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ARCTIC TERRAIN CHARACTERISTICS DATA BANK

S. J. Mock, et al

Cold Regions Research and Engineering Laboratory

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S.J. Mock, V. LaGarde and W.B. Tucker

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13. ABSTRACT

An arctic terrain characteristics data bank was established as part of a program to evaluate advanced surface effect vehicle (SEV) designs for Arctic use. The data bank contains approximately 4300 kilometers of terrain profiles in digital form acquired with an airborne laser profilometer system, and approximately 50 digital terrain maps for areas ranging from 0.01 km^2 to 1 km^2, photogrammetrically derived from aerial photography. The development and data processing techniques are described along with descriptions of the data bank contents.

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PREFACE

This report was prepared by S.J. Mock, Research Geologist, Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory; Dr. Victor LaGarde III, Research Physicist, Terrain Analysis Branch, Mobility Systems Division, U.S.A. Engineer Waterways Experiment Station; and Walter B. Tucker III, Research Oceanographer, Polar Oceanography Division, U.S. Naval Oceanographic Office.

The authors would like to acknowledge the assistance of David J. Langston who handled much of the final data processing at USA CRREL.

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PART I: INTRODUCTION

A major effort within the Advanced Research Projects Agency (ARPA) Arctic Surface Effect Vehicle (ASEV) Program has been the development of an Arctic Terrain Characteristics Data Bank, often referred to as a terrain model. This terrain characteristics data bank contains topographical information characterizing terrain types found in the arctic pack ice, tundra and littoral areas. The data are of specific concern to ASEV designers since discrete and random terrain characteristics provide the forcing functions and geometric boundary conditions for evaluation of the various vehicle design concepts, dynamic motions, ride quality, interface fluid dynamic behavior and vehicle performance. The requirements for providing arctic terrain data were specified in Aerospace TOR-0059 (S6858)-1, representing data needed by the SEV industry for vehicle technology development and design.

The need for vast amounts of detailed topographical data in a form allowing rapid and repeated access of discrete portions by government and/or industry users dictated the need for a computerized system. Thus, the Arctic Terrain Characteristics Data Bank was formulated by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). While CRREL has had primary responsibility for the development of the data bank, the program has been successful only because of the participation of the U.S. Army Engineer Waterways Experiment Station (WES) and the Polar Oceanography and Photogrammetric Divisions of the U.S. Naval Oceanographic Office (NAVOCEANO). The names and addresses of the project officers of the various participating agencies can be found in Appendix A.

NAVOCEANO has had primary responsibility for data acquisition. This activity has been performed in conjunction with NAVOCEANO's continuing "Birdseye" project. Several thousand miles of laser profilometer track has been recorded as part of the program and hundreds of stereo aerial photographs have been taken of selected areas. The Photogrammetric Division of NAVOCEANO (now part of the Defense Mapping Agency) has had responsibility for producing terrain elevations for selected sites from the aerial photography.

WES has had responsibility for developing the format and structure of the data bank including the software necessary for efficient storage, retrieval, and manipulation of the contents. WES receives elevation data derived from aerial photography for checking and editing before they become a part of the data bank. In addition WES has developed the routines used to produce the initial "Standard Terrain Tapes."

CRREL, in addition to serving as a supervisory agency, has actively participated in data collection and reduction while having primary responsibility for site selection, data analysis, and design of " standard" terrain tapes.

The terrain characteristics data bank has been structured to accept any type of terrain information subject to the following constraints:

1. The terrain characteristic must be expressable in digital form.

2. Data point locations must be referenced to an evenly spaced, rectangular grid system. A profile or line is considered a one-dimensional grid.

3. In practice the terrain characteristic of primary interest in the ASEV program has been ground elevation specifying the geometry of the surface. The requirements of individual sample size, total number of samples and sample resolution necessary to satisfy the specifications of the aerospace TOR dictated the use of data collection systems with as high a degree of automation as possible. Inasmuch as the sea ice terrain of the Arctic Basin is dynamic and therefore undergoing constant change in shape with time, a statistical approach to its characterization was necessary.

The terrain characteristics data bank contains two types of data:

1. One-dimensional data, i.e. profiles of terrain elevation.

2. Two-dimensional data, i.e. terrain elevations for an area with elevations taken on a grid.

The one-dimensional data have all been acquired using an airborne laser profilometer, while the two-dimensional data have been derived from photogrammetric analysis of aerial photography. In general the one-dimensional data have been used to define the statistical characteristics of the region, while the two-dimensional data have been used to examine discrete features as well as to provide the basis for the "standard" terrain tape series.

The purpose of this report is to describe the terrain characteristics data bank completely, from site selection to final digital form, including a description of its present content. The data bank is not directly available to vehicle contractors but rather should be viewed as a library from which data can be extracted upon request. This document serves as a guide to the development of the library as well as an index of its contents.

PART II: DATA ACQUISITION

All laser profile data and approximately 80% of the aerial photography were acquired by NAVOCEANO. The Polar Oceanography Division of NAVOCEANO operates an NC-121K Super Constellation aircraft equipped with a variety of remote sensors and configured for visual ice observations. Prior to 1969, the aircraft was used to assess ice conditions in the Arctic Basin throughout the year via visual observations. Since late 1969 the aircraft has served mainly as a platform for remote sensors with visual observations of general ice conditions as a supplement to measurements.

Seven missions were operated under the aegis of the ASEV program, commencing in April 1970 and continuing through October 1971. The purpose of these missions was to collect high quality terrain elevation data using the laser profilometer and an aerial photographic camera. Laser profile data were collected on all missions while aerial photography was confined to those four missions during which there was sufficient light. Missions were scheduled to provide both seasonal and geographic coverage of the western sector of the Arctic Basin. In some cases, where sampling was inadequate during the original data collection missions, NAVOCEANO has supplemented the data bank with later data. The 26 basic sampling regions are shown in Figure 1. Detailed information on sampling is found in Appendix B.

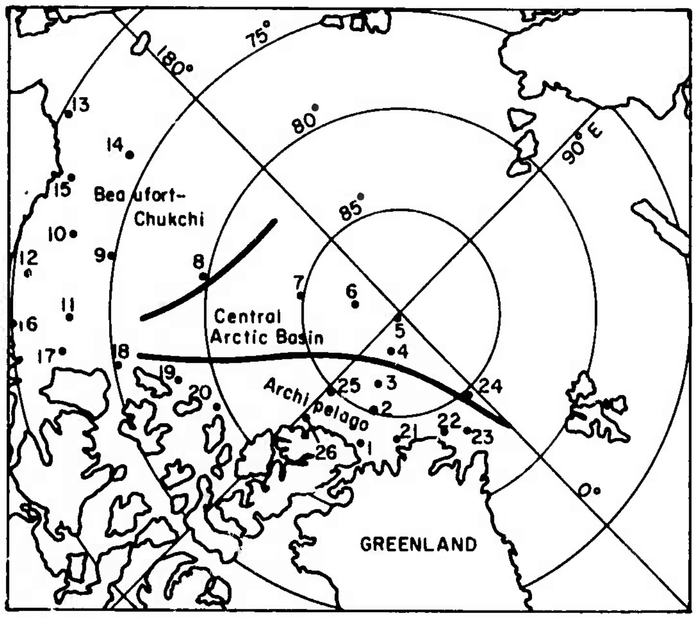

Figure 1. Geographical sampling regions for laser data.

Laser profiling

Laser profiling is a remote sensing procedure by which the distance between the aircraft and the terrain is monitored at very short time intervals in order to produce an analog record of the terrain elevation beneath the aircraft. A single range measurement is accomplished through a phase comparison between the laser beam directed at the terrain and the reflected light from the terrain. Since the time required for sampling and phase comparison is on the order of milliseconds, the output of the device is most easily recorded as an analog signal with amplitude proportional to the phase difference between the transmitted and reflected beams. The remainder of this section deals with a description of the instrument package used in terrain profiling and of the data gathered.

The laser package consisted of a Spectra Physics Geodolite Model 3A amplitude-modulated CW laser (6328Å). The modulation frequency is selected so that the phase delay of the reflected signal is one wavelength for a desired range scale of 10^1, 10^2, 10^3, 10^4 or 10^5 ft to maximize instrument sensitivity. The output range signal can be chosen as 1, 2 or 4 multiples of the basic range scales. Thus by choosing 4× and a basic range scale of 10 ft, continuous measurement of distance changes is made through a 40-ft interval. When this range interval is exceeded, rezeroing of the instrument to a new 40-ft range interval occurs automatically.

The response time of the phase measurement circuit, defined as 95% response to a step input, may be selected to optimize the signal to noise ratio, depending on the reflective surface and the amount of solar radiation present. Available response times include 1, 2, 5, 10, 20, 50 or 100 miliseconds (msec). For example, response times of 1 to 5 msec may provide high signal to noise ratios in winter (dark) months, yet loss of phase lock occurs at these response times when operating in summer months over surfaces of low reflectivity such as water. The normal response times used on data missions were 5 and 10 msec, corresponding to data point spacings of 1.5 to 3.0 ft, respectively, at a ground speed of 180 knots.

Signal outputs from the laser include the range analog voltage and the photomultiplier output (return signal amplitude), as well as indicator signals for range step, range multiplier, phase lock, phase mode and response time. The photomultiplier output (also called reflectometer signal) provides a means of distinguishing open water areas from ice since signal return is extremely low from open water. The phase lock indicator provides a continuous record of whether the range measurement is functioning or not. Lack of phase lock (no range measurement) occurs when the return signal amplitude is too low. This happens when poor vertical visibility exists or when the terrain has poor reflectance characteristics in the vertical direction. Examples of this latter condition are situations in which the beam illuminates a steeply sloping surface or surfaces having low reflectivity.

Other instrumentation operating in conjunction with the laser includes a 14-channel analog recorder, a frequency modulated magnetic tape recorder, a Varian Statos II analog strip recorder, a Pressure Port Calibrator, and a time code generator. All of the previously mentioned laser output signals as well as outputs from the time code generator and the Pressure Port Calibrator are recorded on magnetic tape. The time code generator provides the necessary time base for search and retrieval of data. The Pressure Port Calibrator, a high sensitivity differential barometer, measures changes in atmospheric pressure and is intended as a reference system to sense flight altitude variations. Experience has shown that the Pressure Port Calibrator data cannot be used to remove these variations from the profilometer data as isobaric surfaces are not parallel to mean sea level.

Approximately 14,000 nautical miles of acceptable laser profile data was recorded on the seven missions. Factors contributing to the acceptability of the data were: proper functioning of the laser system and its associated electronic equipment, unobstructed vertical (downwards) visibility, and the ability of the aircraft to maintain a reasonably level altitude.

Two methods of laser data collection were carried out during these missions. The first was long track profiling (e.g. Barter Island, Alaska, to North Pole to northern Greenland), used primarily to assess geographic and seasonal variability in ice roughness conditions. The second method was known as a "star" flight pattern. A star pattern consisted of four or more 10-nautical-mile flight lines approximately intersecting at a common center with similar angles between them. These patterns were flown at three altitudes, 1000, 2000 and 5000 ft, with laser profiling at the first two altitudes and aerial photography at the second two. The star patterns served a dual purpose. Their individual locations were chosen to provide detailed photographic coverage of the various ice provinces (geographic divisions based on varying ice characteristics) in the Arctic Basin. Also the pattern allowed the two-dimensional character of the ice (i.e. nonrandom spatial elements, lineations, etc.) to be examined using the intersecting laser profiles and/or stereo photography. Examples of these types of analysis have been given by Hibler (1972) and Mock et al. (1972).

Aerial photography

Aerial photography provides the maximum information content of any remote sensing tool. By designing photographic coverage to have both suitable overlap of adjacent frames and a sampling at several altitudes, a unique record of the surface is acquired which is then available for quantitative measurement at a variety of scales.

The aerial photographic system was continuously improved during the course of SEV flight missions. The system described herein was in operation at the conclusion of the flight program phase of the project.

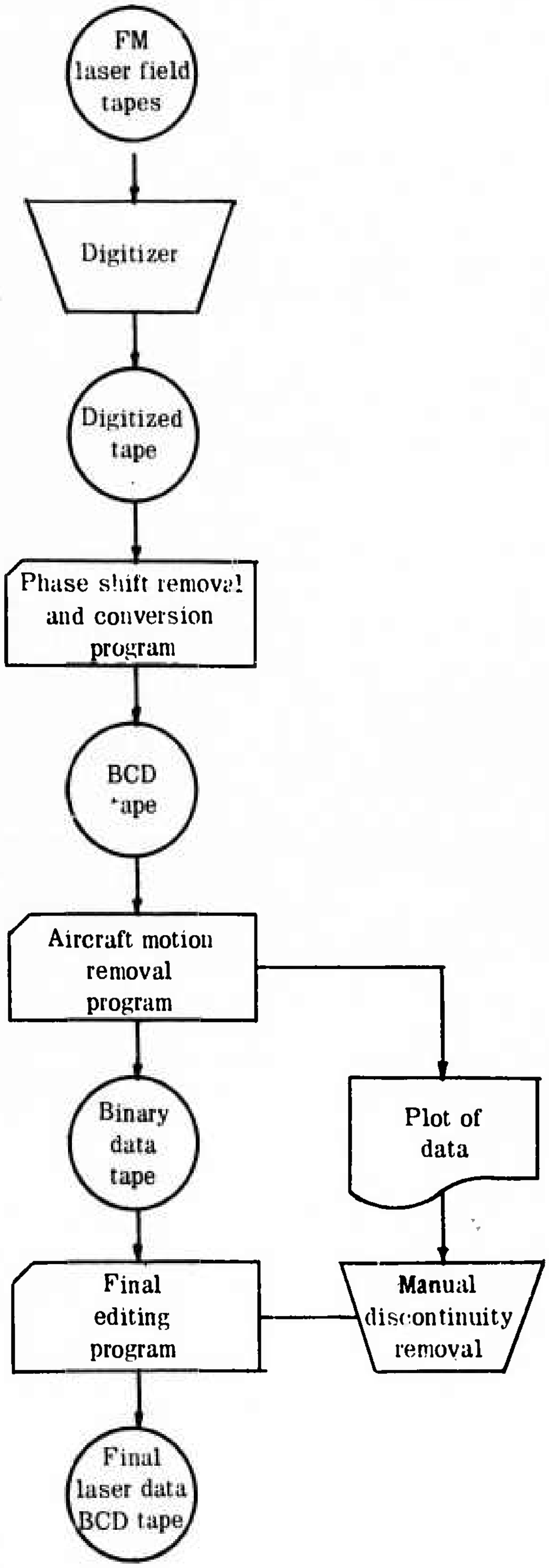

Figure 2. Flow chart of laser data processing.

The basic component of the system was a CA-14 aerial mapping camera. The camera had a 6-in. focal length and used standard 9-in. format aerial film. The camera was held in a gyrostabilized vertical camera mount which provided vertical stabilization and remote azimuth control.

The aircraft was equipped with a camera control station that provided the photographer with readouts of pressure-sensed altitude, aircraft heading and Doppler ground speed. Operational control of the complete camera and mount system was provided by power switches at the control station while a check of real-time system status was maintained through various indicators. Stereo photo overlap requirements were translated into framing time intervals prior to a run based on the Doppler ground speed and aircraft altitude.

Aerial photography was acquired at the "star" pattern sites referred to previously as well as on selected flight lines along the northern Alaska coast and interior. Supplemental photography was acquired by CRREL at Barrow, Alaska, and at the site of the 1972 Arctic Ice Dynamics Joint Experiment (AIDJEX).

PART III: DATA PROCESSING

Laser profilometer data

Processing the laser profilometer data began with the digitization of the analog magnetic tapes collected on the various missions. Figure 2 is a schematic flow chart of the reduction procedure. The data were digitized at a rate of 200 samples per second or approximately 1.4 ft ground distance per sample at normal flight speeds. The result of the digitization process was the production of another magnetic tape with voltages (corresponding to ranges in feet) recorded in a binary format compatible with digital computers.

A computer program was then used to convert the voltage signals to profile elevation measurements in feet and to simultaneously remove the phase shifts from the data. Phase shifts (exceeding the chosen laser range) occur nearly instantaneously and are therefore removable with a simple algorithm within the program. The output of this program is a magnetic tape with the laser data and identifying records in a BCD format. All acceptable laser data collected on the missions were carried to this step of the data reduction procedures. Aircraft altitude variations and phase discontinuities (range measurement errors caused by momentary loss of signal return) however are still present in the data at this point.

