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MICROFILMED

GAMMA RAY SPECTROMETER SURVEY

NORTH EAST TASMANIA

DENVER-DALLAS-BRISBANE OFFICES OF

GEOPHOTO SERVICES LIMITED.

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PART I

THE MULTIPLE LARGE CRYSTAL DIGITAL AIRBORNE GAMMA RAY SPECTROMETER SYSTEM USED IN THE TASMANIAN SURVEY

INTRODUCTION

Subsidiaries of Texas Instruments have developed and used an airborne geophysical system that applies gamma ray spectroscopy for determining the distribution of uranium, thorium and potassium near the surface of the earth's crust. Potassium is measured from potassium -40, the naturally occurring gamma ray emitting radioactive isotope present in all potassium minerals. Uranium and thorium are determined indirectly from bismuth -214 and thallium -208, gamma ray emitting daughter products in the uranium and thorium natural decay series (Figures 1 and 2).

THE SYSTEM

At the outset it is important to realise that this system is not just a simple "4 channel type" small crystal instrumen similar to those used extensively in routine reconnaissance surveys for uranium in Australia in the last year. This latter instrument has drawn criticism, firstly on the theoretical grounds that it does not allow proper discrimination of the gross spectrum into significant components and secondly, by sections of the industry after practice that it performs little better than a gross count scintillometer. The Geophoto system is a sensitive geochemical tool of the multiple, large-crystal type using digital processing.

There are but two units of this type of system in existence, both now employed outside Australia in large surveys in Canada. Government agencies in North America are developing similar systems.

Initial research on the development of the system was begun 12 years ago. The prototype of the present system was designed and constructed in 1964 and has been utilized in numerous surveys for government agencies since then. The system has been constantly modified throughout its life period in an effort to achieve greatest significance of the digital data. The data are recorded in digital form for these reasons:

1) To provide gamma ray energy spectral shape necessary to allow calculation of radiation from uranium and thorium decay and potassium -40.
2) To allow accurate and precise data reduction by subsequent computer operation.
3) To provide high volume data reduction in less time at less cost.
4) To allow isoradiation and radiation profile arrays of the minerals to be plotted automatically in the most easily read form.

Final results are isoradiation contour maps indicating concentrations of the minerals, their ratios, and total count. Stacked profiles can also be provided.

MEASUREMENT TECHNIQUES

Separation of the natural radiation of earth surface materials caused by the presence of uranium, thorium and potassium is based on measurement of the amplitude spectrum of light created upon gamma ray capture in thallium-activated sodium iodide crystals. These crystals must be sufficiently large to permit total absorption of the incident gamma ray photons. Several of these large detectors, placed in parallel, are necessary to provide a spectral counting rate

sufficiently intense to give good statistical measurements in very short periods of time (a few seconds), and thus provide an airborne survey system for accurately measuring the surface distribution of uranium, thorium and potassium.

The electromagnetic spectrum covers the range from low-frequency radio waves, through visible light, to high-energy gamma radiation. The range of energy characteristic of emission from the nucleus of the U and Th daughter-products and from K^{40} is between 50 KeV and 2.615 MeV. Cosmic-created radiation extends to higher energies. The detector size is set by performance giving best total capture of energies up to the 2.615 MeV line emitted from Tl^{208}, a Th^{232} daughter. Assembly of many small (4- or 5-in.) NaI detectors will not allow us efficient total capture of the higher energy radiation from the decay of U, Th and from cosmic radiation and will cause partially-absorbed radiation to increase relative to the number of counts at lower energies.

Figure 3 shows the 11½-in. dia. by 4-in. thick NaI(Tl) detector used. The detector light is monitored by seven photo-multipliers which convert light photons into electrical pulses of varying pulse heights. Several of these detectors must be used to provide a sufficient counting rate over the energy spectrum necessary to allow statistically acceptable 2.0 second datum accumulation periods. Figure 4 and 5 show six aircraft-installed thermally-shielded detectors and electronic equipment.

Gamma ray spectra at altitudes from 6 to 500 ft. over a specific location are seen in Figure 6 for a single 11½-in. dia. by 4-in. thick detector. The spectral shape as a function of altitude is preserved through the use of the large crystal. Six of these large crystals are used in the Texas Instruments system.

The basic schematic of the instrumentation for performing the measurements is shown in Figure 4. This shows six 11½-in. dia. by 4-in. thick detectors supplying pulses for analysis to the multichannel pulse height analyzer. The analyzer assigns the amplitude of a given pulse to one of the possible 400-channel pulse height levels. A counter then records the counts/channel/counting time period to a maximum count/channel of 10^6-1. At the end of this period the data stored in the analyzer memory are read out onto magnetic tape at the rate of one millisecond/channel. The schematic shows a single visual recorder which displays the summation of the counting rate of a selected group of channels. This counting window is normally set to encompass the main energy peak of U, Th or K-produced gamma radiation.

THEORETICAL BASIS AS AN EXPLORATION TOOL:

Several recent papers have been given on gamma ray spectrometry and it is not intended to more than summarise some principles.

Natural Radiation

Radioactivity is associated with all natural materials as a result of the distribution of uranium and thorium daughter-product radionuclides and potassium -40. The abundance of these radioactive materials in soils and rocks varies with the original lithology, geologic age, metamorphism and metasomatism, and present and past weathering and supergene history of the material (see Figure 1). Uranium is normally present in its equilibrium abundance as measured by its gamma ray emitting daughter-product, Bi^{214}, in regions where leaching, hydrothermal action and other disturbances have not allowed the removal of the gamma-ray-emitting fractions

from the parent. Thorium is found in equilibrium abundance with its daughters because of its very short time period of decay from the parent Th^{232} to Pb^{204}. Potassium -40 is present as .012 per cent of natural potassium and there is very little geochemical differentiation of K^{40} on metamorphism or migration of potassium.

Most minerals other than those of uranium thorium and potassium are associated with these elements in their natural form. Measurements of the gamma ray gross intensity have been used in the past to detect high-magnitude anomalies caused by outcrops containing enrichment of uranium and thorium minerals, but gross measurement of these anomalies does NOT identify the emitting materials (see Figure 2). Gamma ray spectroscopy by analogue devices has been used recently, but does not permit accurate and complete separation of the several radio-activity sources from variable source locations. In regions where low levels of anomalous radiation are significant through association with particular minerals, gross counting and analogue spectrometric methods have limited value.

Instrumentation allowing the amounts of U, Th and K to be measured and the relative proportions of radiation to be determined provide for the identification and location of radionuclide concentration halves, trains and other trends. Measurement from an average 400 ft. surface elevation gives a total count measurement which does not allow small perturbations to bias the average intensity, and effective separation of U, Th and K gamma-ray-emitting fractions allows location of much less intense anomalies.

Detection from the air

Of the basic radiation components measured with airborne equipment, all originate from the terrain except that from cosmic sources. Each of the isotopes, as well as the cosmic has its own spectral signature. The shape of the cosmic radiation spectrum is shown in Figure 5. The main photopeak is the result of the positron emitted as the cosmic ray loses energy. A positron then annihilates with an electron and provides .51MeV radiation in the atmosphere. The shape of the cosmic spectrum is essentially constant to altitudes beyond 20,000 ft. and varies with altitude as shown in Figure 9. The contribution of the cosmic-created counting rate is about 10 per cent of the total count at the earth's surface at sea-level.

The airborne thorium daughter-product spectrum is seen in Figure 6.

The uranium daughter-product spectrum measured over a mine is given in Figure 7.

Natural potassium has .0119 per cent K^{40} which provides the spectrum of Figure 8.

How do these individual spectra composite themselves at altitude? Figure 9 illustrates the summation of several hundred 2.0 second spectra giving a total accumulation time of 17.5 minutes. The summation groups involved with data processing are shown.

The summation group chosen to represent K, U and Th represent the energy group giving the best count for that spectrum with respect to the other two. The summation groups of K, U and Th consist of sufficient numbers of channels to cover the main photopeaks of each isotope. Each of these energy groups contain counts of cosmic plus counts from at least one other isotope. Comparison of the spectral signatures reveals that:

1. Thorium and uranium-created radiation modulates the potassium radiation energy group.
2. Thorium and uranium-created radiations modulate each other.
3. Potassium-40 radiation does not modulate uranium or thorium-created radiation.
4. Cosmic radiation modulates potassium-40, uranium and thorium-created radiation.

Accurate separation of the counts from each of the radiation sources within each of the summation groups can be accomplished through data processing where accurate energy calibration is performed on all spectra prior to data reduction by matrix algebra or least squares techniques.

The aim of the Geophoto system is to screen out all contaminating sources of radiation in atmosphere and aircraft and allow for topographic corrections so that a measure of radiation emitting from the actual ground surface and below it can be had.

The Natural Gamma Ray Flux

At an altitude of 400 ft. this consists of radiation from four main sources : cosmic, decay products of U and Th and radioactive potassium. When along a flight line closely spaced airborne measurements are taken. The data may be used to characterize accurately the gamma ray emission from the terrain surface.

Cosmic Contamination

Since the cosmic ray contribution to the gamma ray spectrum is more than 10 per cent at sea level and thereby forms a considerable

fraction, it must be removed during the data reduction. Cosmic intensity is a function of altitude above sea level and the flying height must be considered in data reduction. The cosmic rays are easily eliminated from interfering by spectral identification. Their position in the 400 channel analyzer is well known which enables the system to automatically discriminate them.

Other Atmospheric Contamination

The decay of thorium and radioactive potassium give no measurable contaminating atmospheric sources so that measurement of surface concentrations is readily accomplished by proper analysis of the airborne gamma ray spectral data with a reproducibility of ± 2% with absence of rainfall.

Measurement of surface uranium, however, is much more difficult. The decay of uranium provides gaseous radon which decays, giving the gamma ray producing daughter Bi^{214}. A large fraction of the Bi^{214} which is measured by surface detection equipment or from an aircraft may exist in the atmosphere. The magnitude of this concentration is dependent upon meterological conditions. Only if this atmospheric contribution of Bi^{214} is measured and removed from the data will the airborne measurement be representative of the surface Bi^{214} concentrations.

How Discovery of Subsurface Radioactivity is Feasible.

With sensitive multicrystal instruments the detection of uranium in the subsurface is feasible due to the migration of Rn-222. The radon gas is produced by radium -226, an earlier daughter product in the series (Figure 1). It can migrate from buried ore bodies through fracture or grain permeability to the surface and be detected should the detection system be suitably sensitive.

AIRBORNE DATA ACQUISITION SYSTEM:

Airborne gamma radiation flux has been measured by multiple (4 to 6) 11½-in. dia. by 4 in. thick NaI(Tl) detectors which send data to a multichannel analyzer for analysis, as shown in Figure 3. Gamma ray spectra are analyzed on a 400 channel basis and recorded onto magnetic tape in a form directly compatible for computer entry. Included with each recorded spectrum are the necessary peripheral data for each spectrum.

Other large detectors are used to measure the atmospheric radon daughter product Bi^{214} intensity. A 4 in. thick lead floor beneath this detector screens out surface radiation and allows the detector to measure only the atmospheric Bi^{214} above the level of the aircraft. These data are also recorded onto magnetic tape at short periods for computer reduction.

Figure 4 depicts the airborne radiation detectors and measuring equipment. Data are normally acquired at an average surface elevation of 400 ft. with an accumulation time of 2.0 sec. per spectrum with 0.5 sec. used for data readout of each spectrum. Aircraft speed is about 120 m.p.h. Approximately 3100 spectra are recorded on each 2400 ft. of magnetic tape. Aircraft position is located by use of a 35 m.m. tracking camera which gives the centre location of each measured spectrum. These locations are digitized and subsequently matched to the gamma ray spectra.

DATA REDUCTION:

Data which provide initially the total measured intensities of cosmic, thorium, uranium and potassium-created gamma radiation are reduced by direct entry into a computer. Each field spectrum is energy calibtated to give constant pulse height amplitude for the

specific energies for all data. Although energy shift is low as a result of thermal insulation of the large detectors and the stable high voltage supply, energy gain calibration ensures the use of proper pulse height amplitudes.

The airborne radiation flux is composed of radiation from several environments : cosmic, aircraft, atmosphere and surface. Radiations from these several environments provide the spectrum shown in Figure 5. The spectrum, taken over terrain near sea level, indicates the composite of all data from all sources and environments. These data, when reduced, will give the intensities of the surface-emitted radiation only if the contributions from each invironment is determined. Figure 6 shows the results of data reduction as a function of mean sea level altitude above a large fresh water lake (MSL altitude = 600 ft.) and indicates the accuracy of data reduction by the constant intensity of thorium and potassium at all altitudes as the relative intensity of the cosmic spectrum becomes very large. The count numbers shown in Figure 6 for thorium and potassium represent the average value per 4 min. for the appropriate channel energy groups given in Figure 5. Comparable values for Bi^{214} and cosmic radiation for the 2 π and 4 π data acquisition systems are shown measured at 12,000 ft. MSL altitude. Such data are useful in determining the background levels on-board the aircraft and atmospheric Bi^{214} intensities as a function of altitude which are necessary for separation of the aircraft and atmospheric Bi^{214} fractions.

The upward-viewing 2 π solid-angle measuring detector(s) provides data necessary for the removal of the atmospheric contribution of Bi^{214} based on calibration where equal intensities of atmospheric Bi^{214} existed above and below the level of the aircraft. Data which are gathered in the morning prior to the rise

of a near-surface temperature inversion layer that has trapped the surface-emitted radon must be corrected for the added contribution held by the inversion layer.

OPERATIONAL FEATURES:

The Geophoto Gamma Ray Spectrometer is installed in a modified DC3 aircraft, since the size and weight of the search crystals, upward-looking crystals (including lead shielding) and electronic system prevents the use of light aircraft. The DC3 also has high endurance, permitting continuous flying for up to 8 hours.

The use of DC3 aircraft poses several operational problems, since operating height is 400 feet, at a speed of approximately 120 miles per hour. Areas of rugged terrain, especially those with ridges and valleys striking parallel to the regional grain, may require flight lines parallel to this strike, rather than the geologically preferred "normal to strike" flight path. This problem is further accentuated by the shape of permit areas, which are usually aligned with the long axis parallel to the regional geologic strike.

Despite these problems, flying at 1/4 mile (1330 feet) line spacing produces data from a search path of approximately 800 feet width, giving a fairly complete coverage of the project area.

Water and rain are problems on the ground and in the air, by screening part of the surface radiation, and contaminating the aircraft. Flying can be done only after rain storms and main run-off has ceased.

Navigation is usually done on air photo mosaics or photos. The actual position of the aircraft in flight is recorded on a 35 mm tracking camera, which is synchronized to expose at the mid-point of each 2-second recording period. Tracking camera film is then used to relocate the flight-lines and anomalies. Radar navigating systems merely result in added expense whilst still requiring provision of tracking film for relocation of ground points by field parties, so radar is not used.

COMPUTER DATA SHEETS:

All raw data obtained from the flying phase of the survey is recorded on the computer sheets as well as the final corrected and reduced sums used in the plotting of the contour maps and profiles.

The following paragraphs explain the meanings of the various columns and abbreviations presented on the computer sheets.

Meaning of counting rate data recorded on the computer listings (see Figure 7).

Raw Sums — These are integrals of the counts contained in selected energy ranges or "windows" of the full 400 channel gamma ray spectrum.
These windows are chosen in parts of the spectrum where one or another of the individual types of gamma source dominate, or at least strongly affect, the count rate. The position of the windows, that is, how they are aligned with the 400 channels recorded on magnetic tape is not fixed a priori but is calculated by the computer through a process of least-square fitting of the shape of the peaks in the observed spectrum to theoretical curves.

This insures automatic calibration of every spectrum and that the raw sums are always taken over the same absolute energy ranges, regardless of slight instrument drift alignment. The raw sums are uncorrected except for this absolute energy calibration and normalization to fixed effective counting times.

COS Cosmic window. Between 3.3 and 6 MeV.
No naturally-occurring terrestrial sources emit gamma rays in this energy range, so counts in this window are unambiguous. They can come only from cosmic radiation.

Th Thorium window. Centred on 2.615 MeV.
This is the position of the naturally-occurring gamma ray of highest energy. It comes from the decay product of thorium disintegrated thallium^{208}. Thus the count rate in this window, if a correction is made for cosmic counts, is a measure of the amount of thorium visible to the detectors. Some of this thorium will be on board the aircraft, some on or near the earth's surface. Thorium which is on the ground will have its gamma radiation attenuated by the atmosphere and the amount of attenuation will depend on the aircraft altitude. The term "raw sum" is intended to reflect the fact that this is the count rate observed in the thorium window before any of these corrections are applied.

U Uranium window. Centred on 1.764 MeV.
The uranium decay product bismuth^{214} emits a gamma ray at this energy. If a correction is made for cosmic or thorium radiation degraded from initially higher energies to fall into this window, the reduced count rate can be a measure of uranium, or at least

uranium decay products present. Besides the corrections mentioned above, a further complication present in the particular case of uranium decay products is that they can be largely airborne. This means an additional correction will be required to convert the uranium raw sum to a true surface count rate.

K Potassium window. Centred on 1.46 MeV.
The peak in the energy spectrum in this range is due to radiation emitted by the isotope potassium^{40} which comprises a small fraction of all naturally-occurring potassium. Thus, again if a correction is made for radiation degraded from other higher energy sources, which in this range includes cosmic, thorium, and uranium, this count rate can measure the potassium present.

Reduced Sums These are the untangled and corrected raw sums. The interrelationships of the various components have been separated from each other. The on-board aircraft background has been subtracted. The airborne radiation has been subtracted. The artificial variations induced by terrain-clearance changes have been corrected for.
Except for these corrections, the Th, U and K numbers refer to the same count rates and some energy windows explained under raw sums. The fact that any of the reduced sums, especially U, is significantly different from its corresponding raw sum shows how important these corrections are. Correction for cosmic radiation is not repeated here because none of the corrections change its raw sum value.

Ratios — These are the ratios of the various individual reduced sums. They should be interpreted with caution in that when dealing with statistically fluctuating quantities a ratio is less exact than either its numerator or denominator alone. This is especially true when the denominator gets small as can happen when there is considerable absorption because of altitude, surface vegetation, or surface moisture, or when extreme leaching removes potassium from the near-surface materials.

Meaning of the tag words used for the records on the Computer Listings.

SEQ — Sequence Number.
This relates to a counter by which the computer keeps track of the location of individual records on its input and output tapes. Because input/output is blocked and buffered for processing efficiency and because records written in the field are all edited by quality-control subroutines during the computer processing, this number is not necessarily in one-to-one correspondence with the ID number explained below.

QUAL — Quality Control Identification.
This number tags the record by type and quality. "0" tags the standard, downward looking, digital-error free record. "99" tags the standard, error-free, upward-looking record. Negative numbers correspond to various erroneous or suspicious records. Under normal conditions only one or two percent of the records written in the field end up this way.

In rough terrain the QUAL = "2" tag, corresponding to data taken at 700+ feet ground clearance, can become fairly common. Unless special arrangements are made, only QUAL = "0" records are used in the gridding and contouring programmes.

ID — Record Identification Number.
This number counts the records recorded in the field, regardless of whether they are upward- or downward-looking. The counter starts at zero each time the system is activated, however, so it is ambiguous (unlike SEQ) unless considered in conjunction with the DOY/FL tag as explained below. It is one of the tags used to relate the computer listings with the flight line maps.

TOD — Time of Day.
Twenty four hour clock which is read out in hours, minutes and seconds. For example 141005 is five seconds past 2.10 p.m. local time.

BKG — Background.
This is 10000 plus a digital conversion of an analogue level related to the uncorrected count-rate coming from the upward-looking system in the Bi^{214} window around 1.76 MeV. It is related to the airborne Bi^{214} concentration but not very precisely because of the on-board background and the contributions from the Tl^{208} and cosmic radiation seen by the upward system. The digital recording in the programme of the upward-looking spectra replaces the necessity of this tag column in arriving at final results.

DOY/FL Day of Year, Flight Line.
This self-explanatory tag word, taken with the ID, serves to identify each record in the field with its physical location and listing in the final computer printout. The first 3 of 6 digits denote the sequence number of the day (For example February 10 is 041): the last 3 of 6 digits denote the flight line number as laid out on the pre-flight plan and charted on the post flight map.

ALT Altitude in feet above ground level.

L-T Live Time.
This is a measure of how much of the time during the counting period the instrumentation has actually been "live" or able to accept counts. The data is normalized to preset idealized counting times according to this tag word.

Meaning of Counting Data Recorded on the Computer Listings

X, Y The X and Y Co-ordinates of the Record.
Usually expressed in thousandths of inches in whatever scale is chosen for the flight line map and base map, measured relative to the origin on the flight line map, the computer-drawn contour maps, and the base map.

NOK Number of good records.

IDUP Record identification number for the upward reading crystals.

UAIR Upper air record.

UTOT Total bismuth count.

ISORADIATION CONTOUR MAPS:

These maps constitute the main interpretation of the survey. Recognizable locations of the airborne instrument read-outs are spotted on the navigational aids used. The positions are then transferred to an overlay of the final base map and joined to determine the surface track of the flight path. The segments between the spotted localizations are incremented with respect to the number of records occurring in the intervening segment. The readout locations are then digitized and computer-collated by the sequential number to the radiation data recorded on the magnetic tape. This provides the control for the computer plotting of the contour map.

PART II

INTERPRETATION, ORIENTATION AND GROUND FOLLOW UP

The digital multicrystal Gamma Ray Spectrometer system has been described in the previous section. Some criticisms have been levelled to the effect that the system is too sensitive for many projects of a reconnaissance scanning type. However, very few people have had opportunity to look over much data and possibly fewer still adequately. It is very necessary that skilled geologists with a geochemical bent analyse the data in terms of the total geological picture. Also, apart from uranium and phosphate search few geological problems have been examined with this instrument by outside parties.

Gamma ray data can only be properly interpreted for ground follow up by utilizing all available detailed geologic, geochemical and economic geological information from the survey area. Geologists who are familiar with this data are in the best position to do this. The elements on which quantitative data are sought are very common in measurable and varying amounts inall types of sediments, metamorphic and igneous rocks. Moreover the three chosen elements are three which vary greatly in near surface mobility and leaching and this fact also assists multiple indication of targets and assists in discrimination of targets.

Particular note should be made of the contrasting geochemical behavious of each of uranium, thorium, potassium in different lithologies and also in the weathered zone where the U and K display greater mobility than Th and both U and K vary in their ease of leaching and migration. The permutations and combinations of 6 parameters (three absolute and three ratio indices) can be used in looking over geology to assess anomalies.

ORIENTATION OF MINERALISED AREAS

Many clients have been mainly interested in uranium discovery. However, it should be realised that the T.I. system is a sophisticated and sensitive geochemical tool which with some experience can be used to delineate base metal, rare metal and phosphate targets as well as the radioactive deposits with which gamma ray detection methods are normally associated. Moreover information on many types of problems associated with ore occurrence both lode (vein, stockwork, pipe or a stratiform lens) or placer, and both near surface and buried, may be gained.

