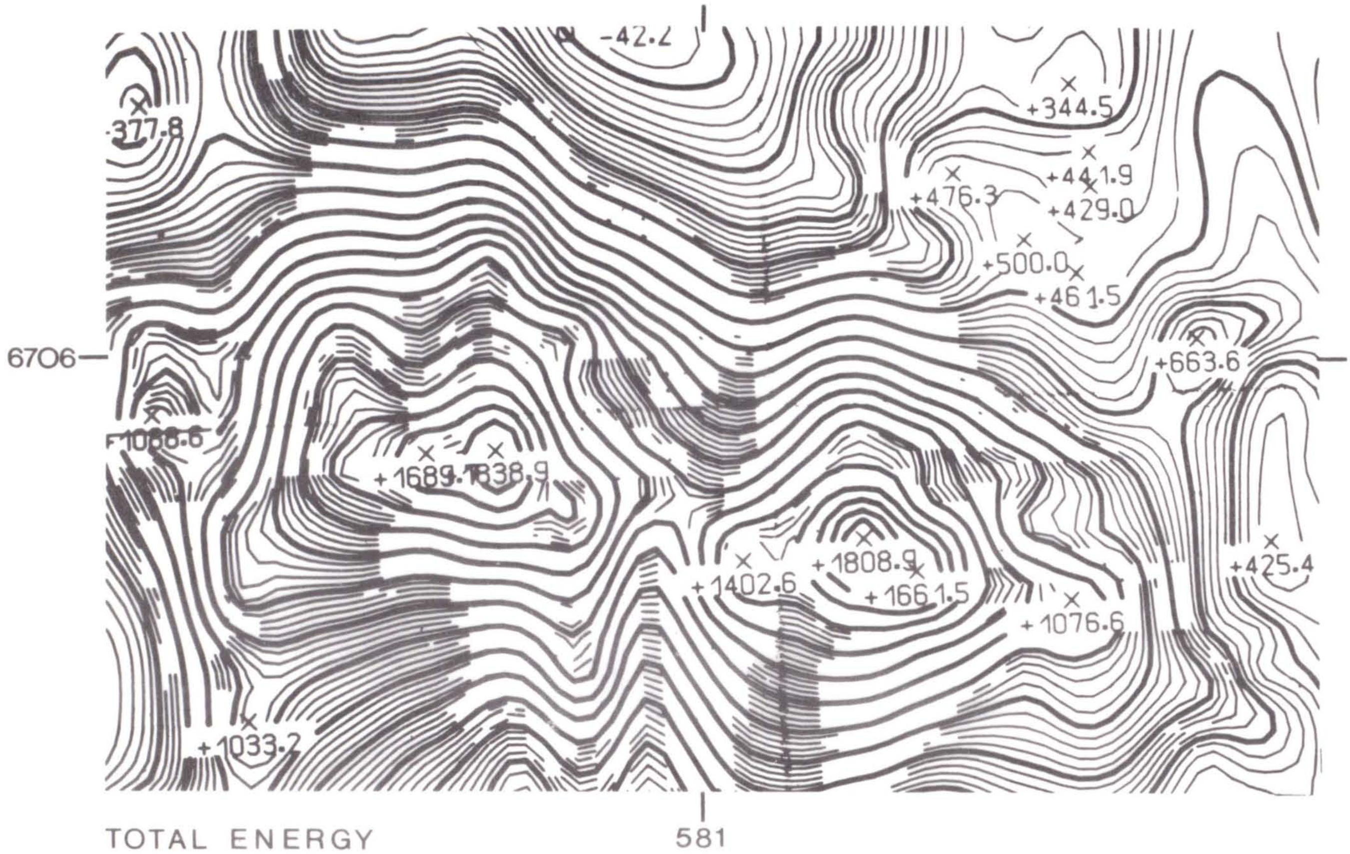
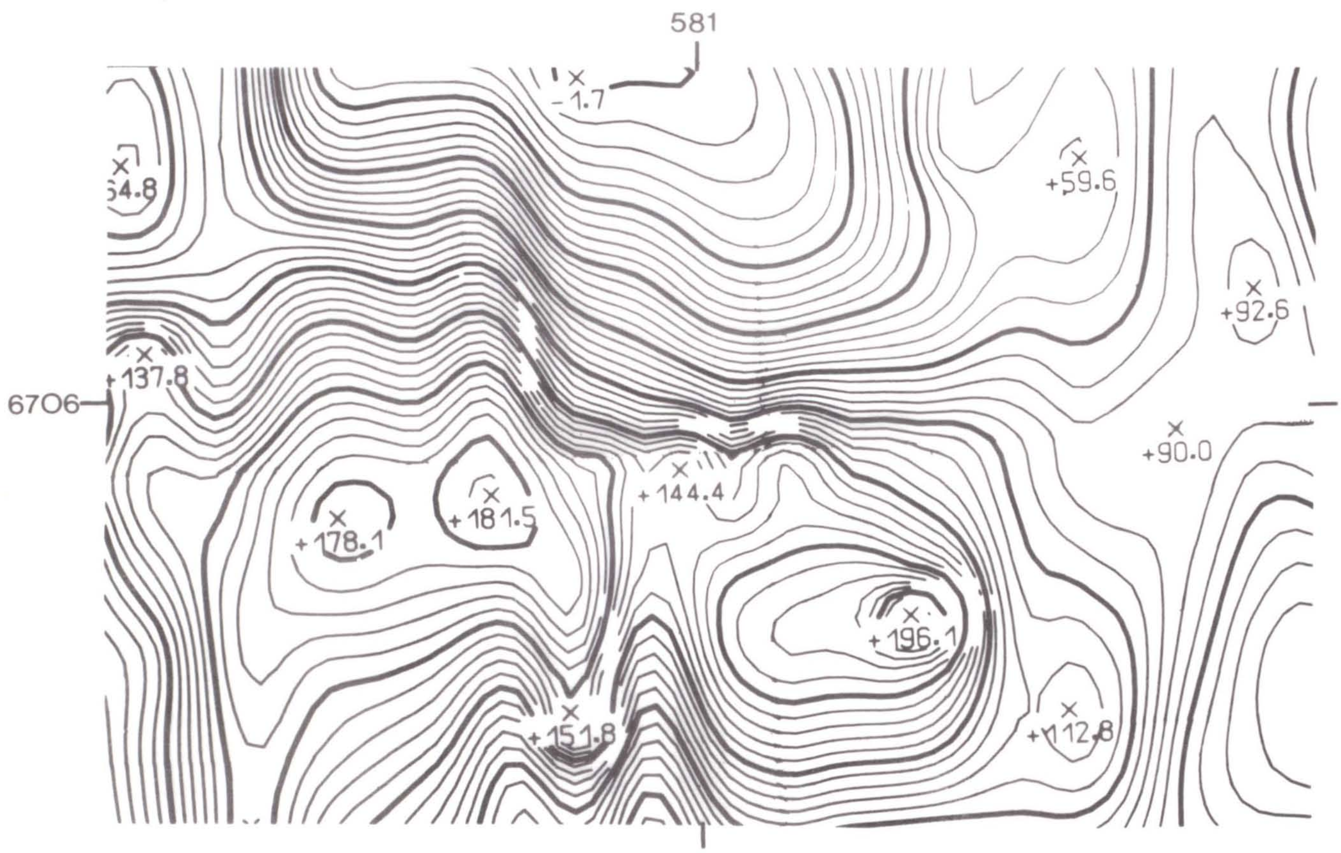