Aircraft motion is removed by a three-step filtering process developed by CRREL (Hibler 1972):

1. The sample is low pass filtered (to prevent aliasing) and resampled at a rate of 66.67 samples per second. Calculations of spectral density verified that no significant energy was lost by this resampling procedure which allowed data records to be three times as long in equivalent ground distance as those sampled at 200 samples per second.

2. The resampled data are high pass filtered to allow selection of a set of minimum points along the profile. The height value on the unfiltered profile corresponding to the position of each minimum point is recorded, and a curve of straight line segments is constructed between these minima.

3. The curve of straight line segments is low pass filtered, resulting in a smooth curve closely approximating the aircraft motion. Correction of the original data is made by subtracting this curve from the original profile.

The entire process of resampling and eliminating aircraft motion is carried out by a single computer program which also generates a plot of the data with and without aircraft motion and produces a magnetic tape containing the corrected data.

The phase discontinuities are both difficult to identify and to remove from the data, since they are not instantaneous as phase shifts are. Quite often the slope of the discontinuity resembles that of a steep ridge, thus making removal by computer quite difficult. The discontinuities are identified by visually inspecting the computer plot. The correction procedure entails noting the data values on either side of the discontinuity and entering them into a computer program which eliminates the discontinuity by adjusting the baseline to provide a smooth and continuous elevation transition from the first to the second point. The corrected data are then output onto a BCD magnetic tape for subsequent use.

The Naval Oceanographic Office has prepared, under contract, 4030 km of laser data which encompass regional and seasonal variation in ice roughness characteristics. This 4030 km contains 93 "sections," averaging 43.3 km each, of varying location and/or season. Basic geographic areas have been selected for sampling and sections within these basic areas have been compiled with respect to season and year.

A "section" consists of two or three files, each containing an identification record and 16,000 or fewer data points, depending on data loss due to phase discontinuities and aircraft speed. Each file is broken into 40 data records of 400 computer words each. The last file of each section is zero filled to complete the 16,000 words in order that a standard format may be used to read each section. The identification record (at the beginning of each file) contains the section number, data collection date, sample spacing in meters and a basic file number. Log sheets containing information such as the total number of samples per section, position, date, sample spacing and its location on the tape accompany each tape. A list of all profilometer data is given in Appendix B.

Aerial photographic data processing

Prior to the inception of photographic missions, guidelines were established to insure acquisition of photographs at suitable scales with required overlap. Flight altitudes were set at 2000

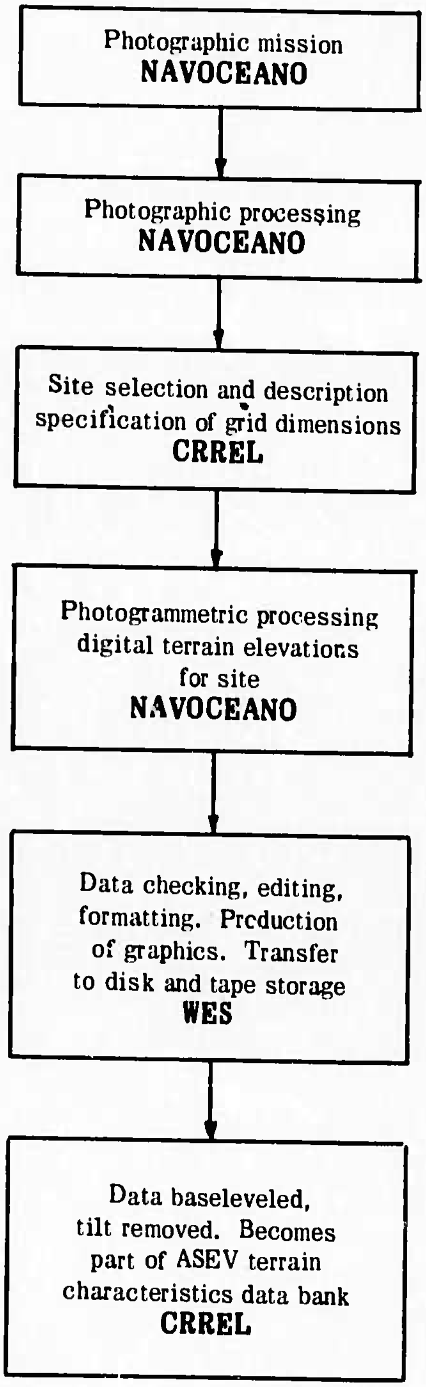

Figure 3. Flow chart of photographic data processing.

and 5000 ft, yielding photographs of 1:4000 and 1:10,000 scales, respectively, with the CA-14 camera system. Given these scales, the photogrammetric height resolution is approximately 4 inches and 10 inches, respectively.

A stereo model is defined as that area viewed in common in a pair of photographs. Overlap of photo pairs was specified at 53%, resulting in stereo models sufficiently large to encompass most sites while allowing bridging for sites spanning two or more models. Figure 3 schematically shows the processing route taken by the photography.

Following photographic missions, all exposed film was processed by NAVOCEANO and complete sets of prints transmitted to CRREL for selection of sites. Site selection was guided by the following criteria:

1. Commonly occurring microrelief morphologic types should be illustrated.

2. Commonly occurring obstacles (pressure ridges, scarps, etc.) in a range of typical geometries should be included.

3. Seasonal variations in surface roughness should be illustrated.

4. Extrema were neither sought nor selected.

While these criteria served as a guide, the judgment of experienced CRREL staff members was exercised repeatedly during the selection process. Later, as much of the laser data were analyzed, statistical results were available to guide selection.

A description of each site, a photographic print outlining the site, along with dimensions and desired grid spacing, were sent to NAVOCEANO for digitization.

The Photogrammetric Division of NAVOCEANO (now part of the Defense Mapping Agency) used standard techniques to provide elevations of grid points of the site. The photogrammetric determination of elevation is based on the parallax formula derived from the geometry of a stereoscopic pair of photographs. The formula is

$$h = \frac{HdP}{P + dP} \quad (1)$$

where h is the height of the object, H is the height of the camera above the base of the object, P is the absolute parallax at the base of the object and $P + dP$ is the absolute parallax at the top of the object.

Various types of stereo compilers are in use which allow rapid and direct solution of eq 1 with h determined when a floating mark is brought into coincidence with the surface of a stereo model. NAVOCEANO has used two types of first order instrumentation systems during this program, initially a Zeiss Model C-8 Stereoplanigraph and later a Wild Stereomat B-8. The Stereomat B-8 is a semi-automated instrument enabling rapid digitization of elevations over a preselected X-Y grid. For a detailed description of the system see Konecny and Refoy (1968).

In general the accuracy of measurements with this instrumentation is approximately 1/6000 of the photographic flying height. The majority of the photography was taken at heights of either 1500 or 2000 ft with a few 5000-ft sets used. Given adequate ground control this would result in accuracy of approximately ±0.25 ft, ±0.33 ft and ±0.83 ft respectively. In actuality, relative accuracy, i.e. from point to point, approaches these values, but due to lack of ground control a systematic tilt is often present in some models. Other errors in data will be discussed later.

PART IV: COMPUTER PROCESSING

After elevation data for each site have been retrieved from the aerial photography by NAVOCEANO and transmitted to WES on IBM cards, the data are checked and edited at WES. Upon completion of this process, data for each site are placed in the digital terrain data base as individual data files. Standard terraindata tapes are prepared from these data files. Lists of all currently available data files and standard terrain data tapes are contained in Appendices C and D.

This part of the report briefly describes procedures developed within the Environmental Systems Division of WES for individual data file and standard terrain tape preparation. Data preparation includes the specification of data formats, editing and manipulation of the data, data retrieval, and terrain tape building procedures.

The initial step in data processing at WES consists of transferring the site elevation data from IBM cards to disc file storage. While file structure and formats have been developed for economy of storage and ease of manipulation, it is sufficient to envision the site data as shown in Figure 4, i.e. as consisting of rows and columns of elevations..

WES editing procedures

A simple program was developed to automatically locate and "correct" easily recognizable anomalies. The program operates upon the data row by row, treating each independently of the others. High "extreme" anomalies are defined as falling outside the range defined by $0.25\overline{x}$ and $1.75\overline{x}$ where $\overline{x}$ is the mean value of five data points and x is the central data point. Anomalies are replaced by values linearly interpolated from adjacent values with the exception of the first or last data point of a row which is replaced by its adjacent value.

Two simple plotting programs were designed to rapidly produce line drawings viewed from top or bottom and from any or all four cardinal positions. Experience has shown that the use of these plots permits almost instantaneous recognition of data errors, even by inexperienced personnel.

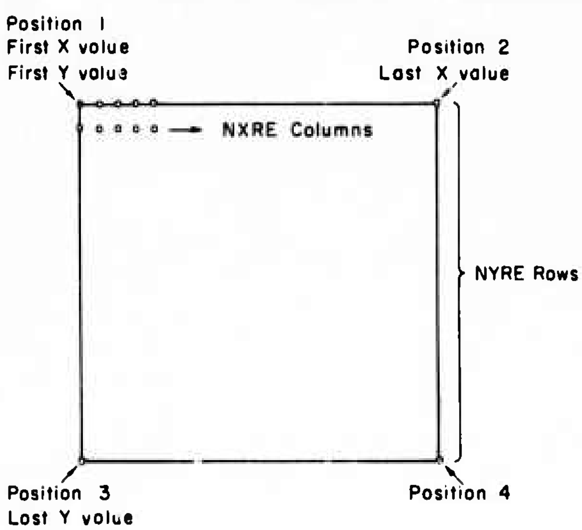

Figure 4. Array arrangement of site elevation data.

CRREL editing procedures

As noted in an earlier section, because of the uncontrolled nature of the photography, stereo models will frequently have a systematic tilt, resulting in tilted digital models. This presents two problems: 1) when splicing swaths of terrain from various models, spurious low frequency spatial elements can become incorporated, and 2) sea ice terrain does not contain any systematic tilts on the scale that is dealt with here.

Hibler (1972, p. 7191) noted in removing aircraft motion from laser profiles of sea ice that "the pack ice surface profile is essentially a one-sided noise trace in that roughness always rises approximately from the water level." This concept is used to develop a simple technique for tilt removal and base leveling of sea ice models.

A data set is subdivided into 10× 10-meter subblocks. The minimum point for each subblock is found, along with its X,Y coordinate in terms of the entire data set. These then form a set of equations of minima. A simple linear least squares fit is made and the resulting planar surface subtracted from the data set.

PART V. STANDARD TERRAIN TAPE SERIES

Introduction

The standard terrain tape series was conceived early in the SEV program as a means of providing all government and industry participants with samples of terrain representing typical conditions in the Arctic. The samples are referred to as "standard" in the sense that all users are supplied the same data, which then represent a standard against which competing concepts can be exercised and evaluated. They are *not* standard in the sense of being statistically exact representatives of arctic terrain conditions.

A standard terrain tape consists of digital terrain elevations written onto a magnetic tape which when read by the users represents a swath of terrain of defined width and length. Each tape is accompanied by a User Document describing the tape contents, the terrain types represented, power spectral densities, and statistical information about the arctic terrains from which the tape samples were selected.

Terrain swath preparation

Swath retrieval from grid array. Software was developed to allow retrieval of a swath or subarray of data from a completely edited data file. The subarray may have any spatial orientation relative to the data file from which it is retrieved, the only constraint being that it be straight. While the primary use of these "swaths" is to form an elevation grid map for construction of standard terrain tapes, the swath data may also be used for studies unrelated to vehicles, such as obstacle spacing or height statistics, route navigation studies, etc.

Swath retrieval parallel to the axes of a data array is quite straightforward. When a swath is skewed, a grid with the same spacing as the master file is cast across the master file with the skewed orientation. Grid values are then interpolated for the skew grid positions, using an inverse square weighted average of the four nearest neighbors for the interpolated values.

Swath splicing. A capability for splicing swaths together to form a master swath is gained using another software routine. This capability is required when various terrain characteristics within the same or different data sites are needed in the formation of a final swath with a surface configuration approximating features desired for vehicle dynamic calculations.

Any number of swaths may be spliced to form a single composite swath (or standard terrain tape file) with a single pass of this program. The first swath is transferred to the output file and the last two rows of data points averaged to form a pedestal value. The data file containing the second input swath is entered by the computer and the first two rows (records) of data points are averaged to form a pedestal for that swath. The ratio of these pedestal values is used to adjust the mean base line of the second swath to that of the first. No generalized algorithm for base line shift is available. The method used is most applicable when rapid surficial variations do not occur within columns in the last or first two rows of the swaths being spliced. As a specific example, no problems should be encountered in splicing when the first swath ends at a cliff base, but effective vertical relief of the cliff will decrease if splicing occurs on the cliff face. This decrease will be relative to the cliff's vertical relief as it appears in the swath. An assumption is made that the surfaces, and therefore the swaths, are rectified prior to operation of this program.

After the mean base line value for the second swath is calculated, the first and second swaths are spliced by means of a normal three-point smooth over the end row of data points in the first swath and the first row of data points in the consecutive swath. Smoothing is performed in columnar fashion. The remainder of the second swath is transferred to the output file with the base line correction. If there are other swaths, the base lines are again calculated and the successive swaths are base line corrected and spliced using the same procedure as described above.

Microrelief on macrorelief overlay. While the Arctic Terrain Characteristics Data Bank contains data with a large variety of spectral and lineal characteristics, it may be necessary to construct additional data files with other characteristics. Data files containing simple features such as ramps or discrete steps are easily generated, but data arrays with complex spectral characteristics are not easily generated. A computer routine was developed to take advantage of the data already present in the Digital Terrain Data Library for this purpose. The general procedure developed allows the overlay of fine grid data (microrelief) or coarse grid data (macrorelief) to achieve a surface containing characteristics of both data sets. It is operationally possible to overlay any microrelief on any macrorelief provided the macrorelief grid spacing is an integral multiple of the microrelief grid spacing.

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APPENDIX A: AGENCIES AND PROJECT OFFICES

U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL)
P.O. Box 282
Hanover, New Hampshire 03755
ATTN: Dr. K.F. Sterrett, Chief, Research Division

U.S. Army Engineer Waterways Experiment Station (USA WES)
Vicksburg, Mississippi 39181
ATTN: Dr. Victor LaGarde III, Environmental Systems Division

U.S. Naval Oceanographic Office (NAVOCEANO)
Polar Oceanography Division
Code 7600
Washington, D.C. 20390
ATTN: Mr. Walter Wittman, Chief

APPENDIX B: LASER PROFILOMETER DATA

Pertinent information for each of the 93 laser profile sections is given in Table BI. Table BII relates the section numbers to the 26 basic sampling regions shown in Figure 1.

Table BI.

