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Acting Chief
Earth Resources Survey
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Code SAR - NASA Headquarters
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Dear Sir:

Transmitted herewith are two copies of:

INTERAGENCY REPORT NASA-169

THE EMPLOYMENT OF WEATHER SATELLITE IMAGERY

IN AN EFFORT TO IDENTIFY AND LOCATE

THE FOREST-TUNDRA ECOTONE IN CANADA*

by

Susan A. Aldrich**
Frank T. Aldrich**
Robert D. Rudd**

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Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

*Work performed under NASA Contract No. W-12589
Task No. 160-75-01-32-10

**Oregon State University, Corvallis, Oregon

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GEOLOGICAL SURVEY

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Susan A. Aldrich, Frank T. Aldrich, and Robert D. Rudd
Department of Geography, Oregon State University

ABSTRACT

Weather satellite imagery provides the only routinely available orbital imagery depicting the high latitudes. Although resolution is low on this imagery, it was believed that a major natural feature, notably linear in expression, should be mappable on it. The transition zone from forest to tundra, the ecotone, is such a feature. Locational correlation is herein established between a linear signature on the imagery and several ground truth positions of the ecotone in Canada.

THE EMPLOYMENT OF WEATHER SATELLITE IMAGERY IN AN EFFORT TO IDENTIFY AND LOCATE THE FOREST-TUNDRA ECOTONE IN CANADA

By Susan A. Aldrich, Frank T. Aldrich, and Robert D. Rudd
Department of Geography, Oregon State University

When TIROS television systems began transmitting cloud photography of the northern latitudes, nephanalysts noticed a seasonally recurrent east-west linear signature across northern Canada. Concluding that it was the boundary between forest and tundra, they included reference to it as the "tree line" in some of the TIROS catalogs. A similar linear signature appeared periodically on the imagery from the early ESSA satellites, but so many new investigation topics presented themselves with the appearance of satellite imagery, the identification of this line was by-passed. It is curious that such is the case since the location of the forest-tundra boundary is imperfectly known despite the long term recognition of its existence.

The Forest-Tundra Ecotone

Such studies as have been made of the boundary zone between the northern forests and the tundra in Canada indicate that this zone consists of a series of transitions which intergrade as the natural vegetation gradually changes from open canopy forest to tundra. There is no sharply defined line or zone of change of vegetation form or species. Indeed, the question of whether vegetation differentiation should be based on form or species allows for several possible boundary locations. The term "tree line" is thus misleading from several standpoints and students of the problem have come to refer to the transition zone as the forest-tundra, or the forest-tundra ecotone or subzone. It is a zone of variable width in which boreal forest and tundra associations intermingle.

Despite the inaccuracy of the term tree-line, the forest-tundra ecotone, reflecting a gross response to temperature-latitude relationships, does have a dominantly linear dimension when viewed in continental perspective. Early weather satellite imagery offered the first opportunity to view northern Canada in continental perspective, with only two photos being required for border to border coverage. The extremely low ground resolution typical of such imagery may be considered a potential asset for this particular problem rather than a liability. The highly generalized signature of the ecotone margin should be reduced in width from a band to nearly a line unless the resolution is so poor that nothing at all is visible on the ground. A pilot study (Aldrich, 1969) was carried out to investigate the degree to which a visible linear signature on the imagery, conceivably the ecotone, would agree with several known ground locations. The results of the study indicated that perhaps at least one boundary of the forest-tundra ecotone, the boundary between the open coniferous forest and the forest-tundra, might be identifiable. The present study is a test of that premise.

PROCEDURE AND SCOPE

Ground Truth

Earlier studies employing field research and/or aerial photos to locate the forest-tundra ecotone serve here as ground truth in three parts of northern Canada. J. C. Ritchie (Ritchie, 1962) used thousands of air photos in establishing vegetation association boundaries in northern Manitoba through the entire transition from closed canopy forest to tundra; his 1962 1:1,000,000 map was used in the present study. H. M. Raup's (Raup, 1946) phytogeographic study of the Great Slave Lake - Lake Athabasca region provides a map of vegetation zonation at a scale of approximately 1:5, 700, 000 for that area. The series of studies by F. K. Hare (Hare, 1959) provided a basis for locating the ecotone in eastern Canada; specifically, his 1959 1:3, 800, 000 map depicting vegetation zonation over all of eastern Canada was especially helpful in this study.

A number of other studies relate to the problem although they were not usable for boundary location ground truth. J. W. Marr's (Marr, 1948) description of the ecotone on the east coast of Hudson's Bay, I. Hustich's (Hustich, 1953) study of the Labrador Peninsula, Lindsey's (Lindsey, 1952) Great Bear Lake area study, and Bryson and Larson's (Larson, 1965) study of the Ennadai Lake area are examples.

The ground truth areas selected, then, are: 1) a zone north and east of Great Slave Lake, 2) a zone just west of Hudson's Bay, and 3) the entire Labrador-Ungava Peninsula (Figure 1). The boundaries delimited by Ritchie, Raup and Hare in these areas were transcribed onto a copy of the grid of each piece of selected satellite imagery, and the imagery then was examined for evidence of a coincident linear signature. This statement while correct, is an oversimplification of several rather time-consuming efforts. Two very important steps had to precede the actual search for the ecotone signature: imagery selection and imagery gridding.

Imagery Selection

The pilot study referred to earlier was made with imagery ordered largely from catalogs. The amount and quality of imagery available at that time (1966) both were substantially below that employed in the present study. In

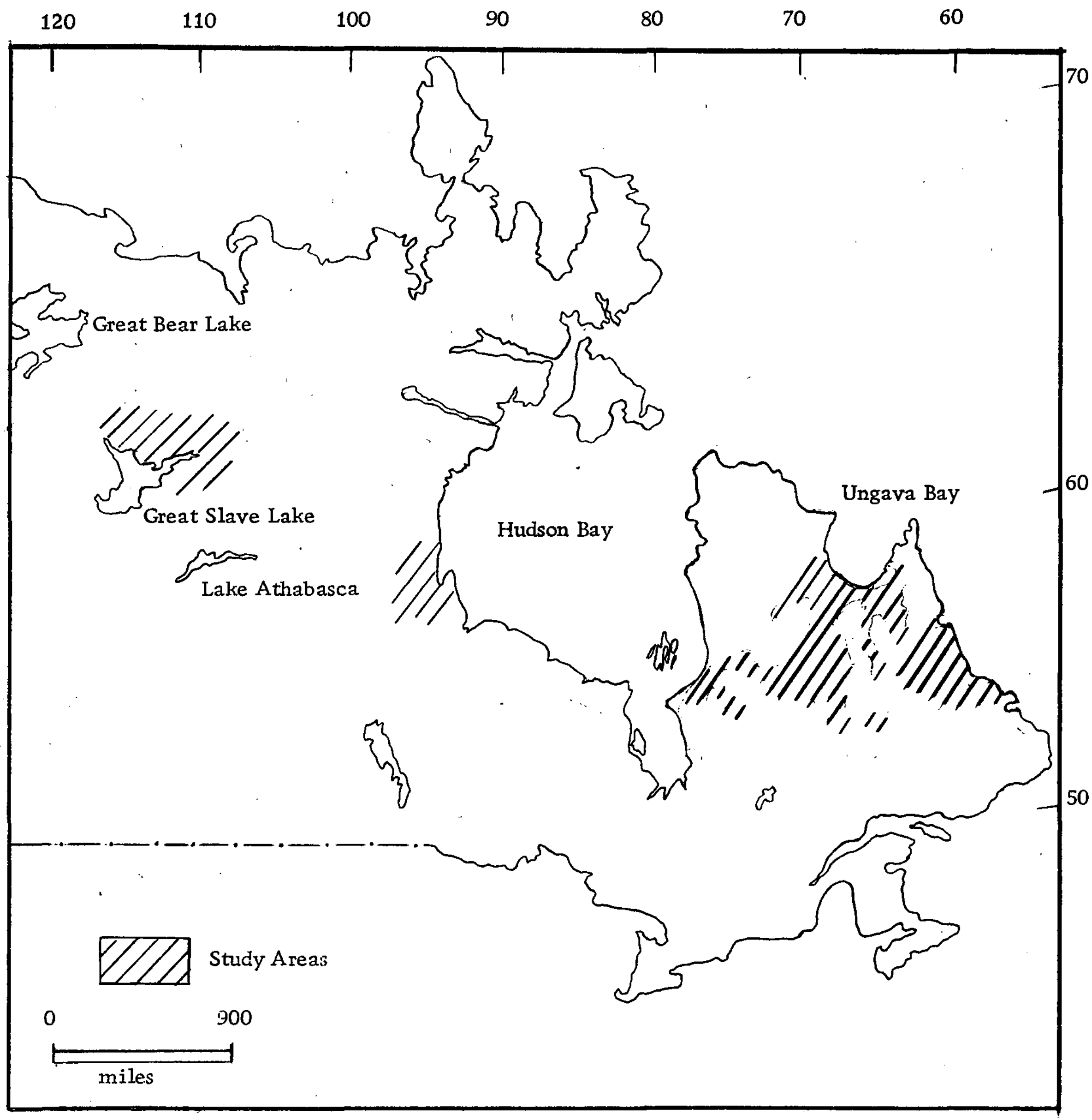

Figure 1. Study areas in the Canadian forest-tundra ecotone.

