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FRESH-WATER ICE INTERPRETATION FROM ERTS IMAGERY

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INTRODUCTION

Two recent publications (McClain, 1973 and Wendler, 1973) have added to the literature dealing with the utility of the ESSA series of satellites for making observations of sea ice in the Arctic. These articles describe the composite minimum brightness (CMB) technique used for the study of ice types, their spatial distributions, and the identification of ice and cloud covered areas. Although much work has been published concerning satellite data for the study of snow and other glaciological features, little work has been presented on the utility of these data for the study of the types, distribution, and movement of fresh-water lake ice.

Data from a new high resolution satellite is now available to the general public. This satellite, the National Aeronautics and Space Administration (NASA) Earth Resources Technology Satellite (ERTS(I)), operates in four spectral bands from an orbit at 915 km and yields data with a ground resolution of approximately 91 m. A single image covers a rectangular area approximately 185 km on a side, with each scene being retaken (within 37 km) once every 18 days. Because the satellite orbit is sun synchronous, each scene is re-viewed at approximately the same time each 18th day, and consequently, major problems resulting from variable solar lighting conditions are minimized. More complete information is available in: A) ERTS Data User's Handbook[a] (description of the satellite system, including the orbital characteristics and processing at the National Data Processing Facility (NDPF) ; B) ROUSE AND SITER (1973) (brief summaries of the ERTS(I) work being conducted under the auspices of NASA); and C) NASA Earth Resources Survey Program weekly abstracts [b] (a continuing update of the progress being made by the ERTS(I) projects).

ERTS(I) STUDIES:

Several papers concerning the interpretation of ERTS(I) imagery with respect to snow and sea ice are available. BARNES and BOWLEY (1973a), in discussing the interpretation of ERTS(I) data for mapping of snow-line elevation in western United States, determined that ERTS(I) Band 5 was the single most useful band. (See Table 1 for spectral range of individual bands). Band 4 also showed a significant difference between snow cover and snow free terrain, while Band 7 was determined to be least useful for this differentiation. Of particular interest is the comment that "Although a thorough investigation of the multispectral characteristics of snow has not yet been undertaken, examination of data from the Arctic has revealed that the multispectral approach can provide information on glacial conditions that cannot be ascertained from observations in a single spectral band."

MEIER (1973) speaks to a similar set of problems in identification of snow-lines and glacial features in high mountains of western United States and Alaska. He notes that mapping of snowlines from ERTS(I) imagery is highly dependent on cloud cover and vegetation, and to a lesser degree, on solar angle, terrain roughness and slope, radiometric fidelity and spectral information. No data are given regarding the last of these parameters, although one would suppose that Bands 4 and 6 were considered to give the best information for this work as these were the bands used in the illustrations. Comments concerning glacial interpretation do, incidentally, support the observations made by BARNES and BOWLEY (1973a) quoted above.

BARNES and BOWLEY (1973b) report using ERTS(I) imagery for the identification of sea ice in the Arctic. Their conclusions are that Bands 4 and 7 are the best two bands for identification of ice features, while Bands 4 and 5 are preferred for identifying ice boundaries. By using several bands in concert their results are more reproducible. Unfortunately, no imagery or attempt at quantification of the spectral responses were included in the report, and the nature of the ground truth is often in doubt.

RADIOMETRIC GROUND TRUTH:

Many radiometric data have been collected over ice and snow surfaces for various types of studies, including remote sensing (e.g., HORVATH and BROWN, (1971)). It is necessary that a proper ground truth operation be conducted in support of remote sensing and that the field data be collected for the same bands of the electromagnetic spectrum as those in which the sensor is operating. To aid in the collection of the necessary radiometric ground truth data in conjunction with the ERTS(I) satellite, three instruments are available: (1) The Bendix Radiant Power Measuring Instrument (RPMI)[c]; (2) the EXOTECH MODEL 100[d]; (3) the Gamma Scientific Monitor[e]. These instruments can be used for obtaining incident radiation (using a 180° hemispherical field of view) and for measuring scene reflectance. For the latter measurements, the RPMI has a solid angle field of view (FOV) of 6° whereas the EXOTECH has a FOV of 15°.

The radiometric response is an integration of the measurement over the entire scene viewed or in the case of the satellite for the data (resolution) cell. Some problems can thus arise, especially where a very detailed reading of the ground may represent only a small portion of the ERTS(I) resolution cell. Consequently, it is necessary not only to measure large areas, but also to obtain numerous measurements over similar surfaces if it is hoped that the ground truth reading may be able to be adequately related to the ERTS(I) images for interpretative purposes.

Another major problem for ERTS(I) image interpretation (which is likely to arise), given the existence of the target reflection data, is the calculation of the atmospheric attenuation scattering of the energy between the ground and the satellite sensors. ROGERS and PEACOCK (1973) have worked on this problem and present the theory for calculating atmospheric parameters (beam transmittance, path radiance), determining target reflectance and then employing these parameters for translating the ERTS(I) data into the desired target reflectance characteristics. Our concern, in the present paper, is to present several modified target reflectance curves for snow and fresh water ice features in the ERTS(I) spectral bands, which upon application of the correction techniques may possibly allow accurate machine and human interpretation of the ERTS(I) data.

