PRAKLA-SEISMOS GMBH

Airborne Gamma-Ray Surveys

Aero Commander 680 E equipped for GAMMA-RAY and MAGNETIC FIELD surveys

Front cover:
Bell 212 twin turbine high performance helicopter equipped for GAMMA-RAY and MAGNETIC FIELD surveys

The only direct economic geophysical prospecting method for NATURAL RADIOACTIVE MINERALS in unexplored or remote areas is AIRBORNE GAMMA-RAY SPECTROMETRY. Since 1960 more than 1 million line-km of airborne gamma-ray surveys have been flown.

Isotopes of the natural radioactive elements thorium (Th 232), uranium (U 238) and potassium (K 40) decay into stable lead within their appropriate half-life of $\sim 10^{10}$ years by simultaneous emission of α,β and γ-rays. Measurements of α, β, and γ-rays are, consequently, a suitable direct indicator.

In general, α, β and, in most cases even γ-rays are attenuated too much, during their penetration through the overburden material of a deposit as to be directly detectable. But fortunately, in the Th- und U-decay series gaseous isotopes occur, radon (Rn 220 and Rn 222), which ascend through clefts, chasms and water of the overburden to the surface. There is no gaseous isotope of potassium, therefore, K-40 only indicates surface occurrances. Radon has strong α-emission, which is often applied in emanation prospecting for extremely detailed surveys (α-cups). However, in normal prospecting, the further decay of radon into solid thallium (Tl 208) and bismuth (Bi 214) yields suitable γ-emitters NOW PRESENT AT THE SURFACE AND EVEN IN THE ATMOSPHERE. Of the latter, atmospheric Tl 208 can be neglected due to the short half-life of Rn 220 (54.5s). The longer half-life of Rn 222 (3.82 days) for Bi 214 however, yields a known effect, called the BISMUTH (AIR)-effect, which – with atmospheric variation – can simulate uranium anomalies at places distant from their outcrops. Carefully applied, bismuth (air) effects can also be used for GEOCHEMICAL Uranium prospecting.

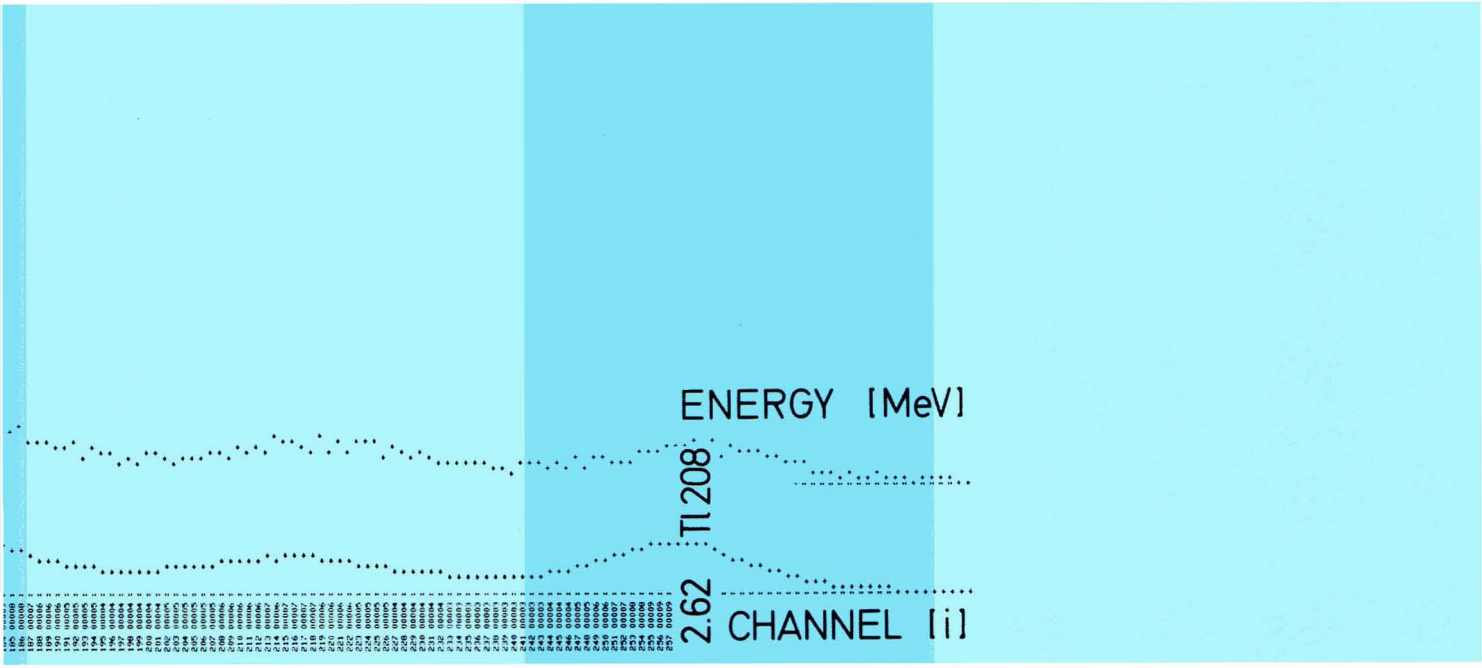
The often debated question of the PROSPECTION DEPTH for Th und U is now reduced to the question from which deposit depth a GAS can ascend, and this can lead to considerable depth figures.

The field prints of two aquired γ-ray spectra presented here show graphically the principle described above. The lower section is a spectrum print of γ-emission from a MIXED-SOURCES TEST PAD (normalized from 10 minutes recording on top of the pad): All sources crop-out, therefore, an ACTINIUM peak (Ac 228 = pre-radon-isotope of Th) appears at 0.91 MeV.

The upper section is a spectrum print of an airborne survey line (normalized from 20 seconds recording during flight), which does not show the Ac 228 peak, as the ore deposit is covered and the γ-emission is caused by ascending RADON GAS.
The main energy peaks (windows), normally used in data processing as indicators for Th, U, K occurrences, are shaded in the graph.

γ-rays are measured by counting their decay during penetration through materials of greater density. Suitable materials are artificially drawn, melted thallium-activated SODIUM IODIDE CRYSTALS Na I (Tl), which have optical properties and permit the observation of photons emitted by γ-excited atoms. A matched PHOTO-MULTIPLIER TUBE (PMT) measures the brightness (quantity of photons) as energy of the γ-quant in Mega-electron-volt [MeV] and the frequency N of the events in counts/second [c/s].

Field Plots of Natural Gamma-Ray Spectra



The equipment conforms to the specifications of the US ENERGY RESOURCES DEVELOPMENT AGENCY (ERDA)

Na I (Tl) Crystals

Modern detectors are composed of four extended square crystals, each 10.2 cm x 10.2 cm x 40.6 cm, yielding 16.9 liters (1,030 cu ins), showing better system resolution than 12 % at Cs-137 energy peak (0.66 MeV).
The crew is equipped to check the individual crystals daily and to determine system resolution on a monthly basis.

The detector cases are thermally insulated and temperature controlled to within 1^0 during flight and standby. Thus no further spectrum stabilization is required.