TOTAL ENERGY

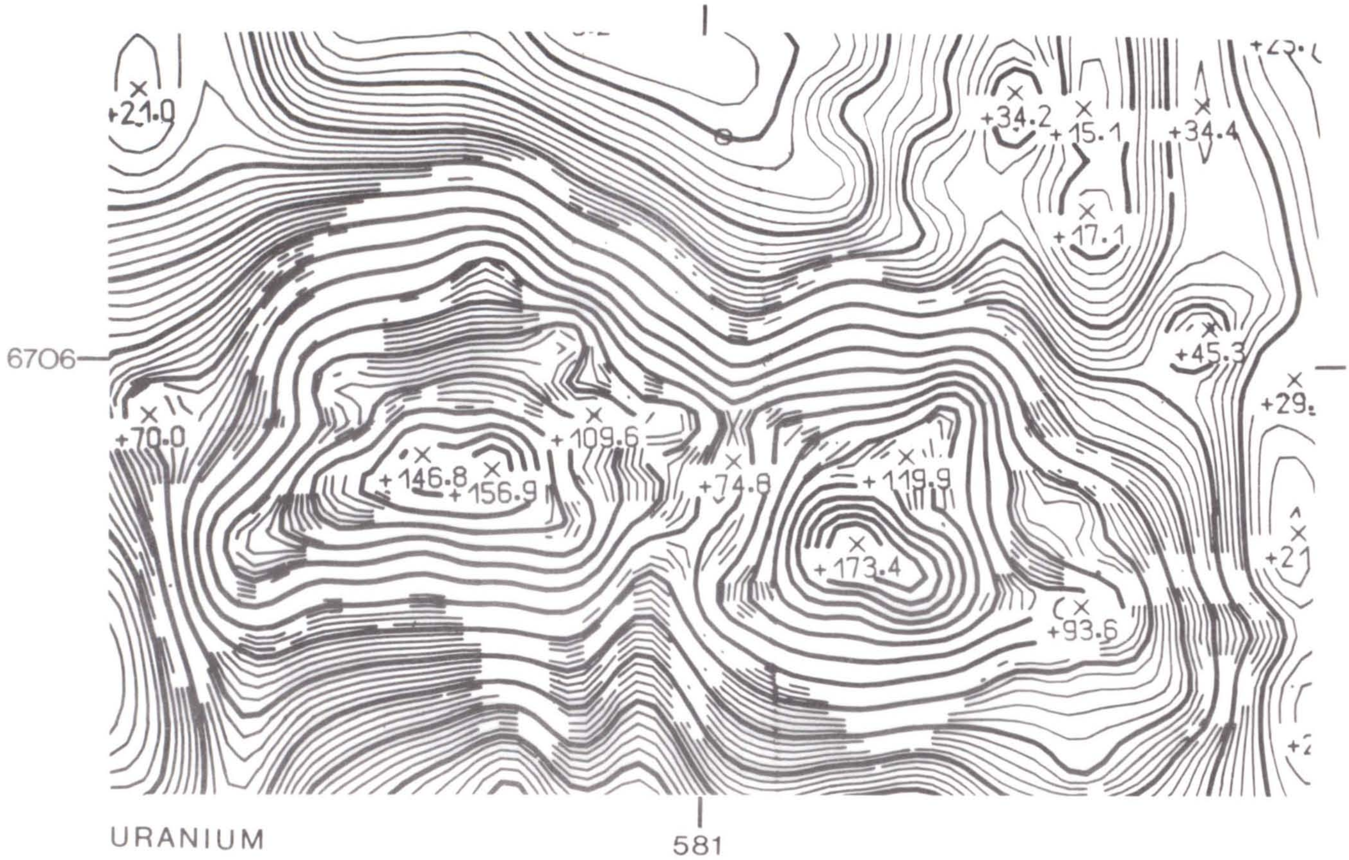


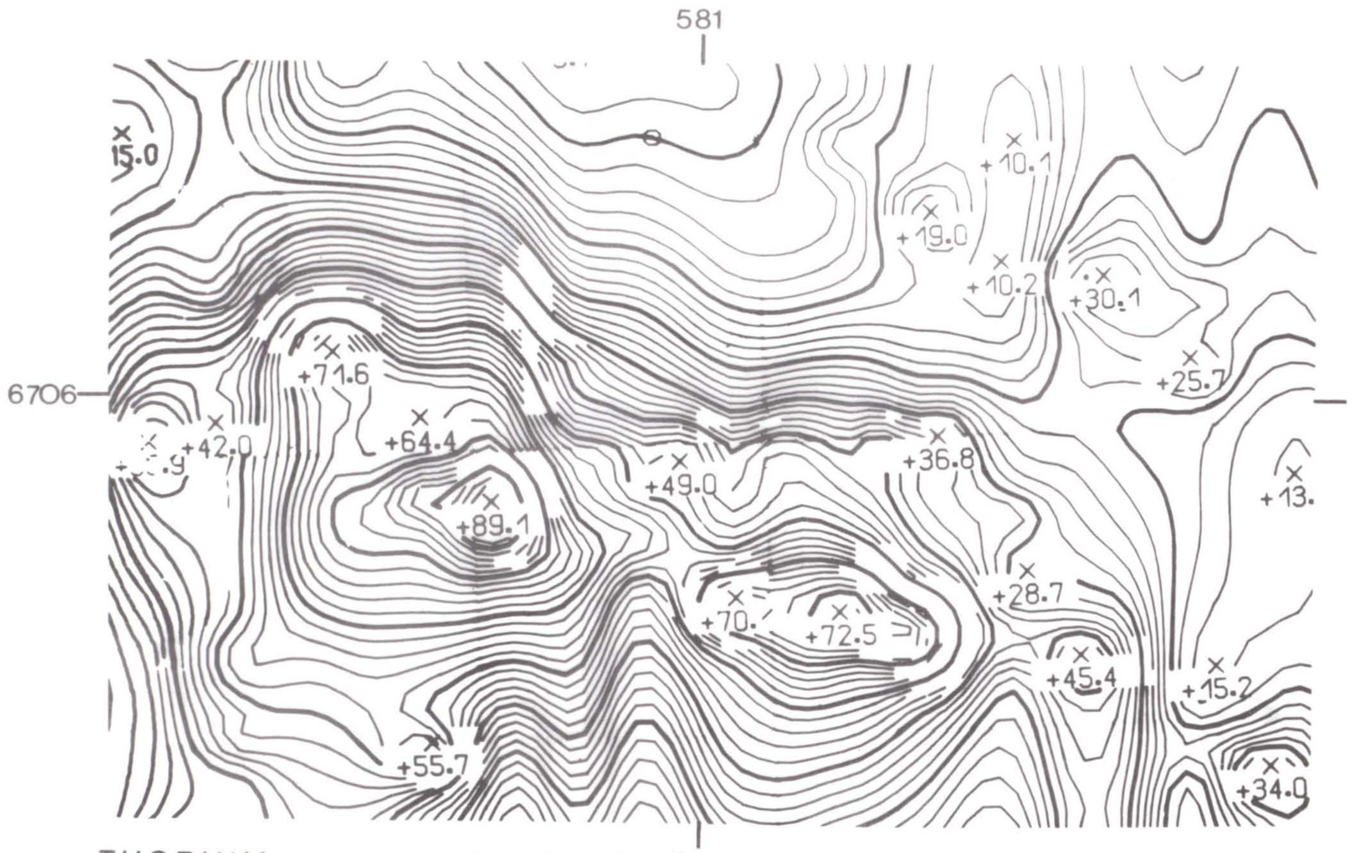
POTASSIUM

RUOKOJÄRVI AREA

500 M

SCALE 1:10000

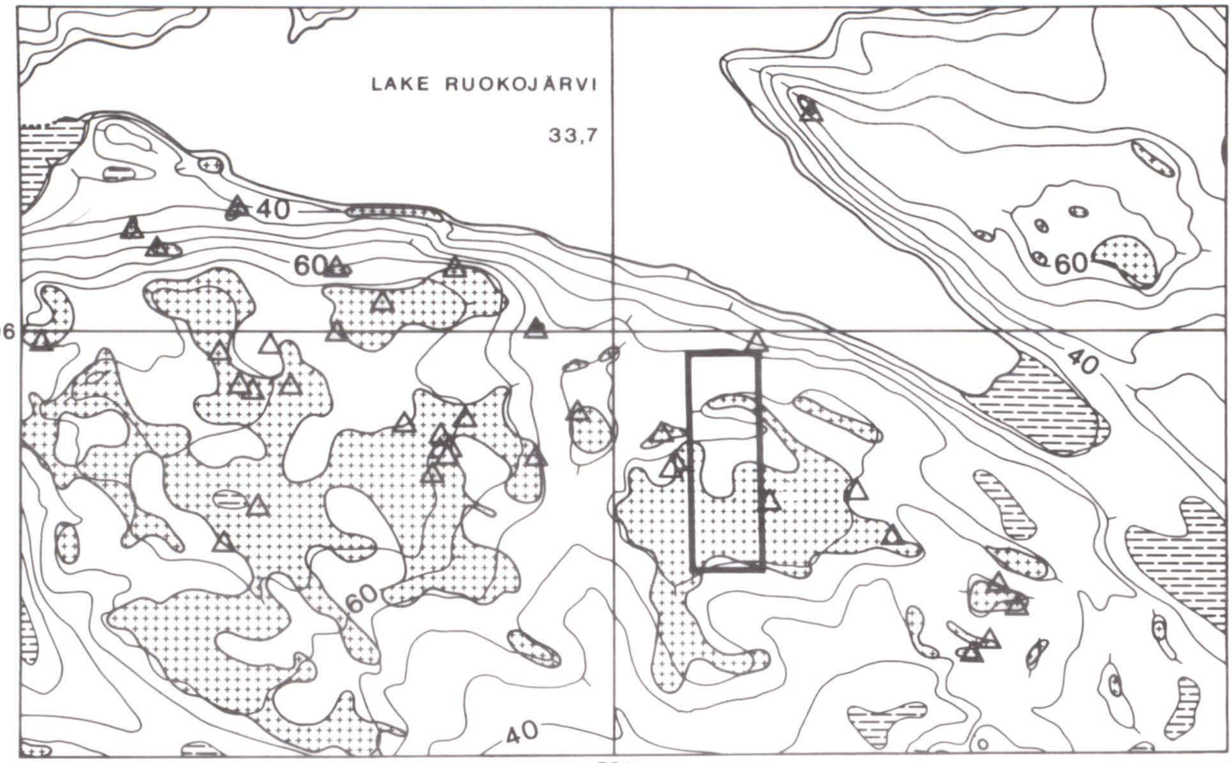




RUOKOJÄRVI AREA

500 M

SCALE 1 : 10 000



2043 12 F