[Cartography by R. Perry]

order to realize the greatest advantage from improvements in both these factors, it was concluded that imagery selection should be made at the site of storage and should be based on preview of the actual imagery. This decision provided an unexpected benefit: preview of the imagery in chronological sequence revealed the importance of seasonality to the appearance of a linear east-west signature. In January and February, northern Canada is in darkness. Toward the end of February, however, darkness begins to recede and a linear feature appears. During March and April, this feature can clearly and consistently be seen during 1967, 1968, and 1969 on imagery which is not cloud obscurred. Then, depending upon weather conditions for that year, a combination of decreasing snow cover, and increasing clouds and fog cause the linear expression to fade into indistinctness, beginning in early May. By mid-June, the area in which the ecotone is located appears uniformly dark in tone and indistinguishable from its surroundings. The situation is worsened by clouds in the fall and recurrent darkness in winter. The seasonality factor thus became a basic imagery selection consideration.

Several categories of ESSA and Nimbus satellite imagery were reviewed for their potential value to this project. AVCS imagery from ESSA satellites #3, #5, #7, and #9 was examined. Although that from #3 and #5 was helpful in establishing the importance of seasonality, the superior resolution on ESSA #7 and #9 imagery made it preferable. ESSA #2 and #4 APT imagery was also considered but this imagery also has lower resolution. All of the imagery from ESSA satellites selected for analysis, therefore was AVCS from #7 and #9. This imagery was the most useful of all the categories investigated (including Nimbus imagery), not only because of the quality of the resolution thereon, but the fact that it covered the critical time period.

Imagery of several types from each of the three Nimbus satellities was considered for use. Both the brevity of the period and the season for which imagery was obtained limited the value of these satellites to this study, however. Nimbus I produced AVCS imagery only for about a month in late summer of 1964. Nimbus II AVCS imagery is for the wrong season also; however Nimbus II provided High Resolution Infrared Radiometer (HRIR) data which was selected and studied both as photographic imagery and in computer-drawn digital printout form. Nimbus III, launched just this year, provided DRID and DRIR imagery which was selected for study, despite the fact that the earliest imagery is for late April.

In view of the number of factors which need consideration in the selection of imagery, the desirability of being able to view the imagery before selection should be evident. Not the least of such considerations, though not discussed here is the degree to which clouds obscure the surface and the loss of detail accompanying image reduction to catalog size. Thus very substantial number of photos of possible use provided in the end a relatively small number for analysis. Of the several dozen best prospects selected at Greenbelt and Suitland, Md., all were subjected to careful analysis in Corvallis. Examples of these constitute the figures in subsequent sections of this report.

Gridding

Since location is so basic to imagery interpretation in this study, the system of parallels and meridians on each photo was subjected to careful scrutiny. Most weather satellite imagery being received today includes a computer-calculated and fitted grid system. While the accuracy of the grid location is usually adequate for the intended use of the imagery, it is not always accurate enough for locating specific surface features (compare the corrected overlay grid with the computer grid on the photo, Figure 2). Sometimes the answer to the problem thus posed is simply to readjust the grid as attention is shifted from place to place on the photo. On the ESSA imagery both the grid and land-water boundaries are shown (Figure 4) making the amount of adjustment evident and the adjustment itself relatively simple. Of the several forms of imagery used in this study, the gridding on the ESSA #7 and #9 AVCS imagery was easiest to work with.

Perhaps the most time consuming aspect of the gridding operation on the computer gridded images had to do with the addition of missing parallels or meridians. Grid intervals vary considerably from one imagery type to another and from place to place on a given photo. In some instances the interval between parallels is as small as 2°; it may be as large as 10 or even 20° between meridians at high latitudes, however. In the instance that the boundary to be identified is in the midst of an inadequately gridded region, missing meridians and parallels must be filled in (Figure 2). Some of the imagery comes with no grid at all (Figure 7); instructions are provided with which the appropriate grid may be constructed. Gridding some imagery is thus quite time consuming; other types may require little or no adjustment. It is an essential prelude to photo analysis, however, since until the grid is correctly located on the imagery the presence or absence of a signature has little meaning.

Scope

This study seeks to establish that a signature for a margin of the Canadian forest-tundra ecotone is visible on routinely available orbital imagery from

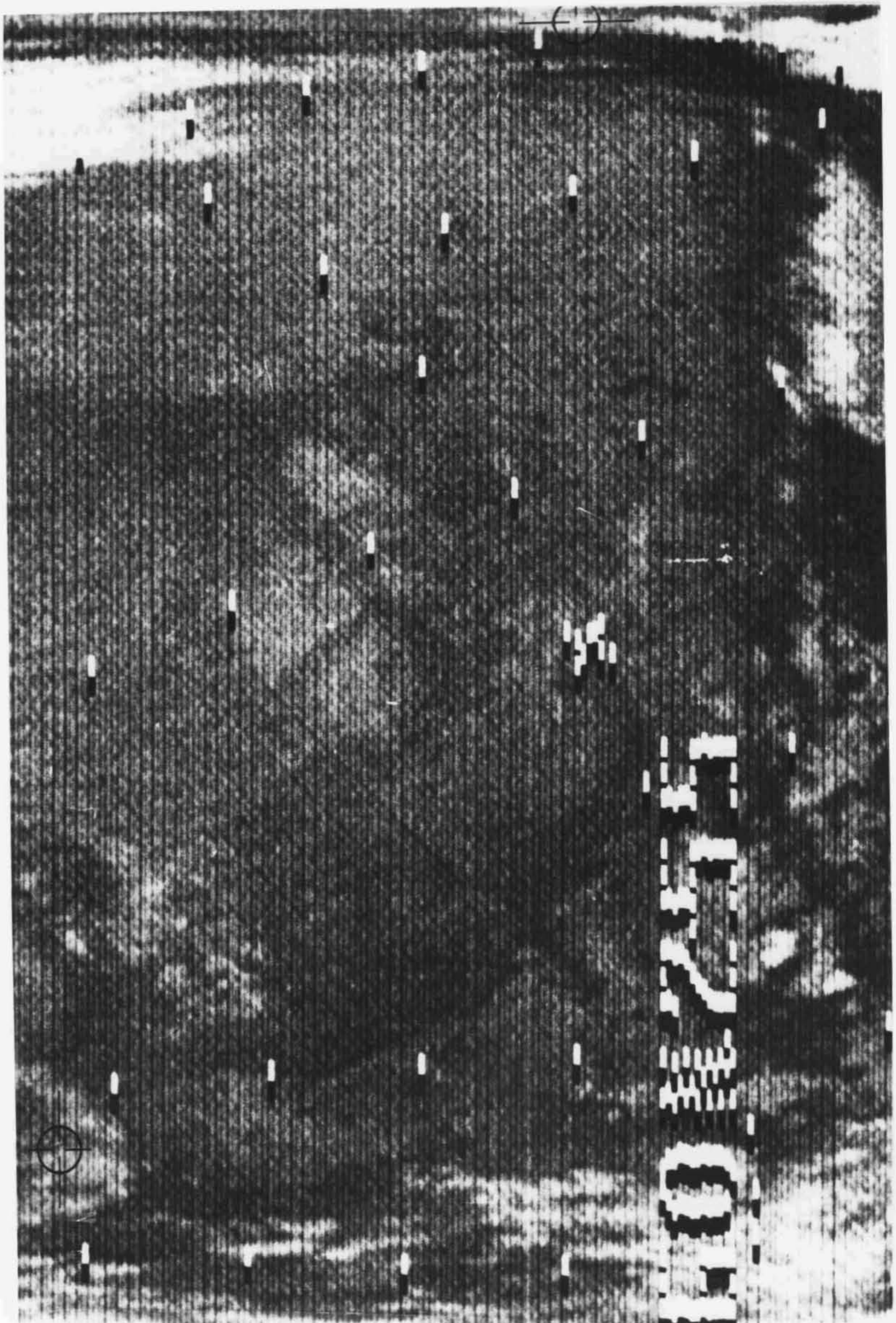

Figure 2. Nimbus II HRIR, July 18, 1966

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weather satellites. Suggested by an earlier pilot study, this study employs more imagery and imagery of better resolution and greater variety. The earlier effort focussed on two areas west of Hudson's Bay in which the ecotone was located by field work and air photo interpretation. In its search for an ecotone signature, the present study includes consideration of work done in eastern Canada, suggests one type of ecotonal boundary believed identifiable in all three areas, and locates it throughout Canada.

