Tanner

Shuttle Imaging Radar (SIR-B):

Summary Report

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INTRODUCTION AND BACKGROUND

Radar is known to provide an important data-set for a range of geologic problems (Elachi et al., 1982). On planets other than Earth, radar data have provided fundamental information on surface properties (e.g. Pettingill et al., 1982) and these data have been applied to unit definition studies (e.g. Masursky et al., 1980) and local problems of geologic processes and evolution (e.g. Campbell et al., 1983; Sharpton and Head, 1982). The potential of radar has yet to be fully realized and there are several areas in the terrestrial environment where radar has not been fully considered as a geologic tool.

Routine access to low earth orbit provided by Space Shuttle holds potential for global studies of terrestrial resources and environment. A shuttle imaging radar (SIR-A) was flown on the Columbia orbiter in 1981. The radar was a side-looking, synthetic aperture radar that artifically illuminated the earth with horizontally polarized microwave radiation in the L-band, corresponding to a wave-length of 23cm.

The system exceeded expectations and comparison of SIR-A data with imagery acquired by Seasat in 1978 provided new insights into the backscattering characteristics of terrestrial terrains. The principal difference between these systems was that Seasat illuminated the surface at a 20° incidence angle (as measured from the vertical), whereas SIR-A illuminated the surface at 50°. Radar backscatter from natural terrain is primarily governed by variations in surface slope at smaller angles of incidence and by surface roughness at larger angles (typically greater than 30°). Large-scale variations in backscatter observed in Seasat and SIR-A imagery of the same area can be directly related to variations in topographic relief and surface roughness. Backscatter differences were also detected in imagery of relatively smooth, flat areas and are probably related to seasonal variations in soil moisture conditions.

Following the success of SIR-B, NASA decided to undertake a more ambitious radar imagery program in the form of SIR-B. The principal differences, compared to the SIR-A experiment, were an extension of the orbital path to approximately 60° latitude and the capability of the instrument for variable incidence angle, thus allowing multiple images of the same area at different radar incidence. This latter capability was designed to significantly improve the utility of the radar to detect a variety of surface slopes and better define structural features.

Given the potential for access to a new data-base for structural interpretation, a joint proposal was submitted in 1983 to NASA with workers at Brown University, Haystack Observatory, Hawaii Institute of Geophysics and Johnson Space Center. The proposal was entitled Geological, Structural and Geomorphological Analyses from Space Shuttle (SIR-B) Radar and was ultimately selected from participation in the SIR-B experiment.

PROPOSED WORK

The purpose of the proposal was to utilize the unique characteristics of the SIR-B experiment to develop a better understanding of the application of radar to geologic studies. From the point of potential Branch programs, the application of radar studies to the interpretation of the tectonic evolution of the Shield is considered a logical goal. Radar images, however, are not as straightforward to interpret as those at visible or near visible spectrum wavelengths, such as are acquired by LANDSAT. Therefore, the geologic environments examined were restricted to a limited number of well-characterized features which had considerable ancillary data, in order to explore and document the range of radar applications for terrestrial geology. Two environments were chosen: (i) deltaic environments - to examine delta morphology and the intertidal zone, the surface expression of shallow bathymetry, the characterization of vegetation cover, and the water balance of

the delta. (ii) impact crater environments - to examine the utility of radar in characterizing structural elements and applying this to the better definition of poorly exposed impact structures. Impact craters were chosen as a test of radar as a structural tool as they represent, to a first order, an externally imposed structural form, which is not dictated by local geology.

The original proposal contains some detailed discussion of the use of two-dimensional Fourier transforms to assist in the development of unit definition maps and is available for inspection. Details of the deltaic environments experiment are also given in the proposal and will not be repeated further here. As it relied in part on the results of past EPB research efforts, some details of the impact crater environment experiment are given below.

For reasons of long-term stability and vigorous crater-search programs, the majority of known terrestrial craters are located on the N. American and European cratons. The potential coverage of SIR-B extended to approximately 60°N and included many of these structures. For structures on the N. American craton (Fig. 1), those occurring on the Canadian Shield represent a sample with relatively constant target characteristics and for which the geology and geophysics are relatively well-known. Accordingly, a selected number of these structures were chosen as primary targets for study. Two principal experiments were proposed.

(1) <u>Establish Radar Characteristics of Exposed Impact Craters</u>: It was proposed to use SIR-B data to establish the radar characteristics of a selected number of large terrestrial craters and thereby augment our knowledge of terrestrial craters. As a first step, the data obtained by SIR-B were to be compared with LANDSAT and geological data to establish correlations between radar characteristics and ground-truth information. The structures selected for study were: Manicouagan (D~ 100km), the twin Clearwater Lake structures

(D~ 32km and 22km), Mistastin (D~ 28km), Charlevoix (D~ 54km) and Sudbury (D~ 140km). The specific scientific rationale for targeting these sites need not be given here. Considerable previous geologic investigations have been undertaken at these structures and, because of their northerly latitude (Fig. 1), SIR-B data had the potential to provide images with look angles other than those provided with solar illumination. These images were considered important in structural studies.

(2) Test Detectability of Very Poorly Exposed Impact Craters Using Radar: It is unlikely that radar will detect impact craters that are completely buried. There are, however, a number of structures which are partially buried or extremely heavily eroded and have little known surface expression. To determine the utility of radar in defining structural elements of craters of these types, the Carswell and Lake St. Martin structures were selected as potential test sites (Fig. 1). Lake St. Martin (D~ 23km) is partially buried beneath post-crater red beds and evaporites of Jurassic age. The geology of the area is poorly exposed, due to a covering of glacial clays. As a result, the structural elements and size of the structure are not well-defined and are known only from a shallow drilling program. SIR-B data on Lake St. Martin was to be analyzed to determine whether it provided additional structural information on partially buried craters. In the case of Carswell, the structure has been eroded to the extent that it has little topographic expression. As with Sudbury, it has considerable economic interest. Uranium mineralization, related to a basement regolith, is exposed in a few places by the structural uplift of the central portion of the crater (Johns, 1970). The Carswell structure is virtually undetectable on LANDSAT images, although a circular pattern is visible on geologic maps as the discontinuous distribution of various lithological units. The area is relatively featureless and geologic outcrop relatively poor. Radar images of

the structure were to help define better the radial dimensions of the structure and details of the uplifted central area, which is of economic interest.

As originally conceived, the proposed experiments and analysis were expected to take three years. The basic work plan was as follows. Prior to data acquisition by SIR-B, support data from published reports would be acquired. Thematic Mapper (TM) images for digital comparison would also be acquired, as would Large Format Camera (LFC) images. These were essential to prepare structural maps to compare with the different illumination direction of SIR-B. In the first year, existing data were to be collected and analyzed. In the second year, structural mapping and unit definition and characterization of SIR-B images was to be undertaken. TM and LFC image analysis was to be initiated in the second year and completed in the third year, during which time correlations between data sets were also to be carried out.

The SIR-B data requested for each of the impact crater test sites included three images acquired at different incidence angles (~50°, 60°, 70°) to acquire scattering information. These images were to be acquired in the same orbital direction (ascending or descending). A fourth image acquired at a different look direction, but at one of the incidence angles, was also required for analysis of illumination direction effects.

THE SIR-B MISSION

The SIR-B experiment was launched aboard Space Shuttle Flight 41-G, which coincidentally had M. Garneau as a payload specialist. Launch was on Oct. 5, 1984 at 11:03 G.M.T. The launch was nominal and 1 hour after launch the radar was turned on and tested successfully. During this test, the data-link with the TDRSS satellite also operated normally.

However, before the first science data-take took place, the first of a

series of problems arose. The TDRSS link antenna on the Shuttle went out of control and began moving erratically over 270° of arc. This led to a complete shut-down of the data link for 24 hrs and meant that data acquisition was limited to the seven magnetic tapes aboard Shuttle, effectively reducing the original planned 42 hrs of data acquisition to 2 hrs 20 mins.

On the second day, the crew and personnel at NASA-JSC managed to lock the TDRSS link-antenna in place so that the Shuttle, itself, could be maneuvered to establish data transmission to TDRSS. This permitted three data dumps per day, with each dump of 20 min duration. Although, this allowed the acquisition of an additional 1 hr of data per 24 hrs, it still did not allow direct data acquisition and transmission through TDRSS, which was a integral concept in the original experimental plan. In addition, as the on-board tapes had only two-thirds the bit-rate of the direct link, the width of the data swath was reduced by one-third. As the data dumps to TDRSS took considerable maneuvering on the part of the Shuttle, they could also only occur while the crew was awake. On the third day, an operator error at White Sands caused the TDRSS satellite to go out of control and all command and communications capability was lost for 24 hrs This led to the additional loss of coverage as well as wrong radar set-up parameters for a number of data takes.

By mission-end, it was possible to acquire approximately 8 hrs of digital narrow-swath data, corresponding to 15% of the original plan. It is hoped that 13 investigators/teams will ultimately get 50% of their planned data, 22 will get 25% and 8 will get few if any frames. Some optical recorder data was acquired for those who had little digital data, but it is of significantly lower quality. Unfortunately, the crater environment study fell into the last category. To date, three analog images of a swath that crosses the Charlevoix structure have been received, as well as a single image of the Deep Bay structure, which was acquired as part of another team's experiment.