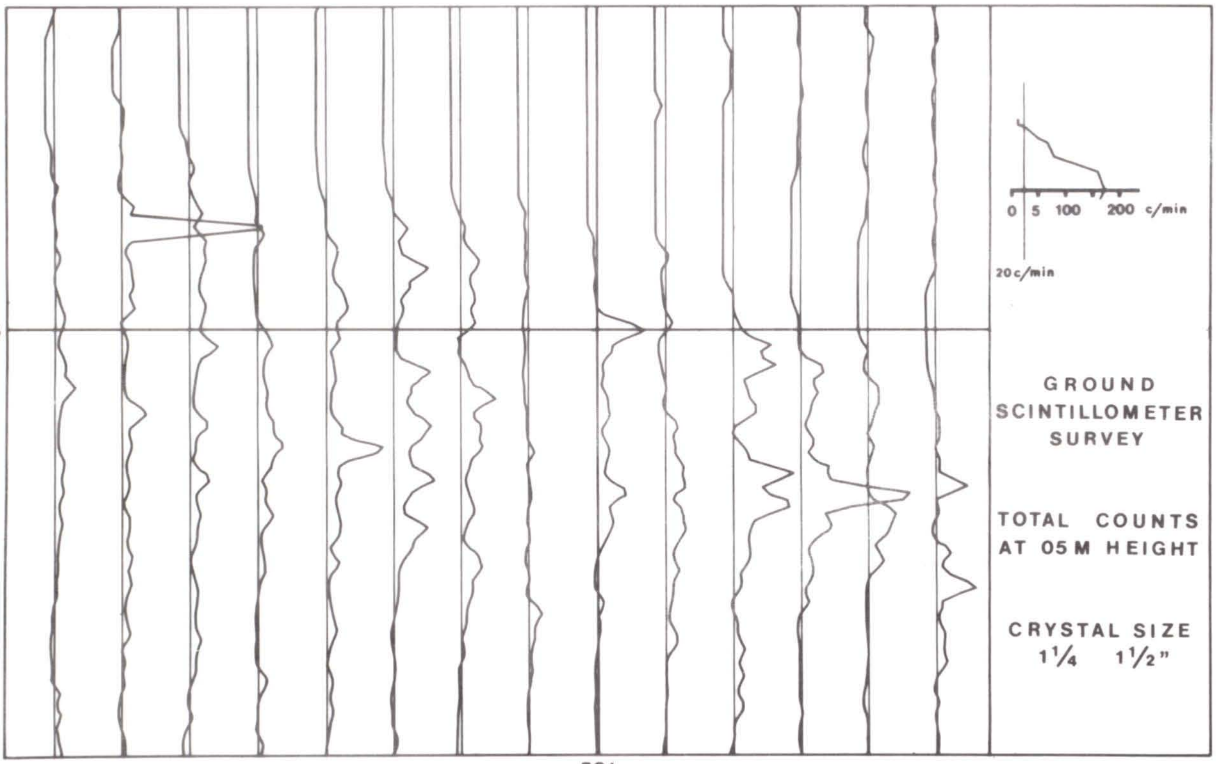
TOPOGRAPHY

1:10 000

OUTCROP OF BEDROCK

URANIUM – THORIUM OCCURRENCE

SAMPLING AREA



2043 12 F

TOTAL ENERGY

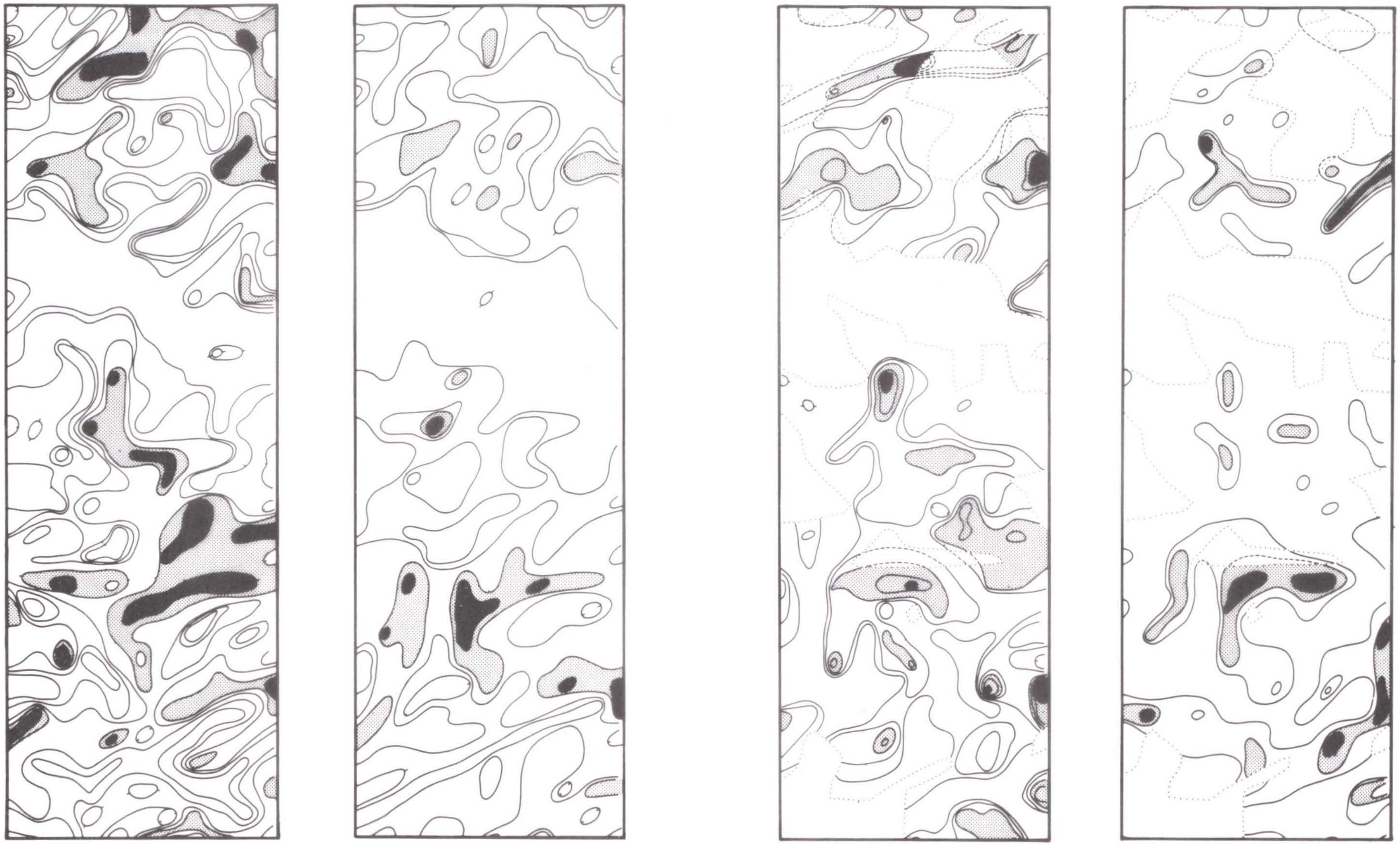
RUOKOJÄRVI AREA

500 M

SCALE 1 : 10 000

GROUND SPECTROMETER SURVEY:

ROCK SAMPLING:



URANIUM (C/10s)
>160 20–40

THORIUM (C/10s)
>80 40–80

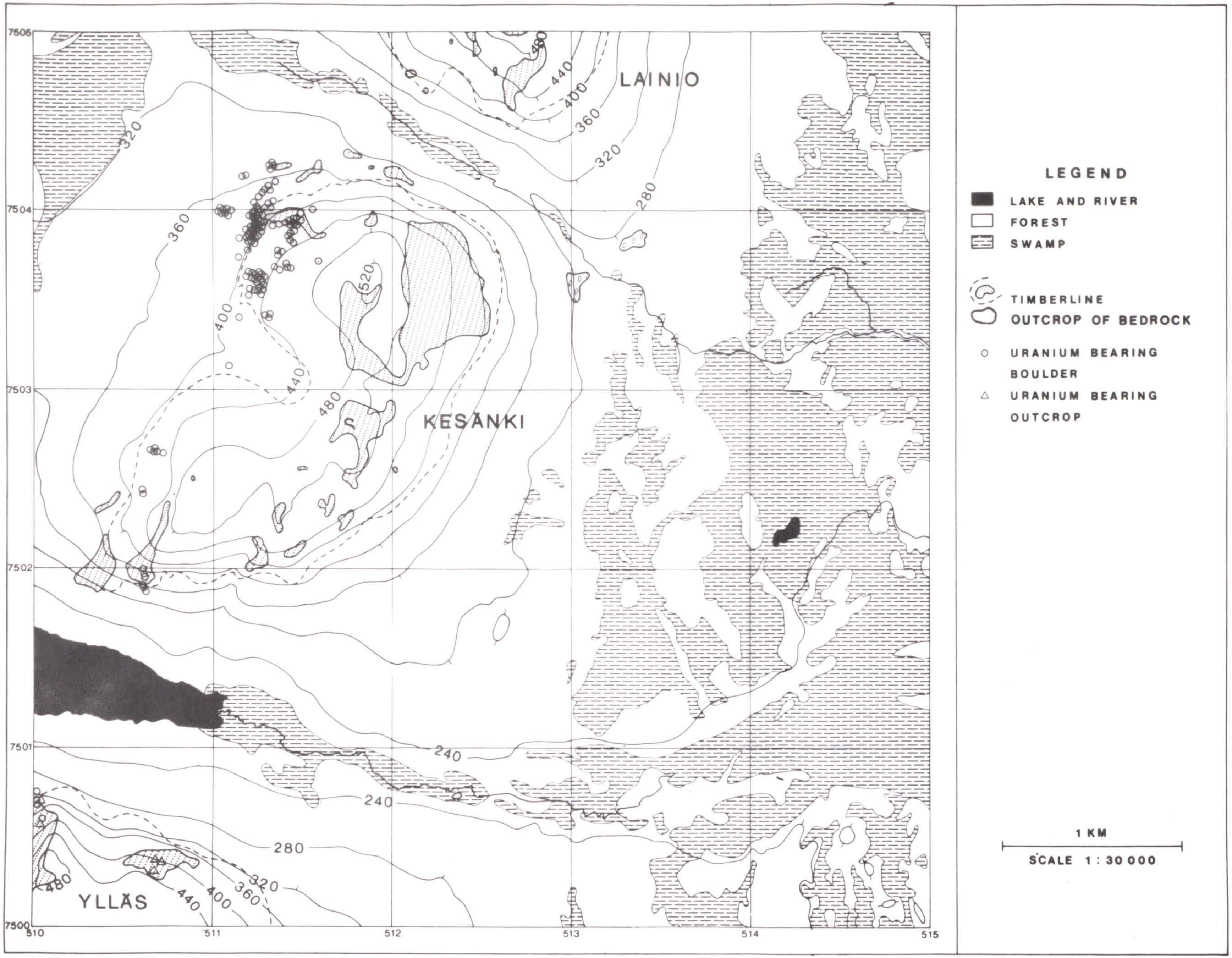
URANIUM CONTENT (ppm)
>160 80–160

THORIUM CONTENT (ppm)
>40 20–40

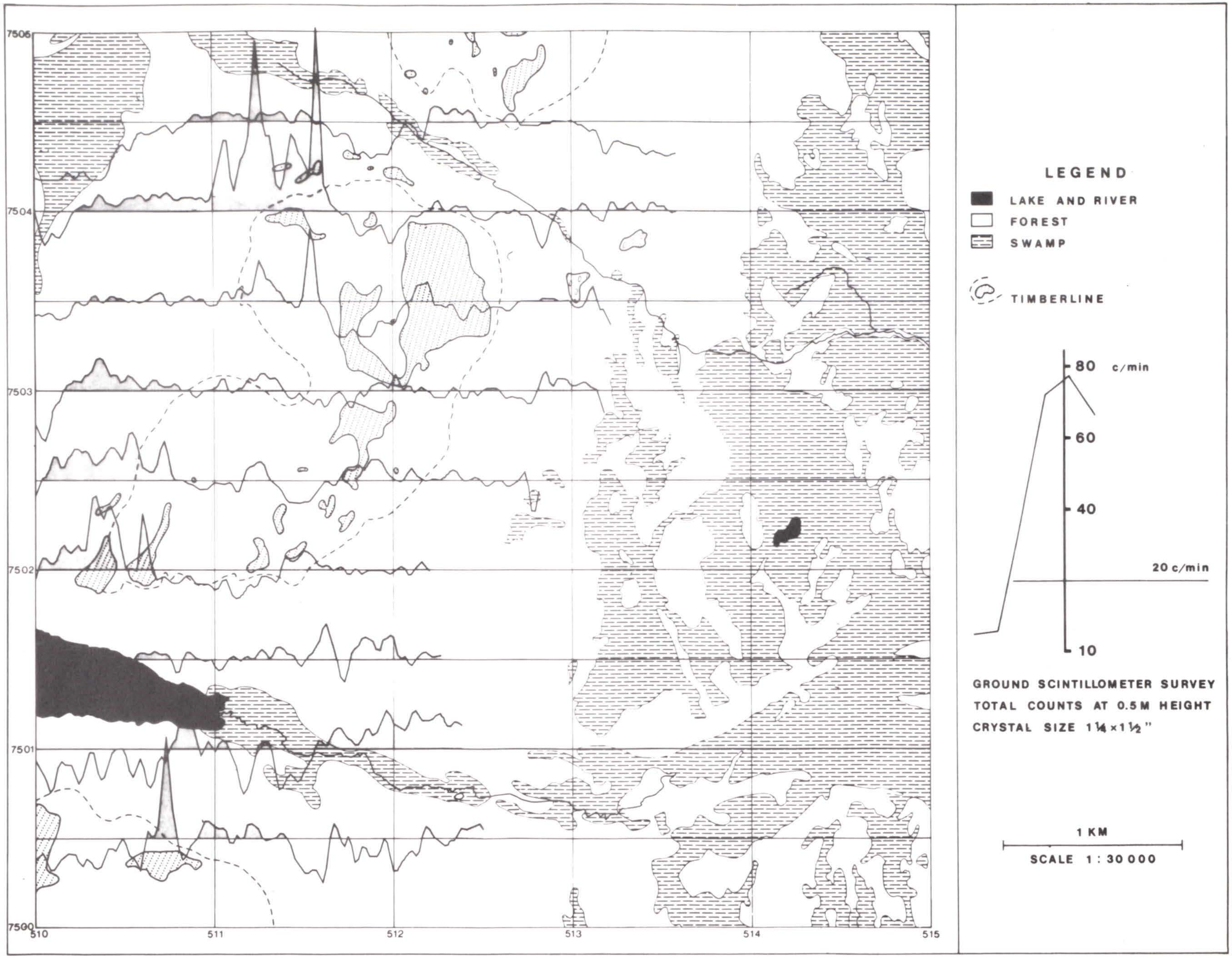
RUOKOJÄRVI SAMPLING AREA

0 50 100 M

SCALE 1:2000



KESÄNKI AREA



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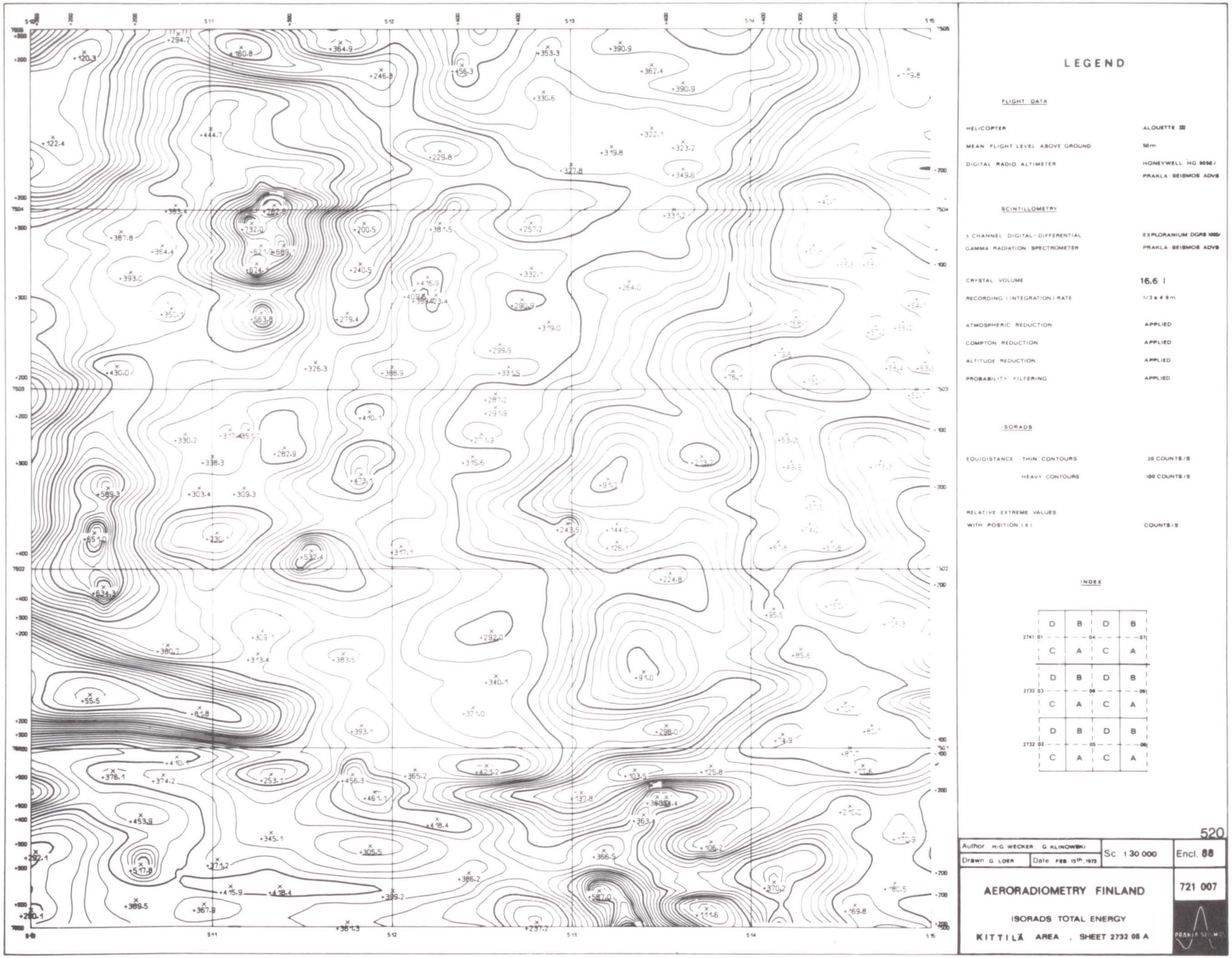

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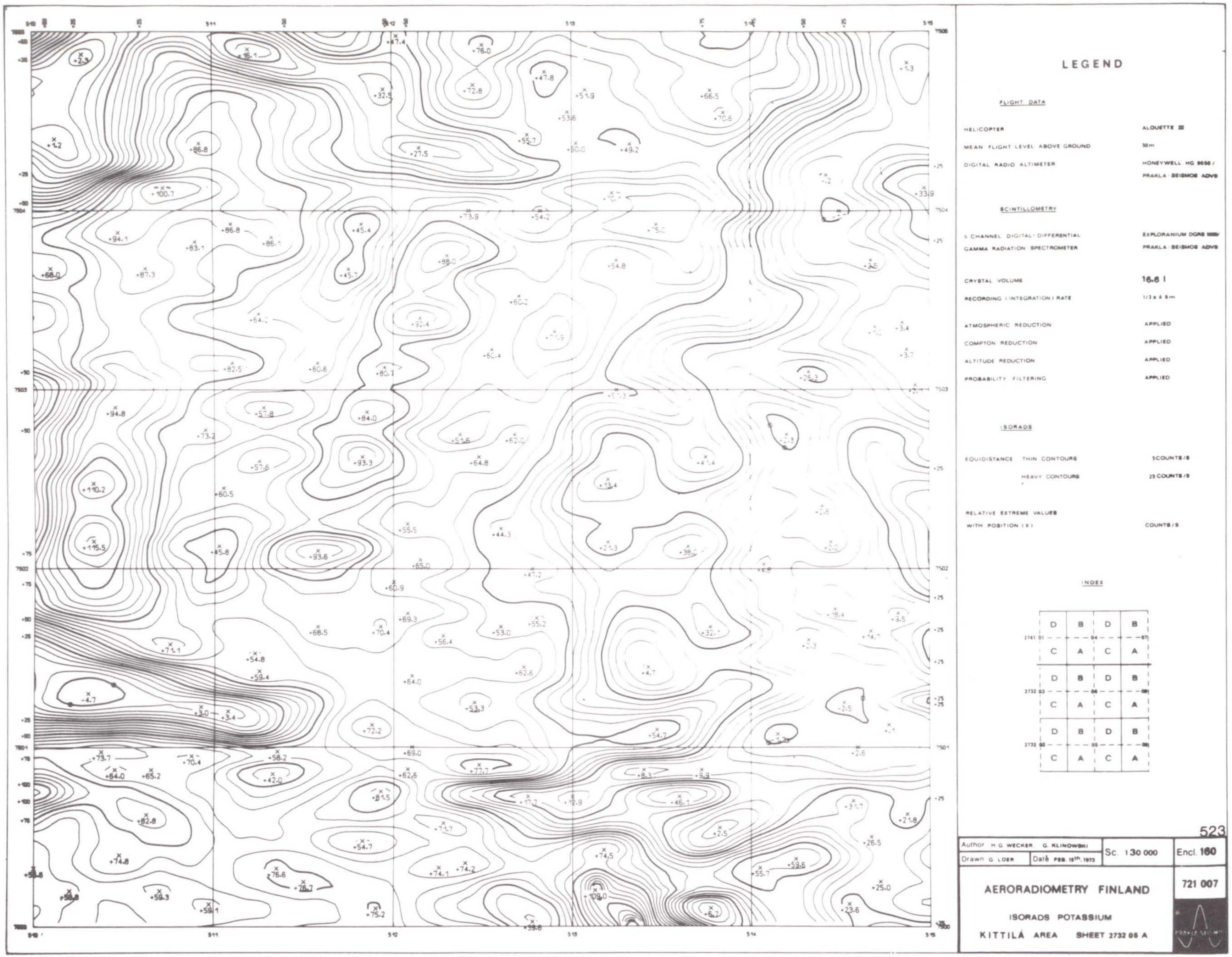