The Ecotone in the Three Field Study Areas

Northern Manitoba

In the area shown in Figure 3, J. C. Ritchie employed aerial photos to map the transition of vegetation from open coniferous forest on the south to continuous tundra on the north. In between these two vegetation associations lies the Forest-Tundra, a mixture of forested slopes and bottomlands with tundra (usually heath) on ridge and hill summits. Although Ritchie established the boundary between the Forest-Tundra and the Open Coniferous Forest in his area on the basis of the amount of scrub forest in the lowland sites, the contrast in the uplands of the resultant classes may be more important from the standpoint of an imagery signature. That is, the non-forested uplands of the Forest-Tundra may cause that category to have a tonal signature very similar to that of the Tundra category during the right conditions of illumination and snow cover, while the forested uplands of the Open Coniferous Forest cause it to differ in appearance from both the others. At any rate, in the approximate position of Ritchie's southern boundary of the Forest-Tundra, a linear tonal-signature appears repeatedly on AVCS imagery. Figures 4 (ESSA #7) and 5 (ESSA #9) illustrate this. From February into early

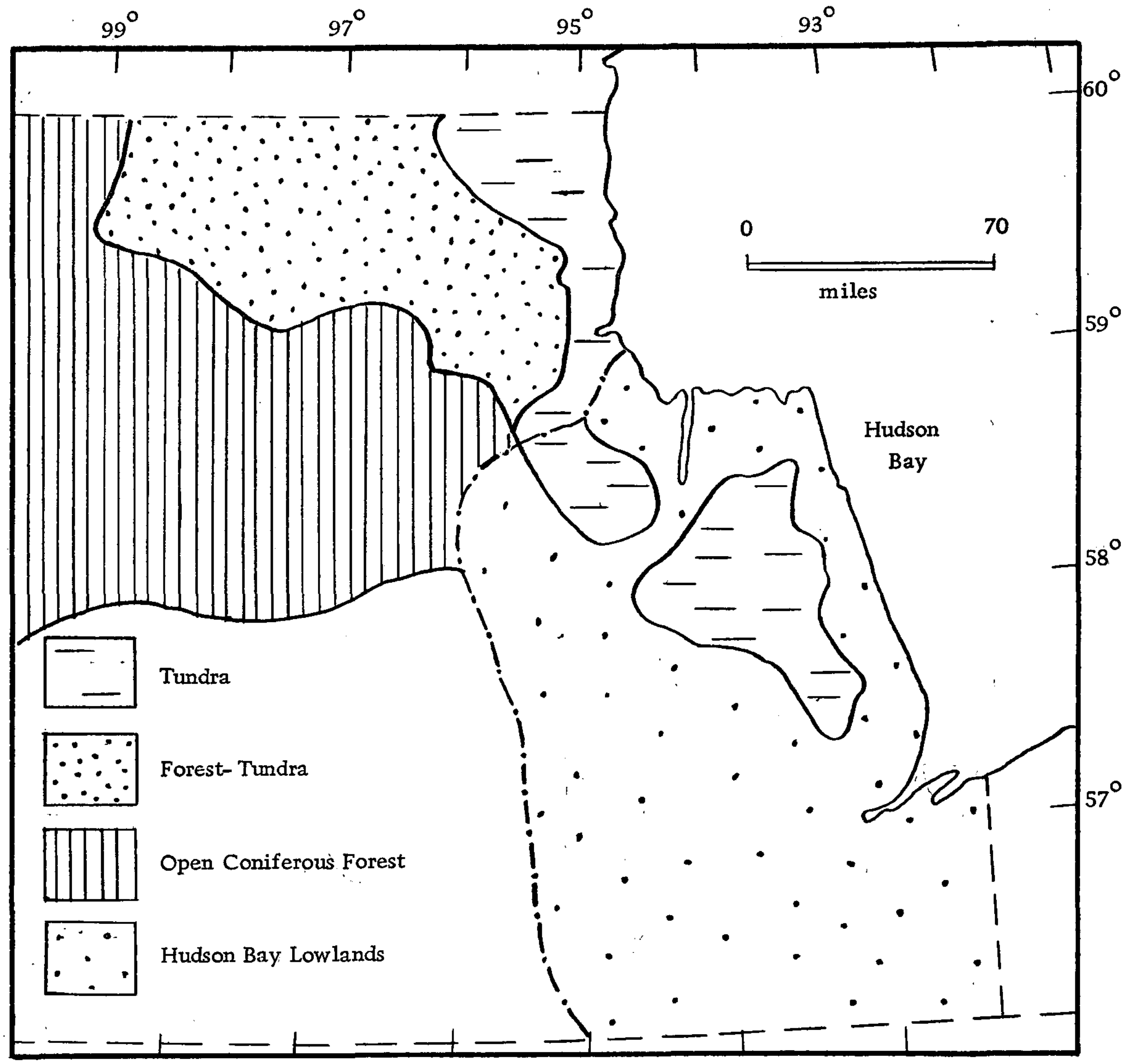

Figure 3. Major vegetation zones in Northern Manitoba.

After Ritchie, James C. "A geobotanical survey of Northern Manitoba." Arctic Institute of North America Technical Paper # 9. March 1962. p. 21.

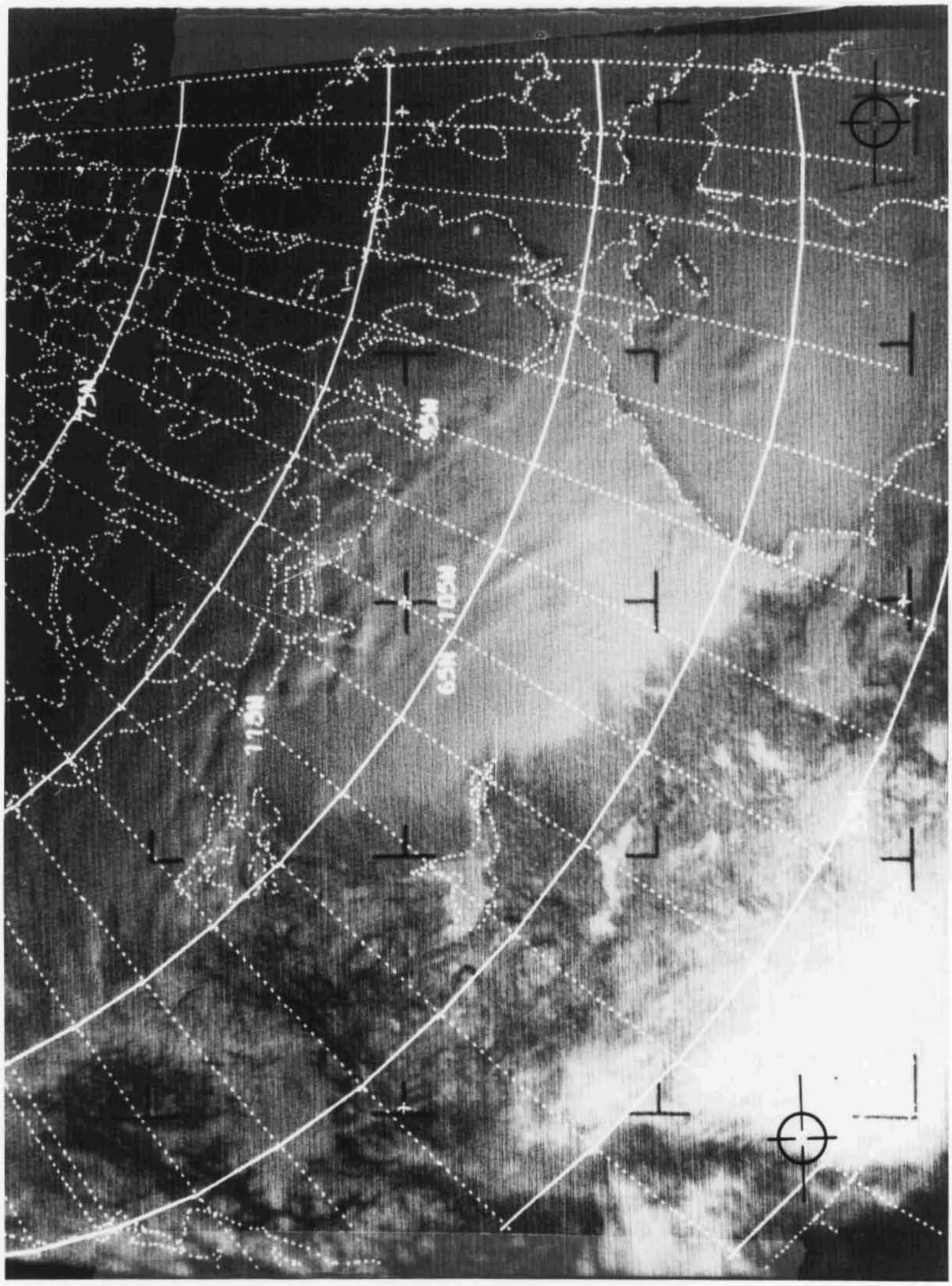

Figure 4. ESSA 7 AVCS, February 24, 1969.

