

INTEGRATED REMOTE SENSING OF THE AMISK LAKE -
WEKUSKO LAKE AREA IN MANITOBA

A Thesis

Submitted to

The Faculty of Graduate Studies

The University of Manitoba

In partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

by

KIRAN S. MISRA

April 1983

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ABSTRACT

An area of about 11,500 sq. km in north central Manitoba between Amisk Lake and Wekusko Lake has been geologically mapped by various spectral and airborne geophysical techniques. The spectral remote sensing techniques included interpretation of panchromatic and colour aerial photographs, Landsat, thermal and radar imagery. Landsat digital data has been enhanced by using the Image Analysis System at the Canada Centre for Remote Sensing. Operations such as linear contrast stretch enhancement, colour component transformation, ratioing, principal component transformation, spatial filtering and combinations of these were attempted to enhance geological features of interest. Airborne geophysical remote sensing included interpretation of colour applicon plots of total field and vertical gradient aeromagnetics and VLF total field and quadrature electromagnetics.

The thesis describes various methods which can be used for mapping of lithological/structural trends and other lineaments such as shear zones, faults and joints, and also formulates an integrated approach for economic geological mapping and exploration of stratabound mineral

deposits. The present study as well as previous studies have indicated that Landsat digital data carries much more information than the paper print outs. Linear contrast stretch enhancement has been found to be very suitable for mapping of lithological/structural trends and ratio images are very good for mapping of other lineaments.

Vertical aeromagnetic colour applicon plots have superior resolution to the total field and have facilitated the photogeological mapping of near surface geological structures and included mineralized zones. This applies not only to exposed areas but also to areas covered by lakes, moderately thick Palaeozoic sedimentary rocks and Quaternary glacial overburden. Interpretation of Very Low Frequency electromagnetic colour applicon plots appeared to be of very limited use in supplementing photointerpretation for regional geological mapping, and was of practically no use in mapping of geological structures in the Precambrian rocks below the Palaeozoic sedimentary cover. However, it is extremely useful in isolating anomalous conducting zones in exposed areas as well as in areas where Palaeozoic rocks are not very thick.

The thesis also describes how the integrated methods

are helpful not only in mapping of lithological/structural trends of various strata but also tracing of extensions of known mineral deposits. In the Amisk Lake - Wekusko Lake area there are approximately 50 known mineral occurrences of gold and copper. The present work demonstrates that these deposits are stratabound and how they might be interconnected with each other. The study further suggests the location of those areas where mineral exploration effort might be most profitably concentrated. Indeed preliminary ground truth examination in a number of these areas has indicated alteration along strike extensions.

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1.0 INTRODUCTION

1.1 AREA

The Amisk Lake - Wekusko Lake area is located within the Churchill structural province of the Canadian Shield, mainly in the south central Manitoba and some adjoining parts of Saskatchewan. The rocks of the area are highly deformed and metamorphosed and broadly belong to two major groups; the Flin Flon - Snow Lake greenstone belt and Kisseynew sedimentary gneissic belt. The southern part of the study area (as shown in Map 1A of Manitoba) is covered by Palaeozoic sedimentary rocks with increasing thickness in a southerly direction. The total area covered during the present integrated study is about 10,000 sq. km. and is bounded by north latitudes $54^{\circ}35'$ and $55^{\circ}10'$; and by west longitudes $99^{\circ}35'$ and $102^{\circ}10'$. An additional area of about 1500 sq. km. SE of Flin Flon is incorporated in this study for mapping of Precambrian lithological/structural trends below the cover of Palaeozoic sedimentaries.

The selection of the area for the present study was prompted by the following factors -

1. Amisk Lake - Wekusko Lake area is one of the very few areas in the Canadian Shield where various types of remotely sensed data are available consisting mainly of panchromatic

Map 1A

aerial photographs on various scales, thermal infrared and radar imagery as well as good quality multitime Landsat imagery.

2. This is one of the only two areas in the province of Manitoba which is covered by vertical aeromagnetic gradient survey and has colour application plots of vertical gradient and total field aeromagnetics; total field and quadrature components of airborne Very Low Frequency (VLF) electromagnetics are available.

3. This area has been mapped in considerable detail by various workers and several published maps and reports have provided a great deal of geological data and thus minimized ground truth collection.

4. Various types of metallic ore deposits are located in the area and therefore it was possible to establish their relationship with interpreted data from various remote sensing techniques.

5. This area presents a typical geological setting of the Canadian Shield and thus various conclusions drawn from this integrated study can be applied to other comparable areas.

6. Much of the study area is covered by claims of Hudson

Bay Mining and Smelting Company for mining rights and they were ready to partly fund this type of study in their area.

1.2 GEOMORPHOLOGY

The Amisk Lake - Wekusko Lake area features low, hummocky rather monotonous topography which is quite typical of this part of the Canadian Shield. The structural grain of the country is characterized by low ridges which are approximately parallel to the regional lithological/structural trend of the underlying rocks. Lakes and swamps are numerous and their shapes in Precambrian rocks are mainly controlled by bedrock structures. The lakes in areas underlain by gneissic or schistose rocks are commonly elongated parallel to the trends of these planar structures. The lakes in the areas occupied by granitic rocks are rather small and their shapes are to some extent controlled by the jointing in the granitic rocks. Lakes occurring in areas occupied by Palaeozoic carbonate rocks are generally larger in size, few in number and have irregular outlines which do not correspond with geological trends. Outcrop densities in most of the study area is of the order of about 15%. Faults particularly those in volcanic rock areas are marked by straight, long, narrow valleys which are often occupied by lakes. The last glacial advance in most of the area



Fig. 1(i). Field photograph showing relationship of lithological trends and Quaternary glacial directions. The compass is pointing in North direction, glacial striations and chatter mark directions are trending $N15^{\circ}E$ while lithological trends marked by colour banding are aligned in more or less E-W direction.

appears to have been from NNE direction and is well marked by striations and chatter marks on the exposed rock surfaces (Fig. 1(i)).

The geomorphological chronology which is evident from the present study indicates that the geomorphological development of the area has probably progressed as follows.

1. The Precambrian rocks were more or less planated before the deposition of Palaeozoic sedimentaries and this surface has been preserved up to Late Tertiary period.
2. With the removal of Palaeozoic sedimentaries the area has started developing minor relief due to normal processes of weathering and erosion.
3. Due to the advancement of Quaternary glaciers this relief has got accentuated at many places in the glacial advance direction and also glacial plucking of weathered and soft material took place along the lithological/structural trends. Furthermore, some areas have got planated during this advancement.
4. After glacial retreat the land surface started rising slowly in response to isostatic rebound and normal denudational processes have started.

5. These processes in due course of time have eroded areas occupied by less resistant rocks into valleys and thus exposing hard resistant rocks as ridges. A whole range of intermediate resistance to erosion in various lithological types resulted in the development of a sort of grooving pattern which marks the structural trends of these lithological units.

1.3 GENERAL GEOLOGY OF THE AREA

The Amisk Lake - Wekusko Lake study area mainly comprises Precambrian Shield rocks but in the southern part they are overlain by Palaeozoic sedimentaries. The Precambrian rocks of the area comprise two main belts having differing lithologies, style of deformational events and grade of metamorphism. These belts are commonly described as the Flin Flon - Snow Lake greenstone belt in the south and as the Kiseynew metasedimentary gneissic belt in the north. Bailes (1971) recorded that sedimentary and volcanic rocks of Flin Flon - Snow Lake greenstone belt are metamorphosed between greenschist to lower almandine-amphibolite facies whereas the Kiseynew metasedimentary migmatite belt is metamorphosed between middle to upper almandine-amphibolite facies. The contact between these two belts engages the attention of geologists ever since Kalliokoski (1949) postulated that a fault extends along

this contact. The age of the strata of both Flin Flon - Snow Lake greenstone belt and Kisseynew metasedimentary gneissic belt is Late Aphebian according to Rb-Sr whole rock isochron studies (Mukherjee et al, 1971; Anderson, 1974; Josse, 1974; Stauffer et al, 1975; Bell et al, 1975). Deformation and accompanying metamorphism of the strata of both belts is also Late Aphebian according to K-Ar dates on metamorphically developed mica minerals (Lowden, 1961; Lowden et al, 1963; Moore et al, 1960).

1.4 PREVIOUS WORK

Various parts of the Amisk Lake - Wekusko Lake study area have been mapped in considerable detail by numerous workers and a fairly complicated picture of the geological setting and history has emerged from these studies. These studies can be grouped in two distinct categories - Earlier work i.e. work carried out before 1971 wherein the emphasis was mainly to map the lithology of different parts of the area and discuss various stratigraphic and structural problems. The significant works include Stockwell (1935, 1937, 1944) in Elbow Lake, Herb Lake and Flin Flon area; Armstrong (1941) in Wekusko area; Harrison (1949) in Kississing area; Kalliokoski (1952) in Weldon Bay area. Recent work i.e. the work carried out

after 1971 is much more diversified and details of various particular problems are highlighted. This includes detailed structural mapping by Froese and Moore (1980) in the Snow Lake area; Froese and Goetz (1981) in the Sherridon area; Bailes (1975) in Guay - Wimapedi area; Bailes (1980) in the File Lake area; Bell (1978) in the Wekusko Lake area. Mukherjee et al (1971); Anderson (1974); Josse (1974); Sangster (1972); Lowden (1961); Stauffer et al (1975) and Bell et al (1975) provided absolute ages of various rock units. Geophysical work in the area has been carried out by various parties in limited areas and mainly using ground geophysical methods.

As far as remote sensing work in the Canadian Shield is concerned Chagarlamudi (1980) did digital analysis of Landsat data for mapping rock outcrops in the coppermine area of the Northwest Territories. He found that the enhanced Landsat images are superior to the aerial photographs in identifying large outcrops and in discriminating among these outcrops.

1.5 SCOPE OF PRESENT WORK

From the above mentioned previous work it is apparent that no attempt has been made to map the whole area by using either spectral or geophysical remote sensing. Although aerial photographs have been used by some workers

in recent years for navigation or for locating extensions of various formations but detailed photogeological maps of neither individual nor entire area are available. A concentrated attempt has therefore been made to interpret individual aerial photographs of various scales for details of lithological/structural trends and lineaments such as faults and fractures. Detailed planimetrically controlled maps of the entire area showing these geological features along with salient topographic details are compiled in three pieces on 1:100,000 scale (Map 1, 2 and 3).

Hogg (1959) applied integration of aerial photo-interpretation and aeromagnetic data to geological mapping. The techniques of remotely sensed spectral data acquisition, its enhancement, analysis and interpretation have become more varied and sophisticated during the last decade. From these techniques generally a two pronged study has emerged as far as exploration of metallic minerals is concerned. Firstly regional study of lineaments probably correlatable with faults, shear zones and related hydrothermal deposits and secondly, analysis of areas of alteration, using multispectral data. During the present study an entirely new approach of mapping the lithological/structural trend lines is attempted which is found to be more suitable for areas where mineralization is stratabound and alteration

zones have been stripped away by Quaternary glaciation.

The techniques of airborne geophysical data acquisition, processing and printing have also improved quite significantly in recent years. The application plots of vertical gradient and total field aeromagnetics and total field and quadrature components of Very Low Frequency electromagnetics are now available. A technique is formulated during the present study to map lithological/structural trend lines from these plots and thus mapping of possible conductive sulphide zones identified from VLF application plots is possible. An integration of interpreted data from both spectral and airborne geophysical techniques has been found to be extremely useful not only in geological mapping but also for exploration for metallic mineral deposits.

1.6 ACKNOWLEDGEMENTS

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The author had very stimulating discussions with Dr. W.D. McRitchie, Director, Geological Services, Manitoba Mines Branch who has readily agreed to provide the facility of colour photo laboratory, reduction and ammonia printing of maps. Mr. Ifti Hossain, Geophysicist, Manitoba Mines Branch, has made available colour applicon plots of airborne geophysical data for interpretation. Mr. Paul Lenton, Geologist, Manitoba Mines Branch, has very kindly explained the printing of colour photographs in colour

photo laboratory.

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The work would not have been completed without the assistance of Image Analysis System at Canada Centre of Remote Sensing, Ottawa and it is thankfully acknowledged.

2.0 REGIONAL GEOLOGICAL SETTING

2.1 GENERAL

The major part of the Amisk Lake - Wekusko Lake study area is occupied by the Flin Flon - Snow Lake greenstone belt. To the north this belt is bordered by the Kiseynew metasedimentary gneissic belt. In the south the greenstone belt is overlain by the Palaeozoic sedimentary rocks. These two Precambrian belts have different lithology, style of deformation and the grade of metamorphism. Lithologically the Flin Flon - Snow Lake greenstone belt is predominantly composed of volcanic flows, derived volcanogenic sediments and volcano-clastic rocks. Locally, however, they have bands of sedimentary rocks and gneissic rocks which occupy the core portions of large domal structures. The Kiseynew gneissic belt mainly comprises a succession of metamorphosed and migmatized sedimentary rocks. As far as deformation is concerned the Flin Flon - Snow Lake greenstone belt is relatively more intensely deformed and comprises intricate fold pattern while the Kiseynew gneissic belt is characterized by open folds and elongated domal structures trending in more or less E-W direction. Bailes (1971) recorded that volcano-sedimentary sequence

of the Flin Flon - Snow Lake greenstone belt is metamorphosed between greenschist to lower almandine-amphibolite facies while the Kiseynew metasedimentary migmatite belt is metamorphosed between middle to upper almandine-amphibolite facies. The contact between these two belts has been engaging the attention of geologists ever since Kalliokoski (1949) postulated that a fault extends along this contact. The age of the strata of both the Flin Flon - Snow Lake greenstone belt and the Kiseynew metasedimentary migmatite belt is Late Archean according to Rb-Sr whole rock isochron studies (Mukherjee et al, 1971; Anderson, 1974; Josse, 1974).

2.2 THE FLIN FLON - SNOW LAKE GREENSTONE BELT

The complexly folded and meso-grade metamorphosed sequence of stratiform volcanic-sedimentary rocks with closely associated granite gneisses occupying domal structures forms an easterly trending belt from west of Flin Flon to the east of the Wekusko Lake, is generally referred to as the Flin Flon - Snow Lake greenstone belt. In the north this belt is bordered by the Kiseynew sedimentary gneisses and in the south it is overlain by the Palaeozoic sedimentary rocks. The subsurface boundary has been apparently marked by the

significant change in the folding pattern as well as gradual termination of lithological bands of strong magnetic signatures which are characteristic of the Flin Flon - Snow Lake greenstone belt. Towards the west this belt continues outside the study area in Saskatchewan. In the east Bell (1978) considered the eastern limit to coincide with the boundary from where pervasive potash metasomatism starts further east of the study area.

The Flin Flon - Snow Lake greenstone belt comprises three main lithological subdivisions.

Missi Group

Granite gneisses

Amisk Group

2.2.1 Amisk Group

The Amisk Group is mainly composed of three broad lithological units -

- A. Mafic volcanic flows, volcanic breccias, agglomerates, tuffs and their metamorphosed equivalents
- B. Metasedimentary rocks
- C. Metasomatic rocks

A. Mafic volcanic flows, volcanic breccias, agglomerates, tuffs and their metamorphosed equivalents.

The predominant members of the Amisk Group are mafic and intermediate volcanic flows, breccias, agglomerates, tuffs and their metamorphosed equivalents. The flows are commonly pillowed indicating submarine extrusion and are quite often intercalated with volcanoclastic sediments. Most outcrops regardless of their metamorphic grade, show some degree of foliation development. Primary volcanic features are relatively well preserved in most of the area. Amygdules range up to 5mm in diameter and are commonly flattened and elongated. Pillow lavas (Fig. 2(i)) occur both in localized patches within otherwise massive volcanic rocks and as thick units with considerable lateral continuity. The size of the individual flows is fairly uniform ranging from 0.5m to 1.5m and width up to 0.5m. The pillows are greatly elongated parallel to the main foliation and at places their elongation has reached to such proportions that the chilled margins of the individual pillows appear to be like bands in the rock.

B. Metasedimentary Rocks.

Greywacke-argillite-sandstone facies rocks and their metamorphosed equivalents are interbedded with the Amisk



Fig. 2(i). Field photograph showing pronounced pillow structures in the mafic flow horizons of the Amisk Group.

Group volcanic rocks. East of Wekusko Lake, Frarey (1950) observed such sedimentary beds evidently underlying the volcanic rocks. Williams (1961) noticed a thick section of sedimentary rocks lying within the Amisk Group volcanic rocks. The individual lithological units show cross bedding and show gradation among each other.

C. Metasomatic Rocks.

These rocks include "quartz eye" gneiss and garnetiferous quartz-plagioclase-biotite gneiss. Large parts of these gneisses contain "eyes" of grey and blue quartz. In the Flin Flon and Snow Lake regions these granite gneisses are associated with mafic volcanics of the Amisk Group. As far as the origin of these rocks is concerned the opinion of the earlier workers is greatly different. Stockwell (1935, 1937), Harrison (1949) and Kalliokoski (1952) believed an intrusive origin. Williams (1961) suggested that they are metasomatized acid volcanic tuffs and agglomerates.

2.2.2 Granite Gneisses

The granite gneisses occupy the core portions of the large domal structures in various parts of the Flin Flon - Snow Lake greenstone belt. These rocks have been mapped

previously by Alcock (1920), Armstrong (1941), Frarey (1948), Harrison (1949) and Quinn (1954). Bailes (1971) suggested that the gneissic domes could be diapirically mobilized "basement gneisses" older than the strata of the Amisk Group. Later Bailes (1975), however, suggested them to be allochthonous complexes of metamorphosed and mobilized sedimentary rocks formed during high grade regional metamorphism.

The present study indicates that these domal structures in the vicinity of Snow Lake are located in the core portion of the large antiformal structure Figure 3(xxxi) and 3(xxxii). The lithological/structural trends in the outer part of the large conical Herblet Lake gneissic dome north of Snow Lake are parallel to the contact of the dome, while in the interior portion these trends are having very complex pattern. This study further suggests that the individual large domes are often composed of many smaller domal structures Map 2.

2.2.3 Missi Group

The Missi Group is mainly a sedimentary sequence of coarse conglomerates and sandstones having well preserved

sedimentary structures (Fig. 2(ii)). The outcrops of the Missi Group are well exposed in the area northeast of Comback Bay and on the eastern shore of the Amisk Lake. The basal unit of the Missi Group is normally composed of a conglomerate that consists of angular to stratabound pebbles of the various lithologies from the underlying Amisk Group with minor amounts of chert, jasper, quartz and granitic material. The matrix is generally greenish to reddish coloured quartzitic while the pebbles of quartzite, jasper and metavolcanics are stretched and elongated along the strong foliation. Froese and Moore (1980) in Snow Lake area designated this group to be composed of metamorphosed lithic arenites. In this area he found that the conglomerates are missing and Missi Group rocks are represented by fine-grained, grey, granoblastic rocks which weather into pinkish grey colour. They are thickly bedded (0.2 to 2m) and break along parting planes into large slabs. Near Flin Flon, Stockwell (1960) considered the base of the Missi to be an unconformity. West of Flin Flon, Byers and Dahlstrom (1954) also found an unconformity at one locality but considered that the Amisk and Missi Groups are structurally conformable and that no major time break exists in the sequence.

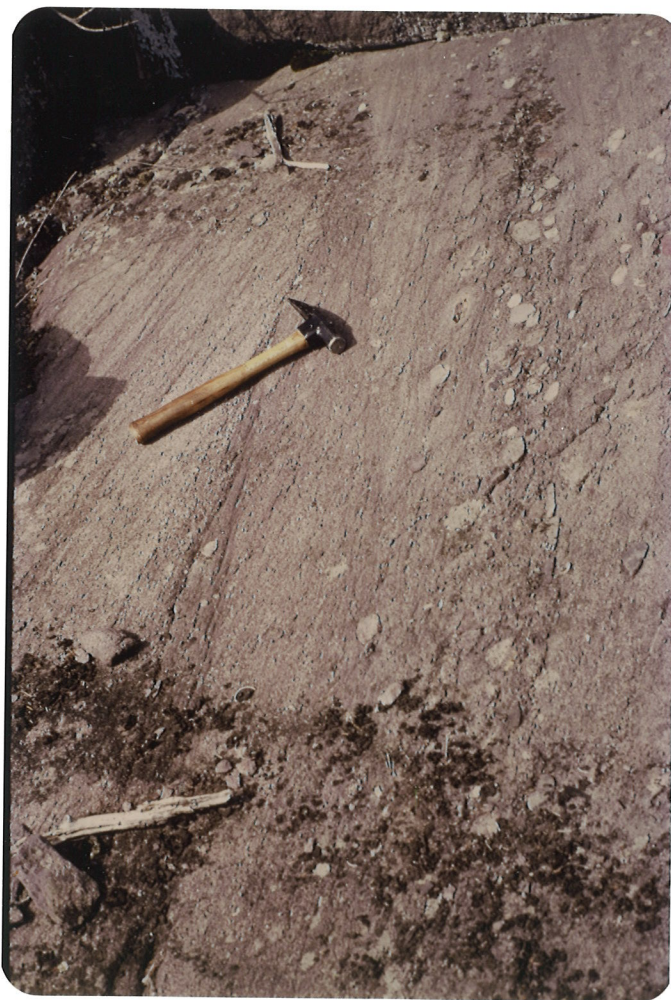


Fig. 2(ii). Field photograph showing the Missi Group sedimentary rocks with conglomerate band and cross bedded sandstone.

2.3 THE KISSEYNEW METASEDIMENTARY GNEISSIC BELT

The Kisseynew metasedimentary gneissic rocks occur in an easterly trending belt, north of the Amisk and Missi Groups. This belt comprises mainly a thick succession of highly metamorphosed and complexly deformed metasedimentary rocks which are intensely migmatized by the granitic material. The metamorphism and deformation are strongest in the central part of the belt and decreases in intensity towards both south and north. Polyphase deformation has given rise to numerous isoclinal overturned folds which are more or less parallel to the margin of the belt.

2.4 STRUCTURAL GEOLOGY

2.4.1 General

The Amisk Lake - Wekusko Lake area, like other areas of the Canadian Shield exhibit an interplay of polyphase deformation pattern. The observations during the present study of various spectral and airborne geophysical techniques were limited only to the megascopic structures which included lithological/structural trends and other lineaments such as faults, shear zones, joints and fractures. It was therefore not possible to evolve a detailed chronology of deformational events. The present

work, however, brought out a detailed pattern of lithological trends and lineaments which have been considered to be of extreme importance in exploration of stratabound deposits. The structural patterns brought out by spectral remote sensing techniques are shown in Maps 1 and 2 and in Figures 3(vii) and 3(ix). Map 3, however shows these features below the cover of Palaeozoic rocks. Maps 4 and 5 show similar features which have been mapped by aeromagnetic colour applicon plots of the total field and the vertical gradient, respectively.

2.4.2 The Kisseynew Front

Kalliokoski (1949) postulated that a fault extends along the Kisseynew - Amisk Group contact. Harrison (1951) listed the following evidences to support this view -

1. Contact marked by persistent lineament.
2. Abrupt change in degree of metamorphism near the contact.
3. Discordance between regional structures of Amisk and Kisseynew strata.
4. Types of mineral deposits are different on different sides of the fault.

5. Heavy shearing occurs in several places along the lineaments.

Robertson (1951), however, considered that the lineament marks, for part of its length at least, a conformable contact between the two rock units. McGlynn (1959) found that the lineaments marks the position of a fault that runs along the south shore of the Loonhead Lake. He thought it to be a continuation of the same fault mapped by Harrison (1949) in File Lake area. Bailes (1980), however, found no evidence for a major fault along the contact between the two belts in the File Lake area and considered that the boundary is marked by a steep metamorphic gradient which increases into the Kiseynew belt where rocks are coarsely recrystallized and partly melted.

The present study has, however, indicated that in the western half of the Amisk Lake - Wekusko Lake area the Kiseynew front is characterized by -

1. A series of fault traces (Map 1) and along these fault traces numerous valleys have developed and thus give rise to a broad lineament pattern on a small scale Figures 3(xxxiv), 3(xxxvi) and 3(xxxvii).

2. Change in the lithological characteristics of the rocks on the two sides of the contact. The Flin Flon - Snow Lake greenstone belt has predominance of mafic volcanic flow horizons are conspicuously absent in the Kisseynew belt which is dominantly composed of migmatized metasedimentary rocks.
3. Change in the style of folds and deformational pattern. The Flin Flon - Snow Lake greenstone belt is characterized by a very complex outcrop pattern of tight folds and complex domal structures occupied generally by the gneissic cores and mafic flow horizons wrapped around these domal structures. The Kisseynew belt, however, comprises mainly E-W trending elongated domal structures.
4. Development of the drag folds along the fault planes associated with this front. In the area west of Wabishkok Lake (Map 1) very prominent drag folds have developed. The pattern of these folds indicates a right lateral movement along these fault planes.
5. Remarkable change in the magnetic characteristics of the rocks across this front (Figs. 4(i) and 4(ii)). These changes include abrupt truncation of magnetic trends as well as the magnetic susceptibility of the rocks.

6. Intense shearing of the rocks in the vicinity of this front.

7. Change in the lineament pattern of the rocks on the two sides of the contact. Lineaments trending in various directions are present in both the belts, but the rocks of the Kisseynew Group are characterized by predominant NNW - SSE trending short innumerable lineaments. These lineaments are best seen in the area north of the Herblet Lake gneissic dome (Map 2). The lineament pattern in the Flin Flon - Snow Lake greenstone belt is marked by long straight ENE - WSW trending lineaments which are depicted on Map 3.

2.5 SYNTHESIS AND DISCUSSIONS

The present study has brought out certain interesting large scale features which are likely to enhance the understanding of the regional geological setting of the Amisk Lake - Wekusko Lake area. The important points emerged from the present study are -

1. The complex patterns of the lithological/structural trends in the Flin Flon - Snow Lake greenstone belt mainly belong to two categories. The circular or elliptical ones are associated with the gneissic domal structures and

intricately folded ones are associated with the stratified volcano-sedimentary rocks which are wrapping round the domal structures. The gneissic domes are characterized by the magnetic lows in the central parts and the mafic volcanic flows are marked by the strong magnetic signatures (Figs. 4(ix), 4(x) and Maps 4 and 5).

2. On the basis of style of folding and magnetic signatures the northern and southern boundaries of the economically important Flin Flon - Snow Lake greenstone belt can be demarcated. The northern boundary is exposed and is marked by several other features associated with the Kiseeynew front. The southern boundary is, however, covered by the Palaeozoic sedimentary rocks. It can be seen from the Figures 4(ix) and 4(x). The characteristic features of the Flin Flon - Snow Lake greenstone belt such as gneissic domal structures and folded mafic flow horizons are not present in the southern parts of these figures. It is therefore believed that the southern boundary of the Flin Flon - Snow Lake belt is located where these characteristic features are ending.

3. Typical mapping of lithological/structural trends from enhanced Landsat imagery suggest that the eastern part of the study area is occupied by a large antiformal

structure closing towards the NE direction. The Herblet Lake conical gneissic dome is situated in the core portion of this structure Figures 3(xxxi) and 3(xxxii).

4. The Kisseynew Front although well defined by several characteristics in the eastern part is less obvious in the western part of the area. The various characteristics observed are mentioned in Section 2.4.2 of this chapter. The present study suggests that the development of this complex front would have progressed following these steps.

(i) A volcano-sedimentary sequence which had original predominance of volcanic and sedimentary rocks at different levels.

(ii) During folding, intense metamorphism and migmatization took place and has given rise to Kisseynew gneisses.

(iii) With continued compressive forces small scale thrusting and shearing along the planes marking the changes in the mechanical properties of the rocks, the migmatites and the volcano-sedimentary sequence took place.

(iv) These effects are more pronounced in the limb portion of the large antiformal structure and gradually diminishes towards the nose portion in the NE direction.

3.0 SPECTRAL REMOTE SENSING

3.1 GENERAL

Remote sensing is the science of deriving information about an object from measurements made at a distance from the object, i.e. without actually coming in contact with it. The quantity which is generally measured in remote sensing systems is the electromagnetic energy emanating from the object of interest. Parts of the Amisk Lake - Wekusko Lake study area are covered by aerial photography which includes panchromatic, colour and infrared on various scales, side looking airborne radar, aerial thermal imagery and by cloud free multidecade Landsat coverage. Of these, aerial photographs and Landsat digital data are mostly used in the present study. The objective of this investigation in this chapter have been to make an assessment of the use of the Landsat digital data after various computer assisted enhancements for identification and mapping of lithological/structural trend lines and other lineaments like shear zones, faults and joints. Visual and computer aided interpretation methods were explored to analyse the data and results were compared with data obtained from aerial photographs. The investigation included visual

interpretation of various sets of aerial photographs stereoscopically, ground truth acquisition and comparative study to evaluate the capabilities and limitations of each of these products.

3.2 AERIAL PHOTOINTERPRETATION

Conventional low-altitude aerial photography is the contemporary system of remote sensing that is most widely used in the present study for economic geological mapping of the Amisk Lake - Wekusko Lake area. Stereoscopic techniques for interpreting panchromatic and multiband imagery and their relevant geological applications have been well described by Ray (1960), Miller (1961), Allum (1966), Newton (1971) and Reeves et al (1975).

Accordingly, no attempt is made here to outline either the practice or the benefits for general geological mapping. Instead, attention is directed to only the identification and mapping of lithological/structural trend lines and other lineaments like shear zones, faults and joints which are most important factors for exploration of stratabound economic mineral deposits.

The study area is covered by aerial photography and good quality panchromatic and colour photographs are available Figure 3(i) and 3(ii). The present investigation

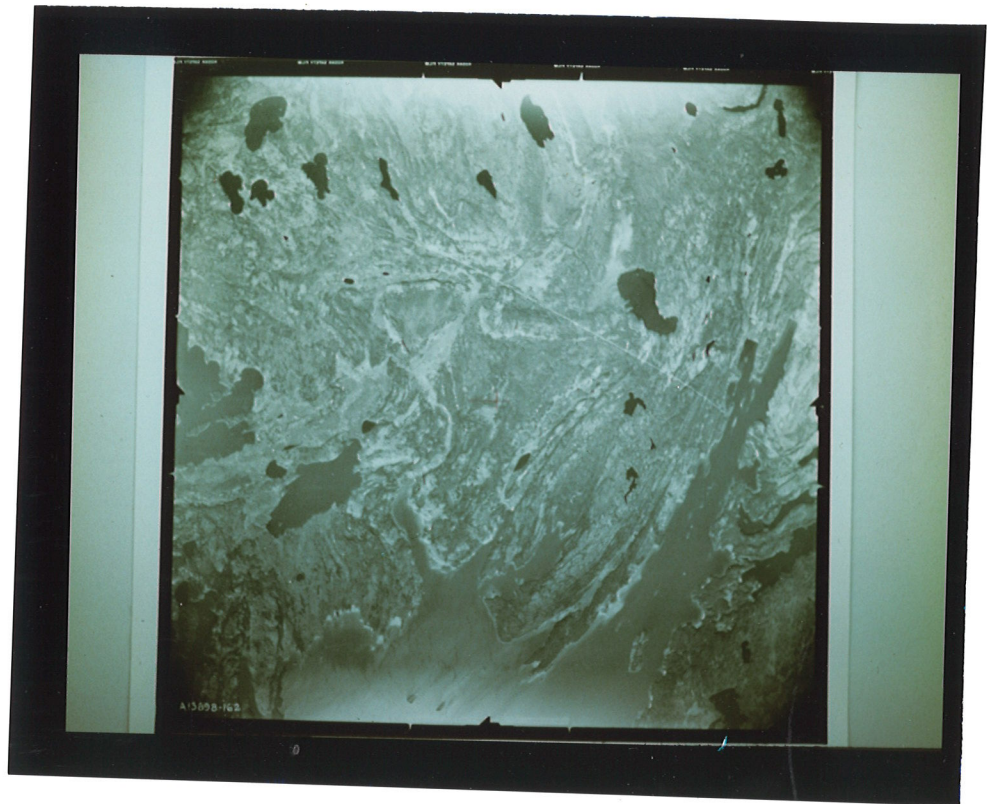


Fig. 3(i). Panchromatic aerial photograph of the File Lake area.



Fig. 3(ii). Colour aerial photograph of the area NE of Snow Lake.

started with the interpretation of these photographs stereoscopically and the interpreted data has been transferred on planimetrically controlled topographic maps of 1:50,000 scale by using a K.E. optical projector. The individual topographic maps were then reduced to 1:100,000 scale and then final tracing of the whole area has been presented in the form of photointerpretation Maps 1, 2 and 3.

3.3 THERMAL IMAGERY

On conventional thermal infrared images Figure 3(iii) and 3(iv) the lighter tones represent the warmest radiant temperatures and darker tones represent cooler temperatures. It can be seen that these images are apparently similar to the panchromatic aerial photograph Figure 3(i), because both are recorded as gray scale variations on film. A careful examination however, reveals that in case of the aerial photographs the tone is related to the spectral signatures of the terrain features while in case of thermal infrared images tone is related to the radiant temperatures. An aerial photography film is both the detecting and recording medium for reflected energy in the 0.4 to 0.9 μ m wavelength region. While in thermal infrared images the energy is detected by a semiconductor device and the

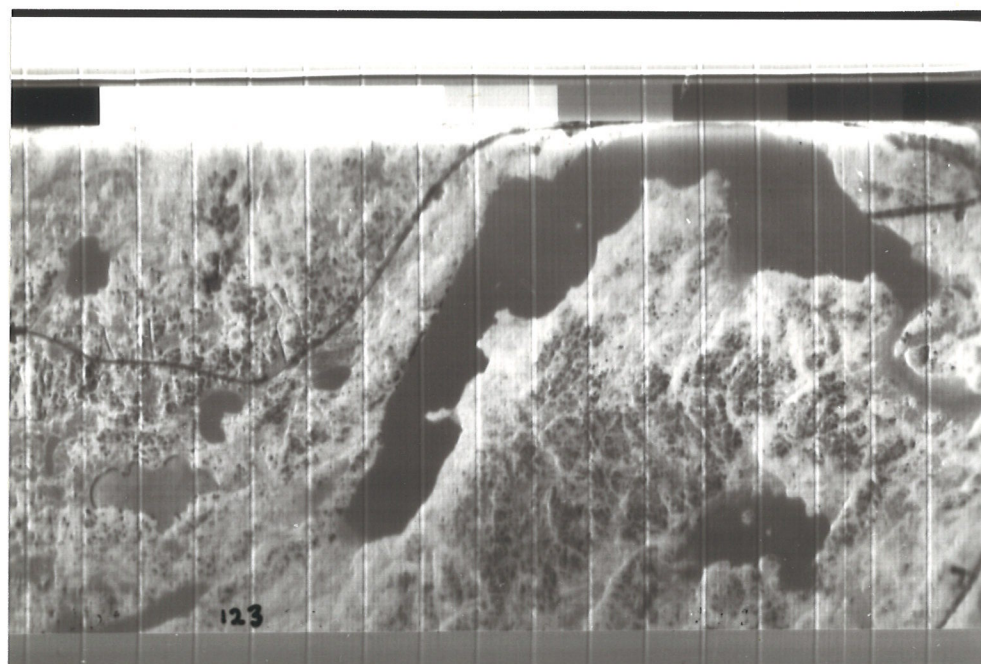


Fig. 3(iii). Thermal infrared image of the area SE of Snow Lake.

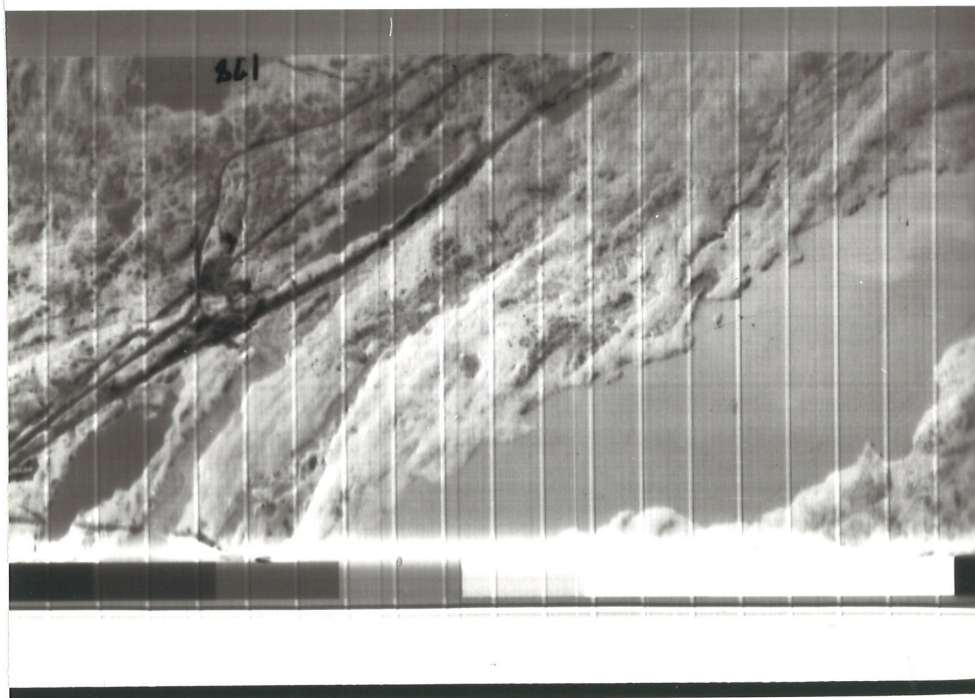


Fig. 3(iv). Thermal infrared image of the area NE of
Snow Lake.

film only serves as a medium to display the imagery.

Thermal infrared images have been found extremely useful in the study of geothermal areas, lava flows, coal fires, oil films, sea ice, thermal plumes, water currents and in Archaeology. But their applicability in geological studies especially in the mapping of lithological/structural trends has been found to be of no practical use when aerial photographs of the area are available.

3.4 RADAR IMAGERY

Side-looking airborne radar systems (SLAR), produce good quality images which provide synoptic information over large areas. In regions of inclement weather conditions when aerial photography is not possible and in areas covered by thick vegetation radar can be a source of valuable information. After detailed comparative study Mekel (1972) concluded that in less adverse weather conditions and at large scales single radar images cannot compete with conventional, stereoscopically viewed aerial photographs. As far as interpretation of radar images is concerned some analytical techniques used in aerial photo-interpretation are used. A detailed account of geological interpretation of radar images has been presented by Mekel (1972).

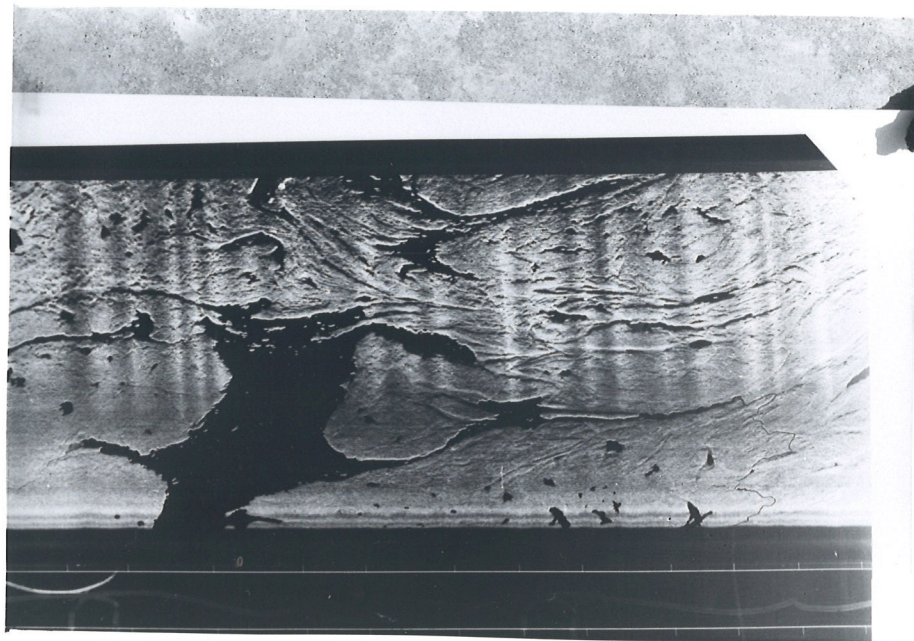


Fig. 3(v). Side looking airborne radar image of the area around Wekusko Lake.