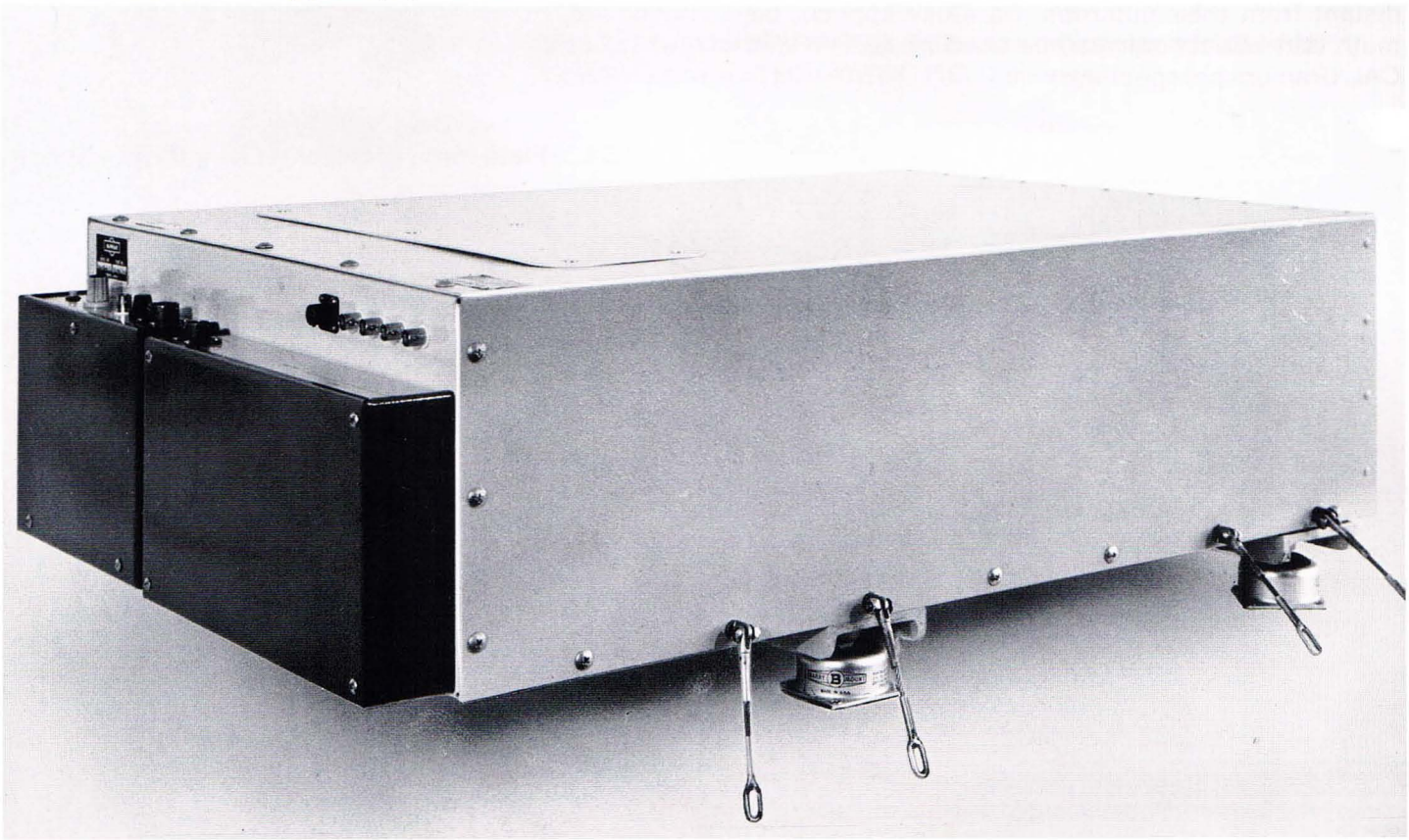
Flying γ-ray surveys, usually at 120-200 m terrain clearance, the quantity of downward (Do) looking or 4 π-detectors applied is governed by the aim of the survey and follows the recommendations of the INTERNATIONAL ATOMIC ENERGY AGENCY:

- 1 detector for ground speed < 80 km/h or reconnaissance survey
- 2 detectors for ground speed < 160 km/h or detail survey
- 3 detectors for ground speed < 240 km/h or detail survey

If a continuous BISMUTH (AIR) monitoring and reduction is required, an additional upward (Up) looking or 2 π-detector of 5.3 [l], shielded downwards by 5 cm lead, is used

- 1 shielded detector for bismuth(air) monitoring in detail survey

Extended Square 16.9 [l] NaI (Tl) Detector



Dual 512-Channel A/D Converter/Analyser

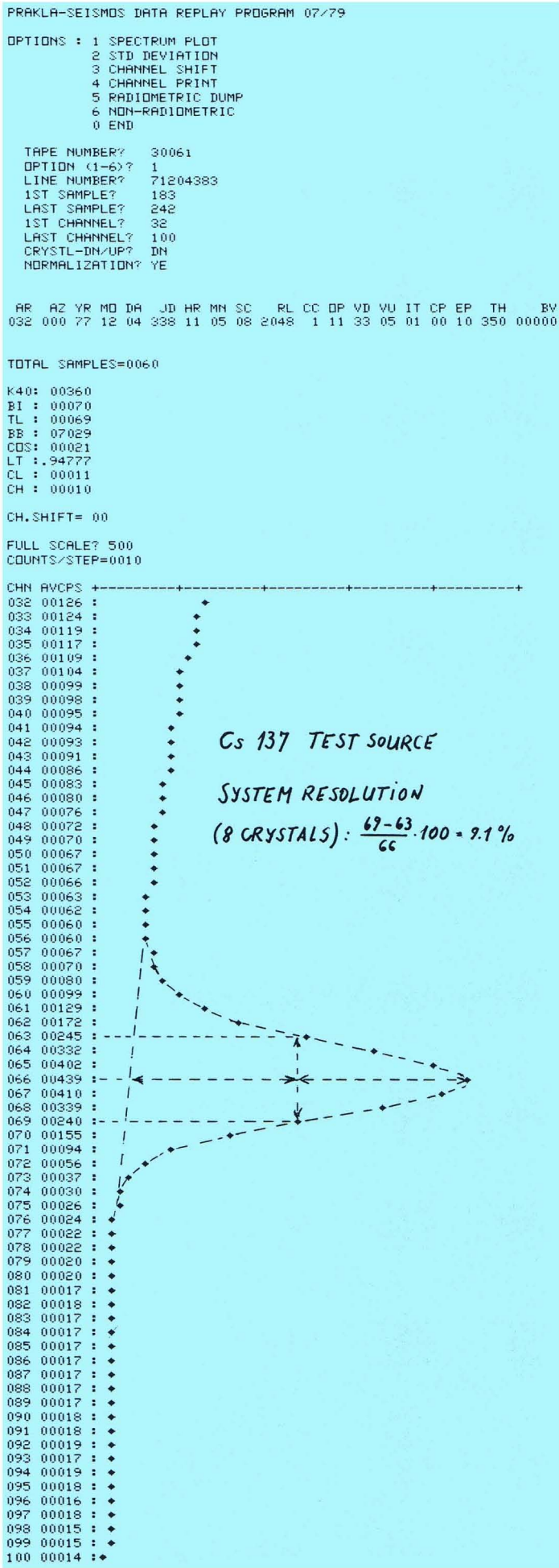
Two parallel WILKINSON RAMP 100 MHz A/D converters provide 9 bit (512 channels) resolution of the 0-10 V PMT pulses or 0.01 MeV energy resolution of the terrestrial and cosmic γ-ray spectrum of 0-5.12 MeV. The DEAD TIME or handling time of the system for every PMT pulse handled is given by DT [μs] = 3.5+0.01 i (i: number of energy channel), which leads under normal field conditions to a measured and recorded $DT_{system} < 3\%$ of the selected integration time.

The calibration of the A/D converter is performed by setting ZERO- and GAIN-potentiometers according to peak appearance of given STANDARD SOURCES on a built-in CATHODE RAY TUBE display (CRT)

- Cs 137: 0.67 MeV
- Bi 214: 1.76 MeV
- Tl 208: 2.62 MeV

STANDARD SOURCES FOR CALIBRATION

The CRT display enables the operator to carry out not only the morning/evening ground calibration checks, but also continuous in-flight-calibration checks without test sources, using mainly the always present K40 peak at 1.46 MeV. Consequently, the data spectrum is available for interpretation purposes down to 0.32 MeV. Linearity of the converter is better than 2%. Pulses of the downward and upward looking detectors are accumulated according to their energy channels in a 2 k x 16 bit dual sample buffer memory. Distinction between Do – or 4 π – and up – or 2 π – detector pulses is maintained by adding an offset address of 512 to the up-pulse channel numbers. The 16 bit memory permits 65,536 counts to be accumulated in the lowest energy (but highest count rate) channel =32 or 0.32 MeV) or even 10 s integration per sample on a calibration pad. The INTEGRATION TIME IT for the general display and recording is selected in this device.



Field Test of System Resolution

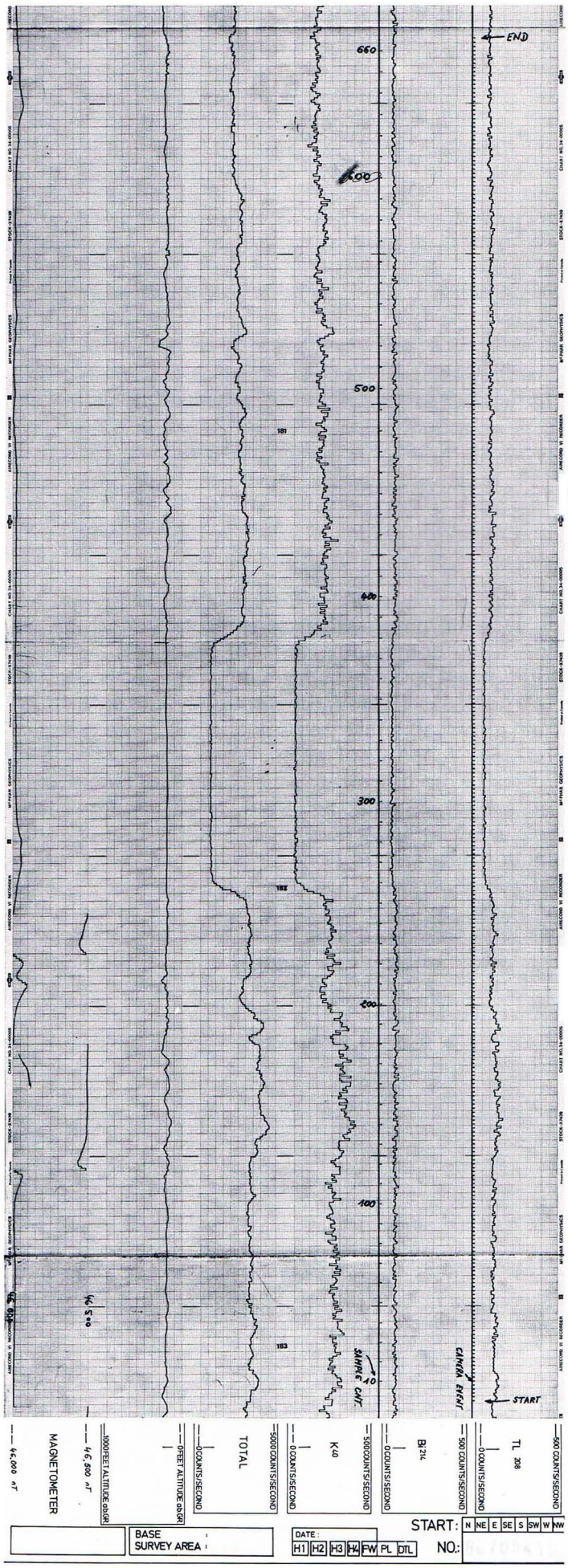
Digital Four Channel Differential Spectrometer

