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PRESENTED PAPER

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SEASAT-SAR DATA EVALUATION FOR STRUCTURAL AND SURFICIAL GEOLOGY

ABSTRACT

One of the paths of SEASAT recorded over Precambrian Shield and Quaternary deposits in Southern Ontario is analyzed and evaluated. The inherent structural characteristics of metamorphosed and igneous rocks are investigated and comparisons are made between the structural patterns interpreted on SEASAT-SAR data and the patterns recognized on LANDSAT images and aerial photographs. Analysis carried out to establish the characteristics of L band radar and look angle with the positions of the bedrock structures is described. The size and positions of surficial deposits such as drumlines are studied and recorded.

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INTRODUCTION

Prior to the launching of SEASAT in 1978, the Canada Centre for Remote Sensing organized a program of experiments to evaluate the applicability for various disciplines of SEASAT and Airborne Synthetic Aperture Radar (SAR) data.

A committee known as the Surveillance Satellite-SAR (SURSAT-SAR) Project Office was formed to invite and select experiment proposals It was also the function of this committee to acquire the appropriate SEASAT data for participants and to organize the acquisition of airborne SAR data through the Canada Centre for Remote Sensing, using the dual-channel Synthetic Aperture Radar sensor of the Environmental Research Institute of Michigan (ERIM). The plan was to obtain airborne SAR data for the same areas for which SEASAT data was to be acquired, for the purpose of assessing the capabilities and limitations of spaceborne radar. Because of the early malfunction of SEASAT, not all planned experiments could be supplied with SEASAT-SAR data. Among the accepted proposals for which SEASAT data was available, however, was one submitted by the principal author of this paper. It concerned the evaluation of SEASAT-SAR data for geological applications.

OBJECTIVE OF THE EXPERIMENT

The objective of the experiment was to evaluate the applicability of SEASAT-SAR data for the following purposes:

1. the study of structural geology
2. recognition of major rock types (e.g. volcanic, sedimentary, metamorphosed)
3. the study of glacial morphology.

DATA EMPLOYED

SEASAT(L band)-SAR

For comparison and/or reference, the following data types were used in conjunction with the SEASAT-SAR data:

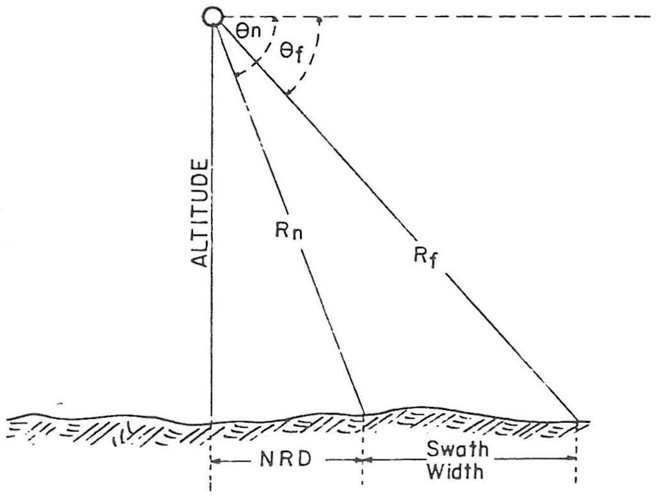
- airborne SAR data, X and L band, with both parallel and cross polarization
- LANDSAT data
- small- and large-scale aerial photography

Table 1 provides technical information on all data types used.

It should be noted that the SEASAT data used for interpretation in this study was not digitally processed. Therefore, the full potential value of SEASAT may not in fact have been realized. For operational use, however, and because of the cost of the digital method, the analogue method of processing will usually be employed. This test was a realistic evaluation of the information that most users will be able to extract from SEASAT-SAR. Examples of digitally-processed imagery which were ordered had not been received at the time of preparation of this paper.

DESCRIPTION OF THE EXPERIMENT SITE

The experiment site is located in the vicinity of Peterborough in South Central Ontario and includes a large portion of the Grenville province of the Precambrian Canadian Shield and the famous Peterborough drumlin fields. This part of the Canadian Shield has been subjected to a high degree of metamorphism, resulting in strong flow patterns and bands around the large granitic and pegmatite plutonic bodies. The Paleozoic sedimentary rocks (limestone and dolomite) overlie the Shield in the south with a few outliers occurring north of the main body. The entire area is mantled by a layer of glacial deposits consisting of bouldery sand, silt and clay of varying thickness. During the last glaciation south of the Shield, these materials were formed into large drumlin fields of varying extent. A few north-south-trending eskers also occur in the area. Detailed geological information can be obtained from the Haliburton-Bancroft map sheet #1957B, 1:126,720-scale published by the Ontario Geological Survey.[1] Detailed information on surficial geology can be obtained from The Physiography of Southern Ontario by Chapman and Putnam (1951)[2]. Figure 1 is a mosaic of SEASAT data for the entire experiment site on which the airborne SAR data flight lines have been marked. The areas selected as examples for detailed analysis are outlined.



SAR IMAGE PARAMETERS:

	SAR 580	SEASAT-SAR
Image Date	1 August 1978	27 August 1978
Altitude (km)	6.52	∿800 km
θn	29.5^{o}	$\sim 73^{o}$
θf	20.3^{o}	$\sim 70^{o}$
R_n (km)	13.3	∿800 km
R_f (km)	18.8	∿800 km
NRD (km)	11.5	∿300 km
Swath Width (km)	6.1	100 km
X-band resolution (m)	2.1(azimuth);1.5(range)	-
L-band resolution (m)	5.0(azimuth);3.0(range)	25(azimuth);25(range)
Polarizations	HH and HV	HH

PARAMETERS OF OTHER IMAGERY USED:

LANDSAT image 21014-14493, November 1, 1977

High-altitude aerial photo, July 17, 1971. Scale: ∿1:130,000.

Low-altitude aerial photos, August, 1978. Scales: 1:24,000 and 1:60,000.

TABLE 1: Technical parameters of the data employed.

INTERPRETATION RESULTS

Analysis of Structural Geology

For the evaluation of the applicability of SEASAT-SAR in the analysis of structural geology, an area was selected where only one major rock type occurred - plutonic rock composed of granite, granite gneiss and pegmatite - so that features of structural geology would not be obscured by different rock types. A second reason for the selection was that airborne SAR data in two look directions perpendicular to one another had been obtained for this area. Figure 2, an enlargement of SEASAT data and Figure 3, an aerial photograph (scale: ∿1:130,000), both show the structural geology example area and indicate the airborne SAR data flight lines. (A stereopair could not be used in Figure 3 because of space restrictions).