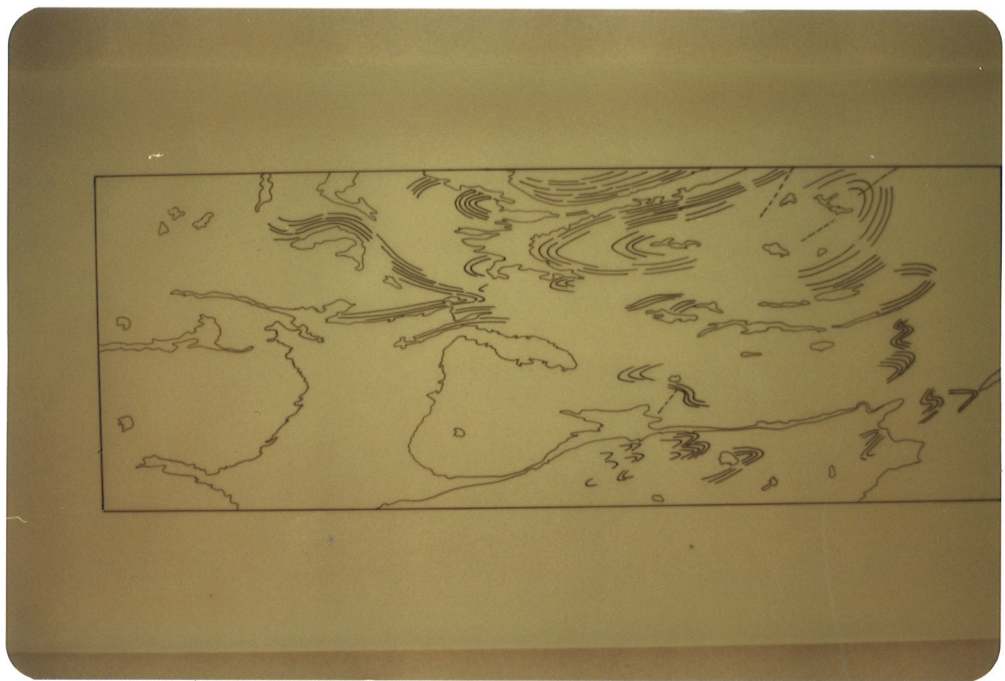


Fig. 3(vi.a). Interpretation of side looking airborne radar image shown in Figure 3(v).

The eastern part of the Amisk Lake - Wekusko Lake area is covered by a strip of SLAR images which have been taken during the flight from Winnipeg to Thompson. During the present study one such scene around Wekusko Lake Figure 3(v) is interpreted and derived lithological/structural trend lines and other lineaments are shown in the Figure 3(vi). It can be seen from this interpretation that radar image is helpful in providing synoptic view of regional lithological/structural trends of the area in comparatively less time.

3.5 LANDSAT IMAGERY

Landsat satellite data acquired over the Amisk Lake - Wekusko Lake study area is visually interpreted and is enhanced by various computer methods for mapping the lithological/structural trend lines and other lineaments. The characteristics of the Landsat satellites, orbital characteristics, the onboard sensors, the data collection and standard data products have been discussed in great detail by Short et al (1976) and Chagarlamudi (1980) and it has been found to be of no use repeating the same information over here. In the present study only the data from the Multi Spectral Scanning (MSS) subsystem is used and its band identification numbers and corresponding spectral

regions is given in Table 1.

The standard Landsat products i.e. 1:100,000 paper print imagery and 1:250,000 colour composites of different bands and seasons present a synoptic view of the whole area. The information contained in them provide a means for studying regional features on a small scale and help in extending local measurements to a regional scale and in isolating critical areas for detailed study. Analysis proper thus started with interpretation of these images for economic geological mapping of lithological/structural trends and other lineaments over large areas and then progressed to successively larger scales confined to smaller areas. This multilevel approach has been the key to present investigation and is illustrated in Figures 3(vi), 3(vii), 3(viii) and 3(ix).

Four aspects of the Landsat MSS subsystem make the images unique and especially useful for geological studies.

1. Synoptic view of the large area.
2. The spatially registered multispectral radiometry.
3. The repetitive imaging.
4. Capability of digital processing of spectral data.



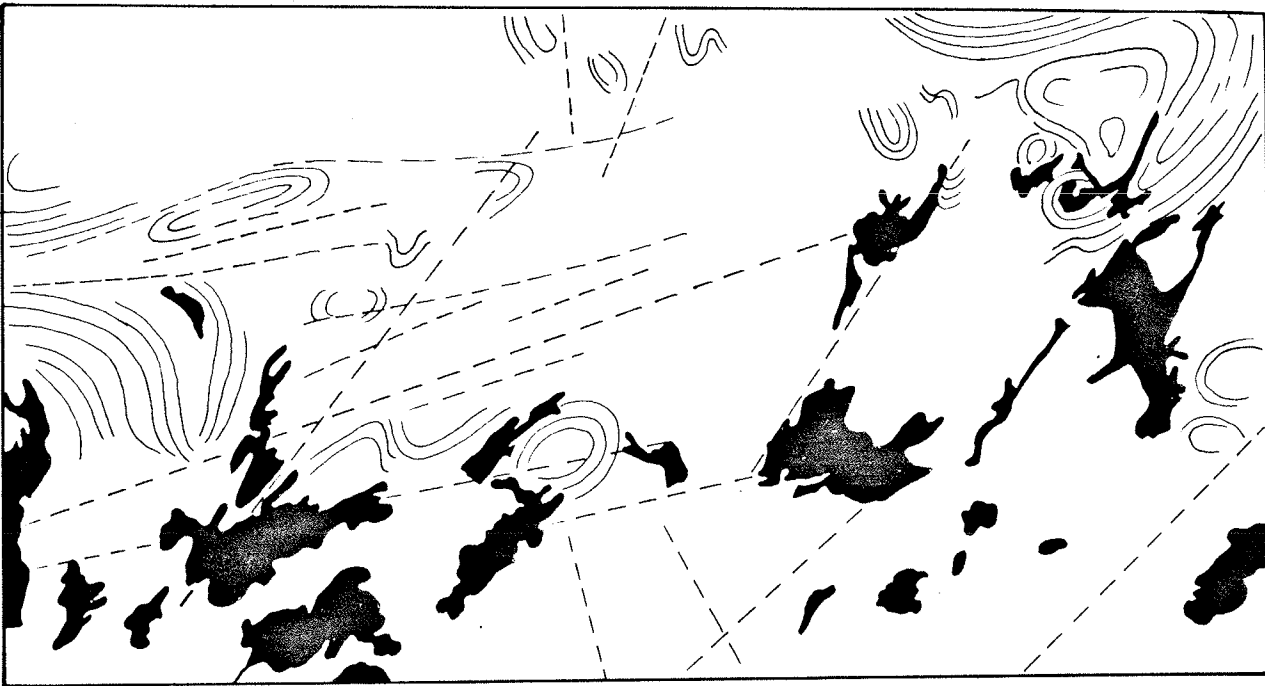


Fig. 3(vii). Map showing the interpretation of lithological/ structural trend lines and other lineaments from 1:1,000,000 black and white imagery as shown in Figure 3(vi).

Table 1. Band Identification Numbers and Corresponding Spectral Regions in the MSS Subsystems on Landsat Satellites.

<u>MSS Band Identification Number</u>	<u>Spectral Regions (Micrometers)</u>	
	<u>Landsats 1 and 2</u>	<u>Landsat 3</u>
Band 4	0.5 - 0.6	0.5- 0.6
Band 5	0.6 - 0.7	0.6- 0.7
Band 6	0.7 - 0.8	0.7- 0.8
Band 7	0.8 - 1.1	0.8- 1.1
Band 8	-	10.4-12.6

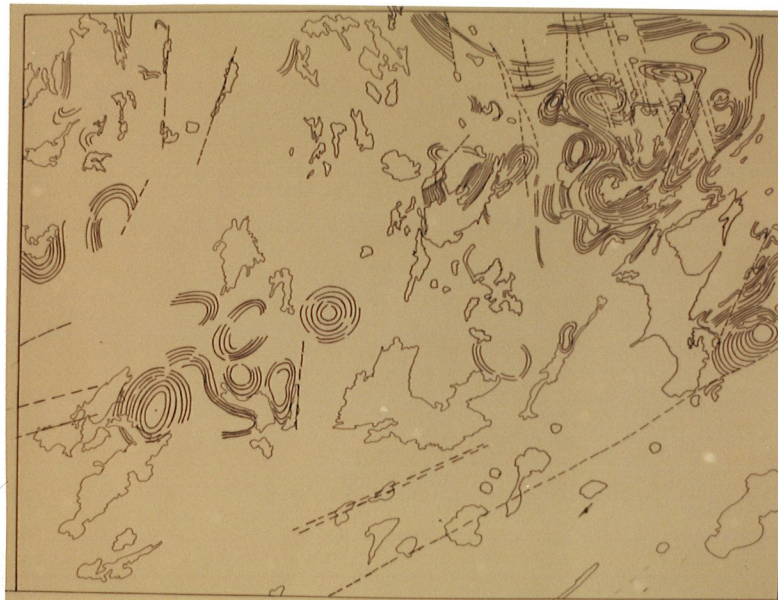


Fig. 3(ix). Photograph showing the interpretation of the lithological/structural trend lines and other lineaments from 1:250,000 colour composite imagery shown in Figure 3(viii).

The computer compatible tape of a Landsat scene contains much more information than is seen in paper printouts as depicted in Figure 3(vi) and 3(viii). Digital enhancement of the data has therefore been carried out and the enhancement products and results obtained are discussed in succeeding sections of this chapter.

3.6 ENHANCEMENT OF LANDSAT IMAGERY

The term image enhancement is generally applied to a number of operations designed to improve the interpretability to the data suitable to the terrain conditions and relevant to the needs of particular interpreter. During the past few years there has been a remarkable increase in the number, variety and sophistication of techniques and equipment for the analysis of images obtained from space. The requirement for enhancement of these images is to compensate for degradation of the image due to atmospheric effects and to improve spatial and spectral image resolution.

On negatives and paper prints of Landsat imagery the human eye can generally differentiate about 10 grey tones, whereas computer compatible tapes record a much larger range of levels of radiance. Donker and Mulder (1976)

have found in the Roermond area that in Bands 4, 5, 6 and 7, a range of 42, 46, 41 and 21 levels of radiance can be differentiated respectively. The computer thus offers the most comprehensive and thorough approach to image analysis based on reflectance values.

Today image enhancement techniques thus have exciting potential in geological remote sensing. Enhancement serves the purpose of emphasizing subtle spectral contrast that have lithological significance in most cases. Also, spectral classifications and transformations can isolate areas with similar spectral characteristics and can help to discriminate lithological types. Although the thematic classification of various lithological units by spectral remote sensing is obstructed by numerous factors. The important ones are as follows -

1. The spectral radiance of lithological units is rarely characteristics in any available waveband and usually requires textural information for even generalized classification.
2. Outcrops of rocks comprise a very limited part of the landscape and vast exposures are very rare.
3. The outcrops are obscured by weathered surfaces, lichen, moss, dust, rain and snow.

4. The outcrops are usually covered by vegetation which seldom has preferential growth on individual lithological unit and is constantly changing the spectral signature depending upon the season.
5. The various lithological units rarely have their own distinguishing colour signature and the overall radiance is controlled by the percentage of various essential and accessory minerals comprising it.
6. The contacts between the lithological units are often gradational.

Because of these factors the absolute identification of lithological types by spectral remote sensing is an unsurmountable task. However, spectral discrimination or separation of spectral units and subtle contrasts generally has helped in mapping the lithological/structural trend lines. The various image analysis procedures that can be applied using the image analysis system at the Canada Centre for Remote Sensing, Ottawa are described in detail by Goodenough (1979). A couple of suitable procedures have been used during the present study of the Amisk Lake - Wekusko Lake area and these are outlined in Figure 3(x) and are detailed as follows.

Simplified Landsat
Image Enhancement
Flow Chart

Symbols

- * Input or Output
- * A Process, Computer or Manual
- * Decision by an Interpreter

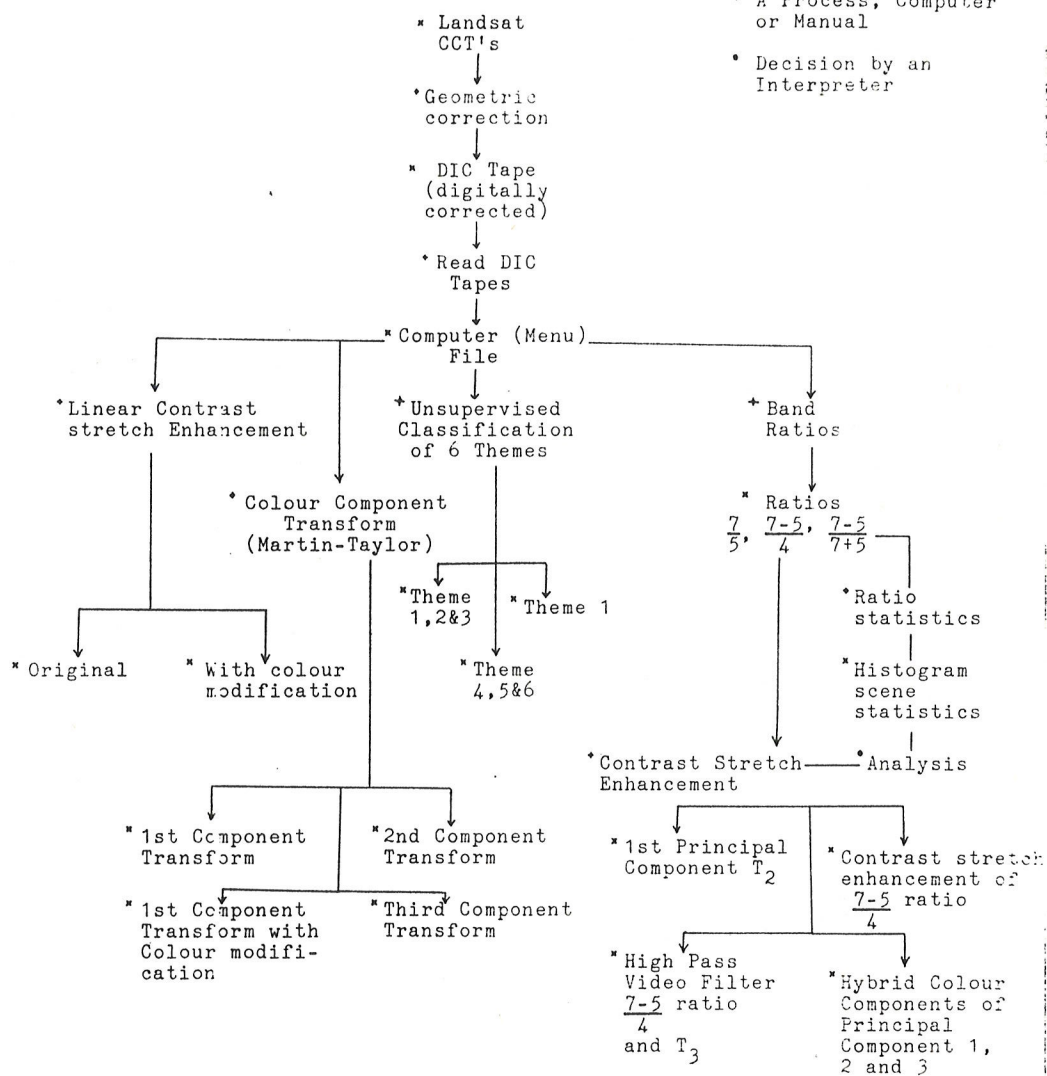


Fig. 3(x)

3.6.1 Contrast Enhancement

Due to the limited dynamic range of high contrast films and overall loss of information at each additional reproduction step in photographic techniques, it has generally been found that digital methods of contrast enhancement are far superior and more satisfactory. They have been found to be very useful in direction and mapping of lithological units. Here brightness levels in a scene are redistributed in such a fashion that it encompasses the entire sensitivity range of Landsat detectors by using pertinent linear algorithms. This is achieved by assigning new digital values to each pixel in the scene as shown in the following equation:

$$DVO = \frac{DVI - MIN}{MAX - MIN} \times N$$

where

DVO = Enhanced digital value of pixel in output image.

DVI = Input digital value of pixel.

MIN = Minimum digital value parameter.

MAX = Maximum digital value parameter.

N = Maximum digital value to be expected in the output.

The minimum and maximum digital value parameters are the cut-off values used in saturating to black and white

respectively. These values are determined by an analyst and are reassigned to minimum and maximum (N) values on the output image. Figure 3(xi) shows the raw data of Bands 4, 5 and 7 as seen on the display screen of the Image Analysis System. Figure 3 (xii) shows the same data as Figure 3(xi) after linear contrast stretch enhancement. The range which were smaller of digital values retained are expanded between 0 and N. When this expanded range of digital values is recorded on film as in Figure 3(xii) it results in an expanded density range providing a higher contrast.

Application of contrast enhancement for lithological mapping thus involves examination of the probability density function (PDF) of the scene and determination of the region of the histogram that contains the area of interest. If it is observed that the most interesting and significant information in an image is contained in bright regions, contrast is increased there at the expense of contrast in the less informative darker regions. As it is apparent from the Figures 3(xi) and 3(xii) the linear contrast stretch enhancement provides better discrimination of lithological banding thus facilitating the mapping of lithological/ structural trends. The image analysis system also has arrangements for colour modifications and one such colour



Fig. 3(xi). Photograph showing the raw data of Bands 4, 5 and 7 as seen on the display screen of the Image Analysis System.



Fig. 3(xii). Photograph showing the data of Bands 4, 5 and 7 after the linear contrast stretch enhancement.

modification of linearly contrast stretched data is shown in Figure 3(xiii). Sometimes these colour modifications help in enhancing the subtle tonal variations.

3.6.2 Colour Component Transformation

The colour of an object is a function of its ability to reflect light in different parts of the spectrum. The three colour theory explains that these primary colours blue, green and red can produced all other colours if the intensity of one or more of the lights is varied. In the analysis of multispectral images, it is found useful to consider any three channels of an image as a colour triplet, regardless of the actual portion of the spectrum which is represented. For example, the colour infrared film is sensitive to green, red and infrared light. To create a colour display, green light produces a blue dye in the imagery, red light is represented by green and the infrared by red. Thus the false colour display is produced which is although not natural but is found to be useful in many cases.

Various colour component transformations of the area East of Snow Lake are shown in Figures 3(xiv), 3(xv), 3(xvi) and 3(xvii). It can be seen from these figures that these transforms are very good in identification of outcrop

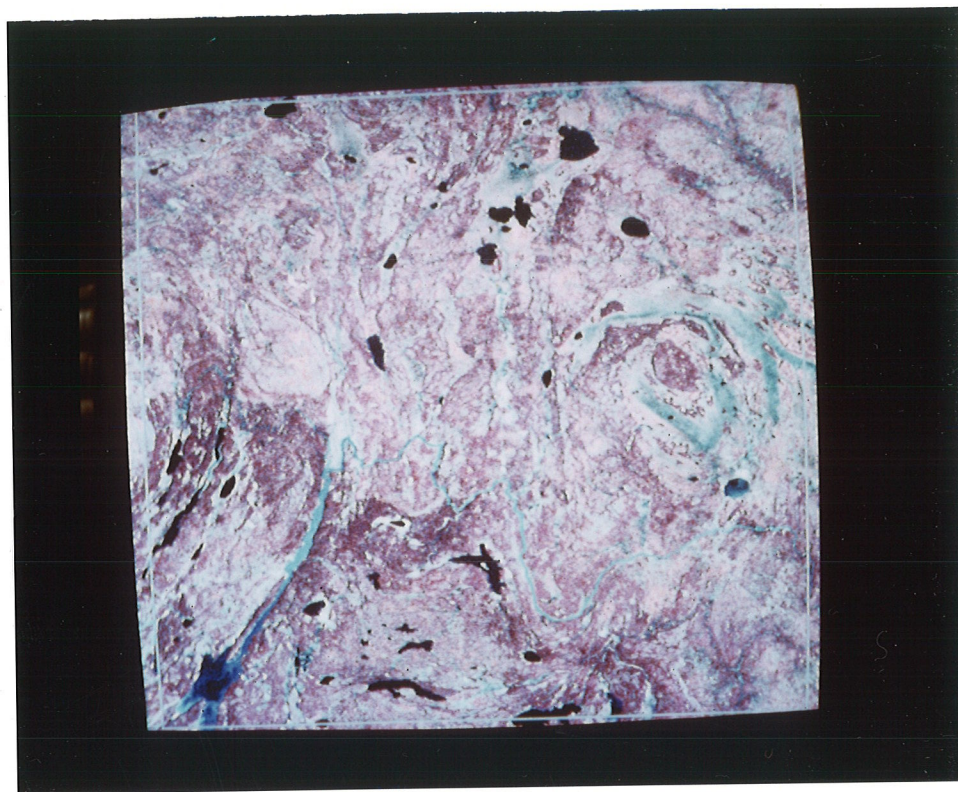


Fig. 3(xiii). Photograph showing linear contrast enhancement data after colour modification.

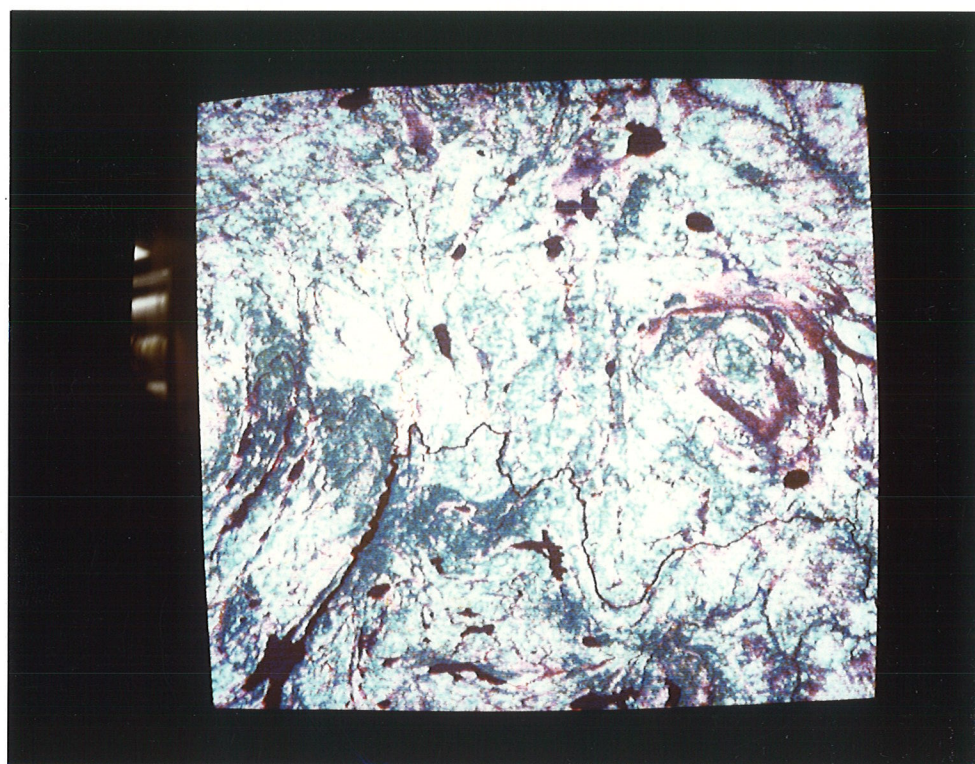


Fig. 3(xiv). Photograph showing colour component transformation (original) Martin-Taylor.

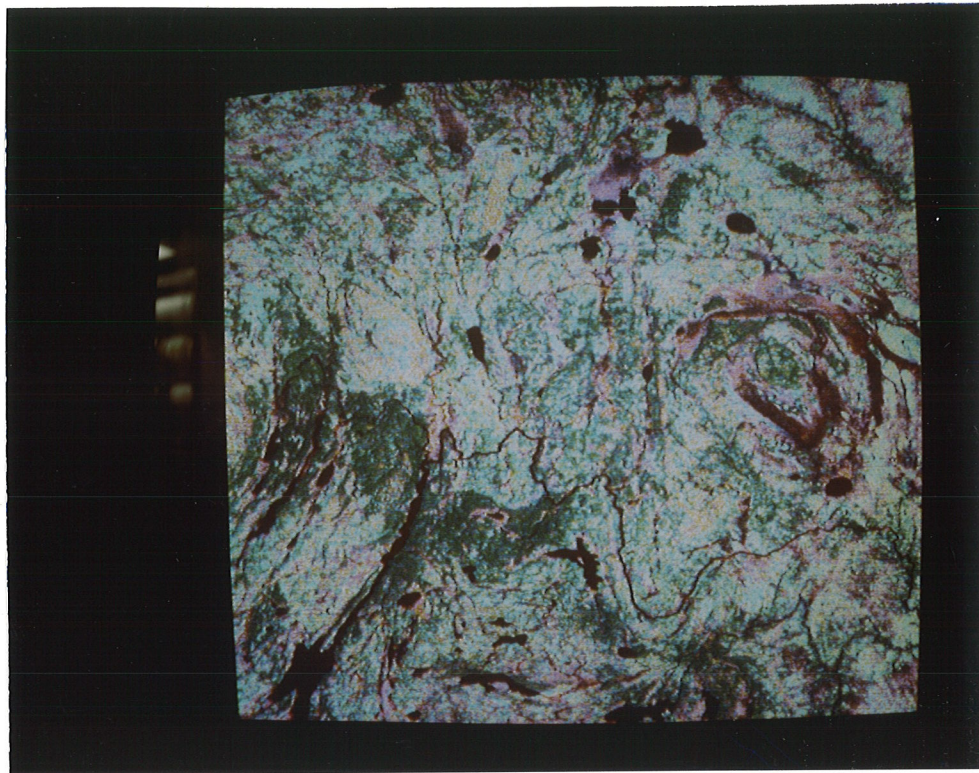


Fig. 3(xv). Photograph showing colour component transformation (original) Martin-Taylor after colour modification.

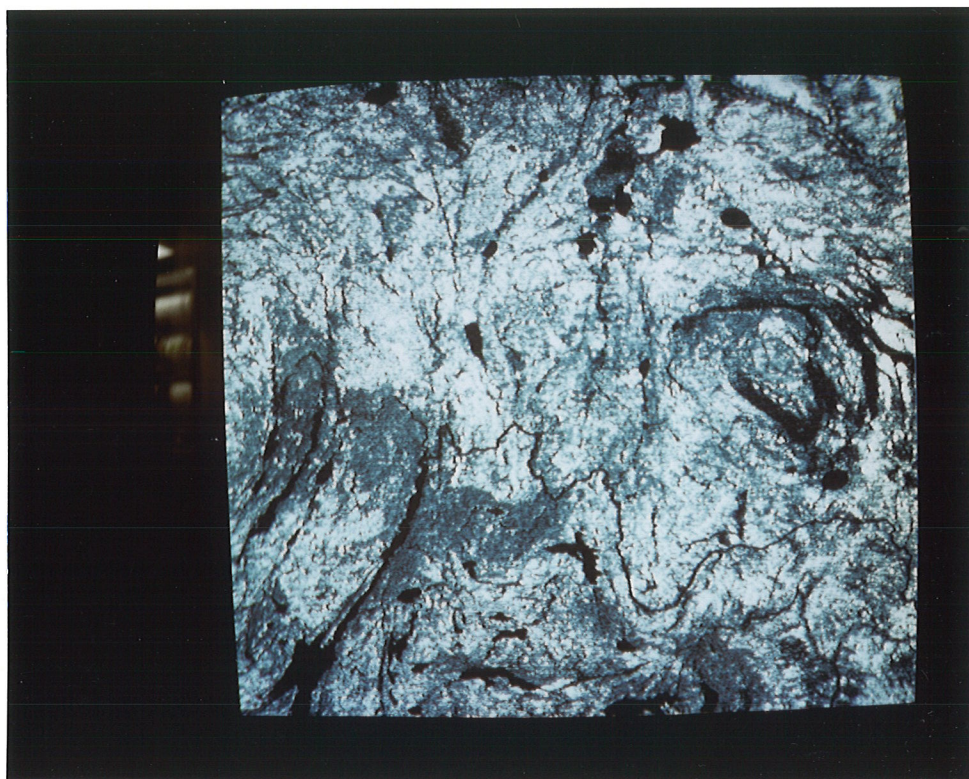


Fig. 3(xvi). Photograph showing second colour component transformation.

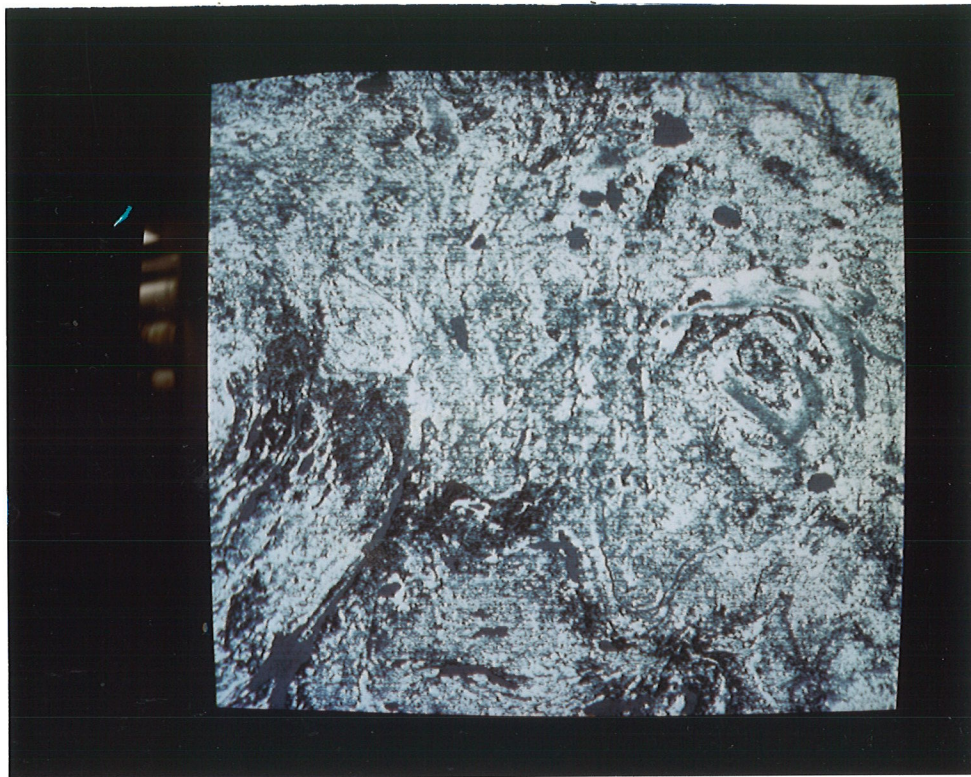


Fig. 3(xvii). Photograph showing third colour component transformation.

areas from areas covered by swamps and are fairly good for mapping of lithological/structural trend lines and other lineaments.

3.6.3 Unsupervised Classification

In unsupervised classification no prior knowledge of ground truth is assumed and the classes obtained are based on actual relations among the variables. The boundaries are objectively determined from a computer algorithm to delineate natural groups or clusters.

A widely used clustering criterion, to which many other clustering criteria have been shown equivalent, is the "sum of-squared-error" criterion. For example, if there are c clusters, M_i is the mean vector for the i th cluster computed as in following equation and C_i denotes the set of data points belonging to the i th cluster. Then the sum of squared errors (SSE) is defined by:

$$SSE = \sum_{i=1}^c \sum_{X \in C_i} \|X - M_i\|^2$$

where $\|X - M_i\|$ is the Euclidean distance between X and M_i . In other words, SSE is the cumulative distance between

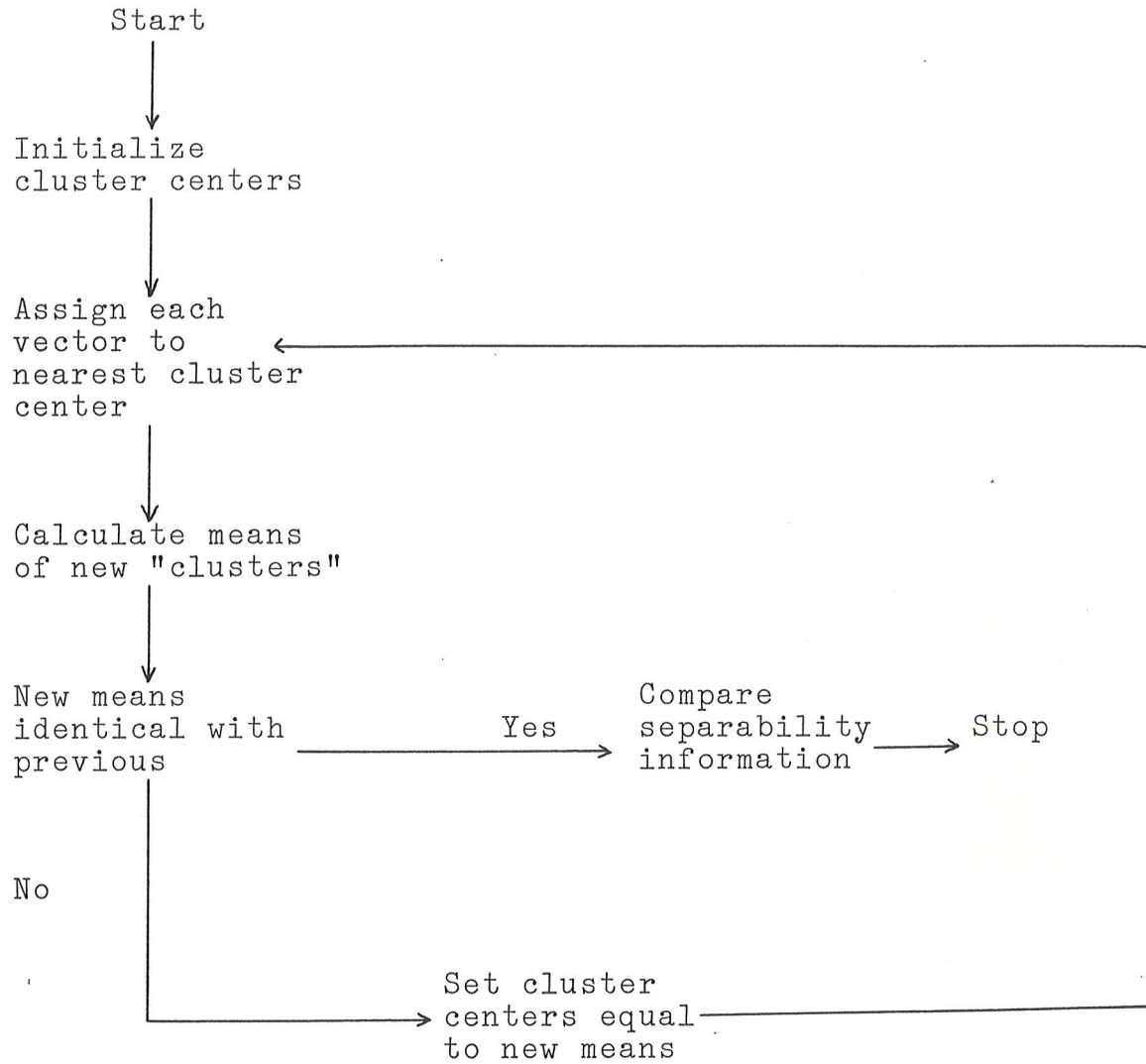


Fig. 3(xviii). Showing the flow chart of a basic clustering algorithm.

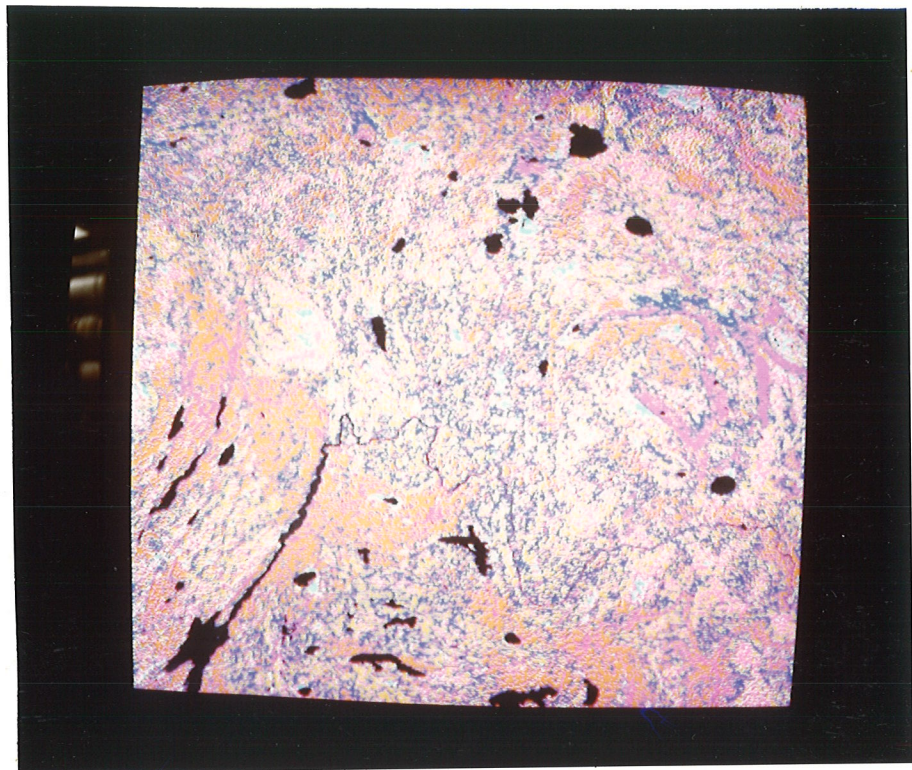


Fig. 3(xix). Photograph showing unsupervised classification (6 themes).