The majority of the workers in the original proposal outlined earlier met at Brown University in April 1985 to decide what, if anything, could be done with the limited data available. Although no multiple-angle data were available and the single images were restricted to two structures, it was decided to proceed as best as possible. This meant effectively restricting interpretation to a lineament analysis and abandoning detailed quantitative analysis. As, at the time, there were rumors of a SIR-B flight, if was felt that this limited study would be more expedient than not attempting any analysis. It was also recognized that this analysis would be of lower scientific quality than required for a publication in Science as was originally planned.

THE RESULTS OF SIR-B ANALYSIS

Initial analysis has been limited to a comparative study of the structure in and around the imaged craters using SIR-B data and data obtained at visible wavelengths (LANDSAT and aerial photographs). These results will be presented at the International Geoscience and Remote Sensing Symposium, Amherst, MA, Oct. 7-9, 1985. A summary of the work is given below.

The Charlevoix crater structure is ~ 54km in diameter and is located on the north shore of the St. Lawrence River, Quebec (47°32'N, 70°18'W). The crater is approximately 360 my old, is heavily eroded, and is partially truncated by Logan's Line, a major structural feature in this region. The area is the site of anomalously high seismic activity. The impact occurred in Precambrian granitic gneisses, migmatites, charnockite gneisses, anorthosite, and minor gabbro of Grenville age, overlain by Ordovician carbonates thickening to approximately 2.5 km towards the SE. (Rondot, 1972). Superposed on the bedrock substrate are extensive glacial deposits and predominently forested regions (mostly black and white spruce), which have been locally cleared for agriculture. SIR-B Data Take 116.2 provided an image of a 37 km

wide swath across the central part of the crater at an incidence angle of 49.9 degrees, a look azimuth of N21.9E and a SW look direction (Fig. 2a).

The Deep Bay crater structure is ~ 12 km in diameter and is located in northern Saskatchewan (56°24'N, 102°59'W) at the southern end of Reindeer Lake. The crater is estimated to be ~ 100 my old and the interior is filled with a fresh-water lake leaving only the rim area and its surroundings visible. The impact crater formed in Precambrian biotite gneisses, hornblende gneisses, calcareous gneisses, and migmatite of Archean and Hudsonian age. The region has been heavily glaciated and the ground is lightly forested with spruce, tamarack, birch, and poplar. SIR-B Data Take 53.2 provided an image of a 23 km wide swath covering all of the crater lake and the surrounding region to the south, east, and west, at an incidence angle of 31.6 degree, a look azimuth of N10.3E and a SW look direction (Fig. 3a).

Lineament maps were compiled from analog SIR-B radar images (Figs. 2b and 3b) and compared with maps derived from LANDSAT data for Charlevoix (Fig. 2c; H.B. Moore, 1979) and aerial photography for Deep Bay (Fig. 3c; M.J.S. Innes et al., 1964). For each SIR-B site, the overlapping areas of the two data sites were digitized to facilitate computer analysis of the lineament distributions. Rose diagrams, scattergrams, and histograms of the lineament orientations, length, and aerial distribution were prepared from all data sets.

Several relations between lineament distribution and either crater structure or regional trends can be seen in the radar data. Regional trends due to glaciation are apparent in all data sets. The Charlevoix radar data set contains a node centered at N47W with a width of ±14 degrees (Fig. 2d,e), which is related to one of the two glacial trends in the area (N45W). The LANDSAT data set contains both this node and another node at N78W (Fig. 2f,g), which does not appear in the radar data, and appears to be related to the other regional glacial trend. The node at N78W in the LANDSAT data set is more evident when the aggregate length of lineaments in an orientation bin is

plotted than in the orientation frequency distribution, implying that this node is characterized by a small number of long lineaments (Fig. 2g).

In the Deep Bay lineament distribution, there is a node which correlates with the regional glacial trend. In the radar data set, this node is centered at N40E (Fig. 3,d, e) and is rather narrow (± 2 degrees), while in the aerial photography data set the node is centered at N35E, has a much higher amplitude, and is much wider (± 35 degrees) (c.f. Figs. 3d,e and 3f,g).

In the Charlevoix radar image, the number of lineaments detected drops off sharply for lineament orientations within approximately 20 degrees of the radar look azimuth, N21 9E (Figs. 2d,e). Several nodes which are apparent in the LANDSAT lineament distributions N5E, N31E, N68E (Figs. 2f,g) or absent in the radar lineament distribution (Figs. 2d,e). Due to the imaging geometry of this particular data take, any lineaments parallel to Logan's Line (Rondot, 1979) are not visible in the radar data. It is interesting to note, however, that these faults, which may be involved in current seismic activity (Anglin, 1984), are also not particularly apparent in LANDSAT data (Fig. 2c). The Deep Bay radar data also show an effect from the radar look direction. The regional glacial trend, which varies from approximately N15E to N30E, displays a much more prominent signature in the aerial photography then in the radar data (c.f. Figs. 3d,e and 3f,g), though it is still evident in the radar data with a minor node at N40E. These results confirm previous findings (J.P. Ford et al., 1980; Yamaguchi, 1985) on the influence of radar look direction on the interpretation of lineament distribution and orientation.

Effects from the impact event are also evident in the radar data. In both the Charlevoix and Deep Bay radar images, lineaments of 1 km or less in length are clustered at a distance of approximately 1 crater radius from the crater center and appear quite clearly to be associated with the interior of the original rim structure (Figs. 2b, and 3b). Also, the interior trough of the Charlevoix crater, excluding the central peak area, contains virtually no

lineaments (Figs. 2,b,c). This is most likely due to the greater depth to bedrock in the present crater interior caused by infilling by post-glacial sediments.

Once the digital data are received, additional work will concentrate on separating the data into spatial domains to study in detail the influence of the impact on the regional structure and a comparison will be made with other available radar data (Seasat) taken over other Canadian impact craters (Manicouagan, Mistastin, Carswell).

FUTURE CONSIDERATIONS

A reflight of SIR-B is currently planned for the Spring of 1987. The mission will be the third launch from Vandenberg Air Force Base and will be flown in a polar orbit at a mean altitude of 270 km. A preliminary orbital node of 18°E has been selected and it is anticipated that there will be time available for 60-80 hrs of radar imaging, depending on orbital and other Shuttle constraints. Although details are likely to change, present ground tracks indicate that it will be possible to image Clearwater, Manicouagan and Sudbury. Unfortunately, the Haughton structure on Devon Island will not be imaged.

NASA has indicated that the teams and science experiments selected for the original SIR-B mission are welcome to take part in the reflight. Accordingly, the science rationale of the original proposal will be retained for the reflight, although there may be some changes in specific site selection. In the meantime, progress will continue towards acquiring ancillary data, particularly Thematic Mapper data and further analysis of the Charlevoix and Deep Bay images will be undertaken, e.g. correlation of radar brightness and topographic variations. The limited and relatively poor quality of these data, however, are not likely to result in any significant scientific product, although they will provide invaluable experience.

It is hoped that experience gained with SIR-B will prove useful and

indicate the ultimate utility of radar as as structural mapping tool. Extension to problems in the tectonic evolution of the Shield could be achieved using Canadian data through involvement in the analysis of RADARSAT data. RADARSAT is scheduled for a 1990 launch and will have a multiple incidence, C-band radar with a nominal resolution of 25m and a 150 km swath width. It will be placed in a near polar orbit with coverage <76°N and will be capable of stereo-imagery. It is hoped that Branch scientific personnel will begin to consider the potential of radar imagery for topographic and structural analysis in their current and future research studies. As with most high-cost complicated data acquisition programs, it is almost too late to become involved once actual data acquisition commences.

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FIGURE CAPTIONS

Fig. 1 Location of currently known impact structures > 1 km in diameter in North America. 1, Haughton Dome; 2. Nicholson Lake; 3, Pilot Lake; 4, Steen River; 5, New Quebec; 6, Lac Couture; 7, Lac La Moinerie; 8, Carswell; 9, Gow Lake; 10, Deep Bay; 11, Clearwater (East and West); 12, Mistastin; 13, Lake St. Martin; 14, West Hawk Lake; 15, Ile Rouleau; 16, Manicouagan; 17 Red Wing; 18, Slate Islands; 19 Sudbury; 20, Wanapitei; 21, Brent; 22, Holleford; 23, Charlevoix; 24, Conception Bay; 25, Manson; 26, Kentland; 27, Serpent Mound; 28, Decaturville; 29 Crooked Creek; 30, Barringer; 31, Wells Creek; 32, Flynn Creek; 33 Middlesboro; 34, Sierra Madera.

Fig. 2. Charlevoix area

a) Analog SIR-B radar image. Dark straight or near straigh lines are power lines, dark patches are either water or areas under cultivation. Image is one of three and is of poorer quality than original image. See text for details of data take.

b) Schematic of radar lineaments defined from three SIR-B radar image.

c) Schematic of LANDSAT lineaments, taken from Moore, (1979). Dashed lineaments are less pronounced. Compare with 2b.

d) Rose diagram of number and orientation of radar lineaments noted from 2b. Note lack of lineaments at 20°E ± 20°. See text for details. 80° E and W are incorrect, they should read 90°.

e) Rose diagram of length and orientation of radar lineaments noted from 2b.

f) Rose diagram of numbers and orientation of LANDSAT lineaments noted from 2c. Compare with 2d and e. 80° E and W were incorrect, they should read 90°.

g) Rose diagram of length and orientation of LANDSAT lineaments noted from 2c. Compare with 2d and e.