A comparison between the aerial photograph and the SEASAT image indicates that the major fractures and lineations are equally visible on both. The strike of foliations and beddings in the metamorphosed rocks, where it is made evident by topographical differences, is well recorded on the SEASAT data. If the look direction is parallel to the strike, however, it will not be possible to recognize the slight ridging which indicates a strike. If the strike has no topographical expression, SEASAT-SAR data will not reveal it.

In order to explore the ability of synthetic aperture radar per se to provide data on structural geology, the area where the airborne SAR data was obtained in two look directions and in both X and L bands (the rectangular area covered by the intersection of the flight lines, Figure 3), was studied in detail. Examples of the X and L band cross-polarized airborne SAR data of this area are given in Figure 4.

The resolution of airborne SAR is between 2 and 5 m, depending upon the band, while the resolution of SEASAT(L-band)-SAR is 25 m. One of the reasons for undertaking an analysis of airborne SAR was to discover the implications of this difference in the interpretation of the structural geology.

It is evident from the first glance that airborne SAR data contains far more finely-detailed structural information than can be seen on SEASAT. In addition to resolution, three possible factors contributing to this difference are altitude, look-angle and band selection. It has not been determined whether altitude has an attenuating effect on SAR recordings. The look angle on SEASAT (70^{o}) is much larger than that of airborne SAR (30^{o}). Generally, the recording of slight topographical differences is more successful if a shallow look angle is employed but structural detail is lost as the angle approaches the vertical. The effect of the more oblique look angle of airborne SAR can be compared to the effect of low sun angle in winter on LANDSAT recordings in the northern hemisphere where considerable structural detail is revealed by the shadows cast by topographic features.

In a report prepared for the SURSAT-SAR Project Office by the authors, the superiority of X band SAR to L band SAR for geological applications was discussed[3]. Other investigators have concurred with this finding[4]. SEASAT-SAR, however, was not primarily designed for geological purposes.

On airborne SAR data it is noted that the appearance of lineaments and faults is more distinct on the X band. Many shadows caused by topographical differences resemble waterbodies on L band, creating confusion in interpretation. On both bands, however, structural features located on a diagonal line to the look direction are the most visible features while structures parallel to the look direction lose their identity. For example, the lineament extending from the lake marked 'A' on Figure 4 is not discernible on the image in which it is parallel to the look direction. However, there is no loss of information on other structural features.

SEASAT-SAR data provides information on major structural patterns if they are represented by a change in topographic relief. When SEASAT-SAR and LANDSAT are compared it is evident that LANDSAT offers much finer structural detail, even with a resolution of 70 m (Figure 5).

Recognition of Major Rock Types

It is only possible to recognize major rock types on SEASAT-SAR by the general topographical appearance and structural characteristics of each rock type. For example, extensive flow patterns formed by thin, closely-set lines on SAR data indicate metamorphosed rocks while a homogeneous surface with no extensive structural interruption indicates the presence of sedimentary rocks. Figures 6 and 7 show examples of interpretations of rock types from SEASAT-SAR data compared with a high altitude aerial photo. Some of the outliers of Paleozoic sedimentary rocks can only be recognized on SEASAT as flat areas. Without further data to relate these flat areas to the rock type, therefore, it is not possible to recognize them directly from SEASAT. Among metamorphosed rocks, plutonic rocks can be recognized by the diversionary flow pattern around rock masses or by the occurrence of multi-directional lineaments within one area. Figure 8 is an example of the recognition of plutonic rock - granite, in this case - on a SEASAT-SAR enlargement and the same distinct rock type on an aerial photograph in a stereopair.

Because the identification of rock types relies on the perception of subtle differences, which is affected by the degree of experience of the interpreter, the results are always debatable. It is more important, however, to make distinctions in rock types than to make positive identifications as, once the extent and distribution of a single set of characteristics are established, the identity of the rock type can be determined from other sources. This is the attitude with which the photo-geologist should approach the use of SEASAT. SEASAT would contribute little additional information in areas for which considerable data already existed. For those areas for which there are no geological maps, however, SEASAT might prove useful for general guidance, particularly for the planning of mapping strategy, if neither aerial photography nor LANDSAT data were readily available.

The usefulness of LANDSAT for the recognition of major rock types has been proved[5]. It would appear that SEASAT is not as valuable a source of this information as LANDSAT.

Recognition of Surficial Geological Features

The bright linear features appearing on SEASAT-SAR which are approximately parallel both to each other and to the orbital path of the satellite, mainly indicate drumlins (Figure 9). The orientation of the drumlins on the physiographic map of South Central Ontario (Chapman and Putnam, 1951) correlated well with those on the SEASAT-SAR image. Using a Zoom Transferscope and an enlarged radar image, the linears were mapped onto a 1:50,000-scale topographic map sheet (Peterborough, 31 D/8, Edition 4). It was found that drumlins and bright linears correlated extremely well although some difficulties existed due to the slight distortion of the radar image. Other linears appearing on the radar image did not match drumlins but were forest-edge boundaries or other slope features such as riverbanks. Drumlins were ranked and described according to radar backscatter intensity, aspect angle, size and side slope.

The drumlins all appeared reasonably bright on the radar image since most had side slope angles complementary to the SEASAT-SAR depression angle (70^{o}) i.e. zero incidence angles and aspect angles close to zero degrees. Maximum backscatter occurred from such geometric orientations. Cover type appeared to have some influence on the radar return, the forested drumlins having a lower return. Forest cover subdued the radar return from the drumlin side slopes in this case. Aspect angles of the drumlin axes and relative height of the drumlins above the surrounding terrain appeared to have no consistent relationship to the radar return (Table 2).

Since SEASAT-SAR responds significantly to the drumlins of South Central Ontario, it is conjectured that similar results would occur over sand dunes. Active or non-active dune areas may be distinguished by the relative radar return since it was found, in the case of drumlins, that vegetation cover influenced the return from slopes facing the radar antenna.