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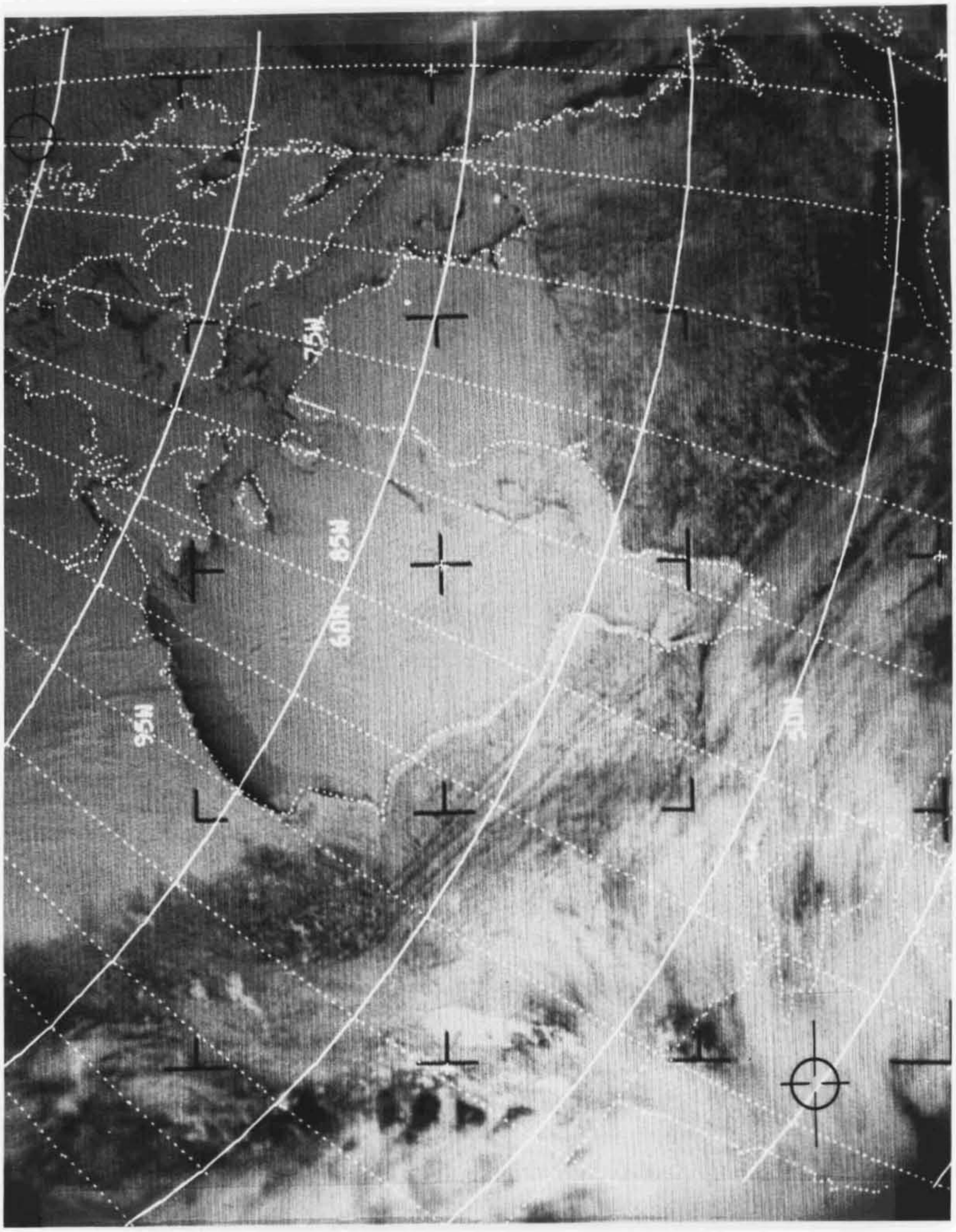

Figure 5. ESSA 9 AVCS, April 4, 1969.

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April 1969, all ESSA imagery which shows the ground exhibits this relationship with one exception. The exception is Figure 6; the linear signature there, however, is believed to be cloud obscurred.

The ecotone location in northern Manitoba was plotted on 17 images. In addition to the ESSA photos it was plotted on 3 Nimbus III DRID and 7 Nimbus II HRIR images. On none of the Nimbus imagery did the linear signature manifest itself as clearly as on the ESSA imagery; indeed, it was not visible at all on most. One of the best results, however, is illustrated by Figure 7, an example of Nimbus DRID imagery. The darkest contours correspond in location with Ritchie's same boundary mentioned above. In other DRID imagery (Figure 8), light gray tones extend across what should be the boundary position. This latter case is from late enough in spring that the aforementioned disintegration of the signature which comes with summer may be the answer.

Probably for the same reason, the Nimbus II imagery failed to exhibit the desired signature. HRIR imagery such as that in Figure 9 shows a diffuse warmer band roughly between the areas of Open Coniferous Forest and Forest-Tundra, but the location corresponds with none of Ritchie's boundaries. A computer-drawn digital map of the same situation was obtained as a further check (Figure 10), but it does not seem to offer consistent results. Yet another digital map (not shown) of a subsequent orbit was obtained, but again, what appeared to be positive results in one area were contradicted by those in an adjoining area.

Several points emerge from the imagery analysis of Ritchie's study area in northern Manitoba. During late winter and early spring, a linear tonal signature is observable on ESSA AVCS imagery. This linear signature corresponds

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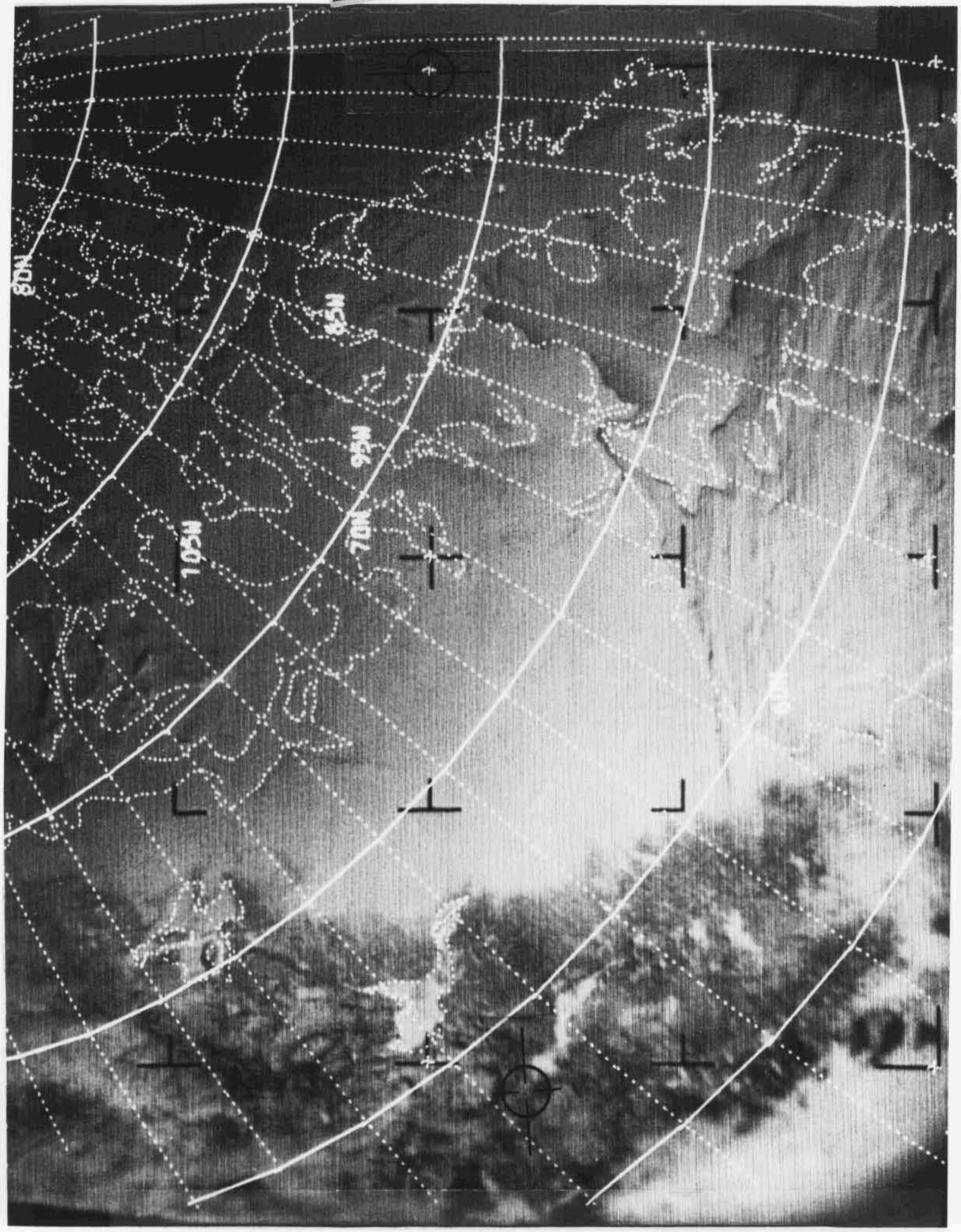

Figure 6. ESSA 7 AVCS, March 14, 1969.

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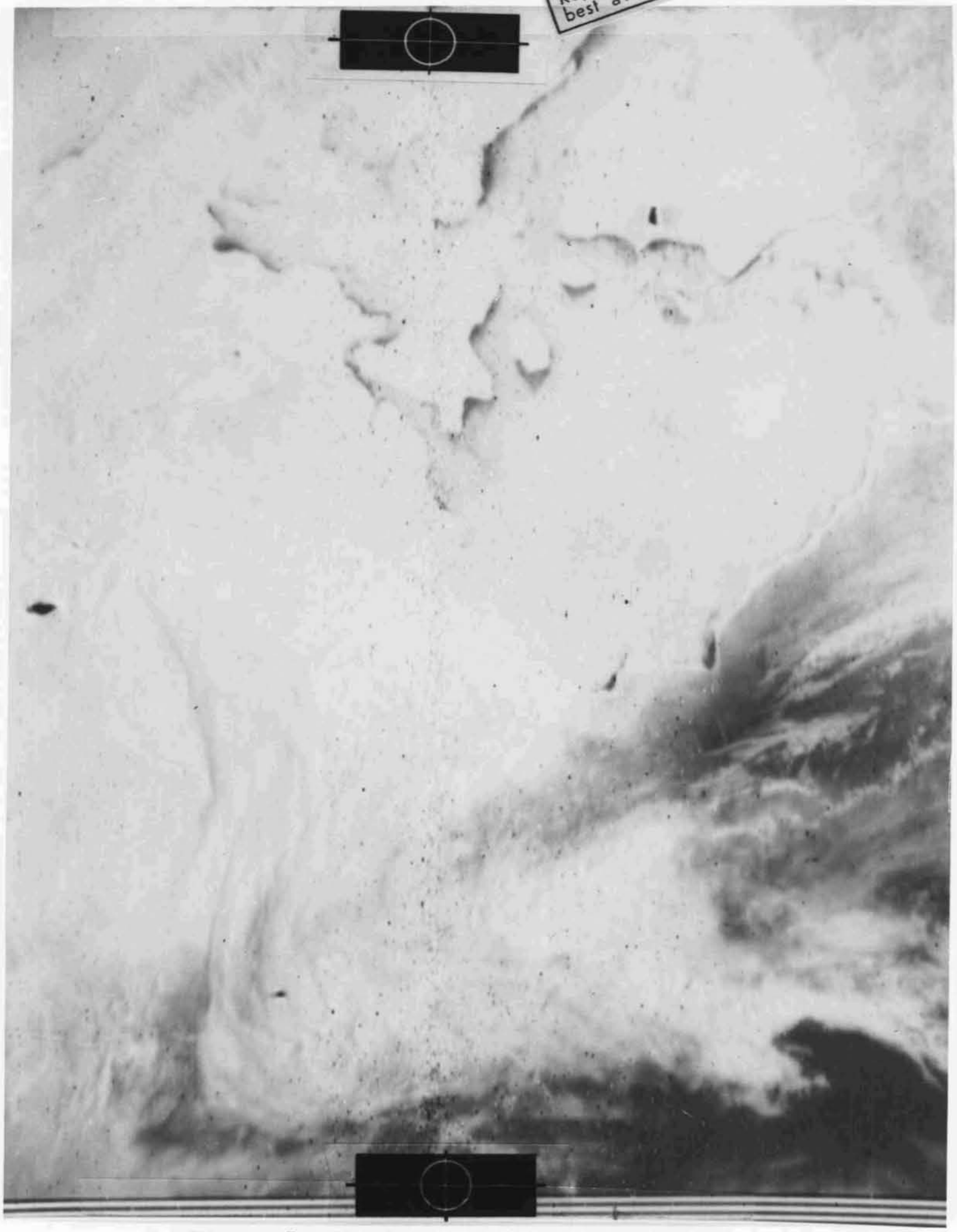