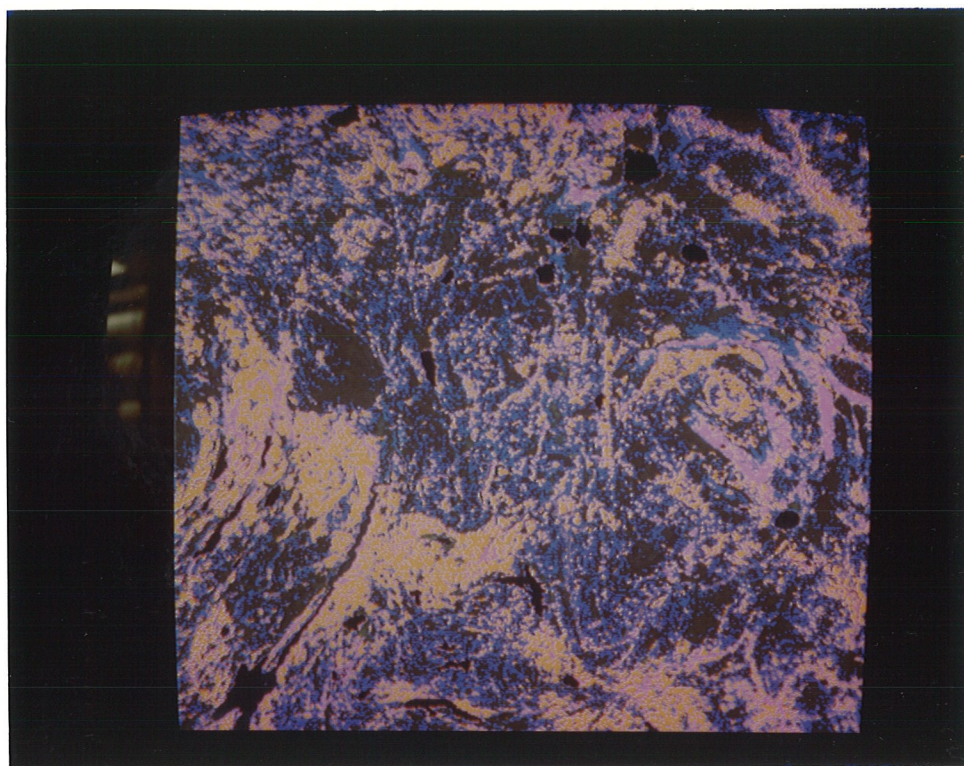


Fig. 3(xx). Photograph showing unsupervised classification (Themes 1, 2 and 3).

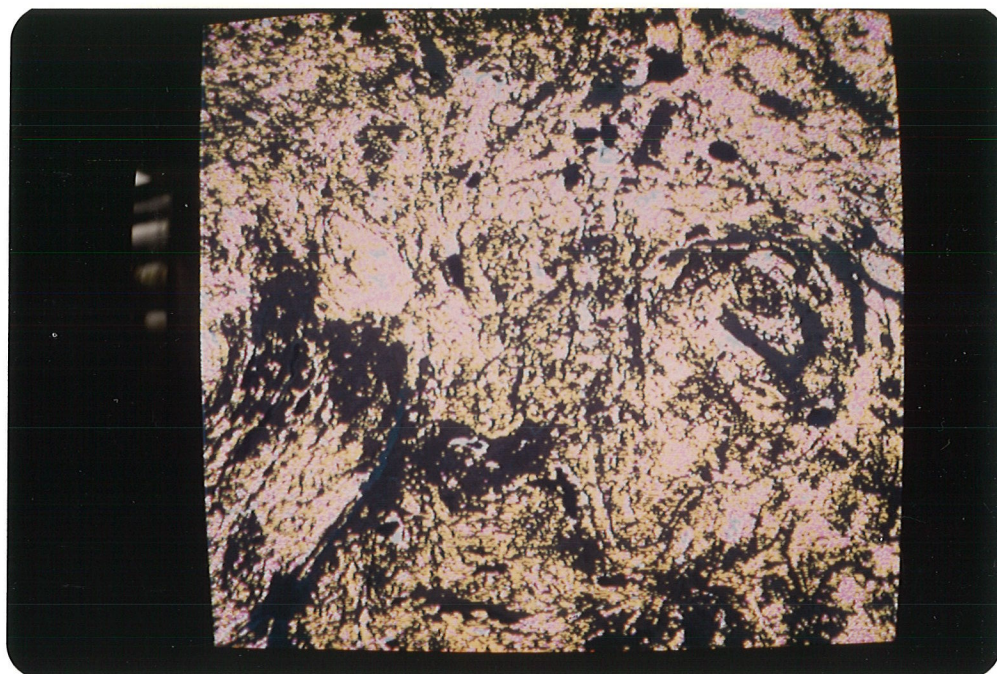


Fig. 3(xxi). Photograph showing unsupervised classification (Themes 4, 5, and 6).

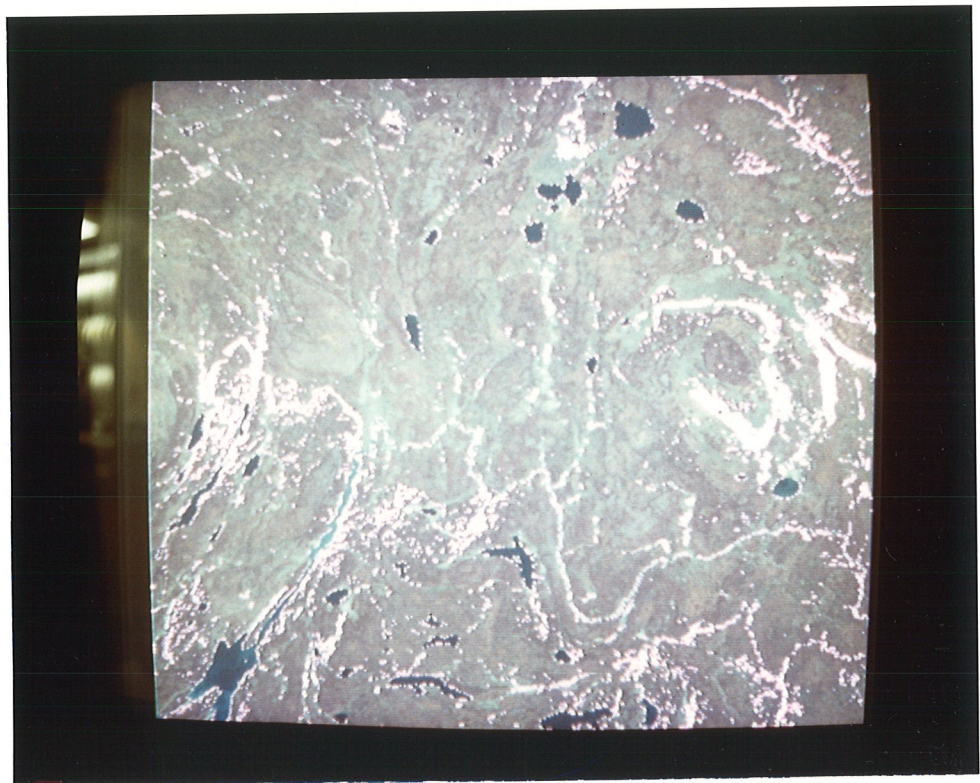


Fig. 3(xxii). Photograph showing unsupervised classification (Theme 1).

each point in the data set and the mean of the cluster to which that data point is assigned. A clustering algorithm proceeds as shown in the Figure 3(xviii).

There are many case histories available indicating successful application of unsupervised classification in land use mapping, agriculture, forestry and water quality monitoring. In general, geological applications have met with very limited success because of the facts already discussed in section 3.6 of this chapter.

3.6.4 Ratio Enhancement

Ratioing is an enhancement technique in which two spatially registered spectral images are divided according to a predetermined formula pixel by pixel. The ratio picture thus produced has individual pixels representing the ratio of digital number (DN) of two channels. It is a process of enhancing minor differences between materials by defining the slope of the spectral curve between two bands. Although, ratio values can theoretically range from zero to infinity, most of the terrestrial scenes observed have ratio values ranging from about 0.25 to 4.0. Suitable ratio features have been determined for specific remote sensing applications by reasoning based on the

physical phenomena involved and by experimentation. Sometimes ratios are used in which numerator and denominator are sums or differences of the pattern measurements. The objective usually being to "subtract out" or "divide out" the undesirable effects of the atmosphere or variable scene illumination. Ratio pictures thus enhance the colour differences and also reduce brightness variations due to topographic relief. If illumination changes across the scene result in the presence of areas of light and shadow but the original tone of the material does not, ratio images will show no change. Therefore ratio pictures have the quality of suppressing the topographic effects, while emphasizing the subtle differences between the rock types. Ratio images are directly related to spectral properties of various materials. Increased information has been obtained by using various ratios that maximize the differences in the spectral slopes of rock types in the scene. Ratio images have been used in many geological investigations to recognize and map areas of mineral alterations. Rowan et al (1974) found that the 4/5, 5/6, 6/7 composite provided the greatest amount of information for discrimination between hydrothermally altered and unaltered rocks, as well as separating various types of igneous rocks in and near the Goldfield, Nevada mining district. The presence of oxidized-iron absorption band at about 0.85 μ m lends itself

well to this technique. The detectability of limonitic areas in a scene would be enhanced by using ratio images that include this wavelength region.

This property has made ratio images quite useful in geologic applications because they exaggerate subtle colour differences in a scene and many geological problems require the distinction between rock types that may appear to be quite similar. The main drawbacks of the ratio images are -

1. Ratioing suppresses the ability of analyst to discriminate between rocks with strikingly different albedos, but similar reflectance spectra.
2. Ratio techniques also enhance noise which appears coloured in multispectral images.
3. Atmospheric effects may also become visible in ratio pictures, because diffuse light scattered onto a scene is strongly coloured blue.

Among various ratio enhancements shown in Figures 3(xxiii), 3(xxiv) and 3(xxv) the ratio 7-5/4 image has been found to be useful in not only mapping of lithological/structural trend lines but also lineaments like faults, joints and fracture patterns.

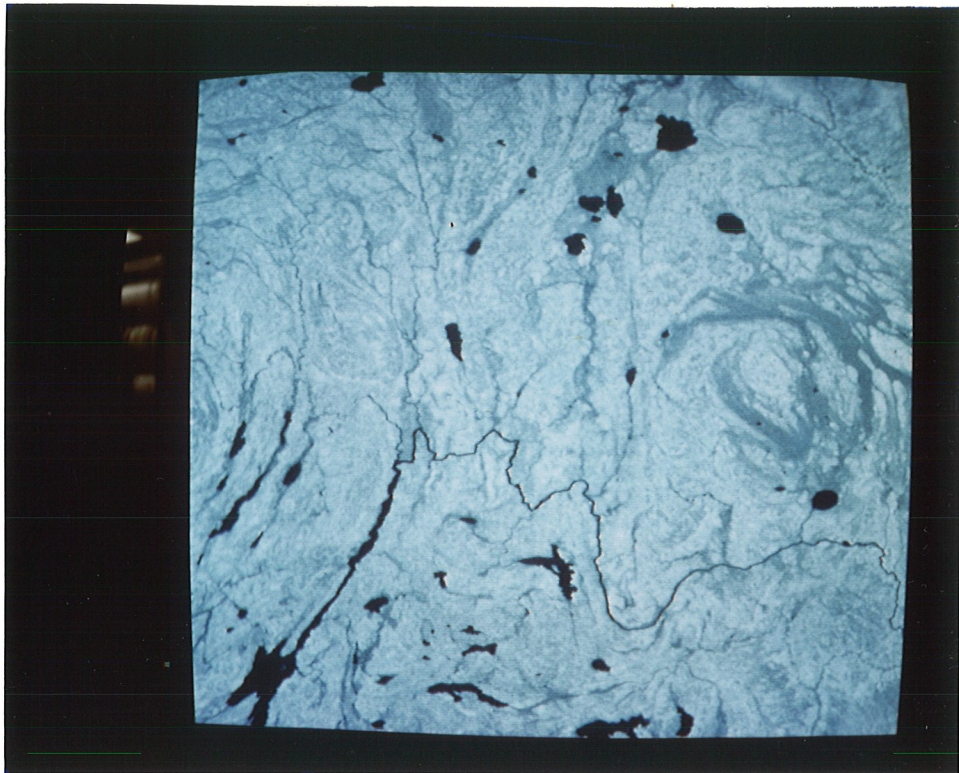


Fig. 3(xxiii). Photograph of the ratio 7/5 image
(Vegetation or Biomass).

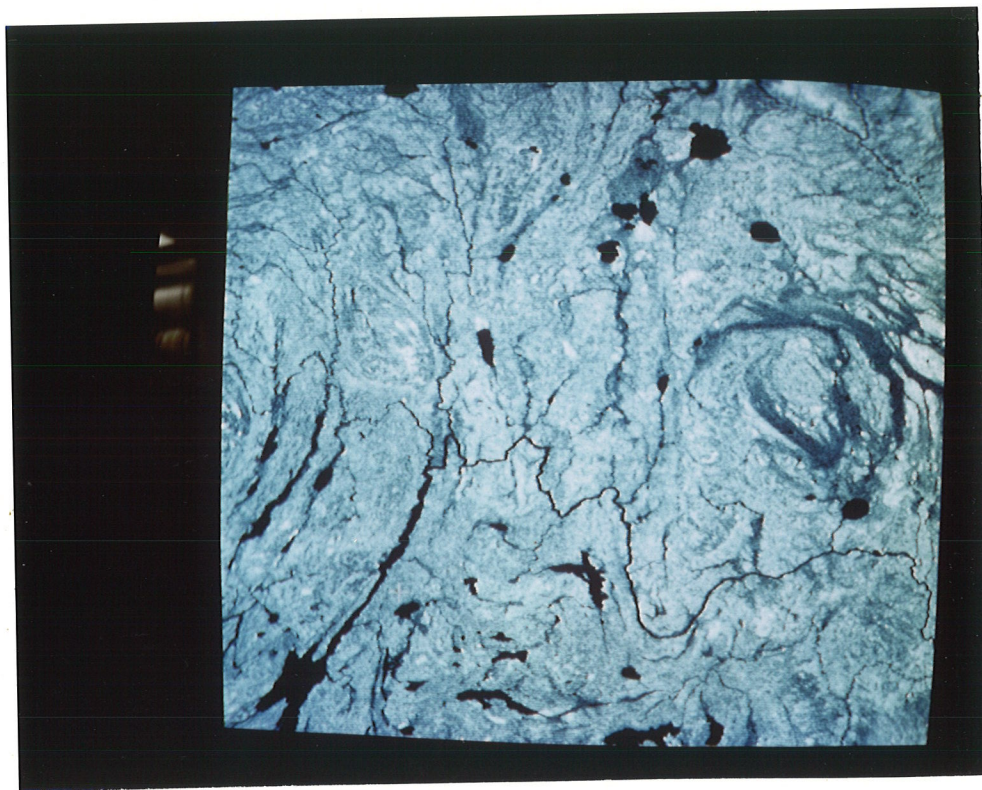


Fig. 3(xxiv). Photograph of the ratio $\frac{7-5}{4}$ image
(Geomass).

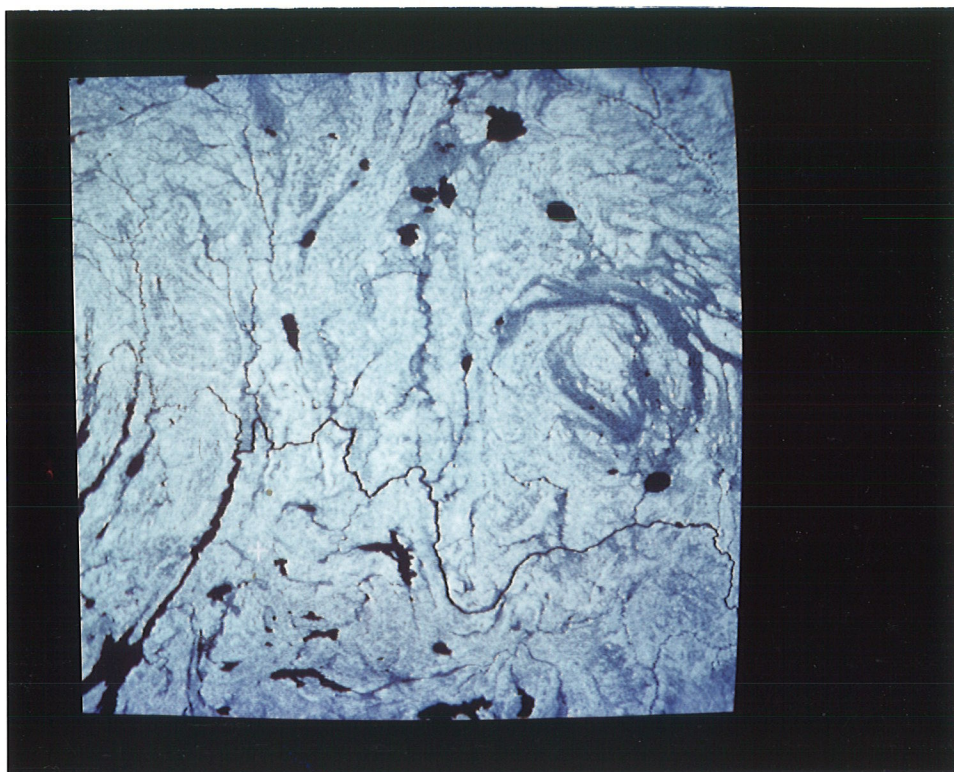


Fig. 3(xxv). Photograph of the ratio $\frac{7-5}{7+5}$ image.

3.6.5 Principal Component Transformation

Various data compression techniques can make possible the transmission or storage of a smaller number of bits of data without the loss of information. Thus, by reference, data compression studies tend to reveal the amount of real information present in relation to the quantity of raw data. One approach for accomplishing data compression is indicated in the Figure 3(xxvi). In which a hypothetical plot of the distribution of data in one dimension versus that in another is shown. If the data are distributed in the region outlined in two dimensional space one can define a new coordinate system with one axis (Y_1) oriented in the long direction of the distribution and the second axis (Y_2) perpendicular to the first. The mathematical operation required to do this is a linear combination of the data values in the old coordinate system achieving the data values in the new coordinate system as shown in the following equations -

$$Y_1 = a_{11}X_1 + a_{12}X_2$$

$$Y_2 = a_{21}X_1 + a_{22}X_2$$

where (X_1, X_2) are the data coordinates in the original coordinate system and (Y_1, Y_2) are the data coordinates

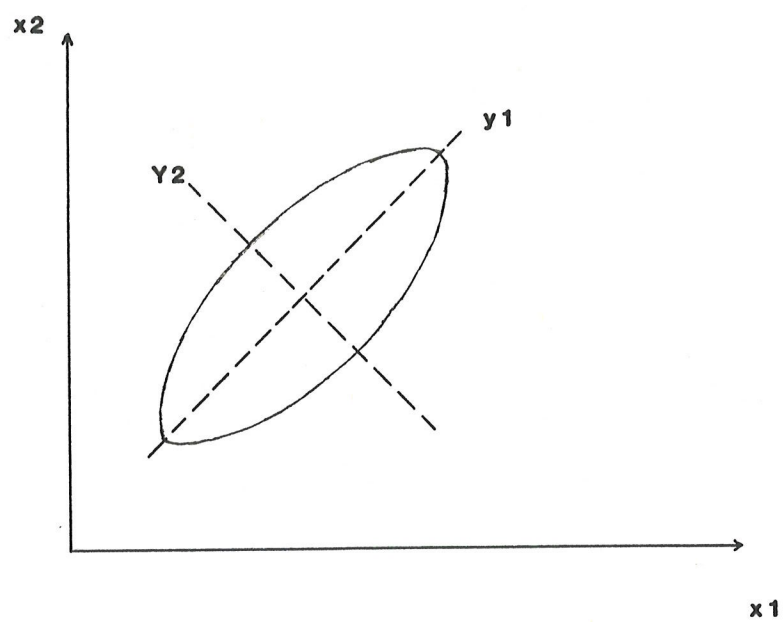


Fig. 3(xxvi). Principal component axes in two-dimensional space. (After David A. Landgrebe 1978).

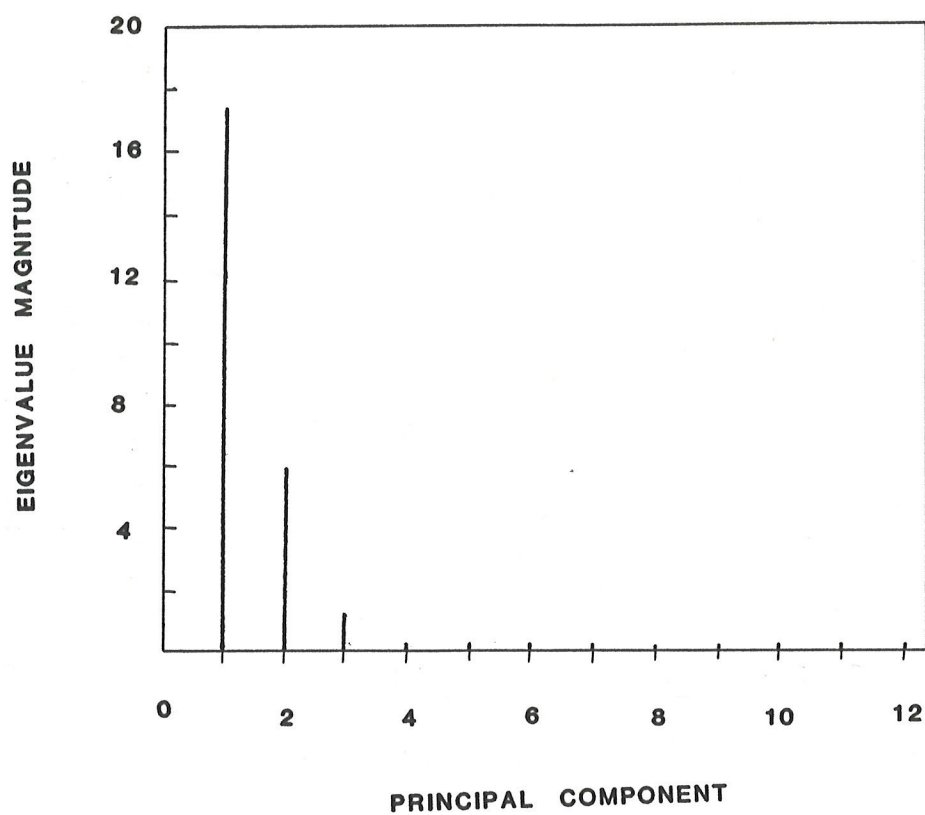


Fig. 3(xvii). Ordered eigenvalues for a twelve-dimensional multispectral data set.
(After David A. Landgrebe 1978).

in the new coordinate system. By such a transformation it can be seen that the dynamic range for the new coordinate Y_1 will be much greater than either of the original coordinates X_1 or X_2 , while that of Y_2 will be quite small.

The same operation can be carried out for data in higher dimensional spaces. New coordinate directions are defined one after another, each time taking the direction of orientation of the new coordinate to be perpendicular to all of the previously selected ones and in the direction of the remaining maximum data dynamic range. Such a procedure is called principal component transformation.

Since Landsat multispectral image data has strong correlation from channel to channel the axes of probability density functions are not statistically orthogonal, thus variables on the axes ($DN_1, DN_2, \dots, DN_n$) are not independent. Principal component transformation can be used to express the data in an essentially lower dimensional space without significant loss of information. The Figure 3(xxviii) indicates the dynamic range present in each of the new coordinates of the transformed coordinate system for 12-feature multispectral data processed in this way. During principal component transformation new images are produced by using n-dimensional probability functions which have

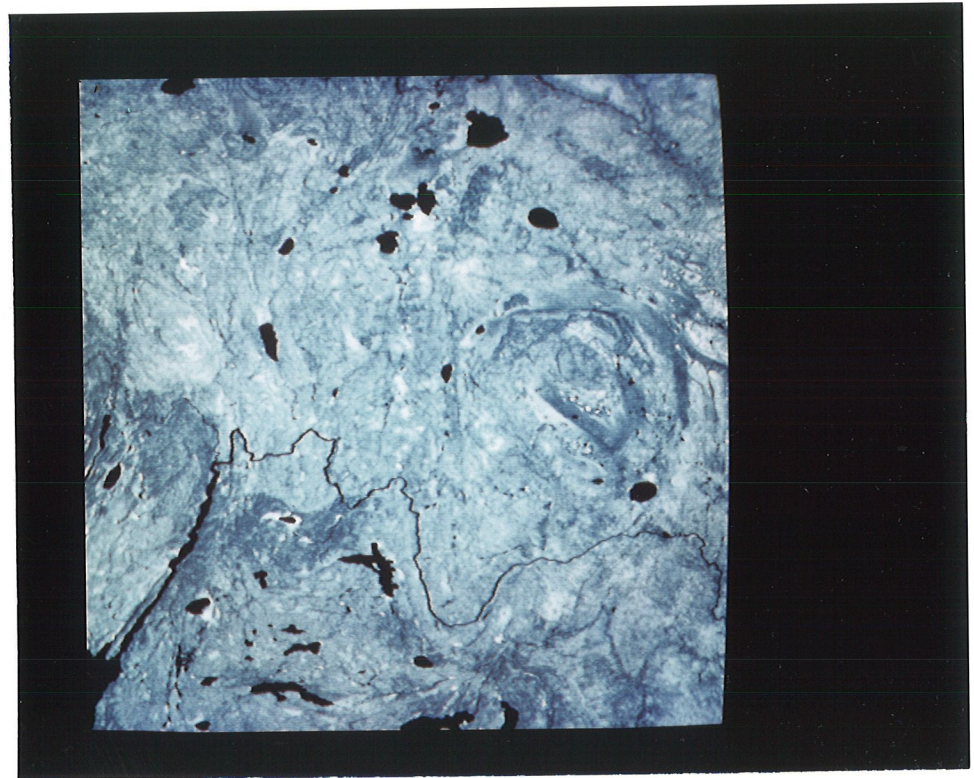


Fig. 3(xxviii). Photograph showing contrast stretch enhancement of 1st principal component transformation.

orthogonal and independent axes. This is done by a linear transformation of variables which corresponds to a rotation and translation of the original coordinate system of the probability density functions.

Generally as observed by Donker and Mulder (1976) in principal component analysis, the first principal component image is just a weighted average picture whereas the remaining images represent essentially pairwise differences between channels. Since variances are arbitrarily arranged in descending order and is the same parameter that is used to describe the width of the DN distribution in each one dimensional probability density functions, the first transformed picture will have the largest spread in data in the form of greatest contrast.

3.6.6 Spatial and Directional Filtering

Whenever operations such as contrast stretch enhancement are performed on a Landsat scene which has an originally high brightness, it saturates large portions of the original probability density functions. Spatial filtering is therefore applied in such cases to help in suppressing gross changes in brightness over the scene while local higher frequency changes are enhanced, thus

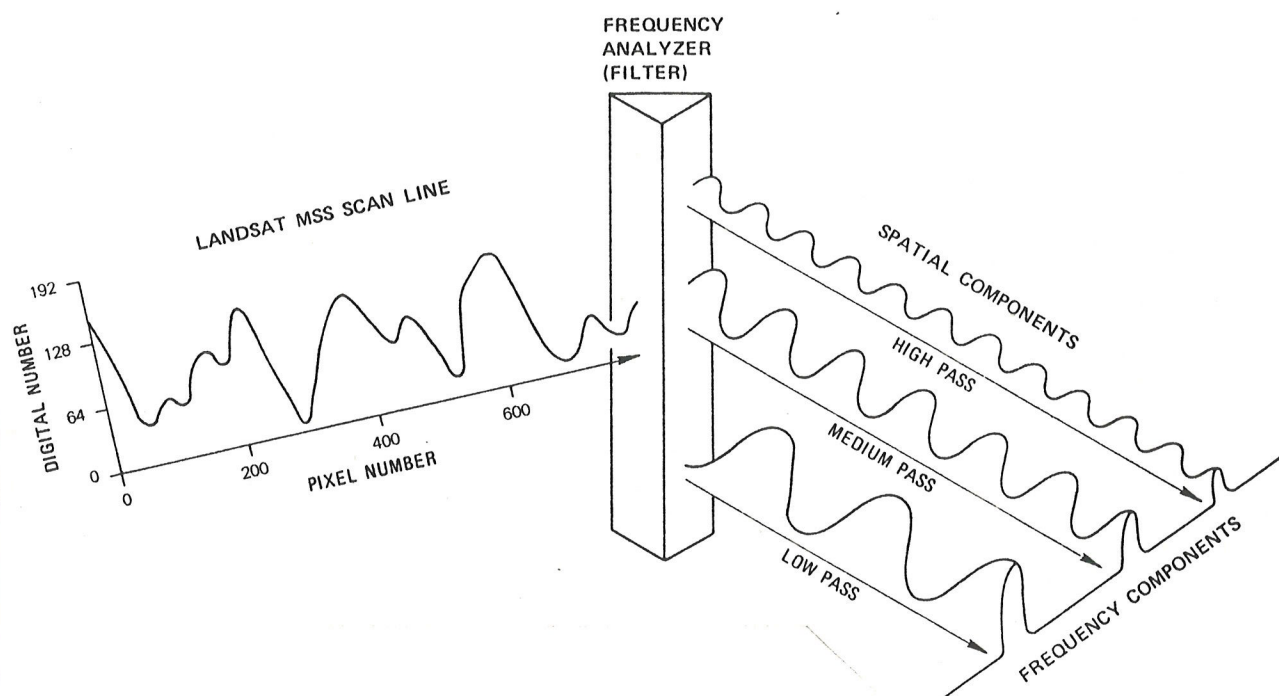


Fig. 3(xxix). Spatial-frequency filtering of Landsat data. (After F.F. Sabins 1978).

increasing the ability to discriminate details.

In spatial filtering the regularly spaced pixels of a Landsat scan line are plotted along the abscissa of a graph with the corresponding DN's as the ordinate. The resulting curve as shown in the Figure 3(xxix) is a complex wave made up of many simple curves, each with its own constant wavelength. As the complex wave of a beam of white light can be separated into its component wavelengths (colours) by a prism. Similarly the complex wave of a Landsat scan line can be separated into its component wavelengths by a mathematical process known as spatial filtering. Frequency filters are designated high pass, intermediate pass and low pass depending on the spatial frequency that is transmitted through the filter.

The distances between major terrain features such as between valleys and hills are measured in tens of kilometres, these features have low spatial frequency, with very long wavelengths. Anticlines and synclines have an intermediate spatial frequency with wavelengths measured in kilometres. Joints, fractures and faults are linear features with high spatial frequency and wavelengths measured in tens to hundreds of meters. High pass filters may be used to enhance these geological features. The

direction in which the filter is passed across the image determines which linear features are enhanced; those trending normal to the filter direction are enhanced while linear features parallel with the filter direction are suppressed.

After spatial filtering however, brightnesses from one locality to another cannot be related. In the case of high pass filtering therefore high frequency data is retained unchanged while low frequency data is suppressed. The important effects of high-pass filters on the image are -

1. Most of the data in Landsat scene is low frequency while the random noise is evenly distributed. When low frequency information is suppressed by a high pass filter the picture obviously becomes more noisy.
2. Sharp edges or boundaries of an image become less conspicuous. This is because the outermost weights of the filter arrive at the discontinuity before the center.
3. Features oriented in certain directions are preferentially enhanced. This is sometimes helpful in identification of less conspicuous lineaments trending in particular direction. Figure 3(xxx) shows that the

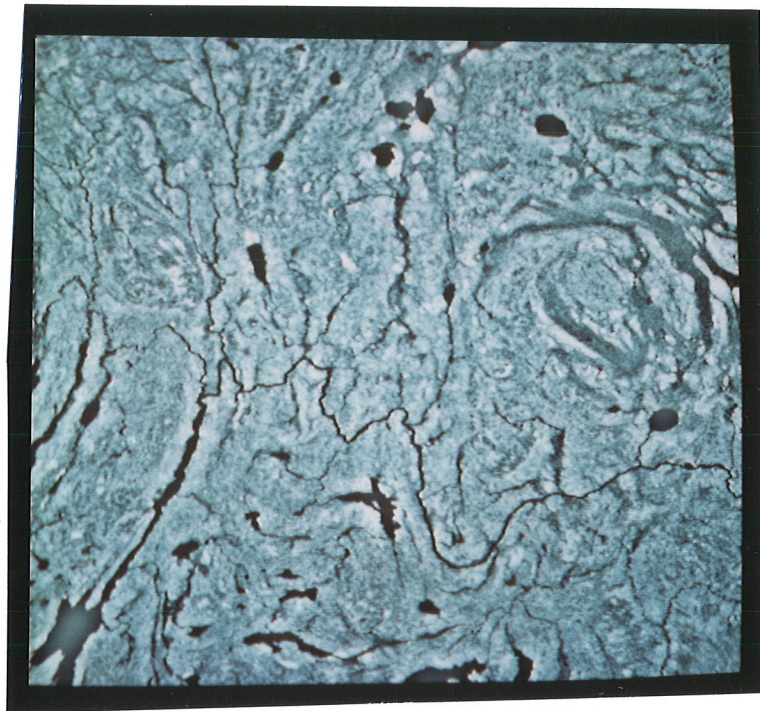


Fig. 3(xxx). Photograph showing data after high pass
video filtering of $\frac{7-5}{4}$ ratio data.

lineaments trending in almost N-S direction are more conspicuous here than other enhancements.

3.7 SYNTHESIS AND DISCUSSIONS

After individual interpretation of various types of spectral remote sensing data, which included panchromatic and colour aerial photographs, thermal, radar and Landsat images the interpreted is plotted on individual compilation Maps 1, 2 and 3, and Figures 3(vii) and 3(ix) they have been critically examined for the details of geology especially mapping of lithological/structural trends and other lineaments. This was followed by computer manipulated enhancements which included contrast stretch, colour component transformation, unsupervised classification, ratioing, principal component transformation and spatial filtering. These enhancement products were then evaluated for their usefulness to various geological aspects which are summed up in accompanying Table 3(i).

The important points that have emerged from the present study are as follows -

1. For effective and efficient geological surveys of large areas the use of Landsat multispectral scanning imagery can be of tremendous aid in conjunction with aerial photointerpretation as first stage rapid mapping technique,

most advantageous at small scales or in situations where it is desired to extend an investigation from a known area to an unknown area.

2. The lithological/structural trends are easy to interpret in this area because of the terrain conditions and availability of good quality aerial photographs. These trend lines in twin brought out a fairly detailed geological picture of the area.

3. Typical mapping of fold structures has mainly been done in terms of delineating lithological/structural trends. Such trends are reflected by the morphological expression of certain lithological types and to a lesser degree to variations in tonal differences due to selective vegetation and rock/soil colourations. Differences in resistance to erosion of a rock series results in an alternate depressions and ridges which are generally occupied by elongated lakes and occasionally by streams and rivers. Where such a linearity is repeated across the area, it is reasonable to infer that the regional lithological/structural trend is parallel to the macro-texture produced by ridges, streams and lakes. These ridges evidently have a rather greater resistance to erosion and are thus lithological in nature. Flexures or folding observed in such units

indicates a similar flexuring or folding of lithological/ structural trends associated with the formation of ridges.

4. Individual foliation planes or planes of schistosity or gneissosity are rarely, if ever recognizable on aerial photographs. However, the regional structural trend direction is generally parallel to any banding or sequence of lithological units.

5. Large bodies of igneous rocks are recognizable by their irregular shape, sometimes combined with a distinctive image texture derived from the topography. The gneissic plutons are outcropping more or less extensively than the surrounding lithology which has resulted in reflectance contrasts. This is also occurring when the pluton has a sufficiently different mineral composition than its surrounding rocks to support a distinct vegetation cover. Virtually all the acidic plutons are recognizable by textural rather than the reflectance characteristics. Lack of foliation and a rectangular grid pattern produced by the intersecting set of major joints, lighter vegetation cover than the adjacent rocks have further helped in their recognition.

6. All the major geological divisions of the study area are broadly distinguishable on the aerial photographs and

enhanced Landsat imagery. The Kiseynew sedimentary gneissic belt in the northern part, the Flin Flon - Snow Lake greenstone belt in the middle and overlying Palaeozoic sedimentaries in the south. The Kiseynew sedimentary gneissic belt is characterized by pronounced almost E-W trending foliation and elongated domal structures, by vaguely bulbous, smoothly textured land surface with very few lakes, generally lighter tones and characteristic nearly N-S trending joint pattern. The Flin Flon - Snow Lake greenstone belt is marked by very complex and tight folding patterns, more or less circular domal structures and innumerable elongated lakes following either the lithological boundaries or the fracture pattern. The flat lying Palaeozoic sedimentary rocks have distinctive light tone, drainage pattern and very few but large irregular lake bodies.

7. Since Landsat images provided a synoptic view of the area, it was easy to bring out large scale geological structures. The Figure 3(xxi) shows the raw data of two adjacent scenes of Landsat imagery and Figure 3(xxii) shows the geological interpretation of lithological/ structural trend lines. It can be noticed that a very large folded structure is closing towards the NE direction and the Herblet Lake conical gneissic dome is situated in the core portion of this structure.



Fig. 3(xxxi). Photograph showing the raw data of two adjacent scenes of Landsat imagery.



Fig. 3(xxxii). Photograph showing interpreted data from
Figure 3(xxxi).

8. Digital images are readily manipulated by the computer to prepare a more effective display of image data for feature extraction depending on the needs of various interpreters. The present study has indicated that Landsat digital data carries much more information than the paper print out. Linear contrast stretch enhancement has been found to be very suitable for mapping of lithological/structural trend lines and ratio images are very good for mapping of other lineaments. When linear contrast stretch enhancement of 7-5/4 ratio data is performed, Figure 3(xxxiii), it can be seen that mapping of both lithological/structural trends as well as lineaments can be successfully performed.

9. As mentioned earlier colour component transforms are not very useful in either lithological/structural mapping or the lineaments. But when hybrid colour components 1, 2 and 3 are performed Figures 3(xxxiv) and 3(xxxv), it can be seen that mapping of both lithological/structural trends and other lineaments can be done successfully.

10. These computer enhancements can also be printed on black and white 1:50,000 scale. Figure 3(xxxvi) shows one such print out of hybrid colour components 1, 2 and 3. These printouts because of their large scale facilitate large scale mapping of geological structures. In the

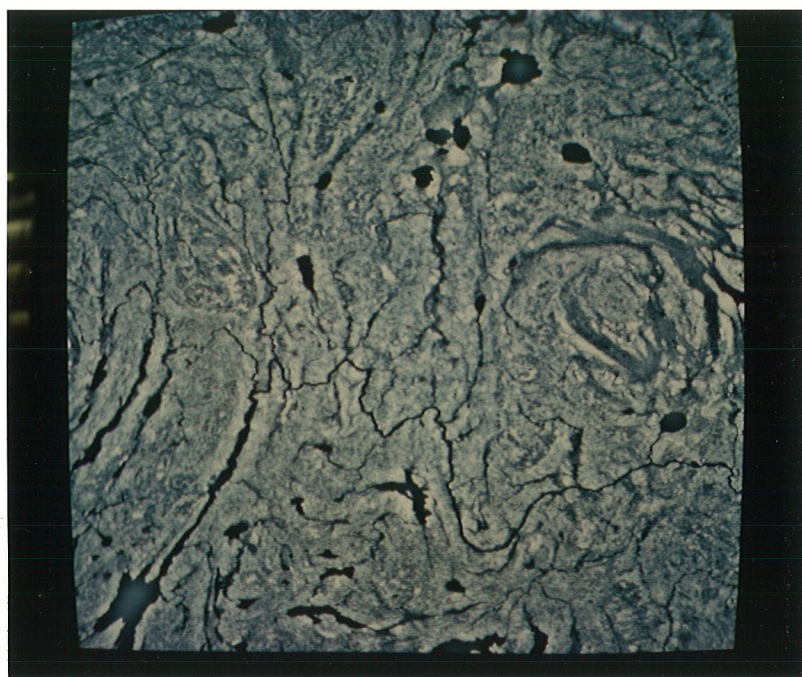


Fig. 3(xxxiii). Photograph showing contrast stretch enhancement of $\frac{7-5}{4}$ ratio data.