The spectrometer uses the digitized pulses of the A/D converter and discriminates the pulses of the downward looking (4π) system by PROM-WINDOW-SETTING for the ranges

- 0.32 – 2.90 MeV : total window
- 1.36 – 1.56 MeV : K 40 window (peak at 1.46 MeV)
- 1.66 – 1.86 MeV : Bi 214 window (peak at 1.76 MeV)
- 2.42 – 2.82 MeV : Tl 208 window (peak at 2.62 MeV)

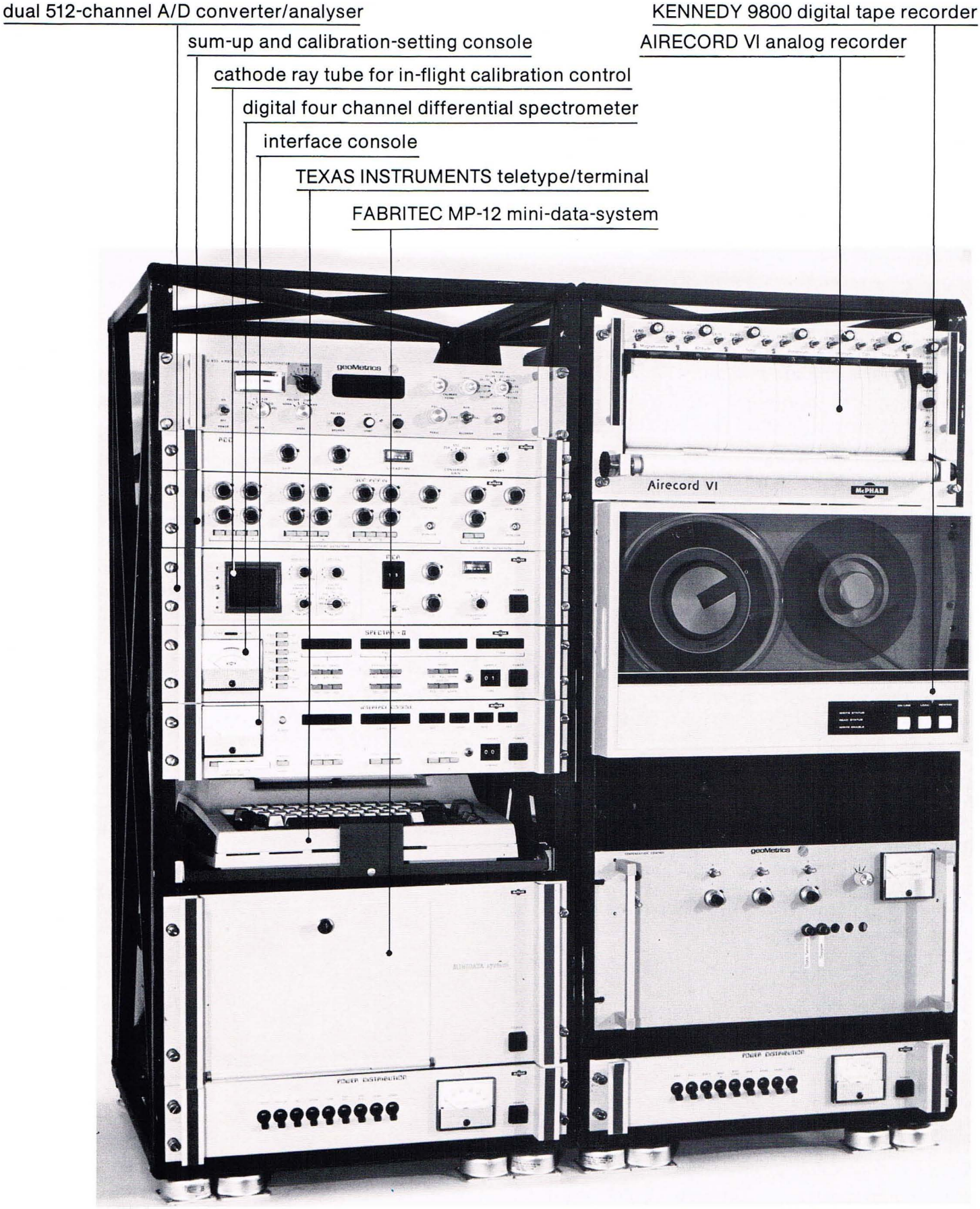
If the device is triggered externally by the A/D converter/analyser, the above window count rates are real-time compared with the accumulated spectral data of channels 32-290, 136-156, 166-186, 242-282, permitting an in-flight check of the formating/recording routines.

The window count rates defined above are transferred to the mini-data-system (ref. paragraph MDS), they are displayed digitally on the front panel on 6 digit-LEDs and, after D/A conversion and ANALOG COMPTON REDUCTION (ref. paragraph:Compton in data processing) provided as 0-10 V DC signals for ANALOG CHART RECORDING.



Analog Field Record (Helicopter Survey)
Horiz. Scale 1:50 000

Instrument Racks 1 and 2



Interface Console

Besides logistic data as sample count, elapsed time since start of line, Julian calendar (year, day, hour, minute, second) and navigational data (Doppler flight track coordinates), the interface enables digital recording mainly for digital γ-ray data reduction of

- Ground clearance, measured by HONEYWELL HG7505 — to ± 1 foot
- Barometric altitude above sea level, measured by ROSEMOUNT ALTITUDE TRANSDUCER 1241-A5-CEF — to ± 1 foot
- Outside air temperature, measured by ROSEMOUNT TEMP. UNIT E-37004-4 — to ± 0.1 K

Mini-Data-System Fabritec MDS-MP 12 / Real Time Data Check

The field proved ASSEMBLER-programmable 28VDC 1.5 μs cycle time computer, with 4k 12 bit permanent program memory and 4k 8 bit data storage memory, controls and formats the entire airborne acquisition/recording system.

The dialog with the geophysical operator is maintained through a TEXAS INSTRUMENTS SILENT 743 teletype terminal.

All relevant flight and geophysical data are either printed automatically or upon manual request. Particularly the following alarm flags are indicated automatically:

- S2 Non-alignment of window sums with spectral data
- TP Tape not ready, tape shortage
- RW Read after write errors
- S1 Non-alignment of data identifiers
- BA No signal from barometer BA
- TE No signal from thermometer TE
- RA No signal from radar altimeter RA
- IU 2 π-Total window exceeding a set threshold (inversion up)
- ID $\frac{\Delta TE}{\Delta BA} \geq 0$ Temperature gradient not inverse with sea alt. (inversion down)

Digital Recording

Digital recording is performed using a KENNEDY 9800/9 TRACK/ 1/2 INCH / 800 BPI tape unit. The MDS provides fix-format data sets of 1024 bytes per sample, two of which form one physical record.