Fig. 3 Deep Bay area

(a)Analog SIR-B radar image. Dark patches are water. See text for details of data take.

(b) Schematic of radar lineaments defined from SIR-B radar image.

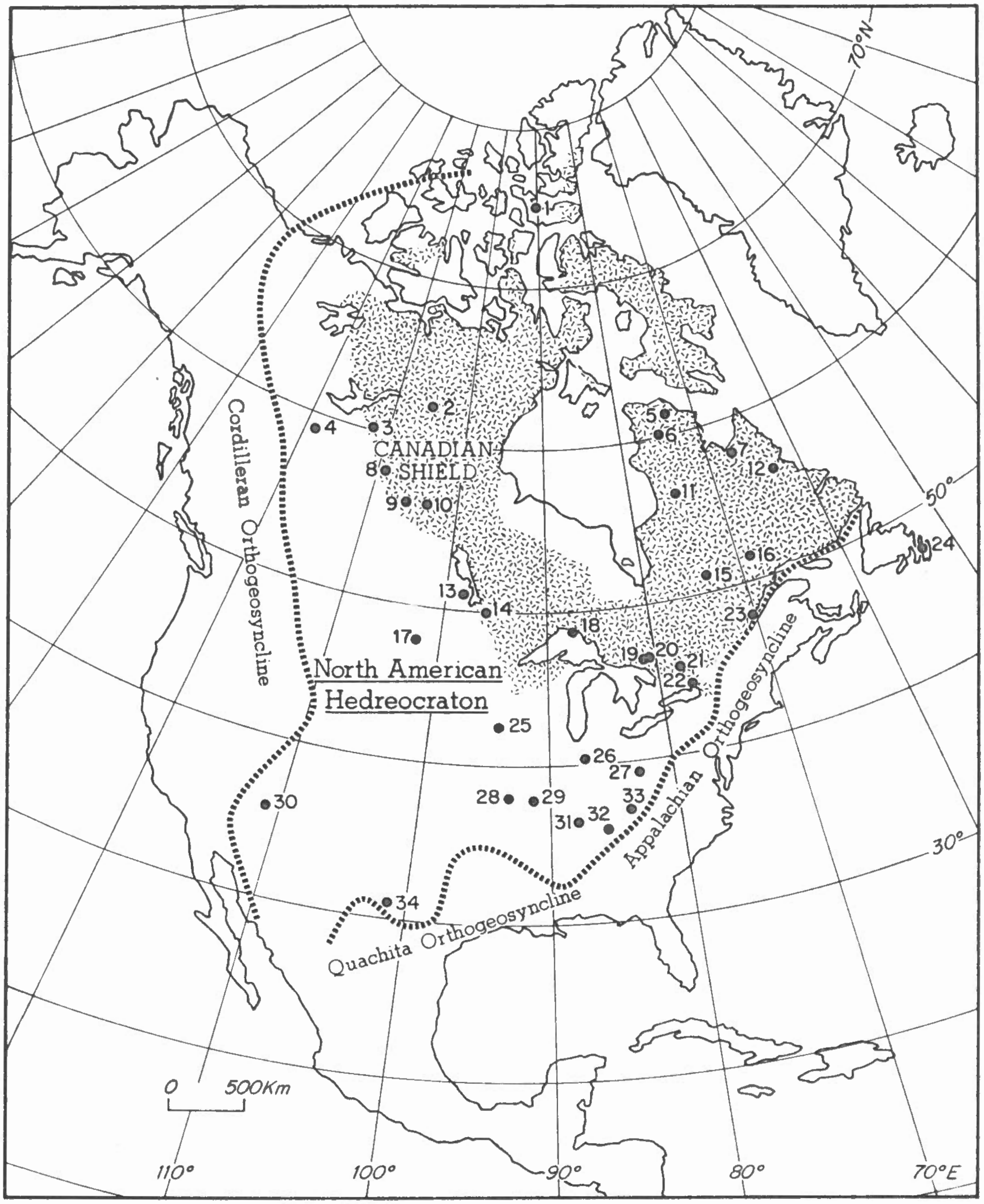
(c) Schematic of air-photo lineaments, taken from Innes et al. (1964).

(d) Rose diagram of number and orientation of radar lineaments noted from 3b. 80°E and W are incorrect, they sould read 90°.

(e) Rose diagram of length and orientation of radar lineaments noted from 3b.

(f) Rose diagram of numbers and orientation of air-photo lineaments noted from 3c. 80°E and W are incorrect, they shoul read 90°. Compare with 3d and e.

(g) Rose diagram of length and orientation of air-photograph lineaments noted from 3c. Compare with 3d and e.


70°N
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North American Hedreocraton
Cordilleran Orthogeosyncline
Appalachian Orthogeosyncline
Quachita Orthogeosyncline
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Fig. 1

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Fig. 26

CHARLEVOIX CRATER, QUEBEC - RADAR LINEAMENTS

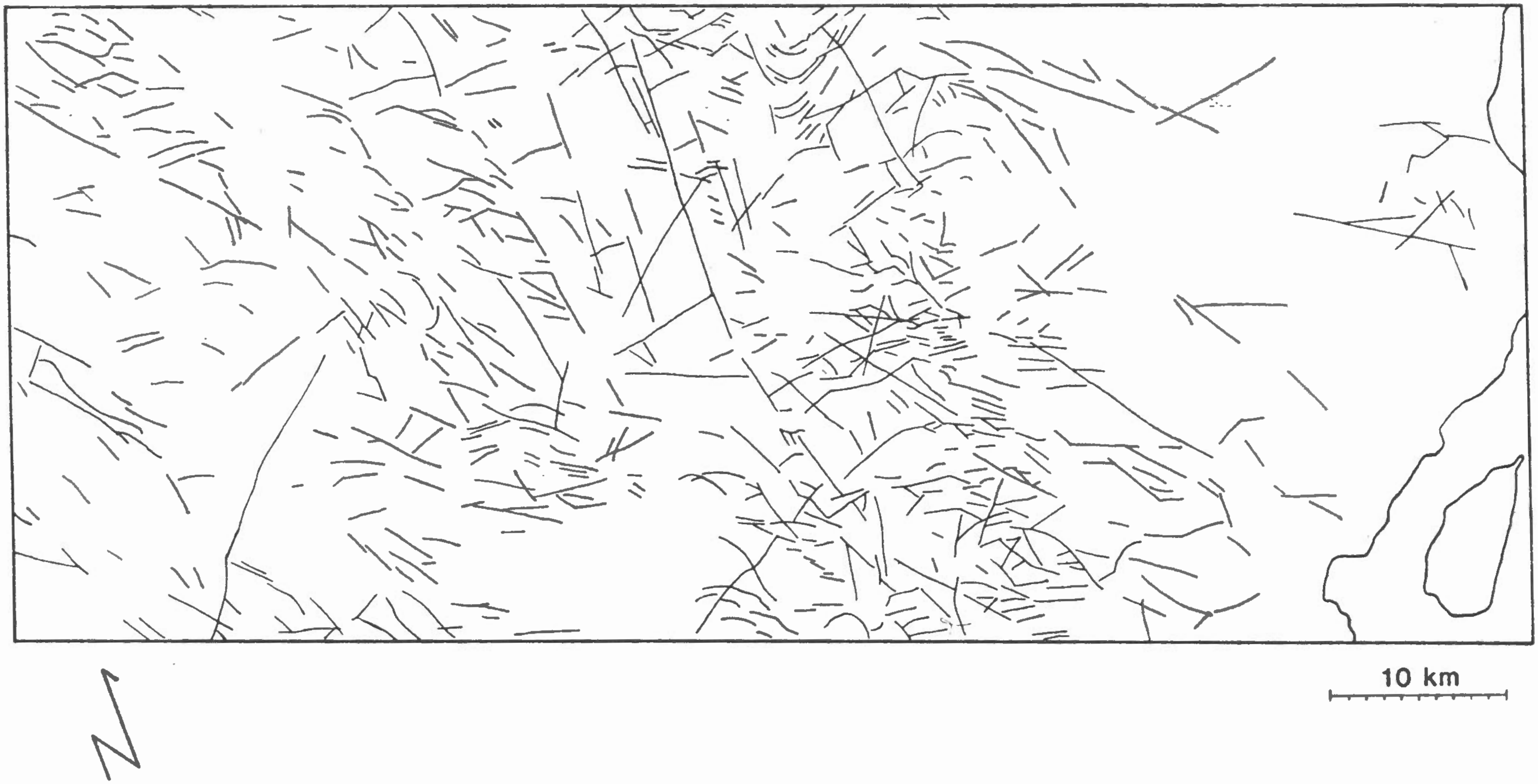
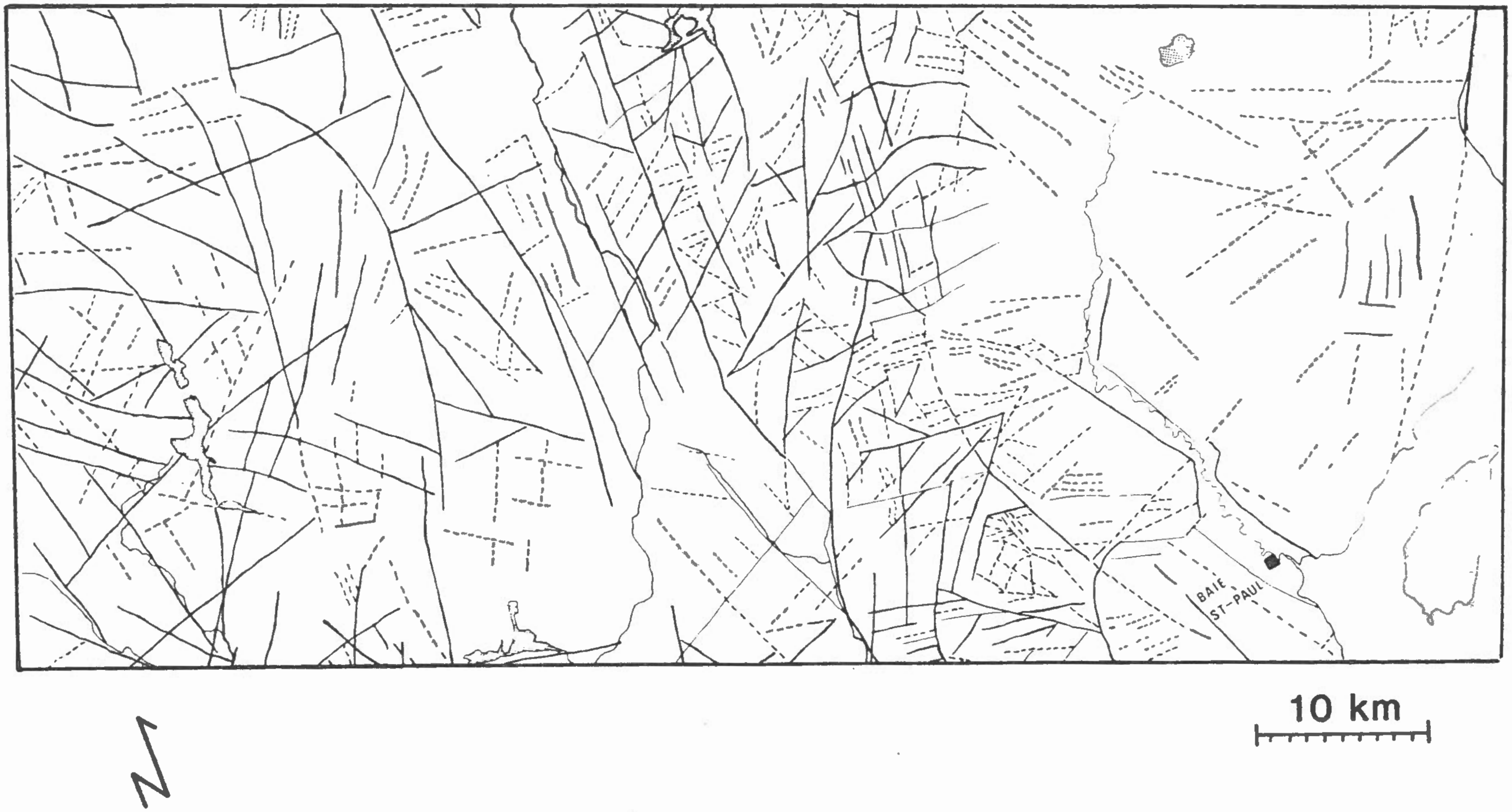