Those whose surveys are directed primarily for uranium may tend to neglect data on other geologic areas on which definitive data can be obtained. A list of some potential uses in mineral exploration follows. Internal orientation has been done by Geophoto on many of these types of target in Australia and elsewhere.

1. Uranium - Indicators Bi^{214}, Tl^{208} and $\frac{Bi^{214}}{Tl^{208}}$ ratios.

   a) widespread stockwork,
   b) widespread flat-lying stratiform lens,
   c) linear, steep-dipping vein or folded stratiform lens,
   d) small annular pipe or lensoid body,
   e) concealed deposits.

2. Thorium and Rare Earths - Indicators Bi^{214}, Tl^{208}, K^{40}, and $\frac{Bi^{214}}{Tl^{208}}$ ratios.

   rare earths, monazite, thorite.

3. Columbium - Indicators K^{40} and Tl^{208}.

   a) Pyroclore associated with carbonatites,
   b) Columbite-Tantalite - radioactivity commonly associated with minerals containing these elements.

4. Base metals - All radiation indices.

a) Co-associated with uraninite - e.g. Carcoar N.S.W..
b) Cu associated with K metasomatism,
c) Mo associated with K enrichment,
d) Sn and W associated with K metasomatism,
e) stockwork fracturing associated with differential leaching of indicators,
f) vein fracturing,
g) distinguishing between K alteration associated with mineralisation and K rich intrusives.

5. Phosphate deposits - Indicators Bi^{214} and Tl^{208}.

Location and rough grading based on the U association with phosphate.

6. Lithologic discrimination

Types:

a) discrimination by variation in K, U, Th and their ratios of -
   (i) beds in a sequence,
   (ii) lateral facies change;
b) discrimination and mapping of -
   (i) igneous intrusives, e.g. high background U or K granites,
   (ii) complex intrusives,
   (iii) volcanic complexes;
c) contact or boundary target indicators -
   (i) e.g. high radiometric background granite associated with U deposits in a contact zone,
   (ii) localisation of contact ore zones,
   (iii) shallow buried plutons - migrating Rn^{222} as indicator for existence of plutons.

7. Fault and Fracture Localisation

a) transection of stratified beds or igneous contacts,
b) zones filled with highly potassic minerals,
c) zones leached of Uranium or Potassium.

8. Beach Sand.

Rough grading on monazite content.

9. Channel localisation for shallow placers in buried granite country.

INTERPRETATION

Seven pieces of data can be processed (Figure 1) Bi^{214}, Tl^{208}, K^{40}, gross count, $\frac{Bi^{214}}{Tl^{208}}$ ratio, $\frac{Bi^{214}}{K^{40}}$ ratio, and $\frac{Tl^{208}}{K^{40}}$ ratio. The geometry of all types of target that might be sought should clearly be in view before programming the flight line spacing and the type of data sought (i.e. digital contouring or profiles).

It should be realised that in digital contouring, the radioactive response plotted represents the mean data from a considerable area running from flight line to flight line and from over about 600 feet along the flight line. This means that peaks for restricted narrow, linear or small, annular pipe-like targets will be strongly depressed in the isoradiation contouring. They may however be prominent in profiles, or individual computer listings of data, if a record is made directly over this type of target. Contours however clearly display wider haloes, about stratiform and stockwork targets are suited for problems involving lithologic and structural features. For economy reasons most clients have opted for contours rather than stacked profiles.

For areas where contours only are obtained the best means of interpretation for follow up work is to overlay the contour maps, or composites therefrom, with geological maps and with the flight line index. These will provide a basis for locating exploration targets. Features of economic geological interest for orientation in each district such as known zones of mineralization and favourable structures or lithologies for ore, may be located on individual flight lines. Reference to the computer listings for the specific readings about these features may indicate an element or ratio which is particularly anomalous in the known specific zone. Using these selected anomaly readings for orientation purposes other anomalous portions of any of the flight lines may be located in the listings and referred back to the geologic base map by means of the flight index for check.

Anomalous readings in the vicinity of known mineralized zones used in conjunction with the geologic maps have shown certain indices for exploration targets involving specific lithologies, facies changes, structural trends and mineralized or geochemical haloes and trains.

Irrespective of more general or regional indices noted it is recommended that intensive examination of all data be made with respect to the known geologic picture and that attention be not restricted to the more obvious peaks, but to discreet anomalies along the flight lines, and any contrast within specific lithologies on contour maps. In regions of great geological interest processing of data according to each lithologic unit may repay attention.

TASMANIAN SURVEY

The data of the Blue Tier Survey is undergoing analysis

and ground check. A huge body of data has to be examined before significance of any of many anomalies recorded can be assessed.

Dr. J.H. Rattigan
Minerals Exploration Manager.
October, 1969.

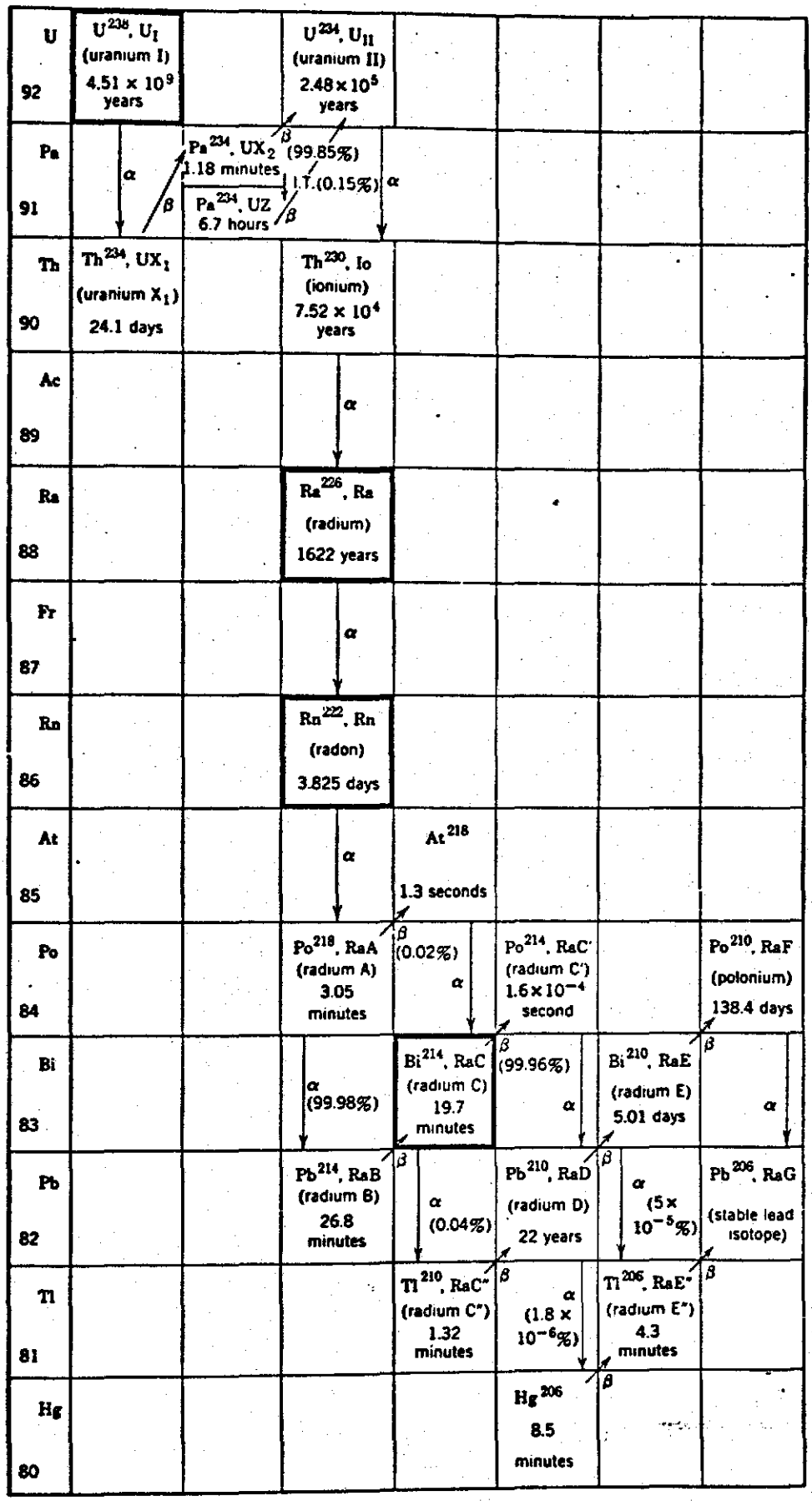

Fig. 1 The uranium series.

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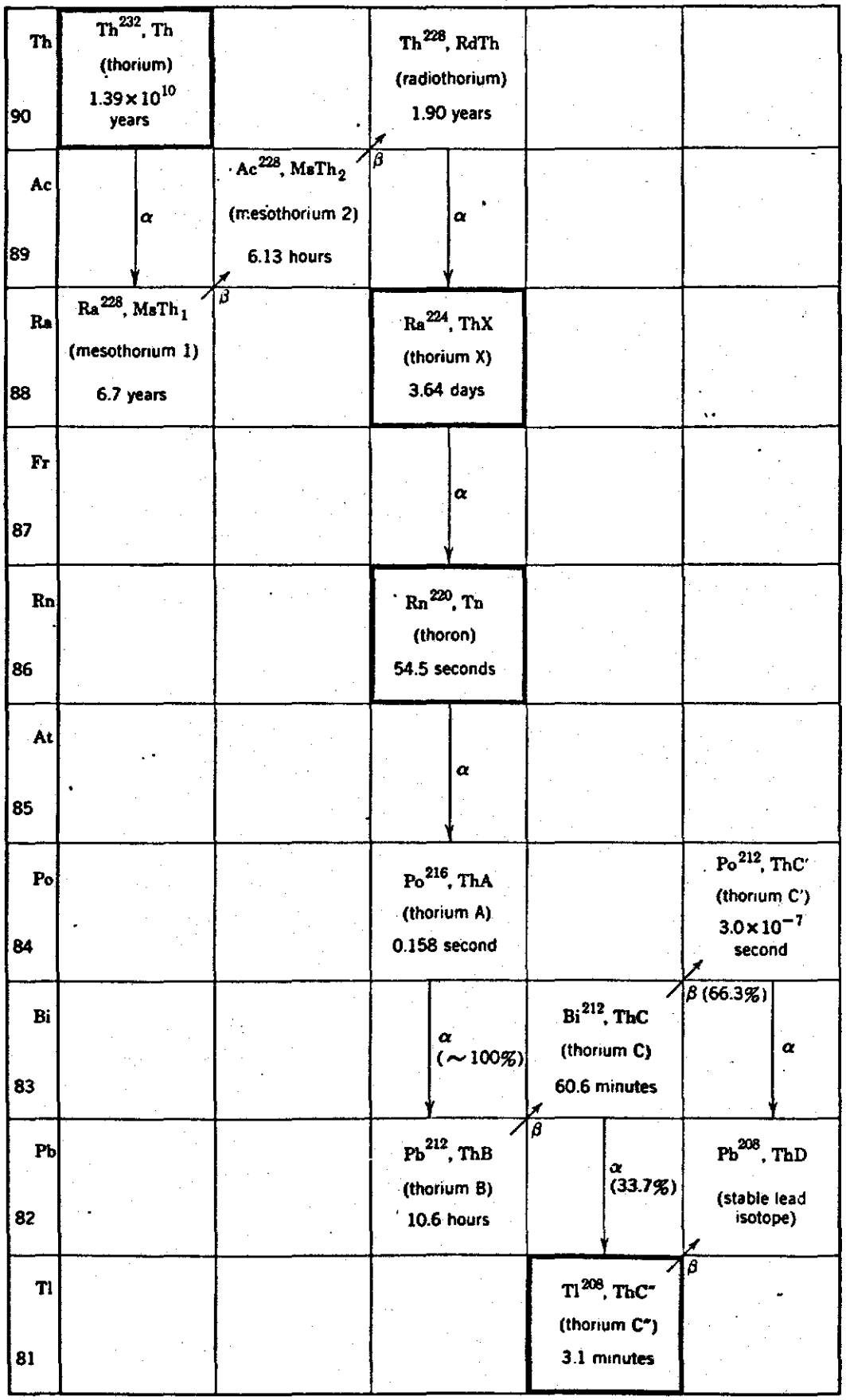

Fig. 2 The thorium series.

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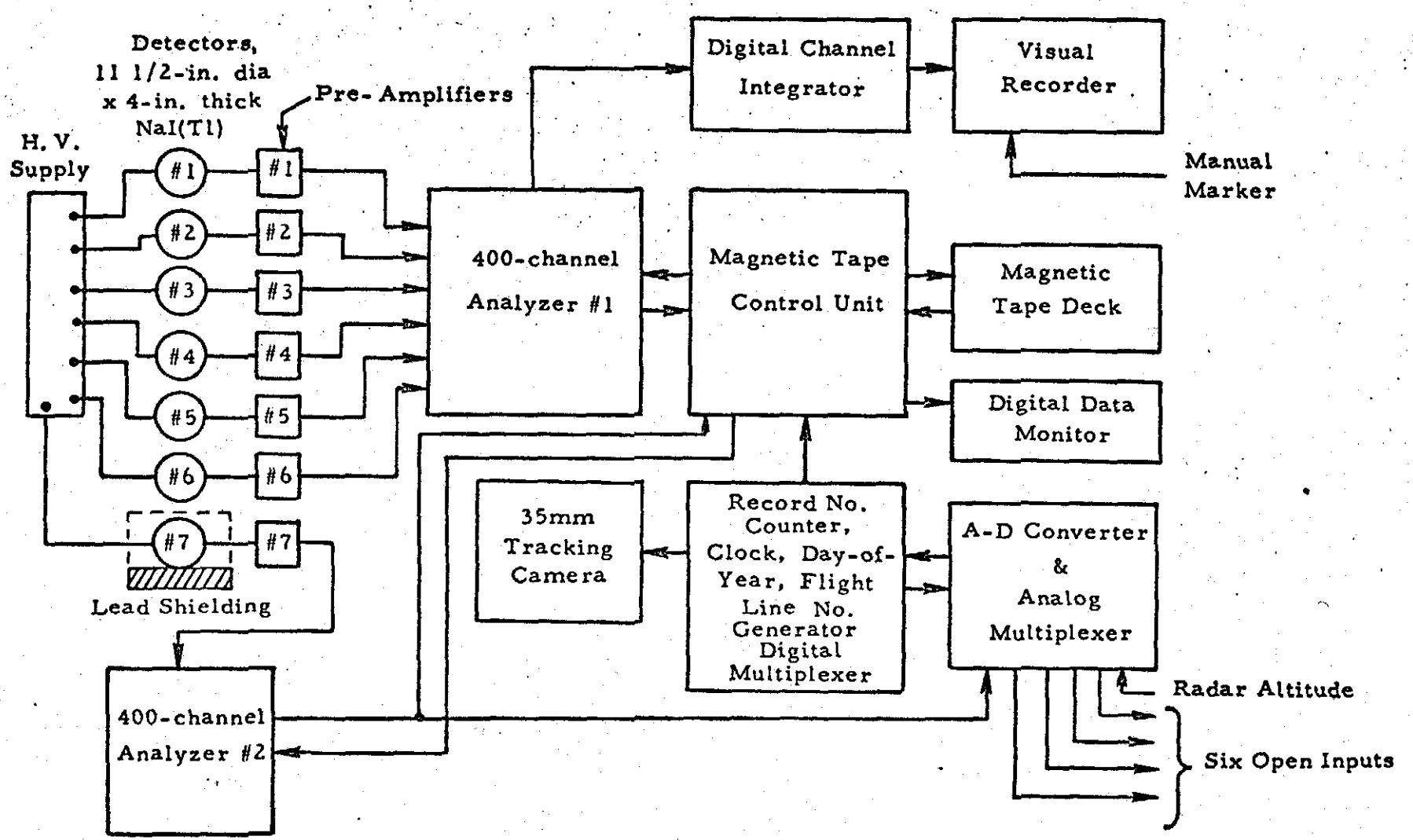

Detectors,
11 1/2-in. dia
x 4-in. thick
NaI(Tl)
Pre-Amplifiers
H. V.
Supply
#1
#2
#3
#4
#5
#6
#7
Lead Shielding
400-channel
Analyzer #1
400-channel
Analyzer #2
Digital Channel
Integrator
Visual
Recorder
Manual
Marker
Magnetic Tape
Control Unit
Magnetic
Tape Deck
Digital Data
Monitor
35mm
Tracking
Camera
Record No.
Counter,
Clock, Day-of-
Year, Flight
Line No.
Generator
Digital
Multiplexer
A-D Converter
&
Analog
Multiplexer
Radar Altitude
Six Open Inputs