The following data form one sample (EBCDIC-CODE)

Non-radiometric Data:
Scan ident, area no., line no., tape no., threshold for bismuth(Air) alarm, Julian date, status bits, Doppler coordinates, radar altitude, barometric altitude, air temperature, compass heading, reference count (map ident.), vector length (travelled distance), barometer setting;

Radiometric Data:

Sample count, System Do (4 π):	Dead time, K-40 window, Bi-214 window, Tl-208 window, Total window, Cosmic window, Spectral data (BINARY) channel 22 to 300;
System Up (2 π):	Dead time, K-40 window, Bi-214 window, Tl-208 window, Total window, Cosmic window, Spectral data (BINARY) channel 22 to 300

Analog Recording

6 + 2 channels are recorded on a heated-stylus McPHAR AIRECORD using 38 cm chart paper.
Each data channel is 50 mm wide, in general,connected as follows:

- Sea altitude (Magnetometer): 0–sealevel
- Ground clearance : 0–500 m
- Total window : ~ 0–5000 c/s
- K-40 window : ~ 0–500 c/s
- Sample count dots : every 10th, 100th, 1000th
- Bi-214 window : ~ 0–500 c/s
- Camera event dots : every image
- Tl-208 window : ~ 0–500 c/s

SYSTEM DIALOG Operator Protocol

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PRAKLA-SEISMOS SURVEY PROGRAM 04/79

MODE:  PL
AR(3): 031
TN(5): 20128
OP(2): 13
DA(2): 77
. (2): 09
. (2): 28
RC(1): 2
BV(5): 00348
WIND:  0

LI(8): 23102600
AZ(3): 360
GO:
200000 00000  01 8701/0001  20490651/80355944 000003
YR: 77D271H13.14.38 /00159
DA: 77.09.28        /00168
MA: 47214.0         /00172
DO303: 000037       /00188

0200 0184 0049 0052 02337 0040 097559 011 0004 003 0181 06 099785

DO304: 001726       /00209
DO305: 000037       /00216
UP303: 000002       /00222
UP304: 000157       /00229
UP305: 000010       /00236
LD: 0.98448         /00243
LU: 0.99859         /00246
ST: 1111111111111   /00251

0400 0152 0044 0044 01994 0038 098159 010 0004 003 0162 06 099825

0600 0203 0048 0049 02398 0031 097708 011 0003 003 0177 05 099802

0800 0229 0055 0057 02734 0030 097792 012 0003 003 0193 05 099814

200001 00845  01 8701/0882  20490621/80361740 003326

1000 0366 0077 0089 04212 0032 096442 015 0004 003 0267 05 099729

1200 0452 0095 0110 05249 0039 096957 019 0006 004 0341 07 099747

1400 0244 0053 0056 02819 0047 098118 012 0004 003 0209 08 099814

1600 0231 0048 0049 02594 0041 097594 012 0004 003 0195 06 099788

FLAGS: 01727  MA
FLAGS: 01797  ID

1800 0251 0069 0077 03314 0044 096710 012 0004 004 0227 07 099747

200002 01853  01 8701/1890  20490550/80363947 007430

2000 0234 0056 0058 02905 0026 095965 011 0003 003 0195 04 099715

2200 0257 0049 0045 02845 0018 097103 011 0003 002 0187 03 099782

HA:
200002 02253  01 8701/2290  20490537/80364743 08902
YR: 77D271H13.49.31 /02252
ST: 1111111111111   /02252
NL:
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At present the spectral data are only used for data check/recovery (very important in case of electronic channel shift) and for spectrum display. However, a procedure is being developed to use the theoretical spectrum for suppression of statistical noise in the window data of consecutive samples, thus enhancing considerably the spatial resolution.

The following devices from our DATA CENTER in Hannover are used:

- Control Data Computer Cyber 175/208
- CALCOMP Flat Bed Plotter 748
- CALCOMP DRUM Plotter 936

9 bit/even parity EBCDIC/BINARY data
2 k records

Second difference format and data check and corresponding corrections

10 sample moving average on cosmic window CosDo.
Dead time reduction for window data N_i.
Optional: statistical filter on window data.

Reduction of γ-ray interaction of Th, U, K sources.
The reduction parameters α, β, γ, δ are determined on test pads or by laboratory standards.

Aircraft background and cosmic window ratio are determined simultaneously by high terrain clearance flights.

Bismuth(Air) reduction is composed of:

- Shield penetration red. of terrestrial into Up-Det.
- Geometric factor for conversion of averaged BiUprates into BiDo (Air) rates
- Reduction of Bi(Air) from BiDo and TotDo.
- Penetration and geom. factors are determined by water/land flights at various terrain clearances.

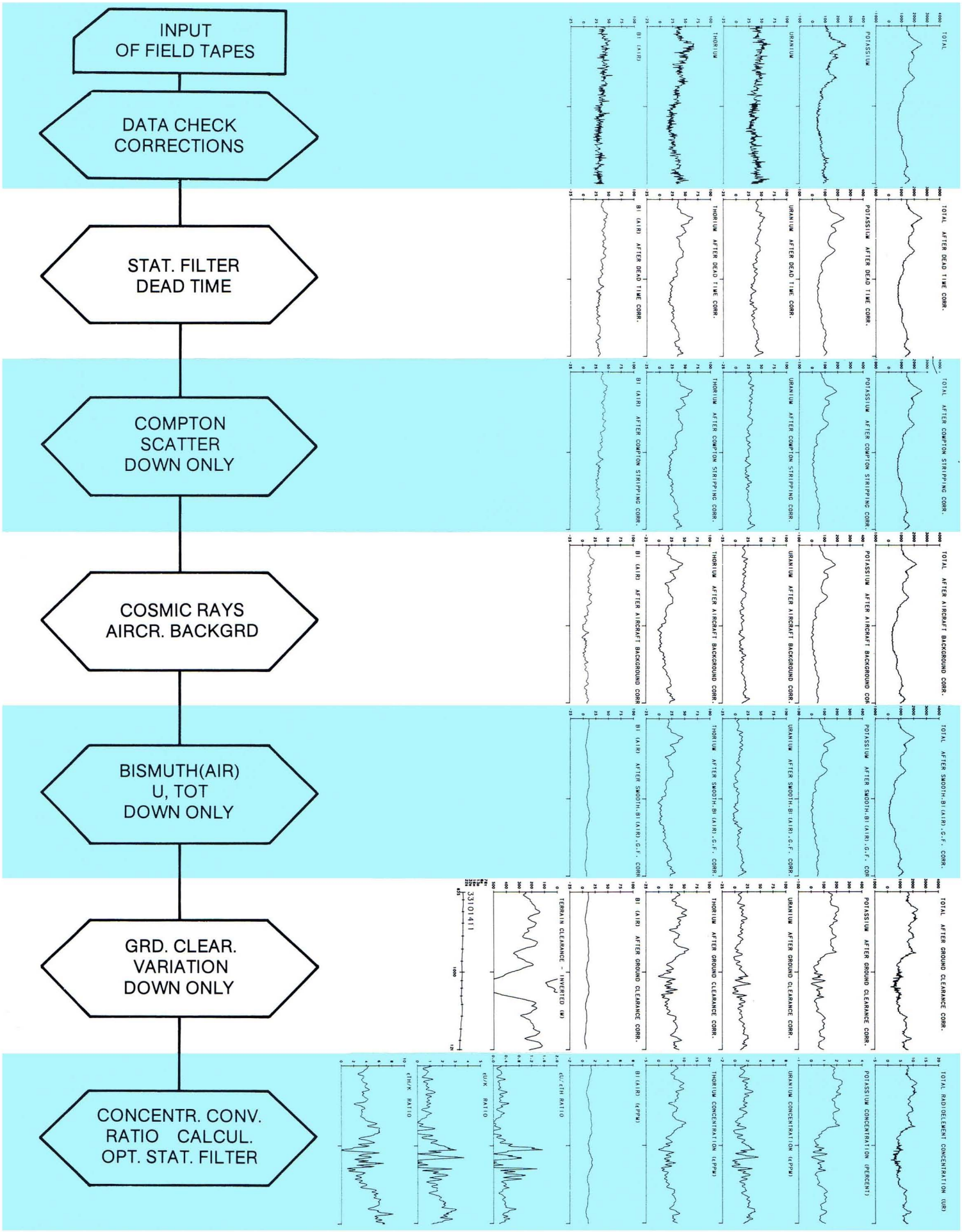
The deviations of ground clearance of the aircraft from selected flight level are reduced applying the exponential attenuation law, considering also variations in air temperature and air pressure.
The attenuation factors are determined simultaneously with the concentration conversion factors by dynamic test base flying at various altitudes.

The reduced window data in c/s are optionally converted into

- Equivalent ground concentration percent, ppm
- Ground radiation in $\mu Ci/m^2$
- Ground radiation in multiples of average ratio

Final data are taken for ratio calculation
Optional: Statistical filter on data prior to plotting.