Section No.	Position	Date	Sample Spacing	No. of Samples
1	82°56'N 60°10'W	3/18/71	1.39M	33797
2	84°58'N 59°55'W	3/18/71	1.37M	33335
3	85°52'N 58°30'W	3/18/71	1.37M	29253
4	88°00'N 58°30'W	3/18/71	1.39M	32900
5	90°00'N -------	3/18/71	1.39M	33823
6	88°07'N 151°00'W	3/18/71	1.47M	28598
7	84°47'N 148°19'W	3/18/71	1.47M	28698
8	81°08'N 148°00'W	3/18/71	1.43M	28959
9	76°09'N 148°00'W	3/18/71	1.43M	26527
10	71°57'N 148°12'W	3/19/71	1.61M	29493
11	72°57'N 136°02'W	3/23/71	1.30M	27704
12	70°56'N 141°27'W	3/21/71	1.38M	28306
13	83°01'N 60°16'W	11/11/70	1.37M	29131
14	85°00'N 60°00'W	11/11/70	1.47M	29614
15	85°54'N 60°00'W	11/11/70	1.47M	28916
16	88°00'N 60°00'W	11/11/70	1.45M	30150
17	89°45'N 148°20'W	11/11/70	1.49M	29263
18	88°15'N 148°20'W	11/11/70	1.49M	30240
19	85°47'N 148°10'W	11/12/70	1.44M	30414
20	80°00'N 144°05'W	11/12/70	1.47M	29854
21	77°31'N 146°45'W	11/12/70	1.58M	30122
22	72°51'N 149°50'W	11/12/70	1.58M	30866
23	70°24'N 166°43'W	11/13/70	1.47M	30267
24	73°47'N 165°27'W	11/13/70	1.47M	30203
25	71°58'N 157°18'W	11/13/70	1.43M	29194
26	84°09'N 39°30'W	11/10/70	1.42M	30127
27	83°25'N 21°33'W	11/10/70	1.42M	30356
28	83°00'N 14°34'W	11/10/70	1.56M	28658
29	84°58'N 00°17'W	11/10/70	1.34M	29970
30	83°28'N 142°32'W	1/12/71	1.51M	29316
31	80°00'N 145°03'W	1/12/71	1.66M	29980
32	76°45'N 147°47'W	1/12/71	1.45M	30582
33	72°51'N 147°37'W	1/13/71	1.37M	30836
34	72°05'N 156°00'W	1/15/71	1.91M	30212
35	70°00'N 166°38'W	1/15/71	1.70M	30501
36	83°15'N 58°35'W	1/21/71	1.39M	29617
37	70°14'N 135°43'W	1/17/71	1.54M	30877
38	73°49'N 131°13'W	1/18/71	1.54M	30326
39	75°32'N 126°00'W	1/18/71	1.20M	29254

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APPENDIX B

Section No.	Position	Date	Sample Spacing	No. of Samples
40	73°09'N 135°29'W	1/18/71	1.27M	30861
41	83°01'N 60°16'W	10/ 4/71	1.64M	27421
42	85°00'N 60°00'W	10/ 4/71	1.55M	27072
43	85°58'N 60°00'W	10/ 4/71	1.54M	27427
44	88°00'N 60°00'W	10/ 4/71	1.50M	27068
45	90°00'N	10/ 4/71	1.54M	28846
46	88°19'N 142°05'W	10/ 4/71	1.36M	27412
47	85°00'N 142°11'W	10/ 4/71	1.39M	28103
48	80°00'N 139°45'W	10/ 4/71	1.35M	29730
49	76°45'N 141°00'W	10/ 4/71	1.37M	30603
50	72°51'N 147°31'W	10/ 8/71	1.47M	30414
51	70°56'N 141°48'W	10/ 7/71	1.47M	29890
52	73°52'N 164°22'W	10/ 6/71	1.51M	29351
53	71°46'N 156°41'W	10/ 6/71	1.51M	29801
54	70°22'N 135°37'W	3/13/72	1.54M	33435
55	73°05'N 127°05'W	3/12/72	1.31M	34245
56	75°36'N 124°57'W	3/12/72	1.30M	33282
57	77°38'N 119°33'W	3/12/72	1.43M	33087
58	79°18'N 112°15'W	3/12/72	1.43M	29334
59	72°51'N 147°06'W	3/26/72	1.35M	35394
60	75°22'N 148°17'W	3/24/72	1.41M	29514
61	73°17'N 156°44'W	3/27/72	1.54M	34763
62	72°46'N 135°10'W	3/14/72	1.43M	33612
63	70°45'N 141°00'W	3/13/72	1.39M	34356
64	77°04'N 120°17'W	4/22/70	1.51M	27054
65	73°09'N 132°35'W	4/22/70	1.51M	29532
66	85°52'N 61°01'W	5/11/71	1.52M	27823
67	88°00'N 70°40'W	5/11/71	1.54M	29406
68	89°34'N 70°00'W	5/11/71	1.54M	29280
69	88°30'N 121°30'W	5/11/71	1.47M	29477
70	85°00'N 139°04'W	5/11/71	1.51M	29652
71	82°06'N 141°44'W	5/11/71	1.51M	29874
72	73°45'N 137°26'W	5/13/71	1.62M	30381
73	72°02'N 155°10'W	5/11/71	1.39M	29871
74	72°51'N 146°08'W	5/13/71	1.70M	30183
75	72°50'N 146°50'W	2/6/73	1.47M	29948
76	75°45'N 144°50'W	2/6/73	1.62M	30008
77	80°03'N 144°25'W	2/6/73	1.62M	29998
78	85°00'N 156°58'W	2/6/73	1.47M	29887
79	87°15'N 162°00'W	2/6/73	1.43M	30196
80	89°18'N 63°00'E	2/6/73	1.55M	30369
81	83°50'N 13°50'W	2/6/73	1.51M	29631
82	83°16'N 23°30'W	2/6/73	1.43M	30764
83	83°33'N 39°10'W	2/6/73	1.24M	28333
84	83°02'N 59°35'W	2/8/73	1.39M	28203
85	85°00'N 60°30'W	2/8/73	1.39M	28609
86	84°53'N 84°00'W	2/8/73	1.29M	27671
87	82°40'N 84°45'W	2/8/73	1.27M	29076
88	79°02'N 111°50'W	2/8/73	1.24M	27775
89	77°35'N 121°05'W	2/8/73	1.26M	29415
90	75°30'N 125°35'W	2/8/73	1.30M	30154
91	72°37'N 127°52'W	2/9/73	1.32M	30339
92	72°05'N 132°15'W	2/9/73	1.30M	30548
93	70°18'N 139°10'W	2/9/73	1.39M	30732

Table BII. Section number as related to basic geographic sampling region.

Basic sampling region	Section number Mar 71	Nov 70	Jan 71	Oct 71	Mar 72	Apr 70	May 71	Feb 73
1	1	13	36	41				84
2	2	14		42				85
3	3	15		43			66	
4	4	16		44			67	
5	5	17		45			68	80
6	6	18		46			69	79
7	7	19	30	47			70	78
8	8	20	31	48			71	77
9	9	21	32	49	60			76
10	10	22	33	50	59		74	75
11	11		40		62	65	72	92
12	12			51	63			93
13		23	35					
14		24		52				
15		25	34	53	61		73	
16			37		54			
17			38		55			91
18			39		56			90
19					57	64		89
20					58			88
21		26						83
22		27						82
23		28						81
24		29						
25								86
26								87

APPENDIX C: STANDARD TERRAIN TAPES

Two Standard Terrain Tapes have been prepared. Tape characteristics for each are as follows:

1. Seven track
2. Binary coded decimal (BCD)
3. Packing density 556 bits per inch
4. Even parity
5. No headers, labels or serial numbers

Both tapes contain a single file although with different numbers of records. The format is as follows:

Record	*Format*	*Contents*
1	(I10, 128x)	N, number of records to follow
2 - 8	(138A1)	Descriptive information
9 to N-8	(21I5, 23x)	Elevation data

Both tapes represent a swath 20 meters wide and approximately 3000 meters long. Both tapes illustrate three distinct terrain types characteristic of the Arctic: tundra, first year sea ice, and multiyear sea ice. Each terrain type is approximately 1000 meters in length with a smooth transition to the succeeding terrain.

A User Document containing supplementary information, i.e. profile, power spectral densities, etc., is available for each type. The essential difference between the tapes lies in the larger sample available for construction of tape 2.

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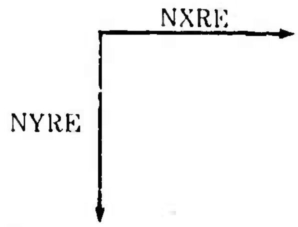
APPENDIX D: DIGITAL TERRAIN MAPS

This appendix contains photographs and descriptions of all digital terrain maps presently within the ASEV Terrain Characteristics Data Bank. The following conventions have been used:

1. The sampled area is outlined in black. Where no area is outlined the sample area comprises the entire photograph.

2. Coordinate convention is as follows:



NXRE number of columns of data
NYRE number of rows of data
Data are stored by rows.

3. Data spacing is given in meters.

4. Plotted profiles are in general along centerline of area.

Data spacing is 1 for all but File 1.

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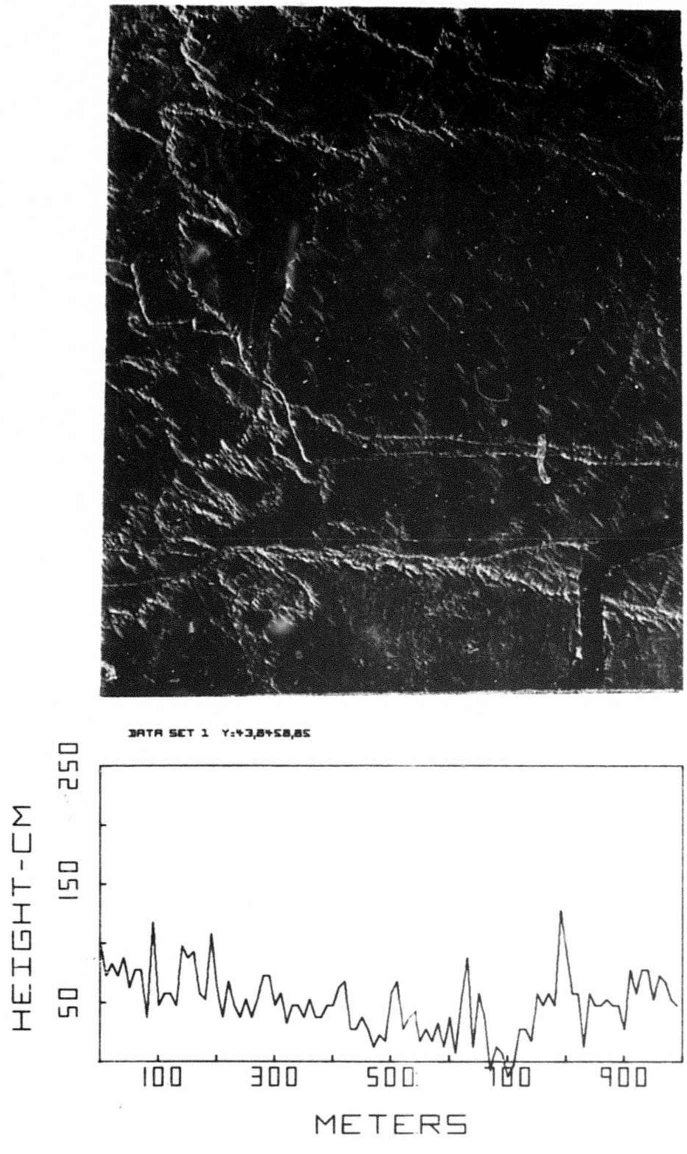
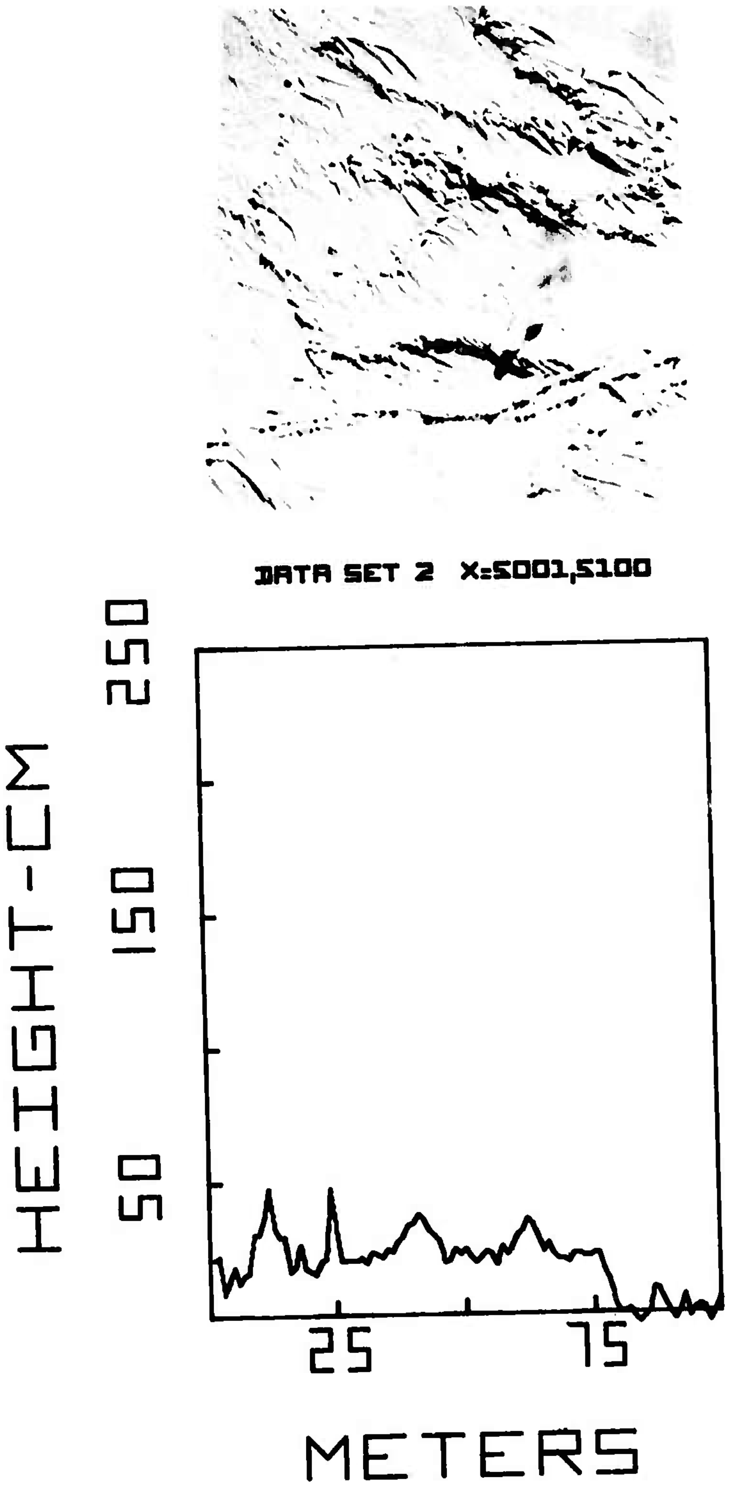
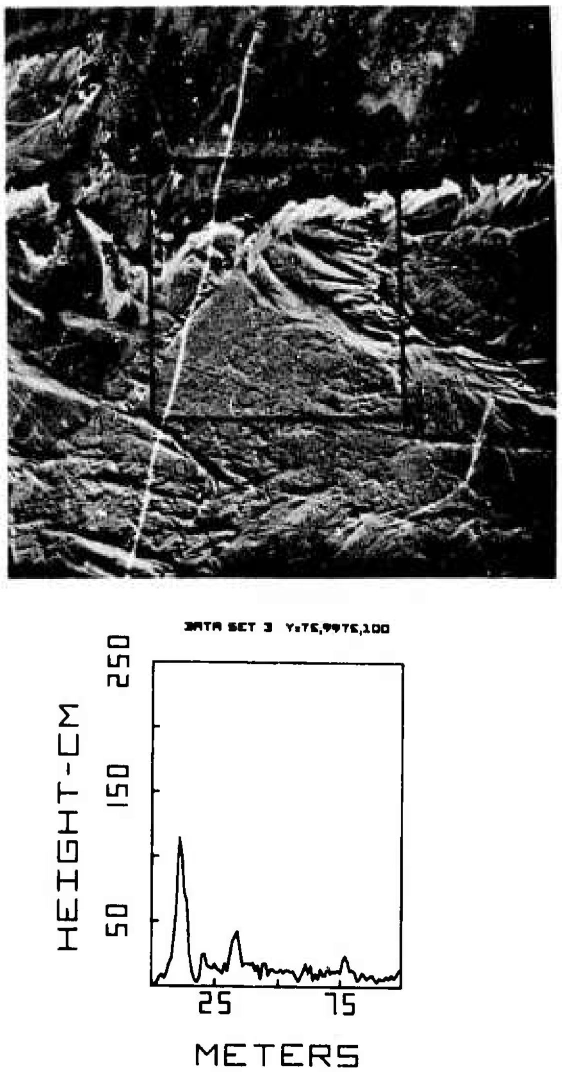


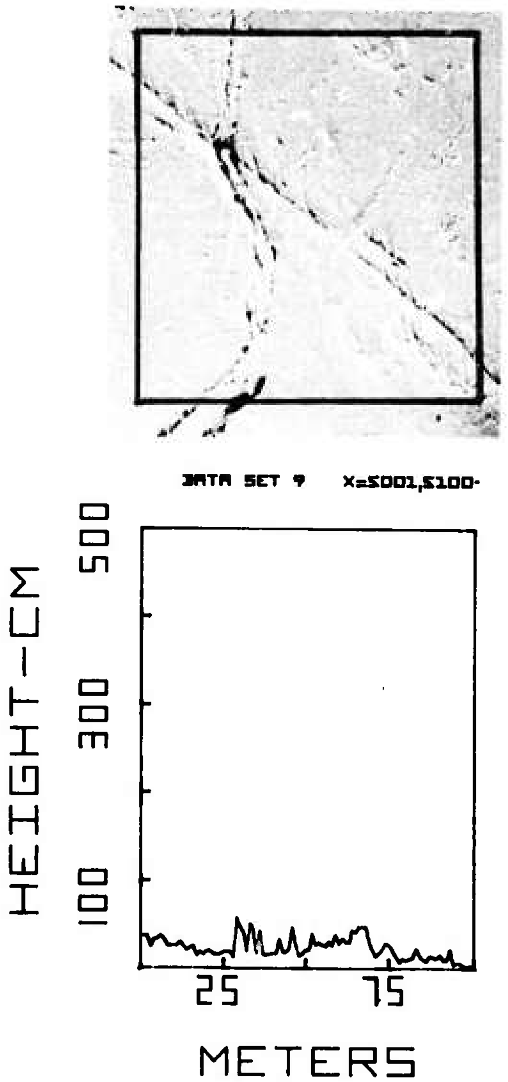
File 1. First year ice showing evidence of finger rafting when the ice was thin. A newly refrozen lead cuts a corner of the area. Two types of relief features characterize the area: low pressure ridges with relative relief of 100 to 150 centimeters and sastrugi with 20 to 30 centimeters of relief. Camp Beta of AIDJEX strain network is included in the area. Roll 9, photo 204, 23 March 1971. Grid size: 85 × 100; Data spacing: 10.