Figure 3

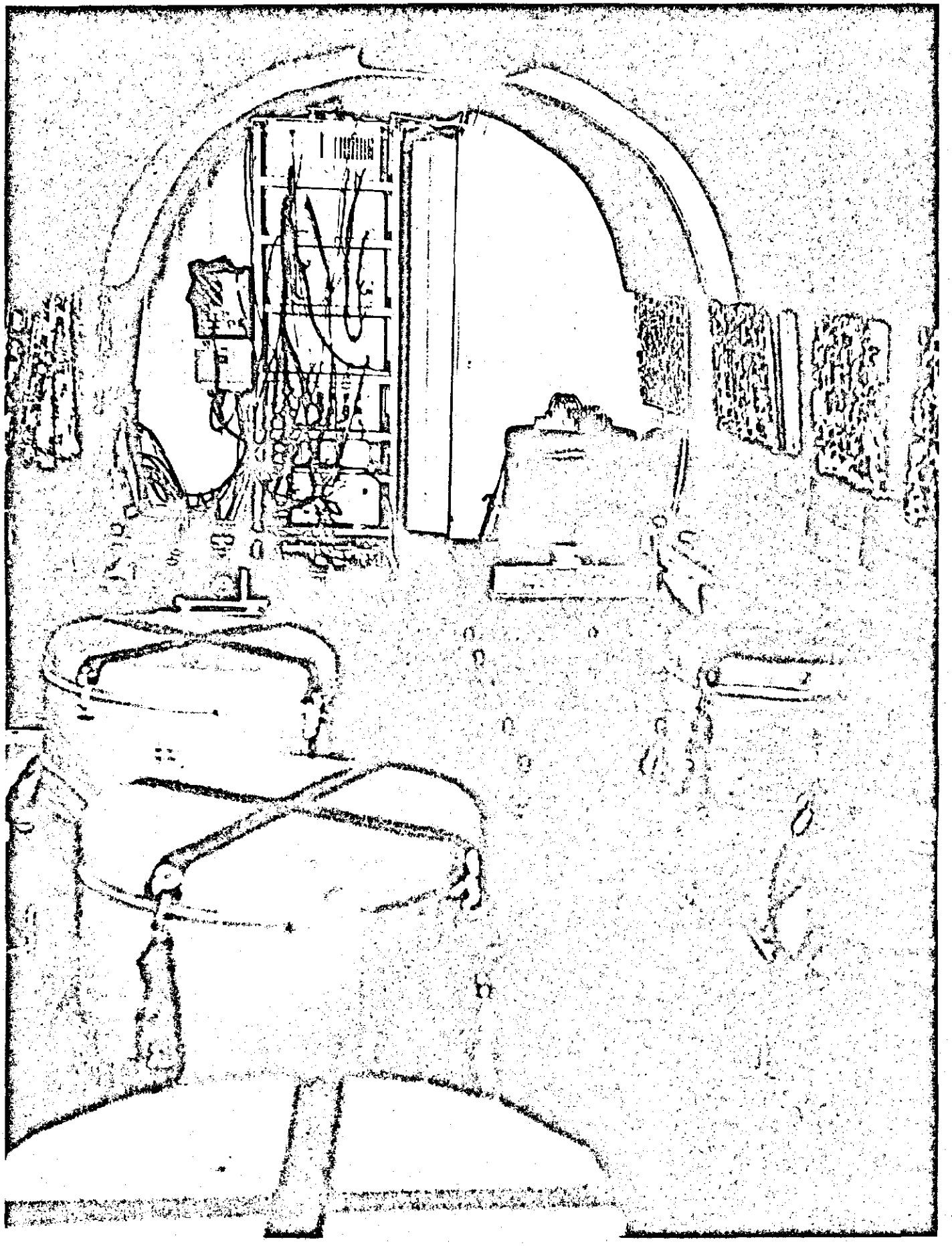


Figure 4

055032

400 ft. AIRBORNE GAMMA-RAY SPECTRUM

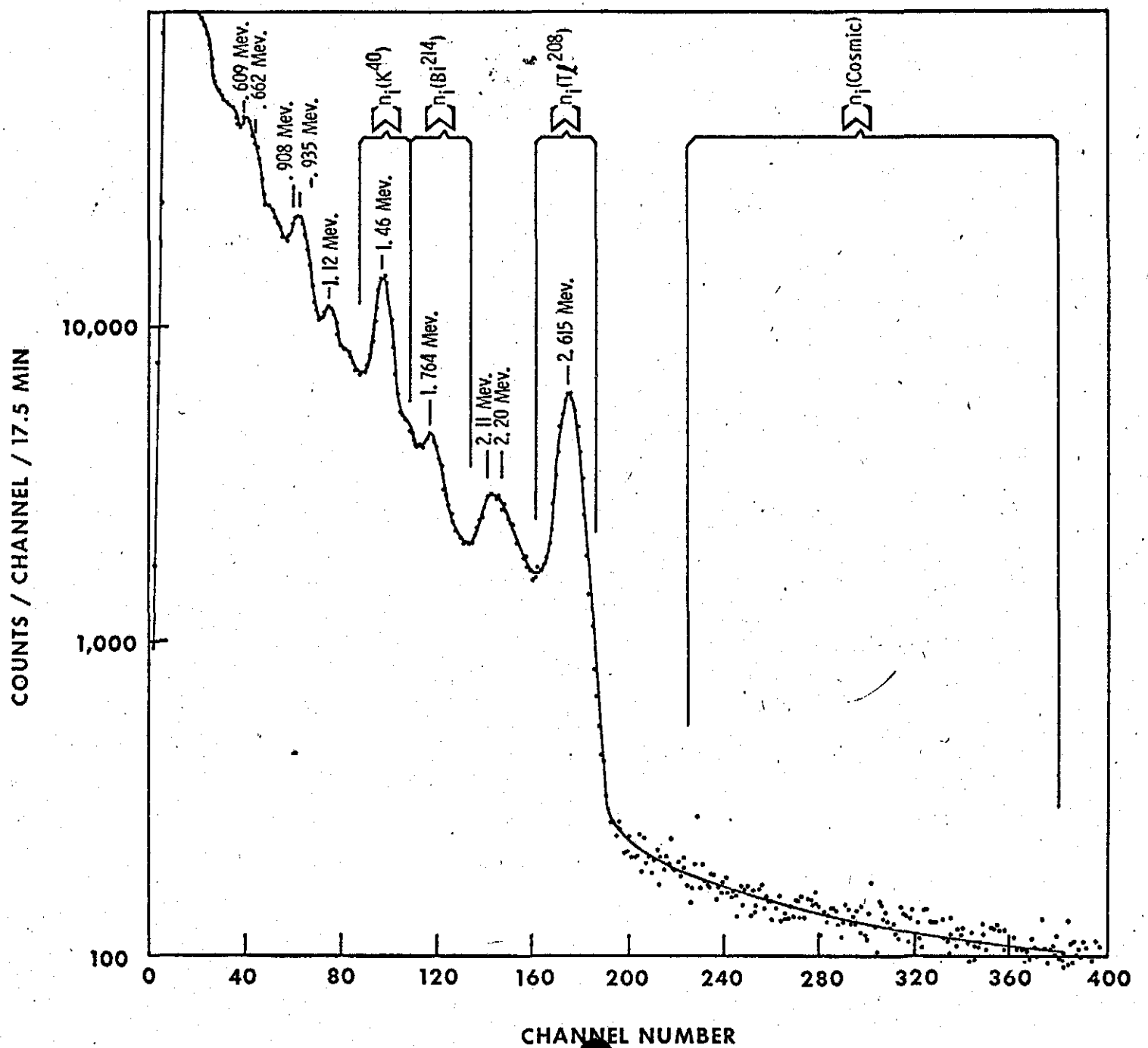


Figure 5

030

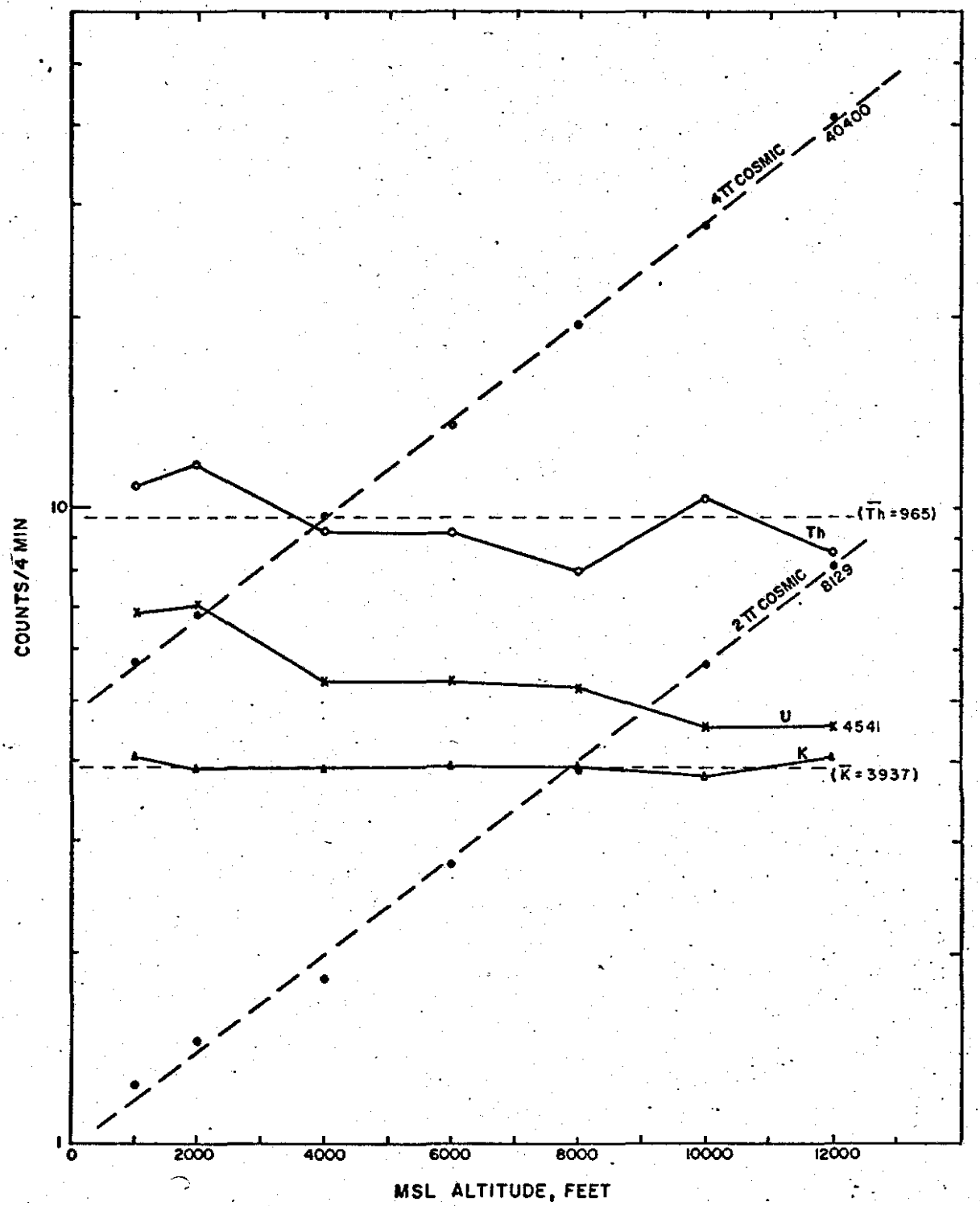

4π COSMIC
40400
2π COSMIC
8129
(Th = 965)
Th
U
4541
K
(K = 3937)
10
1
COUNTS/4 MIN
0
2000
4000
6000
8000
10000
12000
MSL ALTITUDE, FEET

Figure 6

032

BLUE TIER AREA, SHEETS 1A,3A,3B,1B,2B,2A, AND 4B.
BEGIN FLIGHT LINE 101 OF DAY 75, NUMBER 1 OF THIS JOB

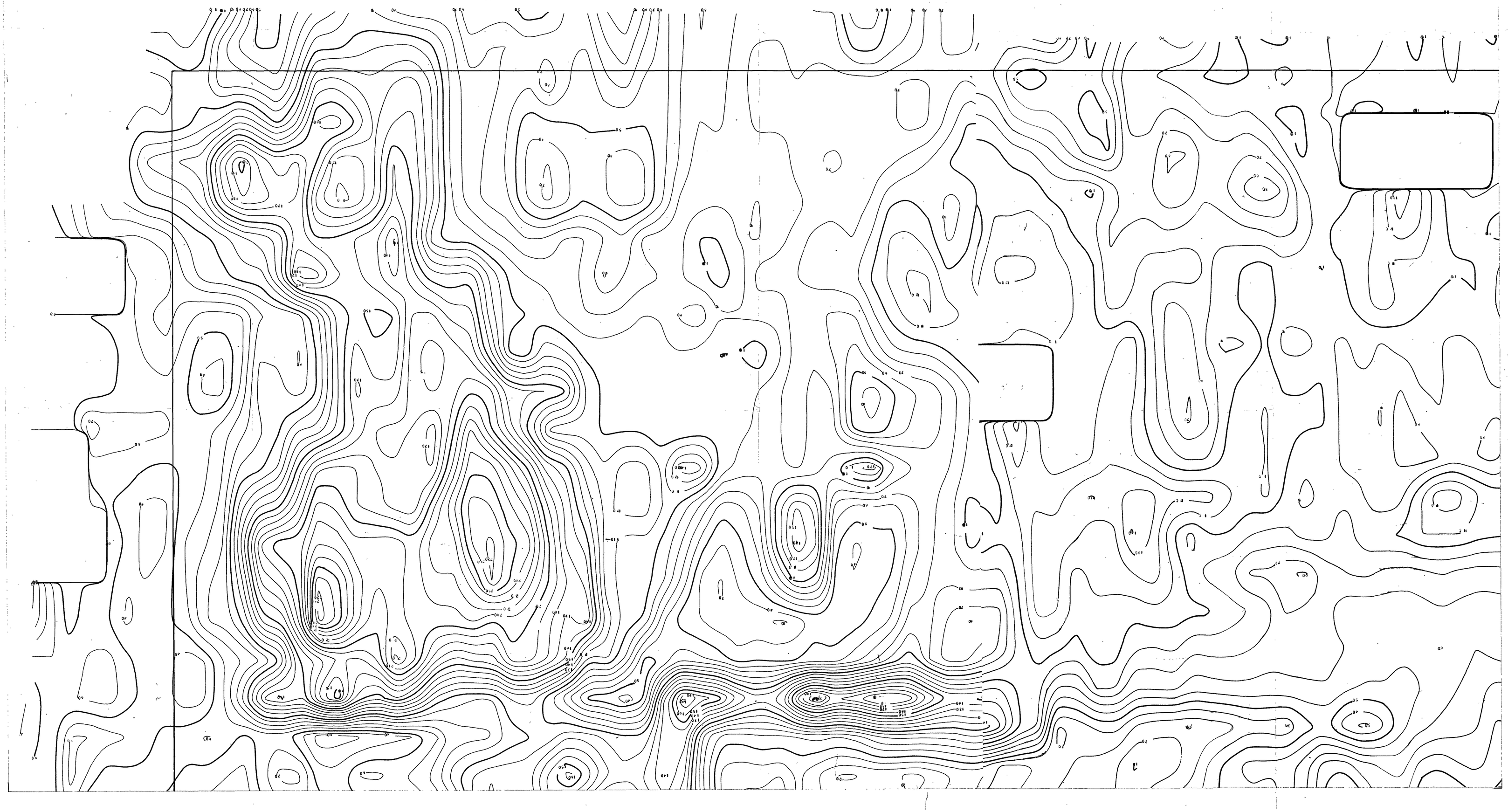
SEQ	QUAL	ID	TAGS TOD	BKG	DOY/FL	ALT	L-T	POSITION X	Y	RAW SUMS COS	TH	U	K	GROSS	REDUCED SUMS TH	U	K	GROSS	RATIOS U/K	U/TH	TH/K
113	0	1	133446	10279	75101	660	304	7523	6466	56	102	163	307	4120	135	101	177	4370	.570	.744	.766
114	0	2	133448	10328	75101	679	303	7537	6466	50	102	156	350	4253	143	95	290	4754	.327	.663	.494
115	0	3	133451	10298	75101	676	301	7550	6466	60	91	126	331	4337	122	41	319	4785	.129	.337	.383
116	0	4	133453	10330	75101	646	304	7559	6466	56	81	118	339	4338	100	34	329	4596	.104	.344	.303
117	0	5	133456	10306	75101	583	297	7570	6467	51	103	185	365	4593	117	119	200	4541	.596	1.018	.585
118	0	6	133458	10302	75101	620	297	7583	6467	45	109	160	366	4557	140	82	269	4796	.303	.585	.519
120	*2	7	133501	10294	75101	704	298	7594	6469	53	91	195	334	4591	124	200	184	5459	1.084	1.605	.675
121	0	8	133503	10330	75101	647	296	7607	6469	65	77	149	400	4777	87	96	385	5182	.250	1.110	.225
122	0	9	133506	10308	75101	639	292	7618	6470	65	93	155	390	4970	111	88	341	5399	.256	.786	.326
124	*2	10	133508	10303	75101	721	302	7632	6472	50	100	150	348	4628	153	93	338	5689	.275	.608	.452
126	*2	11	133511	10349	75101	752	299	7644	6472	55	79	145	347	4289	116	114	385	5342	.297	.971	.306
127	0	12	133513	10321	75101	674	301	7655	6472	60	79	125	314	4102	99	54	287	4411	.188	.545	.346
128	0	13	133516	10303	75101	655	305	7668	6473	43	70	146	283	3995	84	108	166	4245	.643	1.284	.501
129	0	14	133518	10304	75101	600	302	7678	6473	49	84	144	314	4052	95	75	199	3937	.376	.786	.478
130	0	15	133521	10318	75101	638	302	7699	6470	54	98	140	296	4143	124	58	191	4271	.305	.471	.648
131	0	16	133523	10290	75101	648	302	7718	6467	46	107	134	378	4223	145	41	366	4508	.112	.283	.397
132	0	17	133526	10253	75101	612	302	7736	6465	44	98	160	379	4403	120	92	286	4528	.323	.767	.421
133	0	18	133528	10280	75101	589	299	7757	6461	54	107	168	329	4407	125	89	172	4315	.515	.709	.726
134	0	19	133531	10321	75101	610	301	7777	6457	53	111	169	384	4365	136	92	275	4402	.333	.672	.495
135	0	20	133533	10306	75101	633	299	7796	6455	42	100	142	352	4221	131	62	288	4429	.214	.471	.455
136	0	21	133536	10279	75101	679	300	7815	6451	60	101	149	314	4135	138	77	232	4494	.331	.557	.595
138	*2	22	133538	10280	75101	726	302	7834	6449	58	91	126	341	4023	135	52	382	4661	.137	.389	.352
140	*2	23	133541	10350	75101	763	304	7855	6445	43	87	137	321	4058	142	94	346	5128	.272	.661	.412
142	*2	24	133543	10336	75101	750	300	7877	6441	46	90	138	294	4103	144	86	262	5081	.330	.598	.552
144	*2	25	133546	10342	75101	724	302	7894	6441	41	82	138	298	3909	122	95	255	4597	.373	.779	.479
146	*2	26	133548	10281	75101	725	301	7914	6440	45	84	139	331	4061	124	92	333	4819	.276	.741	.372
148	*2	27	133551	10338	75101	727	300	7933	6439	59	86	168	335	4312	121	146	274	5145	.533	1.207	.442
150	*2	28	133553	10269	75101	727	299	7951	6439	39	86	136	334	4370	132	86	348	5398	.248	.652	.380
152	*2	29	133556	10299	75101	743	300	7970	6438	57	97	140	329	4196	152	76	336	5093	.225	.497	.452
154	*2	30	133558	10280	75101	726	297	7992	6435	65	82	172	321	4319	110	163	227	5099	.719	1.482	.485
156	*2	31	133601	10305	75101	724	304	8012	6435	53	104	153	332	4257	162	94	293	5078	.320	.580	.552
158	*2	32	133603	10348	75101	714	306	8030	6435	49	98	132	320	4277	150	53	310	5061	.172	.357	.483
160	*2	33	133606	10274	75101	706	297	8051	6434	65	115	157	357	4579	171	81	322	5362	.251	.475	.529
161	0	34	133608	10280	75101	666	299	8067	6432	62	96	143	327	4337	126	67	263	4692	.256	.534	.479
162	0	35	133611	10331	75101	656	307	8089	6431	49	82	131	309	4031	103	64	249	4262	.258	.621	.415
163	0	36	133613	10308	75101	636	305	8111	6430	56	73	140	325	3976	82	83	252	4005	.331	1.012	.327
164	0	37	133616	10283	75101	635	302	8131	6430	41	82	131	315	4111	102	62	248	4296	.251	.608	.412
165	0	38	133618	10309	75101	693	305	8150	6430	40	85	153	342	4096	120	115	295	4678	.391	.965	.406
166	0	39	133621	10280	75101	660	298	8172	6430	63	97	166	348	4419	123	112	252	4771	.444	.910	.487

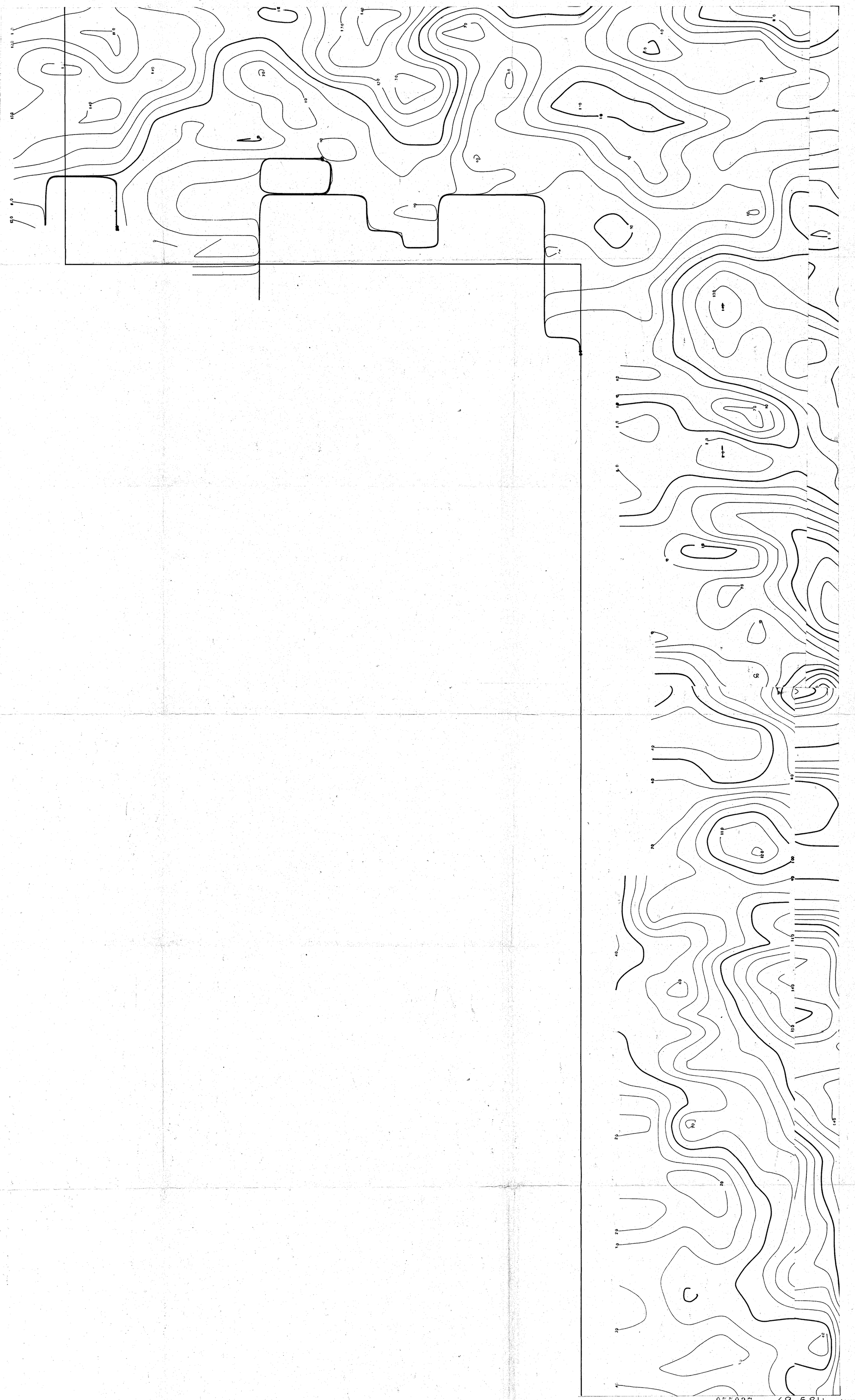
SUMMARY SINCE LAST UPWARD-LOOKING READOUT--

DOY	F-L	FRST-LST ALT	L-T	REC **	NGOOD X	FRST-LAST TOD Y	**	IDUP RAW SUMS -- COS	TH	U	K	GROSS	U-AIR **	REDUCED SUMS -- TH	U	K	GR	** U/K	U/TH	TH/K
75	101		1	39	39	133446	133621	40					5,0							
MIN--		583	292		7523	6430		39,0	70,5	117,9	283,2	3909,5		62,4	34,2	168,4	3937,4	.104	.283	.225
MAX--		763	307		8172	6473		65,3	114,7	195,1	400,1	4970,3		170,5	199,8	385,1	5688,8	1,084	1,605	.766
AVG--		676,1	300,9		7814,	6453,		52,3	92,3	148,2	336,0	4280,3		124,9	88,0	280,3	4791,0	.341	.728	.464