Processing Routines and Results



The results are presented in various ways:

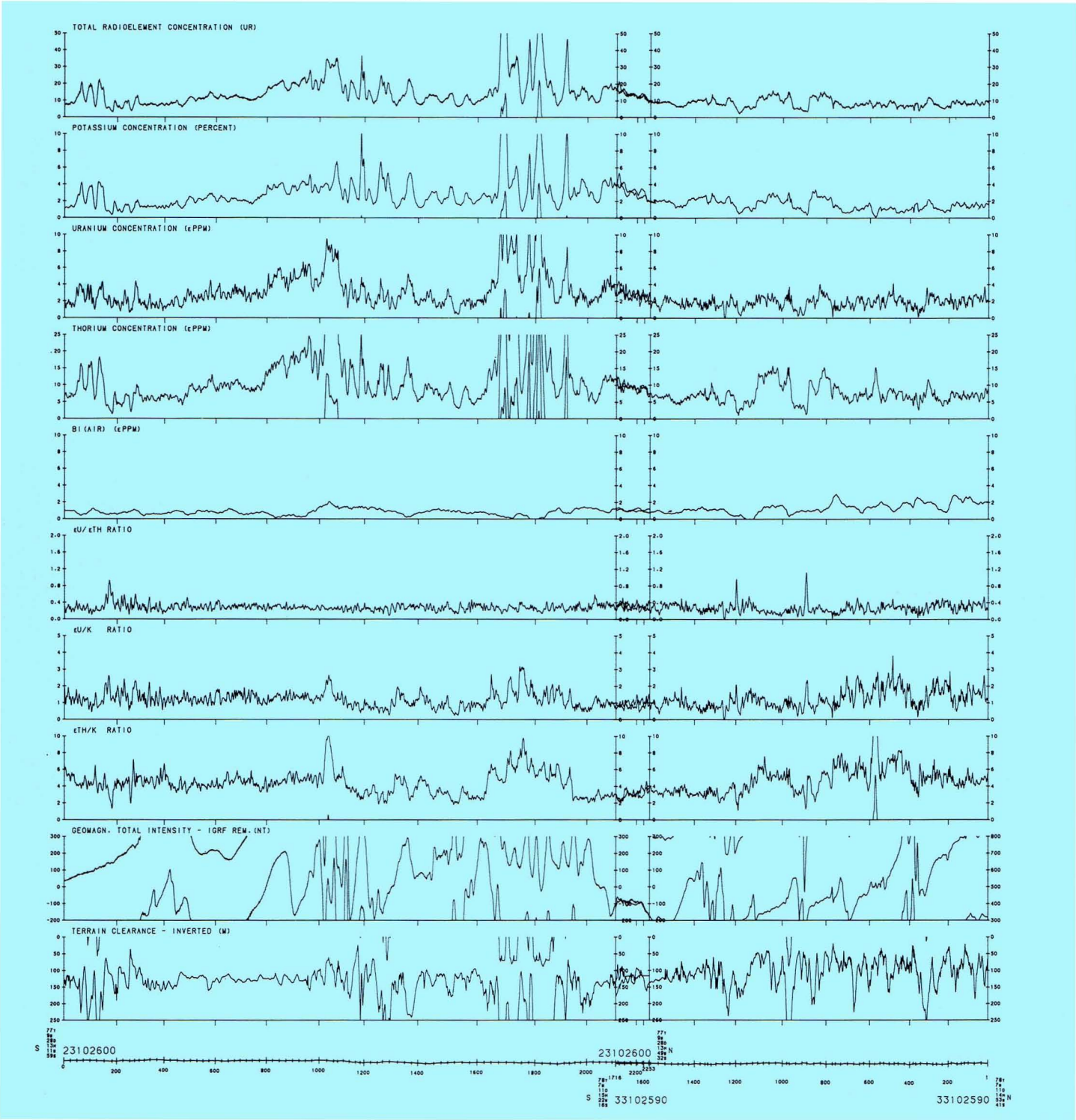
- Magnetic Tape containing final processed data
- Stacked or Calcomp Profile Plots, in arbitrary scales, of selectable scale of the γ-ray window contours, optionally completed by window ratios and/or geomagnetics.
- Contour maps, in arbitrary scales, and scale and equidistance of contours of the individual window or ratio data.

A collection of individual contour maps of the same area is presented on the following pages. Of course, map coordinates and legends had to be omitted for understandable reasons.

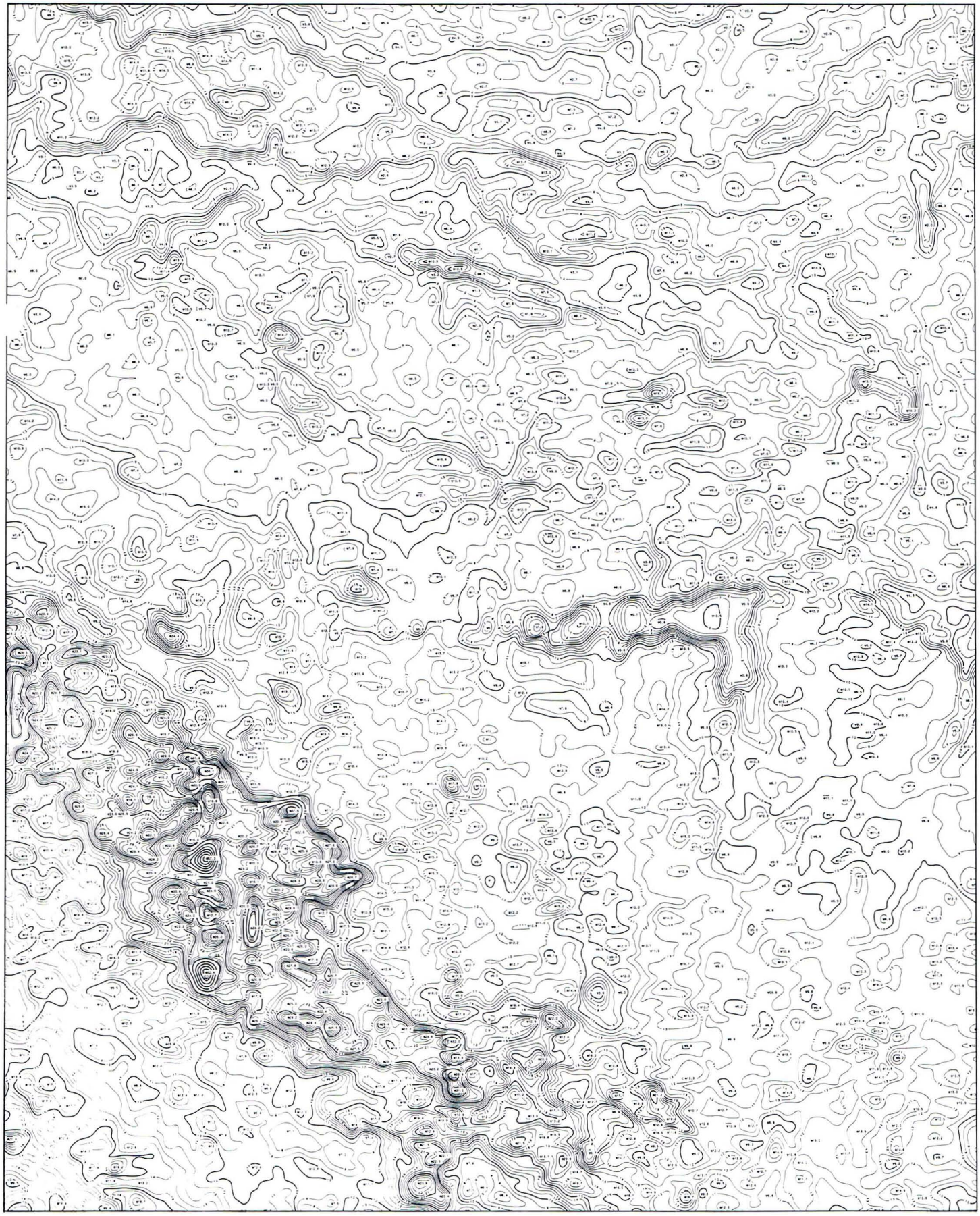
The data were acquired using Bell 212 helicopters over an extremely mountainous area:

Detector volume	: 32 l
Shielded detector volume	: 5 l
Terrain clearance	: 120 m
Line spacing	: 500 m
Ground speed	: 45 m/s
Altitude above sea level	: 1500–4000 m