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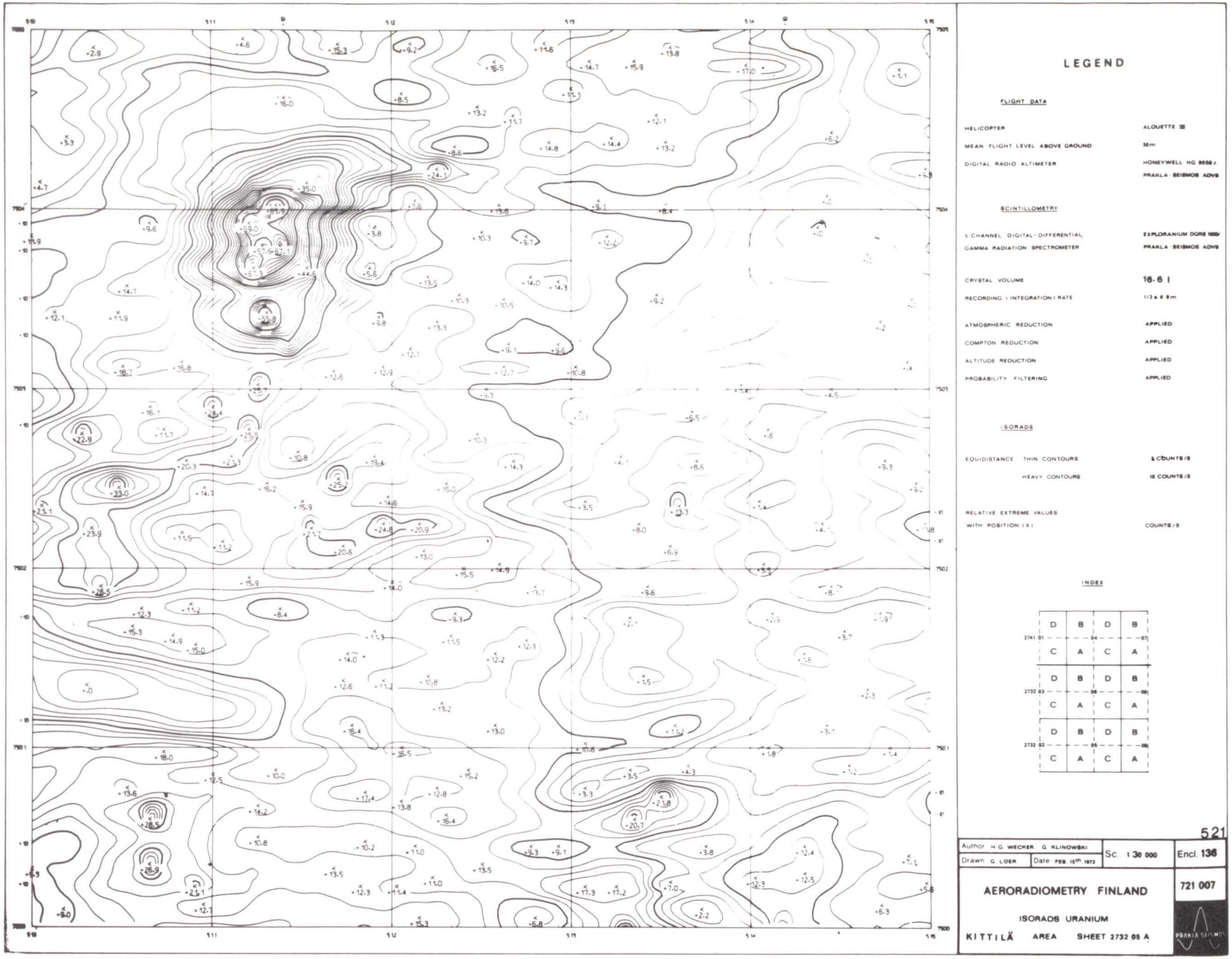

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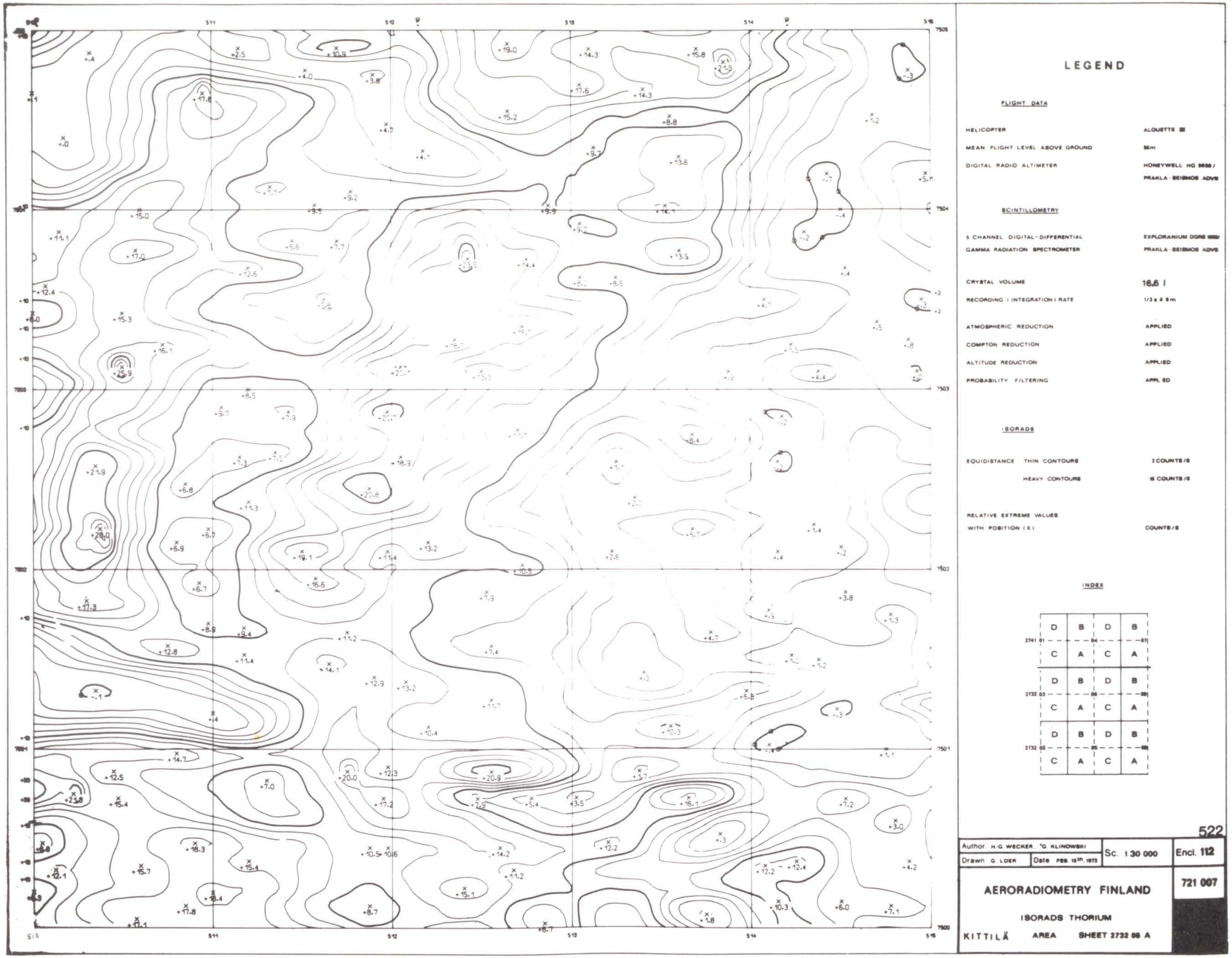

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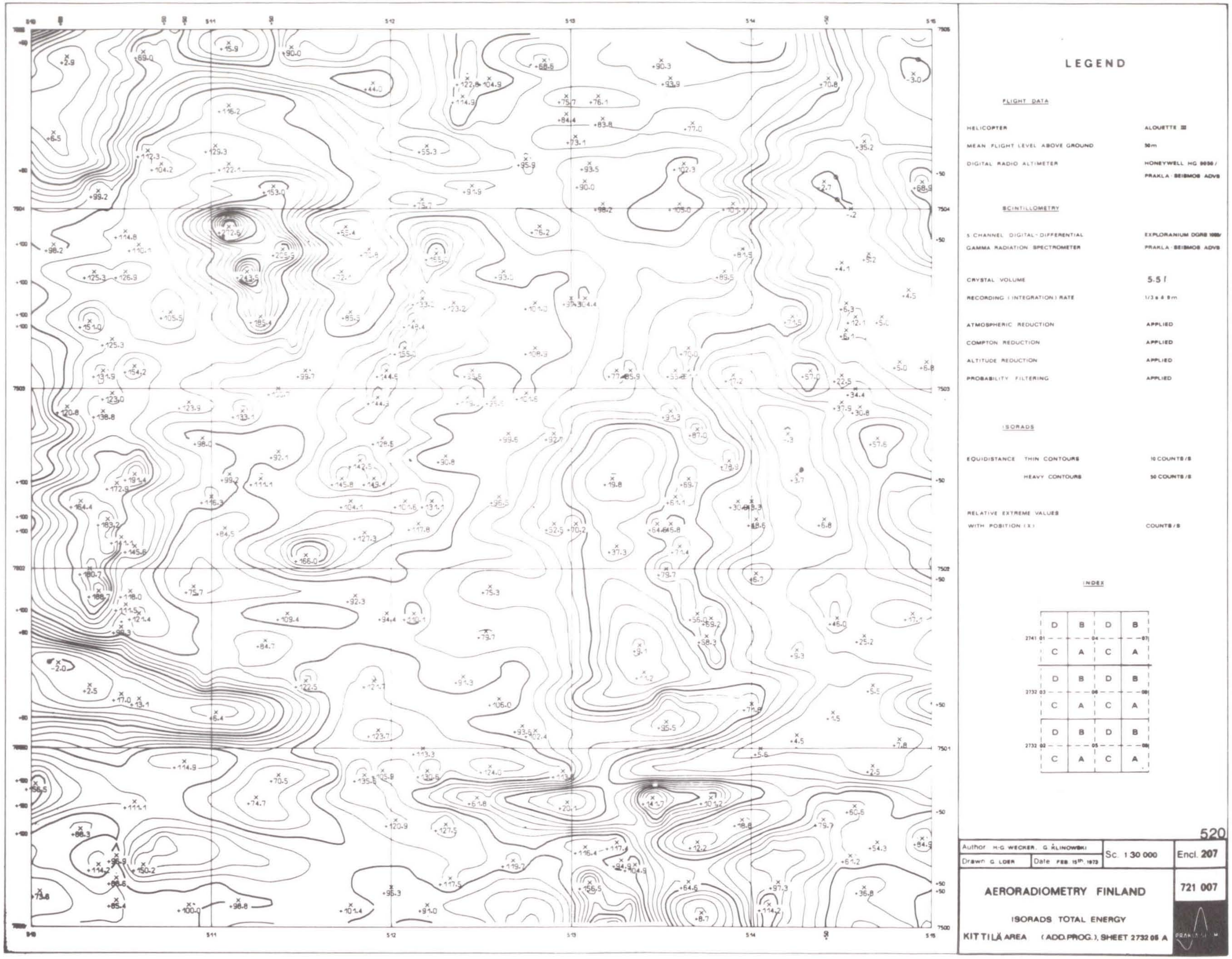