Fig. 2e.

CHARLEVOIX CRATER, QUEBEC – LANDSAT LINEAMENTS



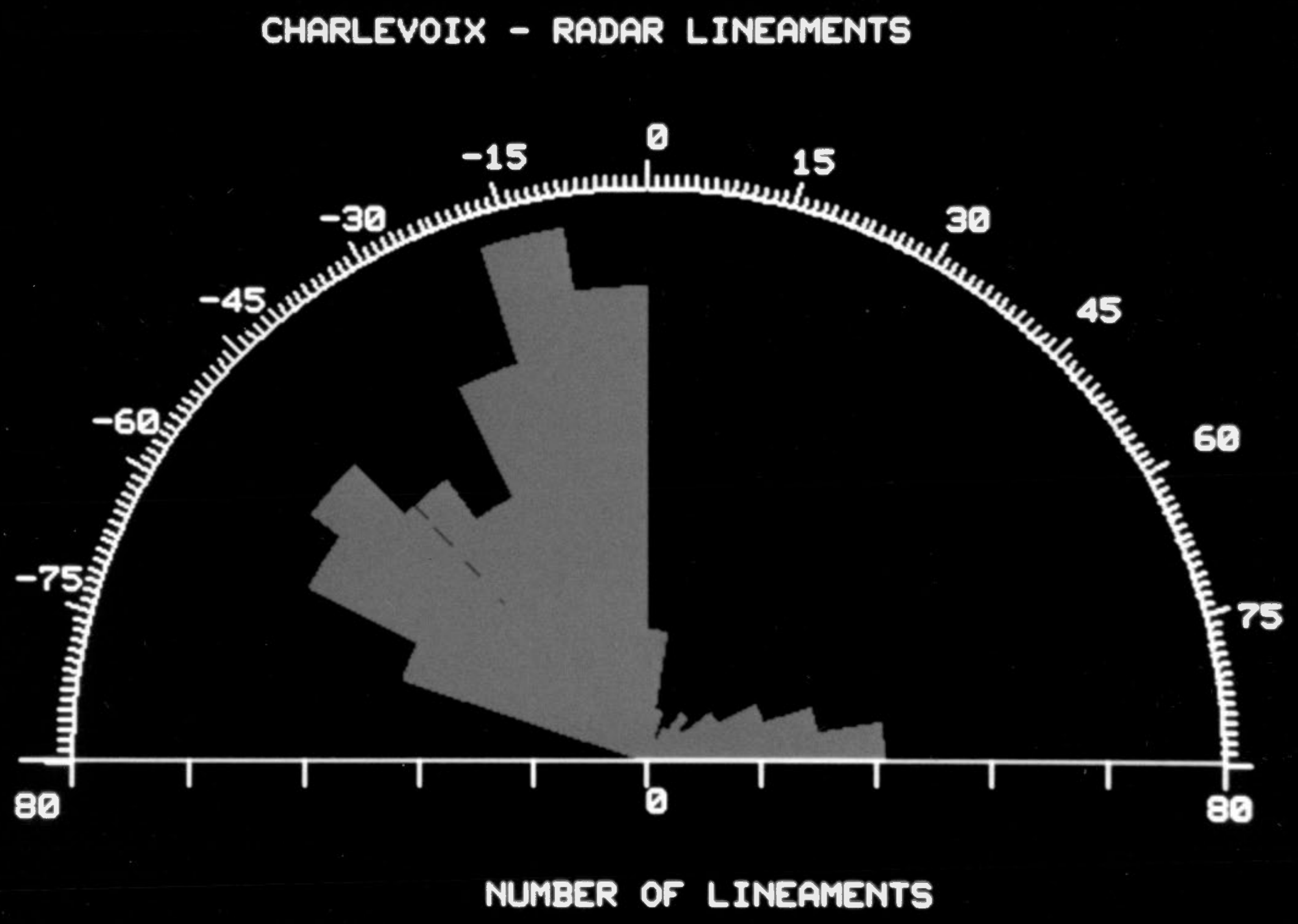

CHARLEVOIX - RADAR LINEAMENTS
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Fig 2d