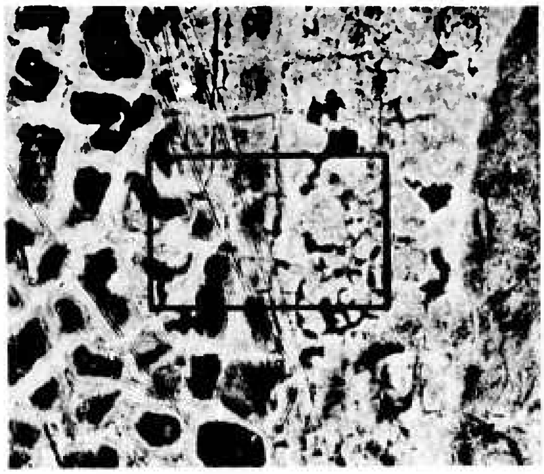
File 2. First year ice with considerable pressure ridging and wind drifted snow in the lee of the ridges. Relative relief is up to 150 centimeters on the larger ridges. The area includes Camp Beta of the AIDJEX strain network. Roll 19, photo 126, 23 March 1971. Grid size: 100 × 100.

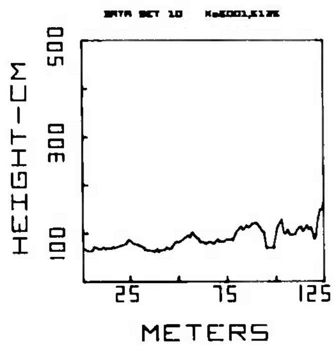


File 3. The area includes the junction of two pressure ridges with well developed snow dunes on the lee side of the ridges. Gride size: 100 × 100.

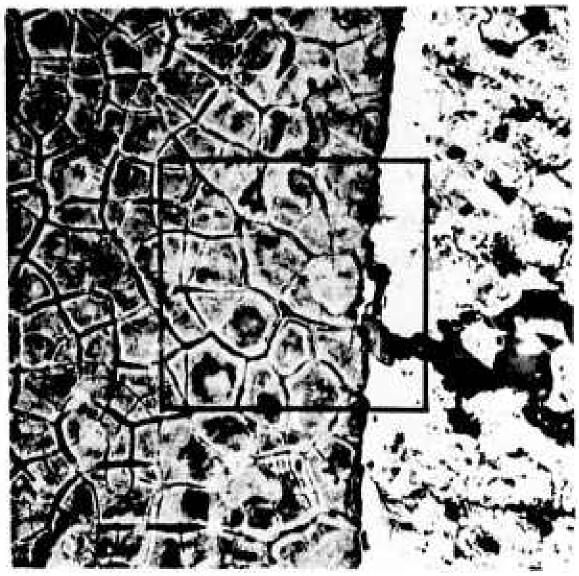


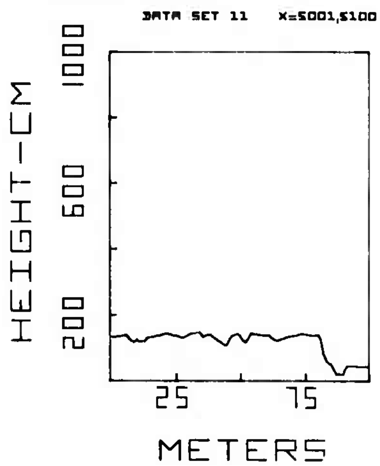
File 9. This area contains two well developed pressure ridges, one of which is split by a central rift. Several classic barchan snow dunes also occur within this sample. Grid size: 100 × 100.



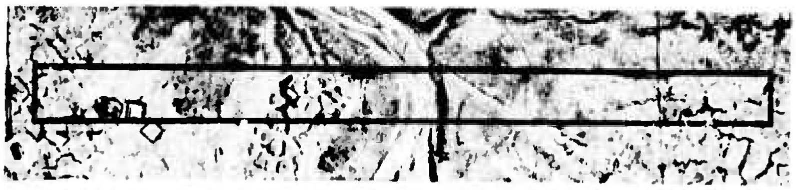


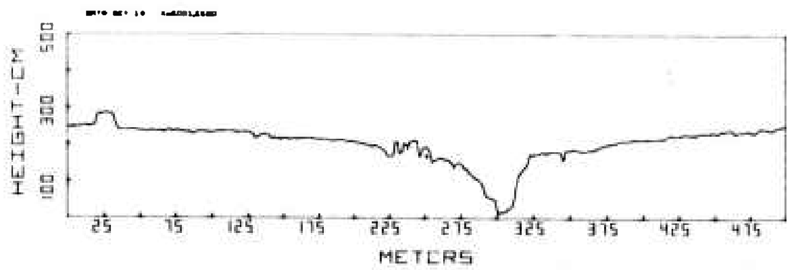
File 10. The left two-thirds of this sample consists of low-centered polygons located within a drained lake basin. The adjacent higher area is covered with high-centered polygons. An old vehicle trail crosses the center of the area with the vehicle tracks particularly apparent in the low, wet polygon area. Grid size: 80 × 125.





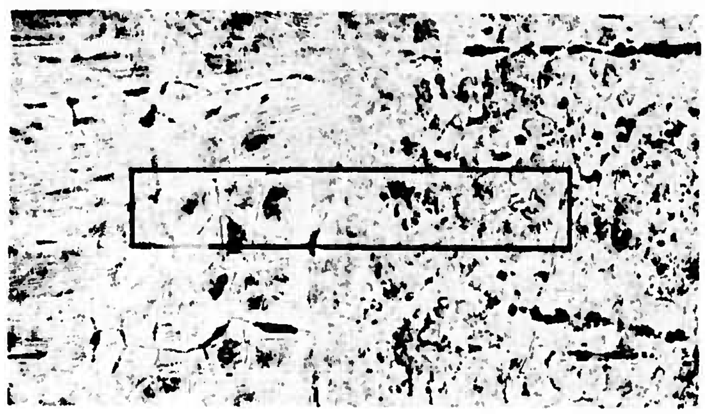
File 11. The polygonal ground is fairly uniform, suggesting a transition from low- to high-centered forms. The low coastal region is ramped with snow except where surface runoff has removed it. The white areas are sea ice. Grid size: 100 × 100.

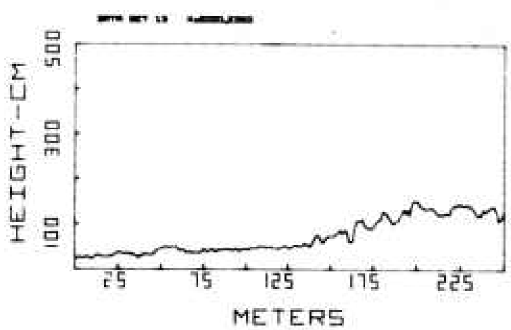




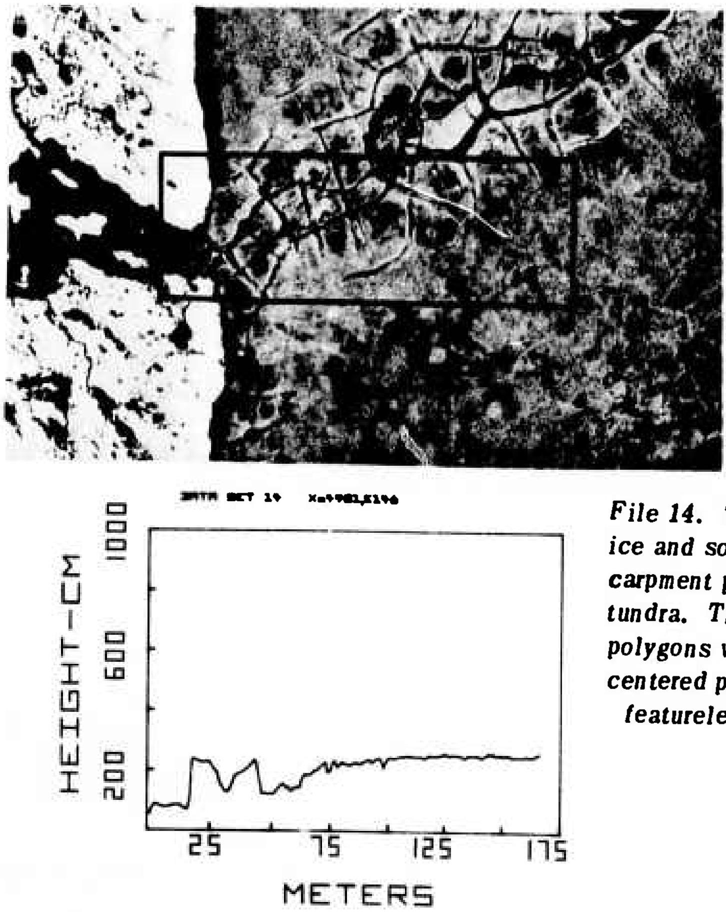
File 12. This site includes a wide variety of relief features near the IBP site. The ground conditions along the transect from left to right are:

1. *High-centered polygons mapped as H 1/C*
2. *Sloping ground that is rather featureless and is mapped as F2*
3. *High-centered polygons mapped as H2/D*
4. *The remainder can be classified as SS. This represents gently sloping relief with little surface irregularity. Approximately 1 cm after the H2/D unit a stream is encountered with major relief associated with the stream margin. Grid size: 20 × 500.*

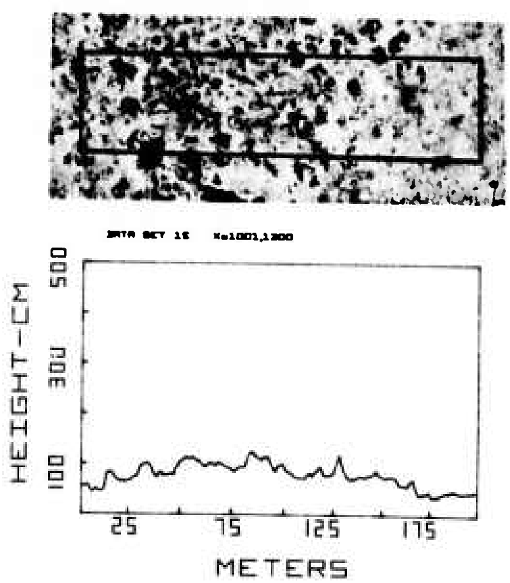




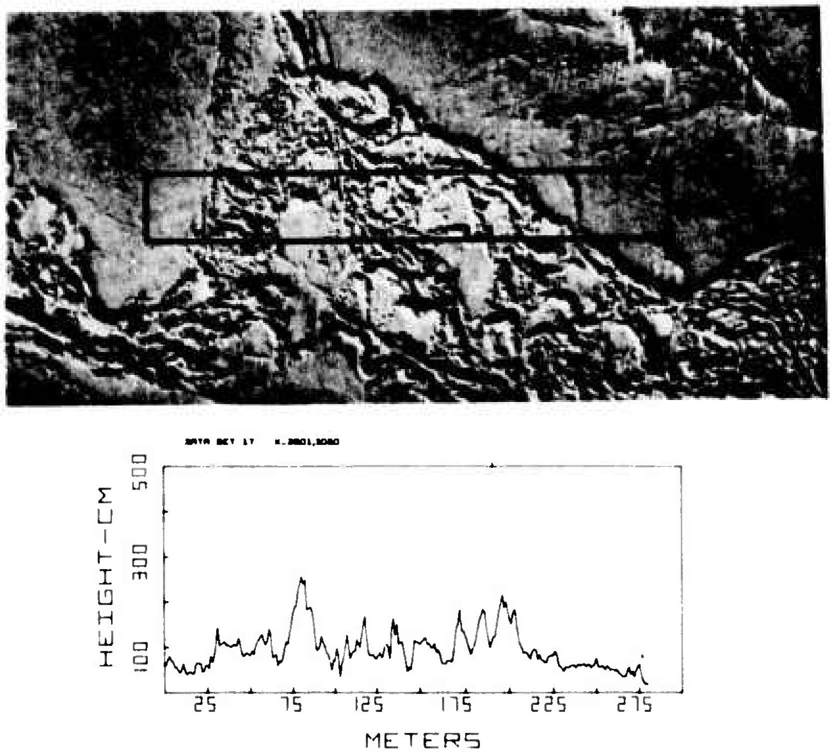
File 13. The transect covers three map units; from left to right they are a drained lake basin, a low relief transitional slope, and high-centered polygons. Grid size: 40 × 250.



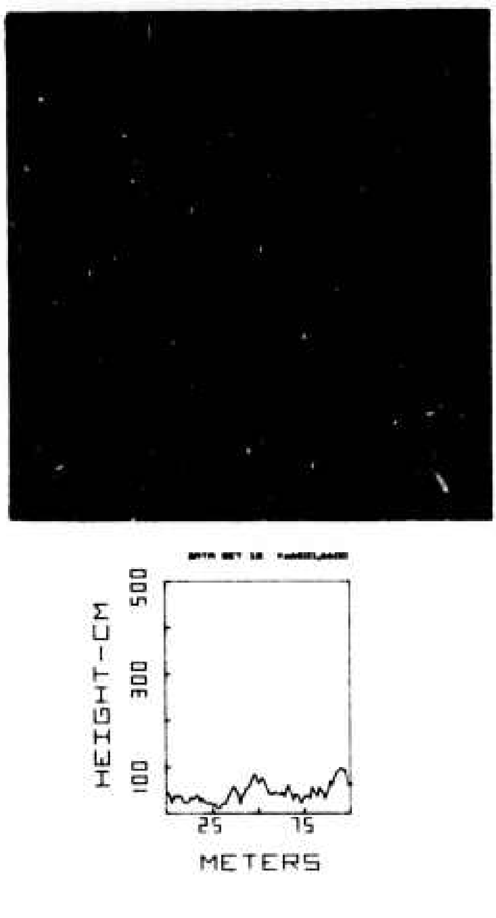
File 14. This sample crosses first year sea ice and some open water, and a coastal escarpment partially ramped with snow onto tundra. The tundra consists of low-centered polygons which transition into indistinct high-centered polygons and thence into generally featureless ground. Grid size: 60 × 166.



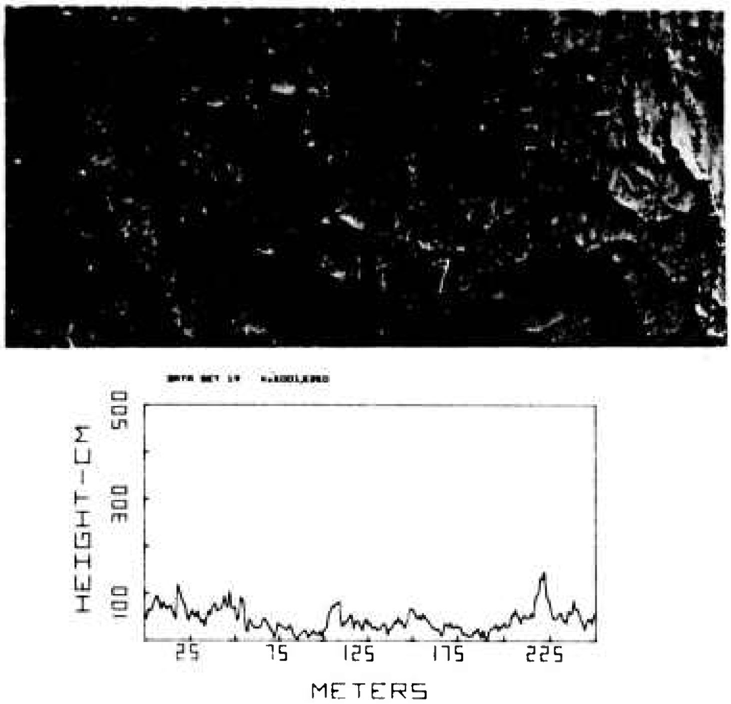
File 15. While fairly uniform, the terrain has a gradation from left to right in the photograph from high microrelief to more featureless terrain. This area was used as a test site for the SK-5 trials at Barrow. Grid size: 50 × 200.