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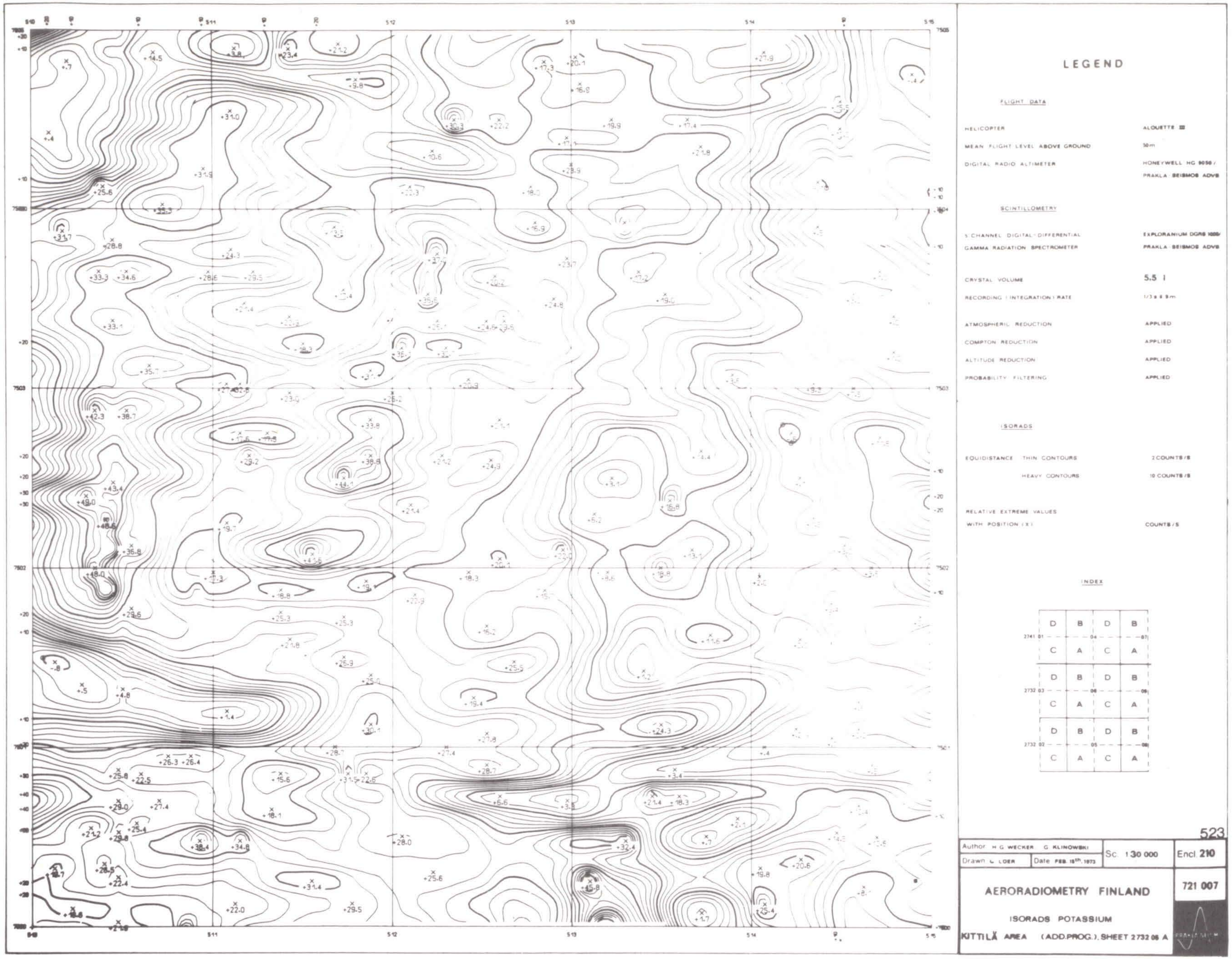

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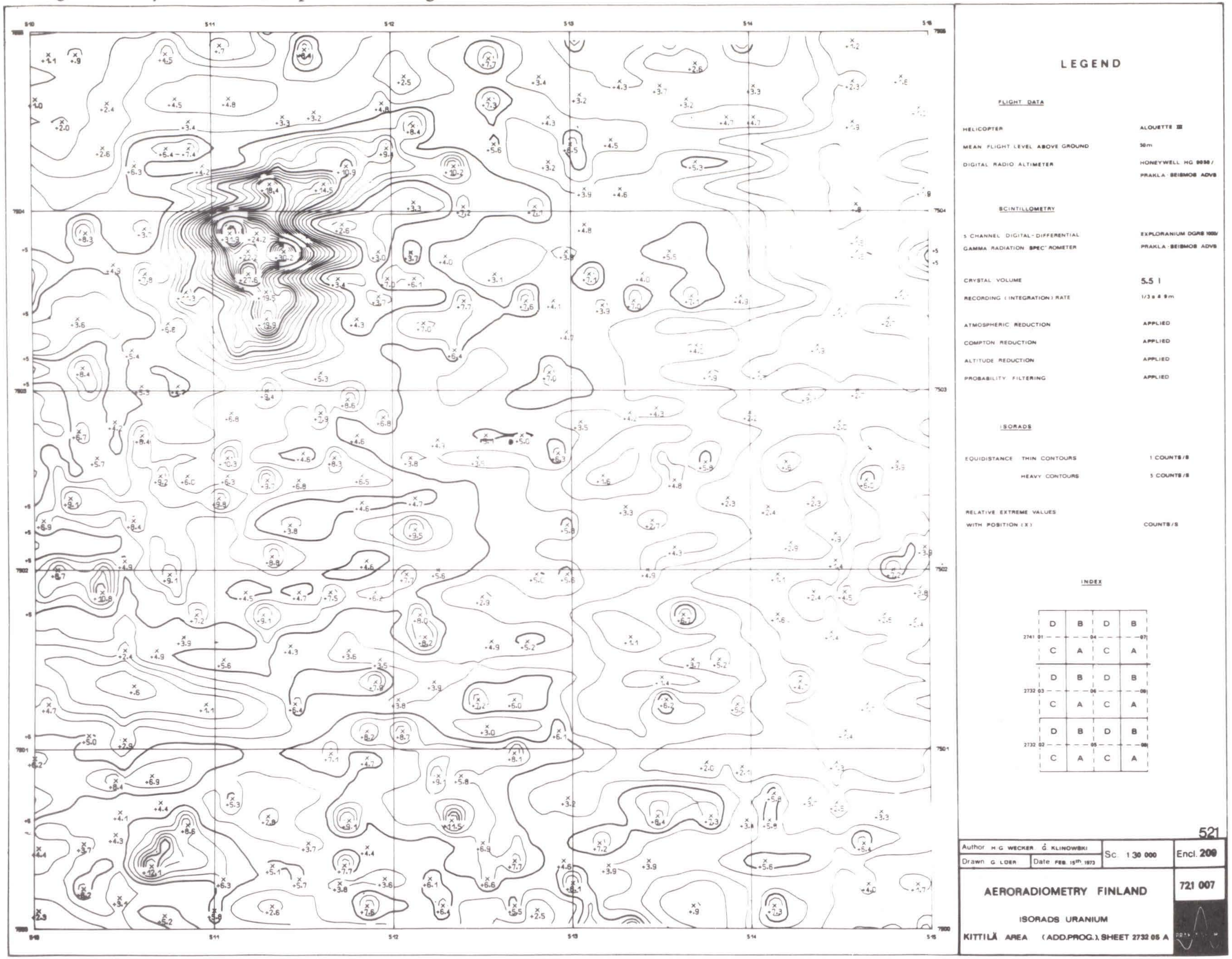