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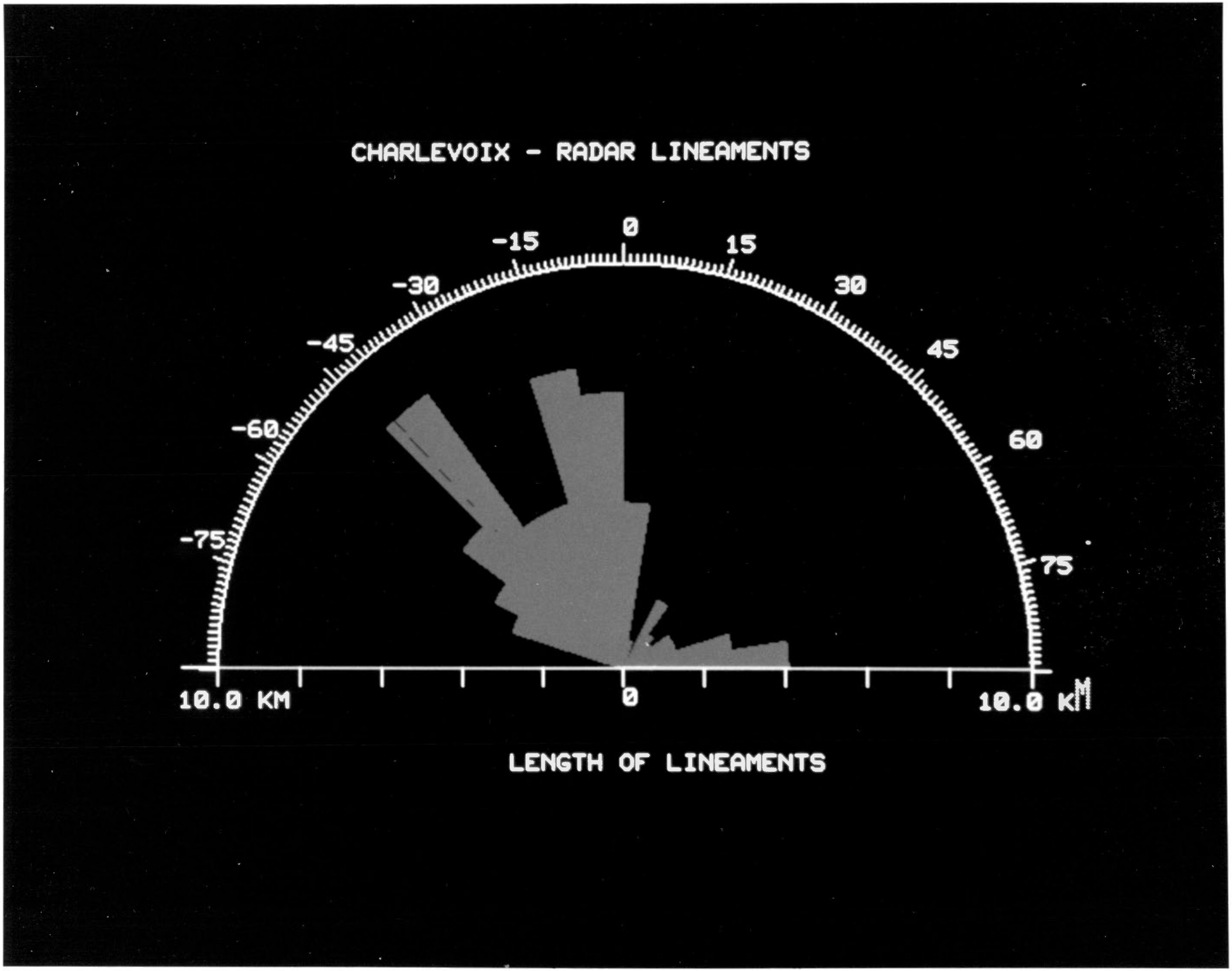
CHARLEVOIX - RADAR LINEAMENTS
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Fig 2e

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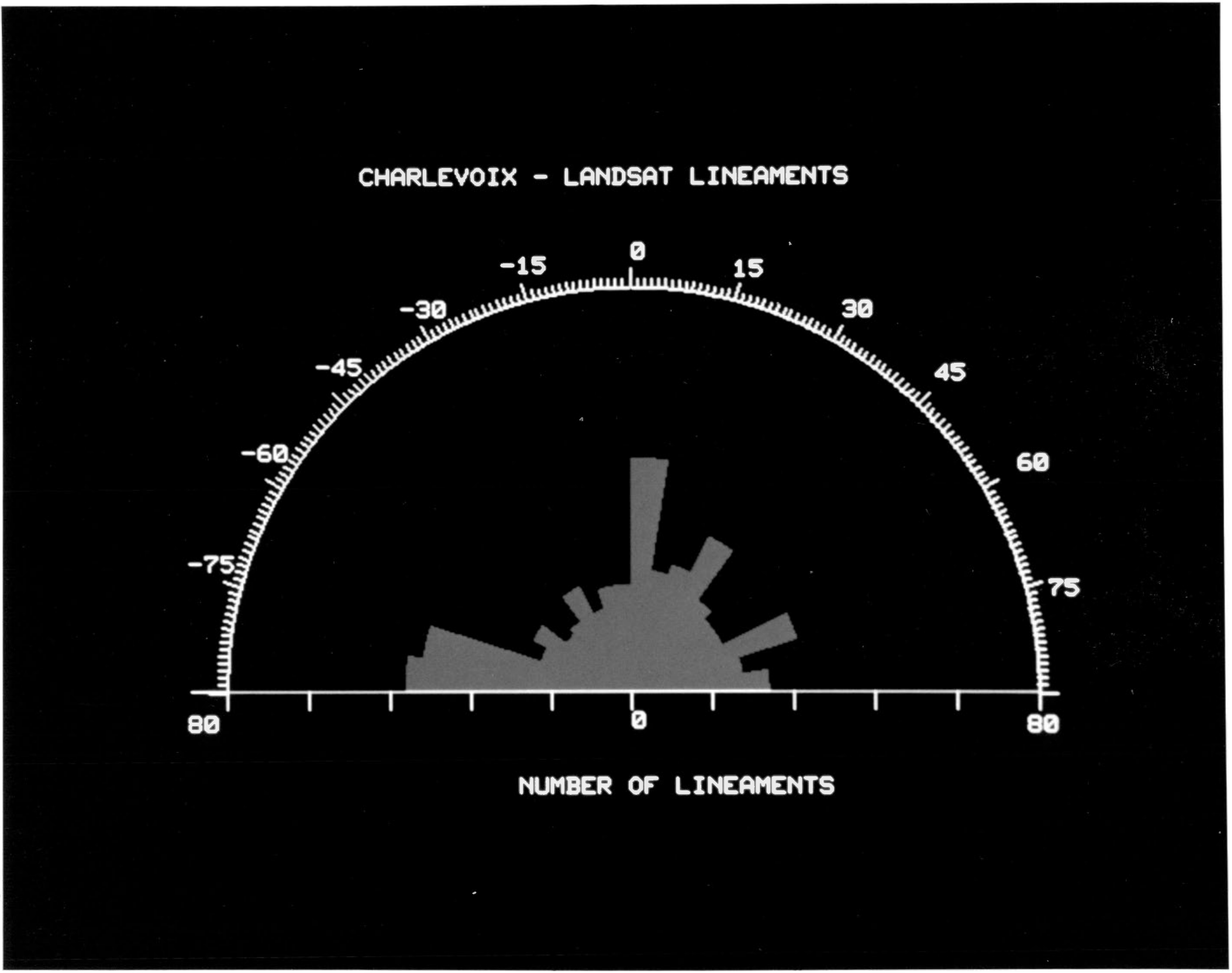
CHARLEVOIX - LANDSAT LINEAMENTS
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NUMBER OF LINEAMENTS

Fig 27

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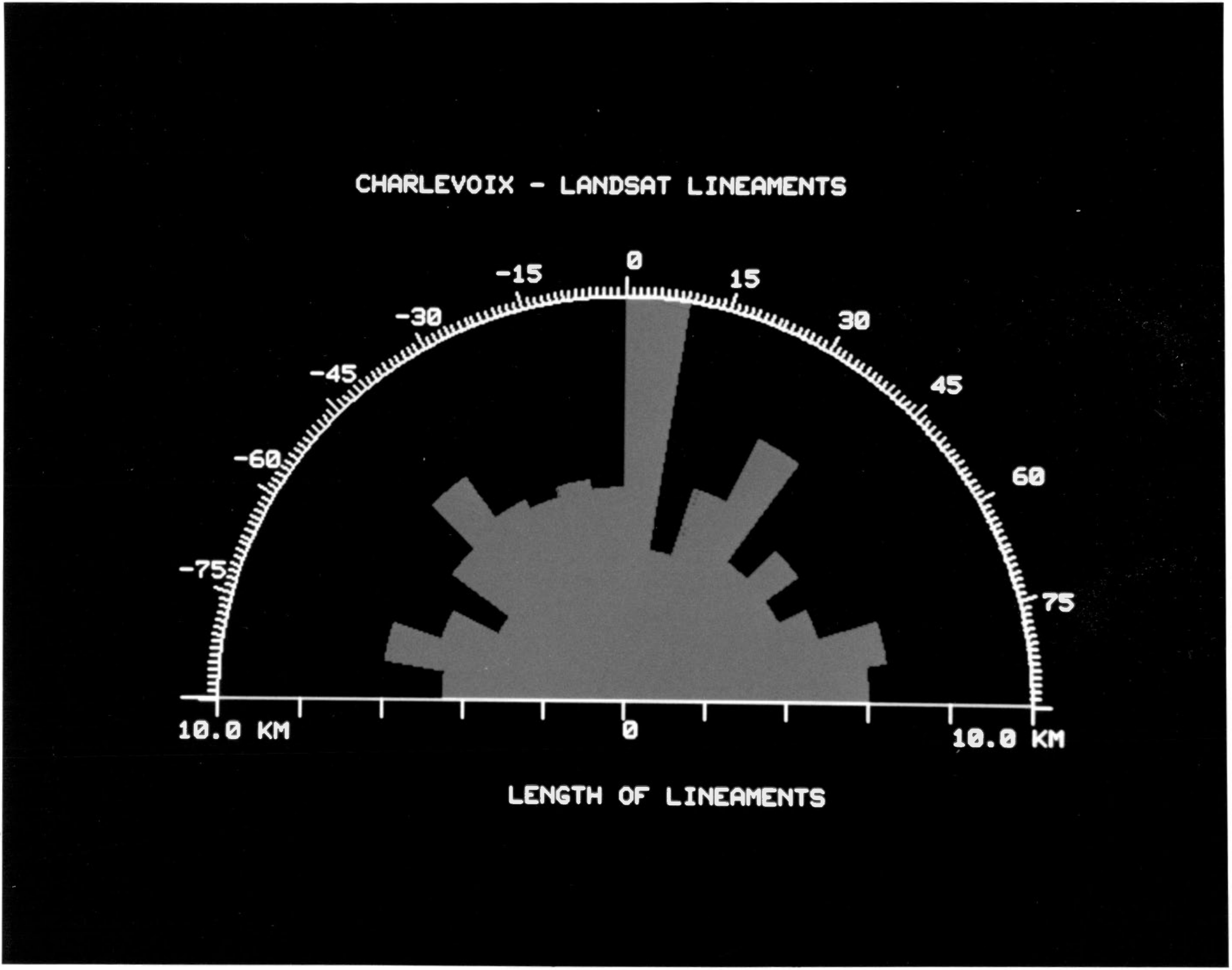
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Fig 25