Figure 7. Nimbus III DRID, Orbit 72.

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Figure 8. Nimbus III DRID, Orbit 126.

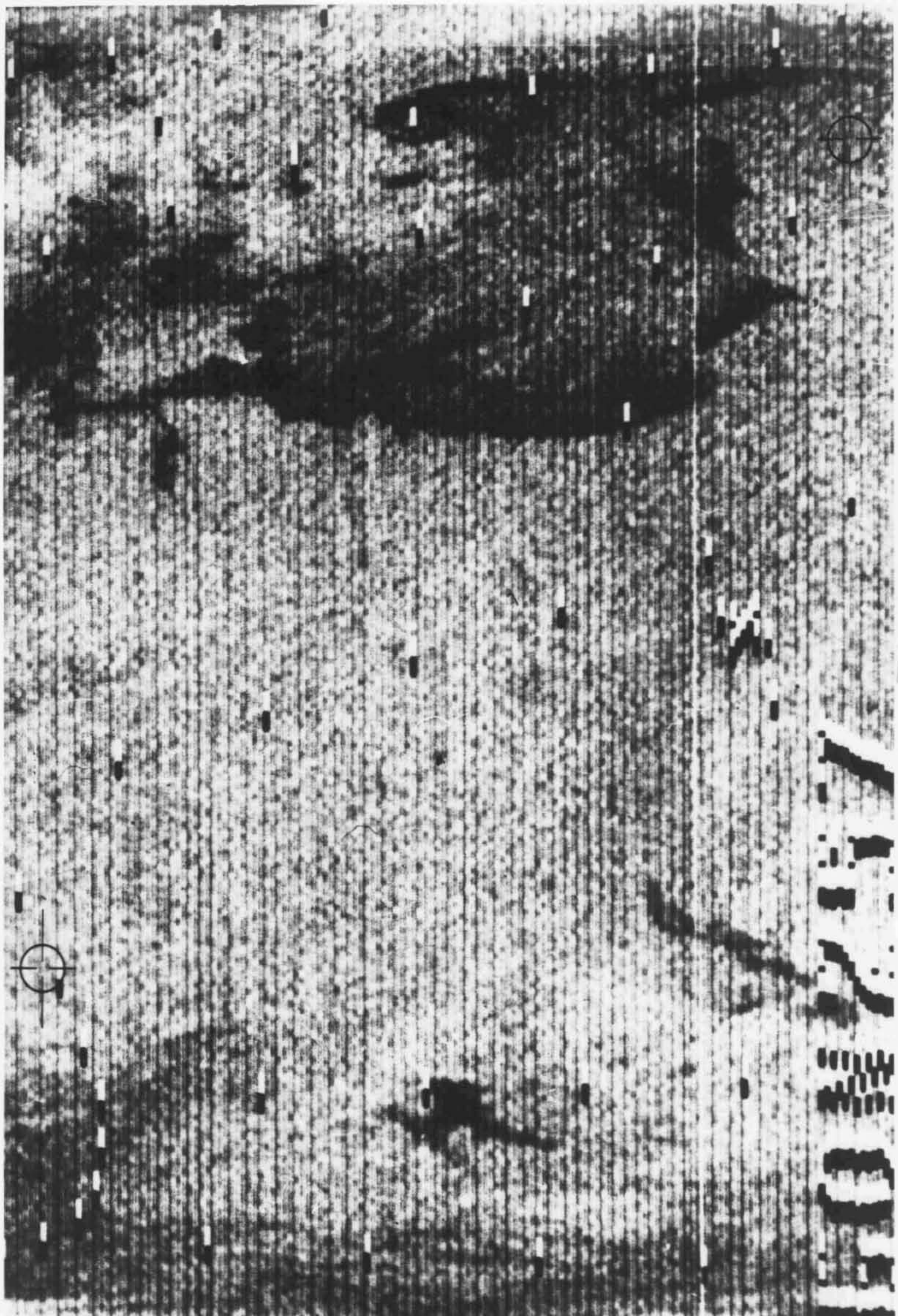

Figure 9. Nimbus II HRIR, November 7, 1966.

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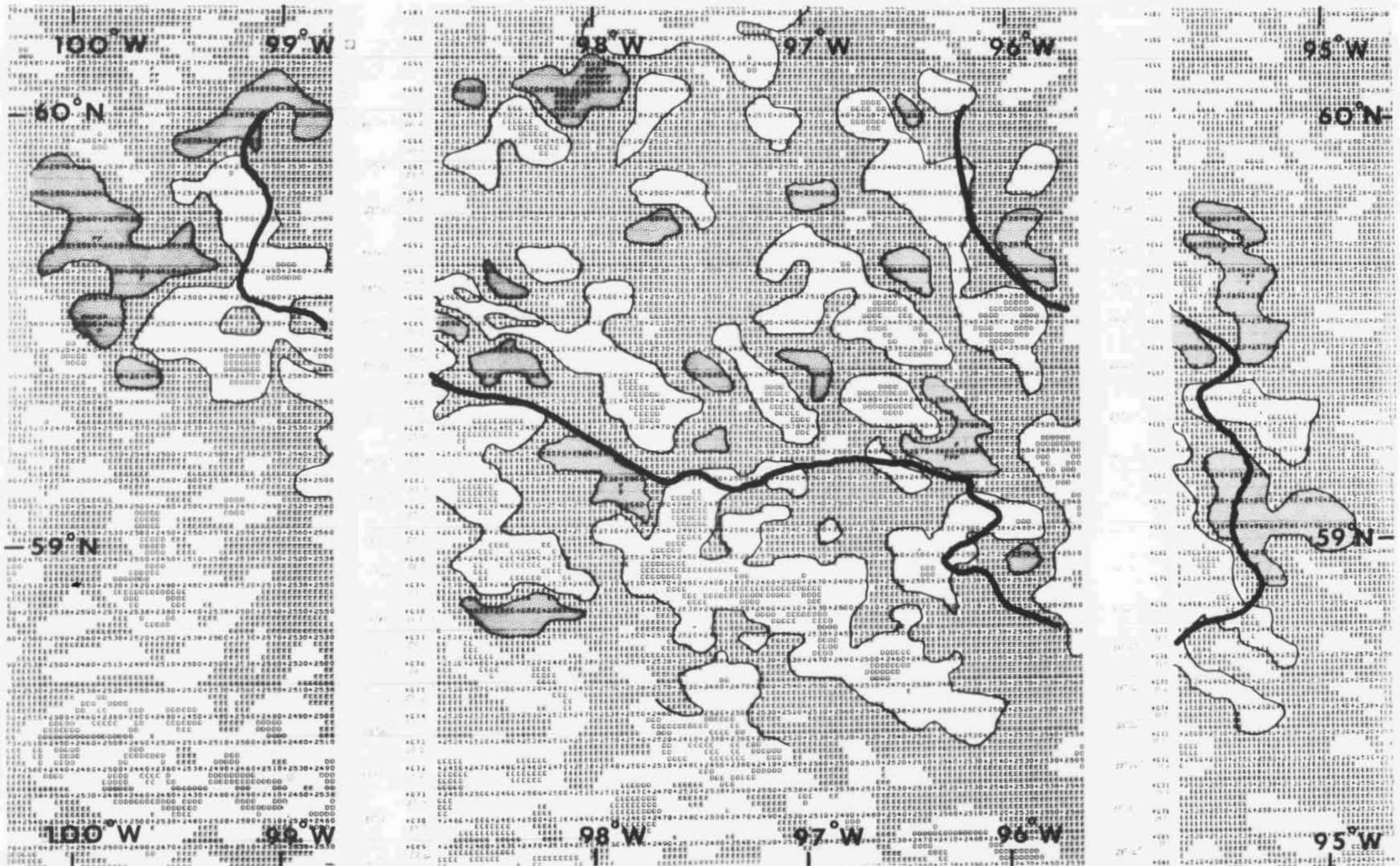

Figure 10. Digital temperature map of the northern Manitoba forest-tundra ecotone area. Warmer areas are indicated by a light gray pattern, cooler areas by white. Nimbus II HRIR, November 7, 1966.