CONCLUSIONS

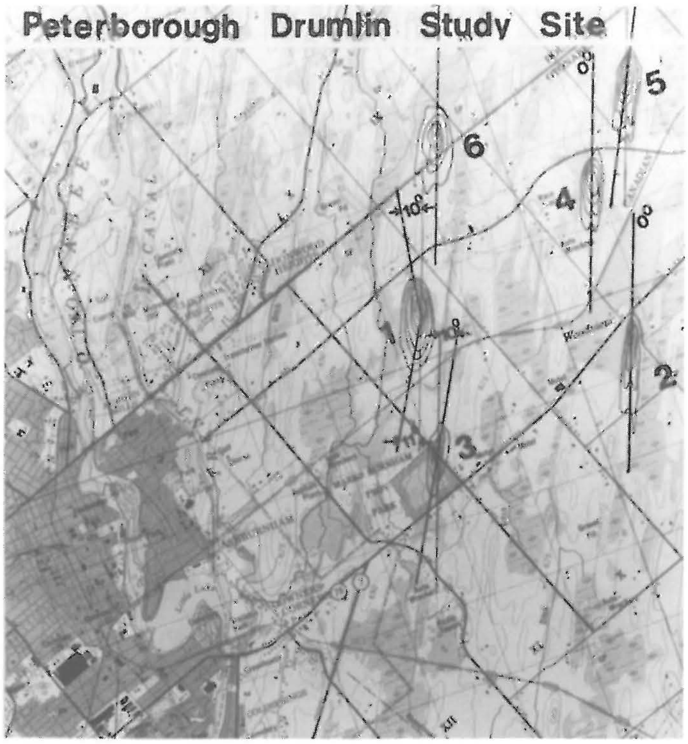
The conclusion of this study is that SEASAT-SAR data has potential use for geological applications. It would not be preferred data in areas for which aerial photography, LANDSAT imagery or airborne radar data were available. The present resolution and wavelength are factors limiting its use for geological purposes. However, because of its capability to record imagery over continuously cloud-covered areas - e.g. tropical regions - SEASAT-SAR could be useful in providing a synoptic view of structure, rock types and certain prominent topographic features. The authors plan to conduct further studies using computer-processed SEASAT data of areas presenting a wider variety of geological conditions.

REFERENCES

1. ONTARIO GEOLOGICAL SURVEY. 1957. Haliburton-Bancroft Area Geological Map #1957B. Scale: 1:126720.

2. CHAPMAN, L.J. and D.F. PUTNAM. 1951. The Physiography of Southern Ontario. University of Toronto Press for the Ontario Research Foundation.

3. PALA, S., R. MUSSAKOWSKI and E. WEDLER. 1980. SAR Imagery Evaluation for Geological Applications. Report presented to SURSAT-SAR Project Office, Energy Mines & Resources, Canada. January, 1980. Also extract in Proceedings, Sixth Canadian Symposium on Remote Sensing, Halifax, Nova Scotia. May, 1980.



DRUMLIN	ASPECT ANGLE		WIDTH	LENGTH	RELATIVE HEIGHT ABOVE SURROUNDING TERRAIN (ft.)	DRUMLIN SIDE SLOPE FACING SAR ANTENNA
	LEADING EDGE	TRAILING EDGE	(m)	(m)		
5	6°	6°	300	1,125	110	24.1°
4	0°	0°	275	950	85	20.7°
2	0°	0°	175	1,100	80	29.1°
1	11°	-10°	400	1,150	130	21.6°
6	0°	0°	400	950	100	17.0°
3	10°	10°	150	900	60	26.0°

NOTE: Drumlins ranked from highest SAR return (No. 5) to lowest SAR return (No. 3).

TABLE 2: The characteristics of six drumlins hear Peterborough, Ontario, and their appearance on a 1:50,000-scale topographic map sheet.

4. PARRY, J.T. 1974. X Band Radar In Terrain Analysis Under Summer and Winter Conditions. Proceedings, Second Canadian Symposium on Remote Sensing, University of Guelph, Guelph, Ontario. April 29 - May 1, 1974.

5. PALA, S. 1974. The Value of ERTS-1 Imagery for Mineral Exploration. Proceedings, Second Canadian Symposium on Remote Sensing, University of Guelph, Guelph, Ontario. April 29 - May 1, 1974.