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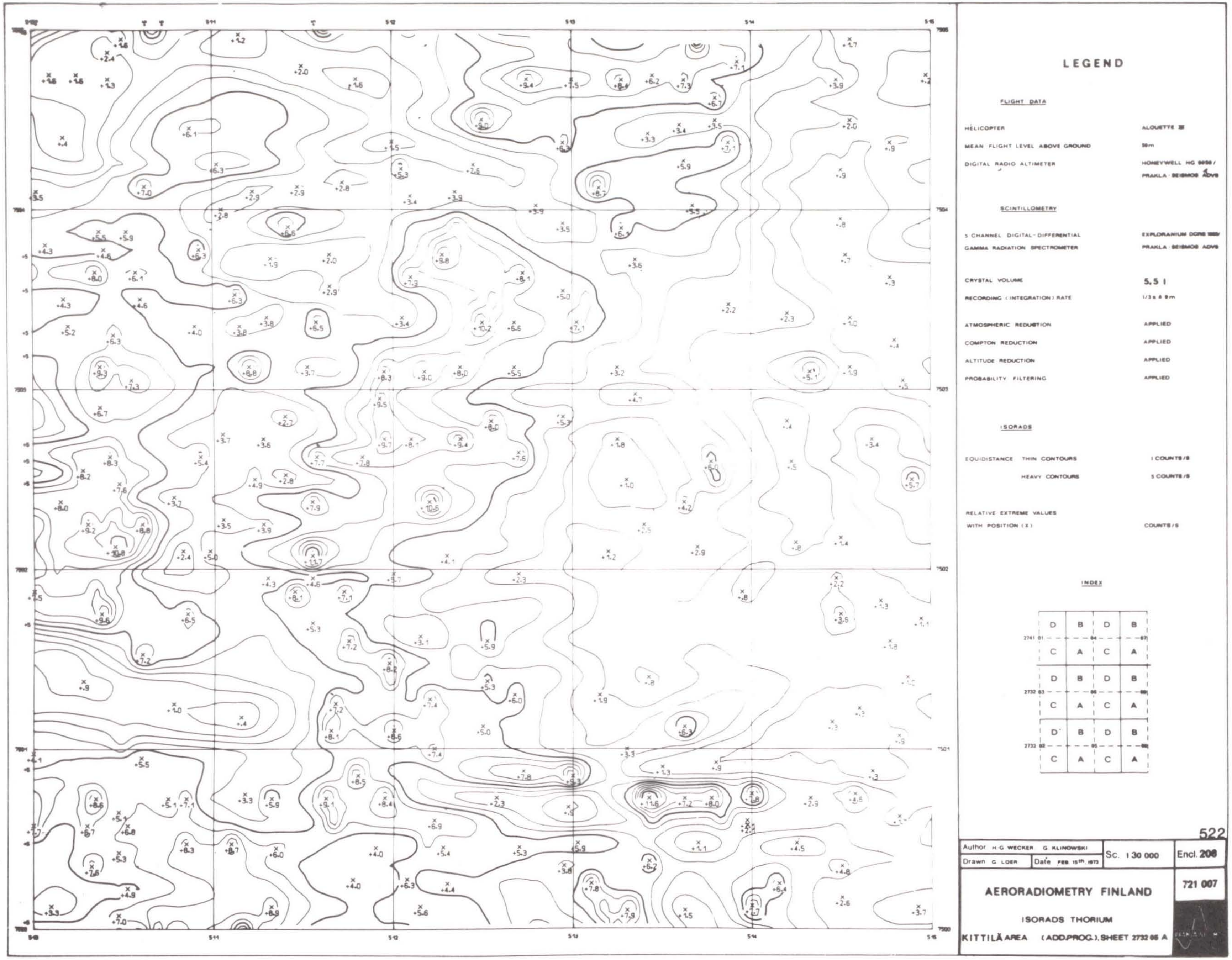

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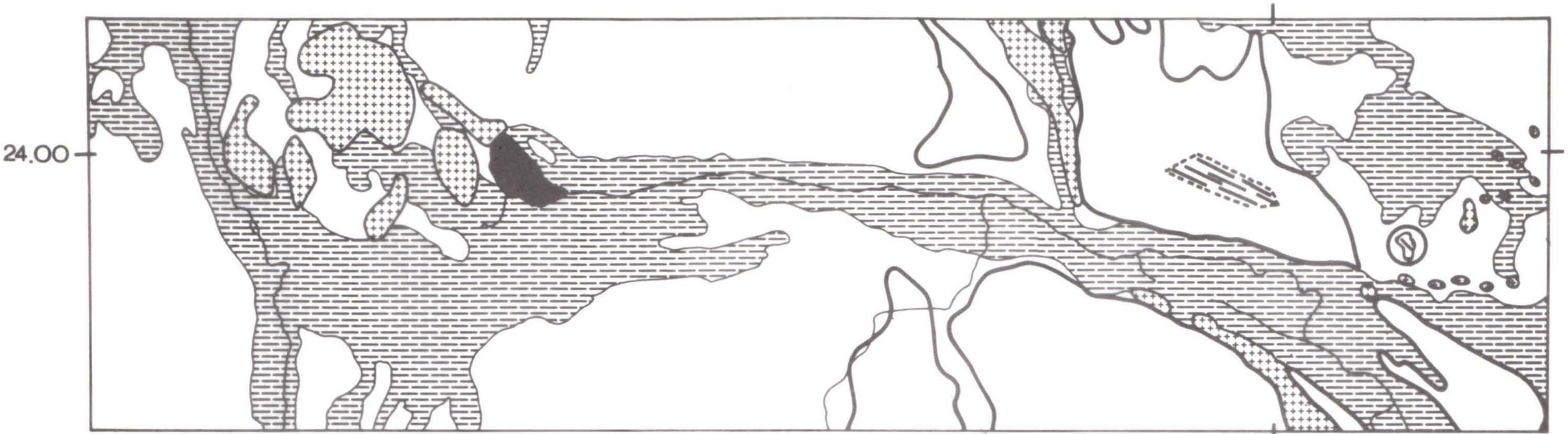
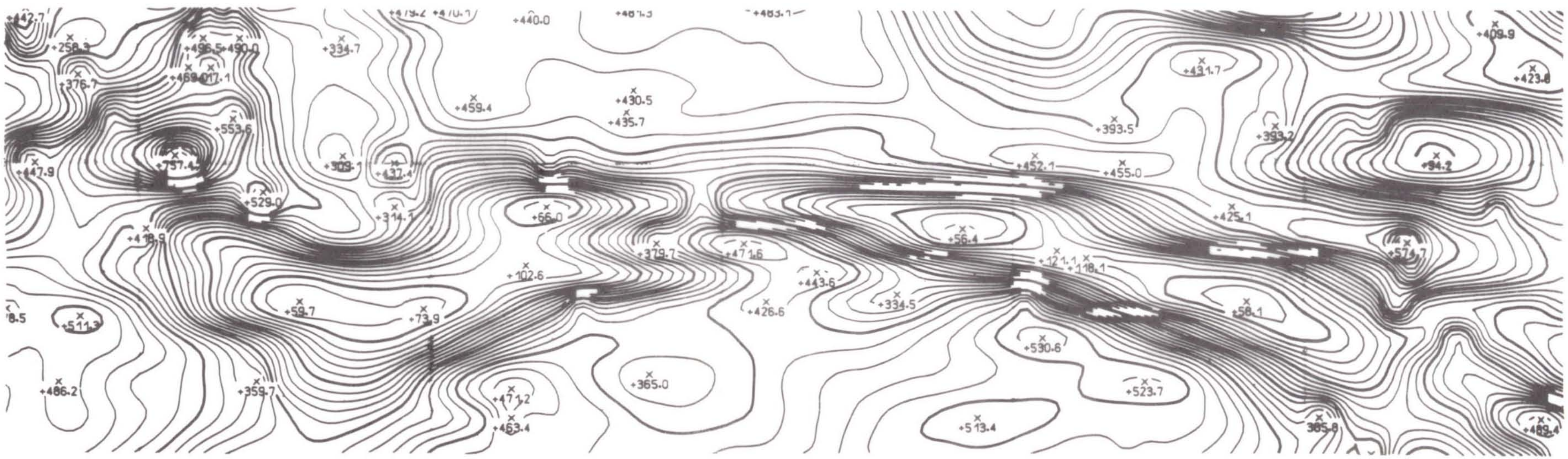