This type of radiometric ground truth is important for snow and ice studies because:

a) The shape, size and location of the subject is, especially in the case of pack ice, constantly changing and consequently cannot always be accurately applied to interpretation over a time series of satellite images;

b) Especially in the spring and fall in higher latitudes and throughout the winter in mid-latitudes, the temperature of the surface material is fluctuating around the freezing point. Consequently, the surface is alternating from wet to dry - the rate of this fluctuation being dependent on weather and meteorological conditions prevailing at the time.

DATA:

Radiometric ground truth data for six types of ice and snow surfaces were collected during the 1972-1973 winter season at two sites (Douglas Lake, Emmett County and Whitmore Lake, Washtenaw County) in Michigan (Fig. 1). The six surfaces studied were: a) drained and refrozen slush; b) new snow; c) dry white ice; d) slush and water mixture; e) close pack (ice concentration .7 - .9); and f) open pack (concentration .4 - .6). For each site, four readings were taken; global irradiance; sky irradiance; direct beam irradiance and reflected radiance. Only the first and last of these are considered in this paper. All data were collected between 1000 and 1400 local sun time on days when the sky was clear and essentially cloud free. No data were taken when clouds obscured direct sun radiation to the observation site. All data were collected using the Bendix RPMI instrument which is thoroughly described by ROGERS and PEACOCK (1973).

Figure 2 illustrates the variations in site reflectance, as a percentage (X 100) of global irradiance, for the six surfaces. These data were collected using the Bendix 6° FOV, with the instrument oriented normal to the surface and at an elevation of 1.0 meters. Essentially, then, this figure is a statement of the albedo in the four ERTS(I) bands for these surfaces. For each surface type, 8 to 10 sets of readings were made. Both the average and one standard deviation of the readings are plotted (Fig. 2) for each surface and for each ERTS(I) band. In this figure G is the outgoing radiation (using 6° FOV); O is incoming radiation (180° hemisphere).

ERTS(I) data, in the form of imagery (Figs. 3 and 6) and included as examples of anticipated application of the radiometric ground truth data of the type presented in Fig. 2. The two study sites are Whitefish Bay, Michigan (29 March 73, ERTS(I) identification number 1249-155582) and Green Bay, Wisconsin (05 Feb. 1973, ERTS(I) identification number 1197-16095). Locations for these two sites are included in Fig. 1.

ANALYSIS OF DATA:

1. Whitefish Bay, Michigan

If we assume that the six classifications of ice (Fig. 2) adequately cover the types to be expected in the ERTS(I) imagery and that all ice in the ERTS(I) scenes are liable for classification into one of these six types, we can then, based partially upon the radiometric data, develop an identification map of the lake ice.

Whitefish Bay, on the Michigan/Ontario border (Figs. 3, 4 & 5), has several features which are immediately apparent. Other than the jet contrail, trending SE-NW across the center of the bay, atmospheric interference with the ERTS(I) scene is of apparently minimal importance for this qualitative study. Shorelines and islands are easily distinguished, as are the Pleistocene beaches on Whitefish Point.

A.) Open Water: the areas of open water are identified as those having, in all four images, very low reflectance, and, from the Band 7 image, essentially no reflectance at all. Although not included in Fig. 2, to use only Band 7 for open water recognition would be to possibly include both types of pack ice and also the slush/water classification. On Band 7 open water could not be confused with white ice, snow or drained slush (Fig. 2). Likewise, leads and other large openings in the ice are clearly identified using the same bands as for open water.

B.) Drained Slush:

Some ice in Tahquamenon Bay is best classified as 'drained slush'. We note from Fig. 1 that there is a slight rise in the reflectance between Bands 4 and 6 and then a rather large (relative to the other bands) drop in reflectance in Band 7. This type of surface is slush which has apparently refrozen slowly during a period when the free water has been draining out - thus it is highly porous, has a relatively low density and has a texture similar to that of a frozen sponge. Consequently, it has a rough surface (at least at these wavelengths) and, because of its porous nature, scatters a great amount of light incident upon it. This ice therefore implies a given height above the water level, or, given a lower elevation, a relatively calm sea during periods of the draining. It also implies the existence of meteorological conditions being very close to the freezing point - sufficient to allow draining prior to refreezing, but not to allow extensive melting of the entire ice parcel.

C.) Snow: Snow has a lower albedo but, contrary to the other surfaces studied, this albedo is approximately constant in all four ERTS(I) bands. Several areas of snow are seen in the northern portion of the ice cover in Whitefish Bay. These areas, if properly identified, indicate ice which has a slight snow cover but of some indeterminable thickness and which is essentially free of free water. It is thus reasonable to state that the ice underlying the snow is solid, free of cracks, and fissures and also that the weather has been sufficiently cold to prevent melting of this snow.