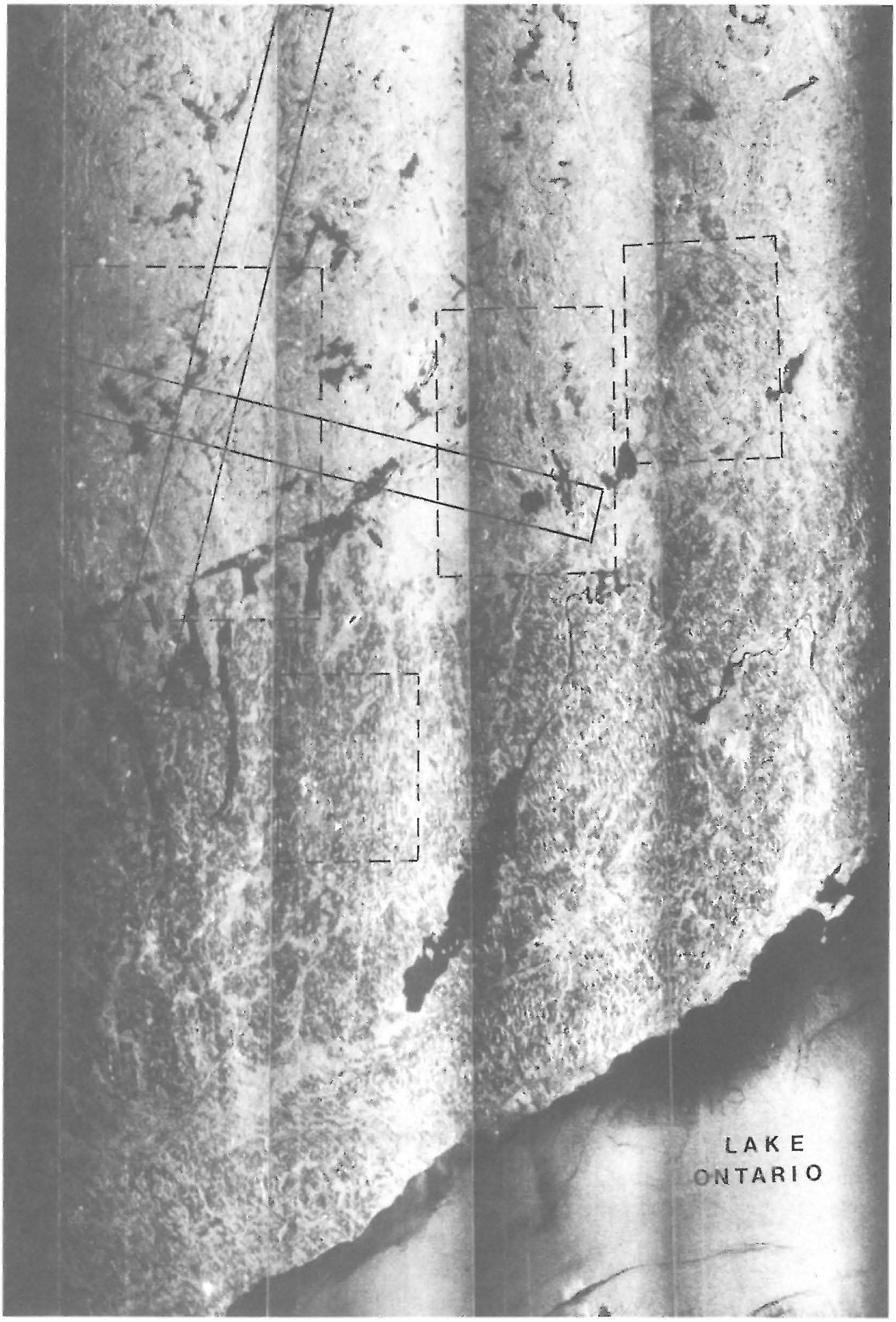


FIGURE 1: SEASAT-SAR data recorded August 28, 1978 showing the experiment area. Continuous lines indicate the airborne SAR data coverage and dash lines delineate the areas of examples detailed in this paper. Scale: ~1:850,000.

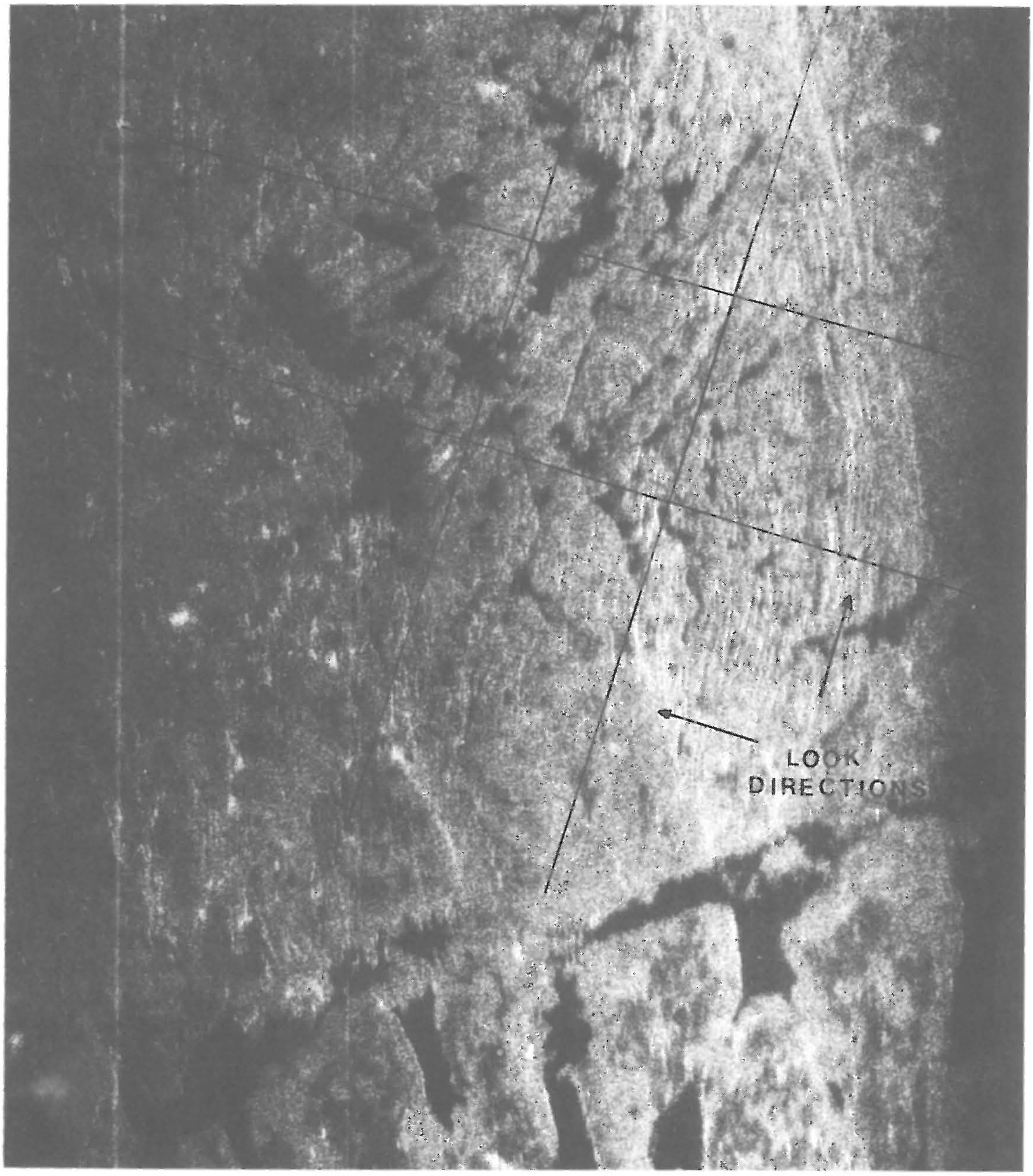


FIGURE 2: Four-times enlargements of SEASAT-SAR data of high altitude structural detail. The airborne SAR data coverage is delineated and look directions are indicated.