Figure 7

0550035 69-584 1749
T1208 SHEET 1 OF 8 SHEETS

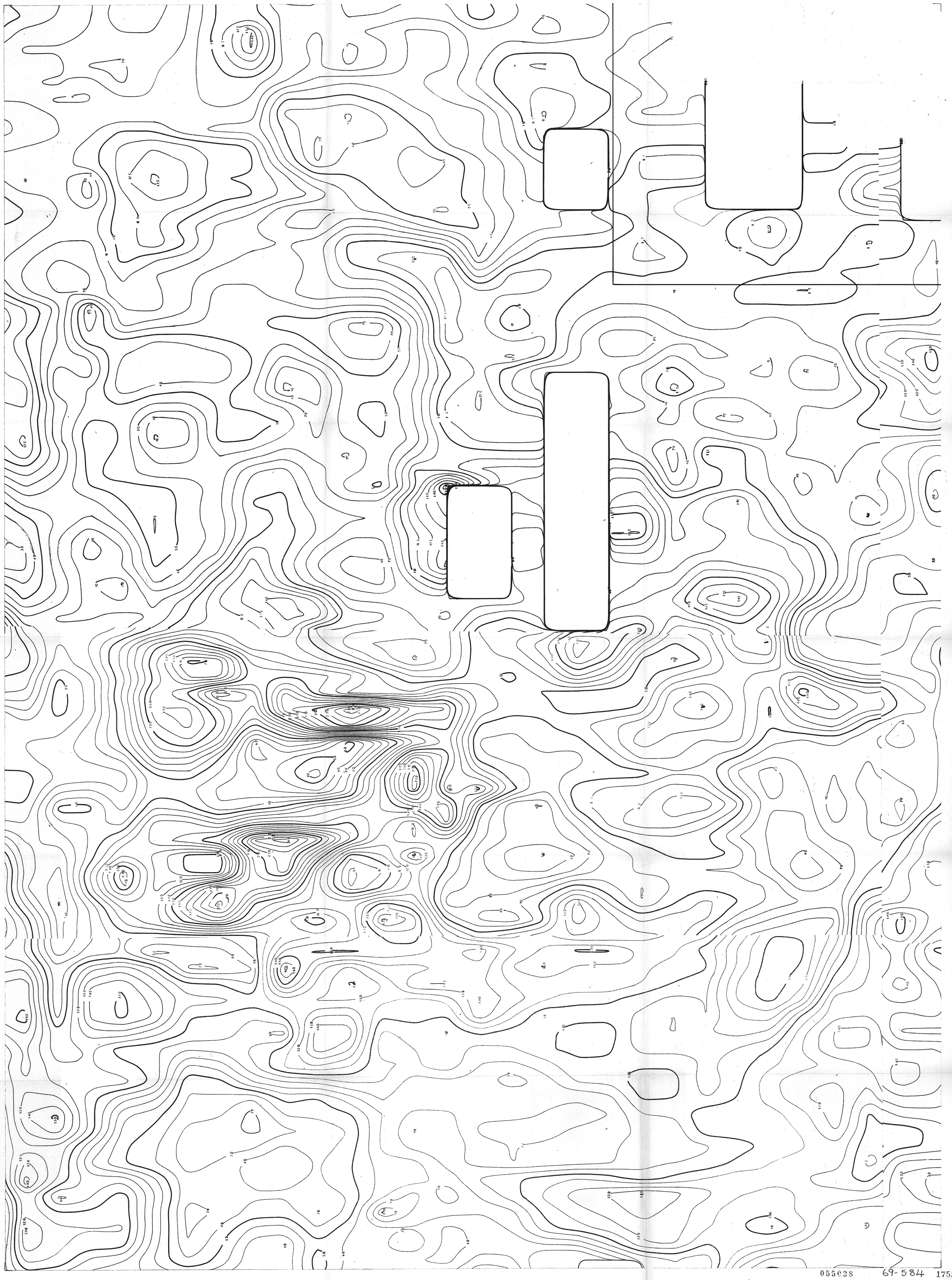




055037 69-584 1751

5 cm

TI^{208} SHEET 3 OF 8 SHEETS



055038 69-584 1752

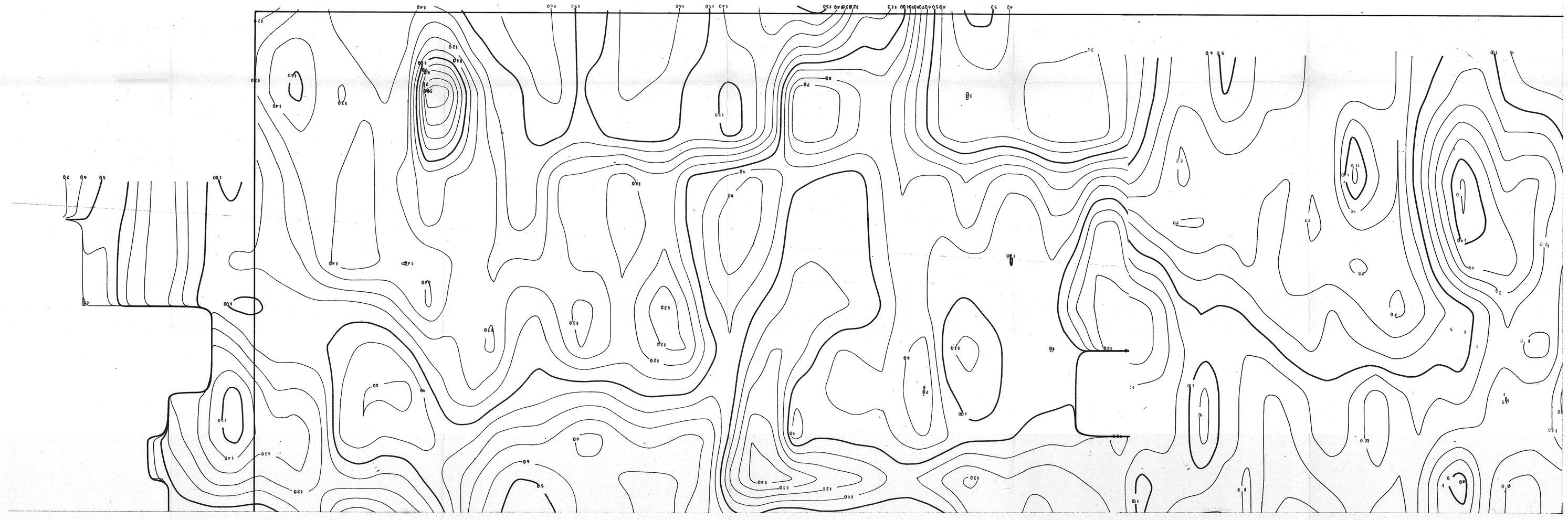
5 cm

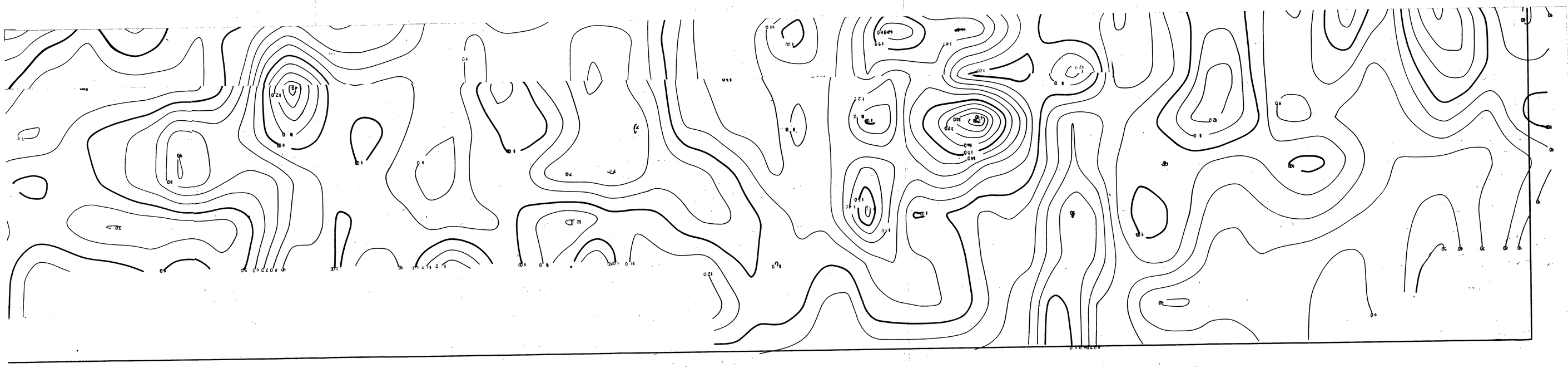
TI^{208} SHEET 4 OF 8 SHEETS

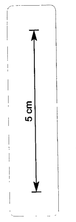
055039 69-584 1753

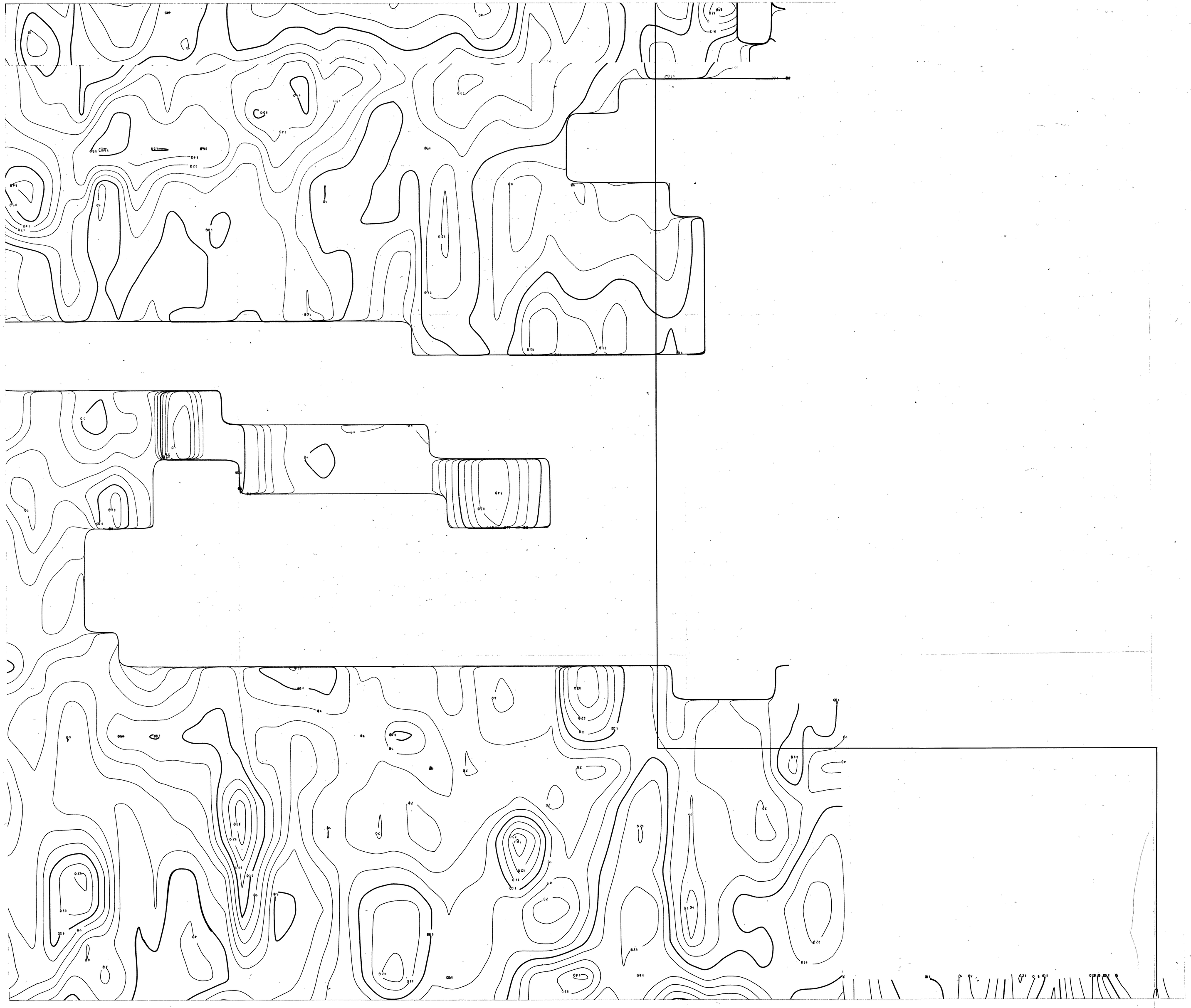
Tl^{208} SHEET 5 OF 8 SHEETS

5cm






5 cm



055041 69-884 1755

T^{208} SHEET 7 OF 8 SHEETS

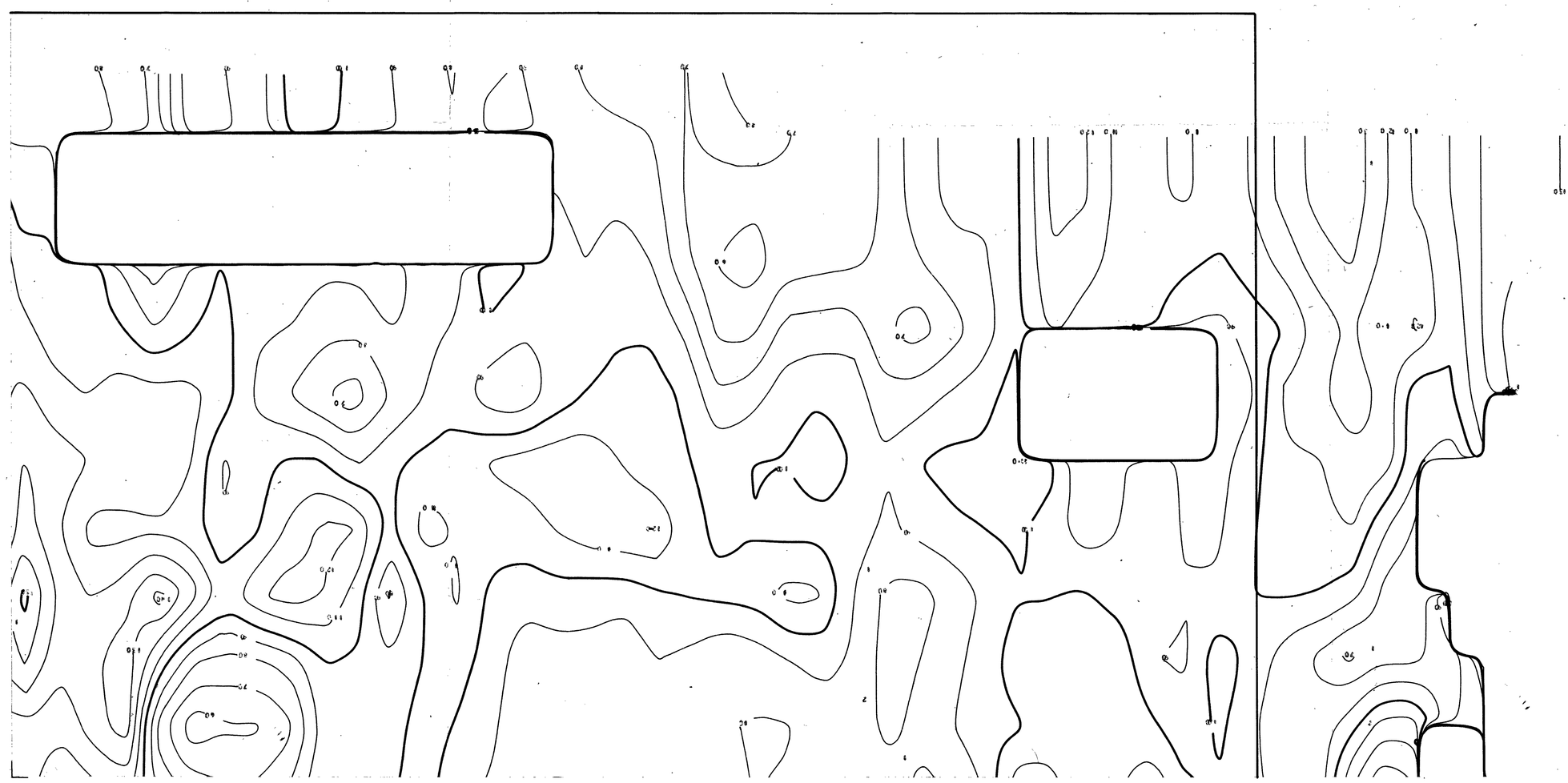
5m

055042

69-584

Tl^{208} SHEET 8 OF 8 SHEETS

1756



1757

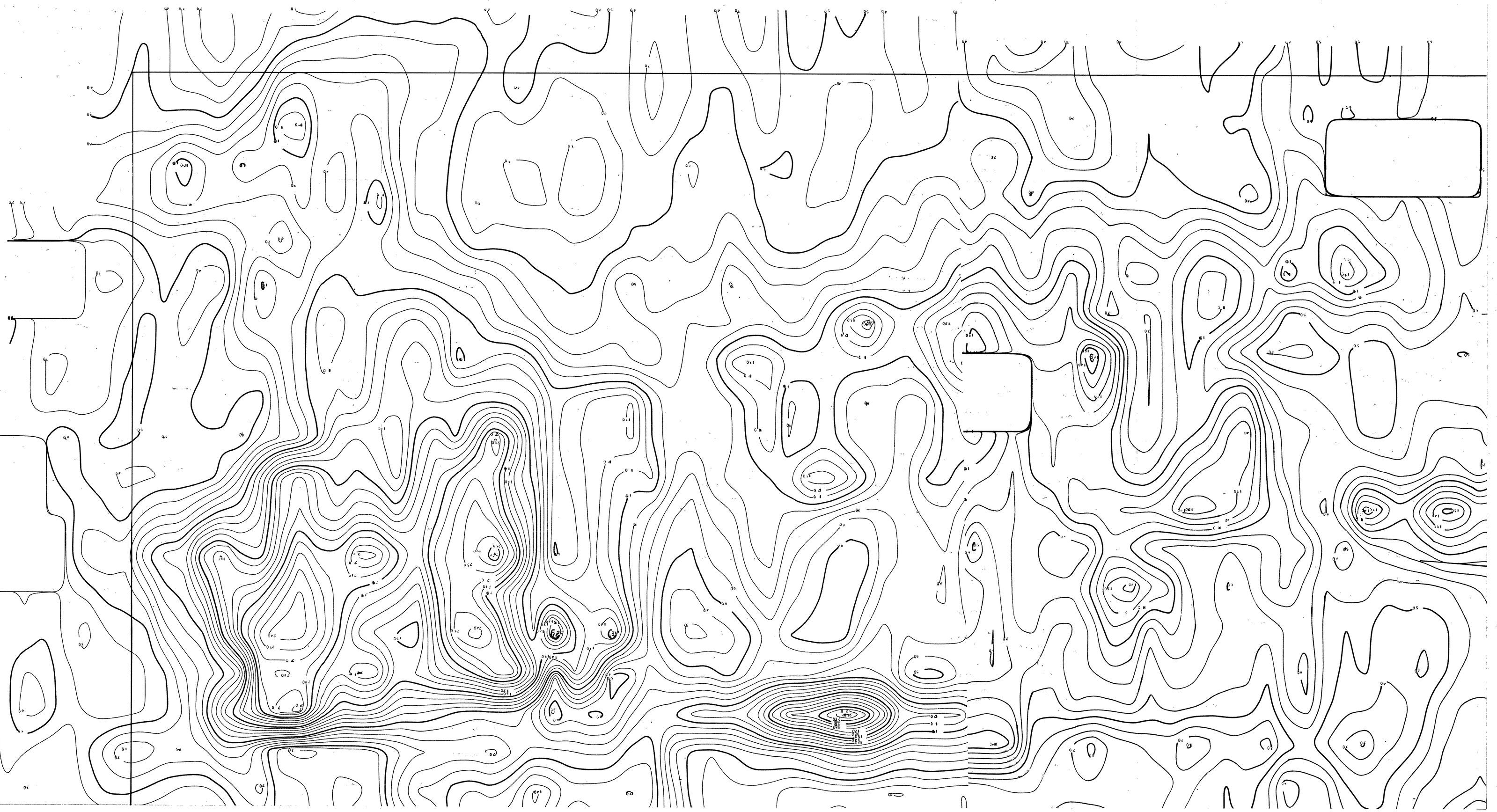
055033 69-584

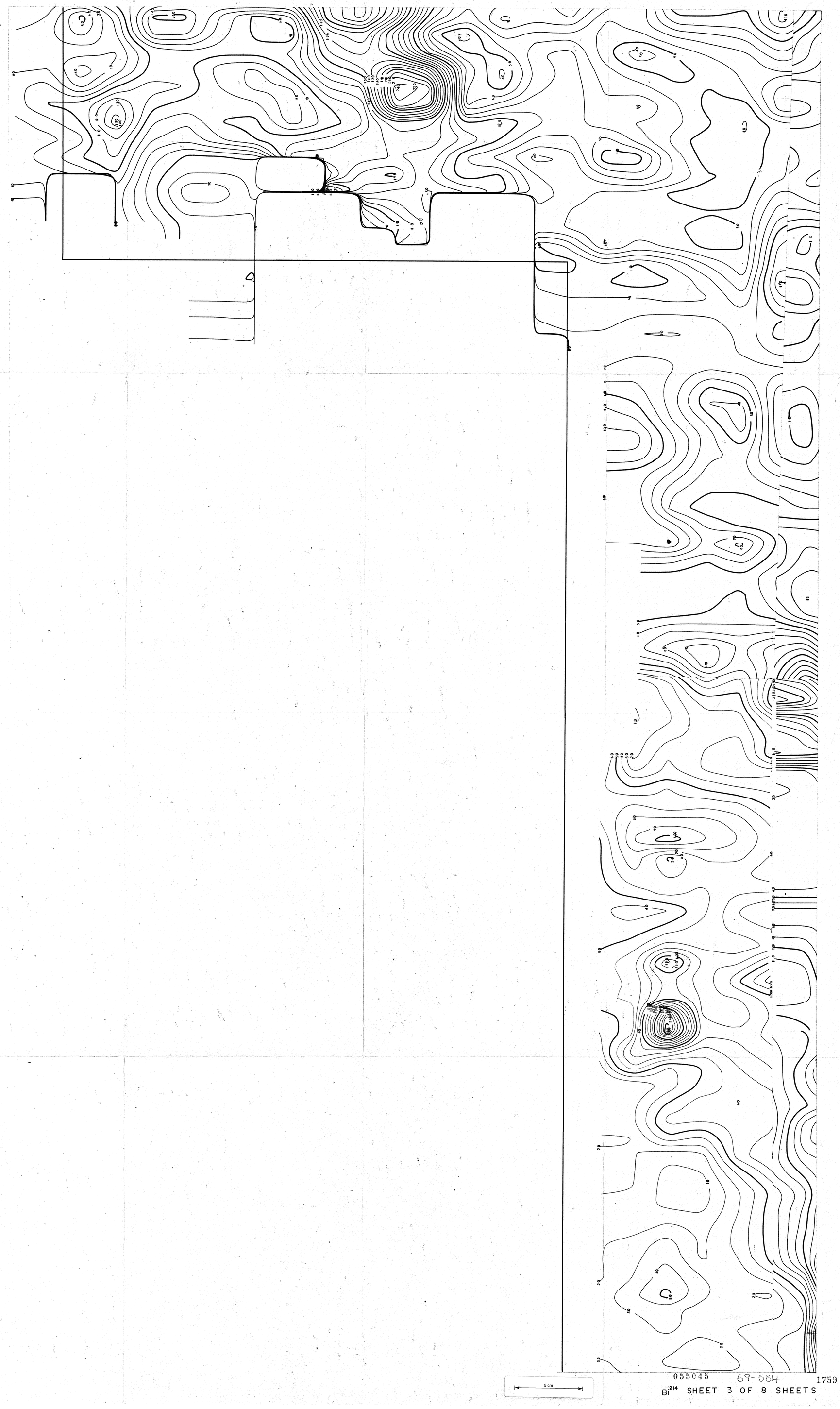
Bi^{214} SHEET 1 OF 8 SHEETS