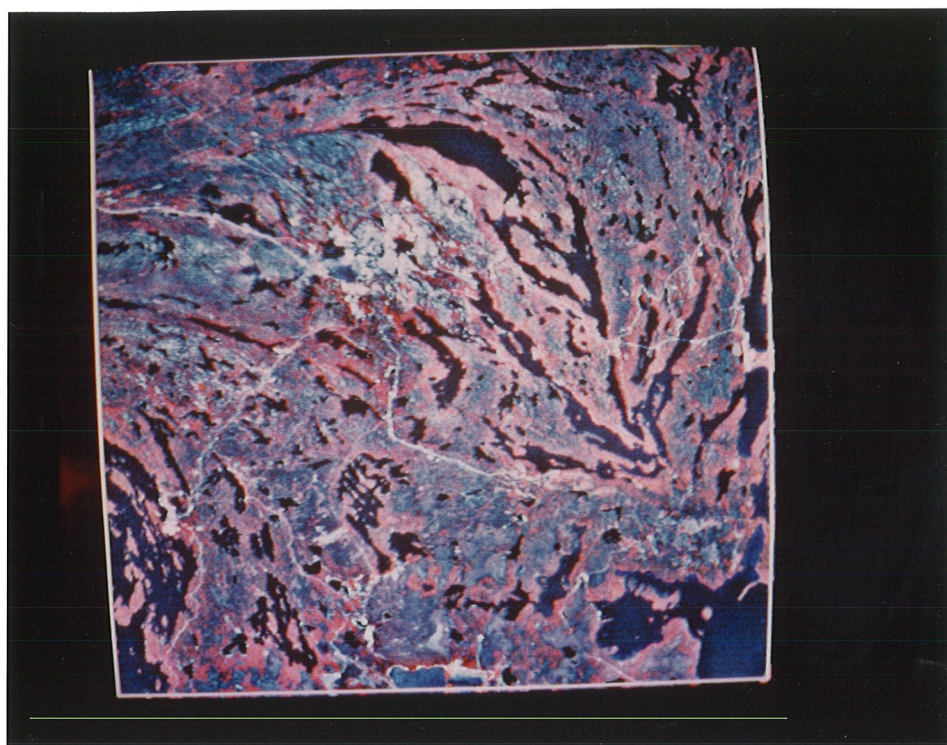


Fig. 3(xxxiv). Photograph showing the hybrid colour components 1, 2 and 3 of the area around Flin Flon.

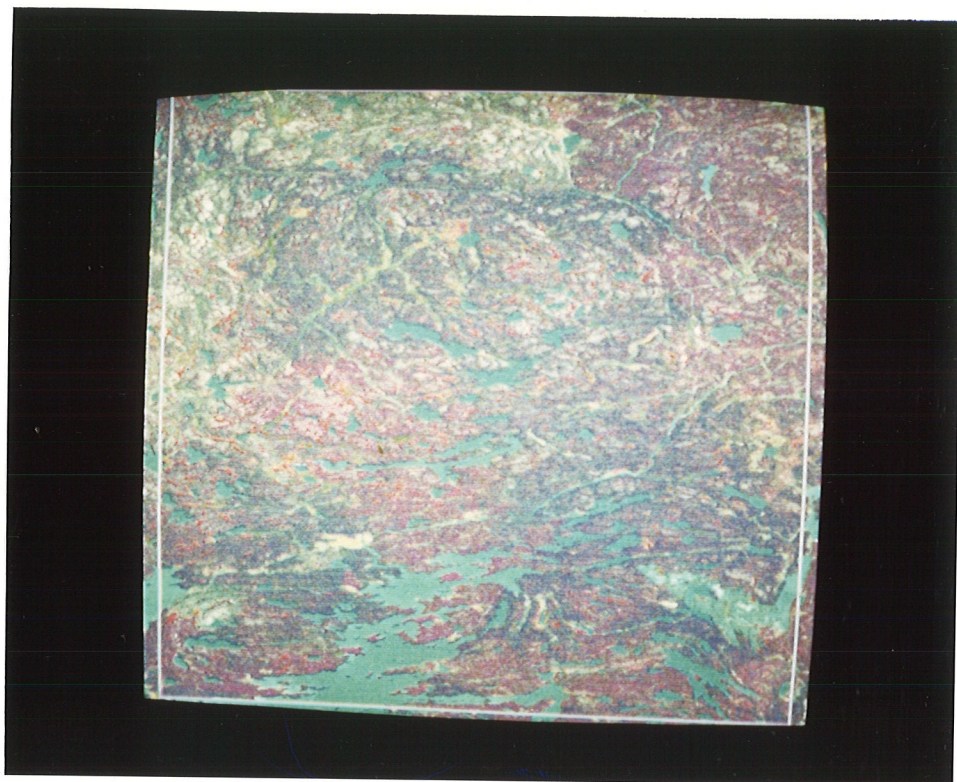


Fig. 3(xxxv). Photograph showing the hybrid colour components 1, 2 and 3 of the area north of Flin Flon.

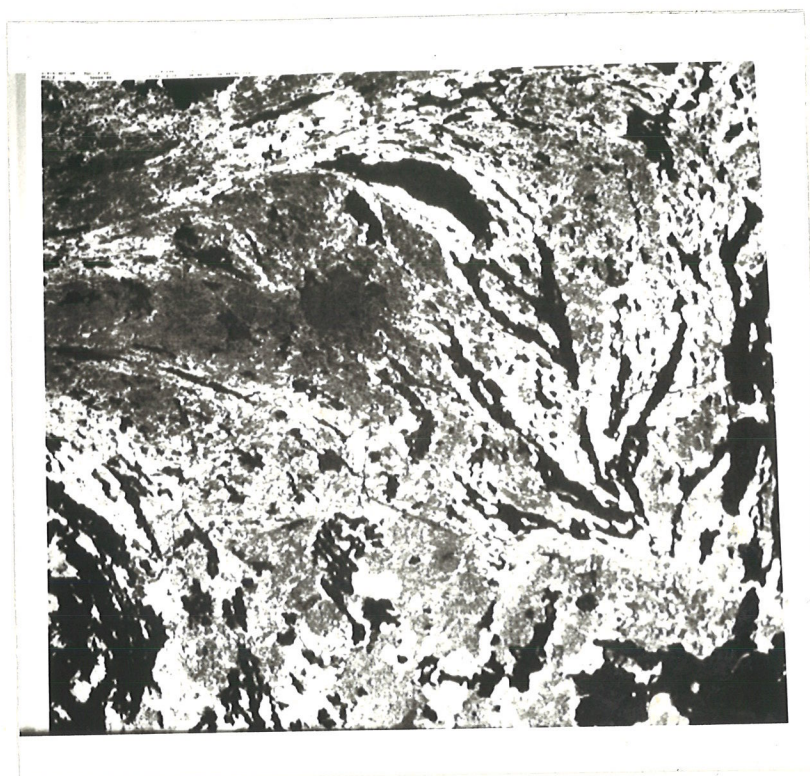


Fig. 3(xxxvi). Photograph showing 1:50,000 black and white computer print out of the area around Flin Flon.

present study it has been found that the lithological/ structural trends can be mapped successfully but they are not of much use in mapping of small scale lineaments because their linearity is lost between the digital values of grey tones. However, very pronounced large scale lineaments can be interpreted from these print-outs. Figure 3(xxxvii) shows interpreted data from this print out. It can be seen that pronounced ENE -WSW trending lineaments which are associated with the Kiseynew Front are clearly seen.



Fig. 3(xxxvii). Photograph showing the interpreted data from the black and white computer print-out shown in Figure 3(xxxvi).

Table 3(i)

The following Table summarizes the relative utility of various enhancement products for geological mapping purposes.

Enhancement Products	Mapping of outcrop areas	Mapping of Lithologies	Mapping of structural lineaments	Cultural features
1. Linear Contrast stretch enhancement	+	++	++	o
2. Colour Component Transformation	++	+	+	o
3. Unsupervised Classification	++	+	o	o
4. Ratio enhancement				
a, $\frac{7}{5}$	+	+	+	o
b, $\frac{7-5}{4}$	o	++	++	o
c, $\frac{7-5}{7+5}$	+	+	++	o
5. Contrast Stretch Enhancement of $\frac{7-5}{4}$ ratio	+	++	++	o
6. High pass video filter of $\frac{7-5}{4}$ ratio	+	++	++	o
7. 1st Principal Component of $\frac{7-5}{4}$	+	++	++	+
8. Hybrid colour components of principal component 1, 2 and 3	++	++	++	++

Key = - poor + good
 o fair ++ very good

4.0 AIRBORNE GEOPHYSICAL REMOTE SENSING TECHNIQUES

4.1 GENERAL

The applicability and integration of various airborne magnetic and electromagnetic techniques with remotely sensed spectral data for economic geological mapping and exploration of stratabound volcanogenic sulphide mineral and gold deposits is discussed in the present chapter. Magnetic methods include interpretation of conventional airborne isomagnetic contour maps and colour applicon plots of total field and vertical aeromagnetic gradient. Among electromagnetic methods, airborne Very Low Frequency (VLF) survey data in the form of colour applicon plots of total field and quadrature are interpreted.

Interpretation of these maps has been carried out visually with the principal aim of mapping the lithological/structural trend lines which have formed the backbone of present economic geological mapping and exploration programmes for stratabound sulphide mineral deposits and gold occurrences in the Flin Flon - Snow Lake greenstone belt.

It has been demonstrated in Chapter 3 that enhanced Landsat images and aerial photographs are of great importance

mapping the lithological/structural trend lines. For obtaining a small scale synoptic geological view it is found that integration of interpreted data from Landsat imagery with total field isomagnetic contour/colour applicon plot is extremely useful. Integration of aerial photointerpretation with vertical aeromagnetic gradient data has proven to be helpful in detailed geological investigation. Interpretation of VLF applicon plots has been helpful in identification of conductive zones which appear to be related to sulphide mineralization and integration of photointerpretation with vertical aeromagnetic gradient data has facilitated mapping of these zones. Furthermore aeromagnetic interpretation has enhanced the understanding of structure and lithology in the area and this in turn has highlighted certain interesting geological aspects which appear to have direct bearing on the distribution of gold mineralization in the Flin Flon - Snow Lake greenstone belt.

4.2 AEROMAGNETICS

Aeromagnetic data in the form of isomagnetic contour maps of total field and colour applicon plots of total field and vertical gradient have been used to improve the resolving power of the photointerpretation technique.

Several case studies Hall (1968), MacLaren and Charbonneau (1968), McGrath and Hall (1969) have indicated in the past that regional aeromagnetic anomalies are closely related to major geological features, especially the tectonic trends of greenstone belts and associated granitic plutons in the Canadian Shield.

The interpretation proper of the aeromagnetic total field data is generally carried out with two objectives. The first is qualitative interpretation in which lithological and structural trend lines are marked and other structural features such as faults and shear zones are delineated. The second is quantitative interpretation in which the geometrical shape, magnetic susceptibility and position of each causative body is calculated. In the present study only a qualitative interpretation is attempted because this alone can be integrated with spectral remote sensing data.

Integration of interpreted data from spectral remote sensing and aeromagnetics has helped in geological mapping and exploration in the following ways -

1. Tracing of lithological/structural trend lines and lithological units in areas covered by lakes and swamps,

Palaeozoic sedimentaries and by overburden of Quaternary sediments.

2. Corroborating the lithological/structural trend lines obtained by visual interpretation of aerial photographs and enhanced Landsat images.

3. Identification and mapping of mafic volcanic flow sequences which are conspicuous due to their stronger magnetization. Mapping the trends of these mafic flows is crucial because it has emerged during the present study that the gold deposits in the Flin Flon - Snow Lake greenstone belt are stratabound and are associated with these flows. This aspect is dealt in detail in Chapter 5. Furthermore mapping of these flows has automatically brought out the structural pattern of interbedded felsic flows with which copper deposits are associated.

4. Identification and mapping of both felsic and mafic bodies which are not recognized by photointerpretation. Felsic bodies are characterized by weaker magnetic signatures ranging broadly between 61150 gammas to 61300 gammas and a general plateau like appearance in case of total field applicon plots (Fig. 4(i)). In case of the vertical aeromagnetic gradient applicon plots they are generally represented by shades of yellowish colours with a mosaic

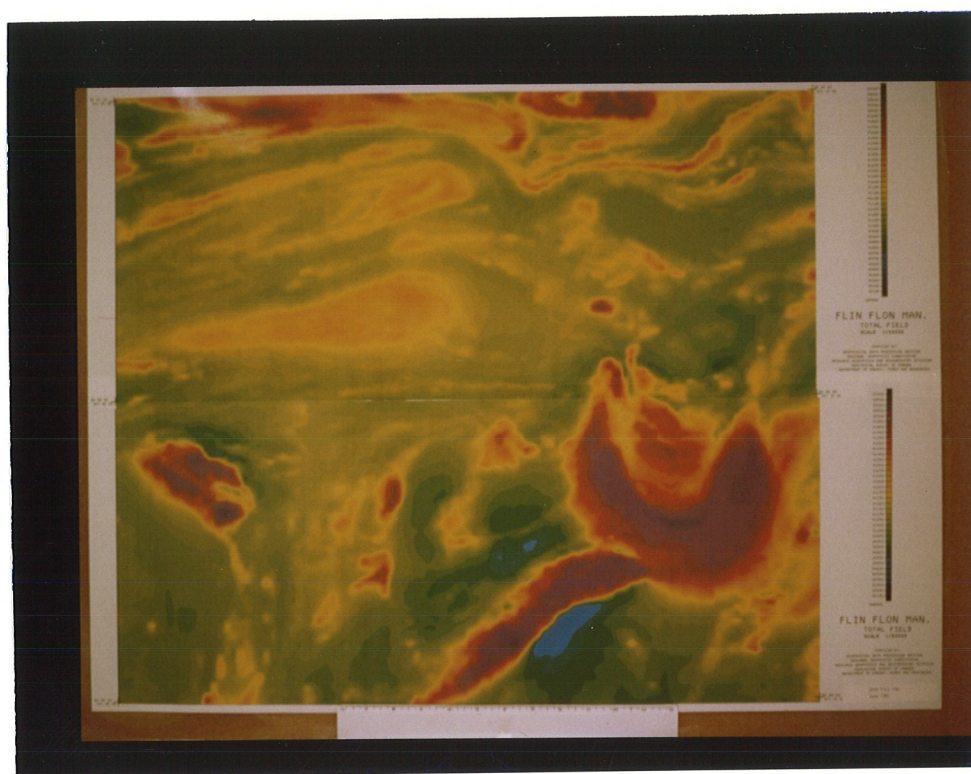


Fig. 4(i). Photograph of colour applicon plot of total field aeromagnetic data East of Flin Flon showing gneissic domal structures marked by yellowish colours with shades of red while mafic horizons are represented by red bands.

of light reddish colours with intensities ranging between 0.000 gammas/metre and 0.100 gammas/metre. These bodies also have more or less circular outline in case of domal structures and an elongated outline in case of anticlinal structures. Mafic flow horizons and gabbroic sills are recognized by very strong magnetic signatures ranging between 61300 gammas to 63500 gammas in case of total field applicon plots and between 0.100 gammas/metre to 7.000 gammas/metre in case of the vertical gradient applicon plots. The mafic bodies are also characterized by linear banded shapes.

5. Aeromagnetic data has been helpful in not only delineating but also filtering out many faults and shear zones from lithological/structural trends identified from spectral remote sensing.

6. Isolating the trends of Precambrian basement - In Precambrian Shield areas of Canada there are trends of different categories; (a) Precambrian grain which is original lithological banding, (b) superimposed foliations of various Precambrian deformational episodes, (c) trends of Palaeozoic sedimentary rocks wherever they overlie the Precambrian Shield areas, (d) strong trends overprinted on all exposed rocks due to Quaternary glacial episodes

(Fig. 1(i)). Since the aeromagnetic signature is not generally affected by last three factors it is possible to identify trends associated only with the Precambrian lithological banding.

4.2.1 Vertical Aeromagnetic Gradient Surveys

Vertical aeromagnetic gradient colour applicon plots of an area of about 4450 sq. km. on 1:50,000 scale are available for the Amisk Lake - Wekusko Lake study area around Cranberry Portage. The data from these maps have been interpreted in this integrated project. The aeromagnetic information on these maps were compiled from digitally recorded high sensitivity aeromagnetic data obtained by two self orienting cesium vapour magnetometers installed in twin tail booms mounted on the Geological Survey of Canada's beechcraft. The magnetometers were vertically separated by a distance of 2.05 metres with each measuring the total magnetic field to a resolution of 0.005 gammas. The survey of the area was carried out along N-S flight lines which are more or less perpendicular to the strike of the geological formations. Flight altitude was 150 metres above the ground surface with a flight line spacing of 300 metres. Double control lines

were flown at an average spacing of 12 kilometres.

The vertical aeromagnetic gradient values, which approximate the first vertical derivative of the earth's total field, are obtained by dividing the differences between the total field readings to two magnetometers by their vertical separation. The vertical gradient data was filtered with a digital operator to remove instrument noise. The vertical gradient data from the control lines were not used in the compilation of the maps. The data was edited, compiled, levelled and gradient values for contouring interpolated onto a square grid (0.25 cm grid spacing at 1:25,000 scale) by automatic computer processes. The contours were then photographically reduced to 1:50,000 scale. The final data grid was contoured and plotted using the automatic contouring programme and digital plotter.

The airborne survey and digital compilation was carried out by the Resource Geophysics and Geochemistry Division of the Geological Survey of Canada by using the following computer automated techniques. Aeromagnetic digital data values were interpolated from the flight line data at the nodes of a regular grid covering the survey area. Each grid cell was 0.08 cm square. A colour code was assigned to each cell according to the amplitude of

the aeromagnetic value within the cell using the colour scale shown in the legend of these maps. The data matrix was output on an applicon plot get plotter to produce a colour map, a photocopy of which is shown in Figure 4(ii).

Hood et al (1979) outlined the following advantages of vertical gradient over the total field aeromagnetic data -

1. Better resolution of anomalies produced by closely spaced geological formations;
2. Anomalies produced by near surface geological features are emphasized with respect to those caused by deeply-buried features;
3. Direct delineation of near vertical lithological contacts by the zero gradient contour;
4. The vertical gradient data is free from regional gradient of the earth's magnetic field and diurnal variation.

In geologically complex areas like the Flin Flon - Snow Lake greenstone belt the aeromagnetic vertical gradient exhibits far superior resolving power which in turn helps in economic geological mapping of lithological/



Fig. 4(ii). Photograph of colour applicon plot of vertical aeromagnetic gradient data East of Flin Flon showing separate anomaly bands of individual mafic flow horizons which give rise to composite anomaly in total field applicon plot (Fig. 4(i)).

structural trends in the following ways -

1. Compound and composite total field anomalies which appear as integrated ones in the total field application plots (Fig. 4(i)) and conceal the intricate nature of the causative individual bands. These bands can be demarcated by using the vertical aeromagnetic gradient data (Fig. 4(ii)).

2. Combined effects of more distinct anomaly location and higher resolution is particularly important in mapping lithological/structural trend lines (Map 5).

3. The most important task in mapping and exploration of stratabound gold and sulphide mineral deposits requires -

- (i) identification of mafic volcanic bands which stand out prominently due to their strong positive magnetic signature,
- (ii) delineation of these bands,
- (iii) demarcation of their structural trends.

Since all these requirements are fulfilled by using the vertical aeromagnetic gradient maps, they may become extremely important in the exploration of stratabound gold

deposits which are found to be generally associated with mafic bands. Also sulphide mineralization which are related to interbedded felsic bands in the Flin Flon - Snow Lake greenstone belt would have a similar applicability.

4. The lithological/structural trends outlined by the interpretation of vertical aeromagnetic gradient colour applicon plots can best be correlated and integrated with these trends obtained by interpretation of spectral remote sensing products. This greatly facilitates the photo-geological mapping of geological structures and their included zones of sulphide mineralization.

4.2.2 Interpretation of total field isomagnetic contour maps and colour applicon plots of total field and vertical aeromagnetic gradient

The general procedure followed in interpretation of various aeromagnetic products for mapping of lithological/structural trend lines and other lineaments is outlined below -

4.2.2.A Interpretation of isomagnetic contour maps

The interpretation of isomagnetic contour maps has been carried out following these steps.

1. Colouring of these maps by selecting a contour interval as well as a colour scheme which enhances the geological features in greatest details. The contour interval and colour scheme adopted was as follows -

Less than 2300 gamma values	blue colour
Between 2300 to 2500 gamma values	yellow colour
Between 2500 to 2700 gamma values	pink colour
Between 2700 to 3500 gamma values	green colour
More than 3500 gamma values	brown colour

2. Since isomagnetic contours are roughly parallel to gross compositional layering they have been used in outlining the general trend lines of these lithologies. This demarcation of trend lines in the entire study area has in turn brought out certain large scale geological structures which were apparently not observed by earlier workers and are discussed in this chapter under the heading synthesis and discussions.

4.2.2.B Interpretation of colour applicon plots of total field

The colour applicon plots of the total field which are interpreted during the present integrated study were compiled by the Geophysical Data Processing Section of the Geological Survey of Canada. The individual plots have

positive magnetic values from 61175 gammas to 64000 gammas, normal magnetic values from 61150 to 61175 gammas while negative values were between 61150 and 60100 gammas. Their interpretation has also been carried out with the primary aim of outlining lithological/structural trend lines, tracing of faults, shear zones and bands of high positive values by using the following steps.

1. Since the colour applicon plots were devoid of topographic information and had only coordinates marked, the first step was to trace the outlines of lakes and important cultural features like settlements and the coordinates from 1:50,000 topographic maps on transparent overlays. The applicon plots were also on the same scale so it was easy to match the coordinates and thus direct interpretation was possible on these overlays. These overlays with interpreted data were then reduced to 1:100,000 scale and final tracing was done as shown in Map 4.

2. The following characteristics of anomalies have been used for delineating the lithological/structural trend lines.

(a) The trend lines are drawn parallel to the lines marking the changes from one magnetic value to another magnetic value.

(b) By joining the elongated anomalies in the direction of their long axes.

(c) Since the colour scheme adopted in these colour applicon plots has paler colours for normal magnetic values and darker colours for higher magnetic values demarcation of trend lines was facilitated by these contrasting colour differences.

3. Faults and lineaments are recognized by -

(a) Abrupt change in the colour characteristic of particular magnetic values along straight or slightly curved lines.

(b) Noticeable displacement of magnetic anomalies.

(c) Since most of the fault zones in the area are characterized by lower magnetic signatures due to shearing and alteration than the enclosing rocks, they have been discerned by lighter tones along straight lines in darker areas (Figs. 4(iii) and 4(iv)).

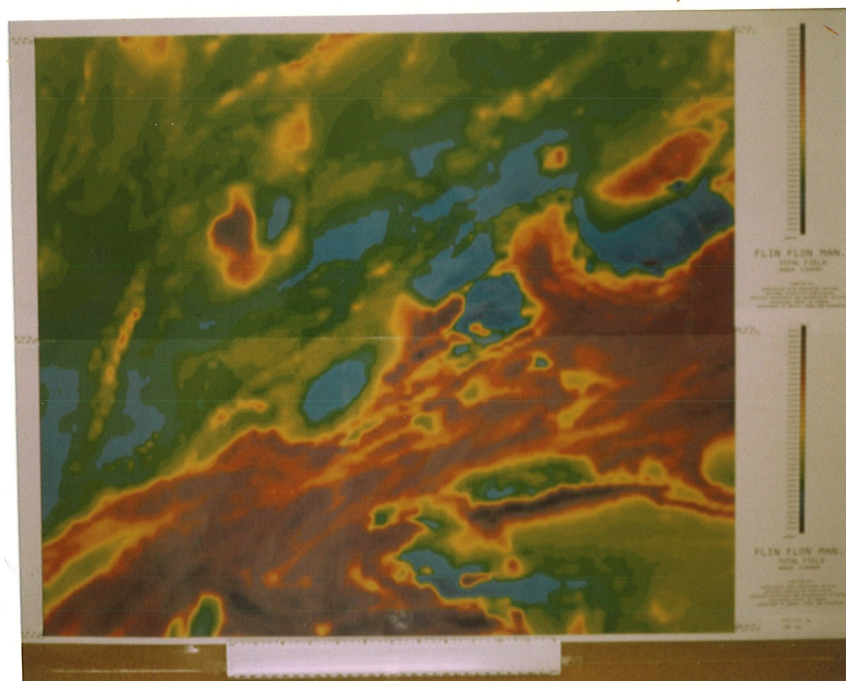


Fig. 4(iii). Photograph of the colour applicon plot of the total field aeromagnetic data SE of Flin Flon showing straight NE - SW trending faults and lineaments.

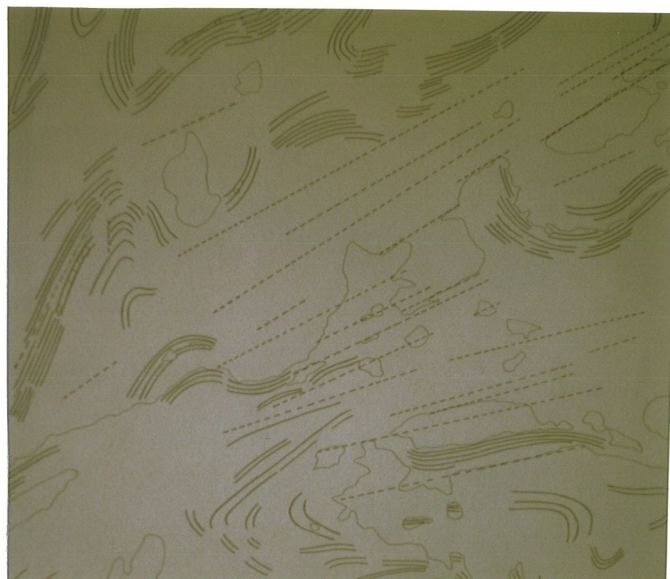


Fig. 4(iv). Interpretation of the colour applicon plot shown in Figure 4(iii). The NE - SW trending faults and lineaments are shown by dashed lines and lithological/structural trends are shown by solid lines.

4.2.2.C Interpretation of colour applicon plots of vertical aeromagnetic gradient

Colour applicon plots of aeromagnetic vertical gradient which have been interpreted during this study were also compiled by the Geophysical Data Processing Section of the Geological Survey of Canada. The plots have magnetic values plotted in gammas/metre and they range from 0.000 to 7.000 for positive magnetic values and 0.000 to -10.000 for negative values. Their interpretation has also been carried out with the main aim of tracing structural/lithological trend lines; demarcation of faults and shear zones, dykes and bands of high positive values. The adopted procedure is outlined under the following steps -

1. The first step was exactly similar to the one followed for interpretation of colour applicon plots of total field mentioned earlier in Section 4.2.2.B.
2. The lithological/structural trend lines were traced using the following parameters.
 - (a) Trends of changes from one magnetic value to another magnetic value. Here both positive and negative magnetic values are used.

- (b) Trend lines joining small elliptical string of bead like anomalies which are aligned in a particular direction.
- (c) By joining elongated anomalies in the direction of their long axes.

3. Faults and lineaments are mainly recognized by following the same parameters used in interpretation of colour applicon plots of total field which are mentioned earlier in Section 4.2.2.B.

4.3 ELECTROMAGNETICS

4.3.1 General

Electromagnetic prospecting techniques are most commonly used in exploration for conducting sulphide mineral deposits. The Flin Flon - Snow Lake study area has been explored by several mining companies by using various ground and airborne electromagnetic systems. During the present study only the interpretation of colour applicon plots of VLF total field and quadrature data is attempted in the western half of the study area. The principal aim of using this data is to evaluate it for economic geological mapping of lithological/structural trend lines and how best this data can be integrated with

the data obtained by other spectral and geophysical remote sensing techniques.

As the name implies, the Very Low Frequency, method involves the propagation of time varying, low frequency (in comparison with radio frequencies) electromagnetic fields in and over the earth. There is a close relationship between the transmitter, receiver and the buried conductor in the electromagnetic situation. Radio transmission stations in the Very Low Frequency range of 5-25 kHz are used as transmitters and an aircraft mounted detector receives its transmitted signal. The VLF antenna is effectively a grounded vertical loop, several hundred feet high. Consequently it is much shorter than a transmission wavelength which for a frequency of 20 kHz, is 15 km. whereas the small loop is equivalent to a magnetic dipole, the short loop behaves as an electric dipole and the electric field component is practically vertical. The magnetic field lines are horizontal circles concentric about the antenna; at distances of several hundred kms the field is practically uniform over a large area and is at right angles to the station direction.

A world-wide network of high power VLF stations are located for marine navigation. The sites are arranged

in such a way that at least two stations can be detected anywhere over the earth's surface. The receiver for detecting VLF signals measures the total field and a quadrature component by means of two mutually perpendicular coils wound on ferrite cores.

4.3.2. Colour applicon plots of VLF total field and quadrature data

The data shown on these plots represents the vector sum of the longitudinal, lateral and vertical components in case of VLF total field and quadrature component of vertical anomalous component in case of VLF quadrature data of the anomalous field. This field is generated by currents flowing in near surface conductive material within or on the earth's crust measured with a Totem 1AEM receiver. The primary field was generated by the VLF navigational station at Cutler, Maine; operating at 17.8 kHz. The data has been filtered using the Fraser coefficients which effectively computes an averaged slope of the measured field, thus centering the anomalies over conductors.

The airborne survey and digital compilation was carried out by the Geophysical Data Processing Section of the Resource Geophysics and Geochemistry Division of

the Geological Survey of Canada. The survey was carried out in June 1980. These maps were compiled using the following computer automated techniques. Very Low Frequency total field digital data values were interpolated from the flight line data at the nodes of a regular grid covering the survey area. Each grid cell was 0.08 cm square. The colour code was assigned to each cell according to the amplitude of the VLF electromagnetic value within the cell using the colour scale as shown in the legend of the maps. The data matrix was output on an applicon colour jet plotter to produce coloured maps, photocopies of which are shown in Figures 4(v) and 4(vi).

In the case of the VLF total field the values were plotted as percentages and are related to increasing conductivities and correspondingly darker reddish tones in the applicon plots. The positive values range from 0% to 180% while negative values are from 0% to 190%. In the VLF quadrature applicon plot the increasing quadrature components are represented by darker bluish tones so that the positive values of VLF total field appear as negative values and negative values as positive ones. Furthermore in quadrature plots the values are also compressed so that they range from 0% to 90% in case of positive values and 0% to -100% in case of negative values.



Fig. 4(v). Photograph showing colour applicon plot of the VLF total field of the area East of Flin Flon. Positive conductivities are indicated by darker reddish tones and negative values by bluish shades.

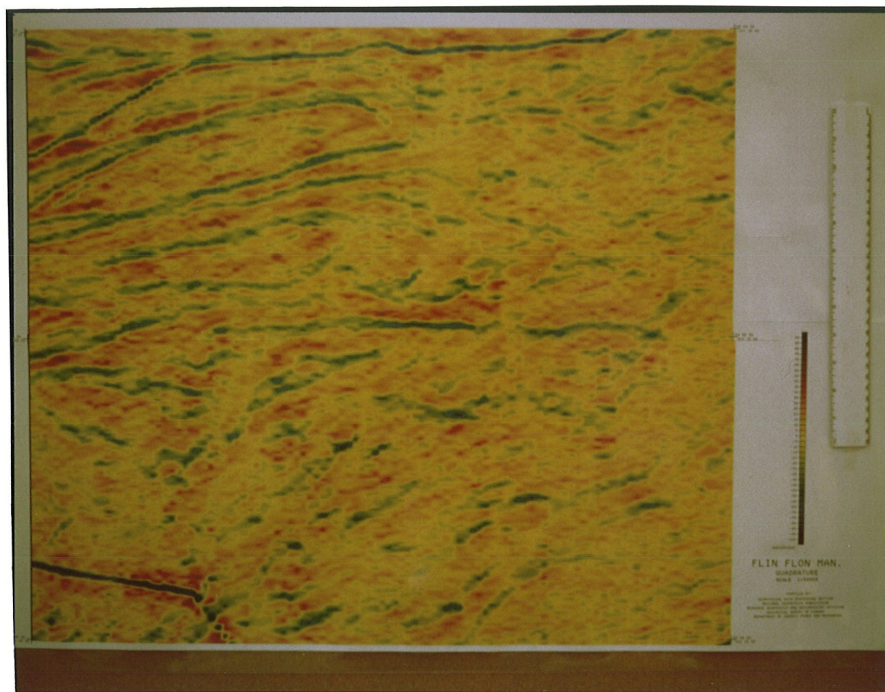


Fig. 4(vi). Photograph showing colour applicon plot of the VLF quadrature component of the same area as shown in Figure 4(v). Here positive conductivities are indicated by bluish shades while negative conductivities are shown by reddish shades. The transmission lines are seen in the extreme northern and south eastern parts of the area.

The main approach adopted in interpreting the VLF applicon plots was the following:

1. Since these applicon plots are devoid of topographic information and had only coordinates marked, the first step was to trace the outlines of lakes and important cultural features like settlements and coordinates from 1:50,000 topographic maps on a transparent overlay.
2. Interpretation proper started with outlining the areas having very high conductivity values above the 90% value which is half of the total range of positive values and are coloured light blue. Furthermore areas lying between positive values from 0% to 90% have been coloured green while areas of negative values have been kept blank as shown in Figure 4(vii).
3. It has been noticed that some of the highly conductive anomalies are related to cultural features like transmission lines and railway tracks. These anomalies are identified throughout the whole area and are isolated by assigning a green colour to them after erasing the blue colour from these areas.
4. Anomalies lying over areas covered by lakes have been identified and left with original blue colour because they

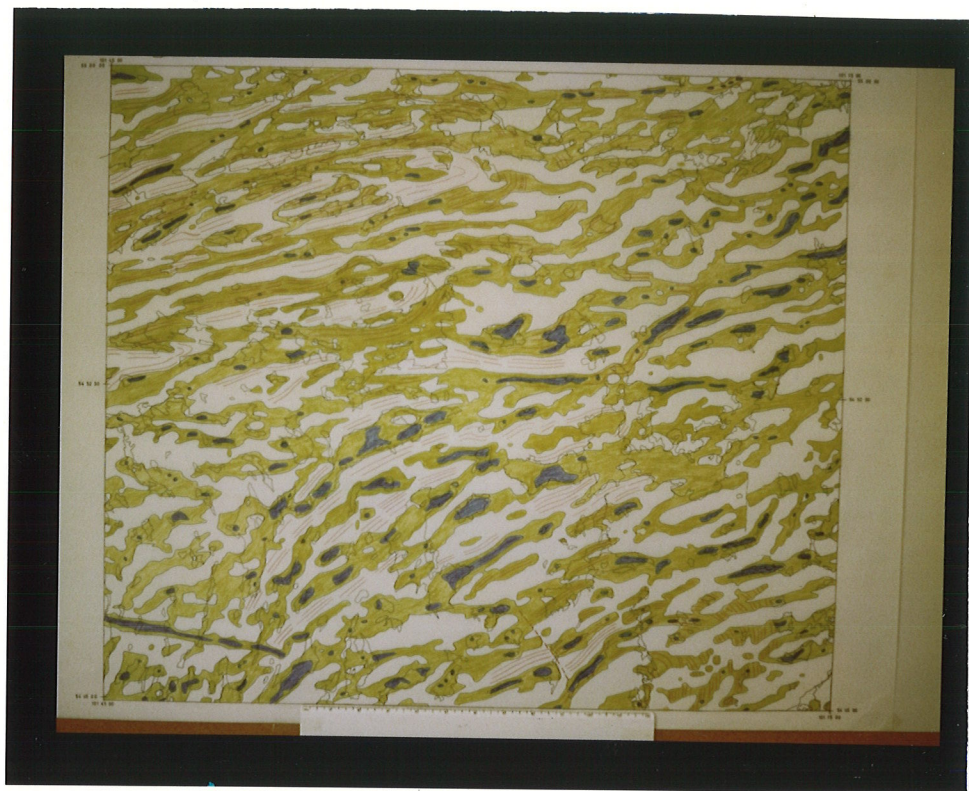


Fig. 4(vii). Interpreted map from the colour applicon plot of the VLF total field of the area East of Flin Flon as shown in the Figure 4(v). The areas shaded with pale green colour are having the range of 0% to 90%, blue ones are having high conductivities over 90%. The red lines are indicating the trends of these anomalies.

are most probably caused by conducting clays deposited in lake bottoms.

5. Anomalies which are related neither with the lakes nor with the cultural features have been filtered out and were assigned a red colour (Fig. 4(viii)).

6. Records showing the mining claims have been consulted and it has been found that most of the red coloured anomalies lie over areas claimed and drilled by various parties. This indirectly confirms that these anomalies may be related to conducting sulphide zones.

7. After identification mapping of these anomalies which perhaps represent conducting sulphide zones has been carried out by using -

(a) Very Low Frequency total field and quadrature data - these data have been helpful in tracing the extension of stratabound sulphide zones by using trends of various conductivities which roughly correspond with lithological/structural trend lines and are marked by red in Figure 4(ix).

(b) Data from various aeromagnetic products which are discussed earlier in this chapter were helpful in tracing the extensions of these conductive zones.



Fig. 4(viii). Map showing EM anomalies of various types, the green ones are associated with transmission lines or railway tracks, blue ones are related mainly to the conductive clays at the lake bottoms and red ones are generally associated with the conductive zones of probable sulphide mineralization.

(c) Photointerpretation data - when photointerpretation data is plotted on the same tracing film it was not only possible to see the extensions of these zones but also the complete pattern connecting these individual zones.

4.4 SYNTHESIS AND DISCUSSIONS

After individual interpretation of aeromagnetics which included total field isomagnetic line contour maps, colour applicon plots of total field and vertical gradient and electromagnetics using VLF total field and quadrature, the interpreted data is plotted on individual compilation maps and has been critically examined along with the original products. The main purpose of doing this was to bring out the interrelationship between various aeromagnetic and electromagnetic products and their usefulness in identification and mapping of various geological aspects. The results obtained from this study are summed up in the accompanying Table 4(1). This was followed by studying aeromagnetic and airborne electromagnetic data in conjunction with the data obtained from spectral remote sensing. The important points which have emerged from this integrated study are as follows -

1. The most striking characteristic of the magnetic field in the Amisk Lake - Wekusko Lake area is that the magnetic

trends generally follow the original lithological banding. While in the field and by photogeological mapping this banding is generally masked by development of strong axial plane cleavage and schistosity and several sets of fracture planes associated with deformational events and Quaternary glacial trends. Therefore aeromagnetism, especially the vertical gradient greatly facilitates recognition of these lithological trends from other trends.

2. Furthermore aeromagnetism helps in mapping lithological trends below the lakes and swamps and the Palaeozoic sedimentaries and Quaternary sediments. Nearly all the southern half of the shield area shown in the colour applicon plots of the total field and vertical aeromagnetic gradient in Figures 4(ix) and 4(x), is covered by the Palaeozoic carbonate sedimentaries which are nonmagnetic and act like a transparent screen for magnetic values. The lithological/structural trends of Precambrian rocks can still be mapped by interpreting the applicon plots as shown in Maps 4 and 5.