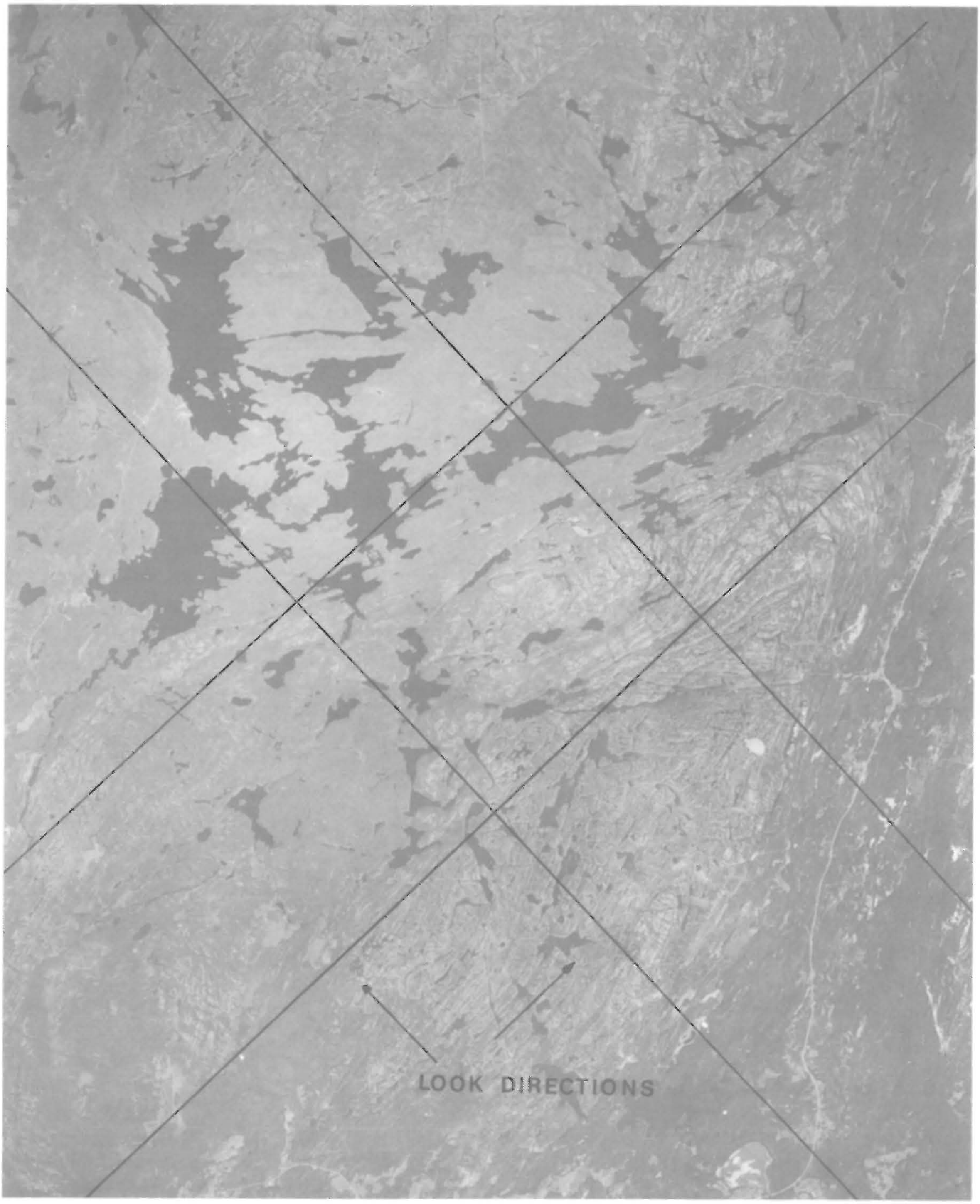


FIGURE 3: High altitude aerial photography showing the same area as Figure 2. Scale: ∿1:130,000. Airborne SAR data flight coverage is marked.