Bi^{214} SHEET 2 OF 8 SHEETS

69-584

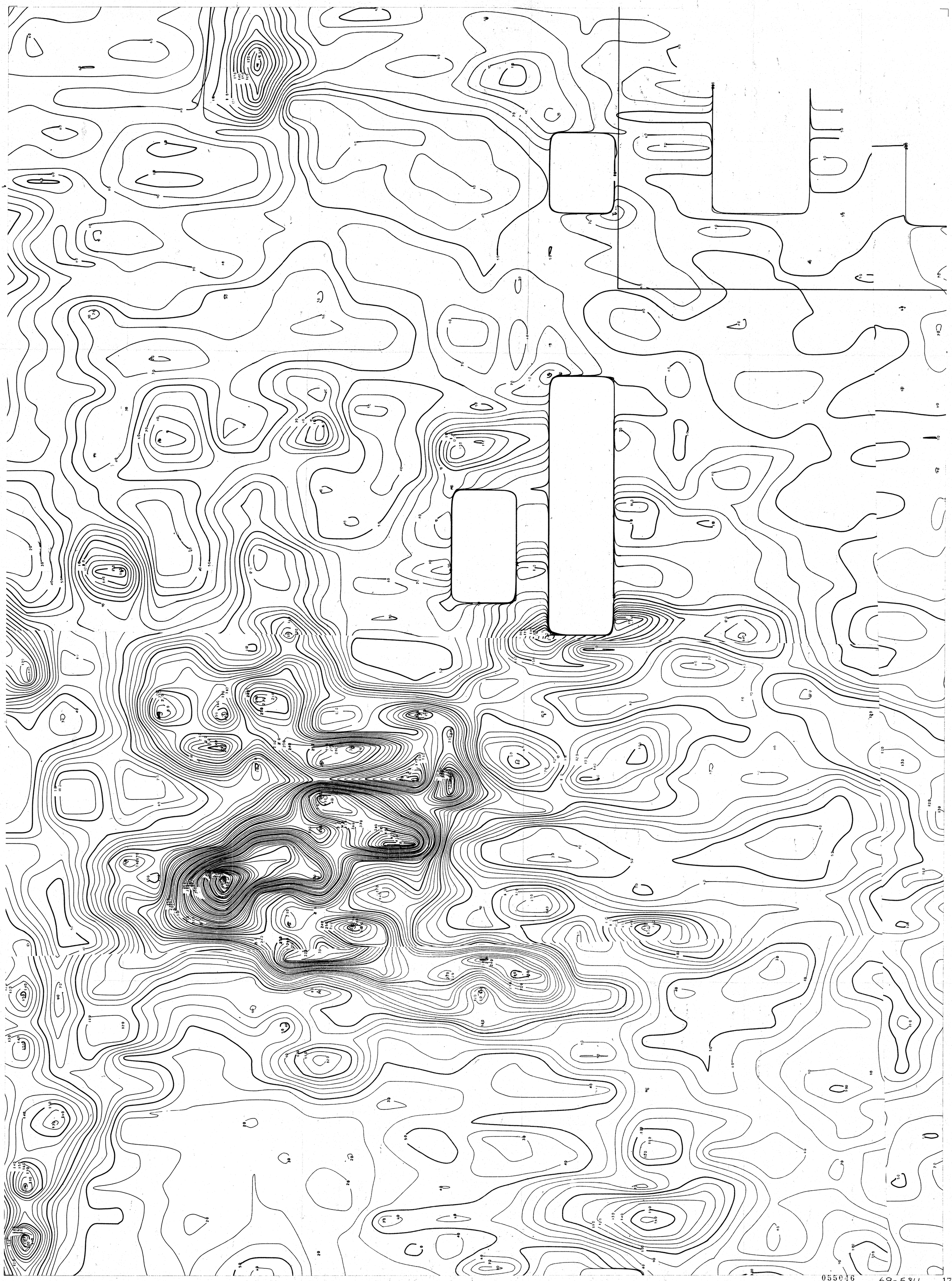
1753





055045 69-584 1759

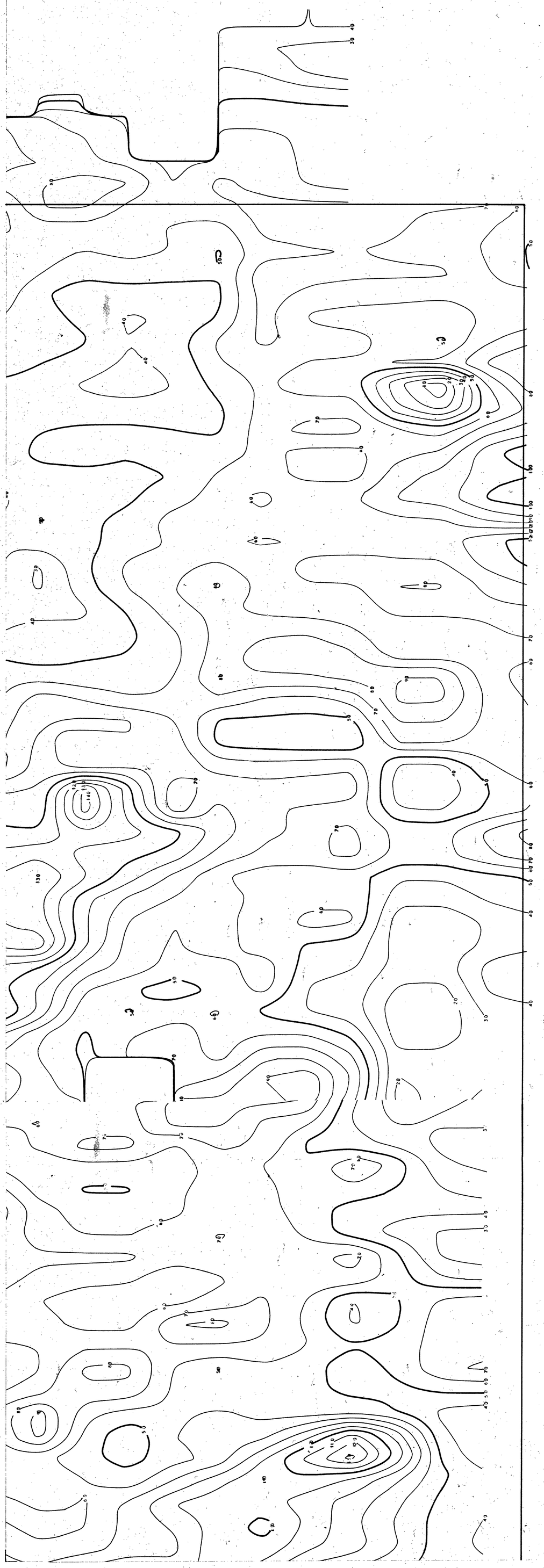
Bi^{214} SHEET 3 OF 8 SHEETS



055046 69-584 1760

5 cm

Bi^{214} SHEET 4 OF 8 SHEETS

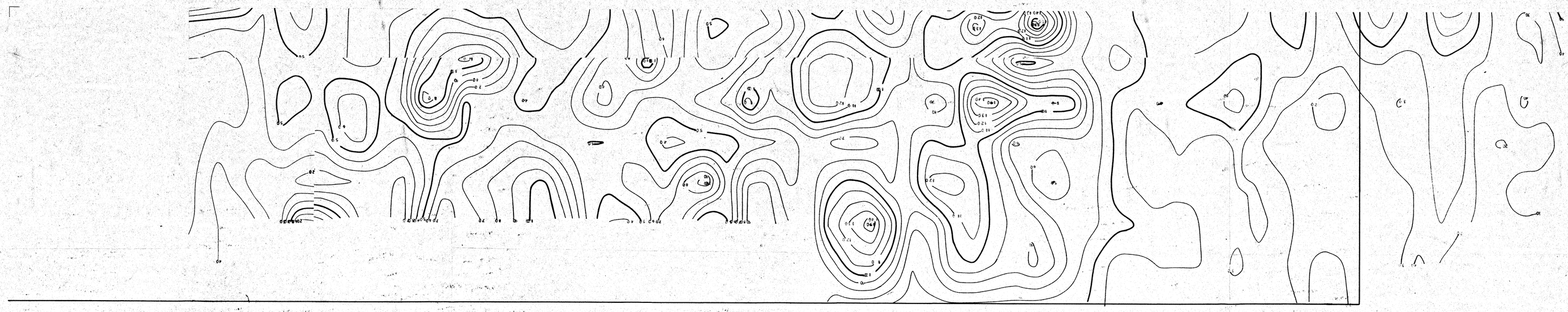


5 cm

055047

69-584

Bi^{214} SHEET 5 OF 8 SHEETS 1761



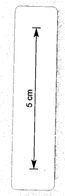
055048
69-584
1762

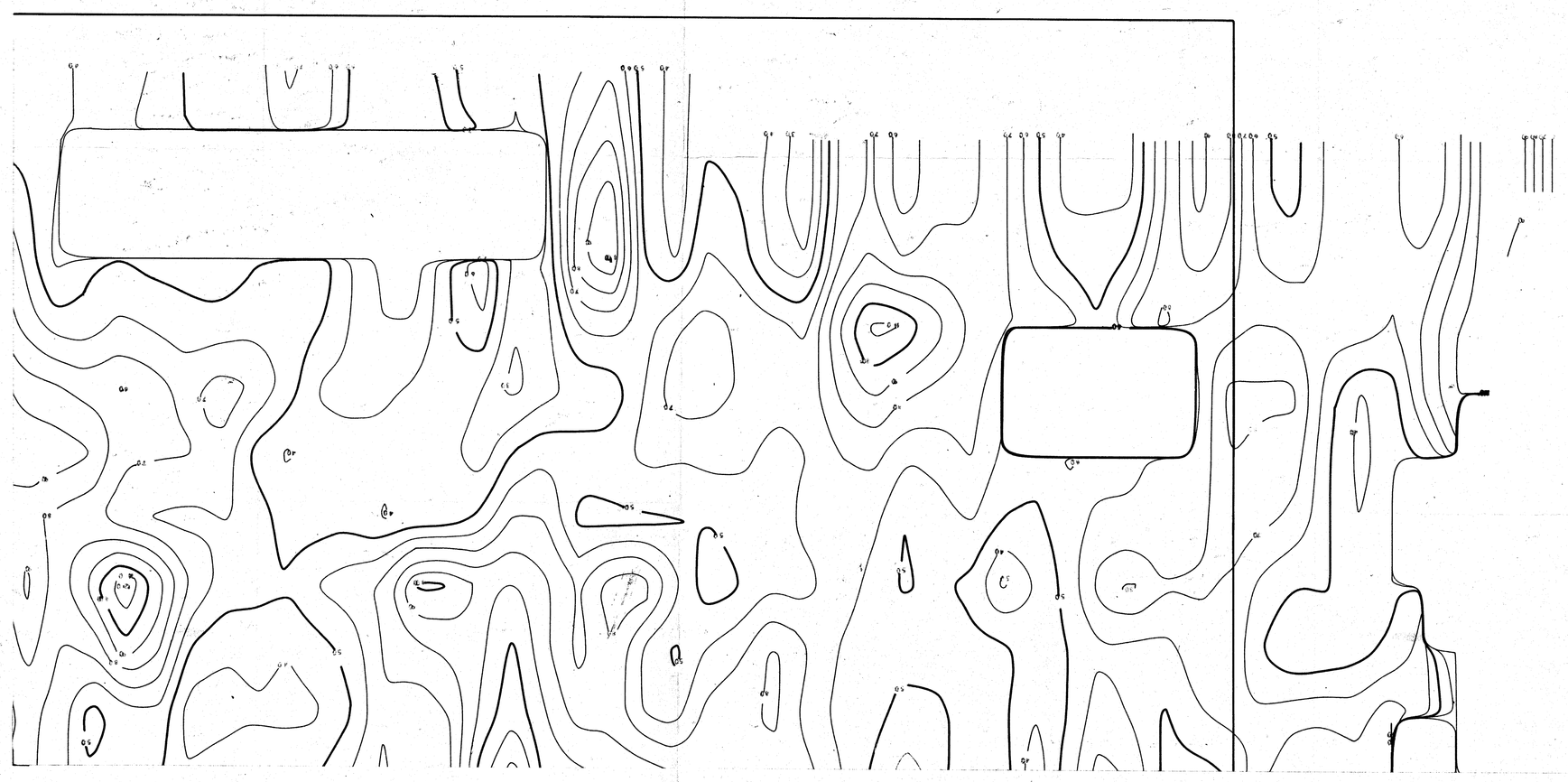
Bi^{214} SHEET 6 OF 8 SHEETS

0550 49
69-584
1763
5 cm
BI214 SHEET 7 OF 8 SHEETS

69-584 1764

Bi^{214} SHEET 8 OF 8 SHEETS





1705

055051 69-584

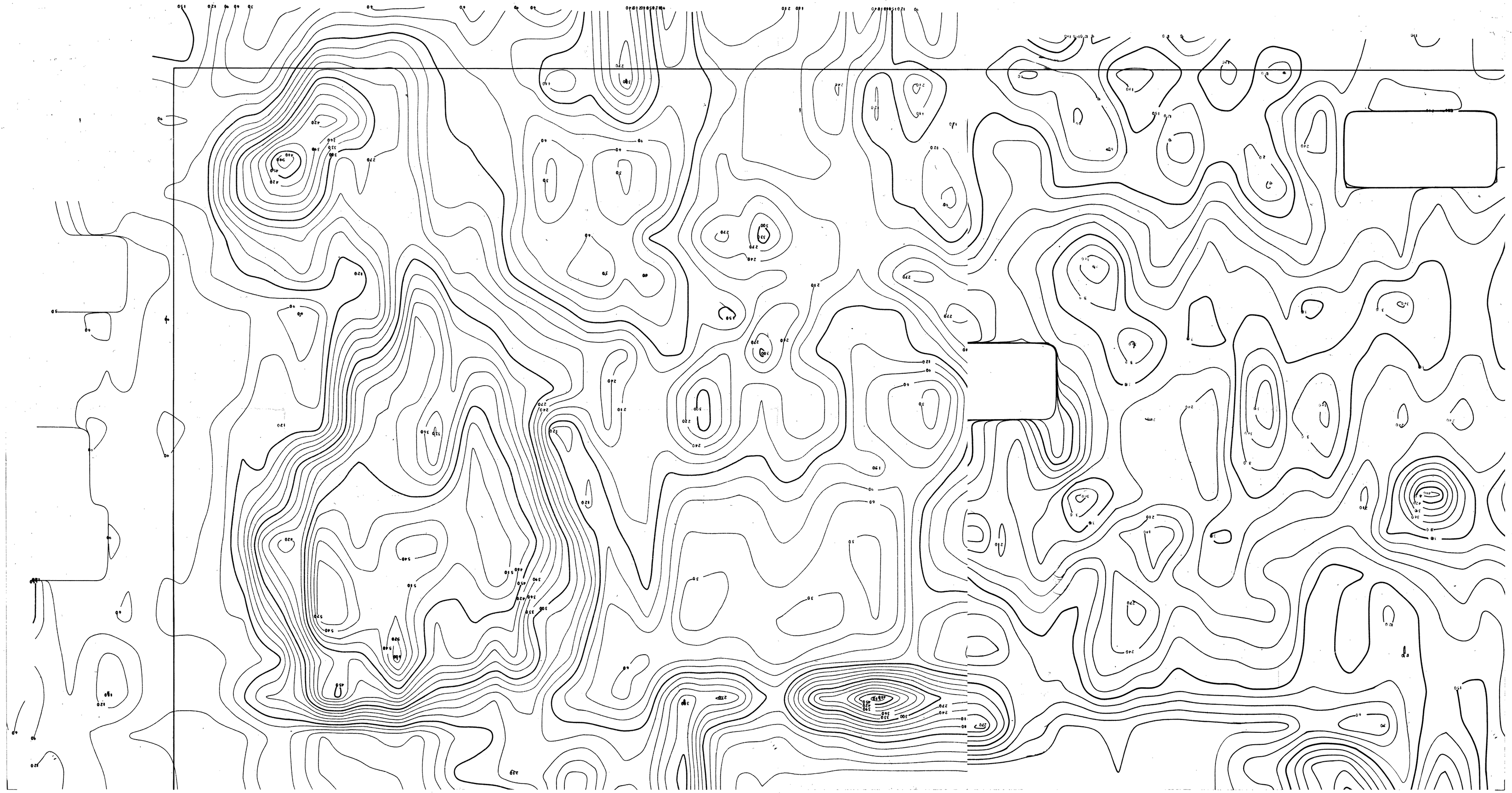
K^{40} SHEET I OF 8 SHEETS

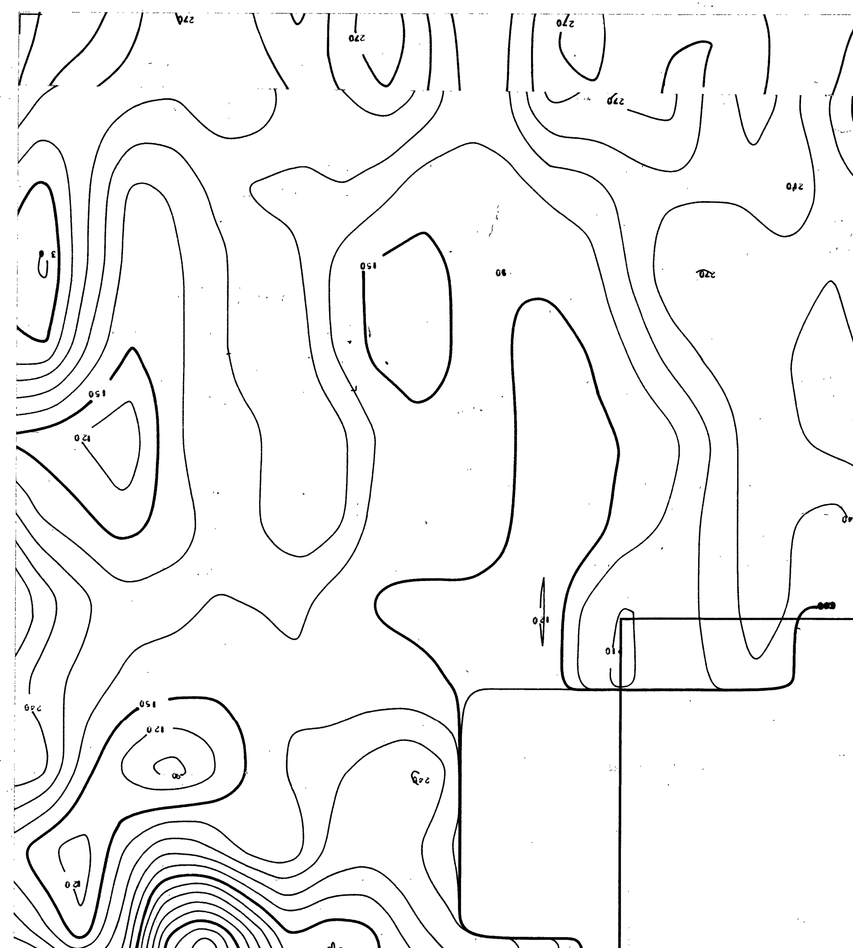
1766

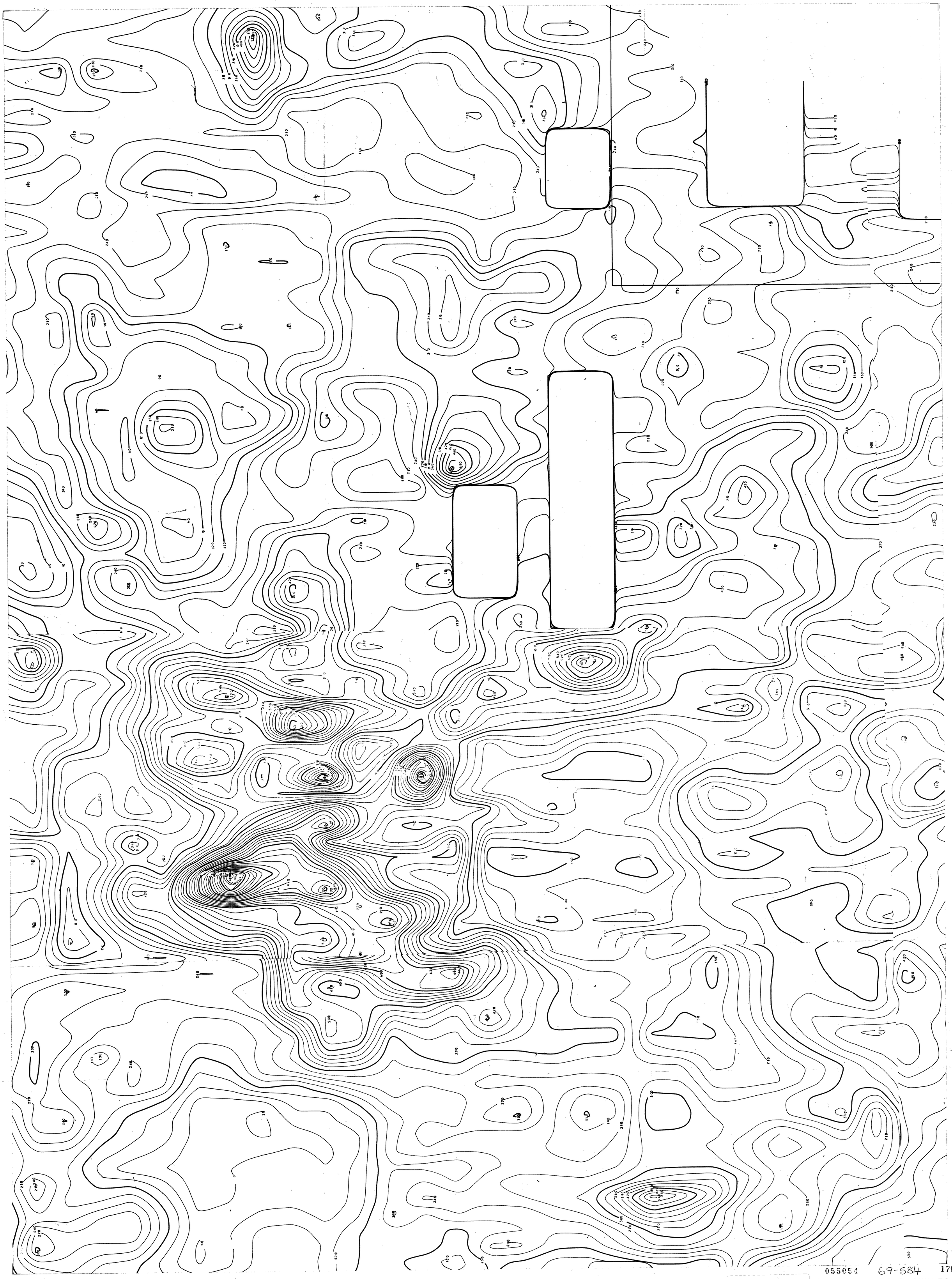