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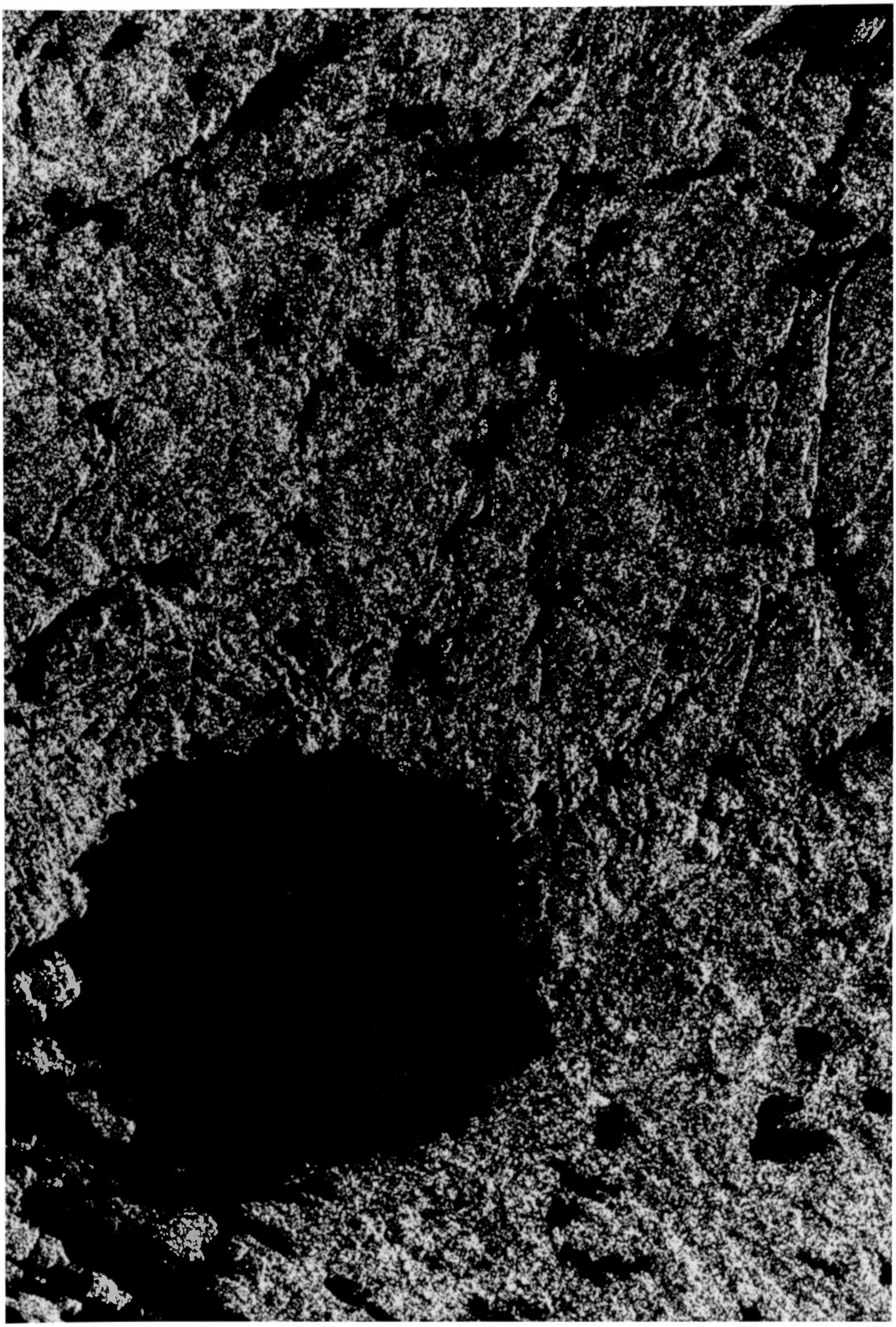

Fig 3a

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DEEP BAY, SASKATCHEWAN - RADAR LINEAMENTS

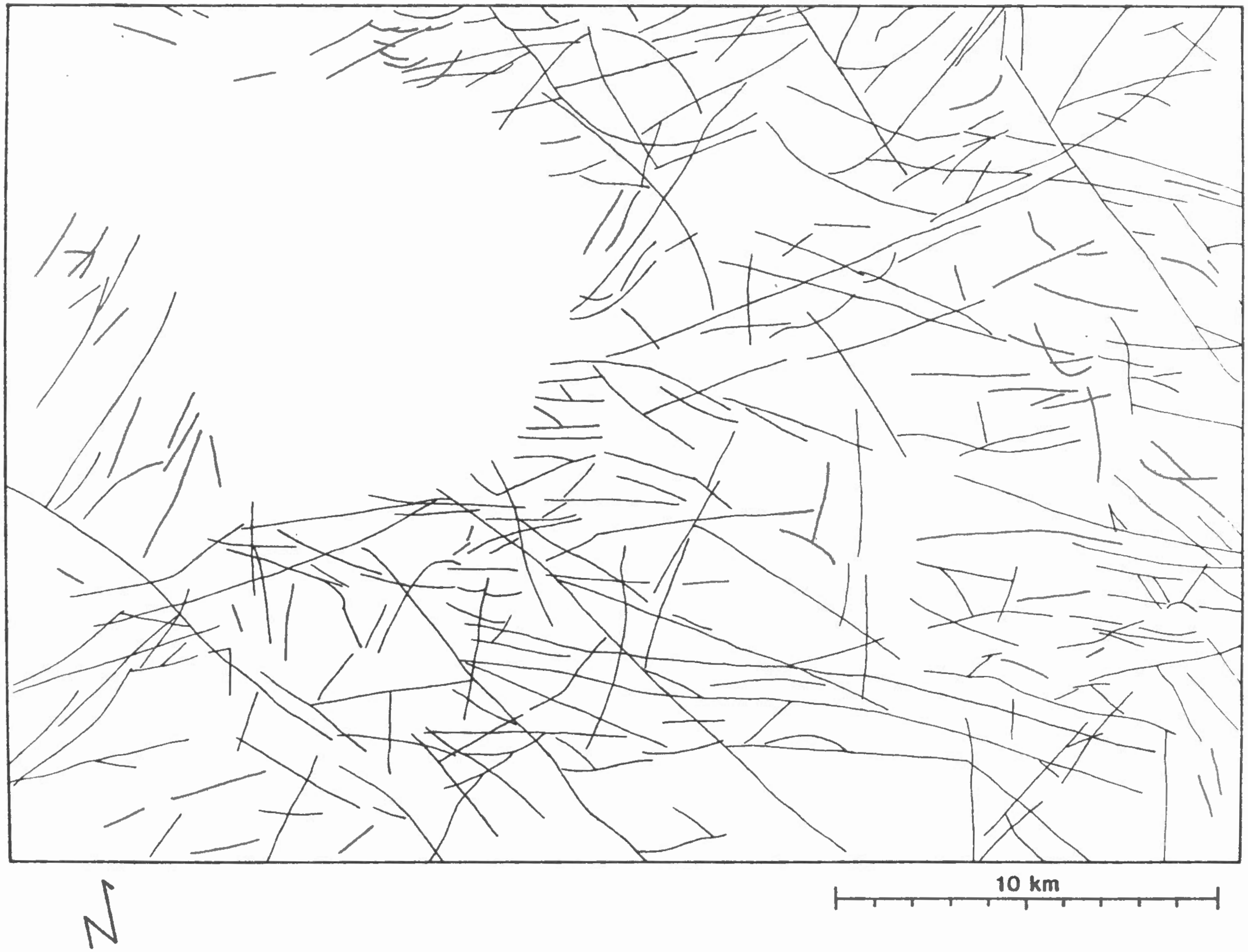


Fig 3b.