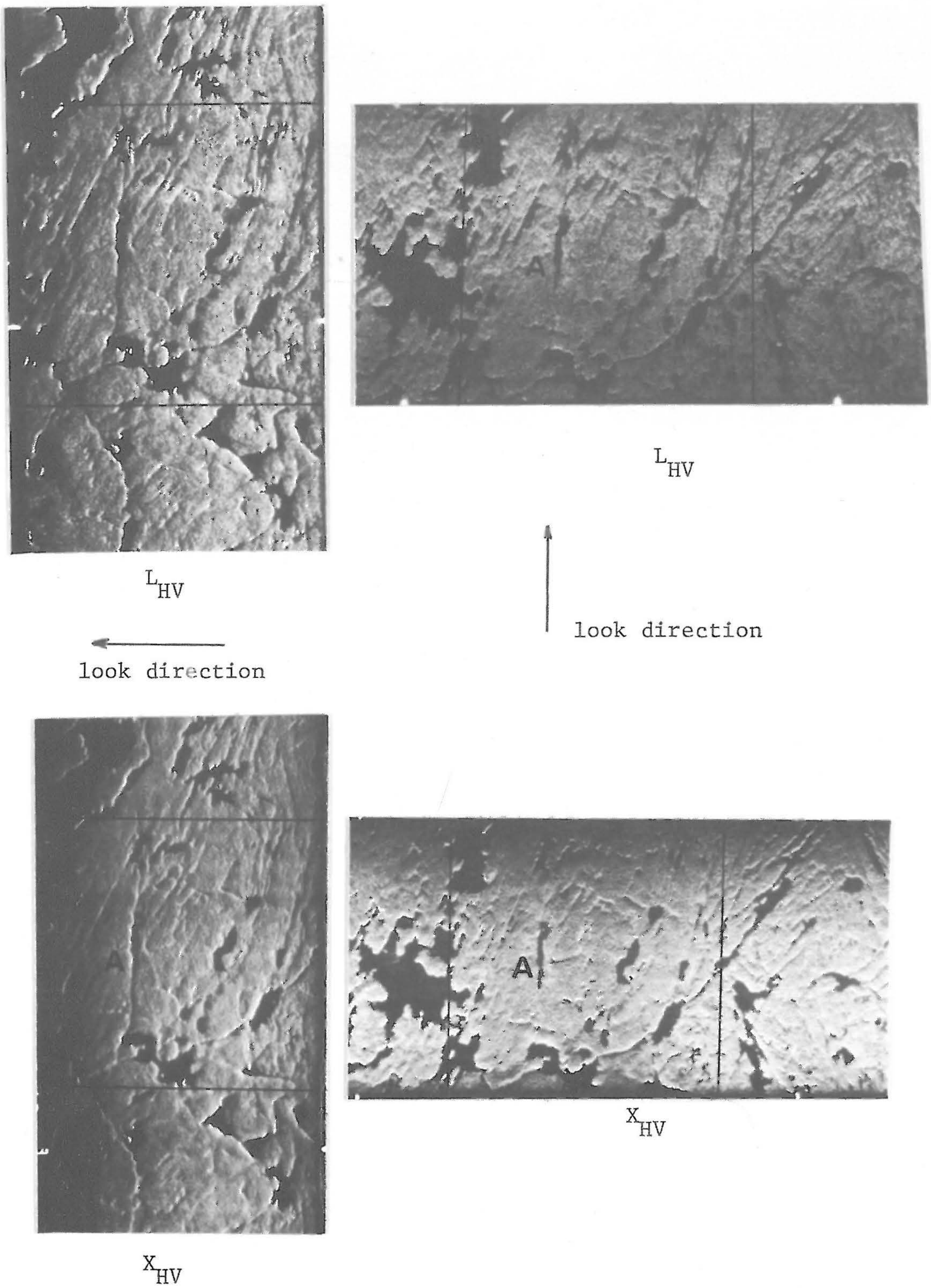


FIGURE 4: Examples of X and L band cross-polarized airborne SAR data of the rectangular area covered by the intersection of the flight lines as in Figure 3. Structural features extending on a diagonal line to the look direction are the most visible features, while structures parallel to the look direction lose their identity.

FIGURE 5: LANDSAT image recorded November 1, 1977 of the same area as SEASAT-SAR coverage. The Precambrian Canadian Shield in the north gives structural detail of the metamorphosed rocks. From the centre of the image to the south the paleozoic, sedimentary rocks are covered mainly with glacial deposits.

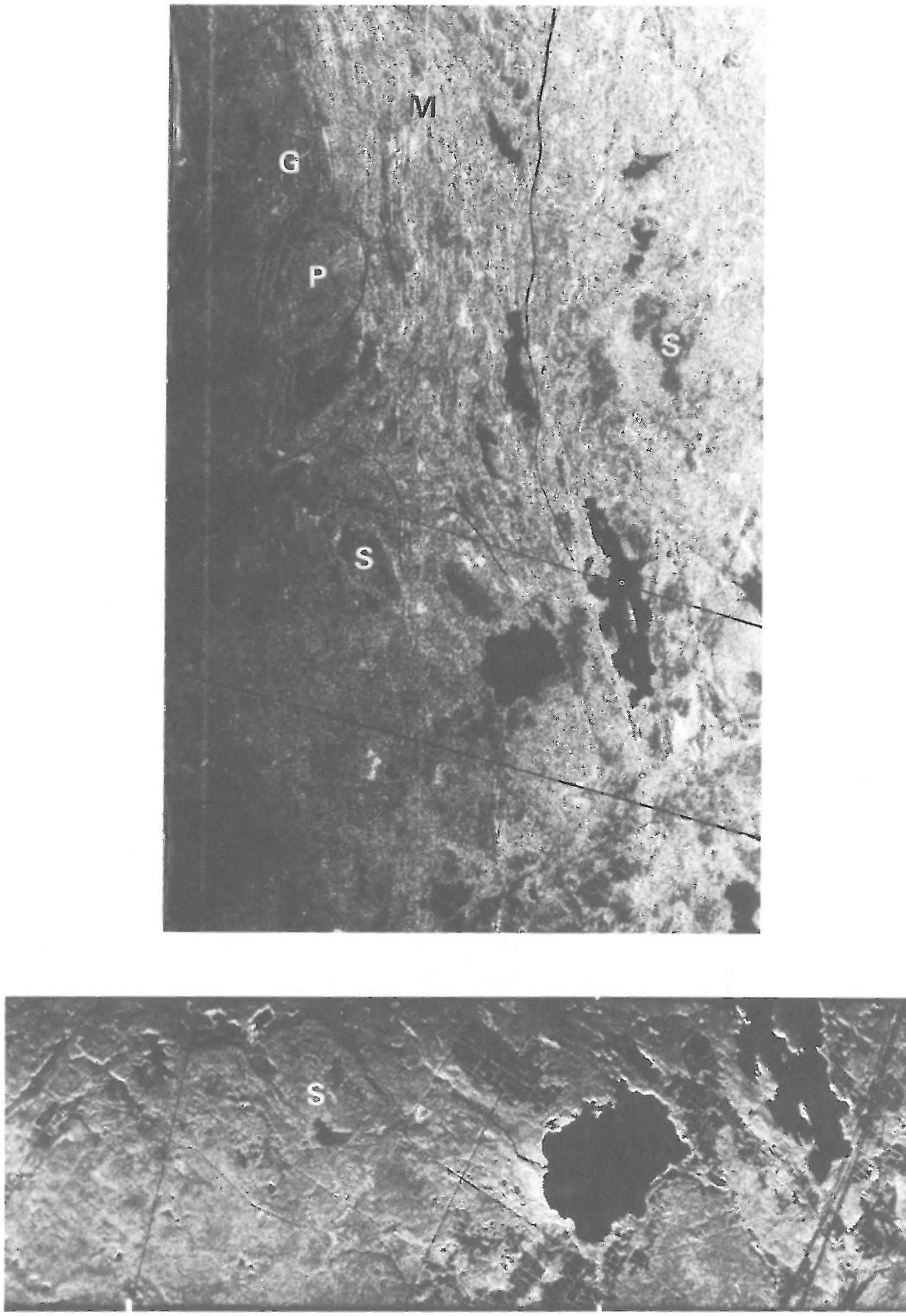


FIGURE 6: Top: SEASAT-SAR data showing differences in the appearance of the rock types. M=metasedimentary; G=granitic; P=plutonic; S=sedimentary.

Bottom: Airborne L-band SAR showing the area between the parallel lines in the top image in detail.