69-584

K^{40} SHEET 2 OF 8 SHEETS

055003







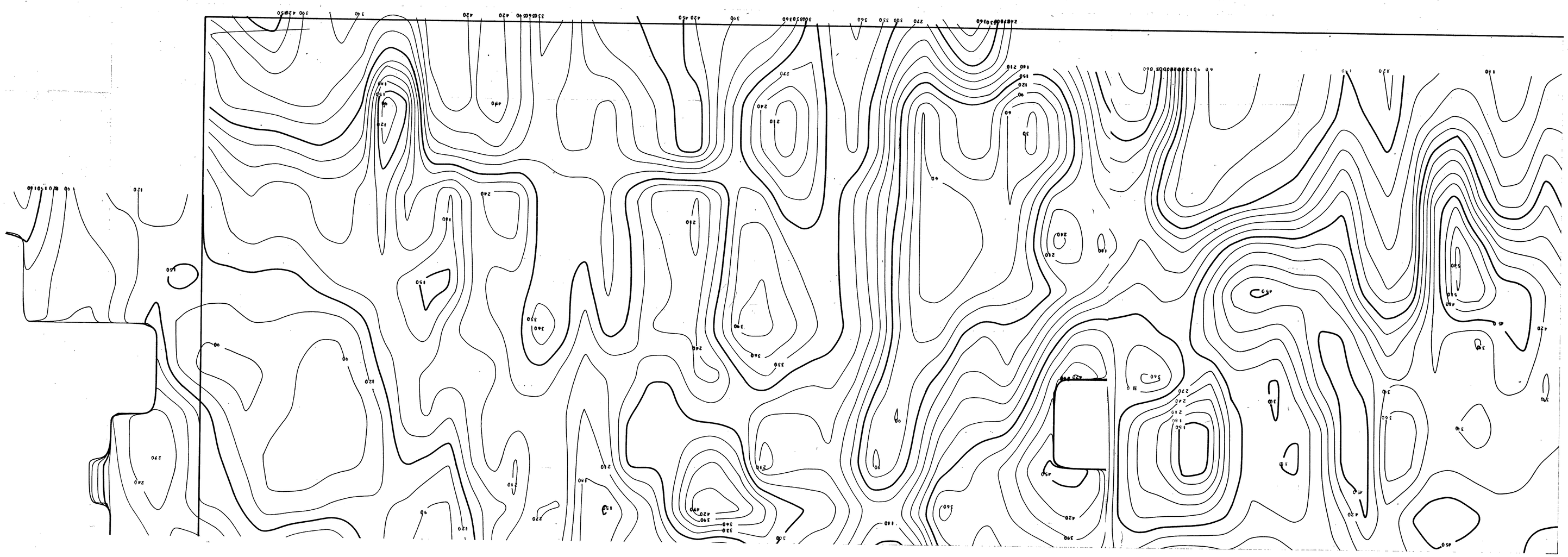
055054 69-584 1768

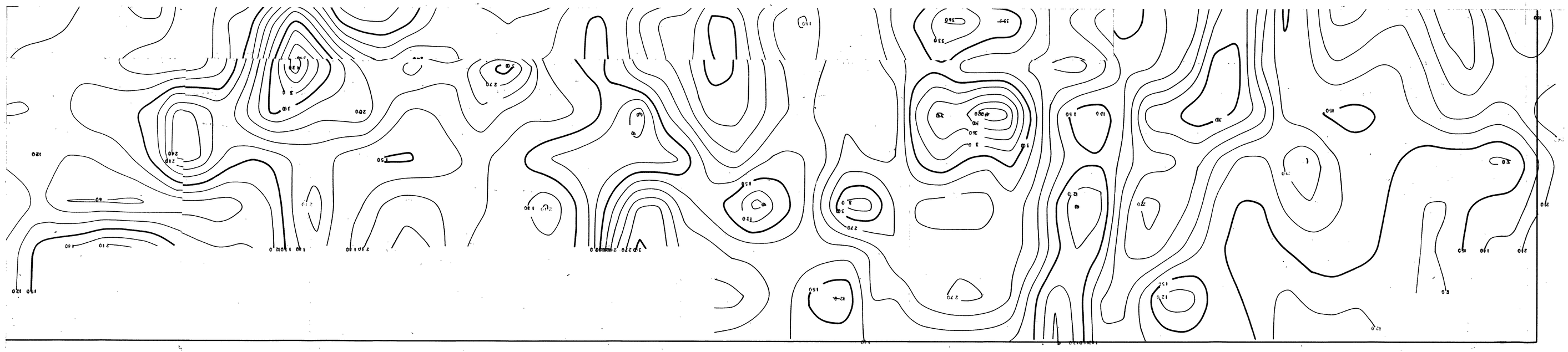
5 cm

SHEET 4 OF 8 SHEETS

055055 69-584 1769

K^{40} SHEET 5 OF 8 SHEETS





K^{40} SHEET 6 OF 8 SHEETS

69-584 1470

055056

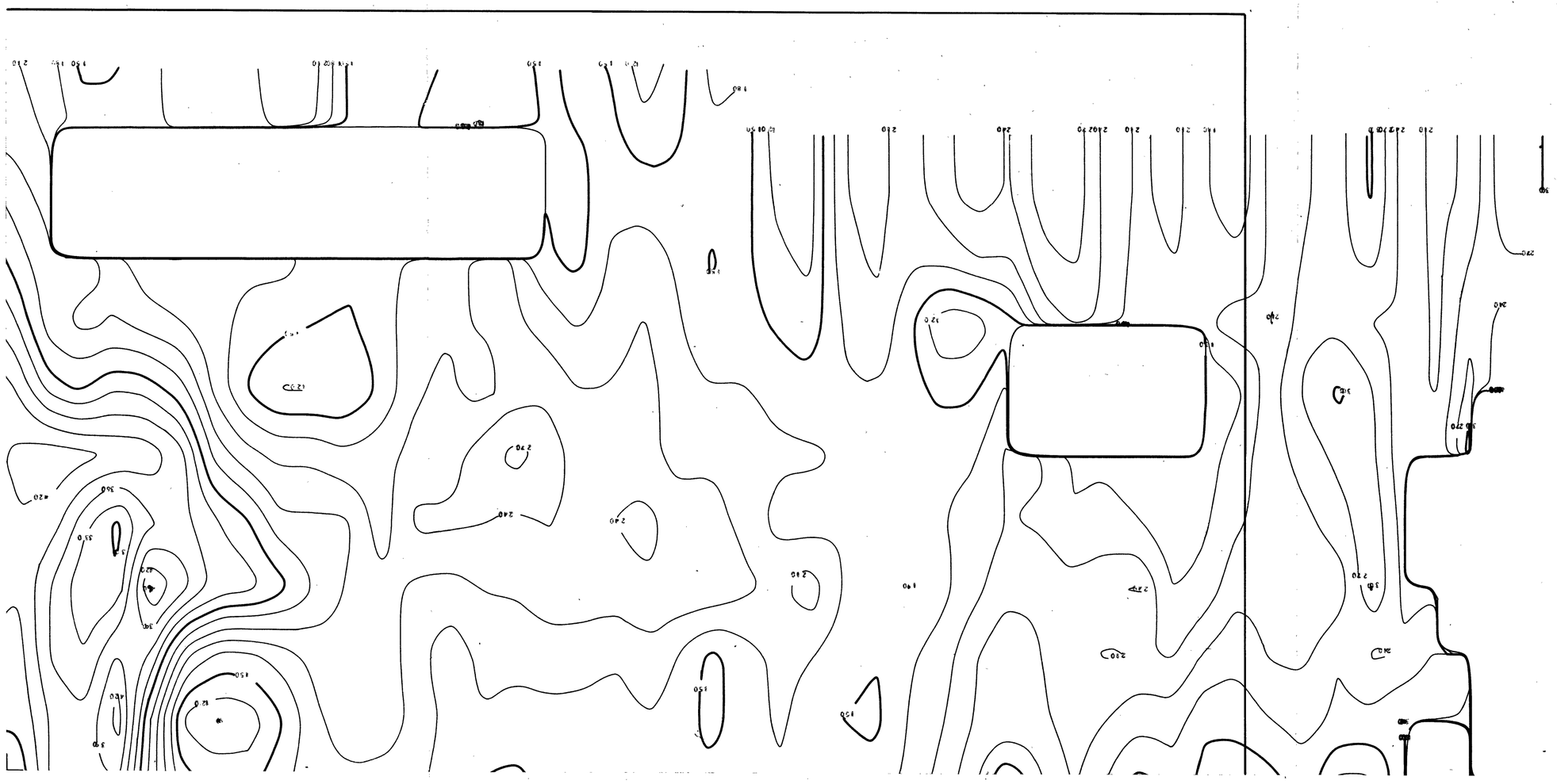
5 cm

055057 69-584 1771
K40 SHEET 7 OF 8 SHEETS

K⁴⁰ SHEET 8 OF 8 SHEETS

69-584 177d

055058



Bi^{214}, Tl^{208} 0550569-584 SHEET 1 OF 8 SHEETS 1773

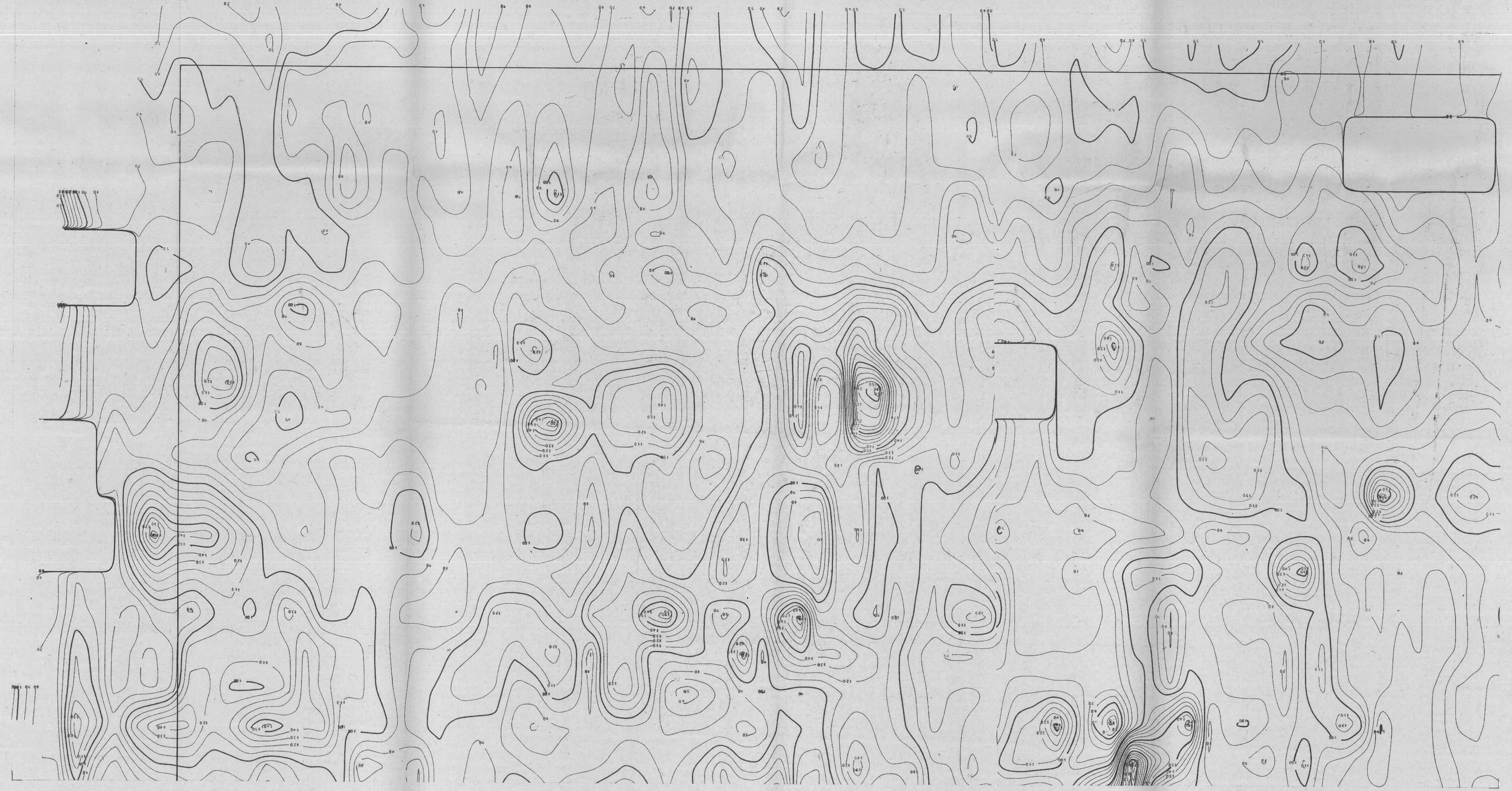
055060

69-584

1774

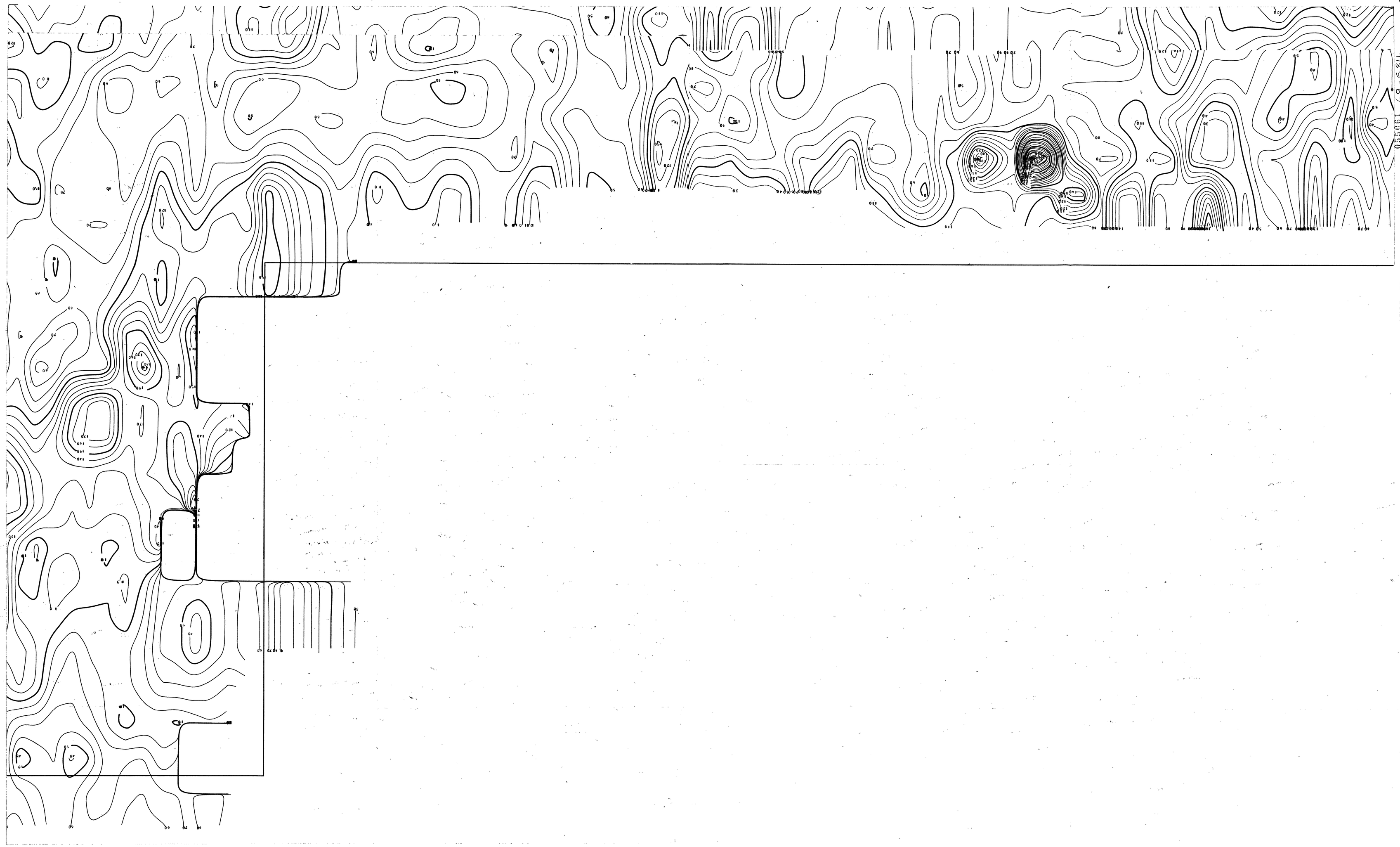
Bi^{214}/Tl^{208} SHEET 2 OF 8 SHEETS

5 cm



1775

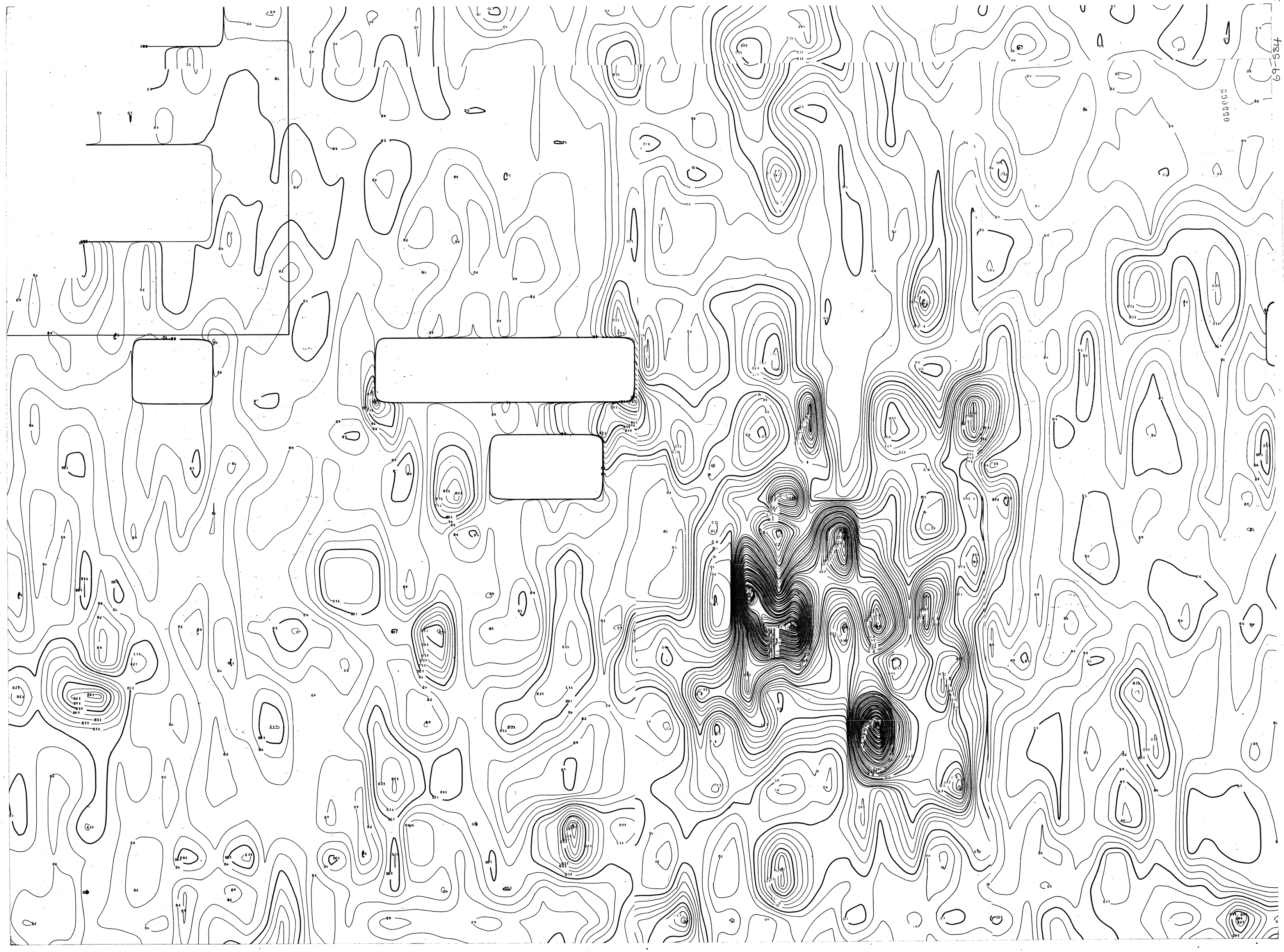
Bi^{214}/Tl^{208} 055061 69-584 SHEET 3 OF 8 SHEETS