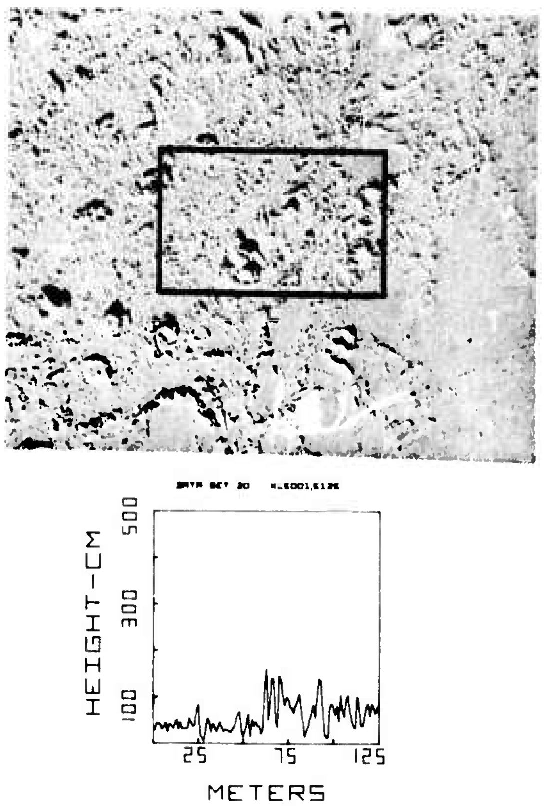
File 17. Transect across a hummock and brash zone in first year ice. Deformation is intense. Grid size: 36 × 280.



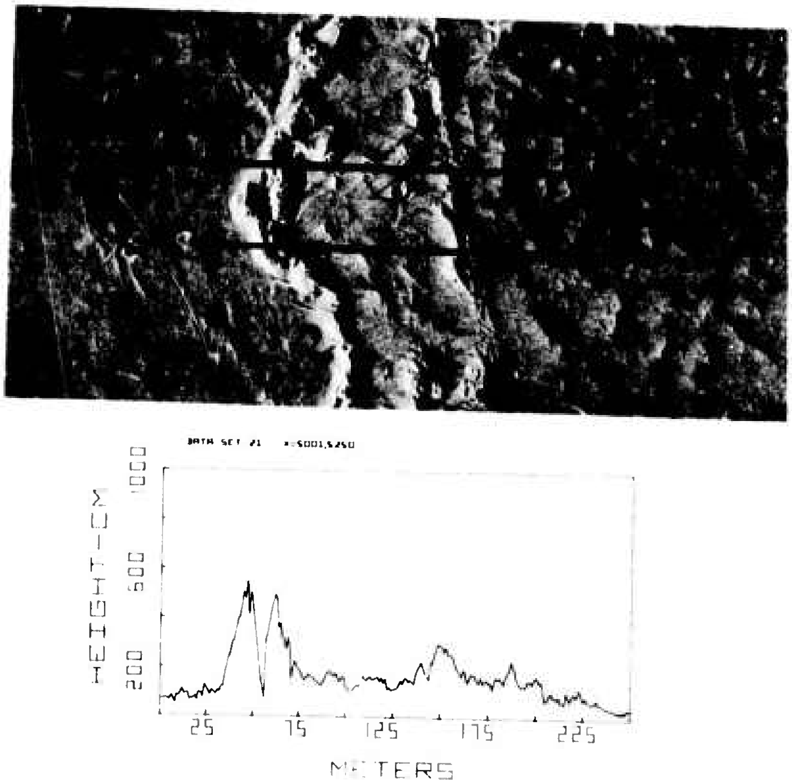
File 18. Area of second (?) year ice showing a "low intensity" rough surface due to rafting while the ice was presumably still thin. The snow dunes which have formed in the lee of the ice blocks are highly oriented. Grid size: 100 × 100.



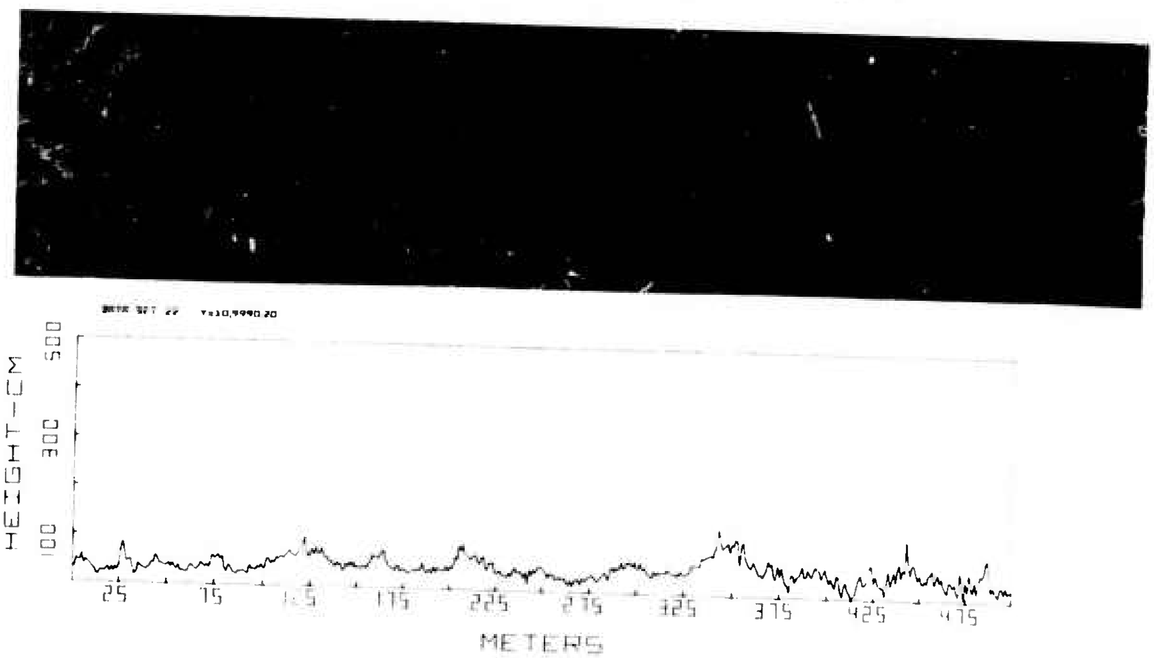
***File 19.** Transect through moderately rough first year ice showing signs of finger rafting. Grid size: 40 × 250.*



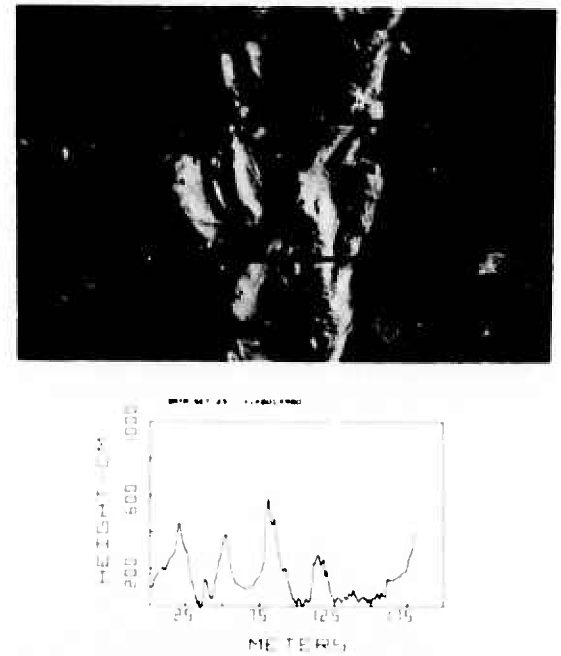
***File 20.** Very rough area composed of multiyear brash. A narrow, refrozen lead cuts the area. Grid size: 80 × 125.*



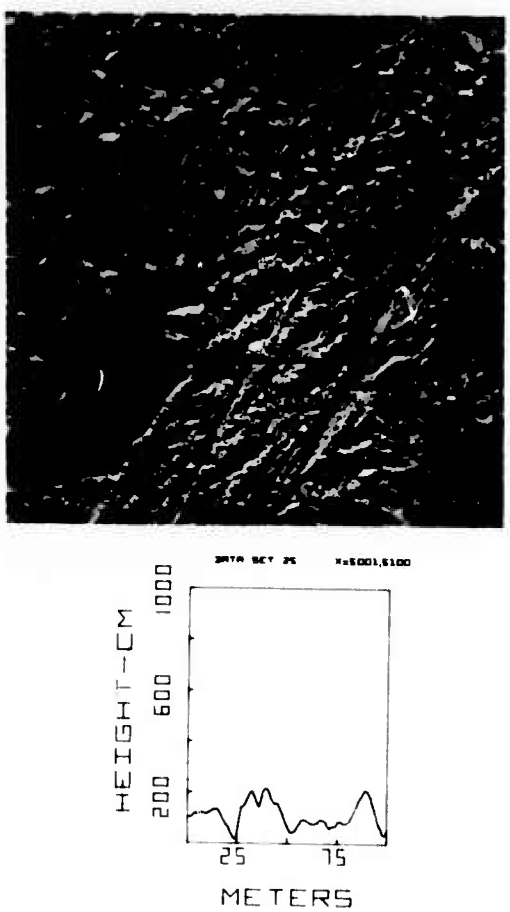
File 21. Transect across a large new pressure ridge that has formed between two multiyear ice floes. Most of the ice in the ridge proper appears to be first-year. Grid size: 40 × 250.



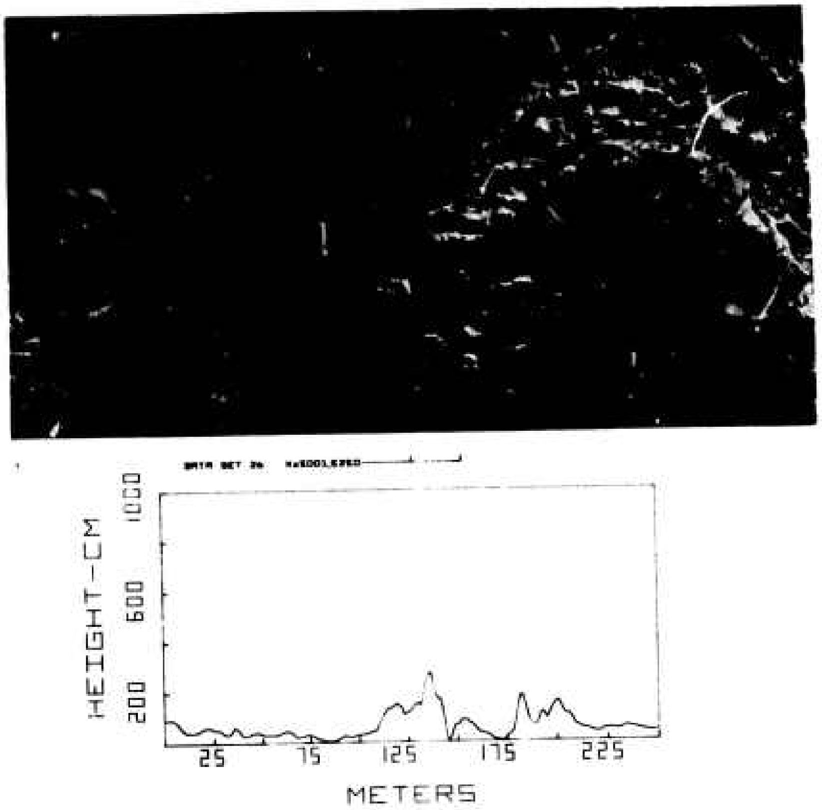
File 22. Transect across a relatively subdued section of a multiyear ice floe. Except for a lack of ridges, this is typical of conditions in the central Arctic Basin. Grid size: 500 × 20.



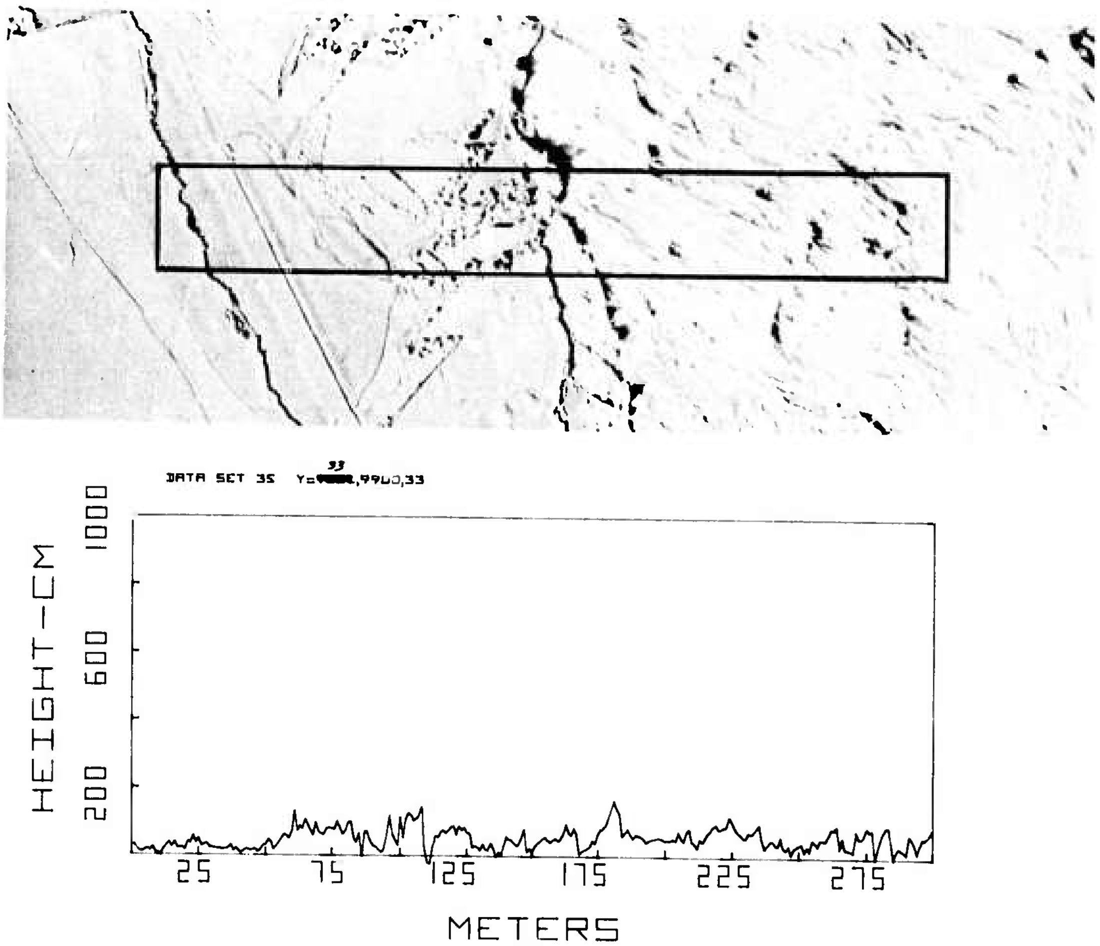
***File 23.* Transect across a large new pressure ridge formed between two multiyear floes. The ridge has a double crest in this subarea with a segment of first year ice enclosed. Grid size: 62 × 160.**