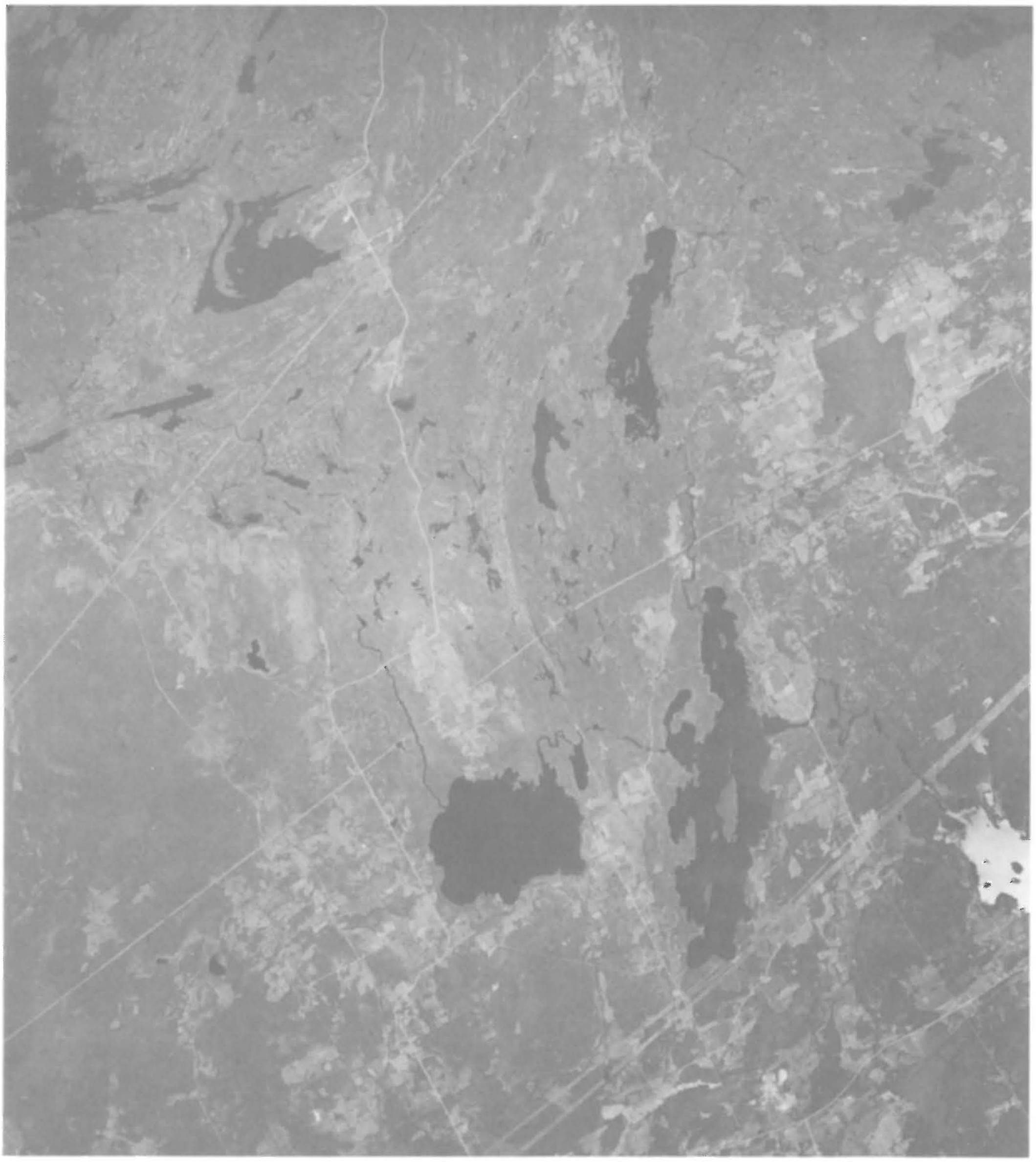


FIGURE 7: High altitude aerial photo showing the same area as Figure 6. The appearance of the rock types can be compared with SAR data. (Because of space constraints a stereogram is not provided).

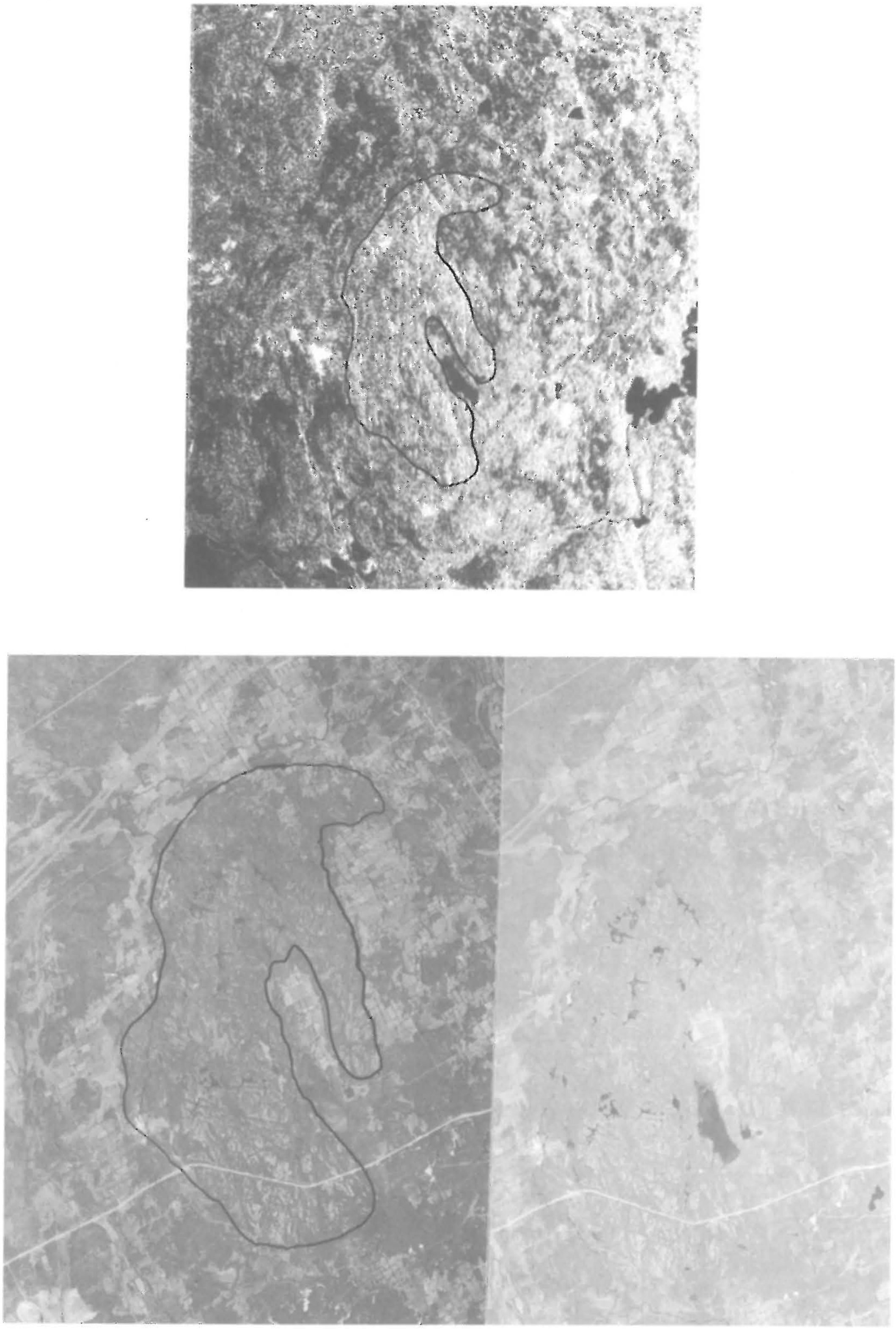
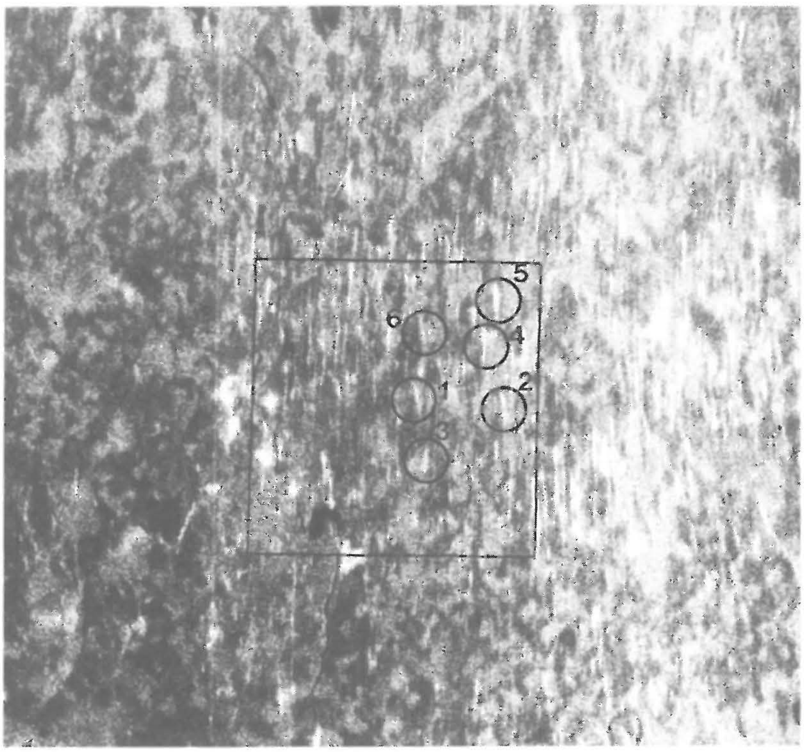