Bi^{214}/Tl^{208} SHEET 4 OF 8 SHEETS

69-584

1776

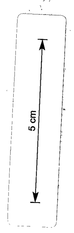


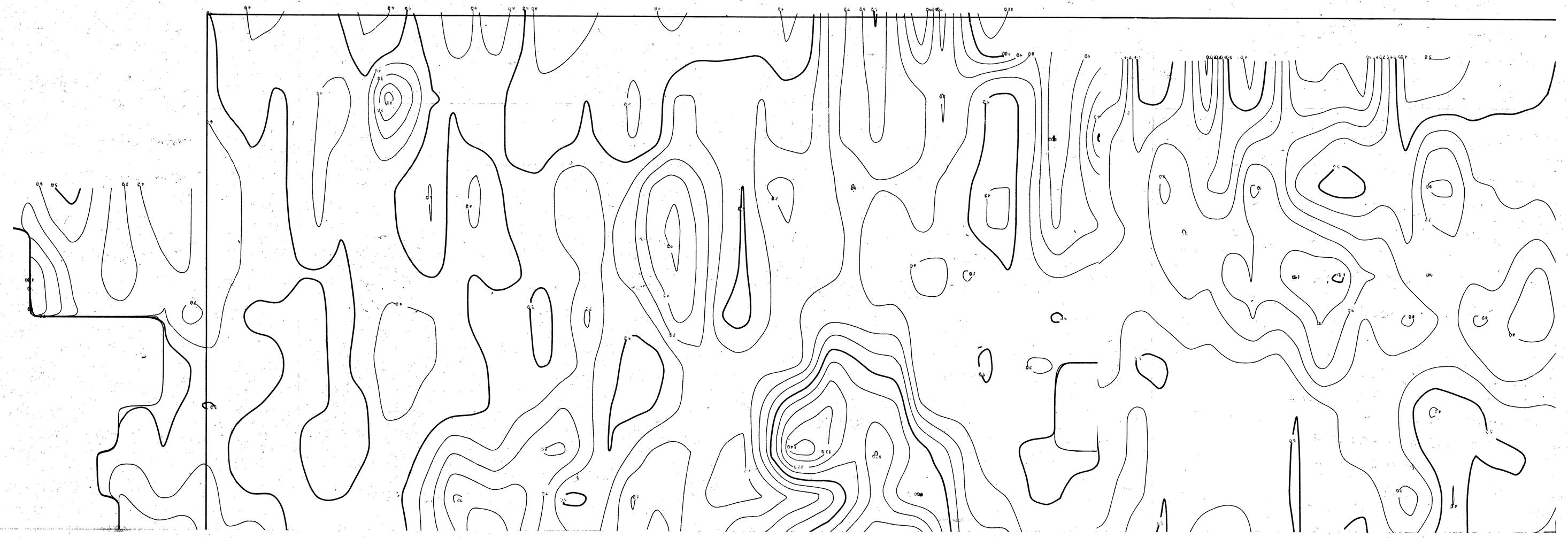
Bi^{214}/Tl^{208} SHEET 5 OF 8 SHEETS

1777

055063

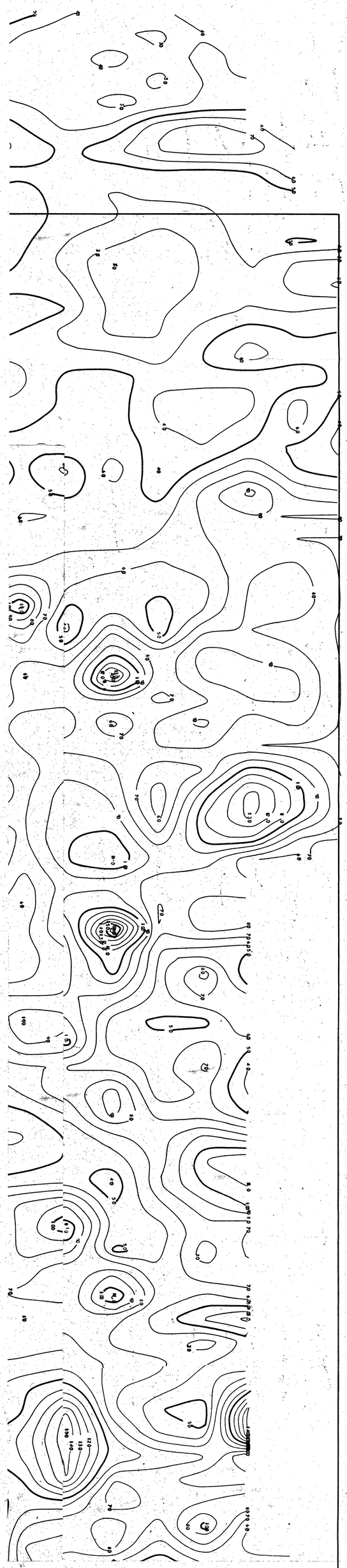
485-9



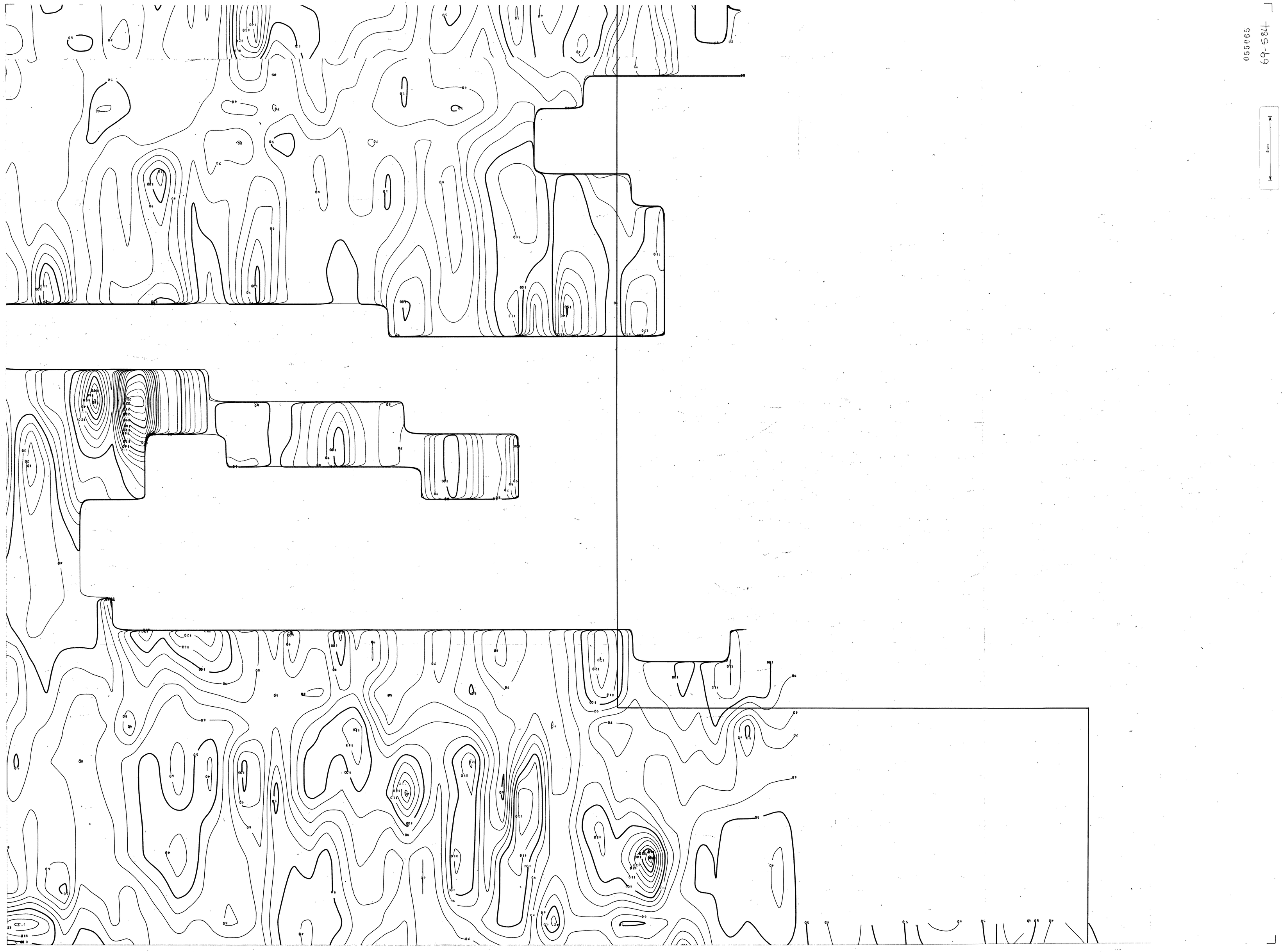


69-581+

055064



5 cm

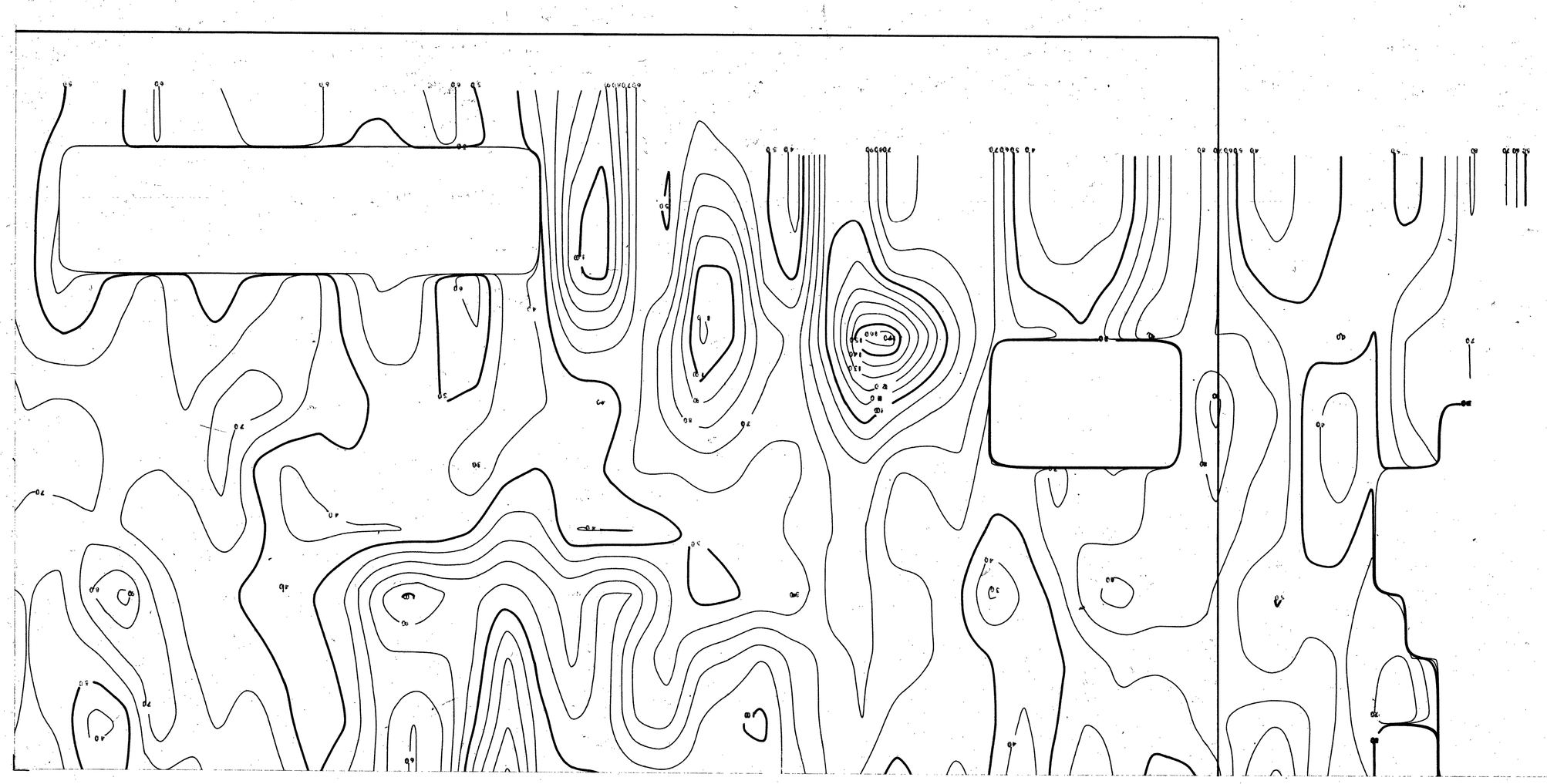


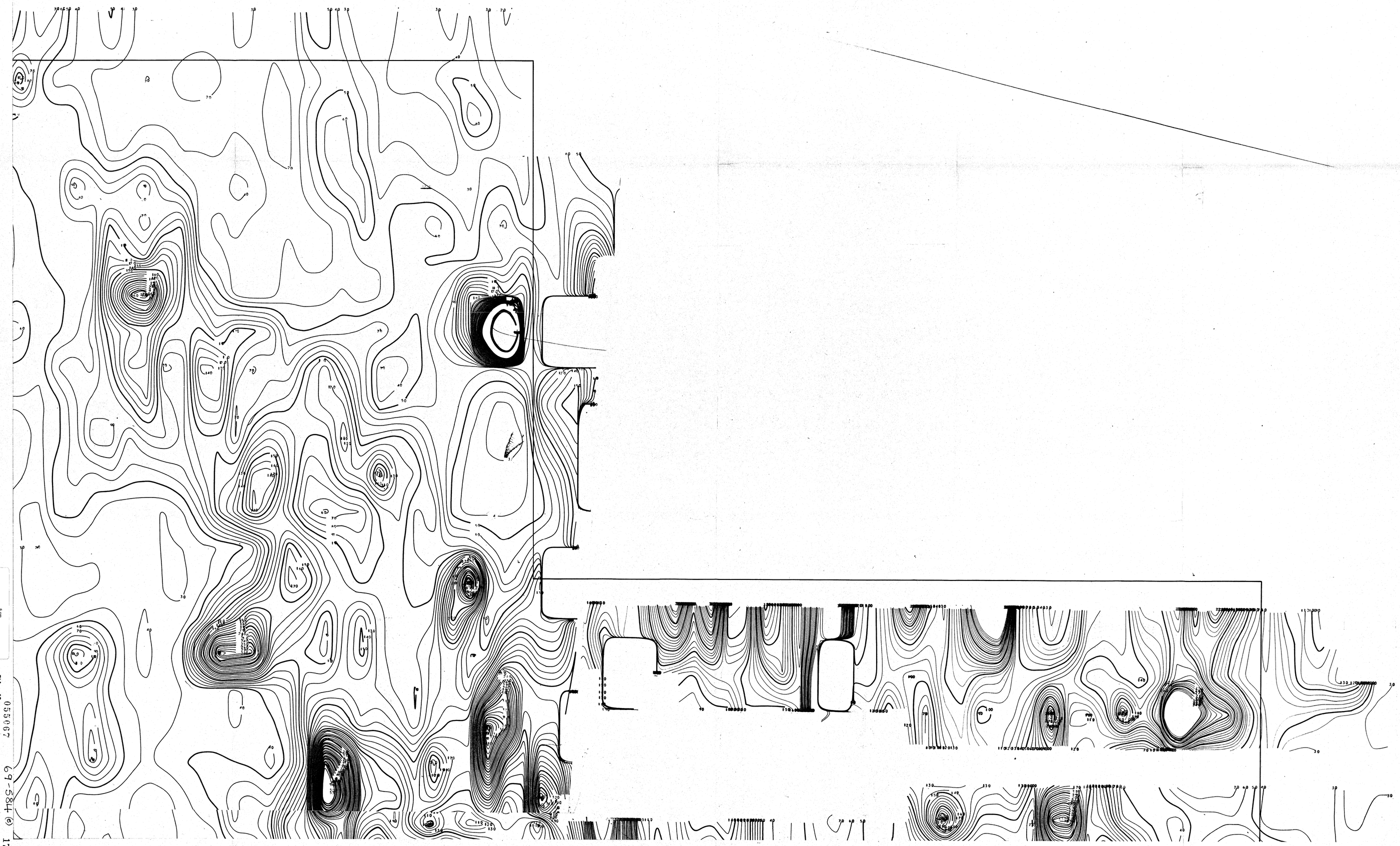
Bi^{214}/Tl^{208} SHEET 8 OF 8 SHEETS 1780