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in location with the south boundary of Ritchie's Forest-Tundra vegetation association, the ecotone. It appears likely that the signature is the result of contrasting amounts of forest and (heath) tundra in the several plant association categories. Nimbus imagery provided little of value compared to the results from the ESSA satellites. Admittedly the season was wrong for results from AVCS sensors; it would seem that it is wrong for the other types also.

Great Slave Lake Area

Raup's study of the area adjoining Great Slave Lake differs from the studies of Ritchie and Hare in several ways worthy of note here. Raup did not employ aerial photos to the extent the other men did, depending instead more upon field observation. Also, his map (Figure 11) does not provide the detail that the others do in two respects: it is a smaller scale map and he does not have a vegetation association category which is clearly the forest-tundra ecotone. From his description (Raup, 1946, p. 37), however, it does appear that the northern boundary of his Park-like White Spruce category is the counterpart of the northern boundary of Ritchie's Open Coniferous Forest. Although Raup does not discuss the species in his Tundra category, his description (see Raup, 1946, p. 65 for example) implies that the category includes the forest-tundra ecotone, and in a letter he confirmed this (Raup, 1969). The imagery was examined at the site of Raup's boundary between Park-like White Spruce and Tundra.

The results here were very similar to those which evolved at the Ritchie site. The best linear signature and correlation between it and Raup's boundary occurred on ESSA imagery during the months February - April (Figure 6). On schedule, clouds, fog, and melting snow contribute in May to disintegration of

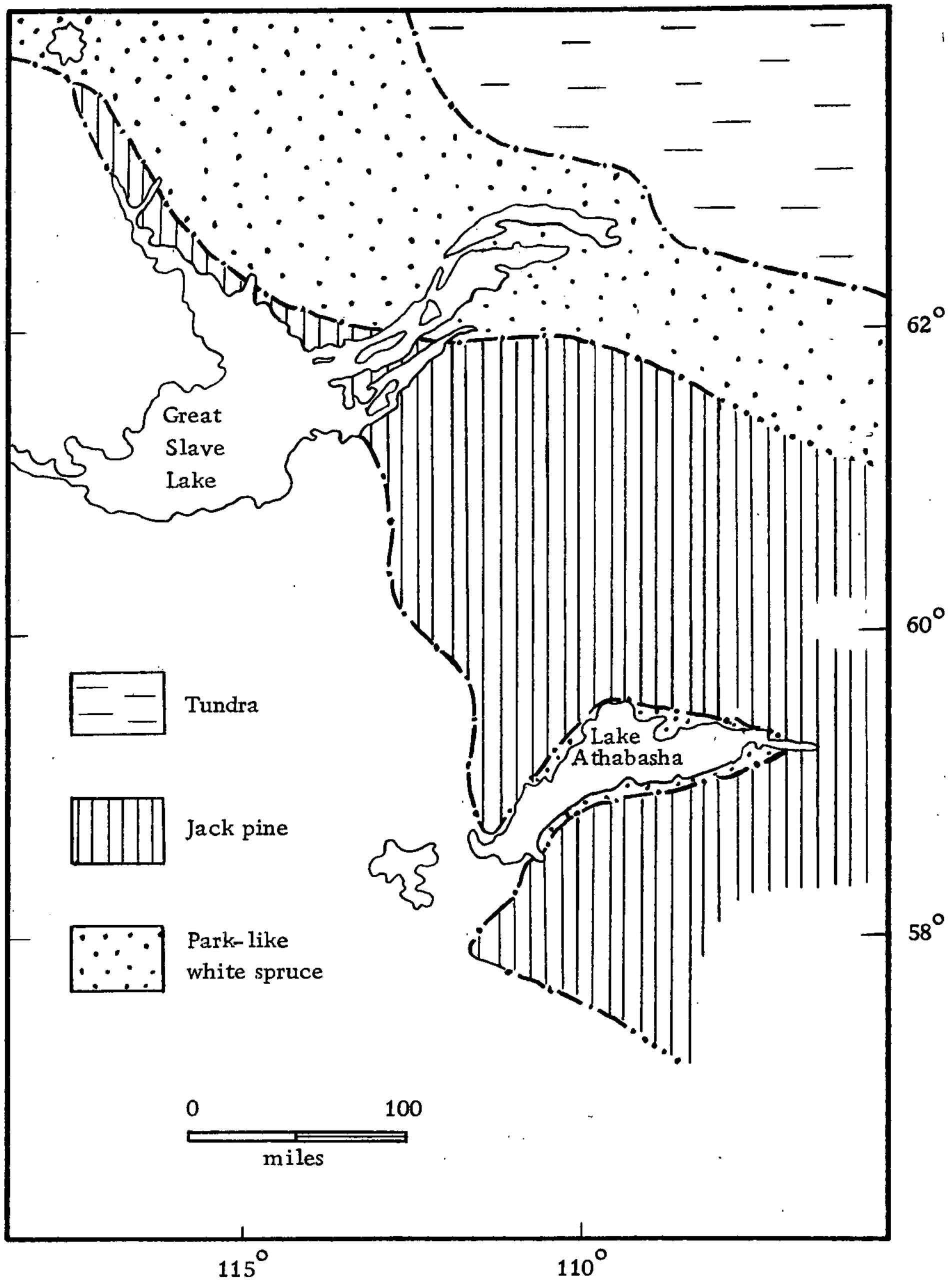

Figure 11. Major vegetation zones in The Great Slave Lake region.

After Raup, Hugh Miller. "Phytogeographic studies in the Lake Athabasca-Great Slave Lake region." II. Journal of the Arnold Arboretum, Vol. 27, p. 26.

the linear signature (Figure 12). One difference was notable: the farther away from the lake, the greater the divergence between the signature and Raup's boundary - both northwest and southeast of the lake. Raup has suggested (Raup, 1969) an explanation for this situation. At the time his map was drawn adequate aerial photos were not available, and he had to depend in part upon notes from others journals. His map is most accurate in the Artillery Lake area on the main access route to Great Slave Lake. It is here also that the closest location coincidence exists between Raup's boundary and the linear signature on the imagery.

The Nimbus II HRIR imagery again exhibited no correlation between features which might have been the signature sought and the boundary locations (Figure 9). A computer-drawn digital temperature map (not shown) was again produced to no avail; the most evident features on it are probably the result of a cloud bank. The results from the Nimbus III DRID imagery were rather more encouraging here than at the Ritchie site, however. Two DRID photos illustrate signature-boundary location correlation almost comparable to the ESSA imagery (Figure 8 for example). They too exhibit the divergence northwest and southeast of the lake seen on the ESSA imagery.

It is considered encouraging that what may be the same boundary located in two different areas by different students employing different methods seems to provide a similar imagery response.

Eastern Canada

The third area to be examined varies from the other two notably in one respect: it is substantially larger (Figure 13). Covering as great a variety of physical settings as it does, it is to be expected, perhaps, that a range of

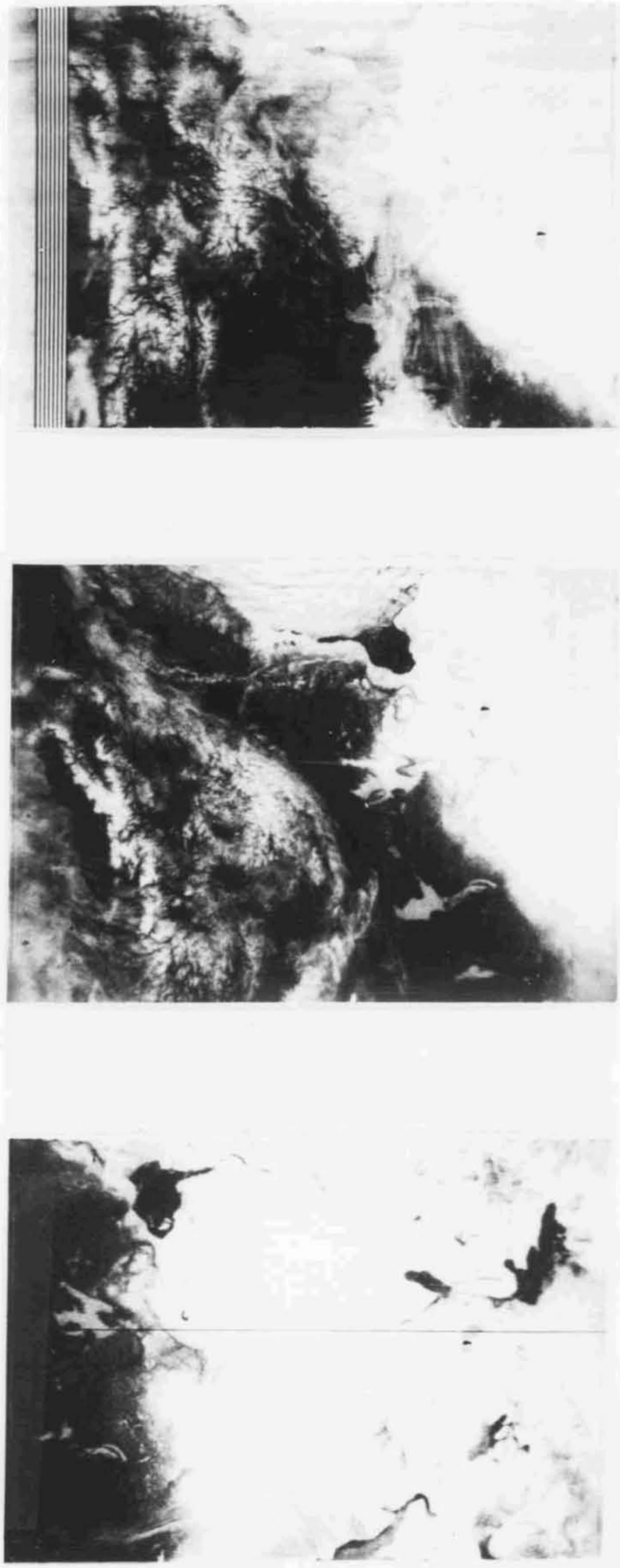

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Figure 12. Seasonal disintegration of the linear signature in the Great Slave - Great Bear Lake areas, May through June, 1969.