3. It has been found that the integration of interpreted data from Landsat images and total field aeromagnetic colour applicon plots is extremely useful for small scale geological view. On the other hand, for detailed geological mapping of lithological/structural trend lines it has been concluded

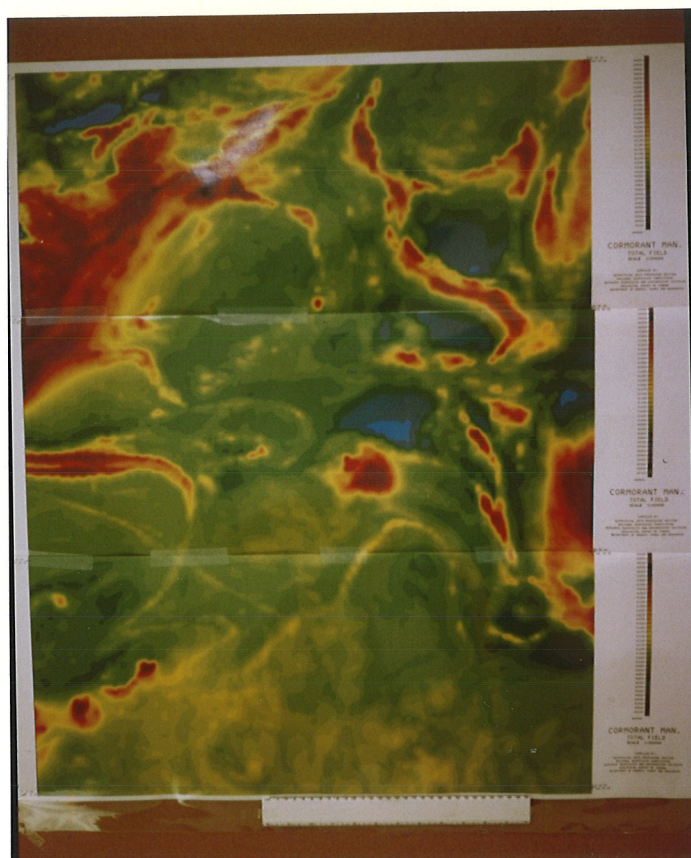


Fig. 4(ix). Photograph of the total field aeromagnetic colour applicon plot of the Cormorant Lake area East of Cranberry Portage.



Fig. 4(x). Photograph of the vertical aeromagnetic colour applicon plot of the same area shown in Figure 4(ix).

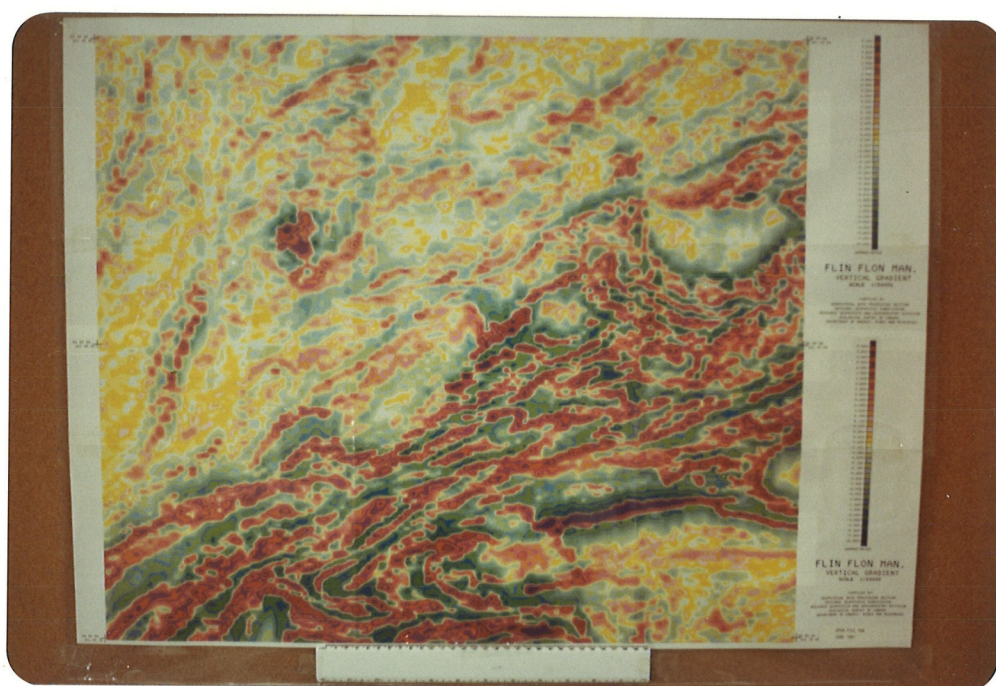


Fig. 4(xi). Photograph of the colour applicon plot of the vertical aeromagnetic gradient of the area SE of Flin Flon shown in the Figure 4(iii).

that better integration is possible when data from the aerial photographs and the vertical aeromagnetic gradient is used.

4. From the structural geology point of view the area is complexly folded by at least two episodes of folding.

This is apparent mainly due to -

(a) Outcrop pattern of the mafic flow units conspicuously standing out due to high magnetite content (Figs. 4(ix) and 4(x)).

(b) Presence of a number of structural domes and plunging anticlines and synclines as interpreted in Maps 4 and 5.

5. The nature of the magnetic field in the Flin Flon - Snow Lake greenstone volcanic belt changes dramatically across the Kisseynew front into the Kisseynew sedimentary gneiss belt in the area North of Flin Flon. The magnetic patterns in the Flin Flon - Snow Lake greenstone belt are very complex representing a typical example of a polyphase deformed greenstone belt, whereas in the Kisseynew sedimentary gneissic belt the patterns are much simpler, corresponding to elongated domal features trending more or less in an E-W to ENE - WSW direction exactly matching those obtained by photointerpretation. Furthermore, the

trends on the two sides of this front show abrupt truncations. Since magnetic anomalies are invariably related to the distribution of different rock types, the zone of change-over appears to be related to a major structural discordance. This is further substantiated by a clear-cut change-over in the style of folds and deformational behaviour (Figs. 4(i) and 4(ii) and their corresponding interpretations on Maps 4 and 5). The rest of the Kisseynew sedimentary gneissic belt is represented by a series of comparatively narrow linear to curvilinear parallel highs and lows. Intensities within the highs are generally lower than those observed within the Flin Flon - Snow Lake volcanic belt.

6. The geology of the Flin Flon - Snow Lake greenstone belt is very complex and many of the large scale geological structures are not apparent in existing geological maps because they tend to be lost in a maze of geological details. The interpretation of 1:100,000 scale isomagnetic contour maps reveals that much of the western half of the study area is occupied by a large folded structure which has its closure in a north easterly direction Figure 4(xii). Furthermore this aeromagnetic interpretation has also



Fig. 4(xii). Photograph of coloured isomagnetic
contour map.

demonstrated that the northern limb of this fold structure seems to be laterally disconnected due to stretching into a number of circular, elliptical and elongated geological structures having very high positive magnetic signatures. Effects of later more or less N-S cross folding on these structures is also conspicuously seen.

7. Large, more or less circular to elliptical low magnetic areas correlate well with the terrain underlain by rocks of granitic composition. On the other hand, remarkable correspondence between high magnetic values and greenstone bands and their metamorphic equivalents is observed in the Flin Flon - Snow Lake volcanic belt. Locally, magnetic highs are also associated with gabbroic sills, iron formations and dykes.

8. Although vertical aeromagnetic gradient applicon plots are far superior than the total field applicon plots as far as mapping of lithological/structural trend lines are concerned better definition of faults and fractures are observed in total field applicon plots (Figs. 4(iii), 4(iv) and 4(xi)). It is therefore recommended that vertical gradient applicon plots should be used in conjunction with total field applicon plots for economic geological mapping of stratabound deposits.

9. Among electromagnetic VLF total field and quadrature applicon plots it has been concluded that the VLF quadrature applicon plots are better than VLF total field in the following ways -

- (a) The anomalous conductive zones are better defined.
- (b) Anomalies associated with cultural features like transmission lines and railway tracks are also better defined.
- (c) The overall outcrop pattern is better displayed, (Figs. 4(v) and 4(vi)) and coincides with aeromagnetic and photointerpretation data.
- (d) The apparent depth of penetration below the Palaeozoic carbonate sedimentaries is more and consequently the definition of anomalies is also sharp, Figures 4(xiii) and 4(xiv).

10. Although the applicon plots of VLF total field and quadrature data are not of much use in mapping the lithological/structural trend lines, they are of great help in isolating zones of high conductivities which are likely to be related to sulphide mineralization.



Fig. 4(xii). Photograph of the colour applicon plot of the VLF quadrature data of the area South of Cranberry Portage which is entirely covered by moderately thick Palaeozoic sedimentaries.

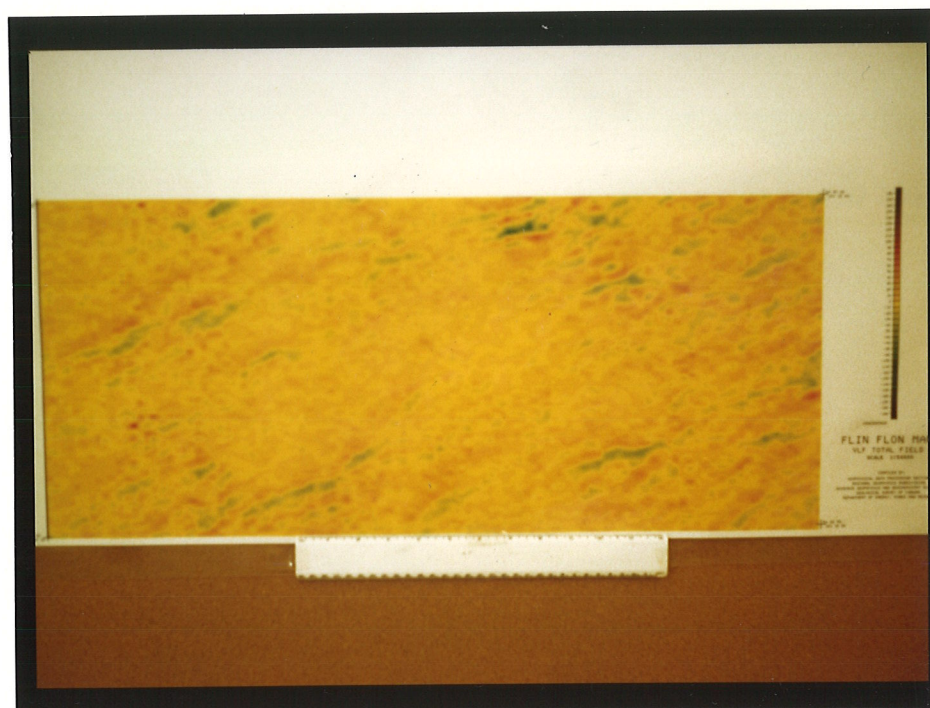


Fig. 4(xiii). Photograph of the colour applicon plot of the VLF total field data of the same area shown in Figure 4(xii).

Table 4(1)
Airborne Geophysics Products

Geological Aspects	Aeromagnetics					Electromagnetics		Spectral Remote Sensing Data	Best results by integrating
	Total field contour map	Colour Applicon Plot of Total Field	Colour Applicon Plot of Vertical Gradient	Colour Applicon Plot of VLF (Total Field)	Colour Applicon Plot of VLF (Quadrature)				
		(1)	(2)	(3)	(4)	(5)	(6)		
1. Mapping of Lithological trends	++	++	++++	+	+	++++	3 & 6		
2. Identification of gross lithological units	+++	+++	++++	-	+	++++	3 & 6		
3. Identification of faults and shear zones	+	++++	+++	+	+	++++	2 & 6		
4. Identification of basic or acidic intrusive bodies	+++	+++	++++	-	-	++	2 & 3		
5. Mapping of geology below lakes and swamps	+++	+++	++++	+	+	-	1,2 & 3		
6. Mapping of geological trends below Palaeozoic & Quaternary overburden	+++	+++	++++	-	+	+	2,3 & 6		
7. Identification of conducting sulphide zones	-	++	+	+++	++++	-	2,4 & 5		

Key: - poor + fair ++ good
 +++ very good ++++ excellent

5.0 APPLICATION OF INTEGRATED REMOTE SENSING TECHNIQUES FOR ECONOMIC GEOLOGICAL MAPPING AND EXPLORATION OF MINERAL DEPOSITS

5.1 GENERAL

This chapter describes the geological application of various airborne spectral and geophysical remote sensing techniques and also formulates an integrated approach for economic geological mapping and exploration of stratabound mineral deposits. Integration of interpreted data from the aerial photographs, enhanced Landsat imagery and airborne geophysical data namely total field and vertical gradient aeromagnetics and VLF electromagnetics has yielded significant results in the Amisk Lake - Wekusko Lake study area. The Flin Flon - Snow Lake greenstone belt of this area hosts numerous occurrences of copper and gold which are presently being mined or have been periodically mined since the beginning of this century. Mapping of lithological/structural trends using airborne spectral and geophysical techniques has provided an excellent tool for mapping and exploration in this belt. Spectral remote sensing techniques alone have helped in mapping of strata but when integrated with airborne geophysical techniques it was possible to map these strata with more certainty.

In areas covered by lakes and swamps, Palaeozoic sedimentary rocks and Quaternary overburden the strata may be grouped in broad categories of mafic as well as felsic rich components. VLF applicon plots have helped a great deal in isolating various conductive zones.

Of prime importance in exploration has been recognition that the copper deposits as well as the gold deposits are primarily stratabound and that it is possible to map these containing strata by various airborne spectral and geophysical remote sensing techniques. Integration of these techniques has suggested an exploration tool in the search for mineralized zones in the Amisk Lake - Wekusko Lake area which could also be applied to other comparable areas of the Canadian Shield. The various maps provide an overview of a complicated outcrop pattern and an information base that might be utilized by exploration geologists and geophysicists to aid in formulation of their exploration strategies.

5.2 MINERAL DEPOSITS OF THE AREA

Copper and gold mineralization in the Amisk Lake - Wekusko Lake area has been known since the turn of the century and up till now more than 50 individual occurrences of copper and gold have been reported. At present it is

generally believed by most of the workers that volcanic exhalative theory satisfactorily explains the origin of known copper deposits (Sangster, 1972). The present study suggests that the gold deposits may also be stratabound on a megascopic scale.

In recent years a considerable amount of exploration has been directed to volcanogenic stratabound deposits. It is partly due to their higher grade than other types of deposits which provides a rapid return on lower developmental expenditure. Furthermore because of their syngenetic origin and stratabound nature their exploration is considerably easier. The present study was undertaken to map the original lithological/structural trends and other lineaments which occasionally displace them by using various airborne spectral and geophysical remote sensing techniques. Mapping of these trend lines by these techniques is cost effective and better suited for stratabound deposits than conventional field methods.

The Flin Flon - Snow Lake greenstone belt can be classified into two broad mutually gradational groups on the basis of the economic significance.

A. Mafic volcanics which tend to occupy the lower parts of the stratigraphic succession and with which most of the

gold occurrences are associated.

B. Felsic volcanics which tend to occupy the upper parts and with which most of the copper occurrences are associated.

5.2.1 Copper Deposits of the Area

The copper ore deposits of the Flin Flon - Snow Lake volcanic belt are massive, stratiform and stratabound and they are closely associated with the felsic volcanism. Sangster (1972) considered the massive copper-zinc sulphide deposits of this belt to be a good example of volcanogenic deposits, because of their volcanic host rocks, internal metal zoning, stratiform and stratabound character, foot-wall stringer ore and $Mg(Fe)$ alteration. He also considered that this kind of deposit forms largely as a sub-aqueous sulphide sediment, over or close to a volcanic fumarole, exhaling metal rich brine. This origin is widely accepted for the massive Cu-Zn sulphide ore deposits of the Flin Flon - Snow Lake volcanic belt.

Most of these stratabound volcanogenic sulphide occurrences in the Flin Flon - Snow Lake greenstone belt appear to occupy approximately the same stratigraphic level in the sequence. Accordingly it seems likely that

these mineral occurrences are collectively related to a single widespread mineralizing event. Studer (1982) observed that all the known copper deposits in the area occur in felsic rocks a short distance below the contact with an overlying mafic rock unit.

5.2.2 Gold Deposits of the Area

The distribution pattern of the gold deposits has been studied to assess the relationship of gold occurrences with the lithological/structural trends of the rock units, their magnetic signatures, nature of rock types and lineaments indicating shear zones, faults and fractures to find out whether gold is stratabound or related to the hydrothermal regime in the Flin Flon - Snow Lake greenstone belt. When various gold occurrences have been plotted on the Maps 1, 2, 3, 4 and 5 showing lithological/structural trends and other lineaments derived from spectral as well as airborne geophysical remote sensing, a close spatial relationship is found between the lithological/structural trends and the gold occurrences in the area. Secondly these occurrences do not appear to be even distantly related to the lineaments like shear zones, faults and fractures. Furthermore it has been observed that the gold occurrences are mainly

related to the mafic flow horizons which are characterized by the strong magnetic signatures.

These facts suggest that the gold is stratabound at least on a megascopic scale. On a macroscopic scale, however, gold apparently occurs in high concentration in quartz carbonate veins which occupy minor fractures and faults developed mainly in the competent members, which are mainly mafic flows of the volcano-sedimentary sequence of the Flin Flon - Snow Lake greenstone belt. Similar occurrences of gold deposits have been observed in the Rice Lake - Beresford Lake area in the southern Manitoba where Stephenson (1971) also recorded a close spatial association between mafic flows and gold rich quartz veins. Association of gold rich quartz veins and mafic flows has also been reported from various shield areas of the world. Woodall (1965) noted that many gold quartz veins in the Archaean of western Australia are closely associated with metabasalts or quartz diabase. Similarly gold deposits of the Archaean gold belts of Zimbabwe and the Transvaal, South Africa and Kolar gold fields of Southern India are hosted by the pillowed basalts or their schistose equivalents (Swift, 1951 and Narayanswami, 1963).

The present work illustrates that the primary source of the gold in the area is the mafic flow horizons and it is during their metamorphic differentiation which accompanied main metamorphic event, has given rise to gold rich quartz carbonate veins by lateral secretion which have got emplaced preferentially along the fracture pattern in these rocks. This clearly explains their close spatial stratabound association with mafic flows on megascopic scale and occurrence of gold quartz veins which are hydrothermal in nature on a macroscopic scale.

The hypothesis that wall rocks may have supplied the bulk of the vein material by lateral secretion is not new and was proposed by many earlier workers in various parts of the world. Lindgren (1906) advanced this hypothesis to explain the Archaean gold deposits of western Australia. A similar mechanism was proposed for the gold-quartz veins of the "Mother Lode System" of California (Knopf, 1929), the gold deposits of the Uchi greenstone belt of Ontario (Bateman, 1940) and Yellowknife gold deposits, Northwest Territories (Boyle, 1955).

At present most of the gold production in Manitoba comes as a byproduct of copper refining. Presence of gold in these stratabound massive sulphide deposits which

are believed to be of volcanogenic exhalative type is of genetic significance and further suggests that the gold in the area is also stratabound. In case of the Flin Flon - Snow Lake greenstone belt there seems to be two broad alternatives. Firstly, the gold may have been added either before or subsequent to the formation of an exhalative copper ore body by separate ore forming process. Secondly, the gold may have been deposited coevally with the copper minerals from the same metalliferous fluids. Thus from logical rather than geological evidence the presence of a minor amount of gold in stratabound copper deposits is believed to be of genetic significant and suggests that gold is also stratabound like the copper deposits.

5.3 ECONOMIC GEOLOGICAL MAPPING AND EXPLORATION OF MINERAL DEPOSITS

Economic geological mapping and exploration, where mineral deposits are stratabound, generally comprises following objectives -

1. Detailed mapping of the trends of various strata
2. Grouping of these strata into various lithological categories

3. Mapping of faults and shear zones which could possibly displace these strata
4. Deriving the extensions of the known mineralized zones and the connections between various zones
5. Identification of new suitable environments of mineralization
6. Tracing of the extensions of these suitable environments of mineralization

The various study methods consistent with these objectives used to produce economic geological Maps 6, 7, 8 and 9 include the following:

- A. Visual interpretation of aerial photographs, Landsat images and enhancement products of Landsat digital data
- B. Visual interpretation of colour applicon plots of vertical gradient and total field aeromagnetic data
- C. Visual interpretation of colour applicon plots of VLF total field and quadrature electromagnetics
- D. Plotting of the known occurrences of the mineralized zones

- E. Demarcation of the extensions of these zones
 - F. Ground truth collection to see whether alteration zones exist along these extensions
 - G. Synthesis and presentation of data
- A. Visual Interpretation of aerial photographs, Landsat images and enhancement products of Landsat digital data

This part of the study methods has been discussed in detail in Chapter 3. The main objective behind the visual interpretation was mapping of the lithological/structural trends of various rocks and other lineaments such as faults, shear zones, joints and fractures. Lithological trends of various rock units are characterized by subtle original colour banding Figure 5(i) or by the alteration bands along the original bedding surfaces Figure 5(ii). Even more or less massive rocks of the area show faint banding pattern Figure 5(iii) which can be seen on aerial photographs quite easily. A micro relief is invariably developed along these lithological trends due to variable resistance to erosion and this micro relief has greatly facilitated their mapping Figures



Fig. 5(i). Field photograph showing primary lithological banding which gives rise to subtle tonal variations in aerial photographs.



Fig. 5(ii). Field photograph showing alteration bands along original bedding surfaces of the rock.



Fig. 5(iii). Field photograph showing faint banding pattern in the rock.

3(i) and 3(ii).

The lineaments such as faults, shear zones, joints and fractures are mapped by their following visual expressions.

- (i) Abrupt, sharp and angular breaks in the drainage patterns
- (ii) Abrupt termination of drainage lines
- (iii) Long, straight or curved stream segments
- (iv) Alignment of several topographic features along straight lines
- (v) Abrupt changes in surface radiance producing tonal changes
- (vi) Straight, persistent cliffs or escarpments
- (vii) Straight or curved breaks in otherwise unbroken topography
- (viii) Displacement of strata along straight lines
- (ix) Termination of strata along straight lines
- (x) Change in the style of folds along straight lines

These visual expressions when found in conjunction with few others have improved the level of confidence in their mapping.

B. Visual Interpretation of colour applicon plots of vertical gradient and total field aeromagnetic data

The various criteria and steps used in their interpretation for mapping of lithological/structural trend lines and lineaments like faults, shear zones, joints and fractures have been discussed in detail in Section 4.2.2 of Chapter 4.

C. Visual Interpretation of colour applicon plots of VLF total field and quadrature electromagnetics

The main approach adopted for the interpretation of these applicon plots for isolating the conductive zones of economic geological interest has been discussed in Section 4.3.2 of Chapter 4.

D. Plotting of known occurrences of the mineralized zones

The locations of various known copper and gold deposits has been taken from Manitoba Mines Branch Map ER 79-6-4 East and West parts which accompany Economic Geology Report 79-6.

E. Demarcation of the extensions of these zones

Once the locations of various copper and gold deposits has been plotted on the interpreted data from spectral remote sensing and airborne geophysics their extensions as well as connections with the nearby deposits have been traced following the lithological/structural trends. In the same way extensions of conductive zones obtained from VLF plots have also been demarcated.

F. Ground Truth collection to see whether alteration zones exist along these extensions

In field the main emphasis was to see whether alteration zones such as gossans exist along the extensions of these mineralized zones. Along several of these extensions alteration zones, Figure 5(iv) have been noticed and in certain places excavations and drilling has been done by various exploring agencies, Figure 5(v).

G. Synthesis and Presentation of data

The data is presented in the Maps 6, 7 and 8 on a reduced scale of 1:250,000.

In exploration for gold deposits the various remote



Fig. 5(iv). Field photograph showing alteration zone also the strike extension of known deposit.



Fig. 5(v). Field photograph showing large alteration zone by reddish brown colour. The yellowish brown colour in the lower part of photograph is the colour of excavated rock.

sensing techniques discussed above have not yet found direct application simply because the economic quantities of gold present in a rock are so minute that they do not change the physical properties of the host rock to any measurable extent. The present work has, however, suggested several indirect approaches which might be used as part of an exploration strategy. These more or less follow the steps A to G. The only additional points which should be mentioned.

1. Since gold is found to be stratabound on a megascopic scale and the trends of these strata can successfully be mapped by various spectral and geophysical remote sensing techniques, it has been found that the extensions as well as relations with other known deposits can be established.

2. Gold is found to be mainly associated with mafic flow horizons which have characteristically strong magnetic signatures and it has been found that these bands can be mapped by using aeromagnetic data especially vertical gradient applicon plots.

3. Situations where gold is associated with copper mineralization in appreciable quantities, it is possible

to detect first the copper mineralization by electromagnetic surveying techniques.

5.4 ECONOMIC GEOLOGICAL MAPPING OF PRECAMBRIAN ROCKS BELOW THE COVER OF PALAEOZOIC SEDIMENTARY ROCKS AND QUATERNARY OVERBURDEN

More than 60% of the Canadian Shield is covered by various types of cover, which includes Palaeozoic sedimentary rocks, Quaternary glacial material and innumerable lakes. In this section an attempt has been made to do economic geological mapping of the Precambrian rocks by integrating the interpreted data obtained from spectral and geophysical remote sensing. This integration has yielded significant results in a test area of about 3000 sq. km south and southeast of Cranberry Portage.

The aim was to find out how far various remote sensing techniques and their integration could be used for unravelling the lithological/structural trends and other lineaments below the cover of Palaeozoic sedimentary rocks and Quaternary glacial material especially for those who are involved in prospecting in these areas. Since mapping of lithological/structural trends and other lineaments has demonstrated applicability in the exploration

of stratabound deposits, an attempt has been made to trace these features below a moderately thick Palaeozoic cover. This mapping is likely to help various exploration geologists and geophysicists by highlighting the cause of the geophysical anomalies, tracing their extensions, making coherent and sensible patterns out of scattered anomalies and by providing more promising targets for drilling.

As has been discussed in this chapter, that the lithological/structural trends and other lineaments derived from the interpretation of aeromagnetic data are very closely related to the lithological/structural trends and other lineaments interpreted from spectral remote sensing techniques. This applies not only to exposed areas but also to areas covered by lakes, moderately thick Palaeozoic sedimentary and Quaternary glacial overburden. With increasing thickness of the Palaeozoic sedimentary cover lithological/structural trends become increasingly less obvious, whereas other lineaments such as faults, joints and fractures are evident even through very thick cover perhaps due to repeated small scale movements related to the earth tides. These lineaments are most conspicuously seen in aerial photographs and Landsat imagery and are less conspicuous in vertical aero-

magnetic gradient applicon plots. This necessitates an integrated approach in order to obtain the total structural picture of an area which forms an essential part of the economic geological mapping.

This study of mapping the lithological/structural trends and other lineaments below the Palaeozoic sedimentary and Quaternary glacial cover has highlighted the following aspects.

1. Determining the extent to which these features can be mapped by spectral remote sensing techniques.
2. Determining the extent to which these features can be mapped by airborne geophysical techniques like vertical magnetic gradient and total field applicon plots.
3. Determine how well conductive zones can be detected by airborne electromagnetics like VLF total field and VLF quadrature.

The anomalous magnetic field associated with the Flin Flon - Snow Lake greenstone belt, in the areas south and southeast of Cranberry Portage, which have a moderately thick cover of Palaeozoic sedimentary rocks, is characterized by a complex pattern of lithological/

structural trends. These trends have circular and elliptical shapes which are probably associated with hidden domal structures. Using vertical gradient data the preferential enhancement of near surface geological details makes it possible not only to demarcate the trends of various beds but also important faults. It has also facilitated the interpretation of the postulated extension of the economically important Flin Flon - Snow Lake volcanic belt in the south below the Palaeozoic on the basis of typical structural and magnetic signatures.

The important results of the present study are as follows -

1. Mapping of lithological/structural trends and other lineaments can be successfully carried out when integrated approach to spectral and geophysical remote sensing is applied.
2. Aerial photographs are exceptionally useful in picking up the lineaments like faults, shear zones, joints and fractures because they seem to reflect through the cover probably due to earth tides.
3. Vertical aeromagnetic gradient colour applicon plots are extremely useful in mapping of lithological/structural

trends because the Palaeozoic rocks are non-magnetic and act like a transparent screen.

4. VLF quadrature applicon plots are better than VLF total field in picking up the anomalous conductive zones below the Palaeozoic cover Figures 4(xii) and 4(xiii) and their lateral extensions can be traced by vertical aeromagnetic gradient applicon plots.

5.5 SYNTHESIS AND DISCUSSION

The present study covers a fairly large area of about 11,500 sq. km and provides detailed information regarding outcrop pattern which is crucial in exploration of stratabound mineral deposits. The salient points that have emerged from the present study are as follows.

1. Systematic mapping of lithological/structural trends and other lineaments using airborne spectral and geophysical techniques have provided an excellent tool for mapping and exploration in areas of stratabound deposits.

2. It has now been generally accepted that airborne vertical magnetic gradient data has numerous advantages over the total field aeromagnetic data, and the present work demonstrates their usefulness in economic geological

mapping of various strata and in the exploration for mineral deposits especially the extensions and trends of the mineralized zones.

3. Spectral remote sensing techniques did not prove to be advantageous as a direct prospecting tool for copper and gold deposits, but they have been found to be invaluable for mapping the trends of the strata, which forms the key for the exploration of stratabound deposits.

4. Standard visual interpretation of aerial photographs has been done basically for two reasons. Firstly, it will help in comparing the amount of geological information gathered by this method and other remote sensing techniques including aeromagnetic and airborne electromagnetic interpretation and secondly it will provide relevant geological information in areas for which detailed geological maps were not available. Furthermore, it was expected to provide some additional information in areas which have been mapped in the past without using the aerial photographs. Published geological maps often give very little information about the lithological/structural trends and other lineaments.

5. It has been noticed that there is always a good

correlation between the lithological/structural trends derived from the aerial photointerpretation and aeromagnetics. When a transparent overlay of trends marked from spectral remote sensing is placed over the vertical aeromagnetic gradient applicon plot it was possible to extrapolate these trends from well known areas to less defined areas as well as below the lakes and swamps.

6. Integration of airborne spectral and geophysical remote sensing has highlighted certain interesting geological aspects in the Flin Flon - Snow Lake greenstone belt which have a suggested bearing on the nature of the gold mineralization in the area. Most of the gold deposits are found to be associated with the bands of anomalously strong magnetic signatures which generally represent mafic flow horizons.

7. A close spatial relationship between gold occurrences and lithological/structural trends of mafic flow horizons suggests that the gold is also stratabound on megascopic scale. This is further substantiated by the fact that these occurrences are not even distantly related to major faults and shear zones in the area which could have acted as channels for the movement of gold bearing hydrothermal fluids.

6.0 CONCLUSIONS

The Amisk Lake - Wekusko Lake area is located within the Churchill structural province of the Canadian Shield. The rocks of the area are highly deformed and metamorphosed and broadly belong to the two major groups; the Flin Flon - Snow Lake greenstone belt and the Kisseynew sedimentary gneissic belt. The southern part of the study area is covered by Palaeozoic sedimentary rocks with increasing thickness in a southerly direction. The total area covered during the present integrated study is about 11,500 sq. km. The present study has brought out certain interesting large scale features which have enhanced the understanding of the regional geological setting and the economic mineral deposits of the area. The following conclusions were reached on the basis of the results obtained in this study.

1. For effective and efficient geological surveys of large areas the use of Landsat multispectral imagery is of great help in conjunction with aerial photointerpretation as a first stage rapid mapping technique, most advantageous at small scales or in situations where it is desired to extend an investigation from a known area to an unknown area.

2. Since Landsat images have provided a synoptic view of the area, it was easy to bring out large scale geological structures. It has been found that the eastern half of the study area is occupied by a large folded structure which closes toward the NE direction and the Herblet Lake gneissic dome is situated in the core portion of this structure.

3. Digital images are readily manipulated by the image analysis system to prepare a more effective display of image data for feature extraction. The Landsat digital data carries much more information than the paper print outs. Linear contrast stretch enhancement has been found to be very suitable for mapping of lithological/structural trends and ratio images are very good for mapping of other lineaments. When linear contrast stretch enhancement of ratio data is performed, the mapping of both lithological/structural trends as well as lineaments can be successfully performed.

4. Integration of interpreted data from Landsat images and total field aeromagnetic colour applicon plots is extremely useful for small scale geological view. Conversely, for detailed geological mapping of lithological/structural trends, it has been found that better integration

is possible when data from aerial photographs and vertical aeromagnetic gradient is used.

5. Although vertical gradient plots are far superior than the total field plots for detailed mapping due to better resolution the definition of faults and fractures is very well seen in the applicon plots of the total field. It is therefore suggested that vertical gradient applicon plots should be used in conjunction with total field applicon plots for economic geological mapping of stratabound deposits.

6. The nature of the magnetic field in the Flin Flon - Snow Lake greenstone belt changes dramatically across the Kiseeynew front in the area north of Flin Flon. Spectral remote sensing also suggests distinct lineaments running parallel to this contact.

7. Among electromagnetic VLF total field and quadrature applicon plots, it has been concluded that the VLF quadrature plots have better definition of anomalies than the total field plots. This is not only true for the exposed areas but also areas covered by the Palaeozoic sedimentary rocks.

8. Mapping of lithological/structural trends and other

lineaments can be successfully carried out below the cover of Palaeozoic sedimentary rocks, when an integrated approach of spectral and geophysical remote sensing is applied.

Aerial photointerpretation helped in mapping of lineaments while lithological trends have been drawn from the vertical gradient data.

9. Systematic mapping of lithological/structural trends and other lineaments by integrated methods has provided an excellent tool for mapping and exploration in areas of stratabound deposits.

10. A close spatial relationship between gold occurrences and lithological/structural trends of mafic flow horizons suggests that the gold deposits are also stratabound like the copper deposits. Secondly, the gold deposits are not found to be related to the major faults and shear zones mapped in detail by the remote sensing techniques.

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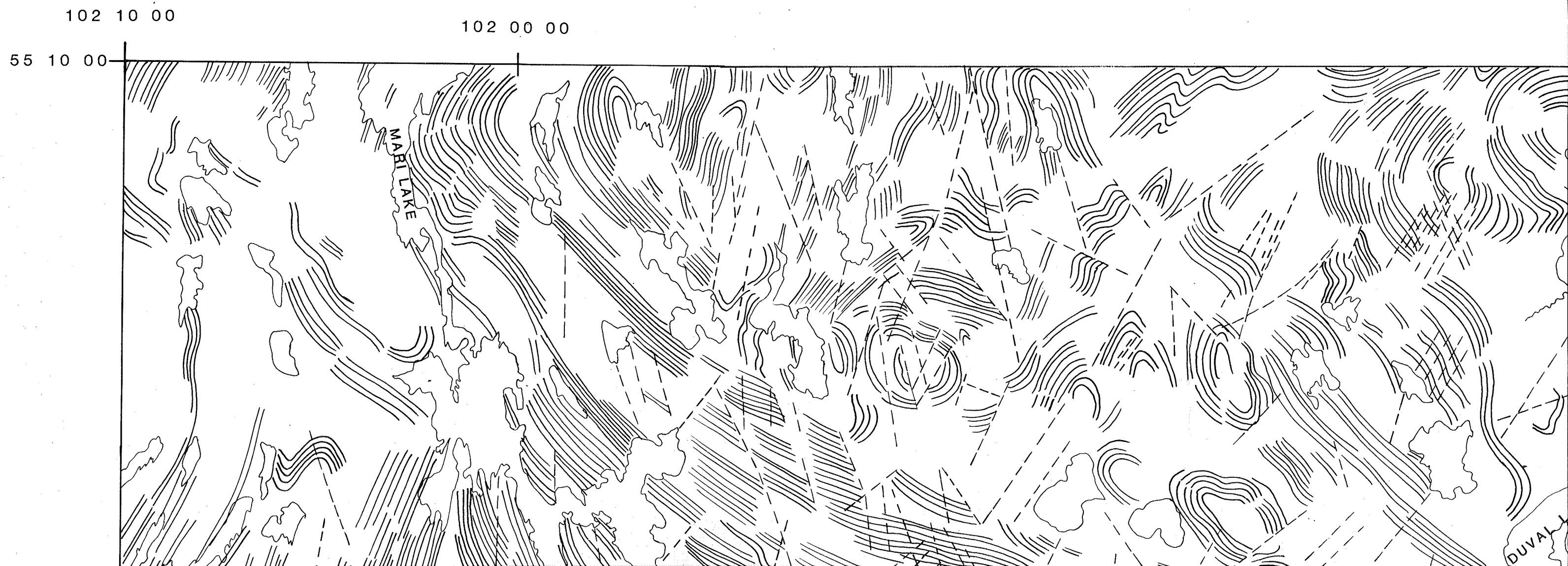
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MAP NO. 1