69-584

055066

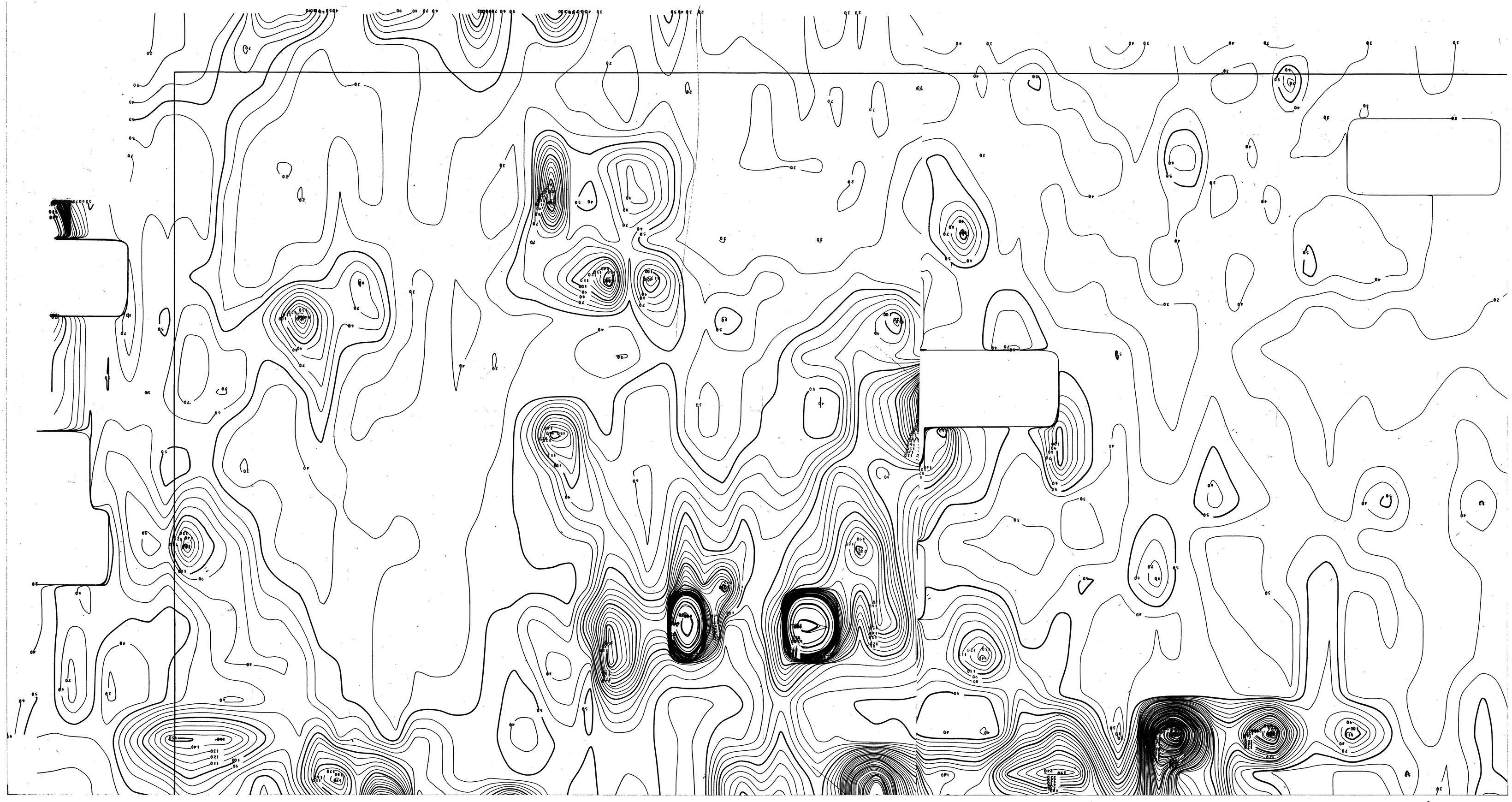
5 cm

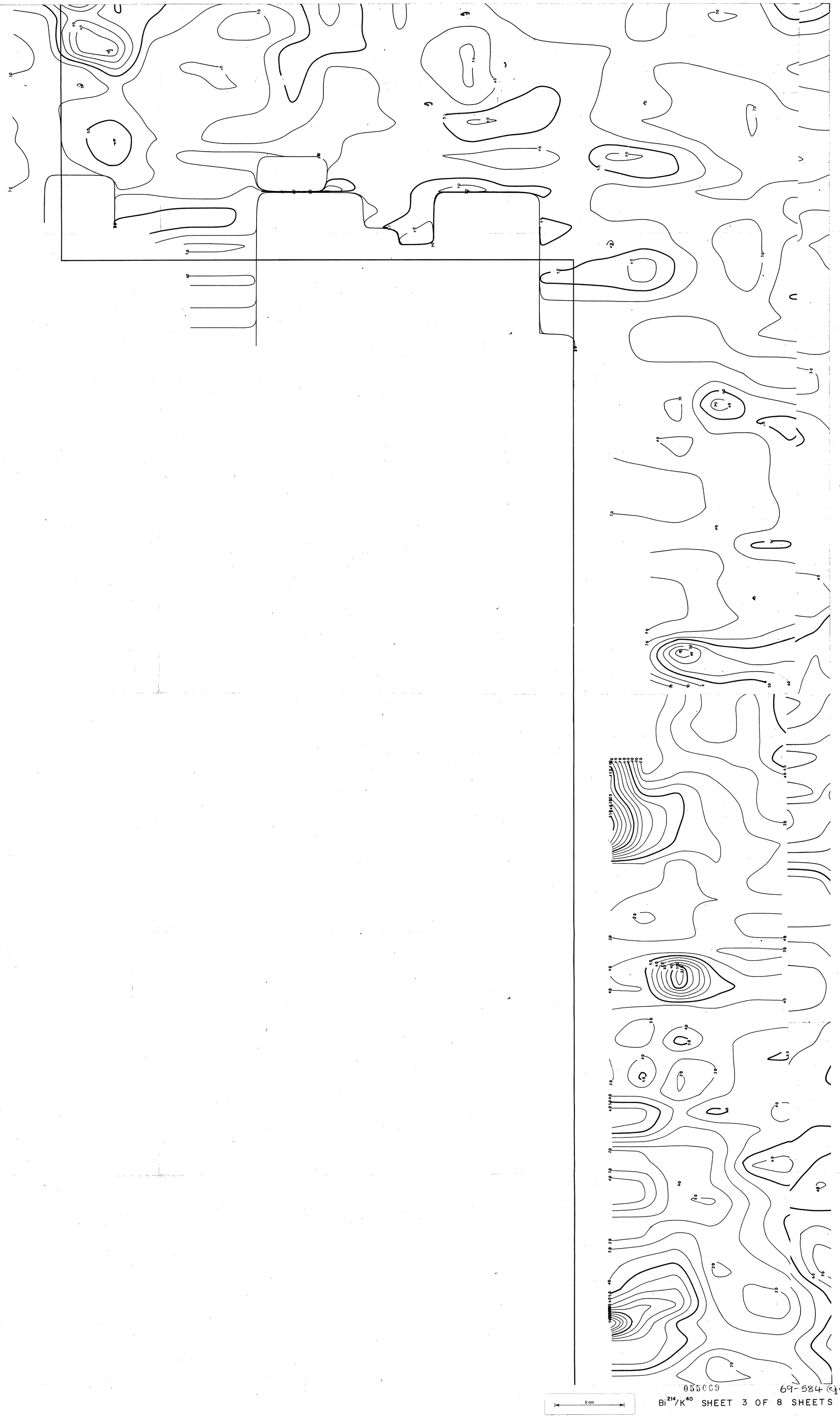




Bi^{214}K^{40} SHEET 1 OF 8 SHEETS 69-584 ® 1781

05067


5cm

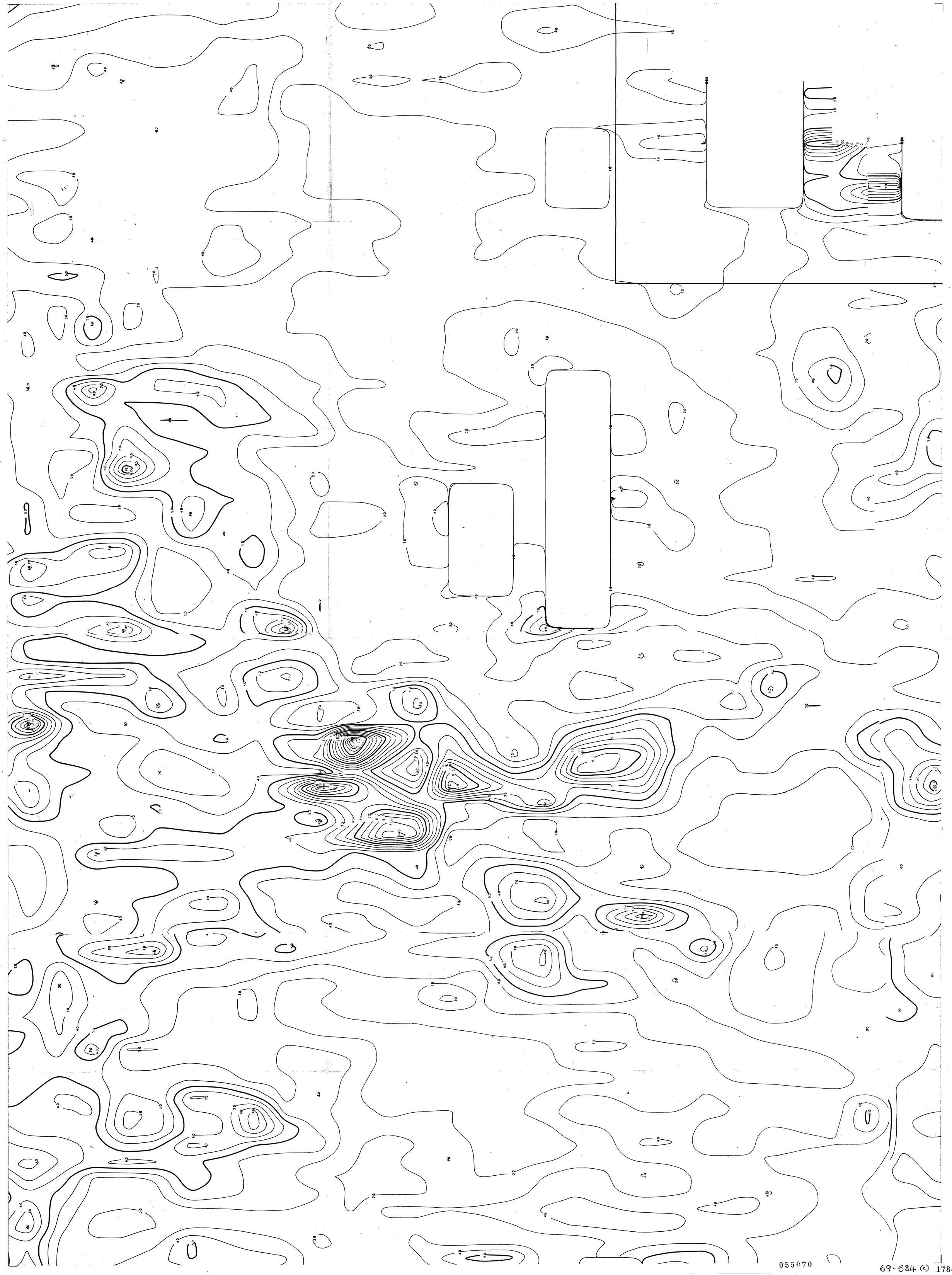


055069

69-584 (c) 1783

5 cm

Bi^{214}/K^{40} SHEET 3 OF 8 SHEETS



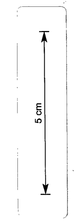
055070

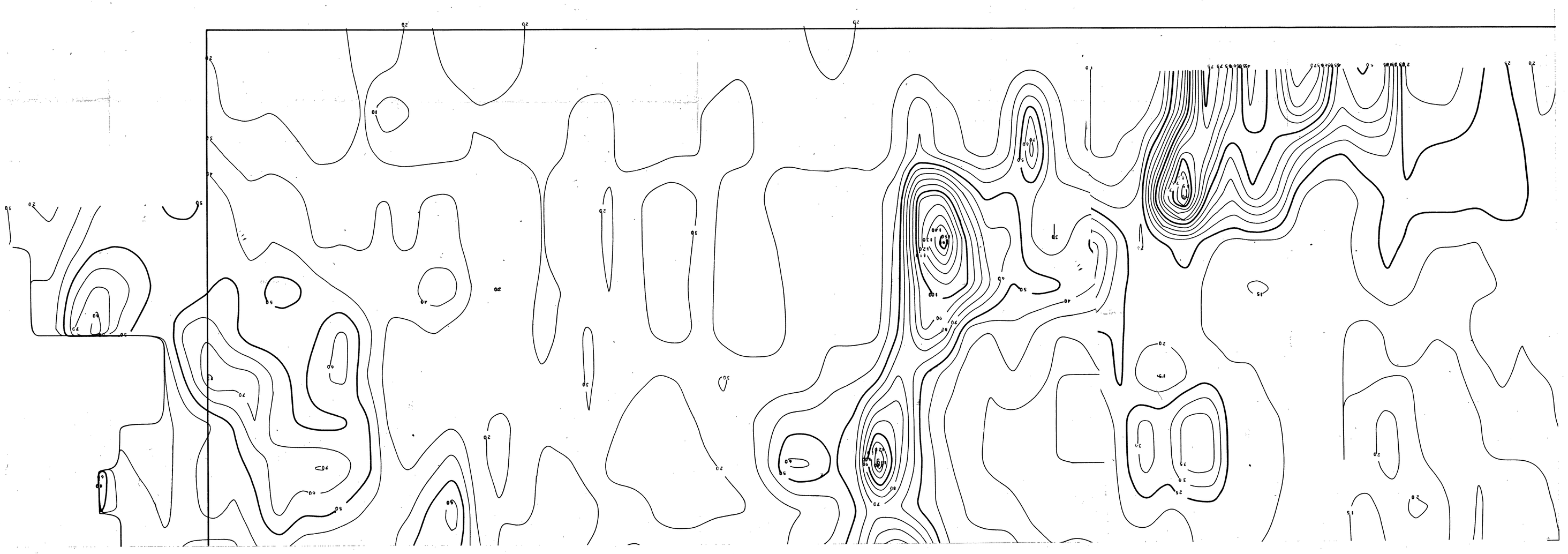
69-584 (e) 1784

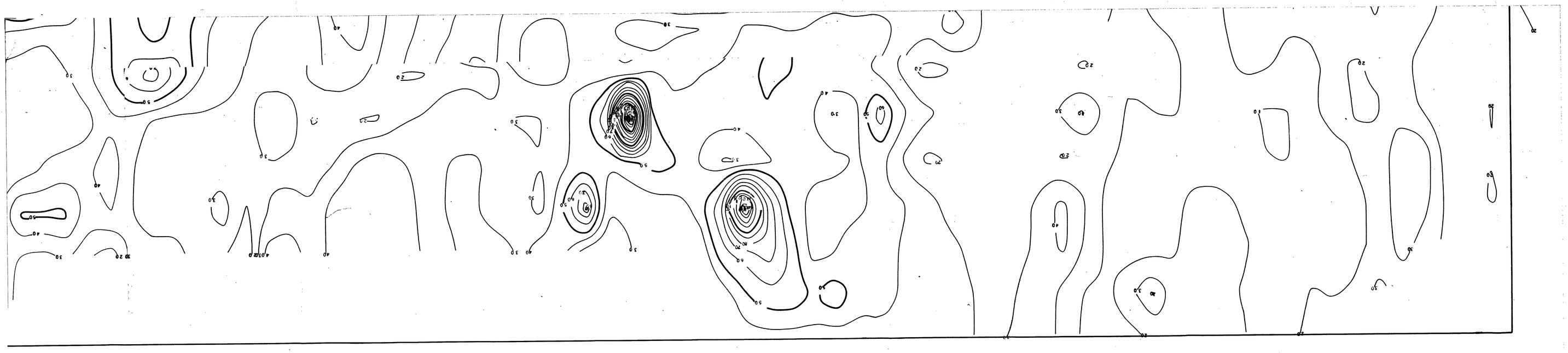
Bi^{214}/K^{40} SHEET 4 OF 8 SHEETS

Bi^{214}/K^{40} SHEET 5 OF 8 SHEETS

1785







055072 69-584(e) 1786

Bi^{214}/K^{40} SHEET 6 OF 8 SHEETS

5 cm

69-584(e) 1787

055073

Bi^{214}/K^{40} SHEET 7 OF 8 SHEETS

5cm

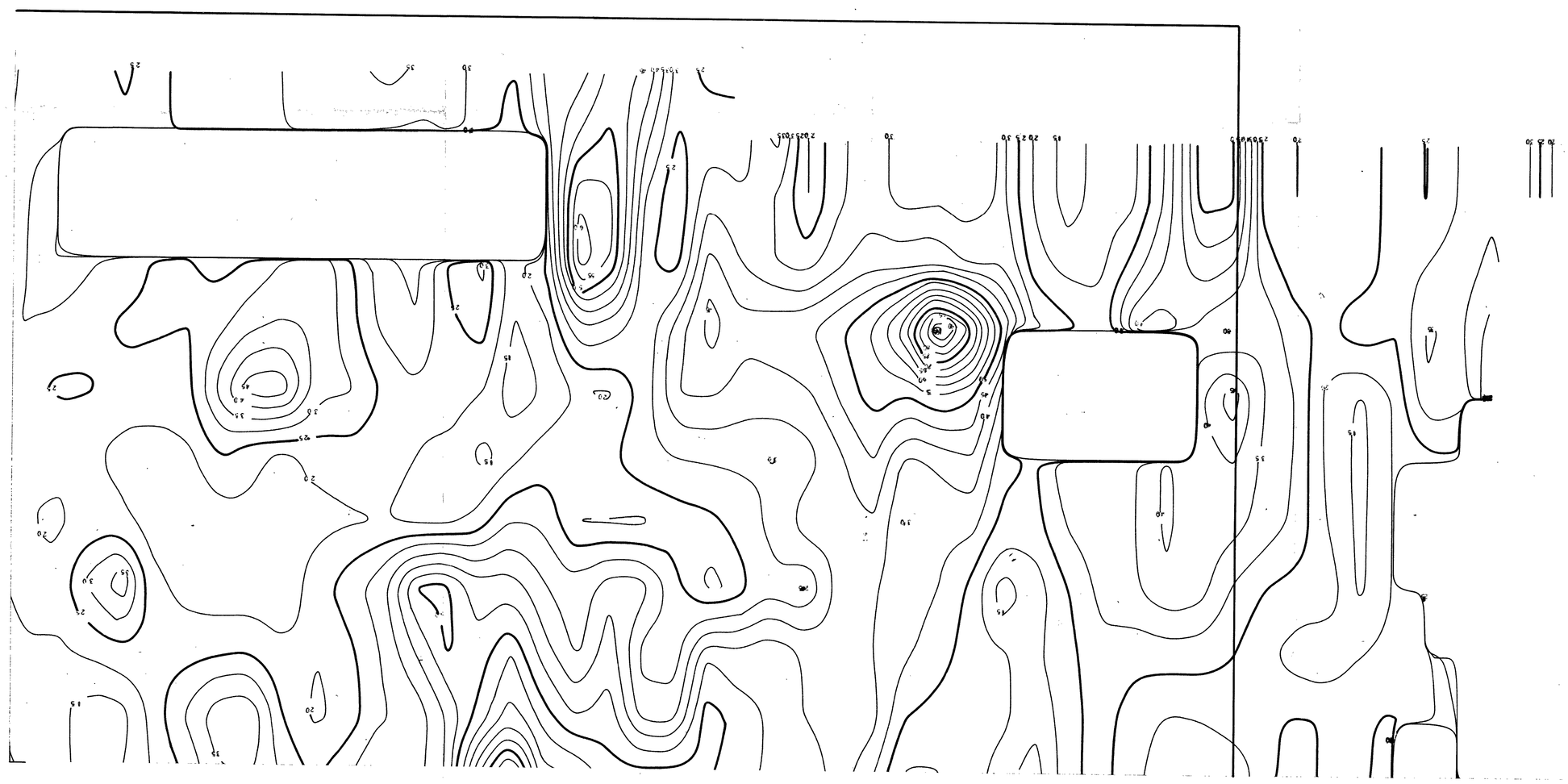
05507A

69-584(e)

1788

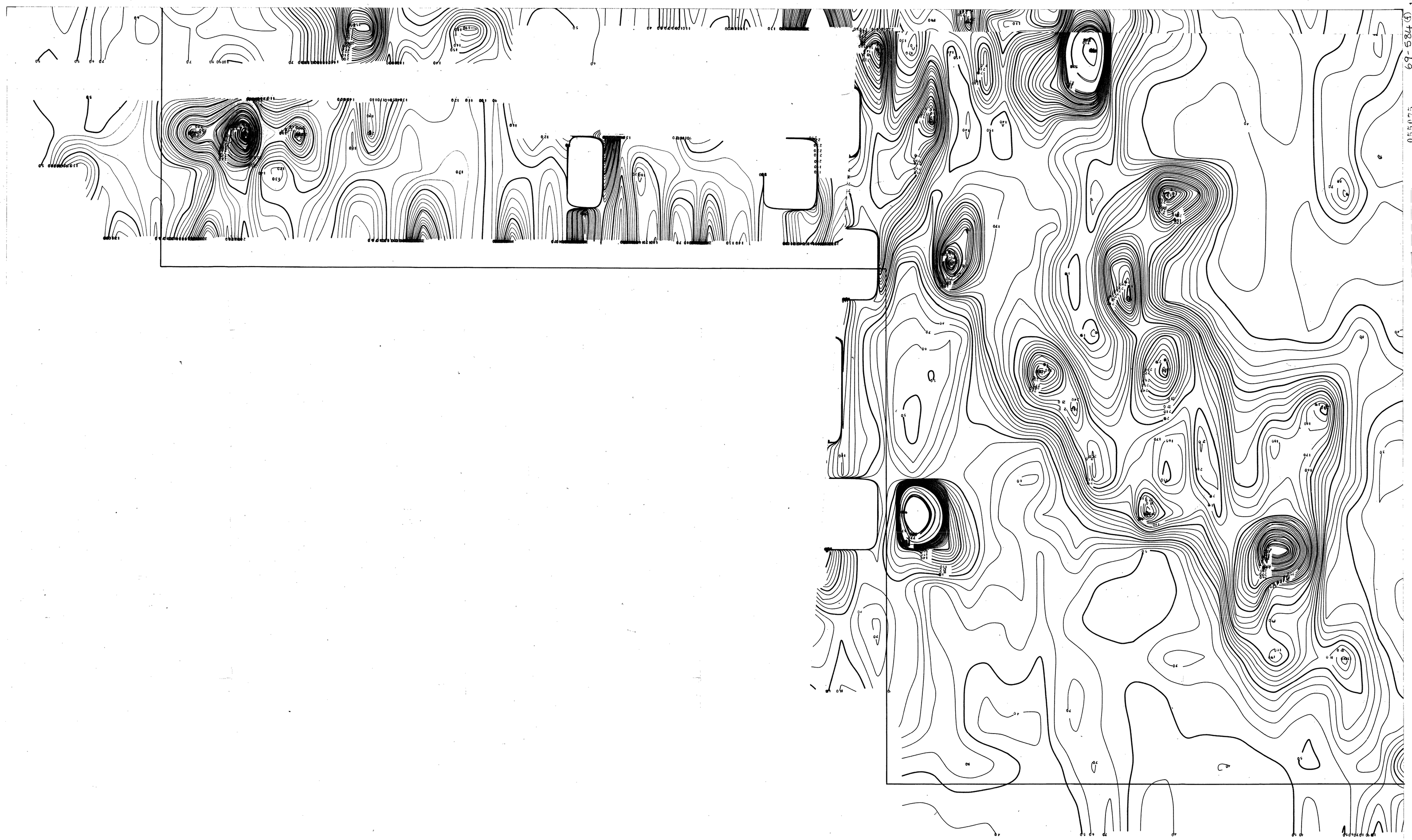
Bi^{214}/K^{40}

5 cm



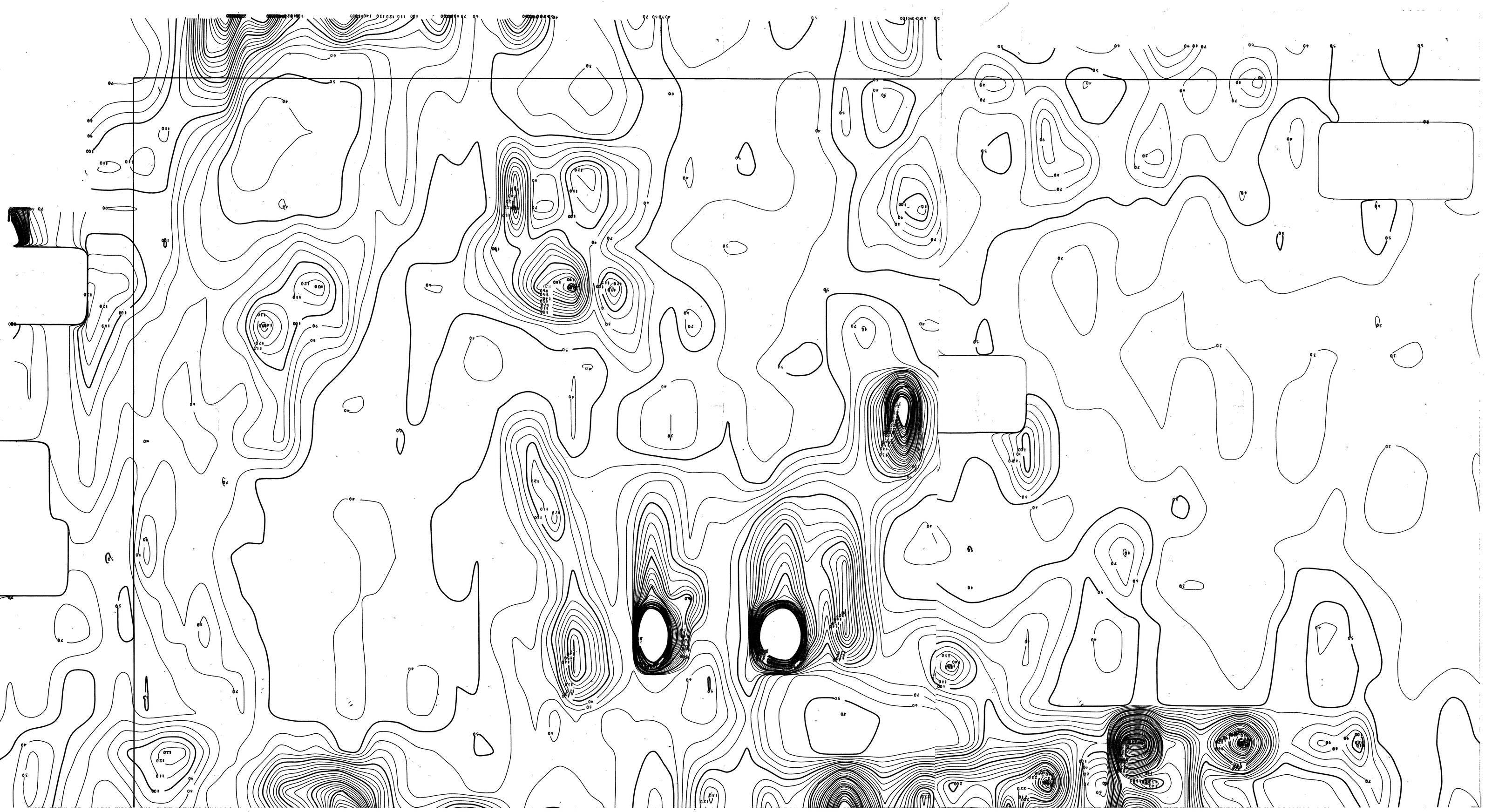
Tl^{208}/K^{40} SHEET 1 OF 8 SHEETS 69-584(4) 1789

055075



055076 69-584(F) 179C

Tl^{208}/K^{40} SHEET 2 OF 8 SHEETS



Ti^{208}/K^{40} SHEET 3 OF 8 SHEETS 69-584 (f) 1791

055077

5 cm

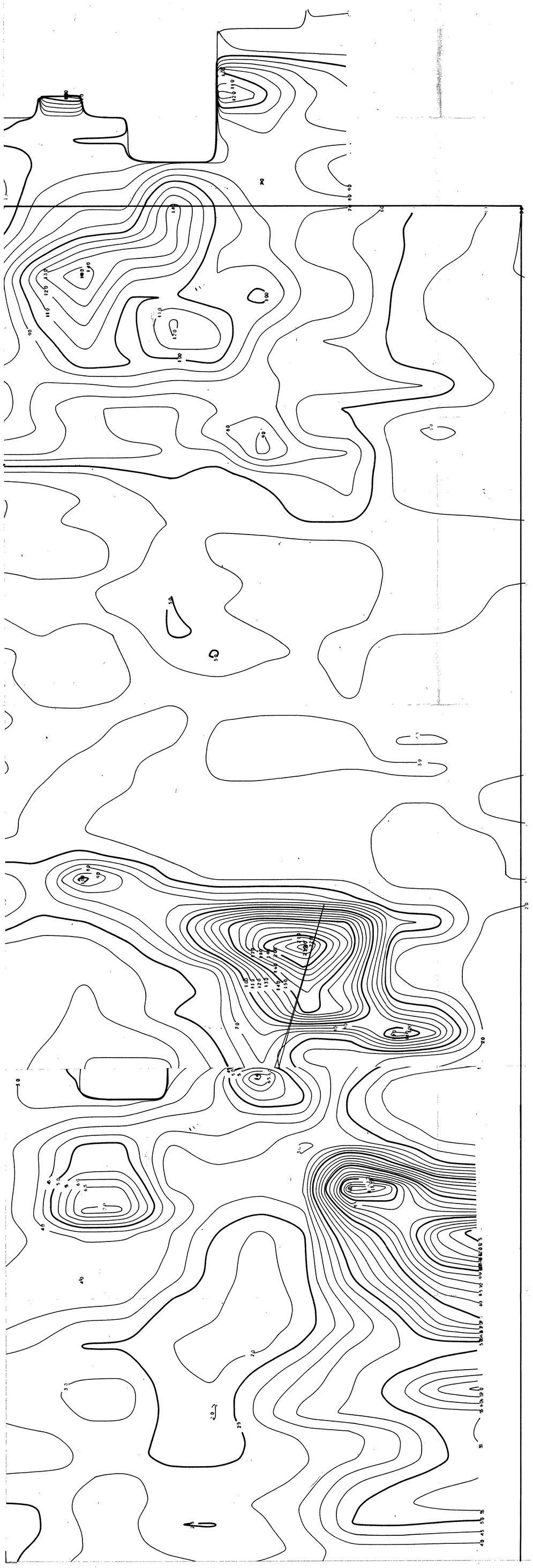
69-584 (F) 1792

SHEET 4 OF 8 SHEETS

Tl^{208}/K^{40}

055078

5 cm



055079 69-584 (f) 1/1793

5 cm

Tl^{208}/K^{40} SHEET 5 OF 8 SHEETS

Ti^{208}/K^{40} SHEET 6 OF 8 SHEETS

69-584(4) 1794

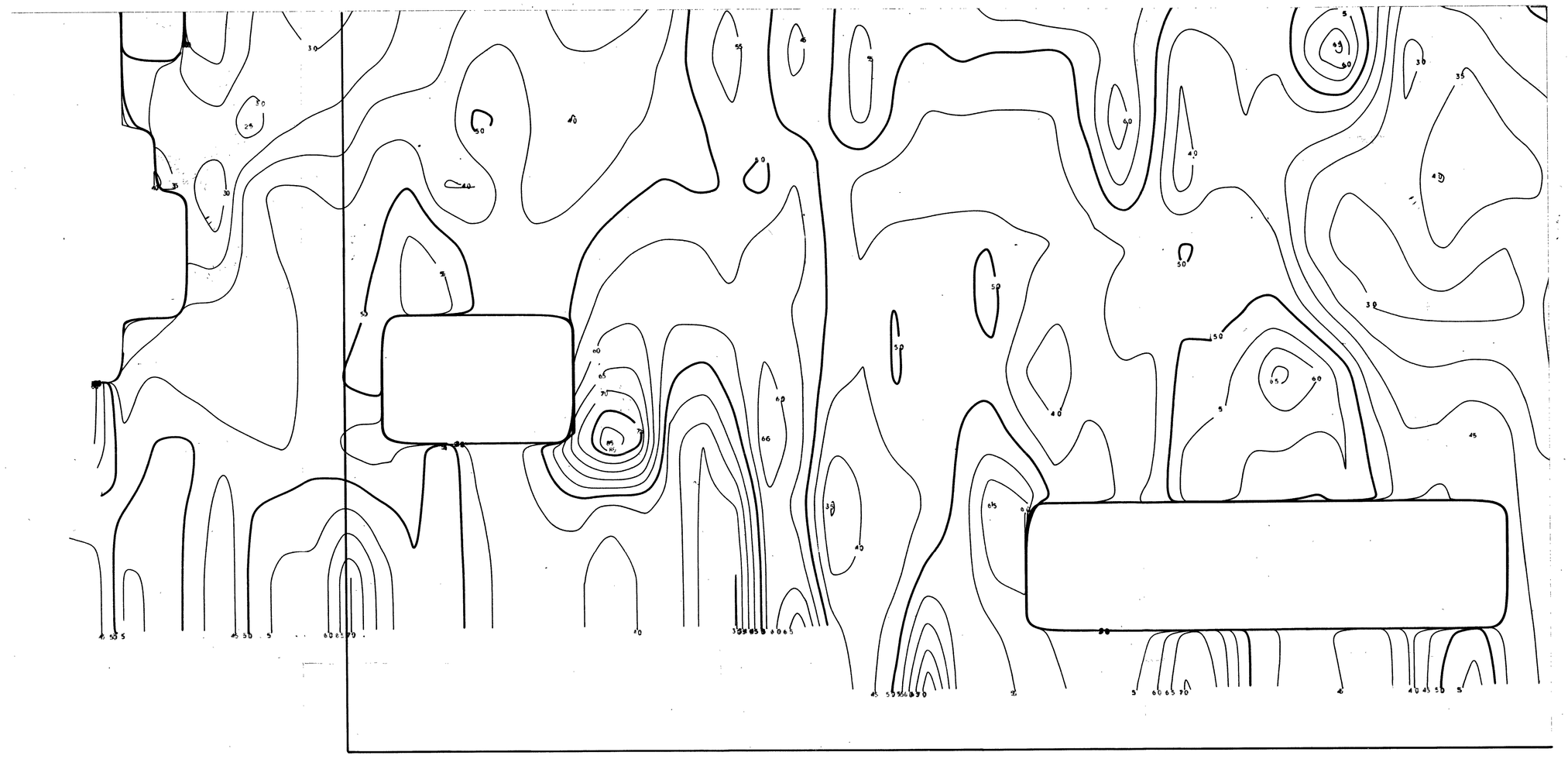
055080

5cm

055031 69-584 (f) 1795

Tl^{208}/K^{40} SHEET 7 OF 8 SHEETS

5 cm



Tl^{208}/K^{40} SHEET 8 OF 8 SHEETS

69-5844(f)

055082