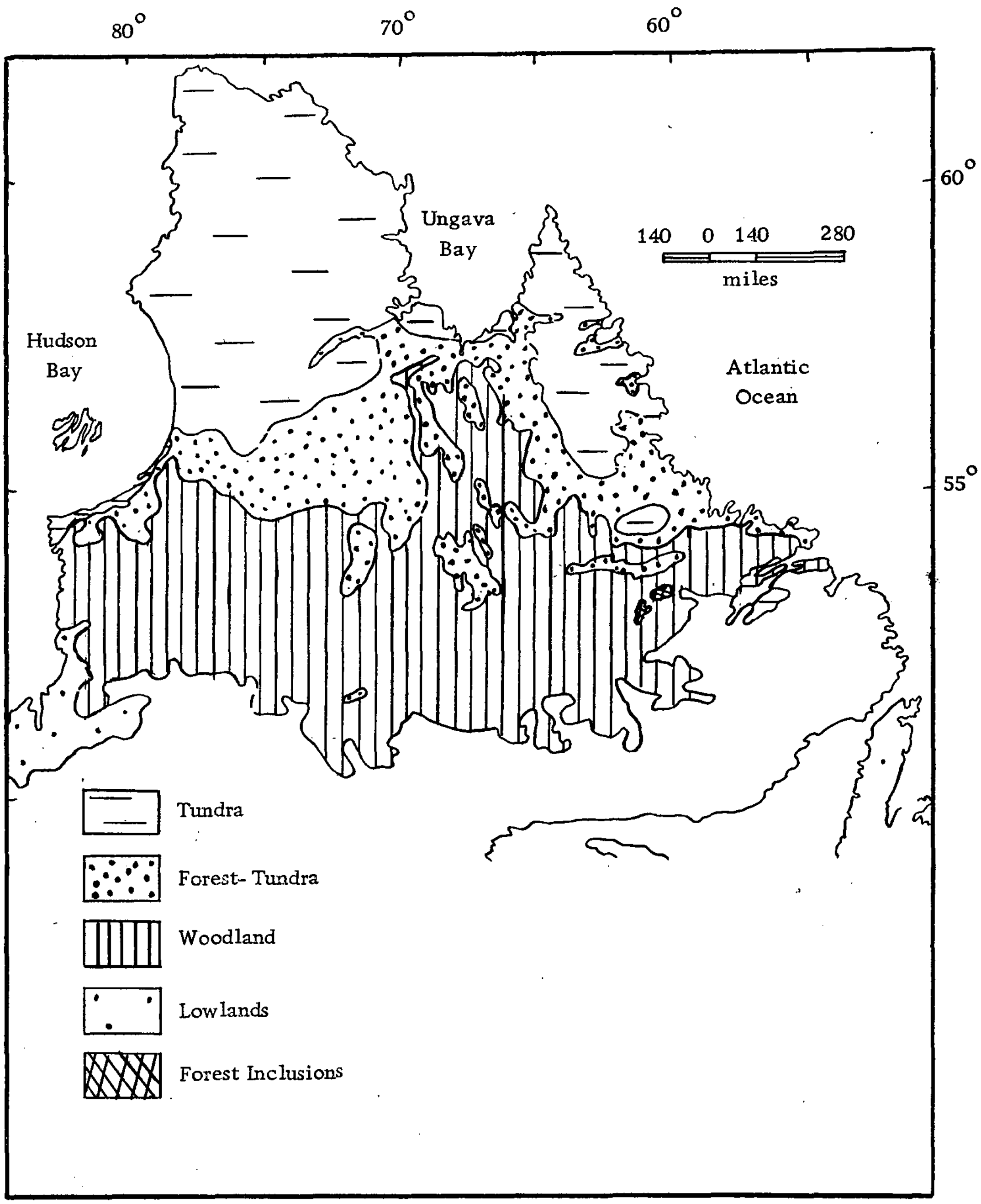

Figure 13. Major vegetation zones in Labrador - Ungava.

After Hare, F. Kenneth. "A photo-reconnaissance survey of Labrador-Ungava." Memoir 6. Geographical Branch, Canadian Department of Mines and Technical Surveys. p. 33.

signature responses would appear along the ecotone site. Variance does manifest itself, but not so much variance in degree of correlation between image signature and map boundary. Instead the image signature seems to correlate well with one map boundary in one area but with another in a different area. The location of the ecotone in eastern Canada as established by F. K. Hare was plotted on 13 images: 4 ESSA photos, 6 Nimbus III DRID photos and 3 Nimbus III DRIR photos. In all cases the characteristic linear signature correlates well with either the north or the south margin of Hare's forest-tundra ecotone. Moreover, the changeover from one to the other is not random, it is consistent. In the western and central parts, notably the Ungava Peninsula, the linear signature corresponds with the northern margin of Hare's ecotone (Figure 5). In the eastern part, the Labrador Peninsula area, the imagery signature is located along the southern margin (Figures 14 and 15) except near the coast.

Of the several vegetation association categories in eastern Canada depicted on Hare's map, it is the "Woodland" category which seems to be the counterpart of Ritchie's Open Coniferous Forest and Raup's Park-like White Spruce. While Raup does not list the ecotone as a separate vegetation association category and Hare and Ritchie do--in each case a linear imagery signature has been found to agree in location with what each of these men has identified as one of the boundaries between the forest and the forest-tundra transition. Generally agreement has been best along the southern margin of the ecotone, or the northern margin of the forest. Admittedly the eastern coastal area lacks agreement with the rest, but this area may in fact constitute a separate problem. The more troublesome exception is The Ungava Peninsula where the

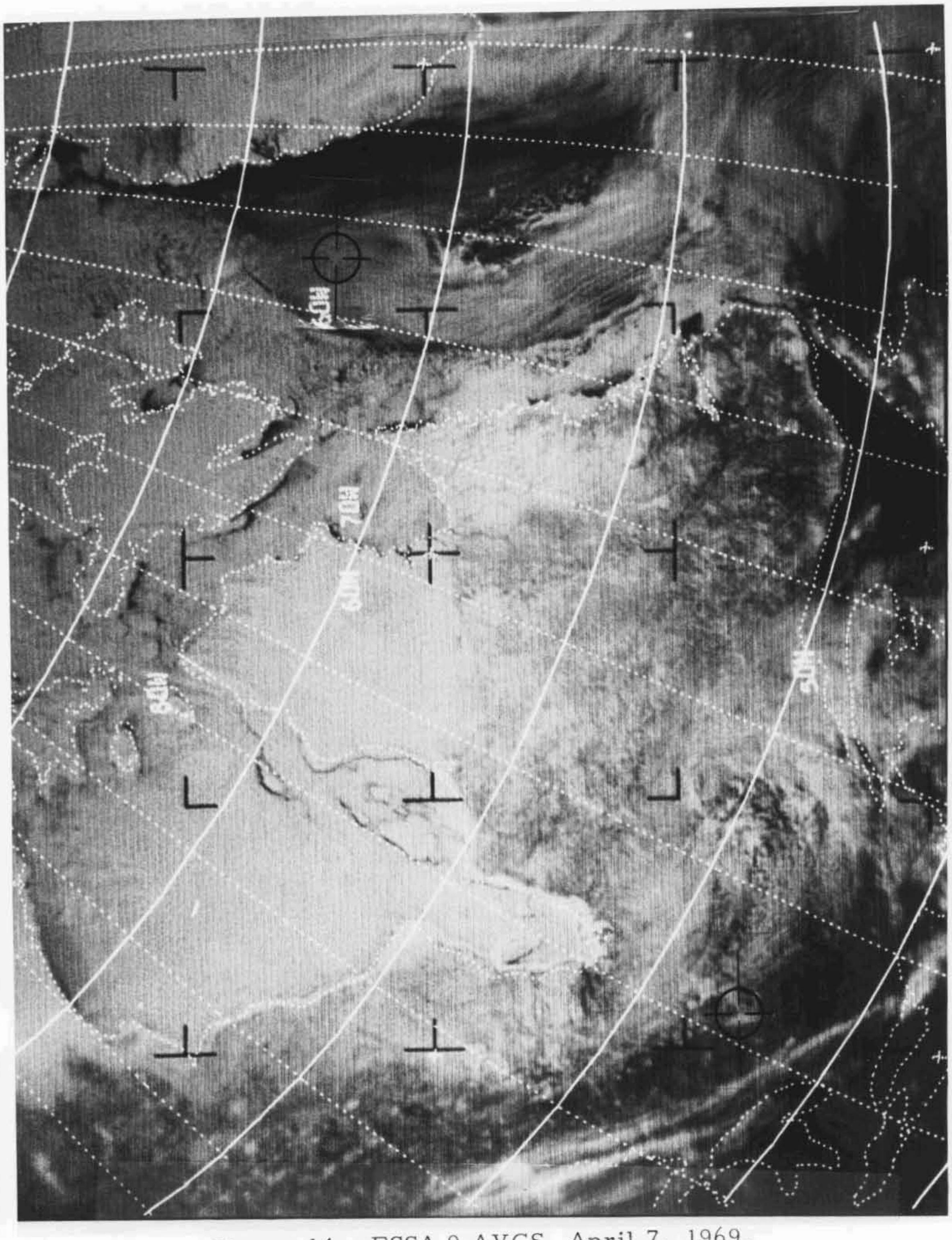

Figure 14. ESSA 9 AVCS, April 7, 1969.