DEEP BAY, SASKATCHEWAN - AIR PHOTO LINEAMENTS

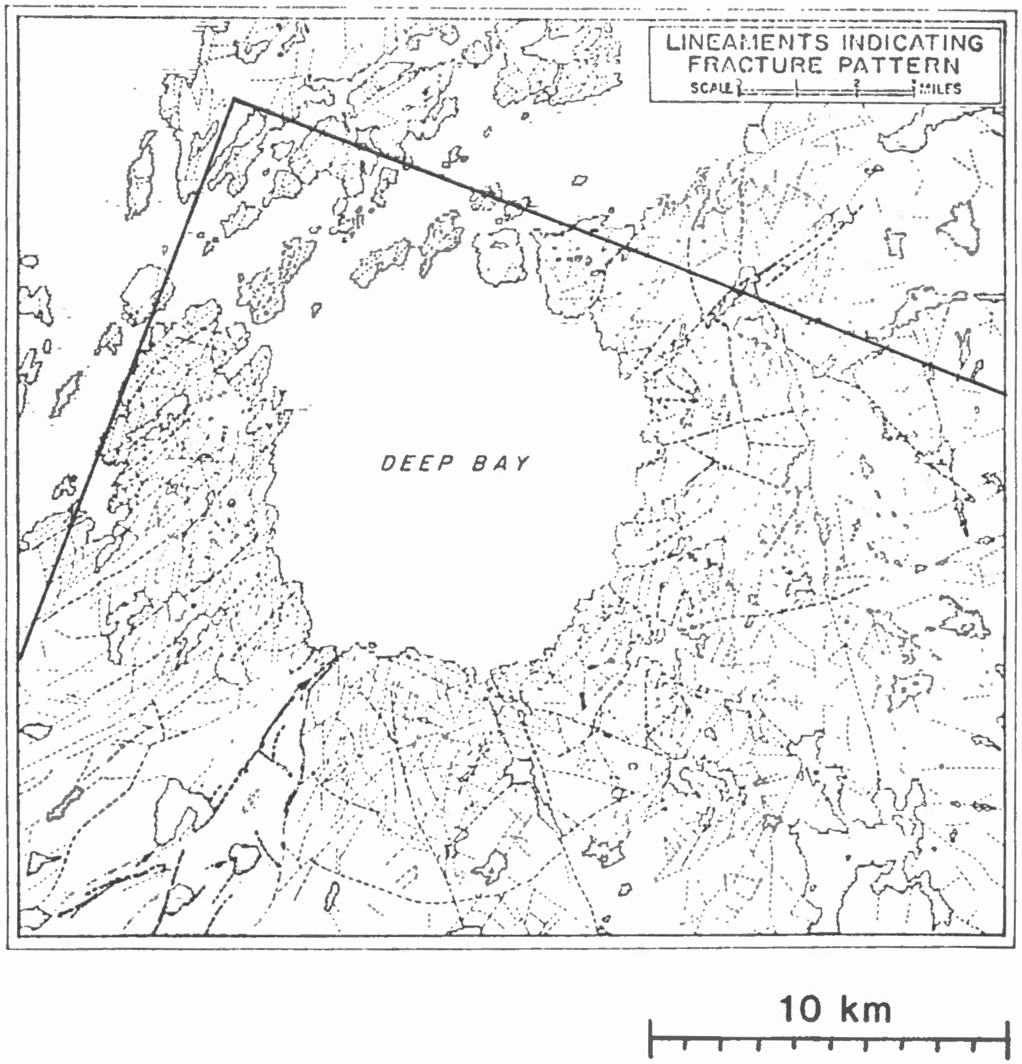
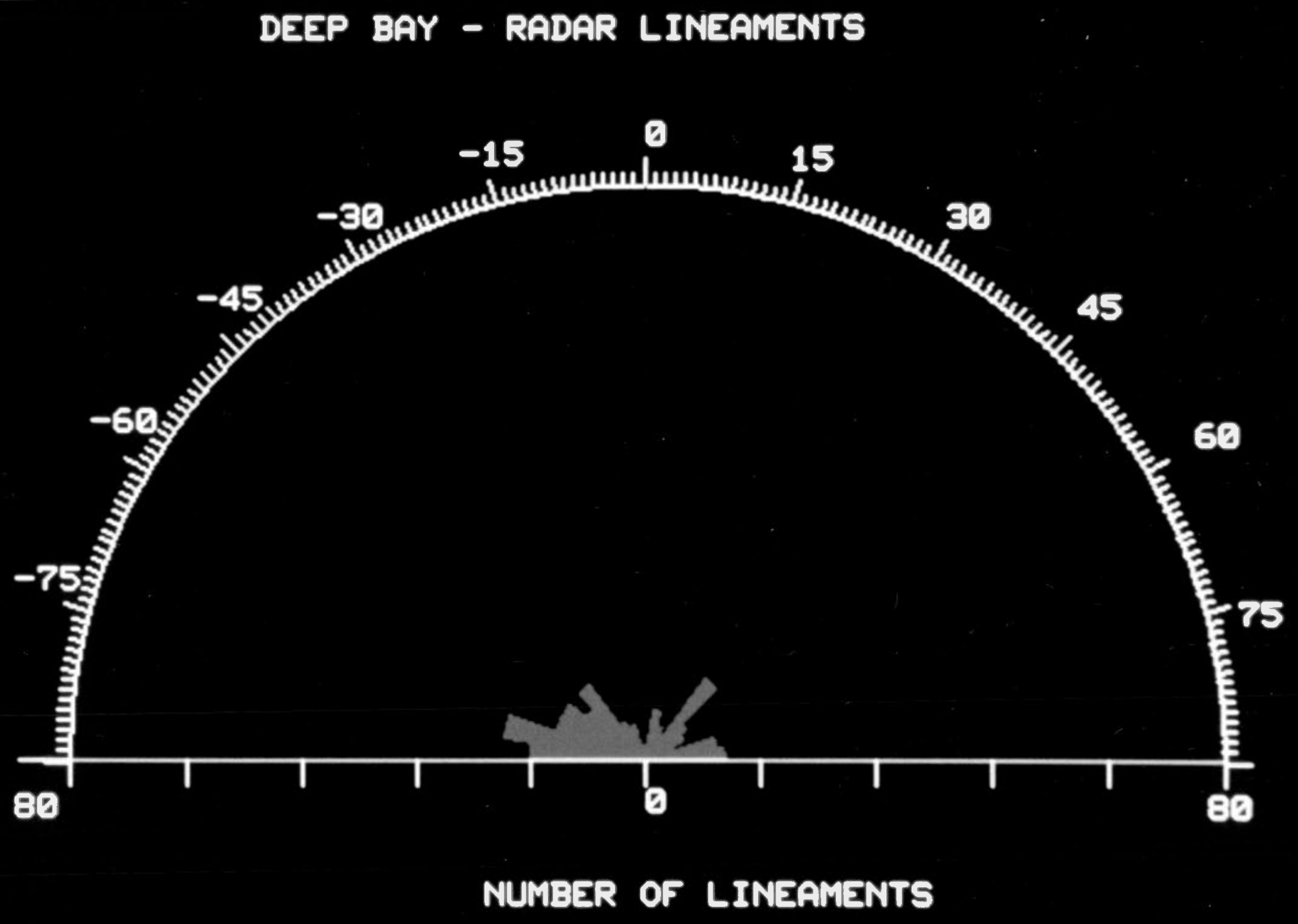


Fig 3e.


DEEP BAY - RADAR LINEAMENTS
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NUMBER OF LINEAMENTS

Fig 3a

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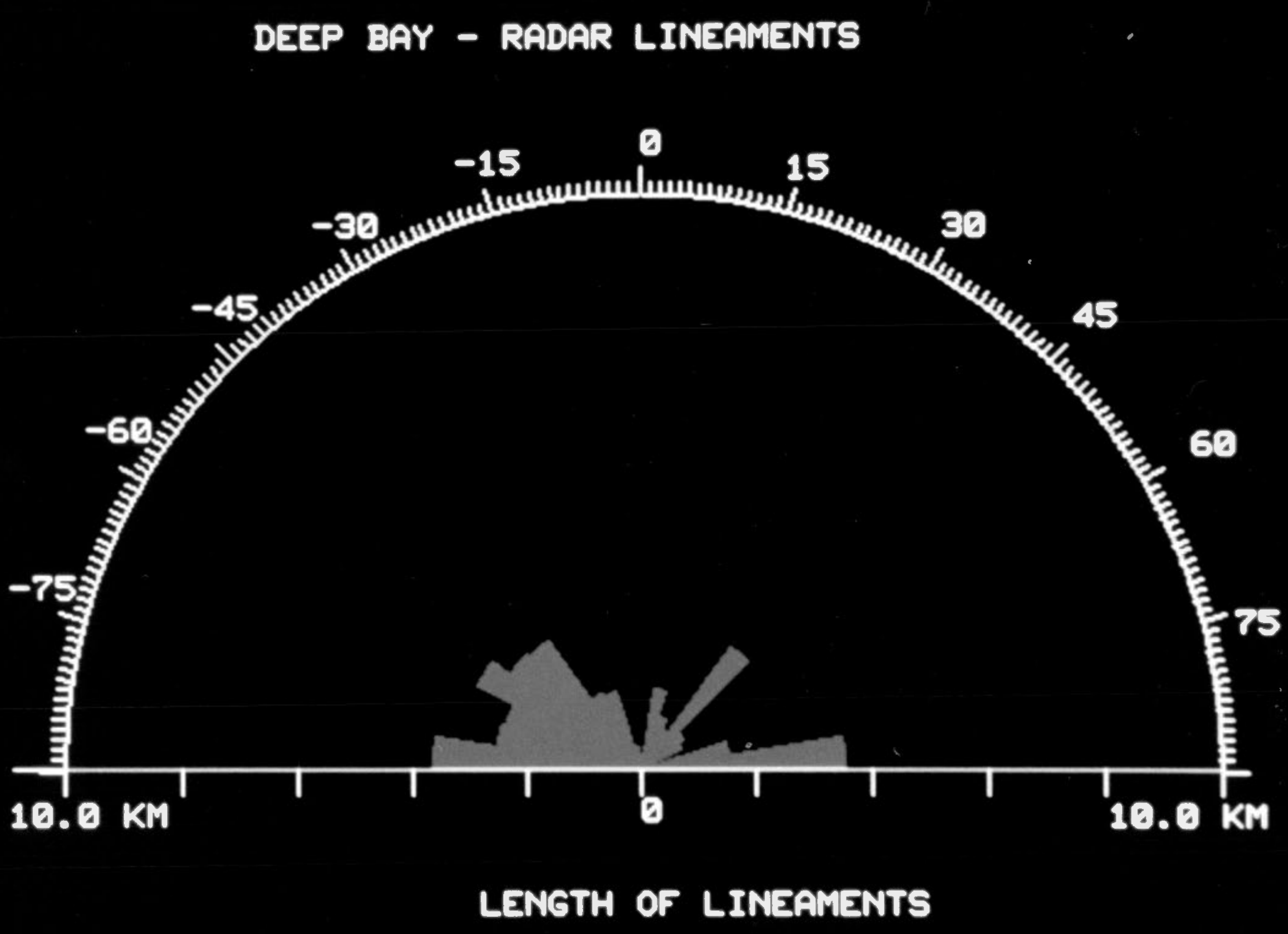
DEEP BAY - RADAR LINEAMENTS
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LENGTH OF LINEAMENTS