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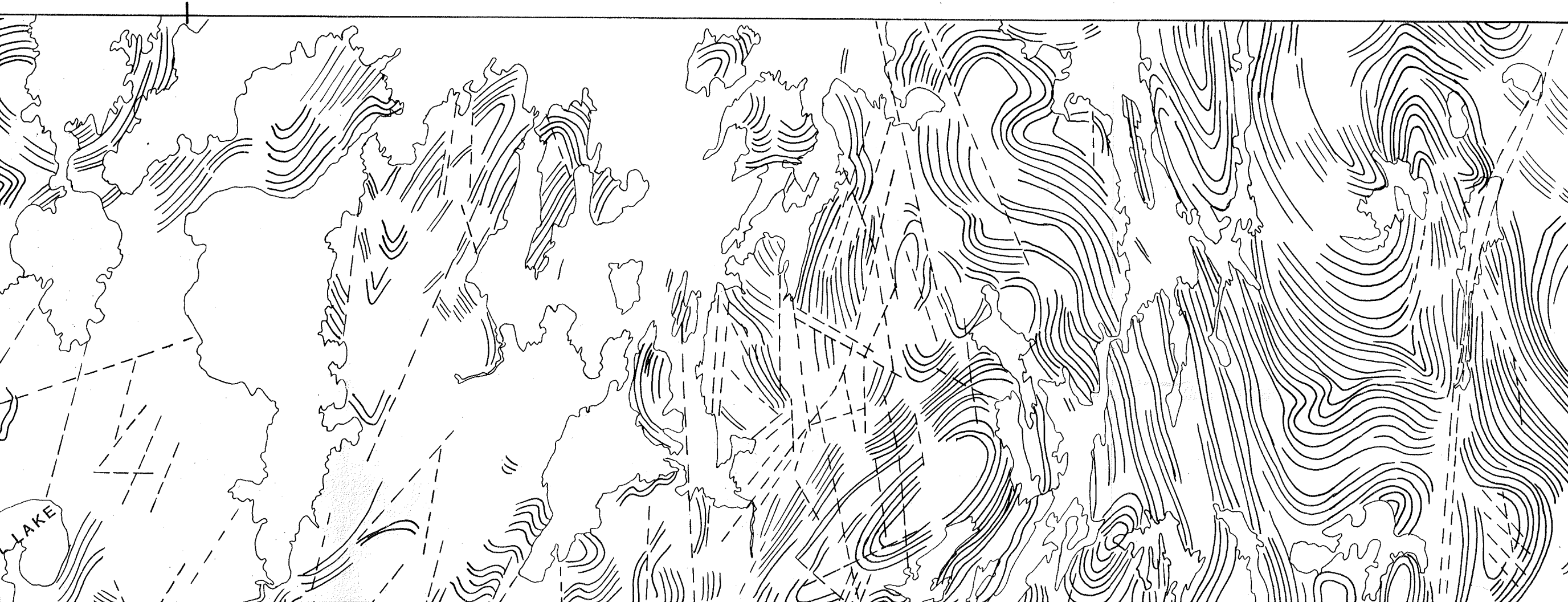
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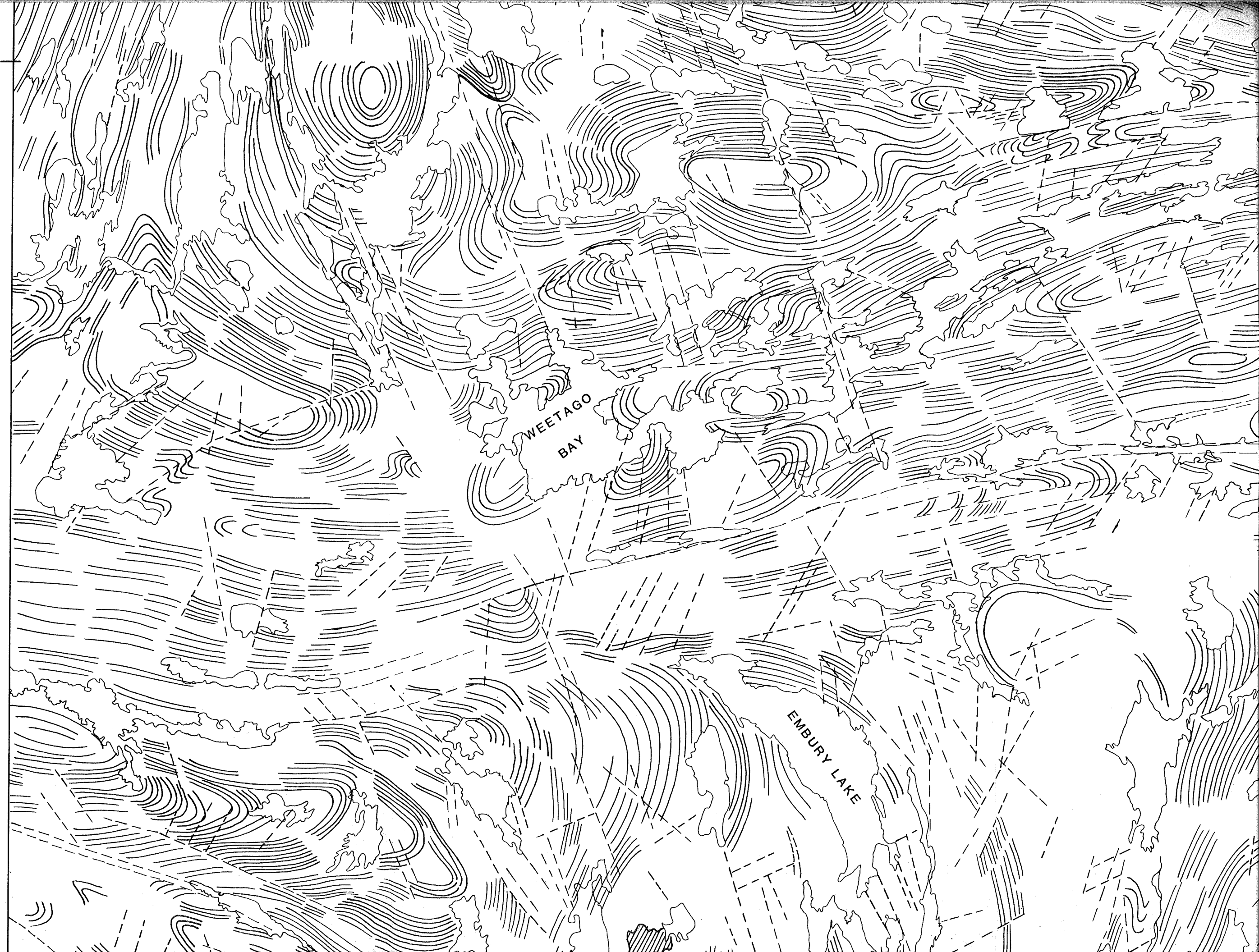
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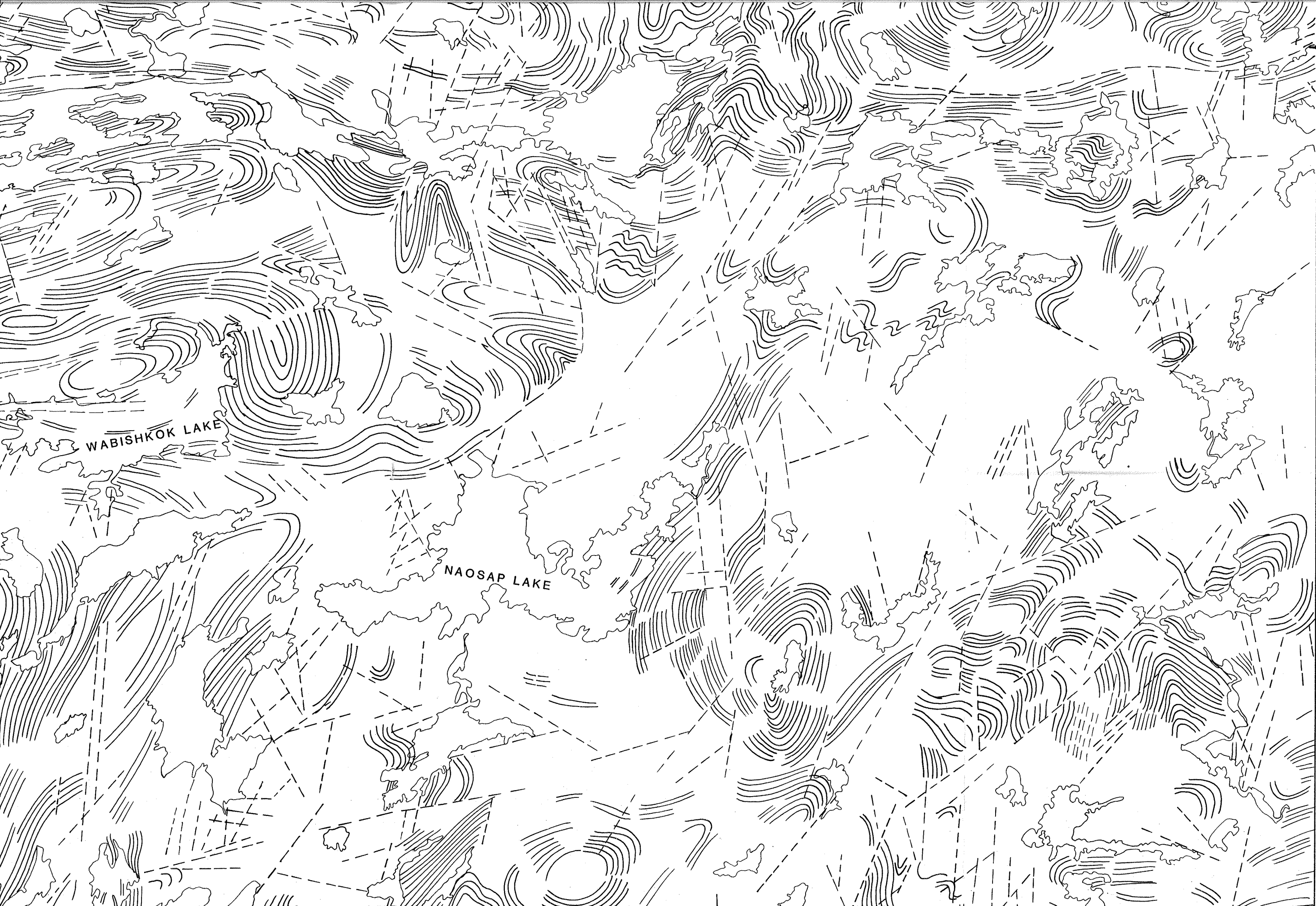
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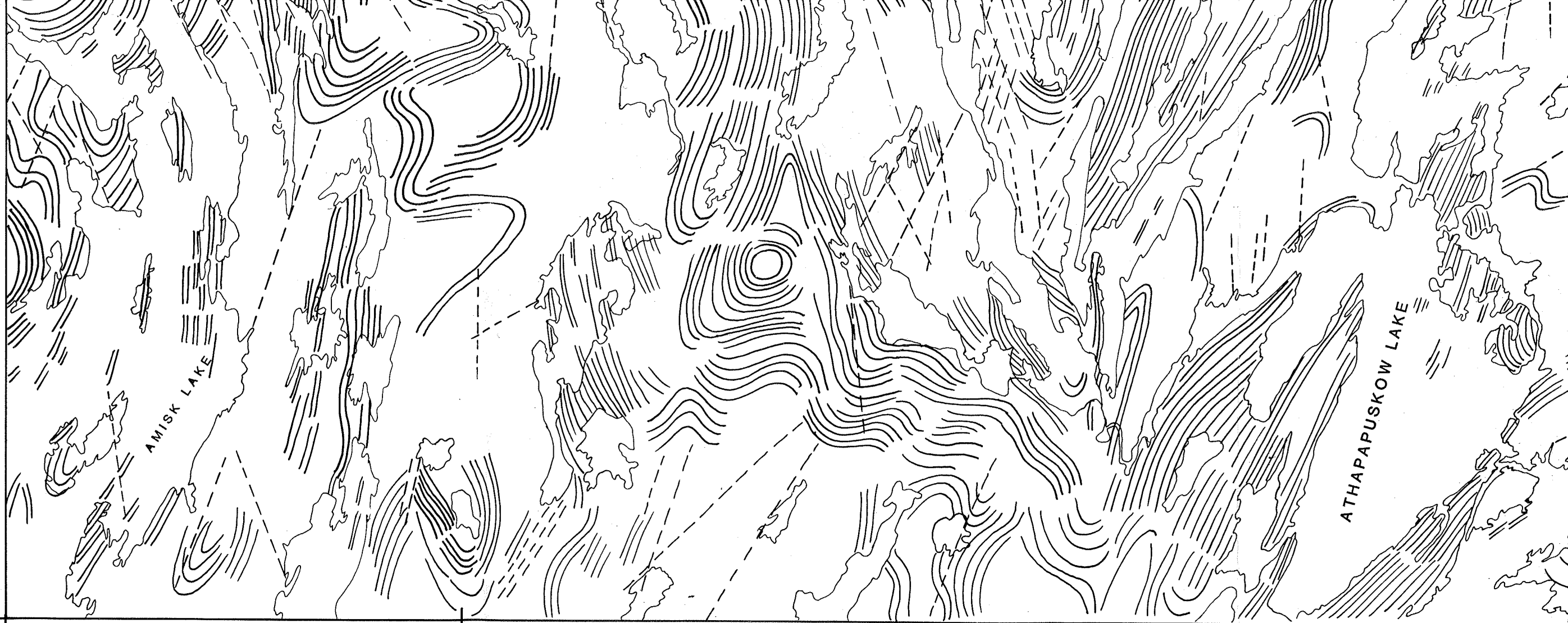
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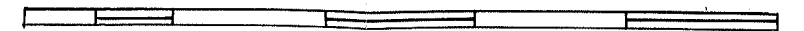
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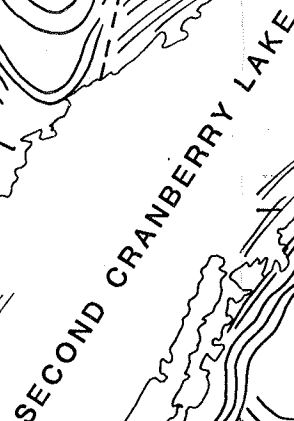
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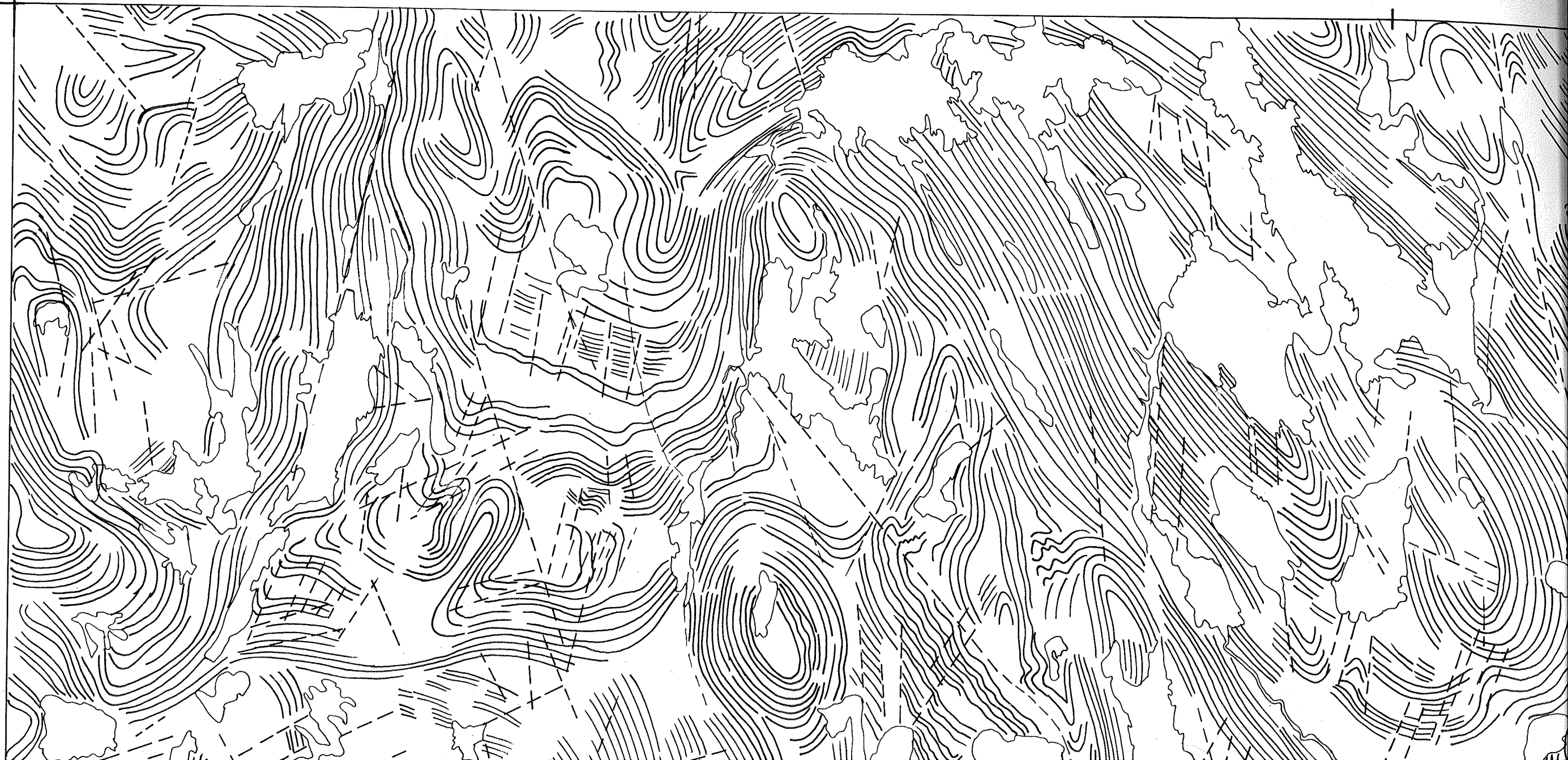
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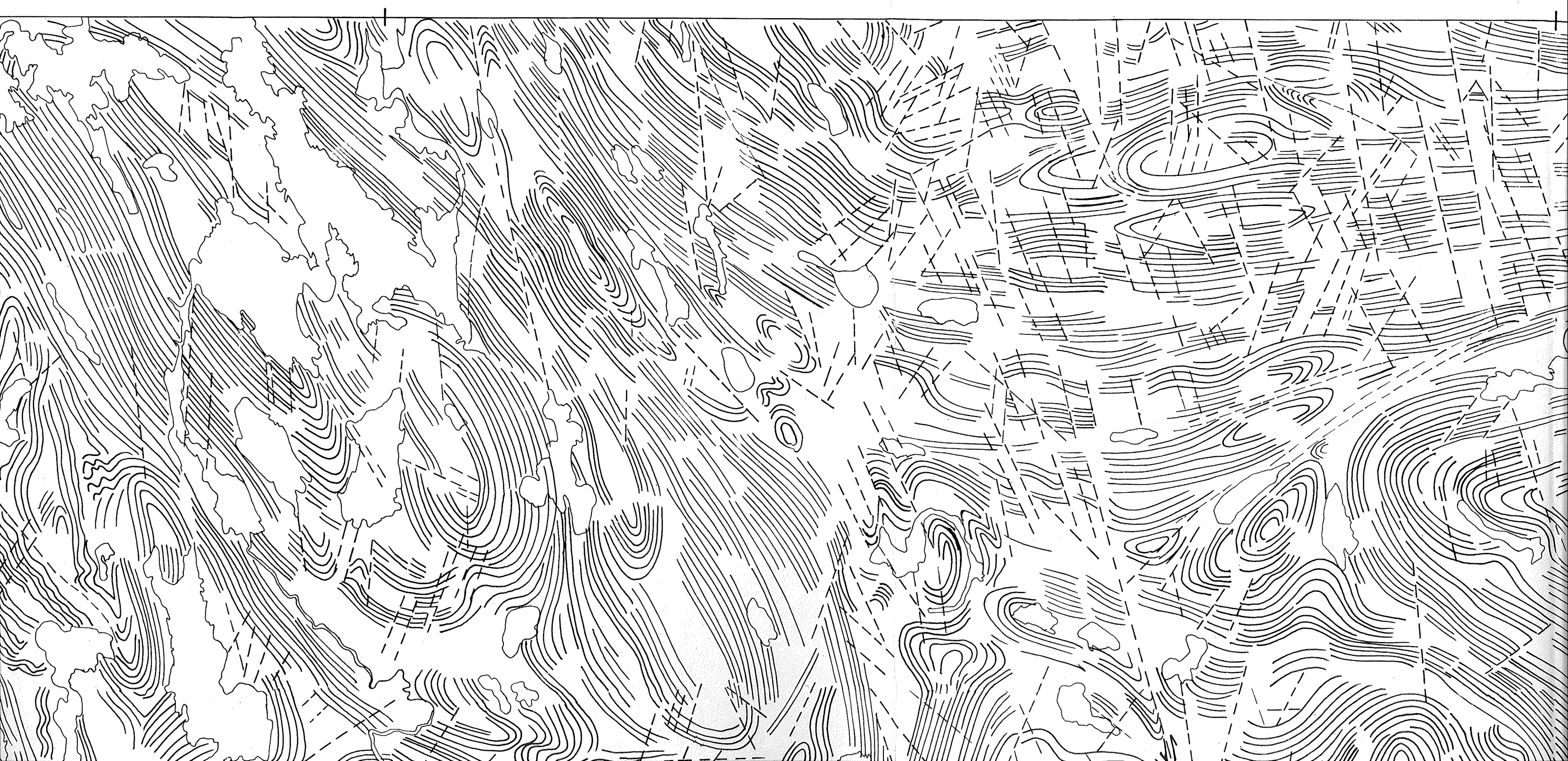


ION MAP SHOWING LITHOLOGICAL/STRUCTURAL TRENDS

(SNOW LAKE AND ADJOINING AREAS)

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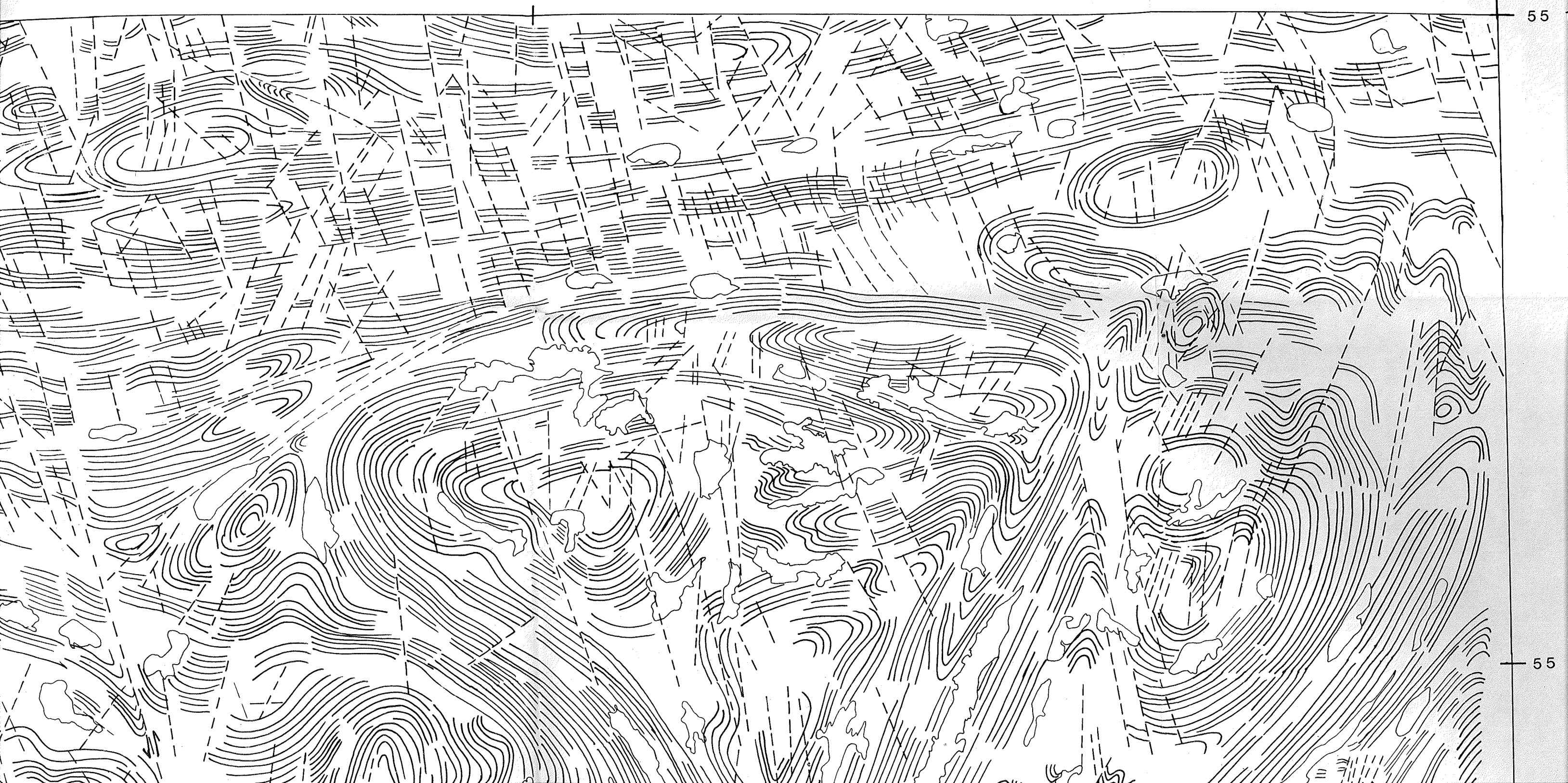
STRUCTURAL TRENDS AND OTHER LINEAMENTS

(PLANNING AREAS)

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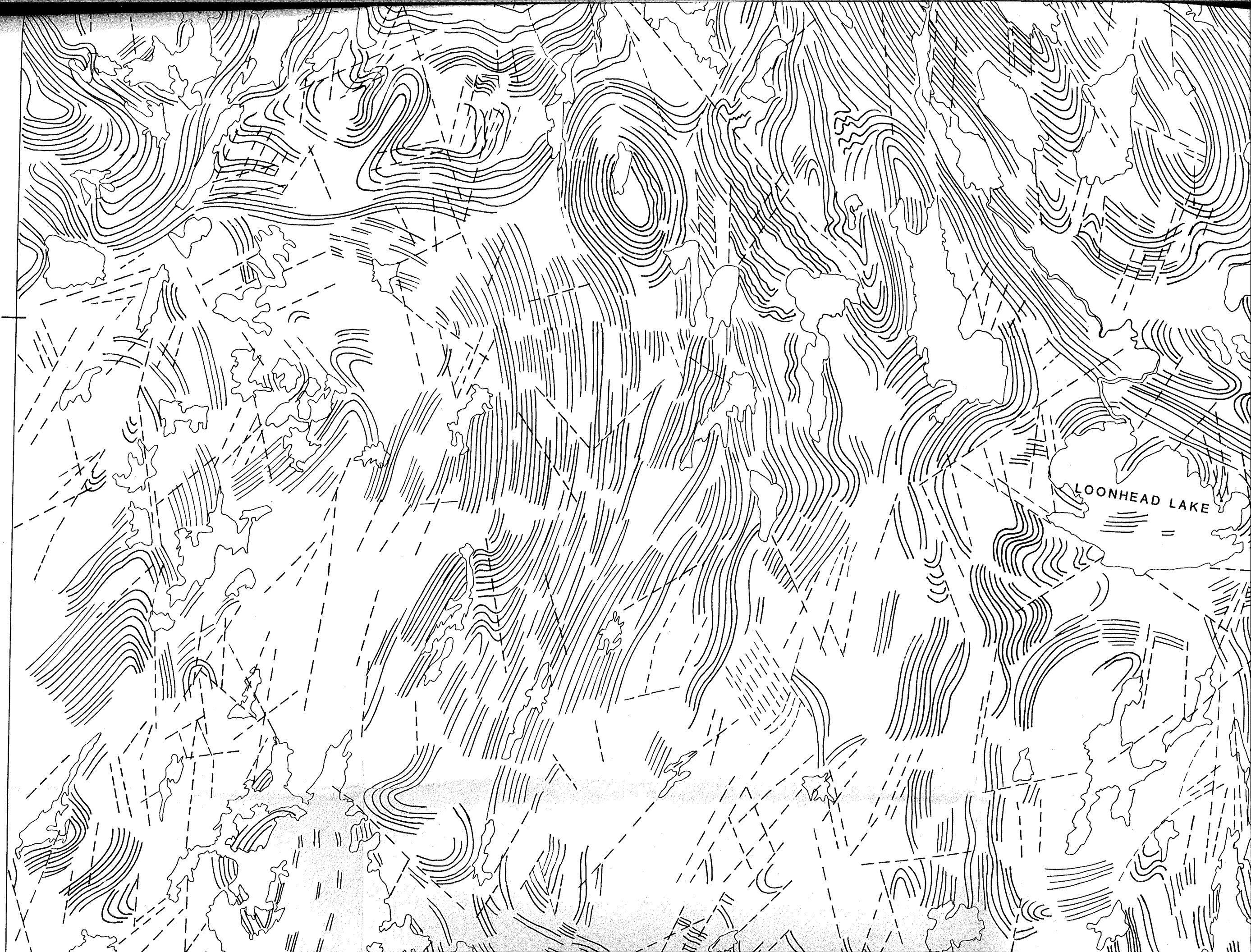
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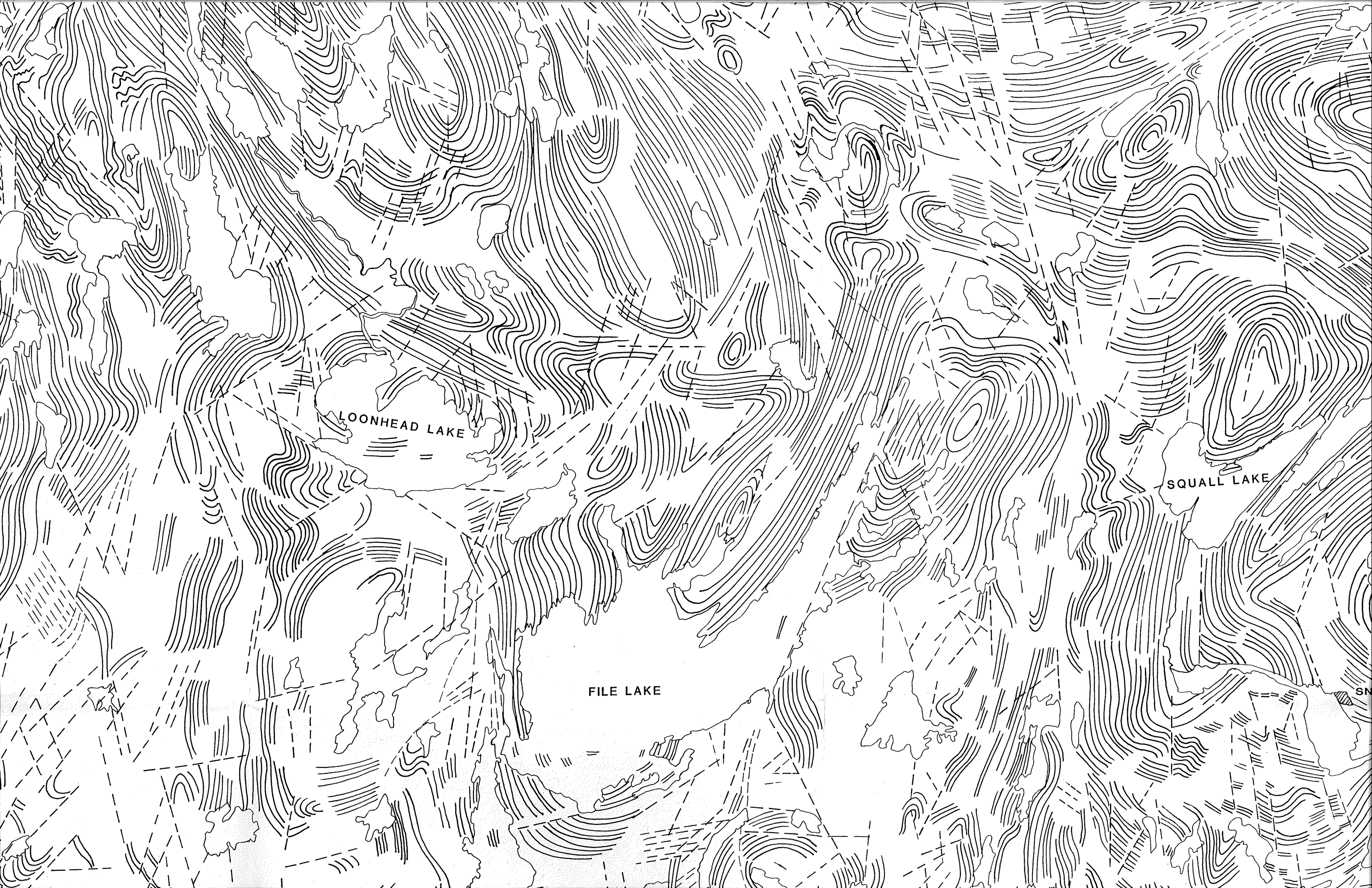
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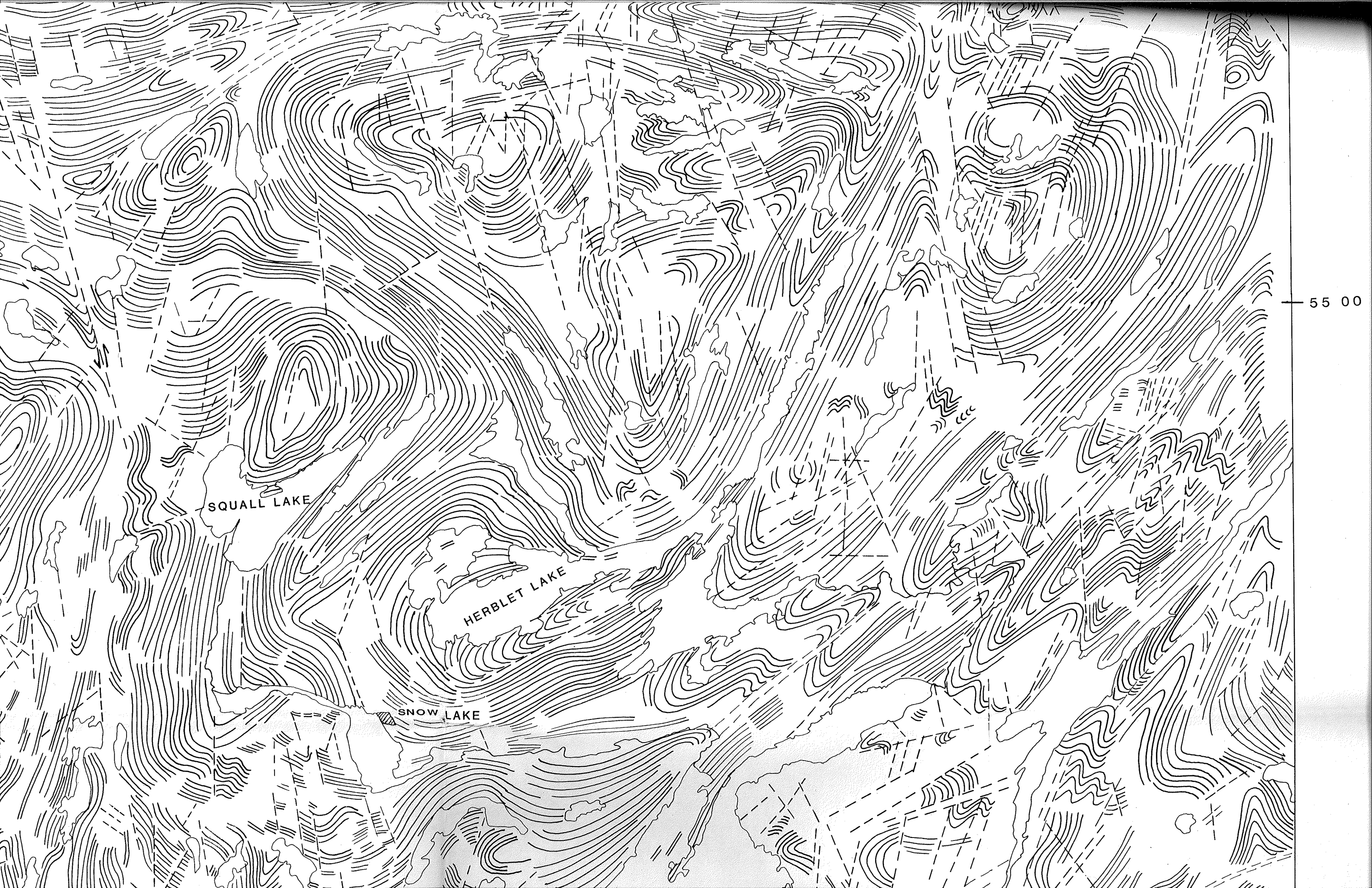