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Figure 15. Nimbus III DRID, Orbit 125.

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image signature corresponds in location to the northern margin of Hare's ecotone. In seeking an answer to the question, "Why should the Ungava region be an exception?", a basis for extending a vegetation association boundary clear across Canada and defining that boundary emerged.

The 30% Coniferous Forest Cover Minimum

Careful study of several types of imagery of eastern Canada and of Hare's map seem to show that the percentage of Woodland vegetation increases at different rates as one approaches the southern boundary of the forest-tundra ecotone at different locations. The implication is that the amount of open coniferous forest (called woodland) included in the forest-tundra subzone varies depending upon location. As noted earlier in connection with Raup's and Ritchie's study areas, the relative proportion of forested land seemed an important determinant of imagery signature characteristics. Therefore an analysis of vegetation association class composition using Hare's map seemed in order.

The forest-tundra ecotone as shown by Hare in Canada east of Hudson Bay was divided into three sectors: western, middle, and eastern. In each sector, a series of east-west lines were drawn, along which the percentage of woodland cover was calculated. The east-west lines were located in each sector to provide the following type of samples: 1) within the tundra, 2) along the northern boundary of the forest-tundra ecotone, 3) within the ecotone one-fourth way into it from the north (line C in Table 1), 4) half way into the ecotone (line B), 5) three-fourths way through the ecotone (line A), and 6) along the southern boundary of the ecotone. Table 1 lists the result of the sampling.

Table 1

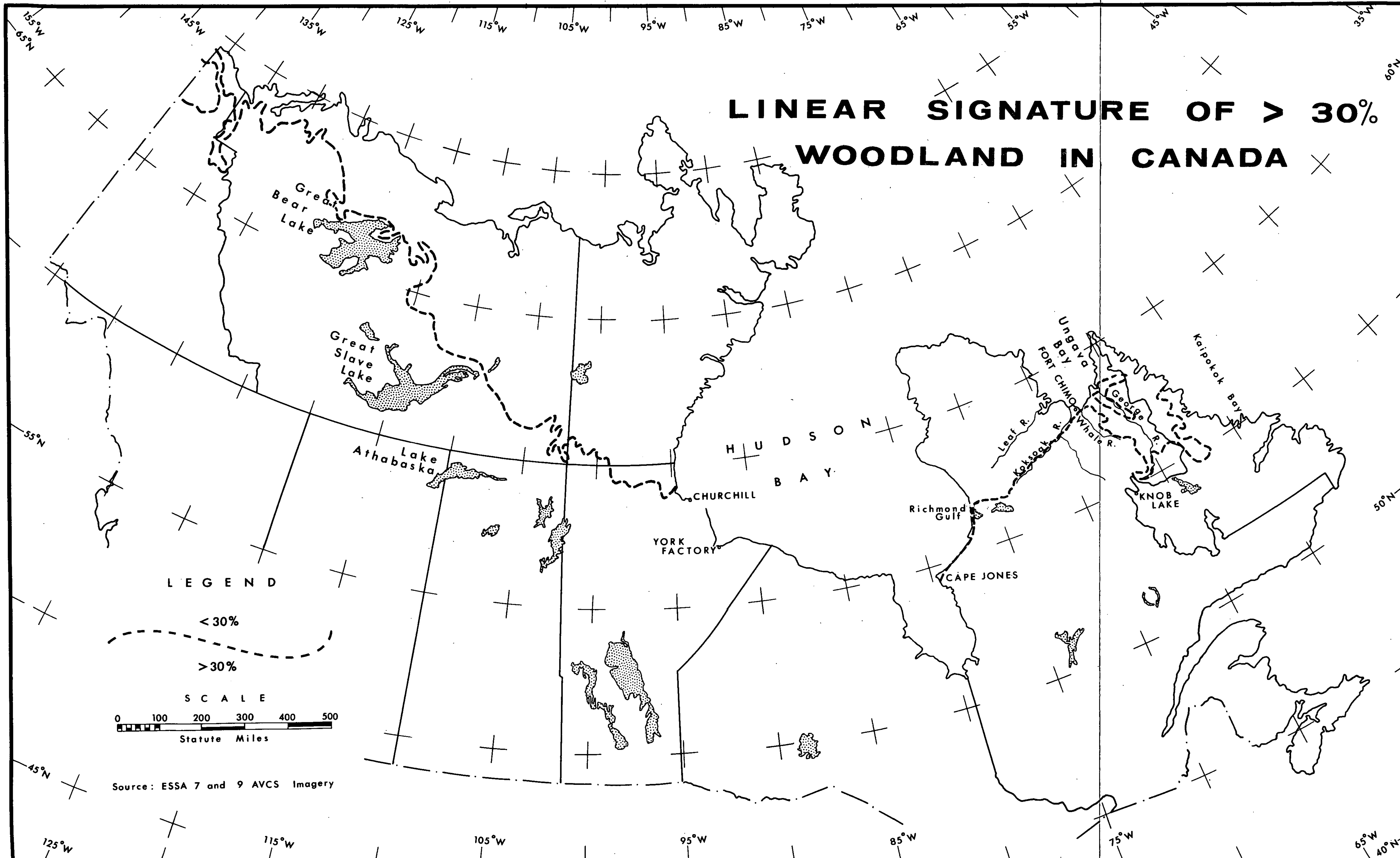
Percentage of Woodland Cover in the
Forest-Tundra of Labrador Ungava

	Western Section	Middle Section	Eastern Section
Extension into tundra	2%	0%	9%
Northern boundary	42%*	47%*	11%
C	21%	8%	36%
B	44%	4%	44%
A	37%	24%	30%
Southern boundary	75%	99%*	0-99%

*Includes stands of closed crown forest

When these percentages are examined in conjunction with imagery for the areas in question, it becomes evident that in most cases a tone change occurs as the amount of woodland in the area reaches or exceeds approximately 30%. This is the situation that produces the characteristic linear signature. The reasons Hare saw fit to vary his boundary criteria in the several parts of eastern Canada are not as important here as the fact of the relative constancy of the basis for the imagery signature. When considered in conjunction with the findings in the Raup and Ritchie study areas, it would seem that a basis has been established for extending a vegetation boundary beyond the limits of the three study areas. Thus Figure 16 portrays the location of the linear signature clear across Canada as it appears on the imagery forms used in this study.

The dashed line on Figure 16 does not portray the forest-tundra ecotone;


LINEAR SIGNATURE OF > 30%
WOODLAND IN CANADA
Great Bear Lake
Great Slave Lake
Lake Athabaska
HUDSON BAY
CHURCHILL
YORK FACTORY
Richmond Gulf
CAPE JONES
Ungava Bay
FORT CHIMO
Leaf R.
Koksoak R.
Whale R.
George R.
KNOB LAKE
Kaipokok Bay
LEGEND
< 30%
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0 100 200 300 400 500
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Source: ESSA 7 and 9 AVCS Imagery
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85°W
75°W
65°W
55°W
45°W
35°W
65°N
60°N
55°N
50°N
45°N
40°N

Figure 16.

as pointed out in the introduction, the ecotone is a zone of variable width. What the line actually represents may be stated in various ways with various degrees of specificity. The line identifies the location of a tonal-textural change on several types of imagery which is the result of change at the earth's surface. Although such factors as snow cover are perhaps more directly responsible, it is believed that vegetation differences are the fundamental cause. The authors believe the dashed line on Figure 16 represents the signature of a vegetation boundary between areas with at least 30% woodland and areas with less than 30%. The signature in question has been found to coincide locationally with vegetation boundaries established in other studies in three areas, more specifically the margins of the forest-tundra ecotone.

Conclusion

This study was a test of the premise that a major natural vegetation boundary, the margin of the forest-tundra ecotone, would be detectable on low ground-resolution weather satellite imagery. It was hoped that if the boundary could be identified in areas in which its location has been established by earlier studies, it would be possible to use the imagery signature to locate the same boundary in areas in which it is imperfectly known. Coincidence between ground truth boundary locations and a distinctive imagery signature in several parts of Canada have been illustrated. Using a variety of imagery types, the location of this signature all across Canada has been mapped. Whether or not the signature locates the ecotone in those areas presently lacking ground truth depends upon how the ecotone comes to be defined in those areas. It is believed that it represents a major vegetation boundary, one that should be considered by those who will establish the ecotone's position.

In addition to the above results, several by-products emerged from this research. Despite relatively low resolution, weather satellite imagery appears to have a mapping potential for high latitudes for which orbital imagery is scarce. Additionally, the importance of seasonality as a consideration for imagery selection, and of gridding checks in data utilization were established.

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