FIGURE 8: Top: SEASAT-SAR.

Bottom: Stereogram of high altitude aerial photos.

These images show an isolated body of granite rock among sedimentary rocks. Its boundaries are clearly identified on the SEASAT-SAR image.



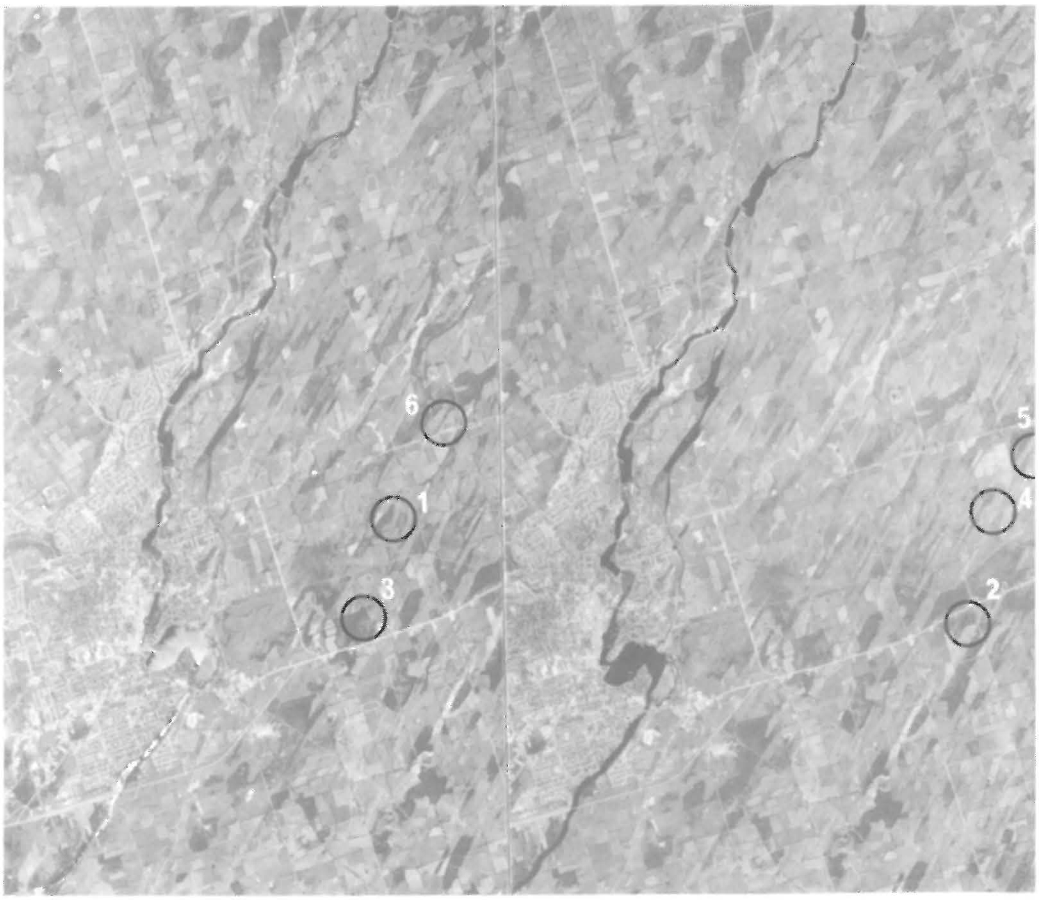


FIGURE 9: Drumlins in the Peterborough Test Site as seen on SEASAT-SAR (top) and high altitude colour photography (bottom). Refer to Table 2 for a description of drumlins numbered 1 through 6.