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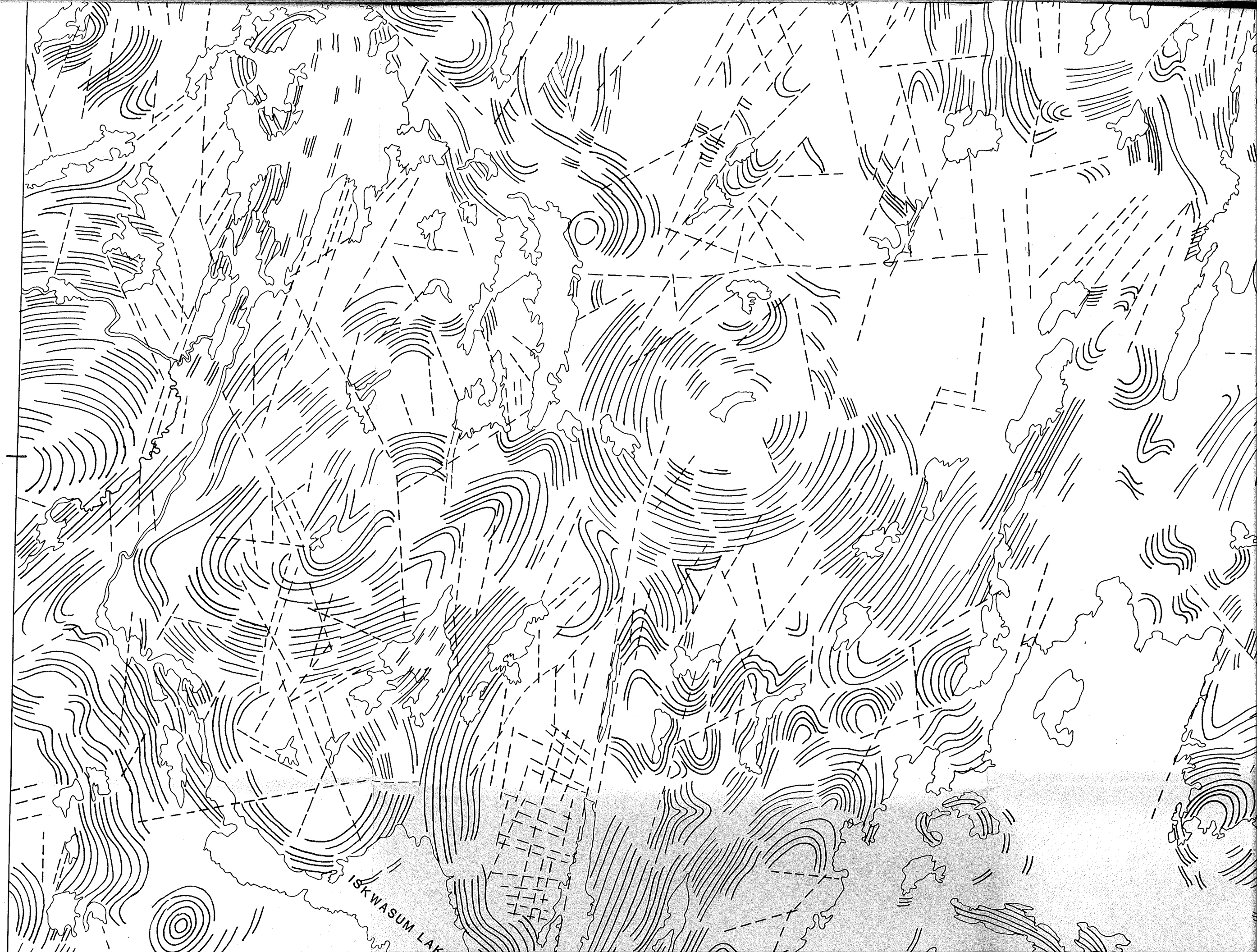
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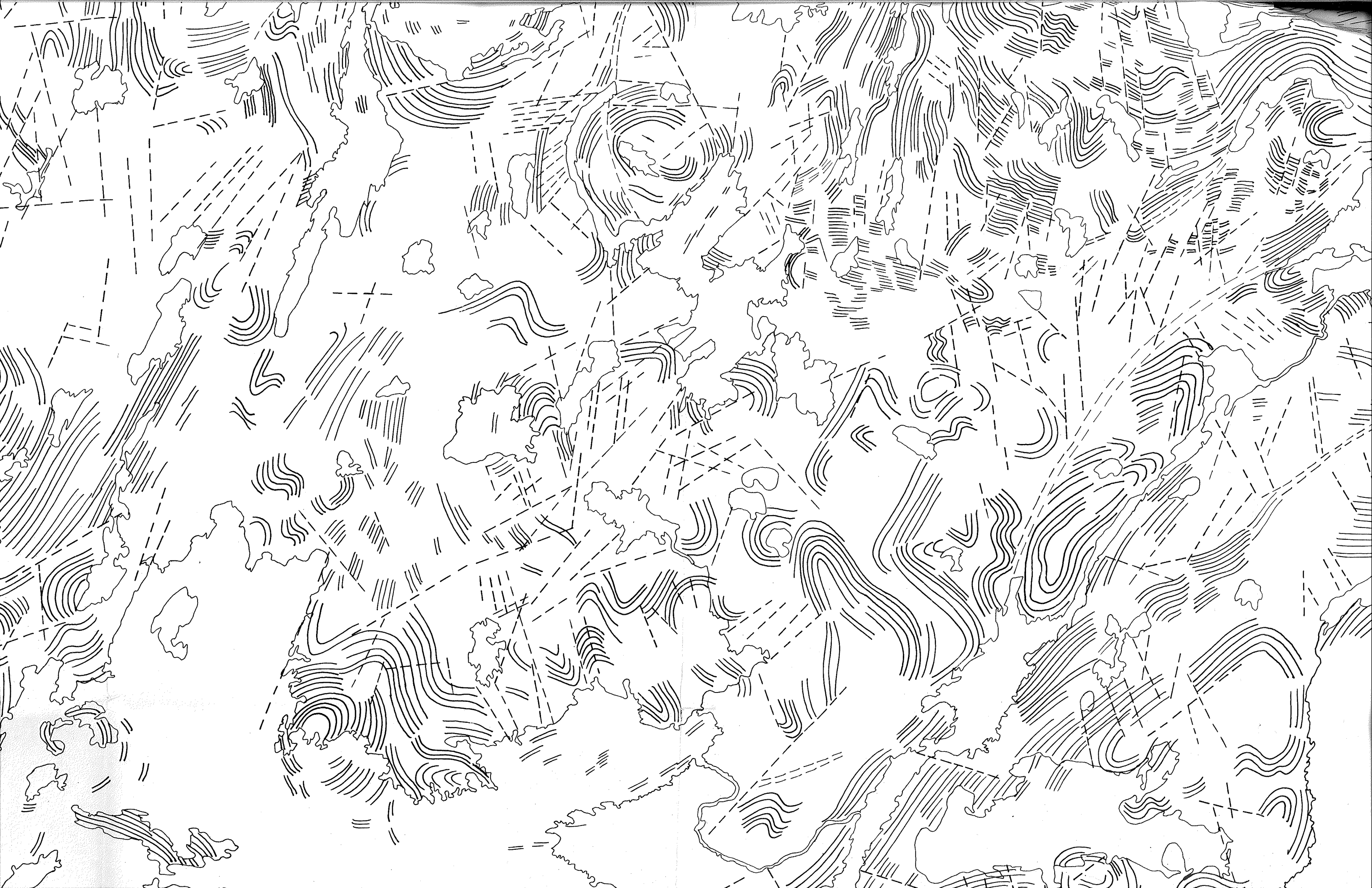
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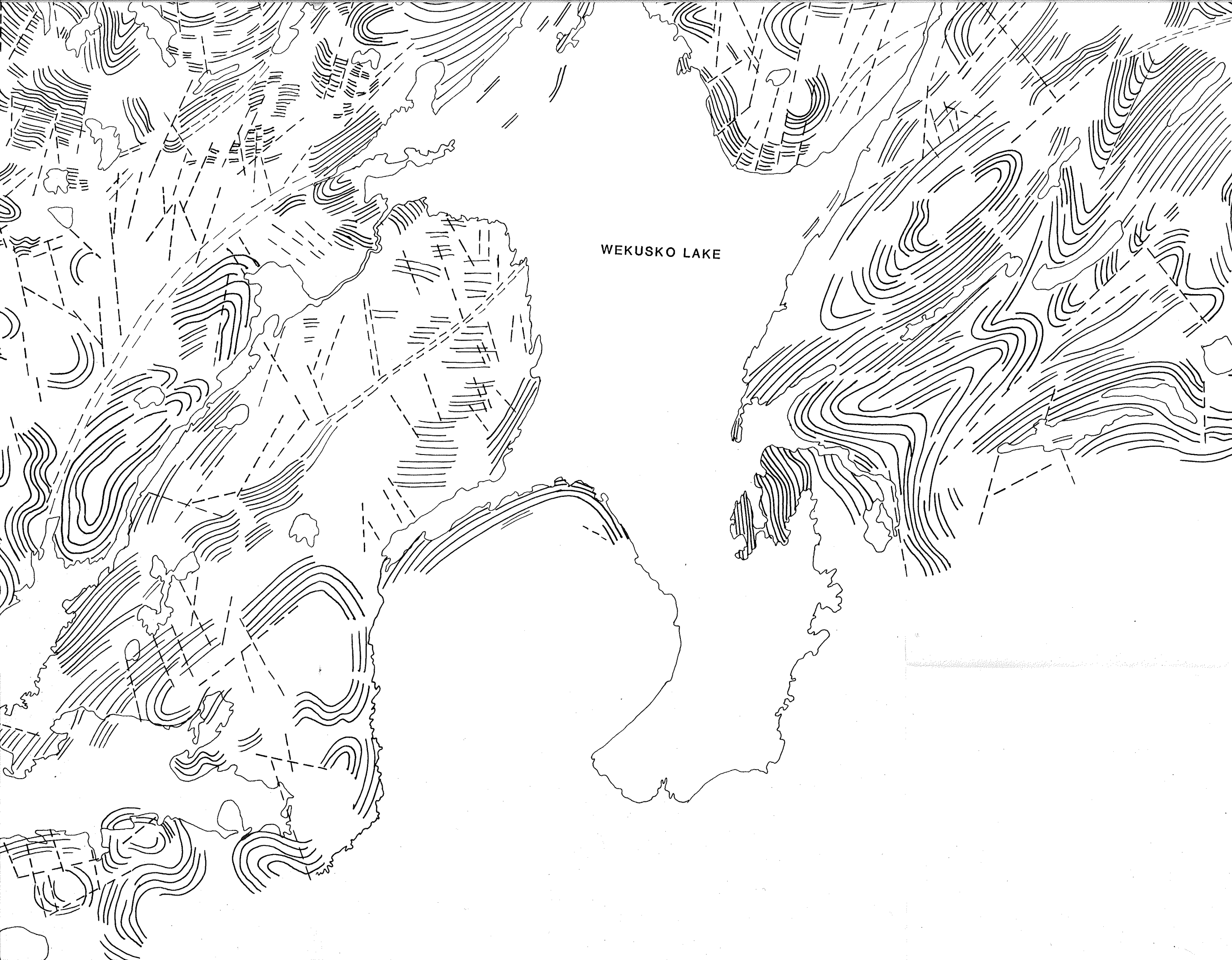
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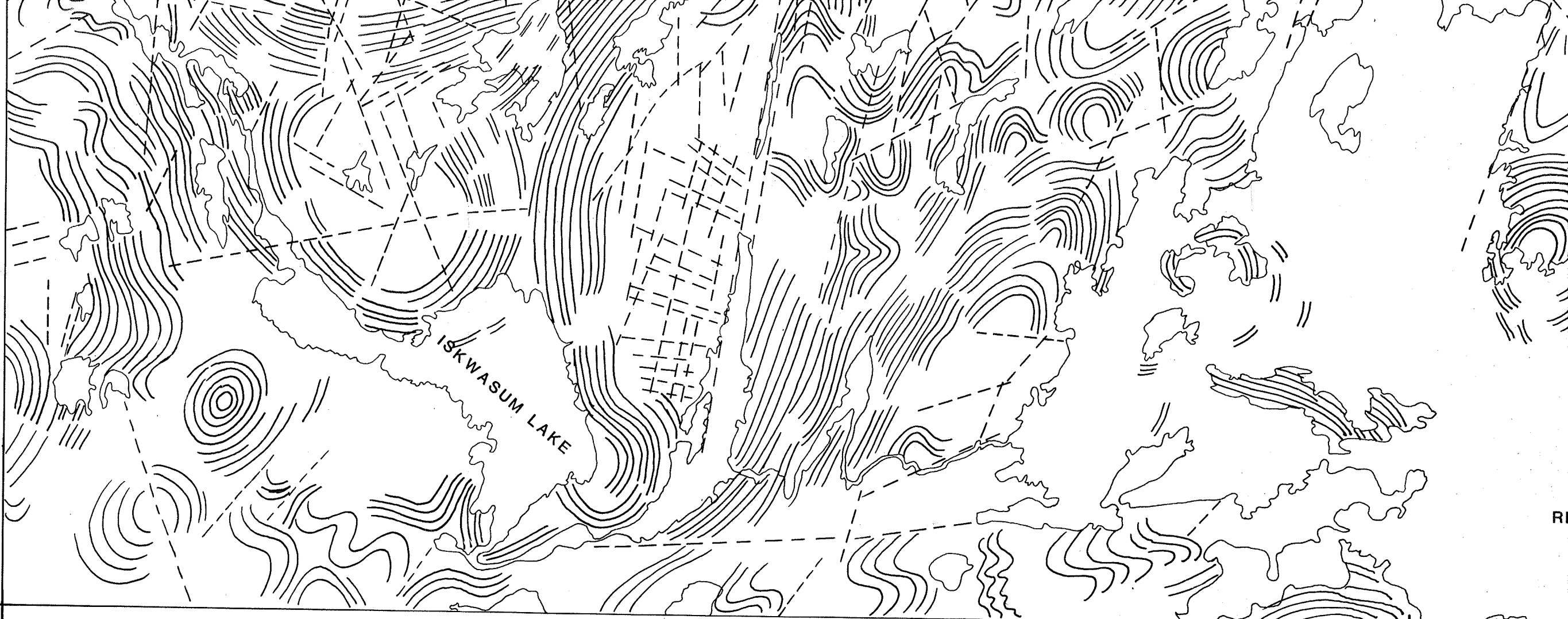






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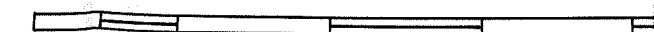
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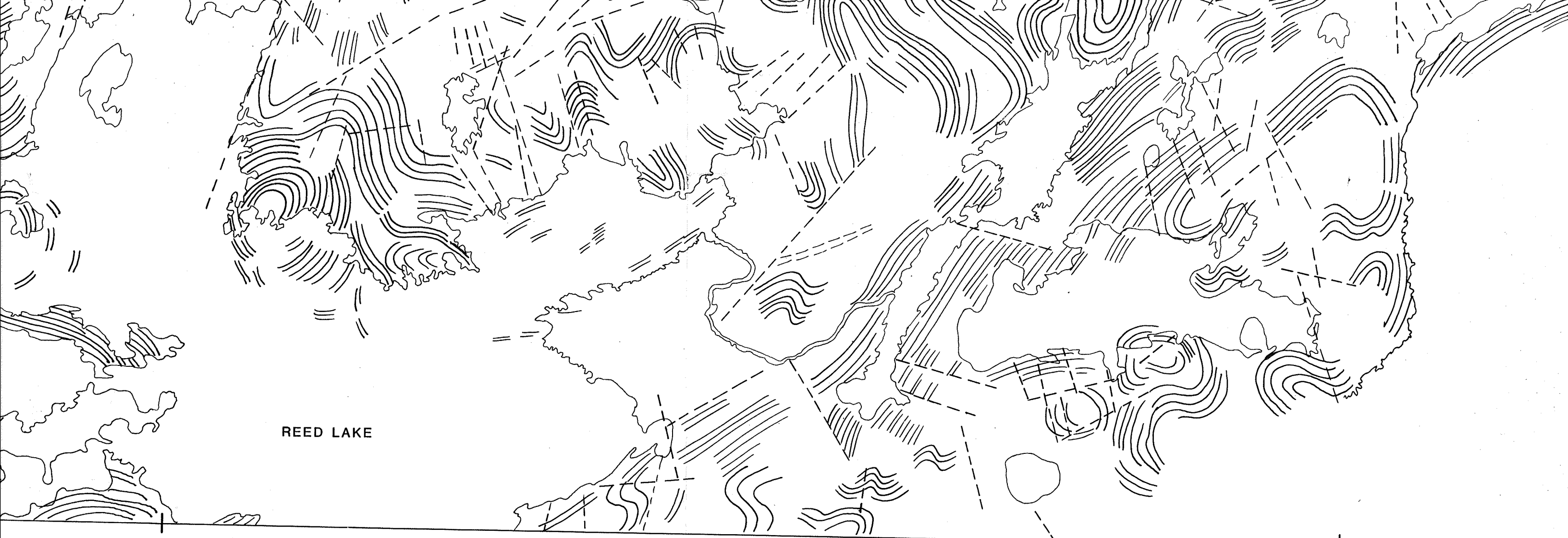
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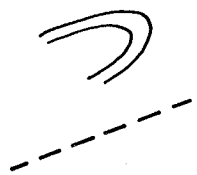
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LITHOLOGICAL/STRUCTURAL TRENDS

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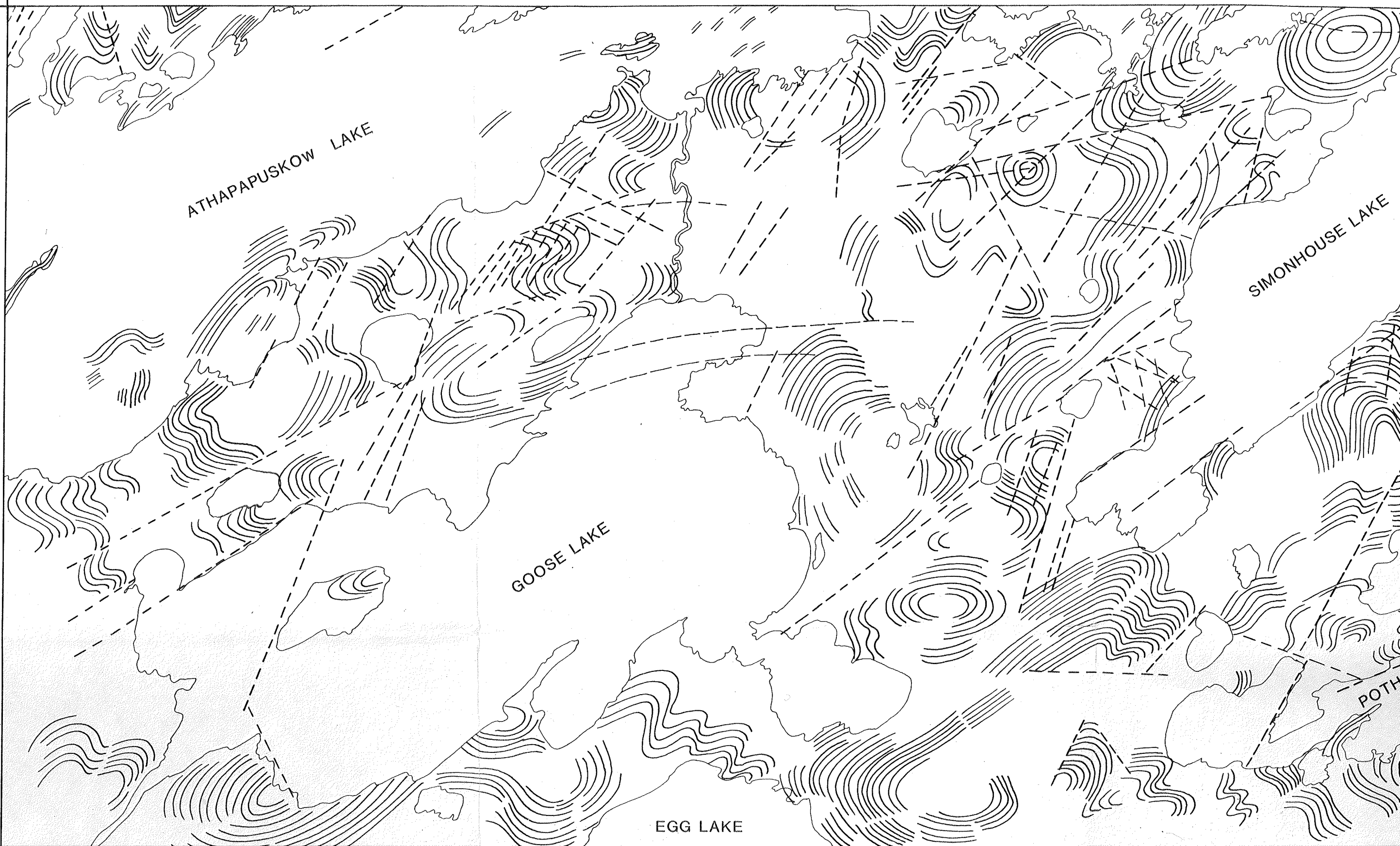
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LITHOLOGICAL/STRUCTURAL TRENDS AND OTHER LINEAMENTS

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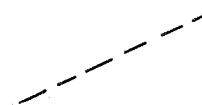
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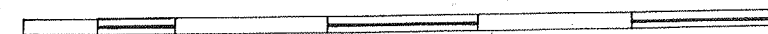
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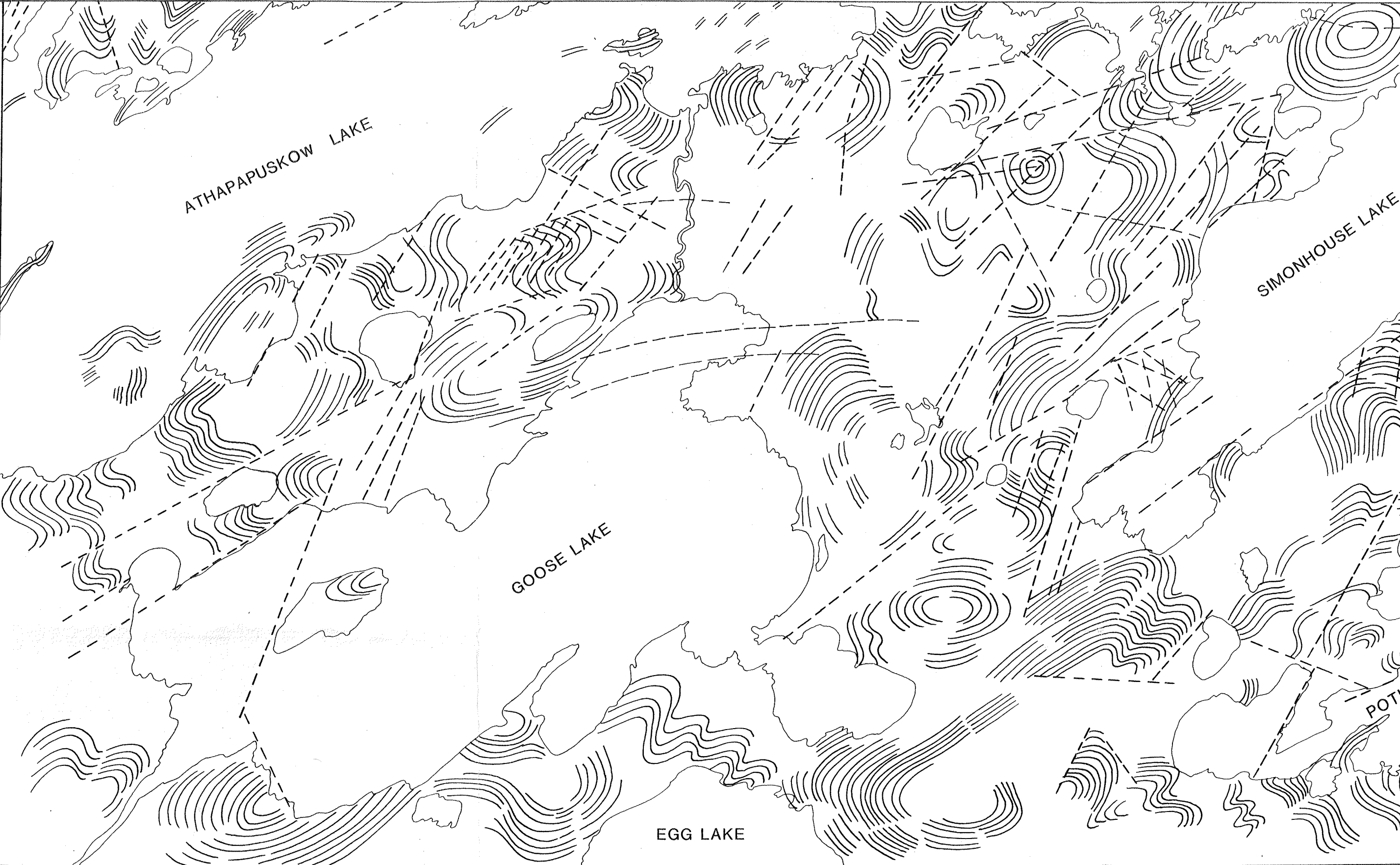
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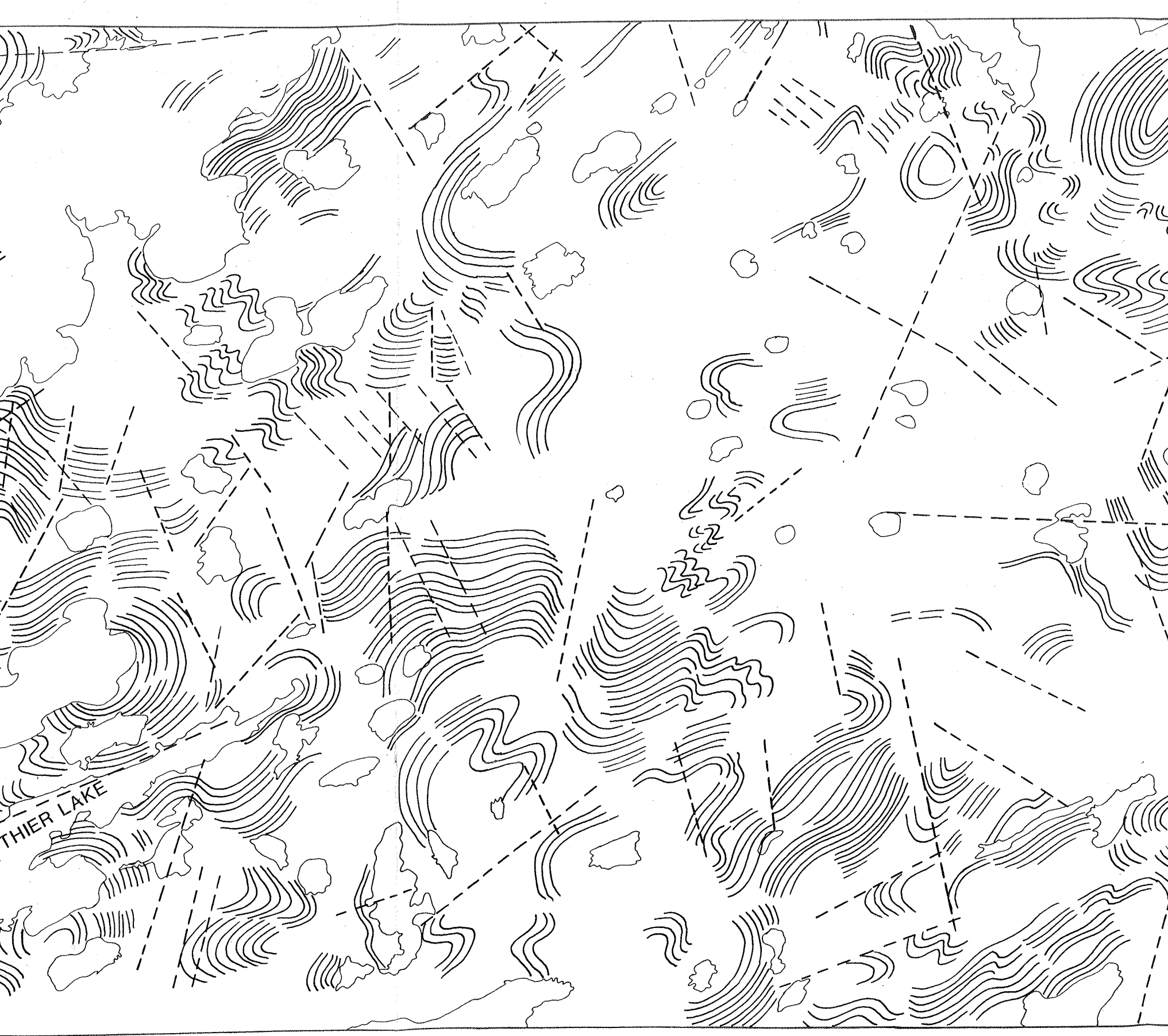
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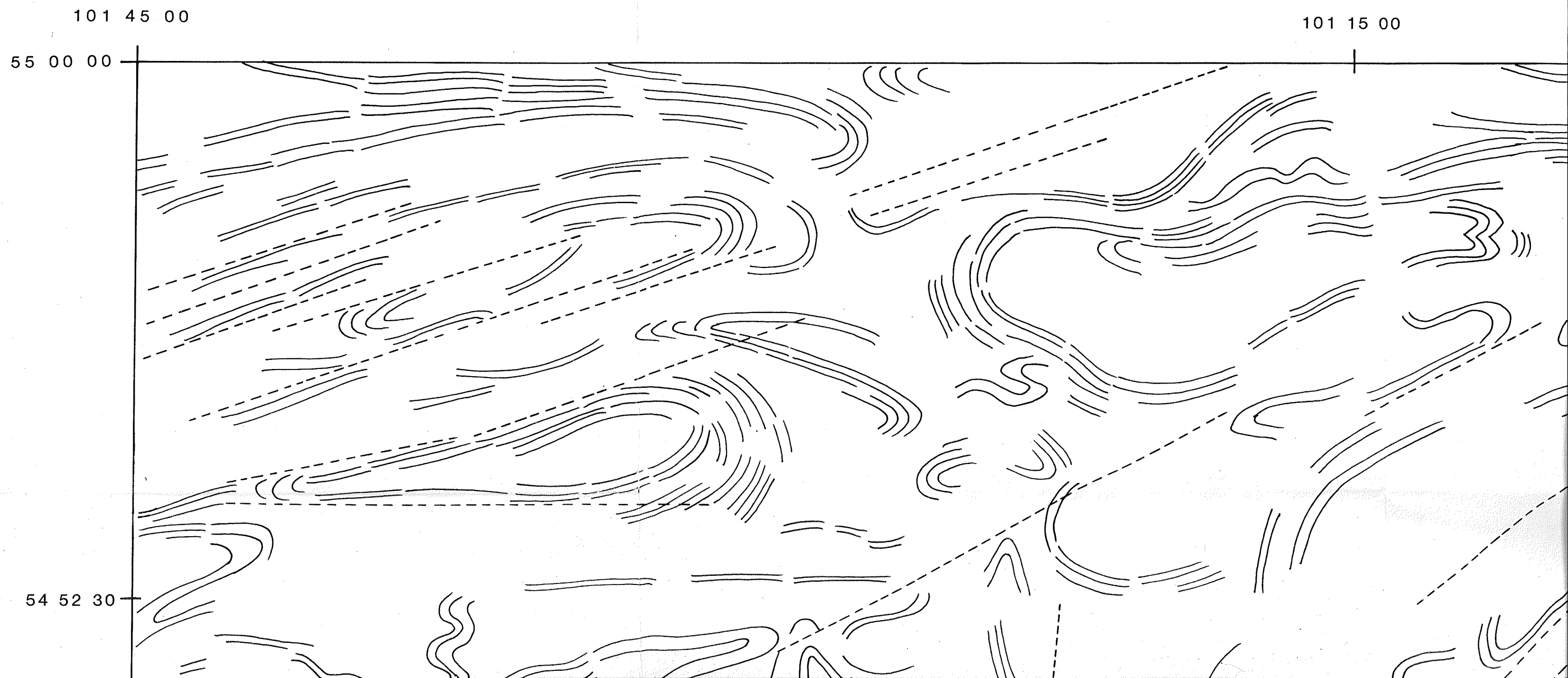
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MAP NO. 4

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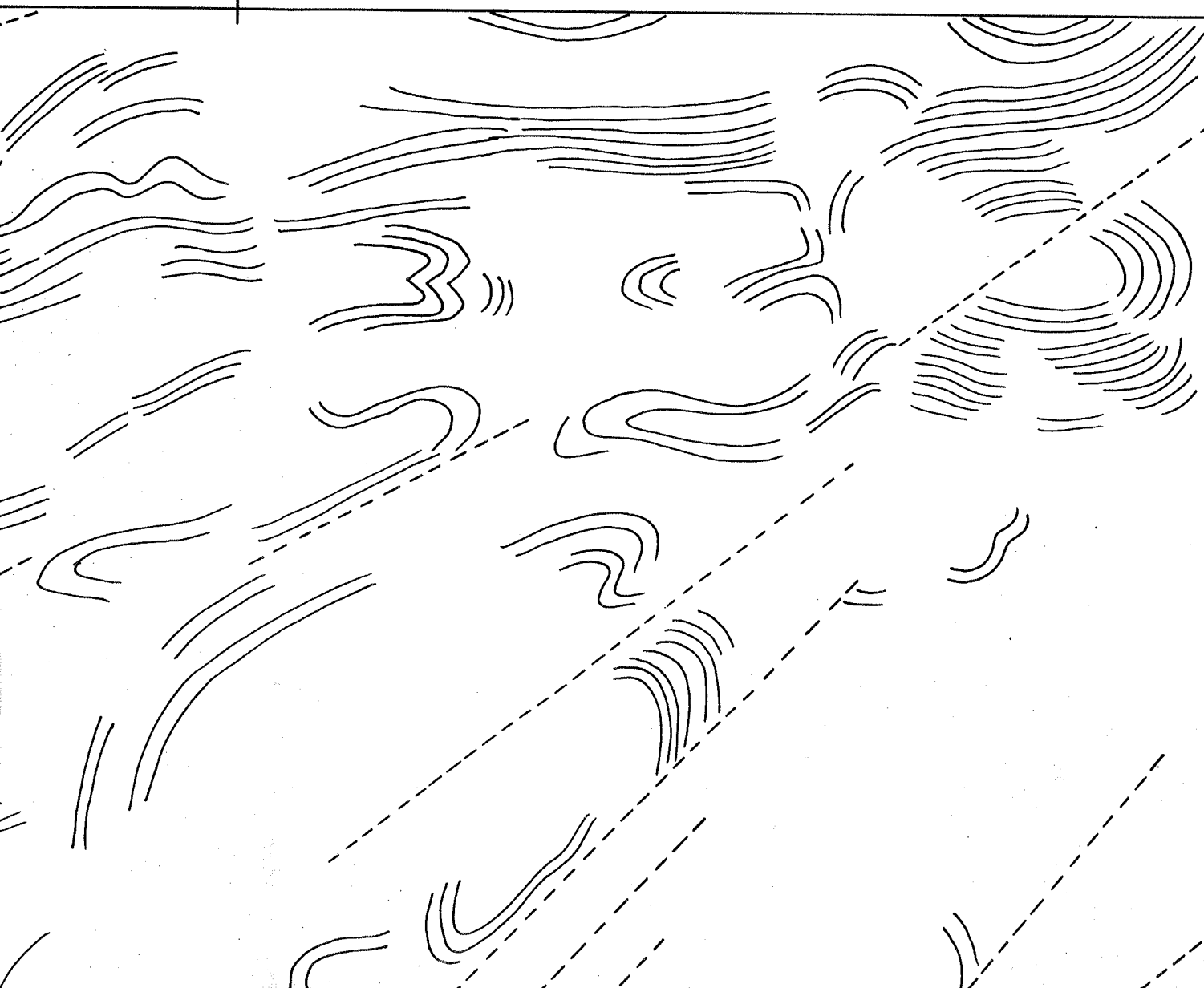


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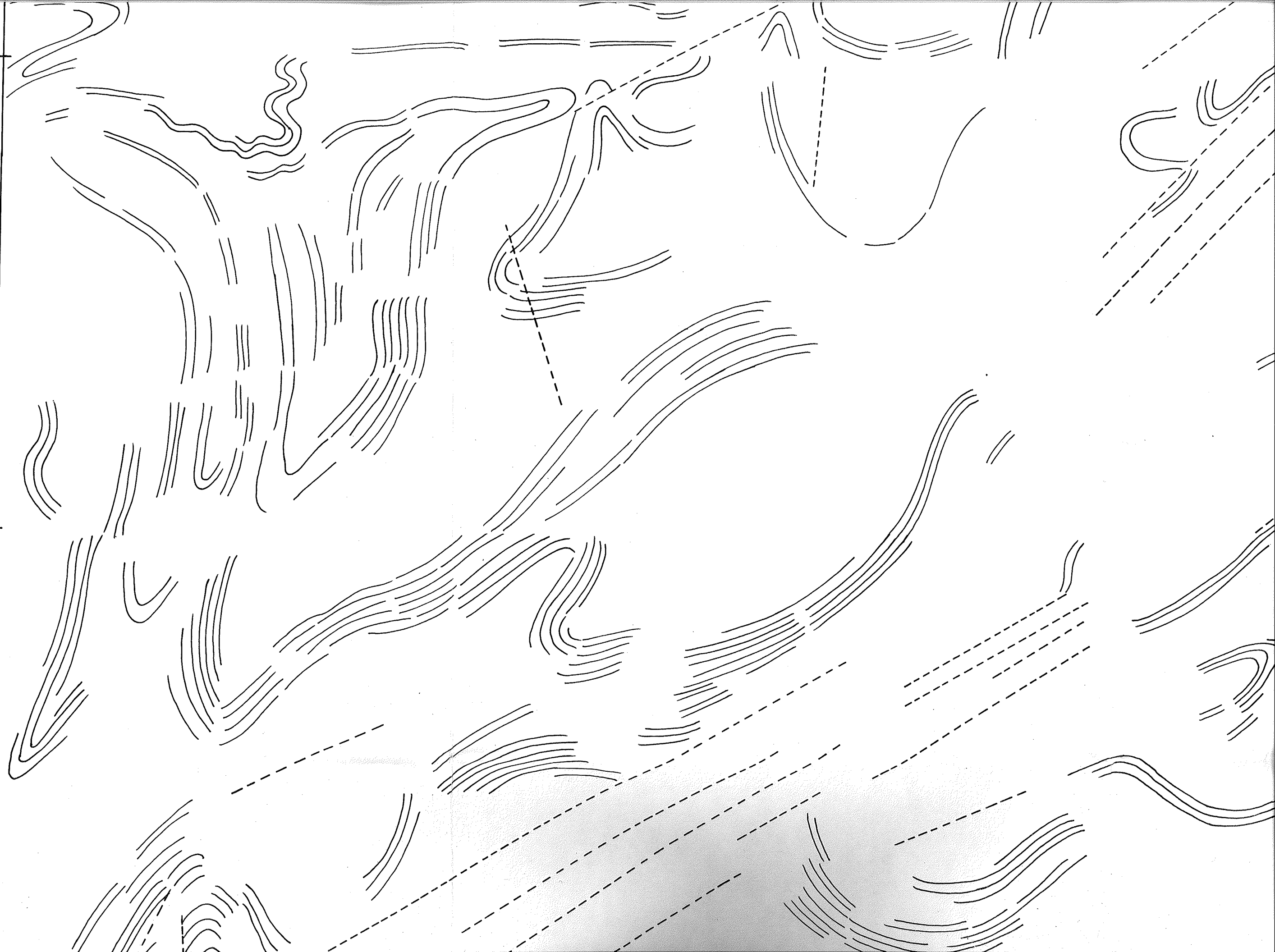
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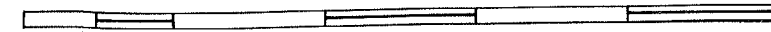
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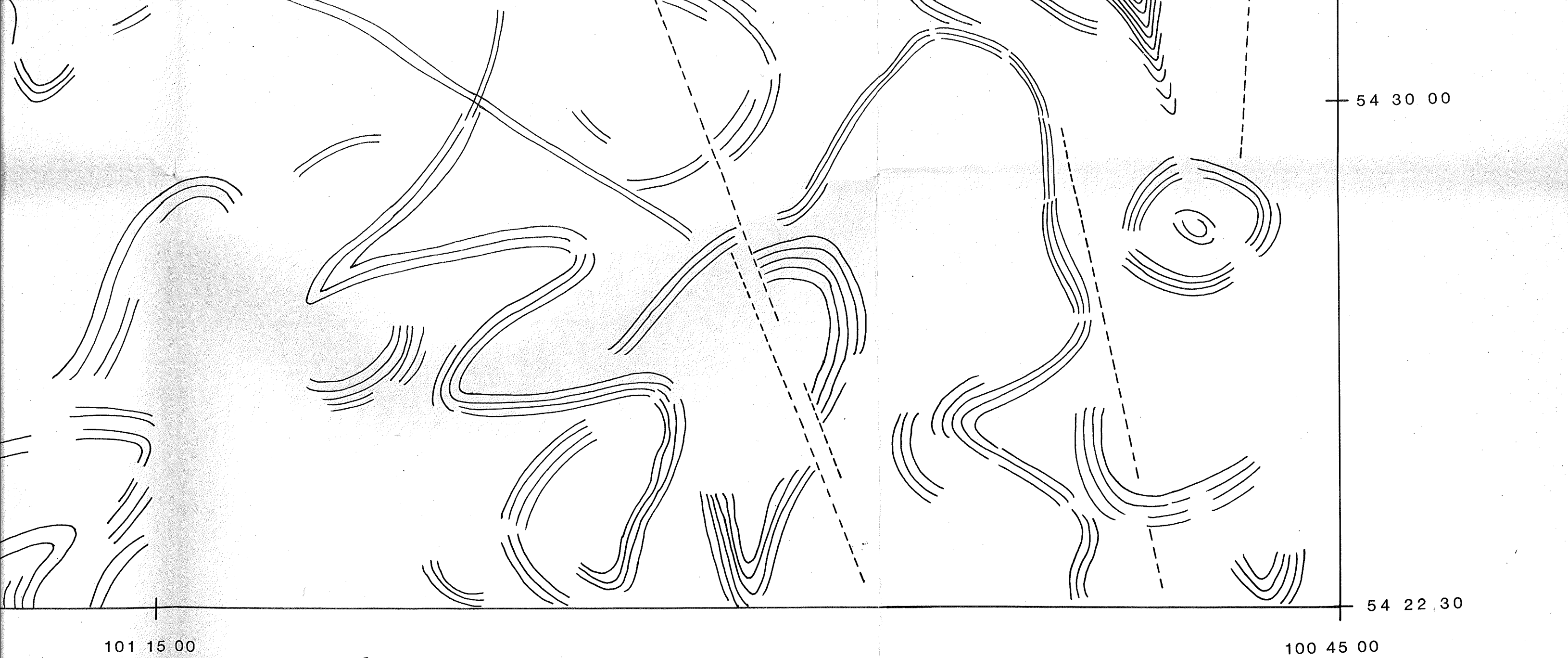
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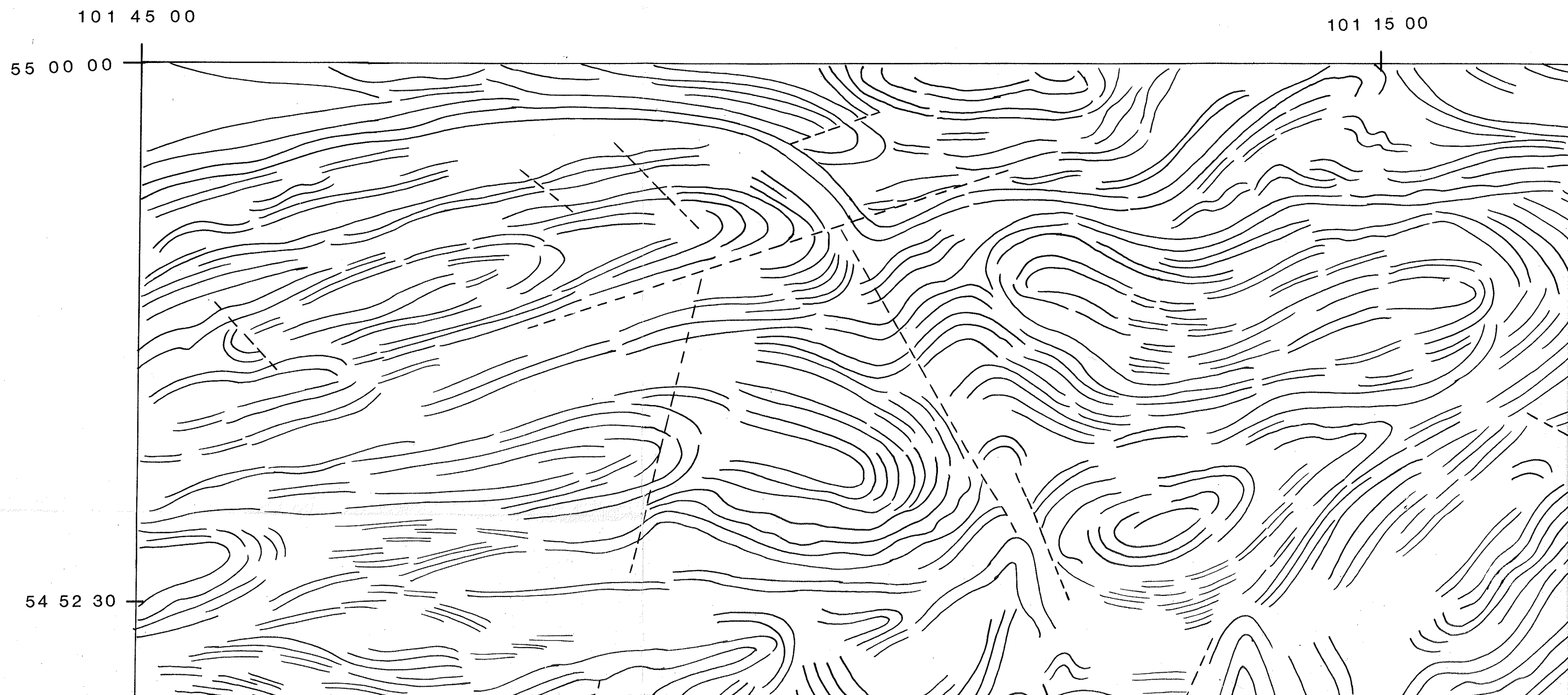