TOPOGRAPHY

EXCAVATION
URANIUM VEINS
FOREST
LAKE, RIVER
SWAMP
ESKER OR SAND
OUTCROP OF BEDROCK

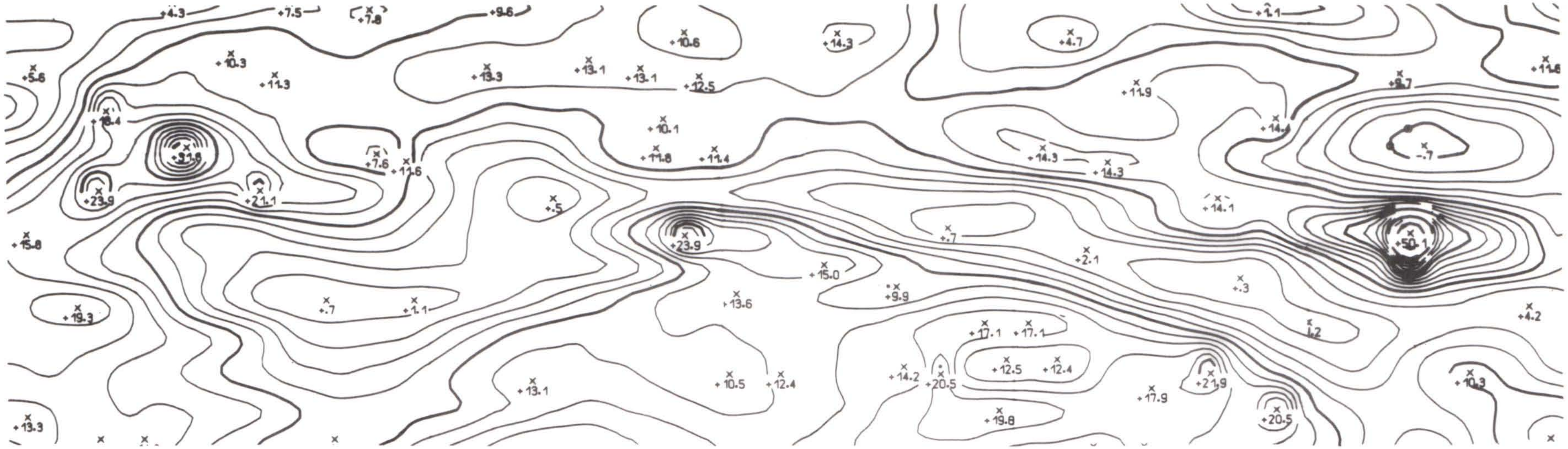


TOTAL ENERGY

PAHTAVUOMA AREA

1 KM

SCALE 1:20 000



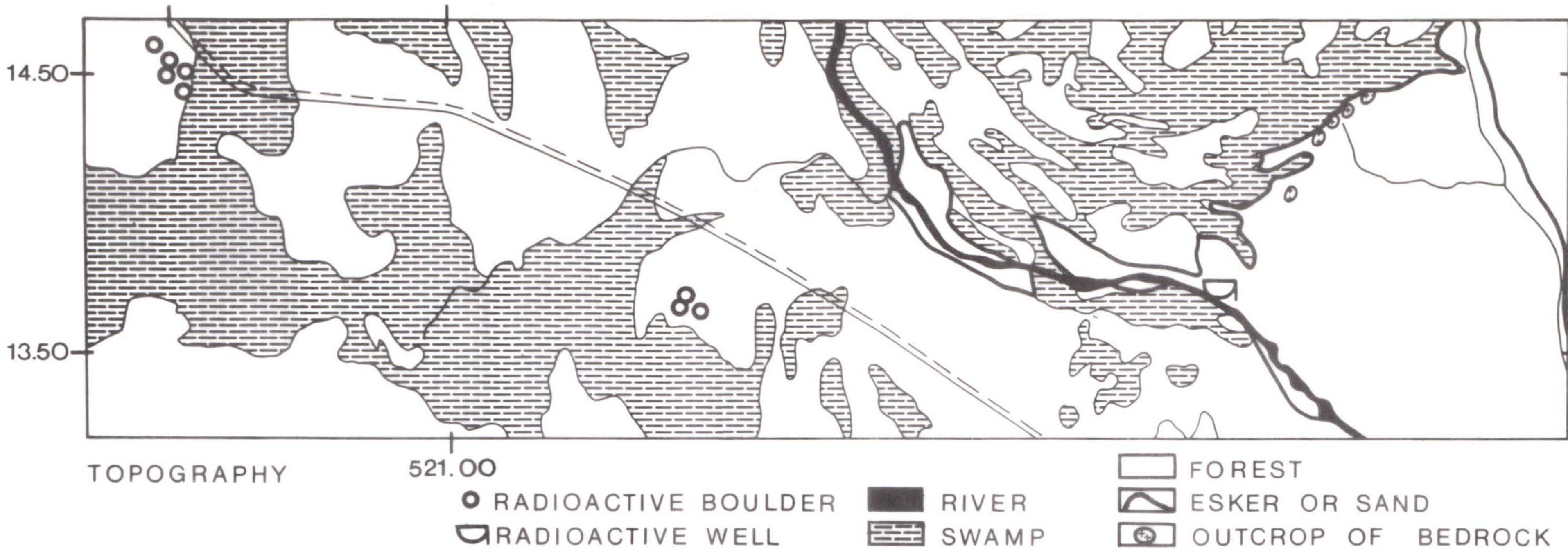
URANIUM

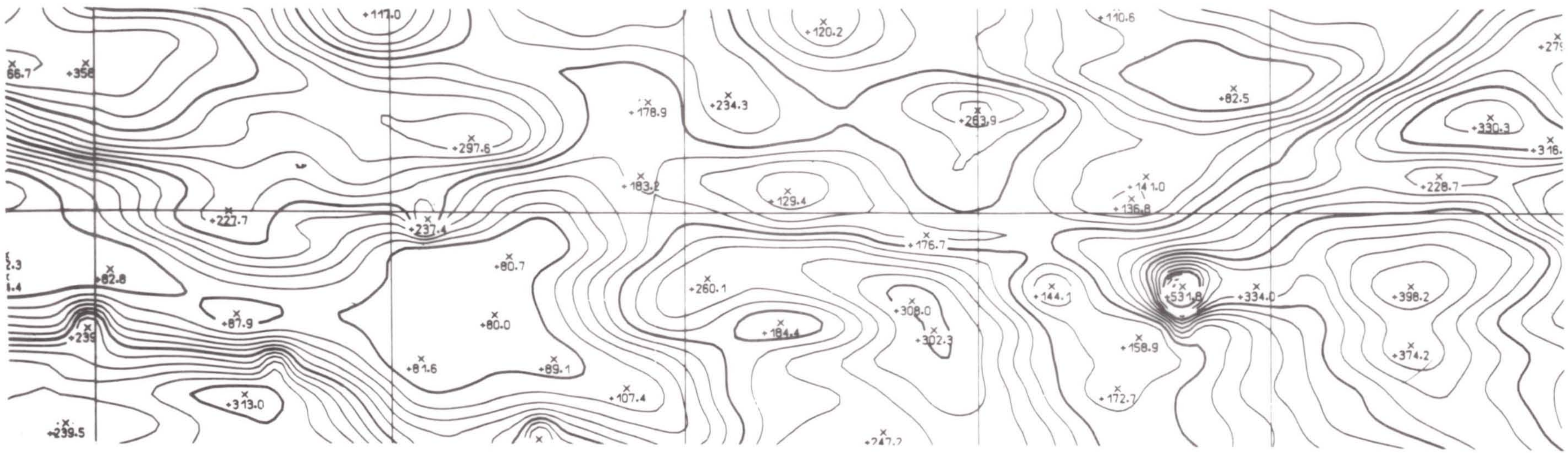
THORIUM

PAHTAVUOMA AREA

1 KM

SCALE 1 : 20 000



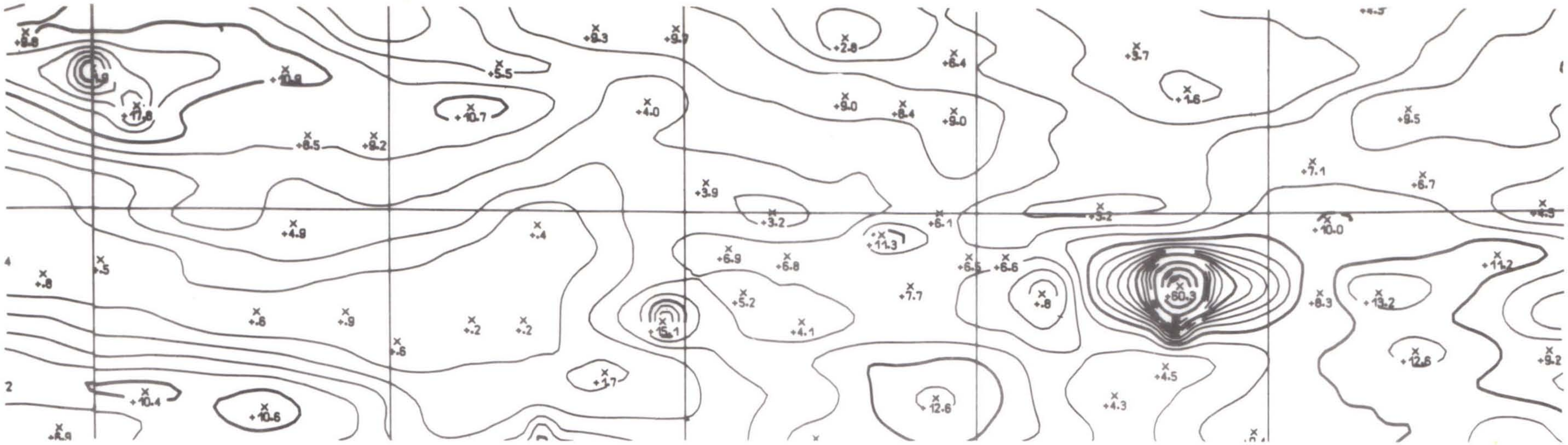


TOTAL ENERGY

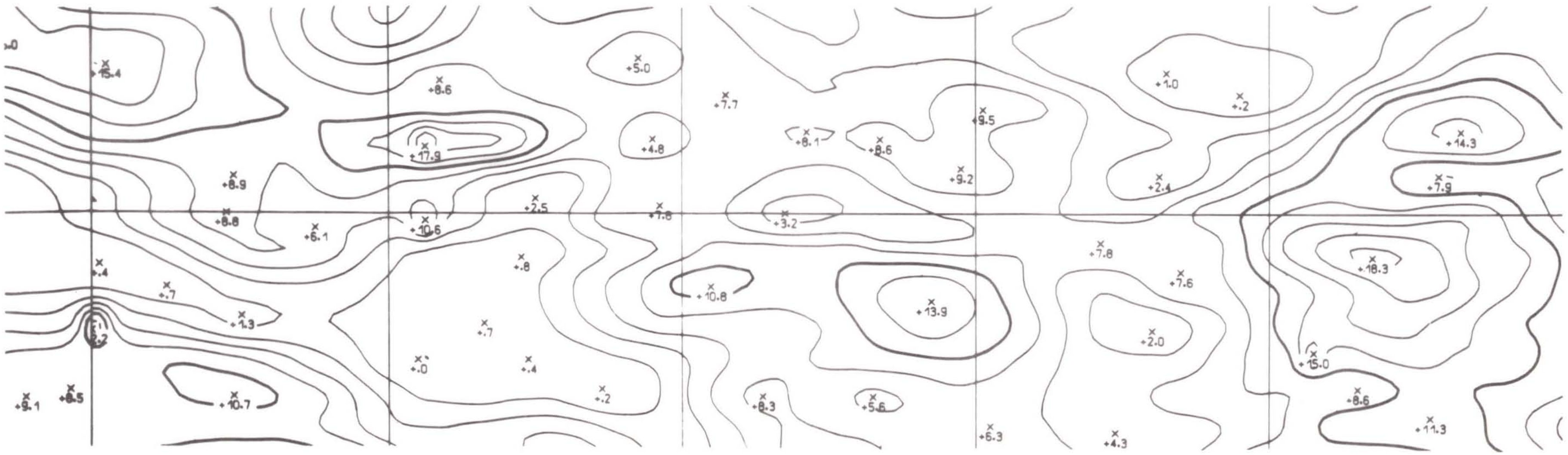
AAKENUSJOKI AREA

1 KM

SCALE 1: 20000



URANIUM



THORIUM

AAKENUSJOKI AREA

1 KM

SCALE 1:20 000

11835—75

ISBN 951-690-032-1