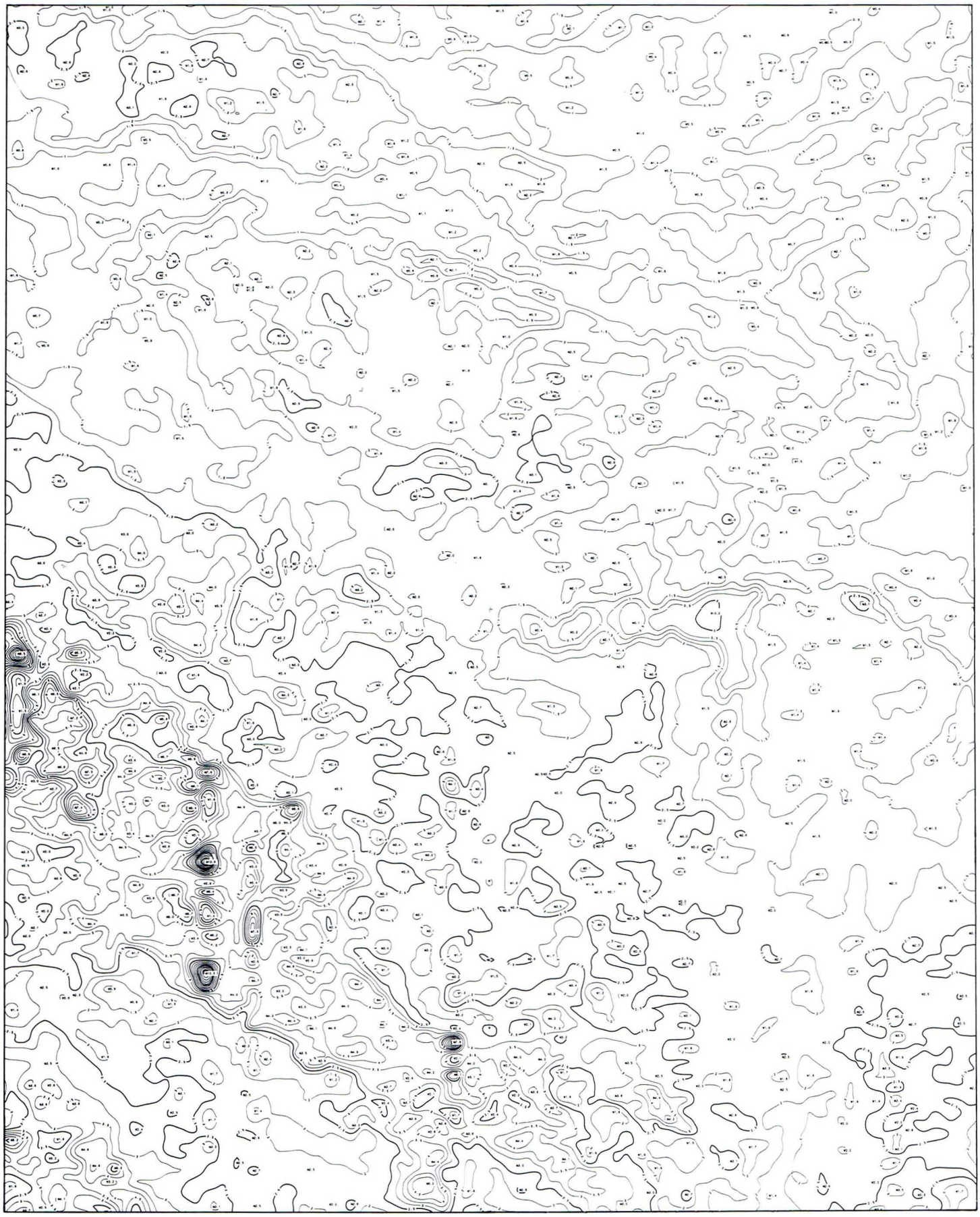
Processed Profile Plot (Helicopter Survey) **True Horiz. Scale 1:250 000**



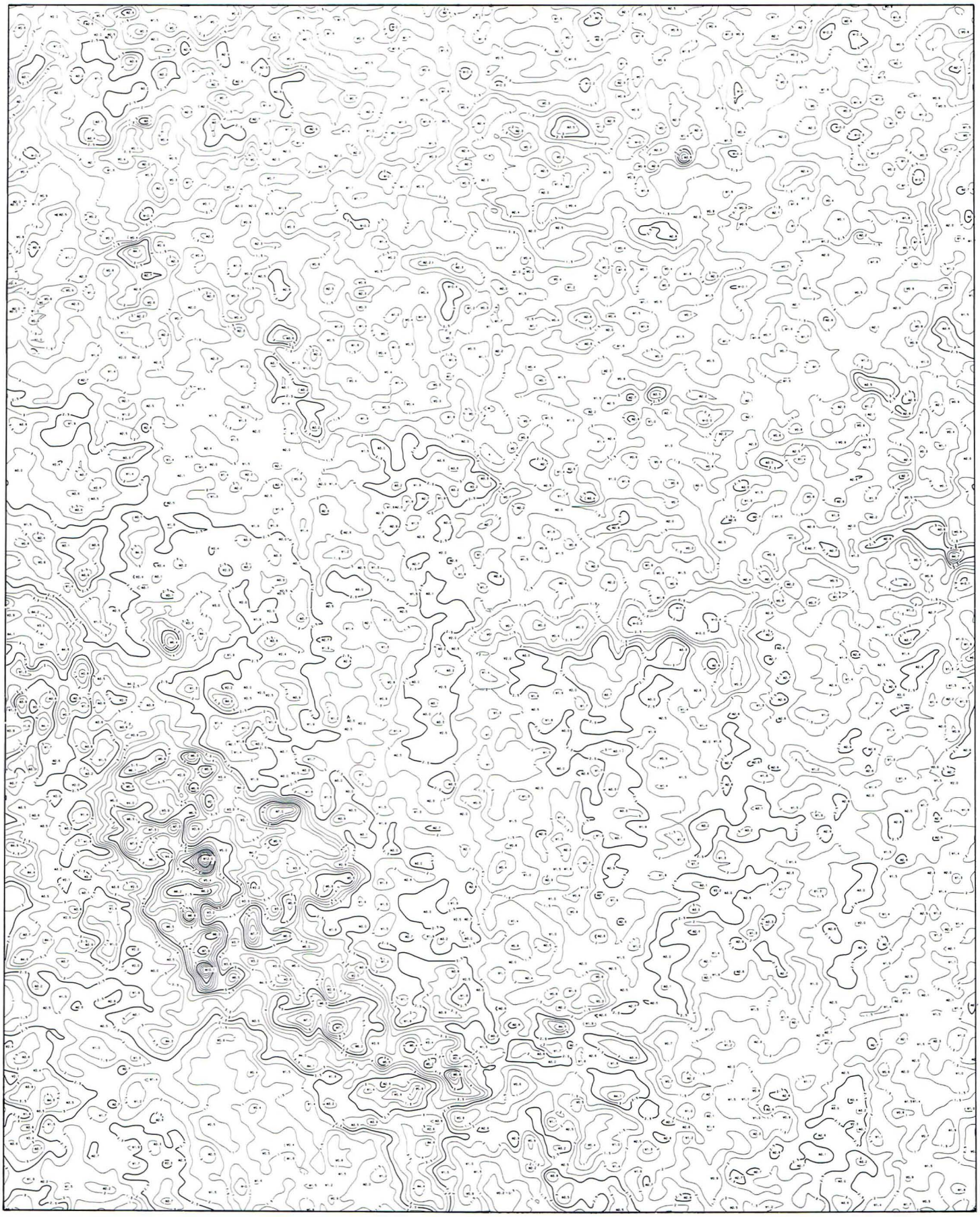
Total Radioelement Concentration Contour Map (ur)
Scale 1:250 000



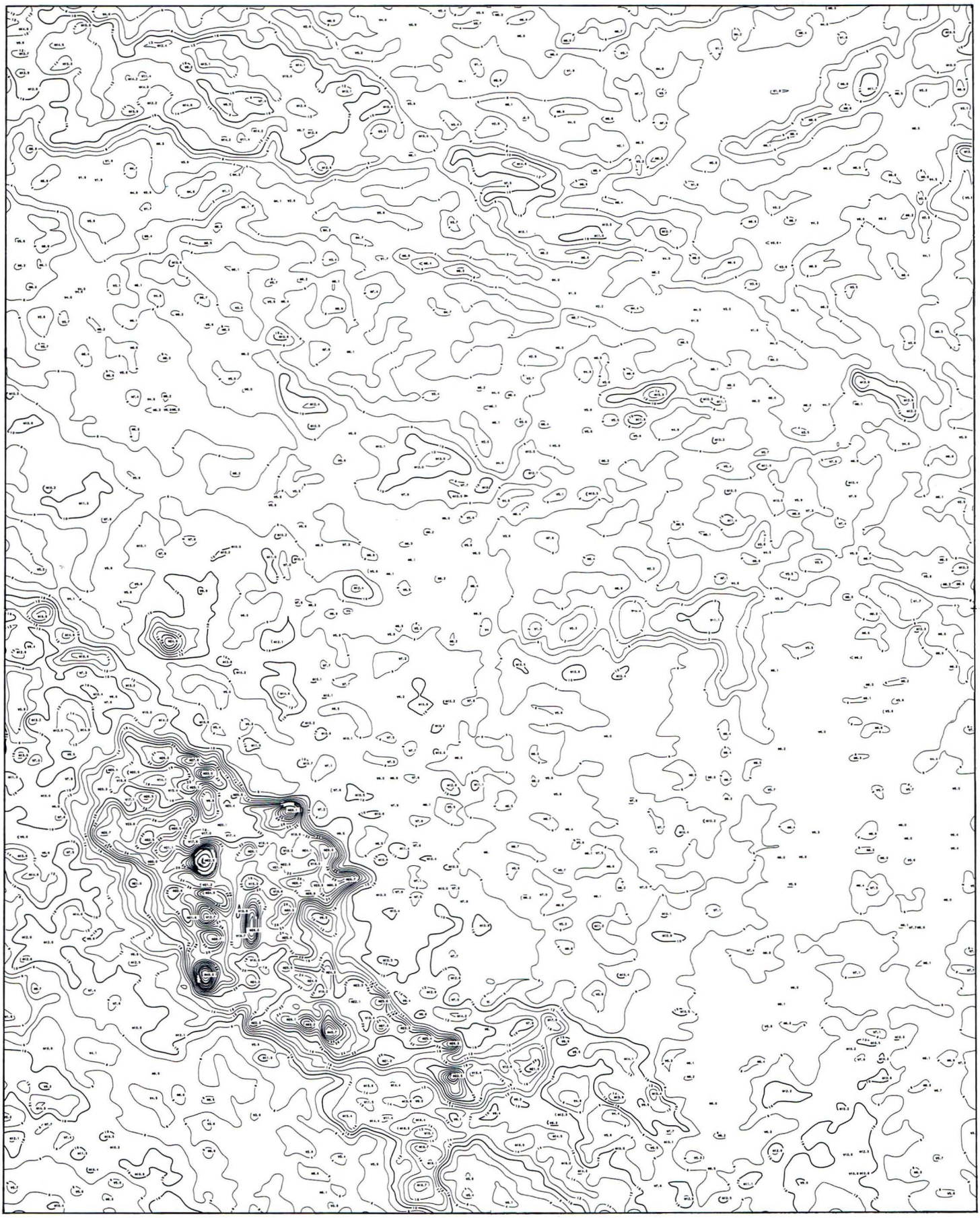
Potassium Concentration Contour Map (percent)
Scale 1:250 000