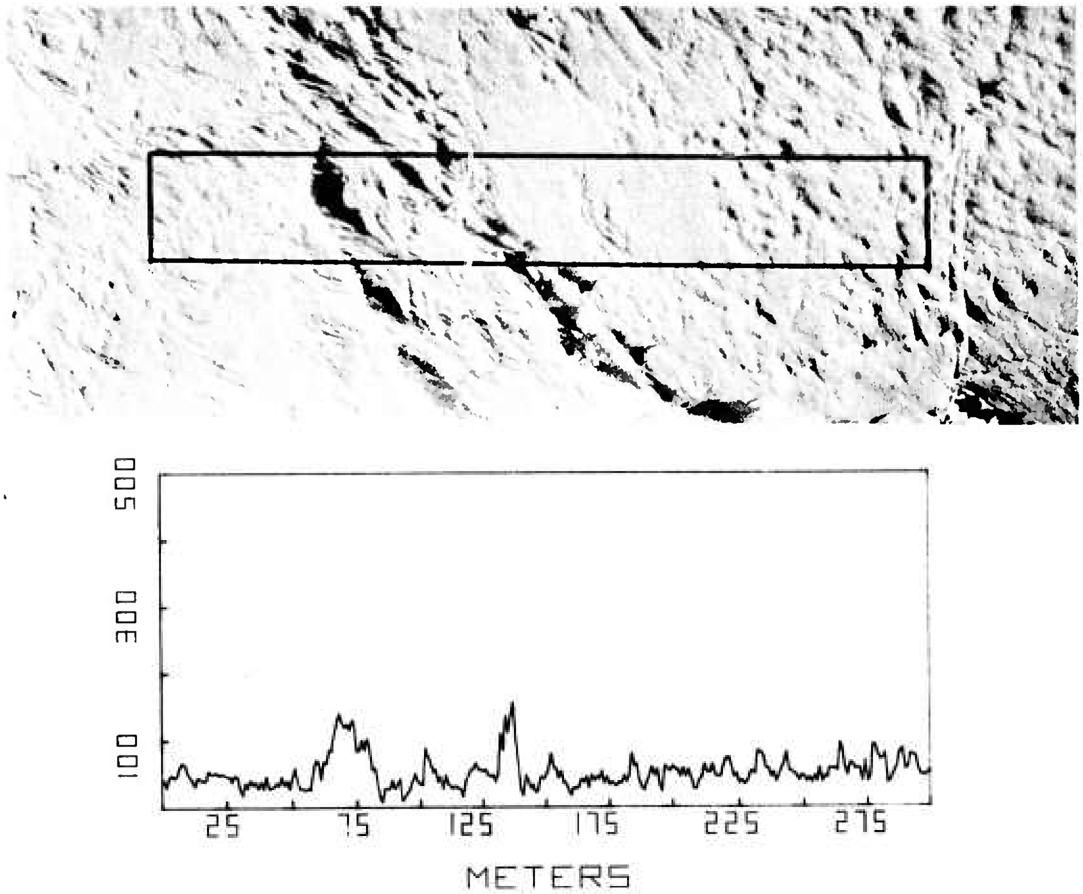
***File 25.* Transect cutting a major shear zone in primarily multiyear ice. Deformation is intense, producing extreme surface roughness. Grid size: 100 · 100.**



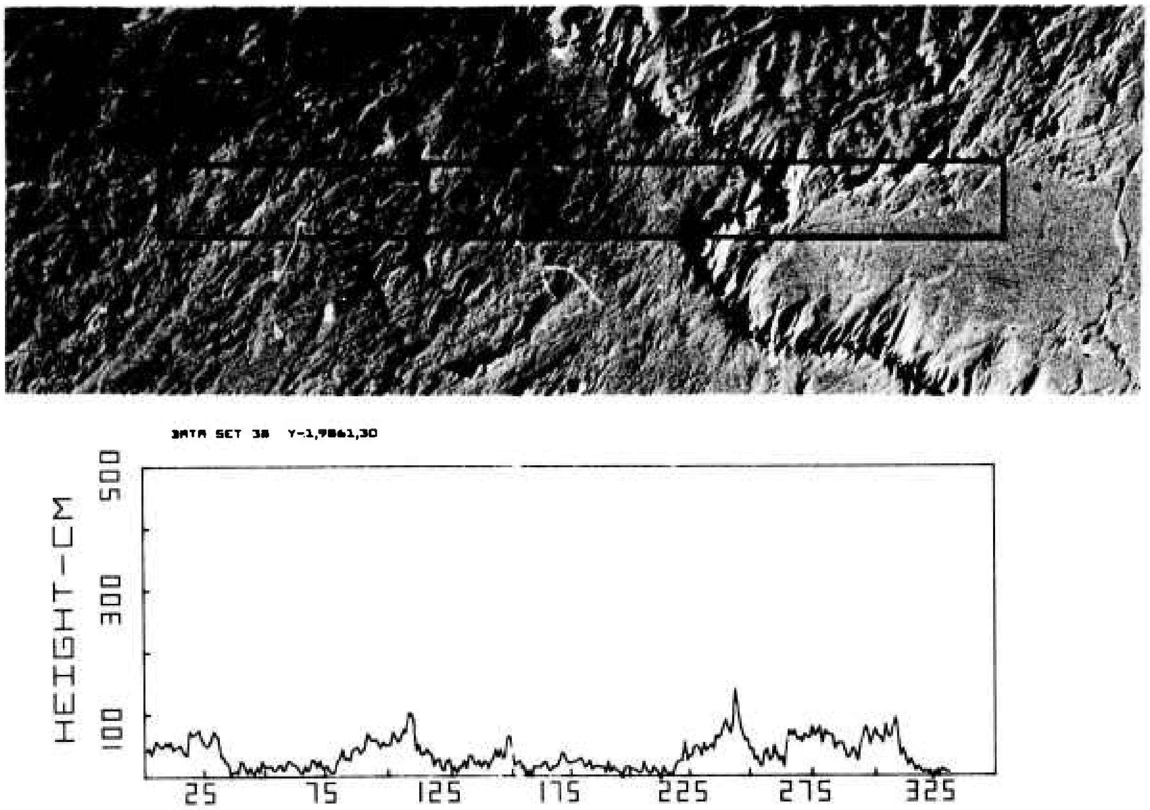
File 26. Transect from a moderately rough multiyear floe into a rough area of refrozen brash. Grid size: 40 × 250.



File 35. This area is approximately one-half young ice and one-half first year ice. The young ice has minor ridging, and a moderate ridge zone occurs at the contact, where flaps of young ice are being thrust over the thicker first year ice. The first year ice has irregular ridging and sastrugi. Grid size: 300 × 30.



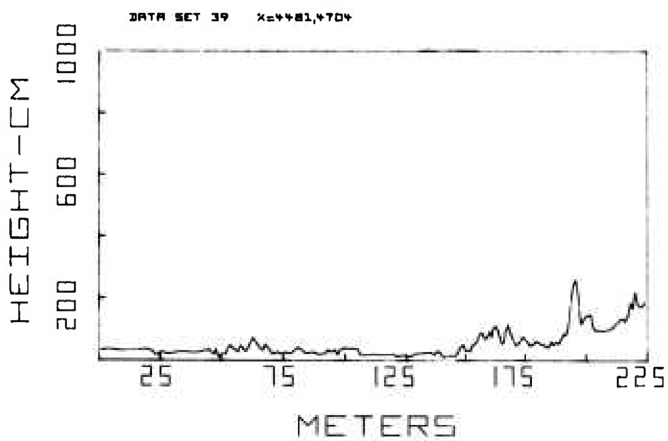
File 37. This is predominantly multiyear ice with a typical surface morphology of rounded melt hummocks. Two subparallel pressure ridges are crossed and two very flat areas, presumably refrozen melt ponds, occur in the area. Grid size: 300 × 33.



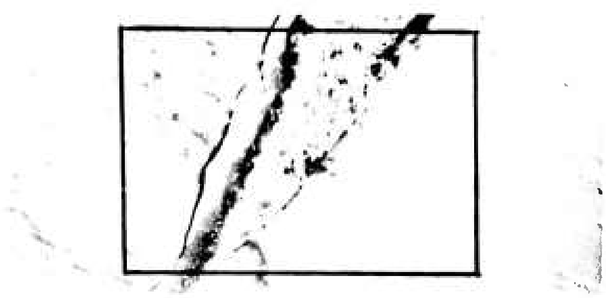
HEIGHT-CM

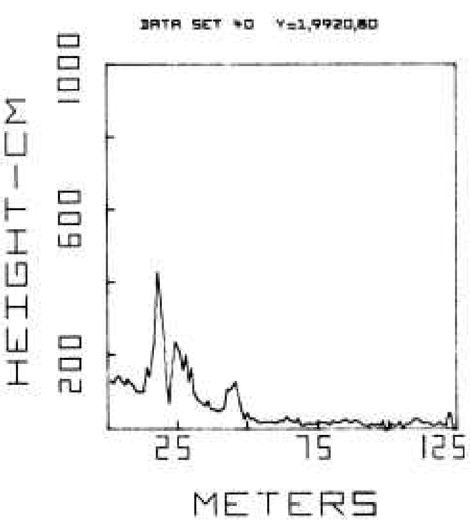
METERS

File 38. *This sample crosses two thick floes of first year ice which have interacted at their boundaries to form a prominent pressure ridge due to thrusting. Grid size: 330×30.*

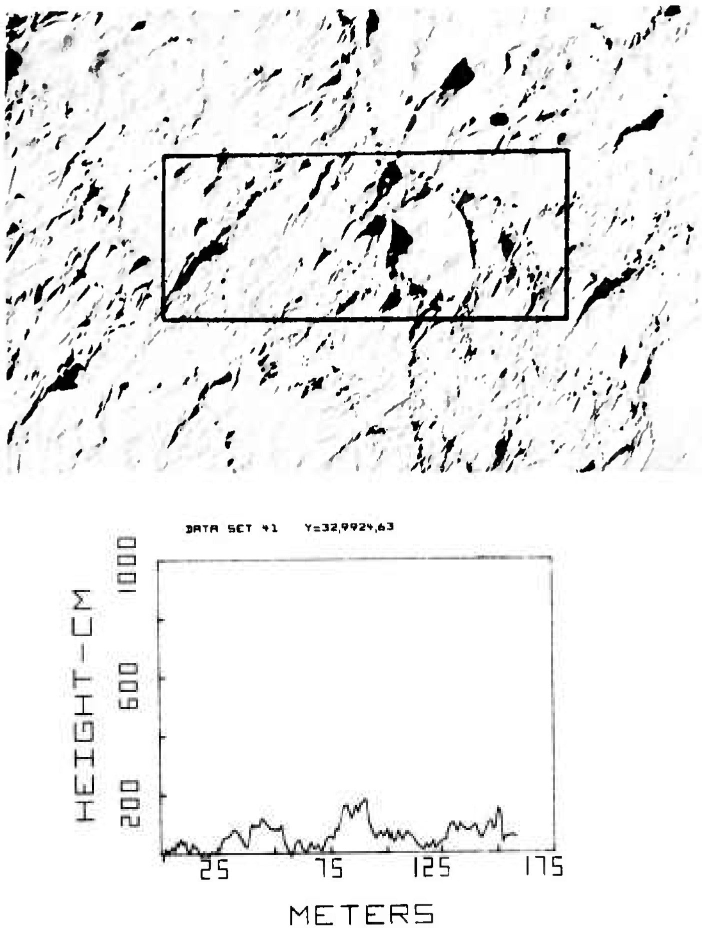


File 39. This sample crosses a pressure ridge formed by thrusting of one floe over another. The sinuous nature of the ridge is well illustrated and shows a small cul-de-sac. Grid size: 45 × 224.

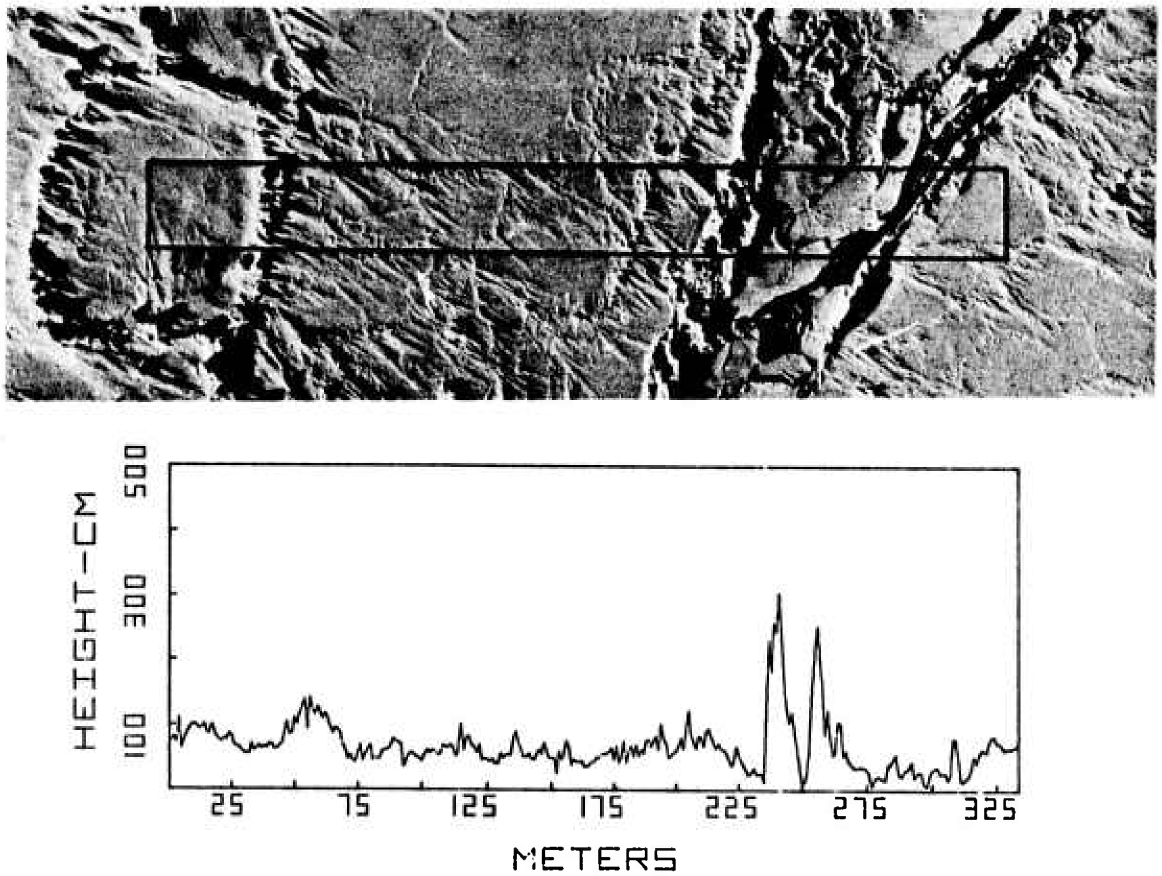




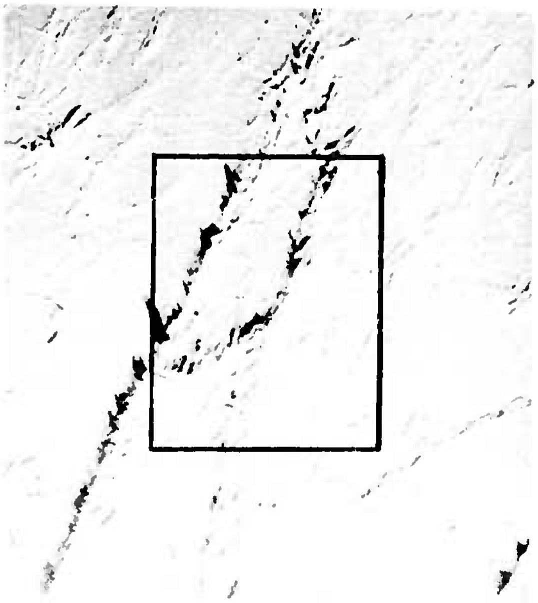
File 40. This area contains an active deformation zone with the following features: new ridge deformation, brash ice, and rotation of broken blocks by edge loading prior to being incorporated into a ridge. First year ice with snow dunes occurs on both sides of the deformation zone. Grid size: 125 × 80.



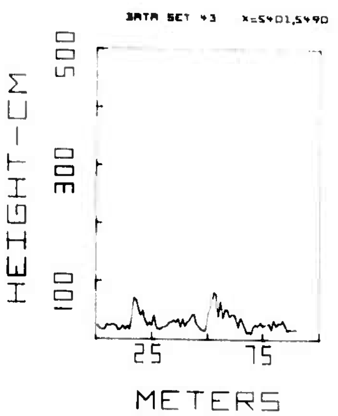
***File 41.* This sample contains multiyear ice fragments with an irregular mélange of ridges and dunes. Grid size: 158×63.**

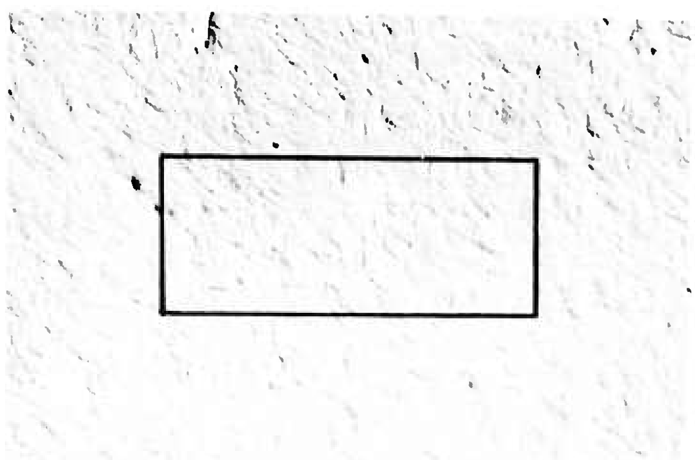


File 42. This area contains first year ice with a number of prominent features: newly formed ridges, a partially refrozen lead partially filled with brash, rotating slabs of ice at the edge of the lead and well developed longitudinal snow dunes associated with the older pressure ridges. Grid size: 30 × 333.