Fig 3e

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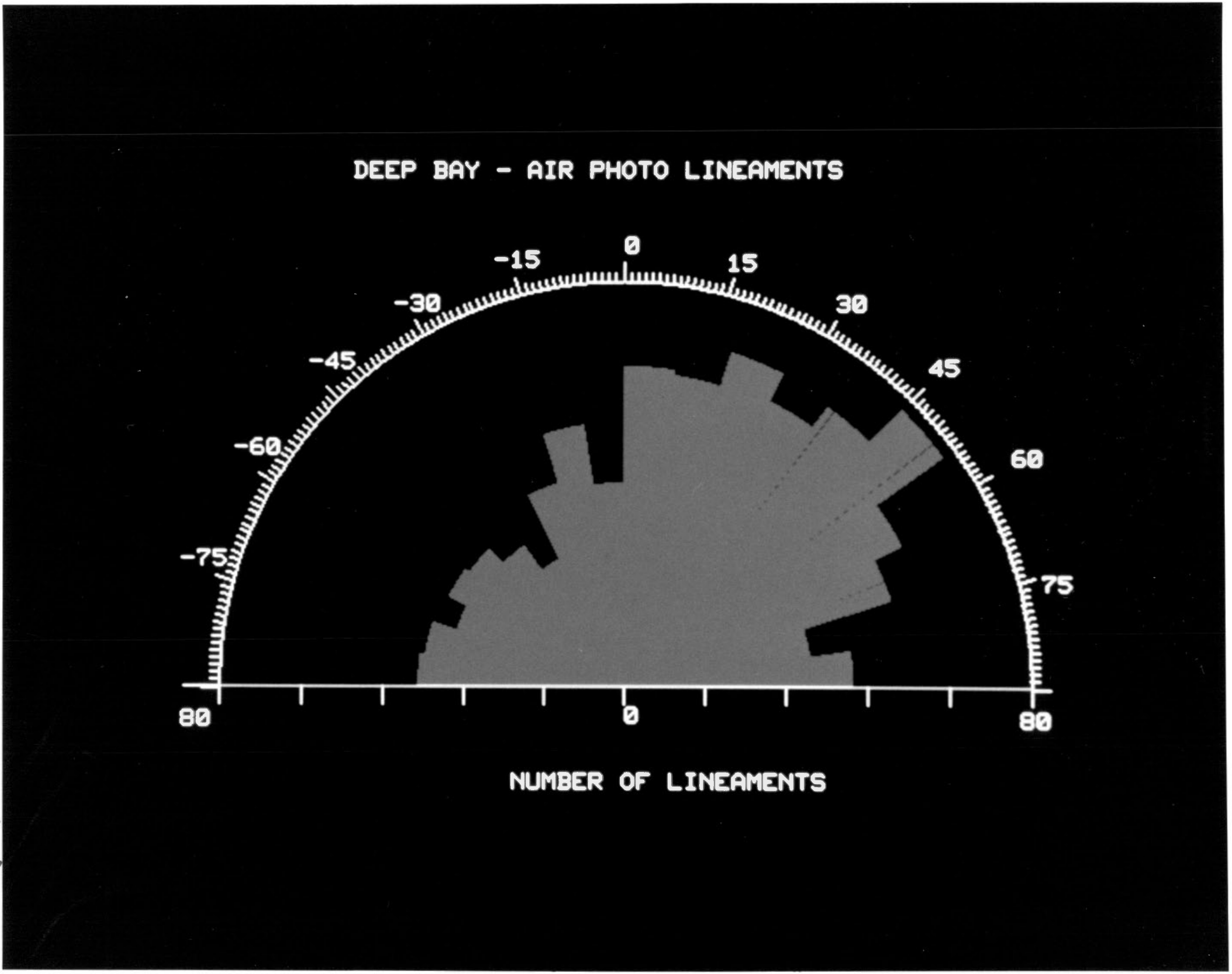
DEEP BAY - AIR PHOTO LINEAMENTS
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NUMBER OF LINEAMENTS

Fig 3f

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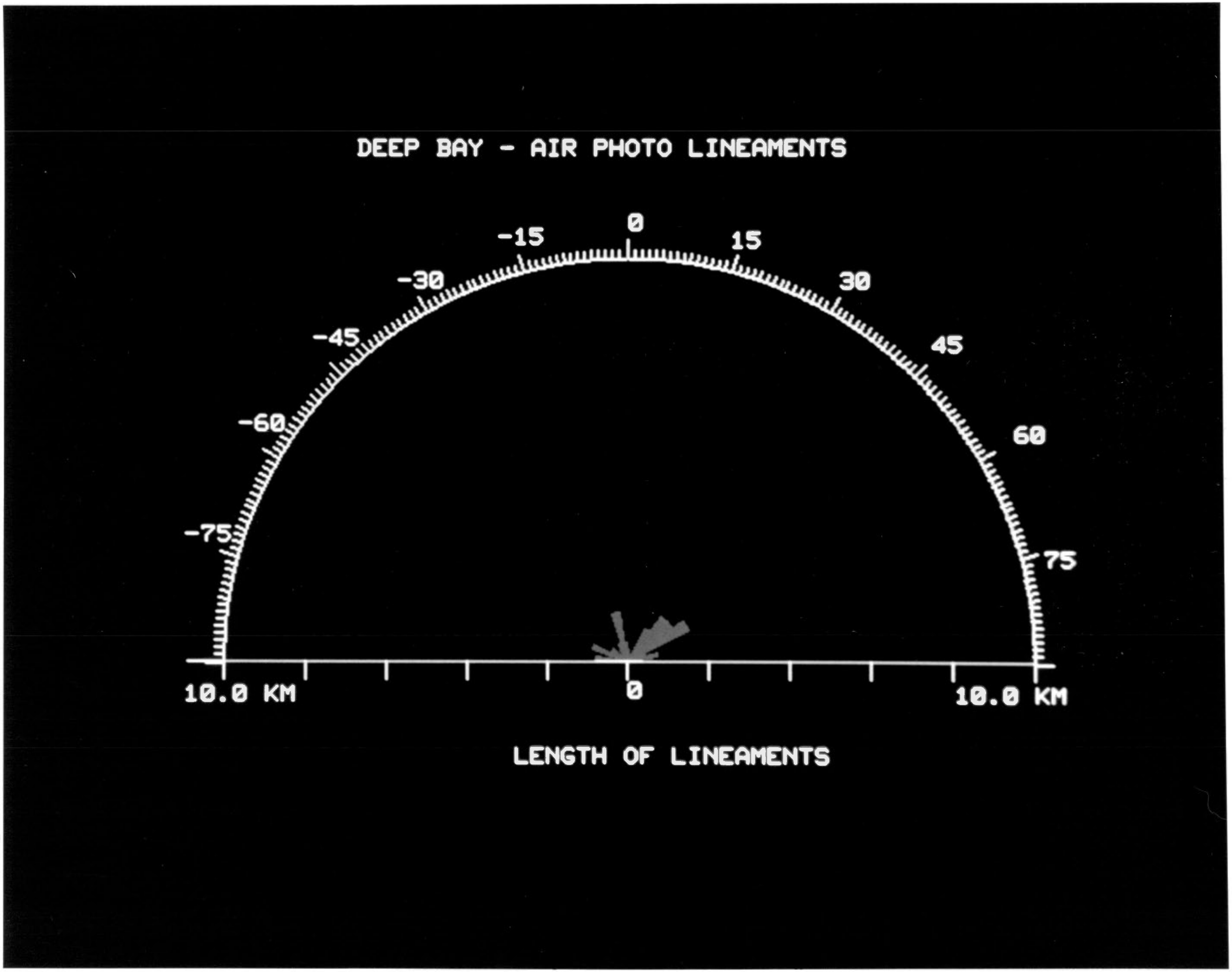
DEEP BAY - AIR PHOTO LINEAMENTS
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-75
75
10.0 KM
0
10.0 KM
LENGTH OF LINEAMENTS

Fig 38

Neg. 850114.2 29.7.85
Reprint 21-8.85