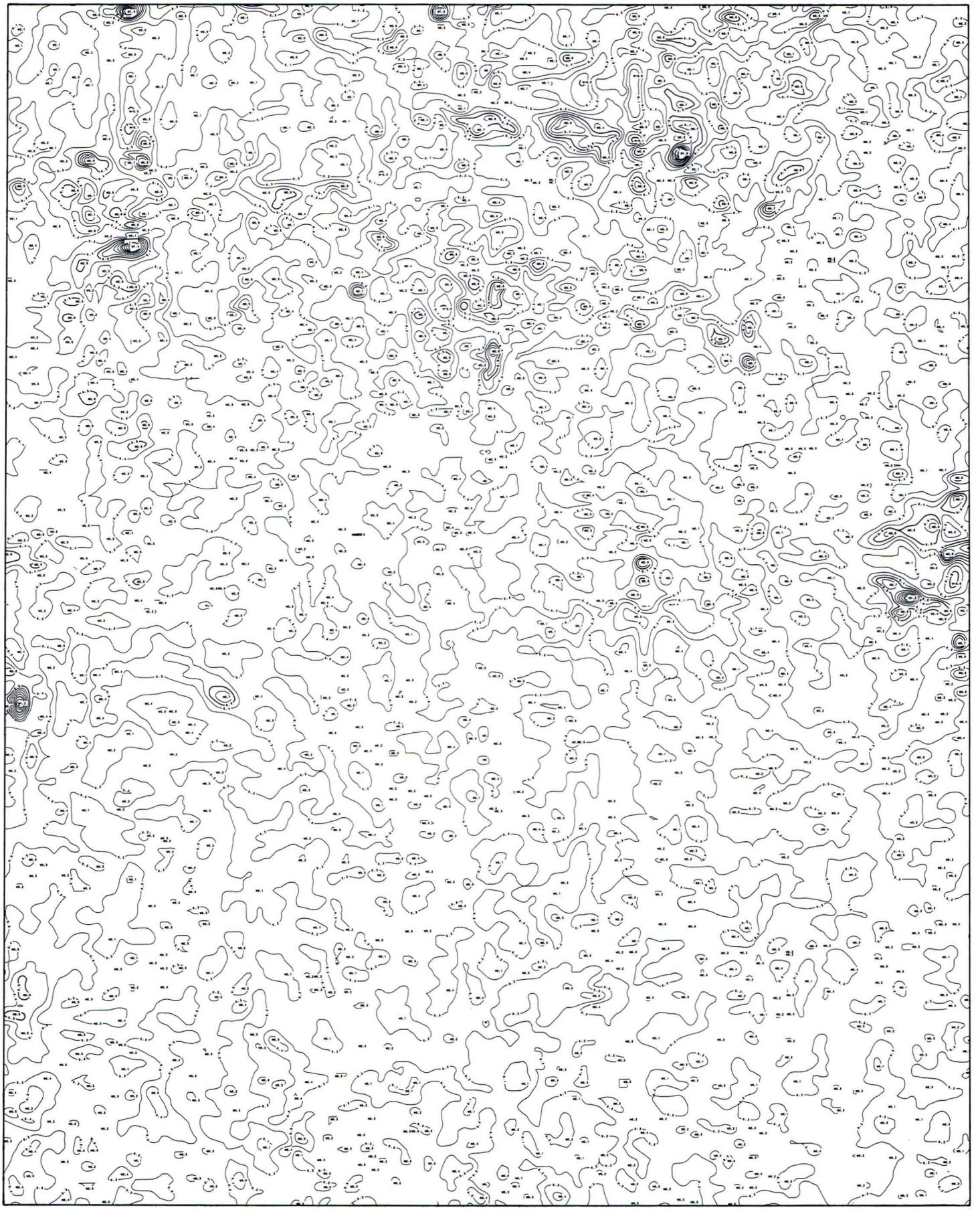
Uranium Concentration Contour Map (e ppm)
Scale 1:250 000



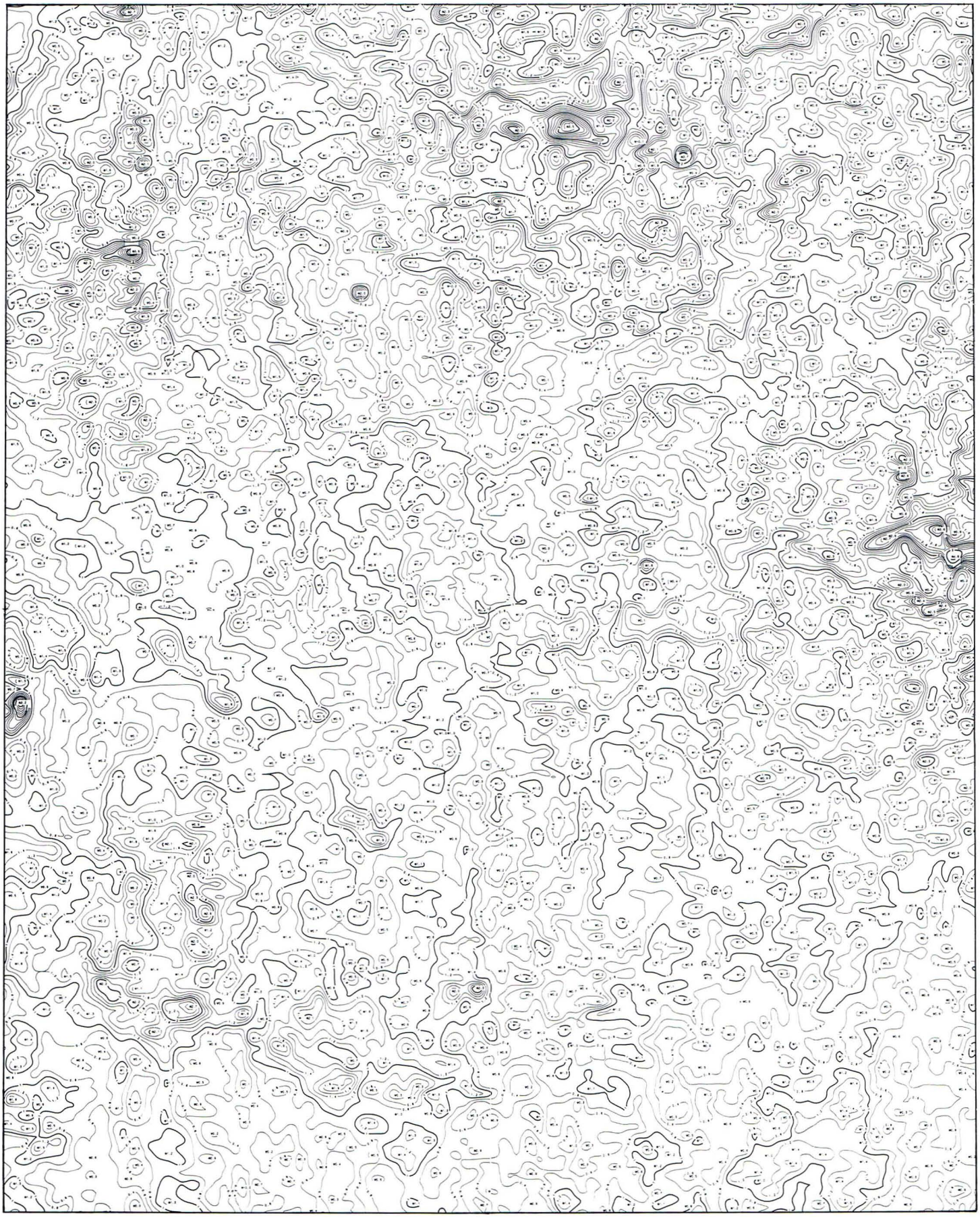
Thorium Concentration Contour Map (e ppm)
Scale 1:250 000