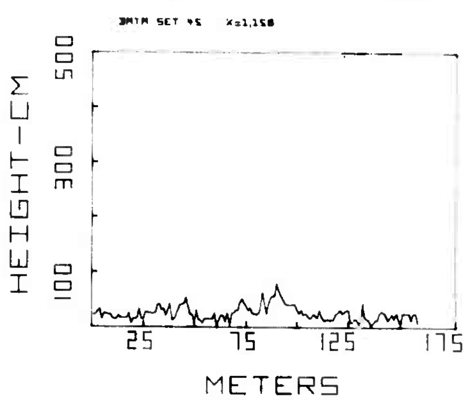


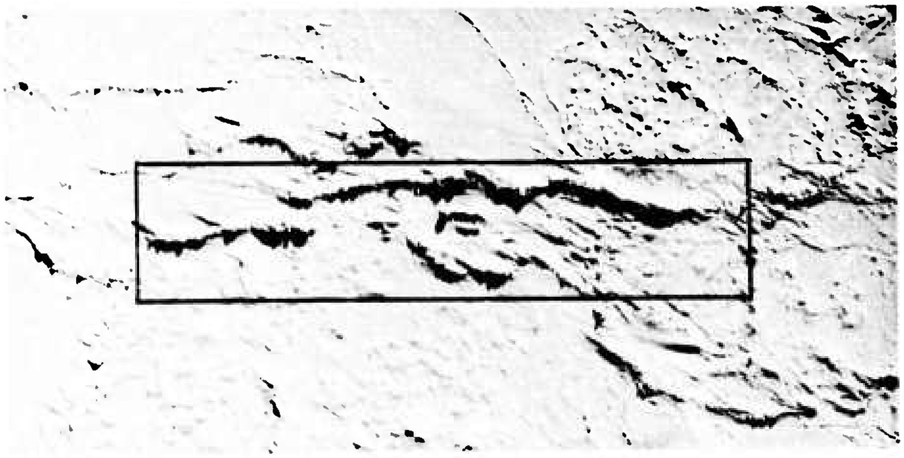
File 43. First year ice with moderate ridging forming a cul-de-sac. Sastrugi and snow dunes are prominent. Grid size: 111 × 90.

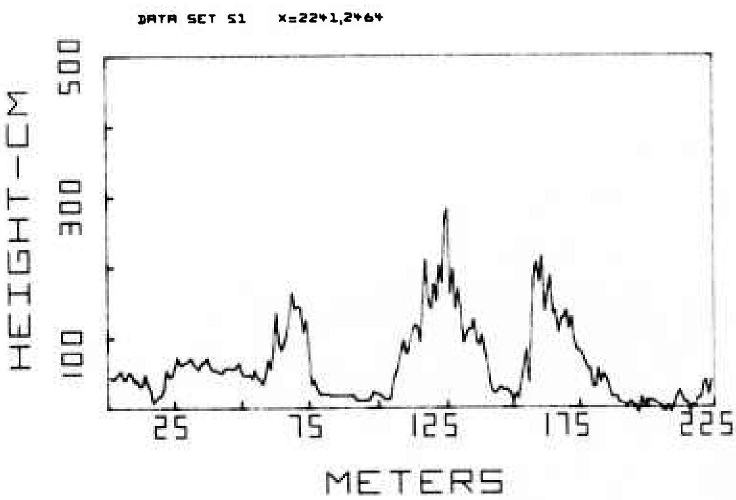




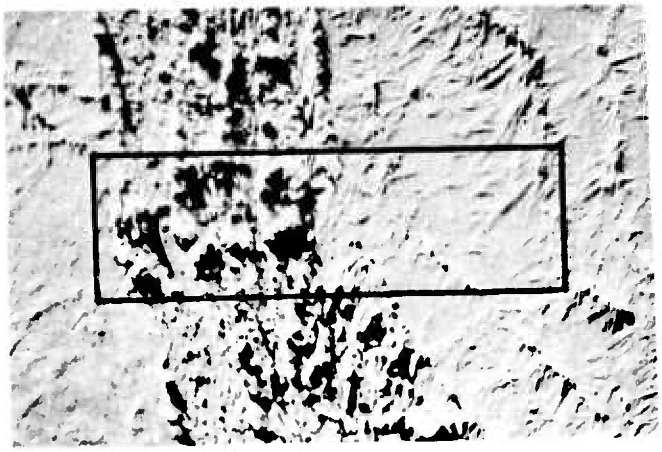
File 45. Surface of multiyear ice illustrating low melt hummocks and irregular snow dunes and sastrugi. Grid size: 63 × 158.

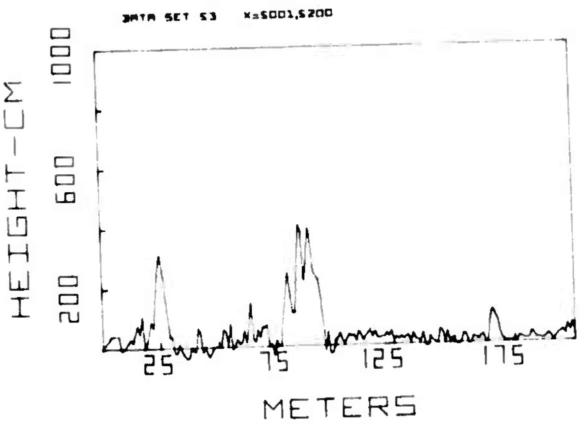




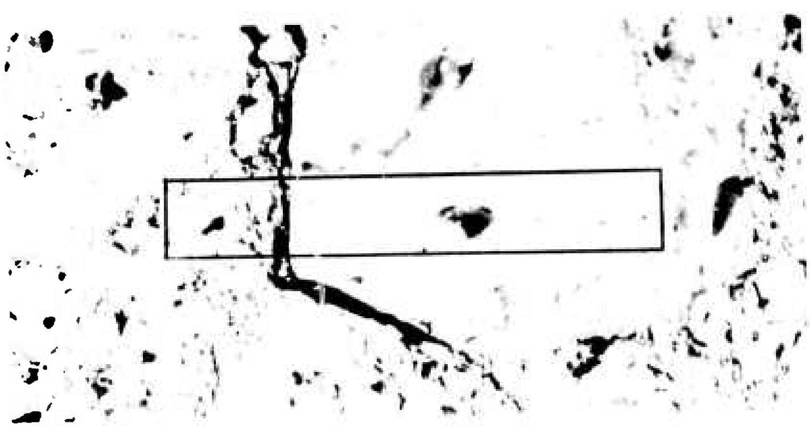


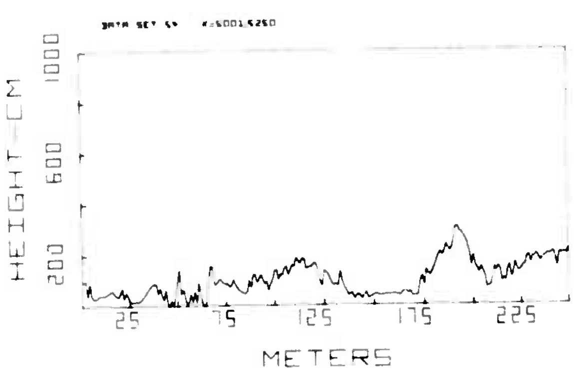
File 51. This sample encloses a portion of a prominent ridge zone separating two multiyear floes. Several subparallel ridges occur within the sample along with longitudinal snow dunes formed on the lee side of the ridges. Grid size 45 × 224.



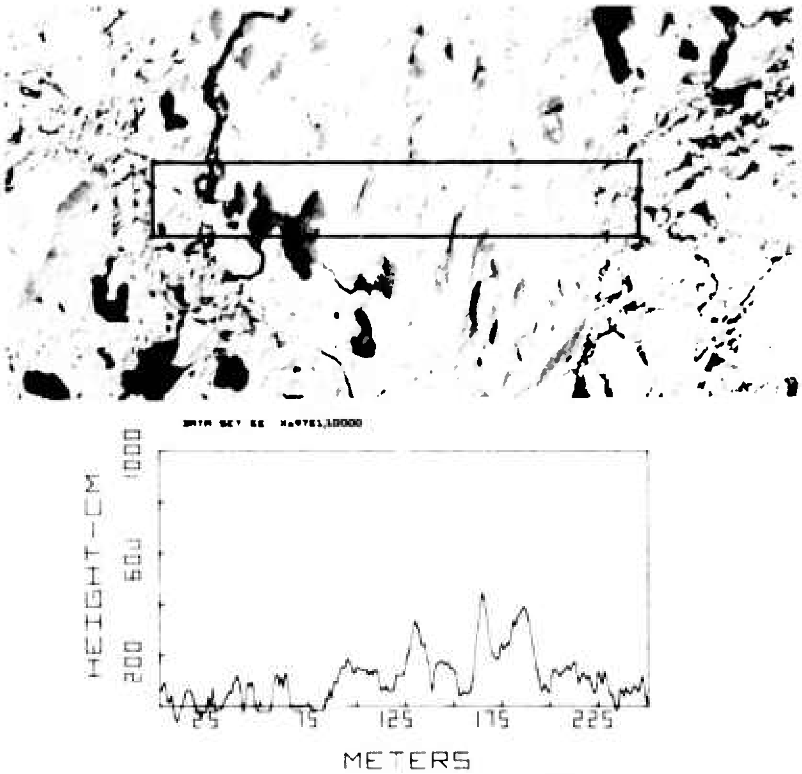


File 53. Track crossing a well developed and generally straight shear zone. Area of crossing is intensely deformed and constitutes a rubble field. First year ice occurs on both sides of the track. Grid size: 50 · 200.

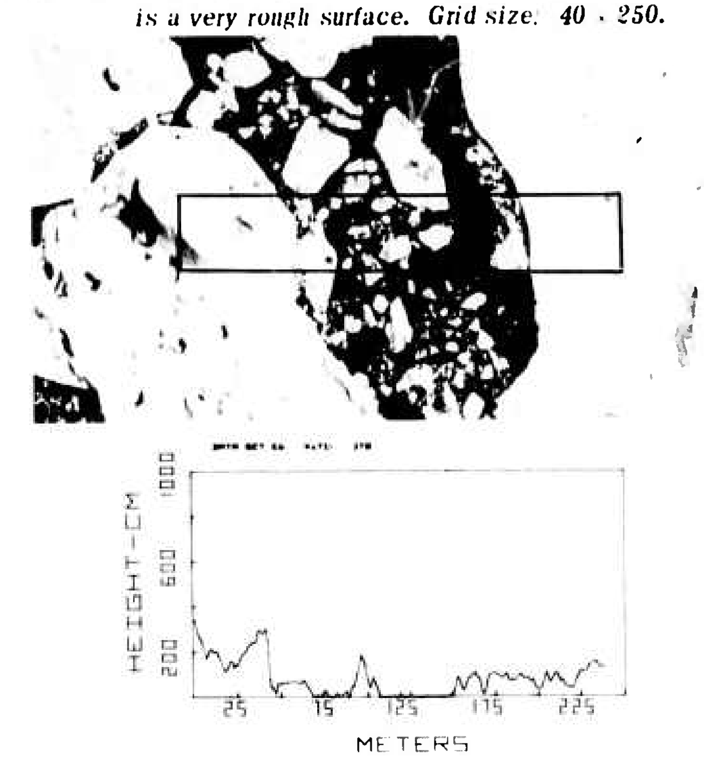




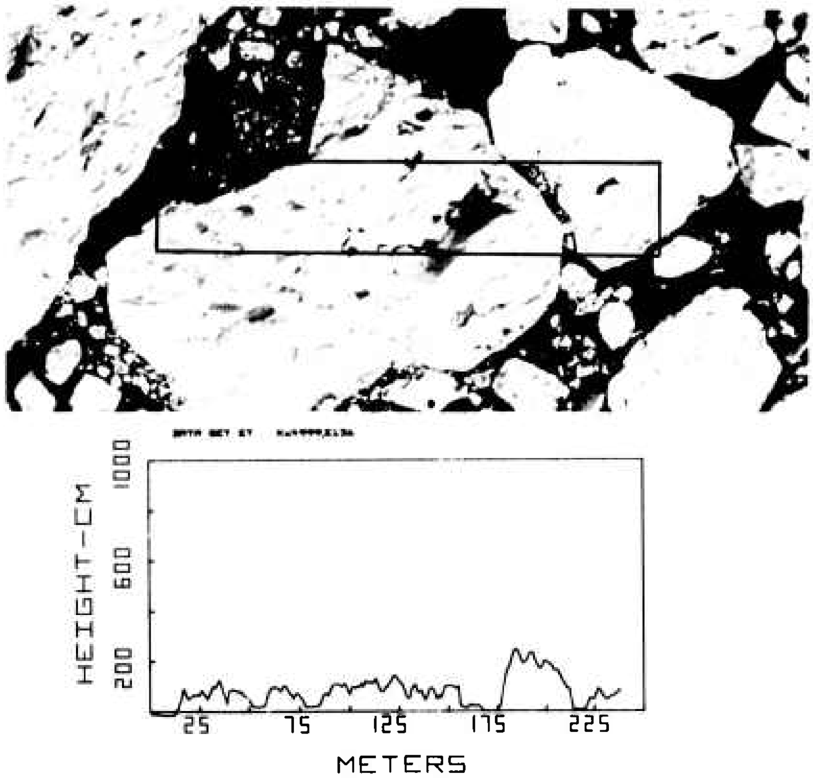
File 54. An old multiyear floe with a rough but melt-modified surface makes up 70% of this sample. The remainder of the area includes a very narrow lead, first year ice and blocks of floating multiyear ice. Grid size: 40 · 250.



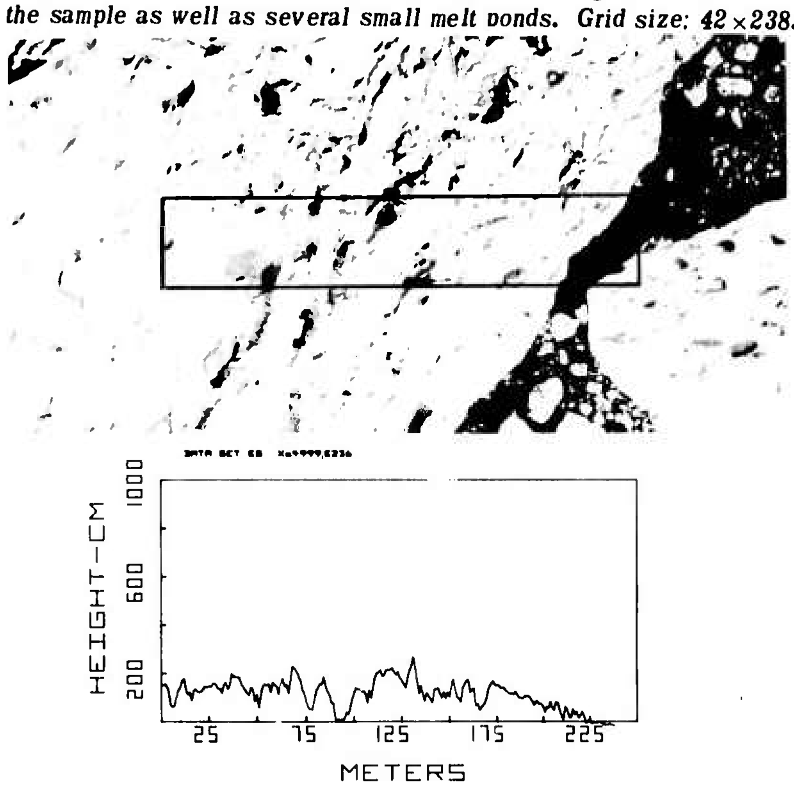
File 55. This sample crosses a series of parallel pressure ridges which have been extensively modified by melt action. Melt ponds with open water and freshly refrozen ice occur in the troughs between ridges. This is a very rough surface. Grid size: 40 × 250.