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MAP NO. 5

LITHOLOGICAL/STRUCTURAL TRENDS AND OTHER

VERTICAL AEROMAGNETIC GRADIENT

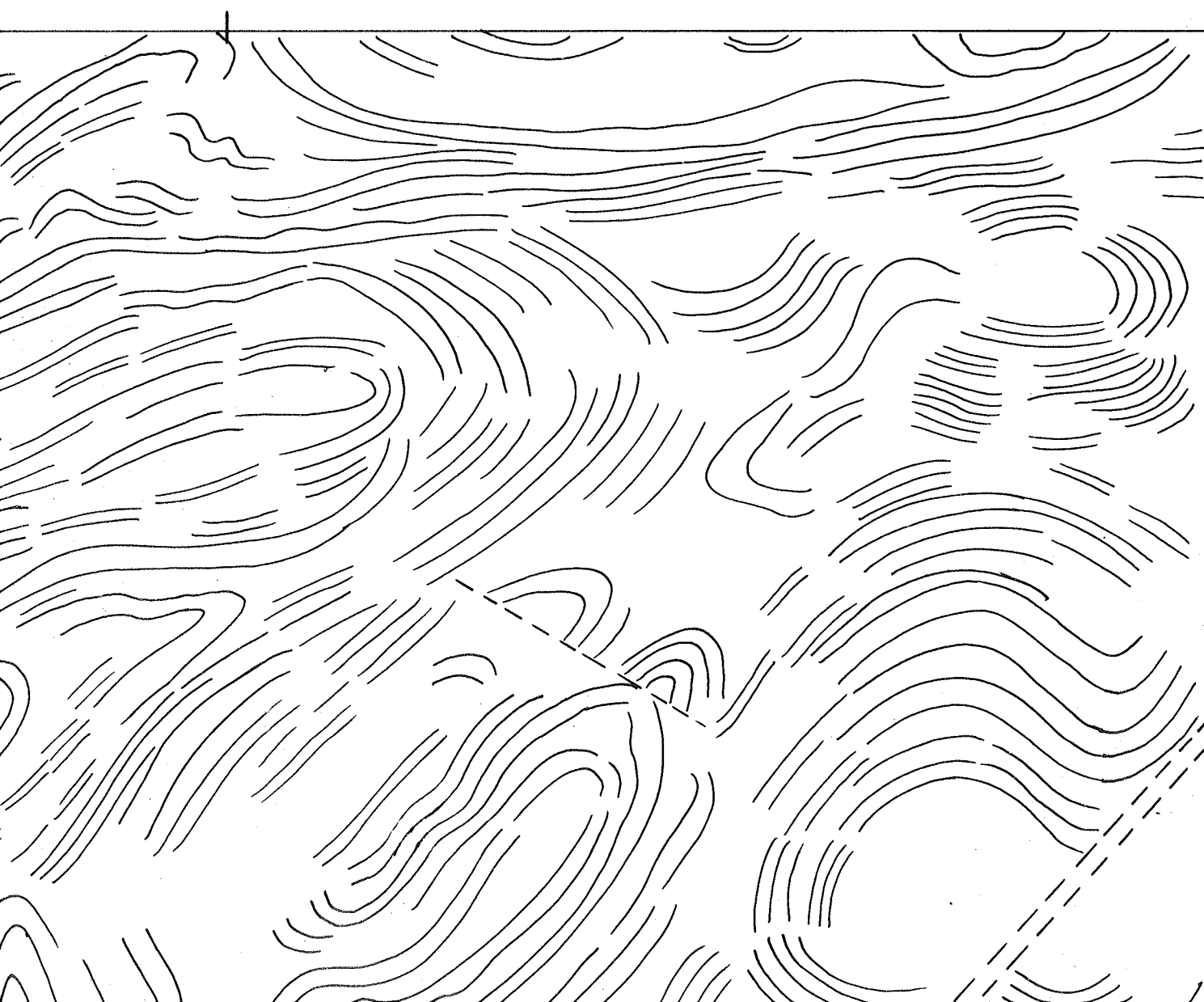


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LITHOLOGICAL/STRUCTURAL TRENDS



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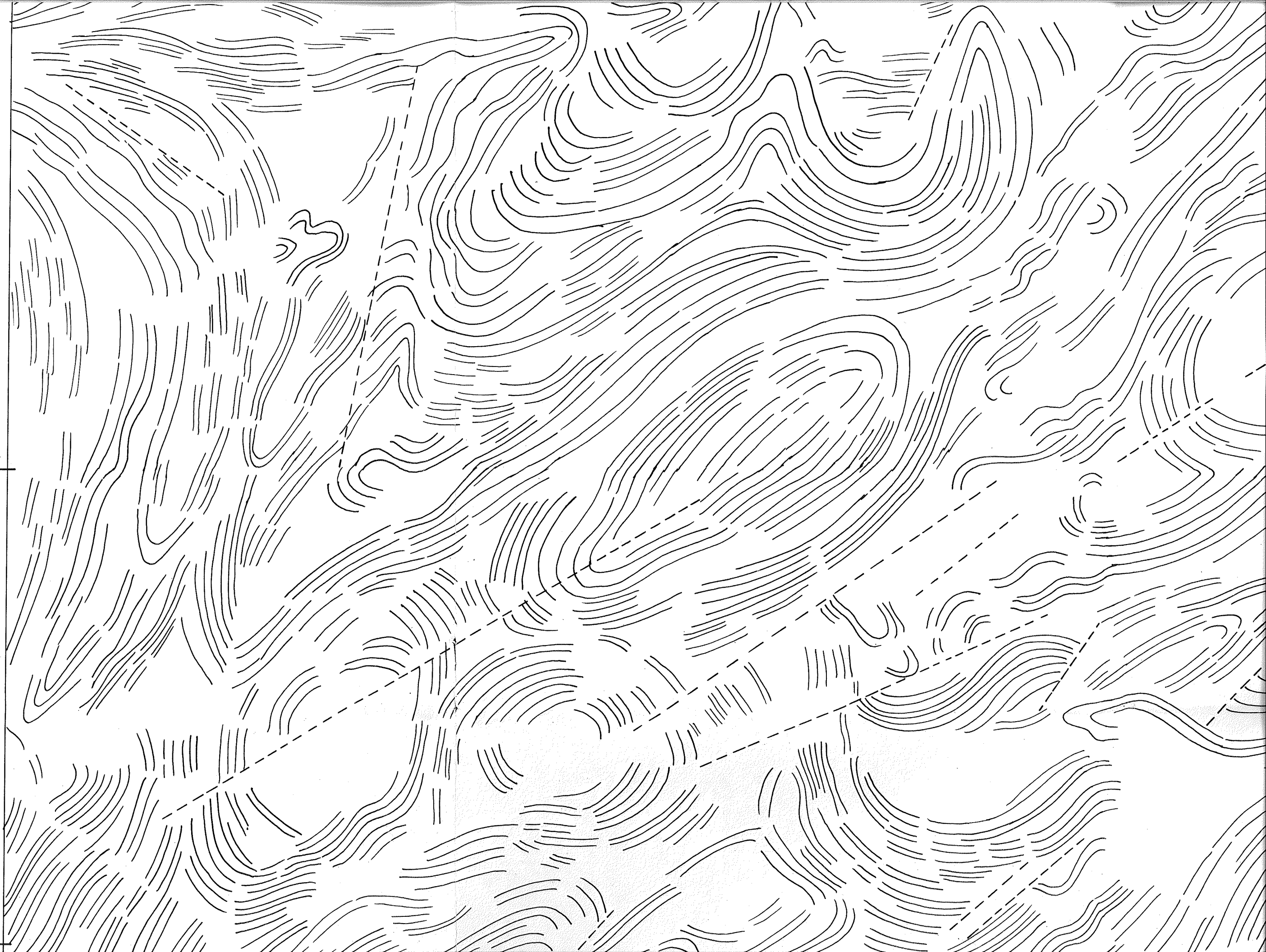


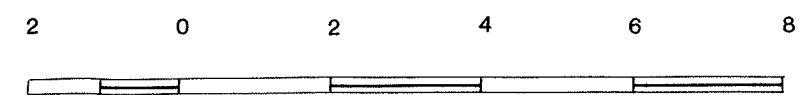
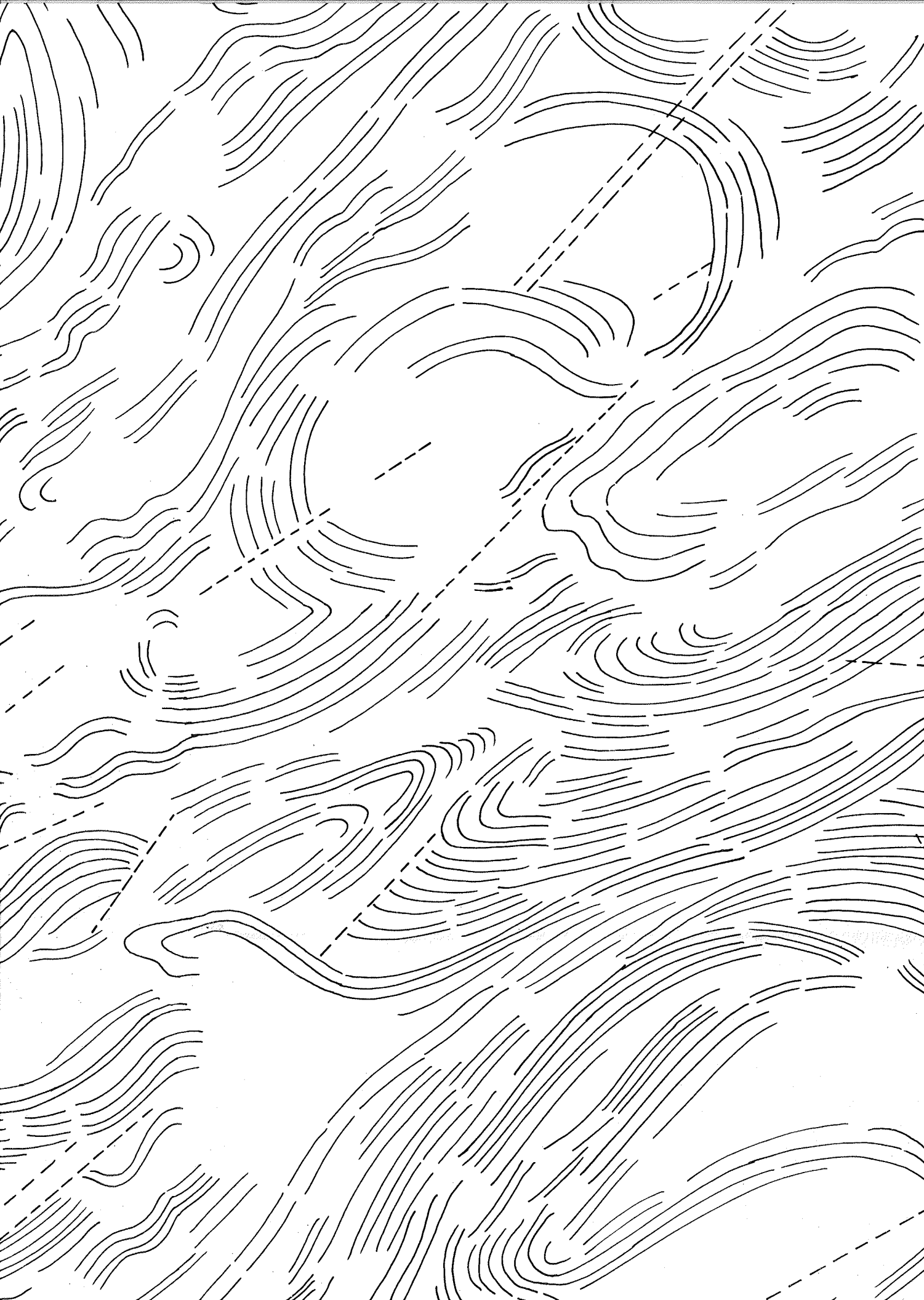
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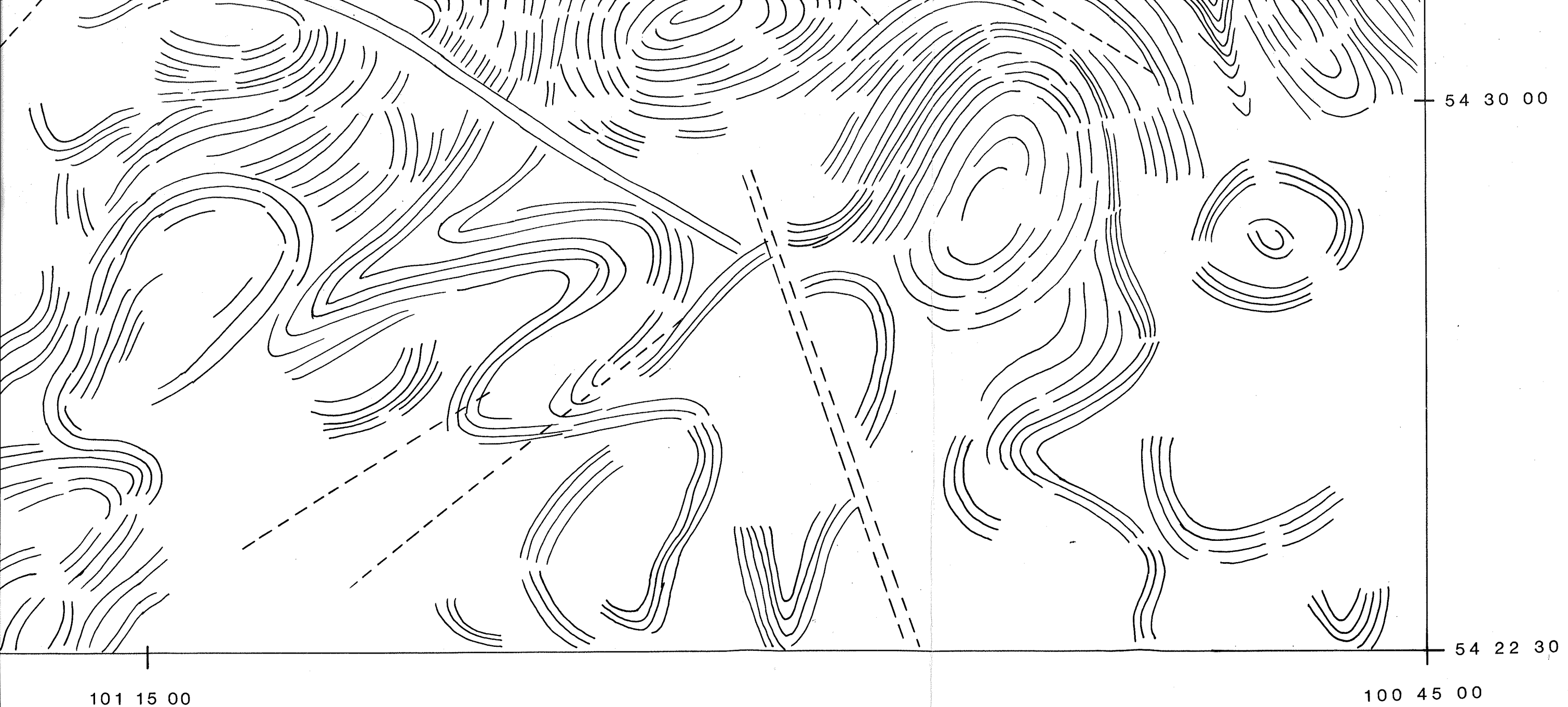
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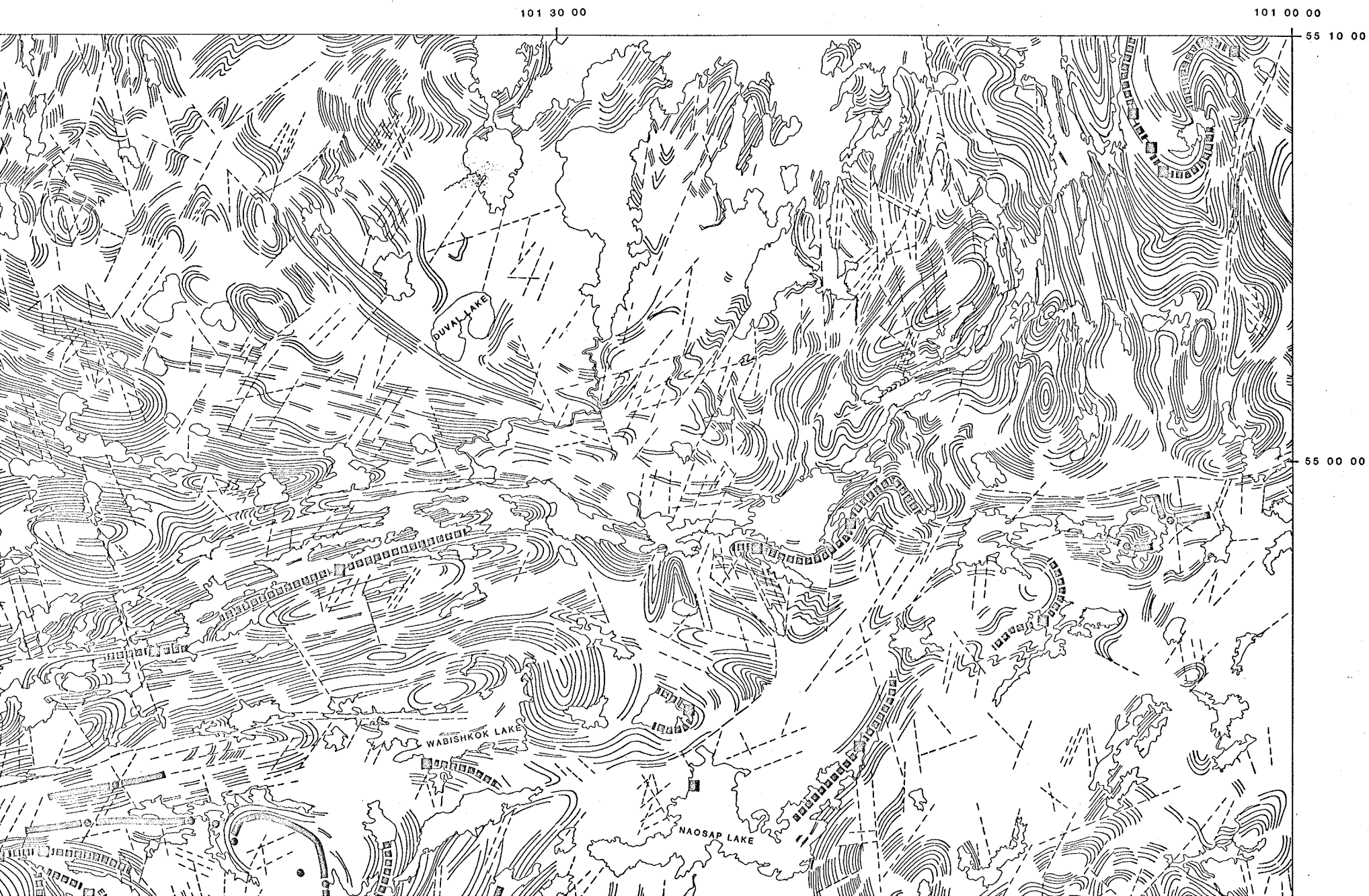
MAP NO.6

PHOTO-INTERPRETATION MAP SHOWING LITHOLOGICAL/STRUCTURAL TRENDS

(FLIN FLON AND ADJOINING AREAS)

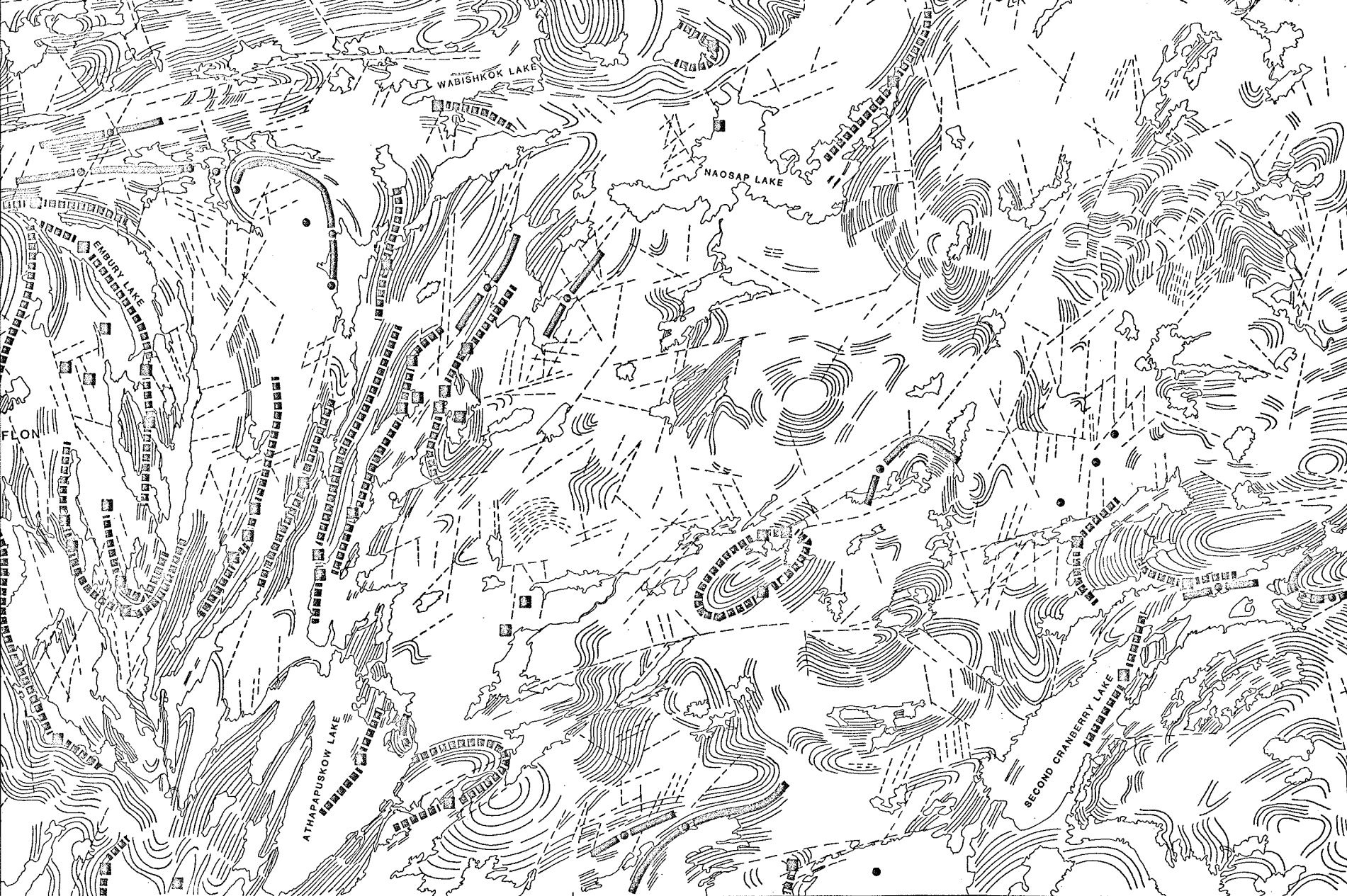


MAP SHOWING LITHOLOGICAL/STRUCTURAL TRENDS AND OTHER LINEAMENTS (FLIN FLON AND ADJOINING AREAS)





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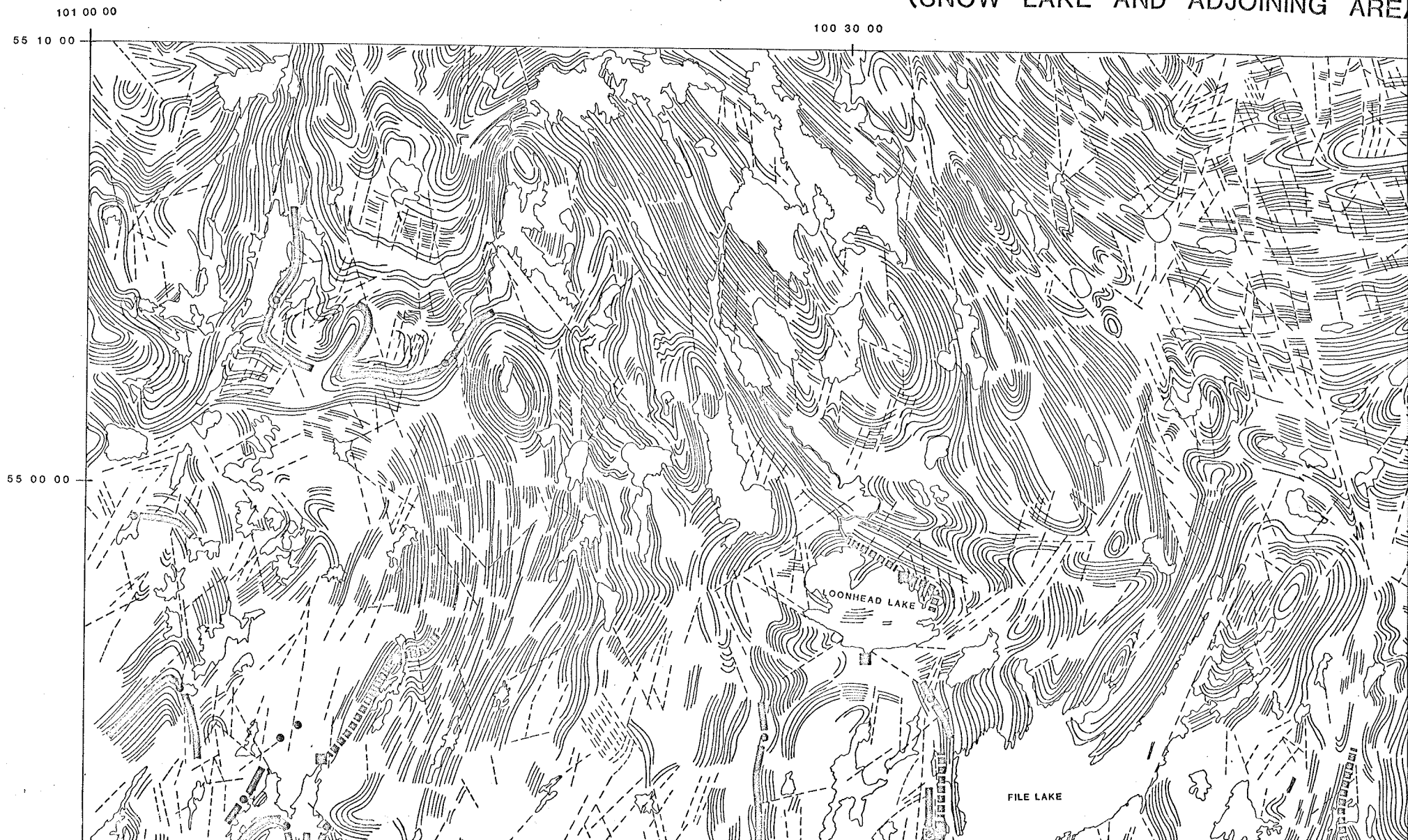
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- LINEAMENTS
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MAP NO.7

PHOTO-INTERPRETATION MAP SHOWING LITHOLOGICAL/STRUCTURAL

(SNOW LAKE AND ADJOINING AREA)



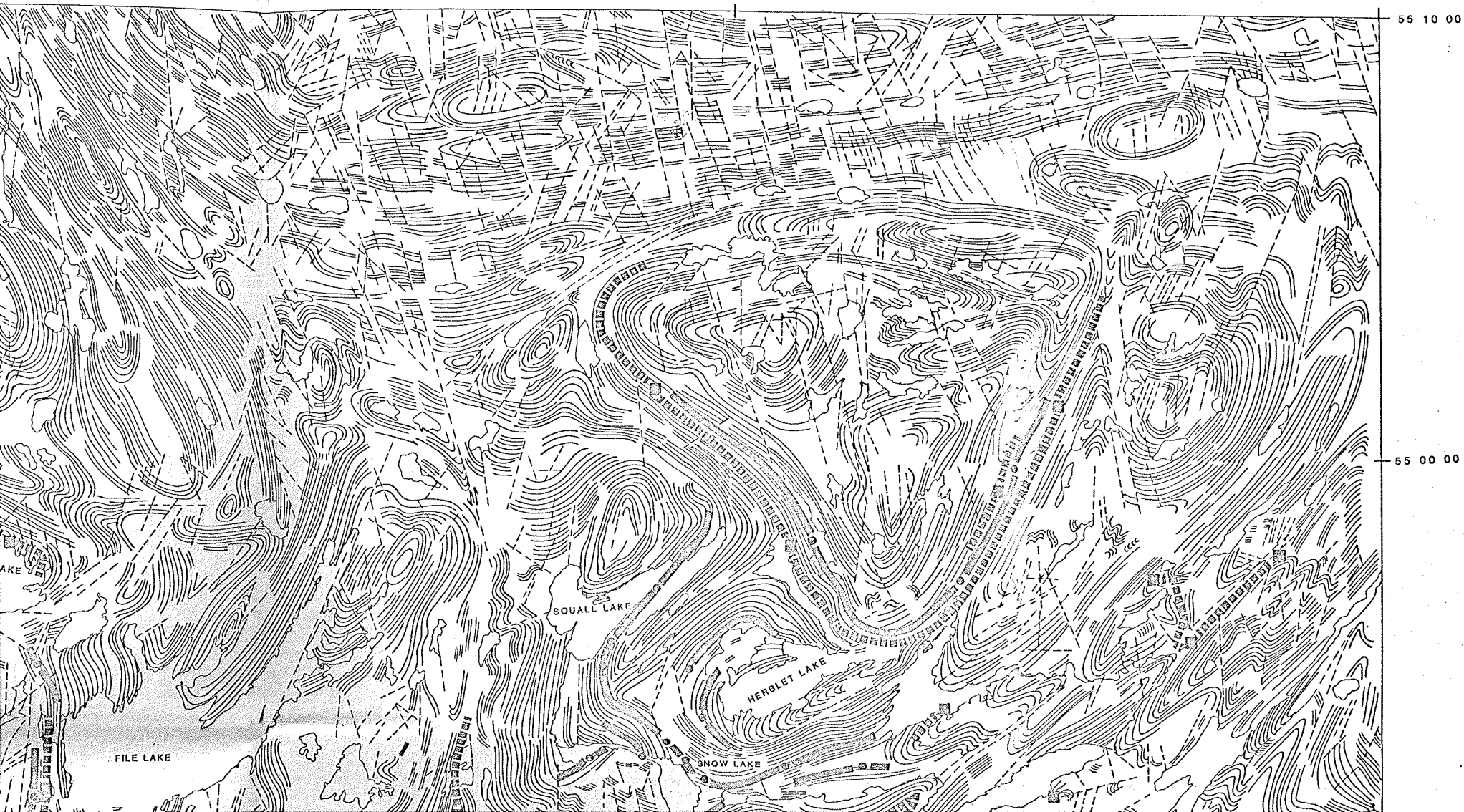
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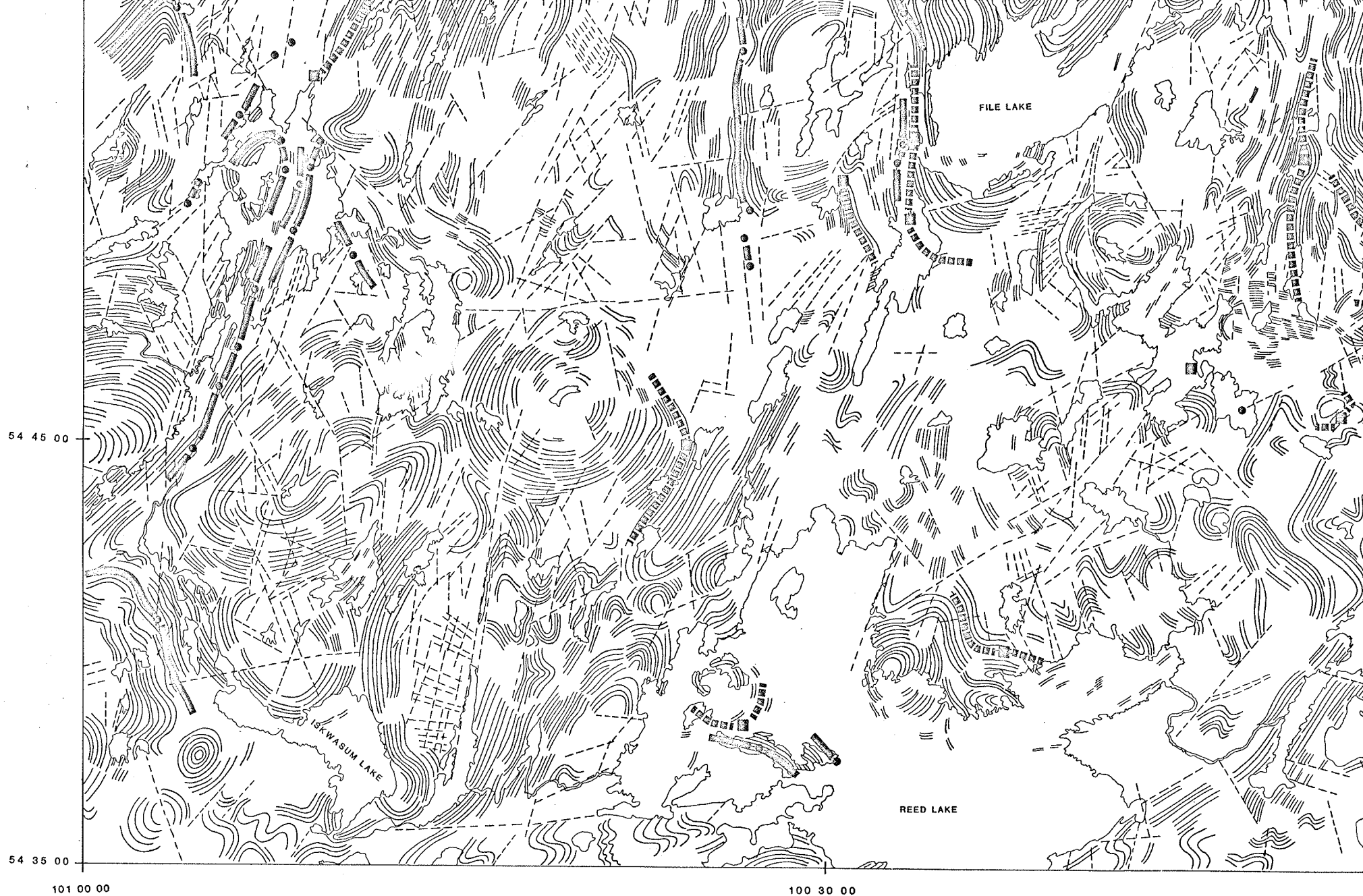
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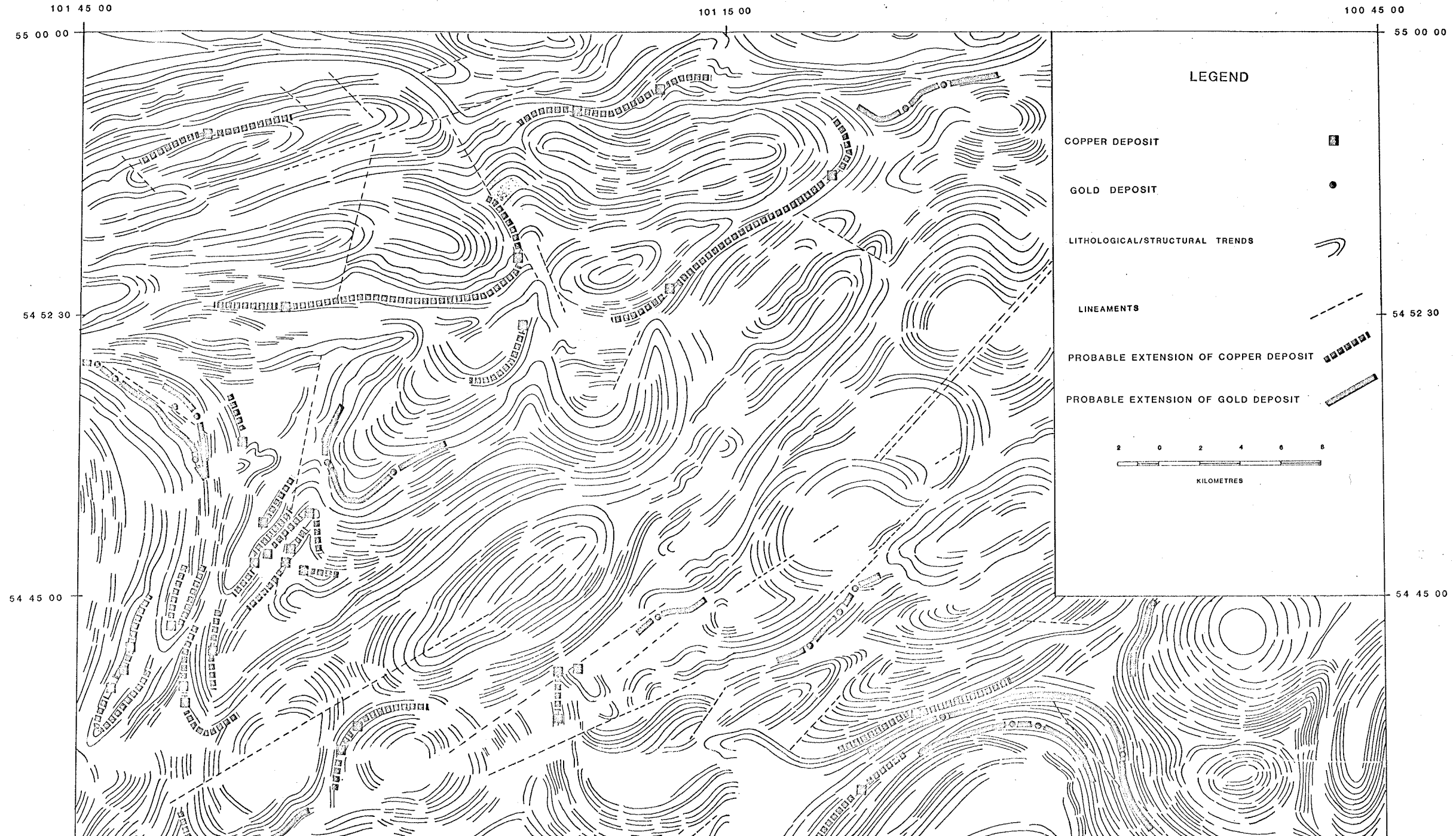
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LITHOLOGICAL/STRUCTURAL TRENDS AND OTHER LINEAMENTS AS INTERPRETED FROM

MAP NO.8

VERTICAL AEROMAGNETIC GRADIENT APPLICON PLOTS





(CRANBERRY PORTAGE AREA)