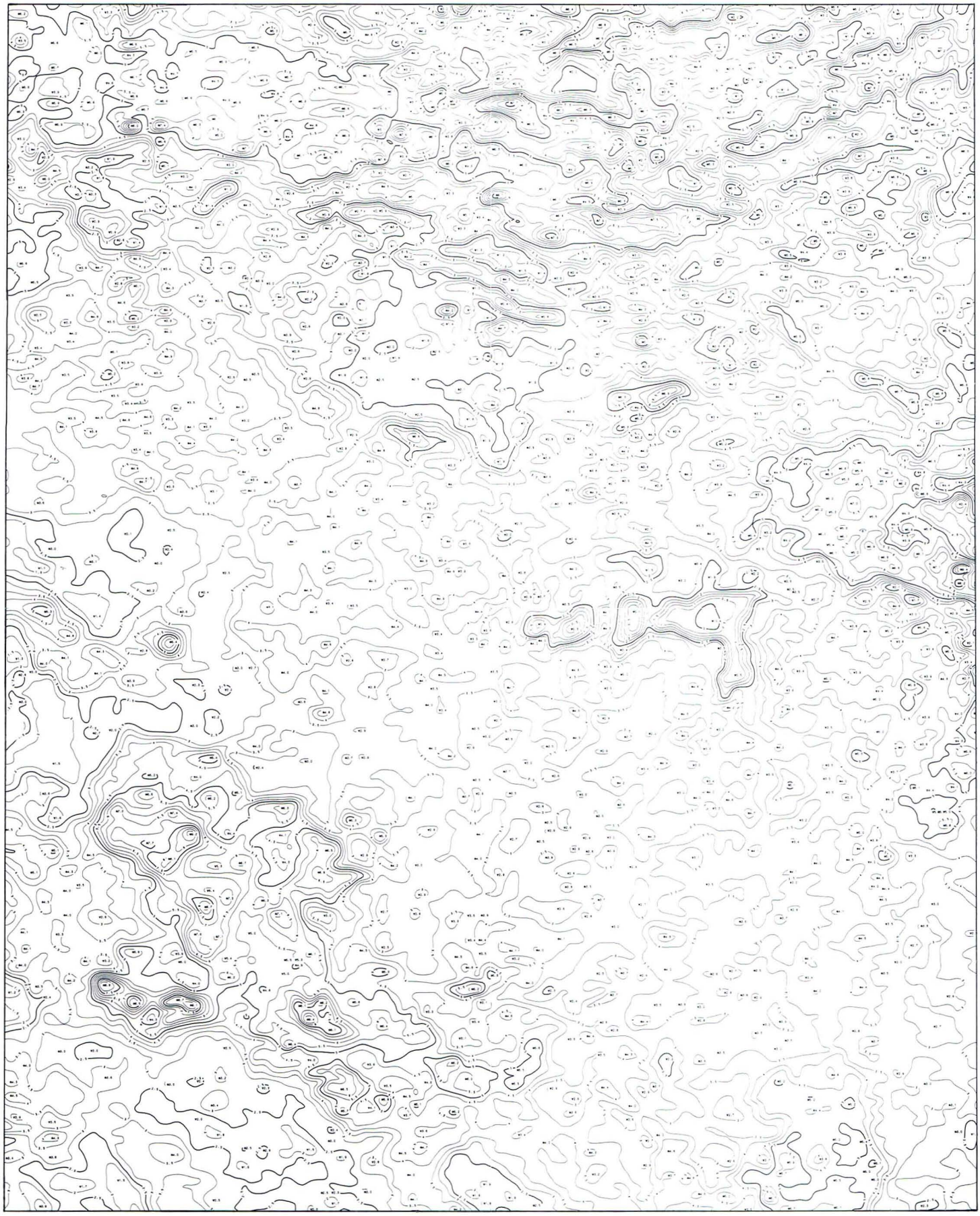
eU/eTh Ratio Contour Map
Scale 1:250 000



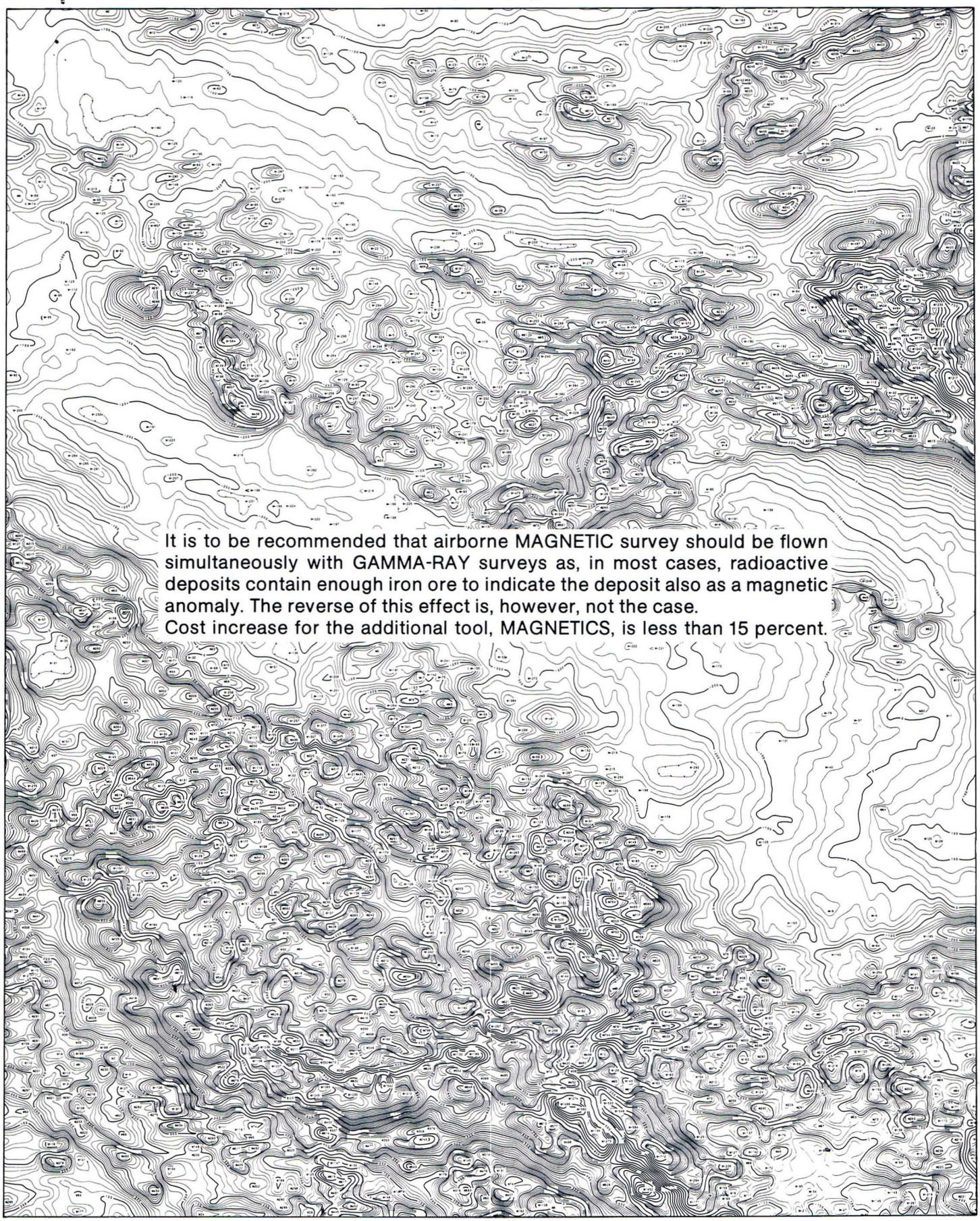
eU/K Ratio Contour Map
Scale 1:250 000



eTh/K Ratio Contour Map
Scale 1:250 000



This aeromagnetic contour map – scale 1:250 000 – is an example of a two method survey. It covers the same area as the maps on pages 13-19.



It is to be recommended that airborne MAGNETIC survey should be flown simultaneously with GAMMA-RAY surveys as, in most cases, radioactive deposits contain enough iron ore to indicate the deposit also as a magnetic anomaly. The reverse of this effect is, however, not the case.
Cost increase for the additional tool, MAGNETICS, is less than 15 percent.

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