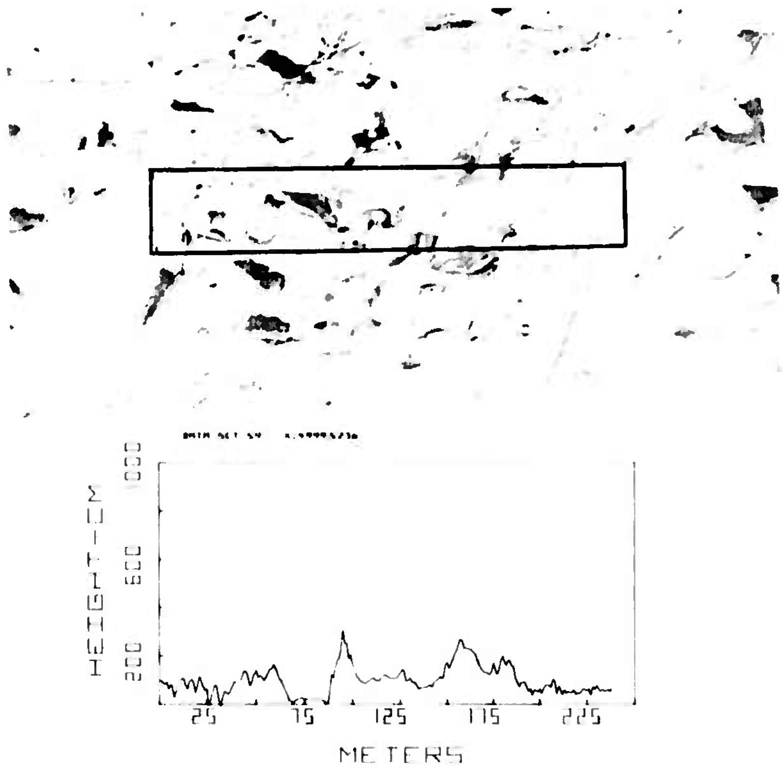
File 56. This sample crosses two multiyear floes and a lead containing 50% ice in the form of brash and disintegrating blocks. Grid size: 42 × 238.



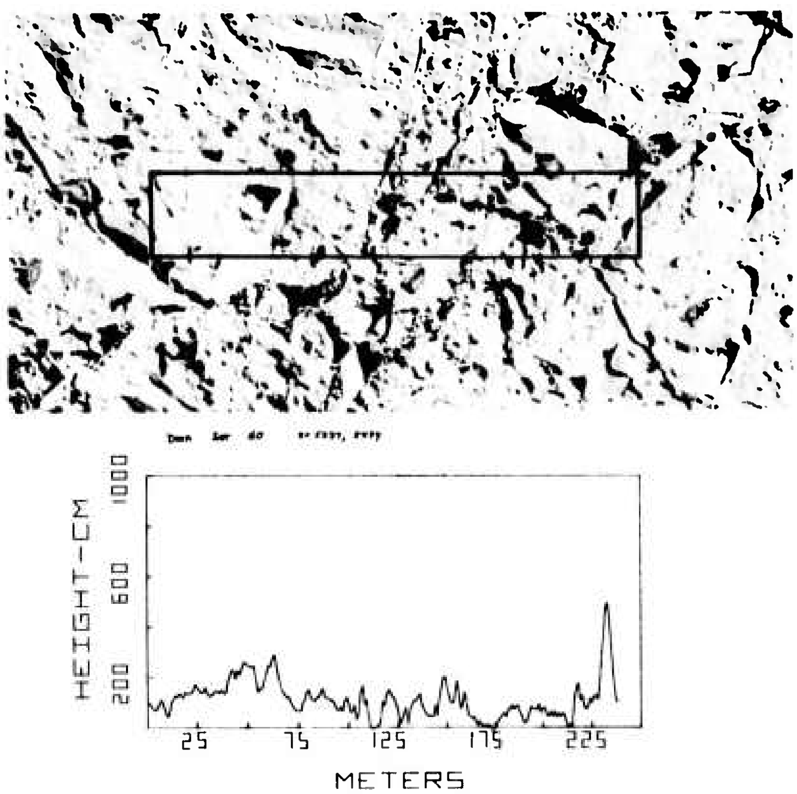
File 57. This sample includes portions of two multiyear floes. A weathered pressure ridge, approximately 9 ft in height, occurs in the sample as well as several small melt ponds. Grid size: 42 × 238.



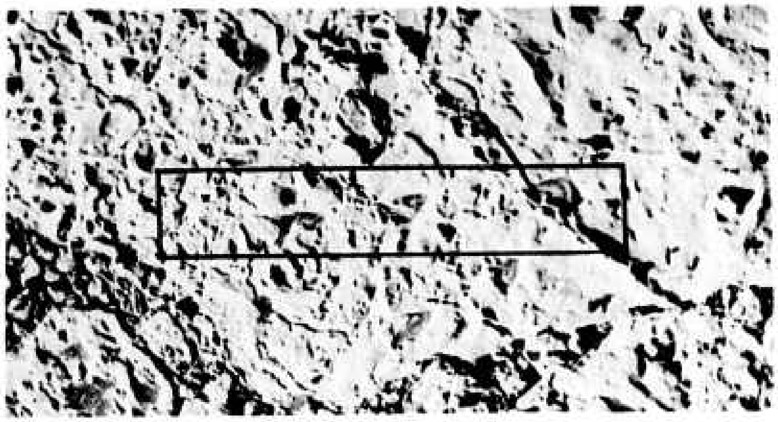
File 58. This is a continuation of the previous sample. This sample includes a narrow lead and a segment of a multiyear floe with a very rough, melt-incised surface. Grid size: 42 × 238.

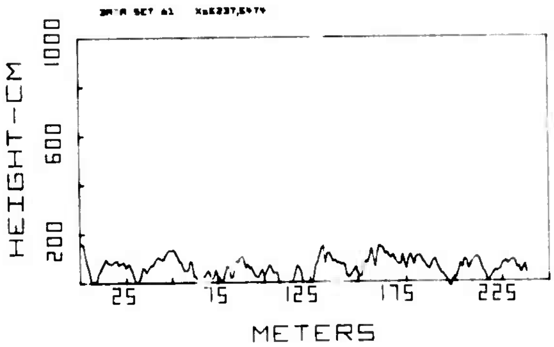


File 59. This sample is entirely on a multiyear floe having subdued relief and many melt ponds. Several low, rounded pressure ridges are crossed. Grid size: 42 · 238.

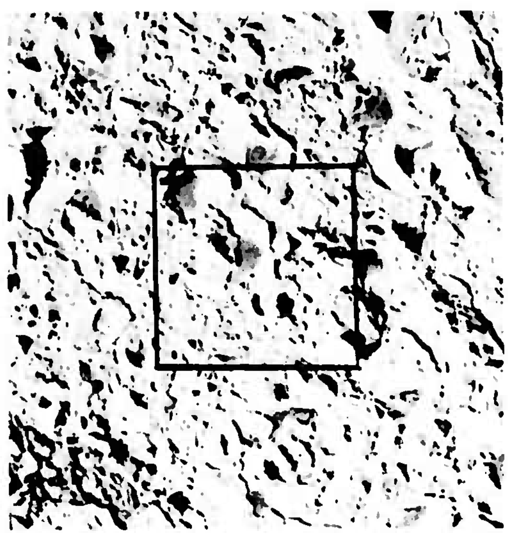


File 60. This sample illustrates typical late summer conditions in the permanent ice pack. The rough surface is being rounded and subdued by melt and numerous melt ponds are present. A poorly defined zone with thick brash and floating blocks occurs where two floes have collided. Grid size: 42 · 238.

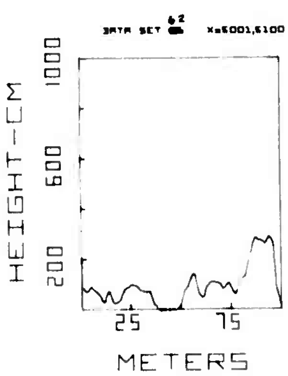


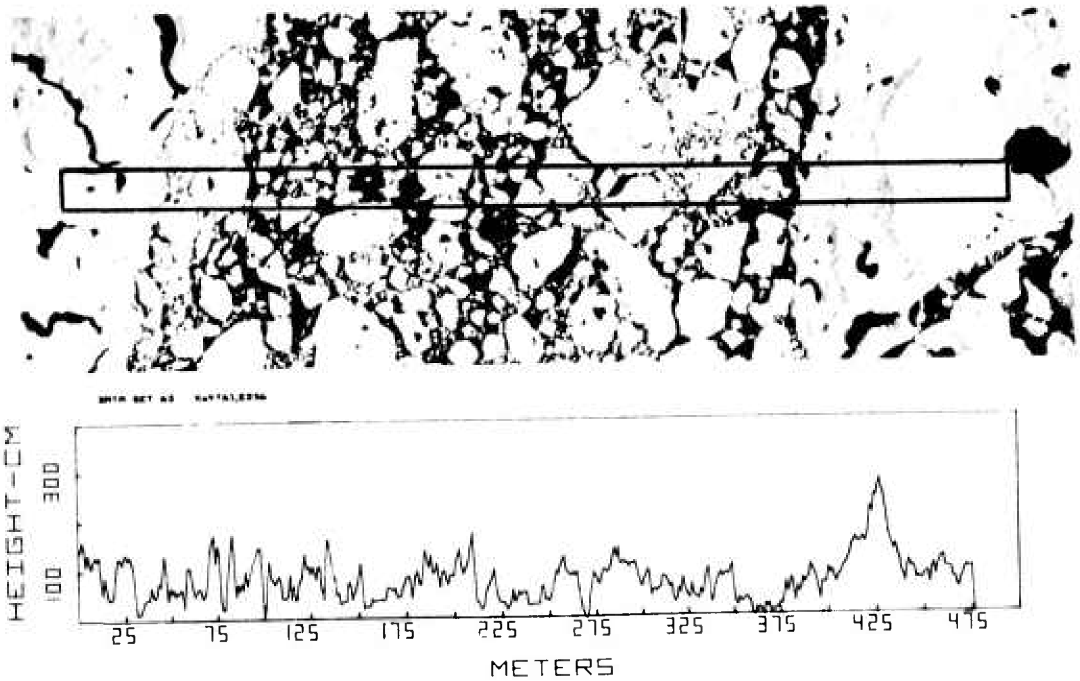


File 61. Typical late summer conditions illustrating melt ponds, melt hummocks and an old pressure ridge, considerably subdued. Grid size: 42 × 238.

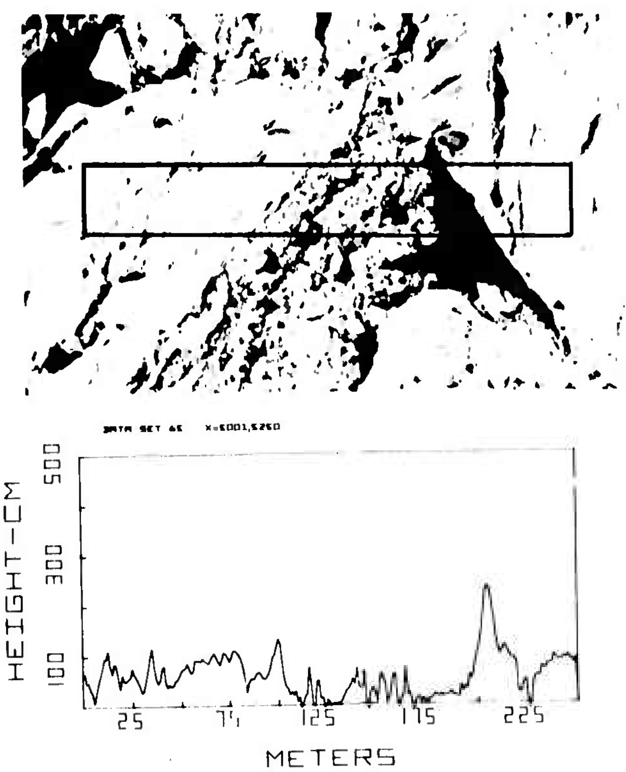


File 62. This area contains rough multiyear ice in late summer, which has been modified by melt but still retains many of the angular features characteristic of winter conditions. Grid size: 100 × 100.

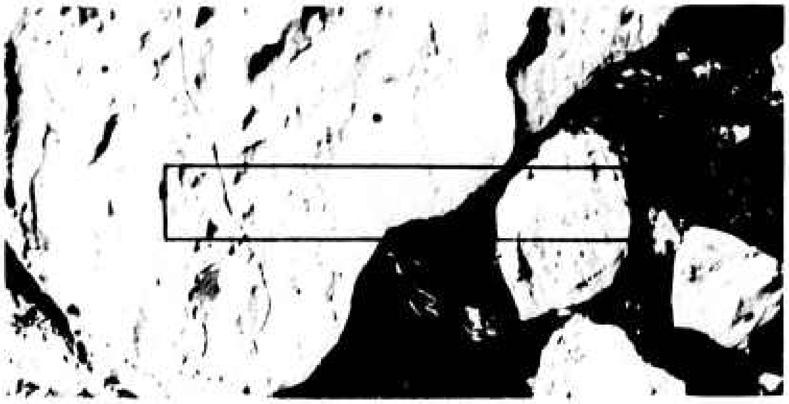


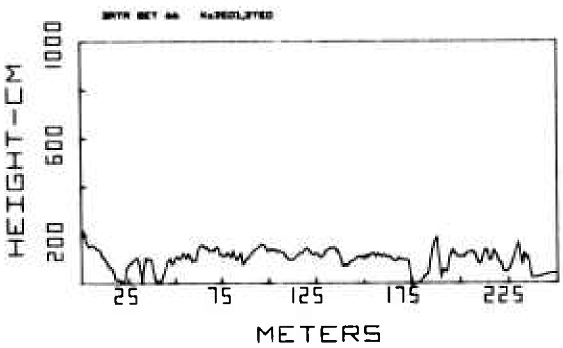


File 63. This sample crosses an ice-clogged lead between two multiyear floes. Ice ranges from brash up to 30-meter-wide pieces of multiyear ice. Grid size: 21 × 476.

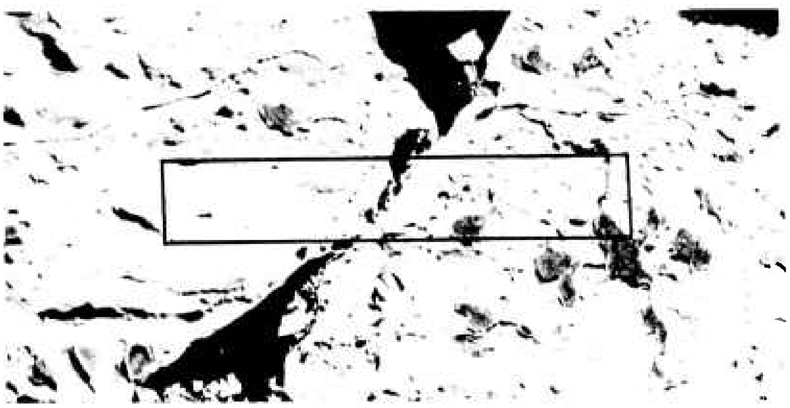


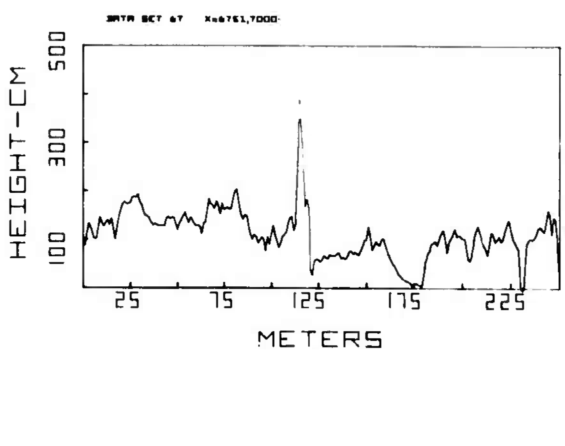
File 65. This sample includes two multiyear floes with typical late summer surfaces, rough but with much rounding of features due to melt. A zone of brash with some new ice and open water separates the two old floes. Much of the brash appears to consist of unstable fragments of a pressure ridge. One floe is bounded by a ridge that presents a formidable obstacle to passage. Grid size: 40 × 250.





File 66. This sample crosses a multiyear floe and a segment of open water and continues onto a fragment of a multiyear floe. The surface has been modified by melt, and a few refrozen melt ponds occur. A prominent crack cuts through the large floe. Grid size: 40 × 250.





File 67. This sample crosses two multiyear floes with minor ridging occurring at their juncture. The surface is typically hummocked and has subdued ridges. Portions of several melt ponds and an incised drainage channel are present. Grid size: 40 × 250.