D.) White Ice: White ice with a dry surface apparently covers a very large portion of the entire imaged area. Figure 2 indicates that although there is a drop in the albedo of this ice type with increasing wavelength, this drop is small and the reflection in Band 7 is still quite sufficient to be detected by the ERTS(I) system. Consequently, the white ice should be easily differentiated from the surface types previously mentioned because of the changes in the reflectance curves and from those of lower reflectance (Fig. 2) due to the reflectance in the 0.8 - 1.1 μm band. White ice is essentially frozen slush and is, in several respects, a variation of the 'drained slush' discussed above. In the white ice case, however, the water has been trapped and has been refrozen in place so that the density is much higher (approximately 0.75 to 0.90) and the porosity is reduced considerably. This ice type does not generally imply any given thickness and is one which, from the navigational point of view, probably should be avoided.

E.) Slush and Water/Light and Heavy Pack: These three types have the common feature of being poor reflectors in the ERTS(I) Band 7. Reflectance at the short wavelengths (Band 4) portion of the spectrum is also decreasing as the amount of water visible to the sensors increases. The reflectance is decreased and generally, in addition to the decrease in reflectance, there is an increase in the standard deviation. The latter is especially prominent in the case of the light pack. Some reflectance will be possible for all surfaces studied depending upon the amount of open water. The total area of ice needed for reflectance has not been determined and would, in any case, be partially a function of the sensitivity of the sensor employed.

In the Whitefish Bay area, several areas are identified. The area in the general vicinity of Waiska Bay is classed as being predominantly slush and water. This decision is based upon reflectance but is also contingent upon the smooth and unbroken texture seen on the ice. One small area (probably dry white ice) extends across the center of this patch in a southwest-northeast direction.

Finally, areas of pack ice are seen to the north and northwest of the bay. These areas have degrading reflectances with increasing wavelengths and are, in many cases, nearly imperceptible on the Band 7 image. No attempt is made to distinguish the heavy and light packs from one another.

No simultaneous ground truth data are available for ERTS(I) scene, but the ice reconnaissance data for the previous day have been located. These data (Fig. 5) are based on visual aircraft reconnaissance.

The two data are not really comparable because they are dealing with two different classifications of ice. (In fact, this is also true of the ERTS(I) reflectance data). They also deal with two distinct time periods. However, we note that the main body of ice in Whitefish Bay is classed as rafted (to heights of 3-15 feet) in areas having coverage of 4-9 tenths ice. The more protected bays (Tahquamenon and Goulais) are, based on these visual observations, free of ridged ice. These visual data also suggest that transportation through the main body of ice in Whitefish Bay would be quite treacherous. However, given the lateness of the season and the amount of open water, ship passage should be safe within several days to several weeks (i.e., the first part of April) during this particular year. In fact, the first ship did clear the locks at Saulte St. Marie just to the east of the study area, on (29 March 1973, SS John Munson), the day these ERTS(I) data were collected

2. Green Bay, Wisconsin

A second area of interest, Green Bay, Wisconsin, was also considered (Fig. 1). The data are approximately six weeks earlier (05 Feb. 73) and, consequently, the ice coverage is more continuous and, in general, the areas of different spectral reflectances are more distinct and sharply identified.

Figure 7 is the interpretation of ice for Green Bay. The ice reflectance from Band 7 strongly suggests that a very large portion of the study area is covered with free water, but the high reflectance of some of the same areas in the other three bands indicates that many of these 'free water' areas are not open ice free water but have underlying ice features. The rationale for the interpretation of Figure 6 is as described for the Whitefish Bay, Michigan case and based partially on the reflectance curves presented in Fig. 2. Figure 7 presents the interpretation of ERTS(I) imagery, and Figure 8 presents the visual aircraft observations.

DISCUSSION:

The extraction of ice information from aerial photography is a well developed and useful aspect of air photo interpretation and photogrammetry (e.g. MARSHALL, 1966). As with other aspects of photo interpretation, the addition of imagery obtained with multiband cameras and the further sophistication of the spectral concept to the multispectral scanners (as used on ERTS(I)) has added a new dimension into the science and also, in many respects, to the level of information and detail which can be extracted. Numerous machine techniques are available for interpretation and for presentation of the data in a visual format. These are generally based upon the spectral recognition of various surfaces which are to be studied. Spectral responses, in the very straight forward manner and as used herein, are one method of approaching the subject. A more sophisticated approach requires computer hardware with a large storage capability and the decision-making software to compare the responses for each data cell in the study area and then to compare various combinations of the spectral responses for each band and for each data cell. A discussion of these methods is quite beyond the purposes of the paper.

Of pertinence in this present data is, however, the fact that ice data from fresh-water areas are available via the ERTS(I) satellite and, more importantly, it appears as if useful information can easily be extracted from these data. The necessary basic inputs, the spectral reflectance curves, for both generic and genetic ice types are necessary if the type of work which is being discussed is to become operational. Spectral curves and a complete spectral library of ice types, possibly collected with both ground and aircraft based sensors, and for the same spectral bands as used on the ERTS(I) satellite should be the next logical step for the progression of this type of work. Then machine processing could be conducted with accuracy and validity.

A comment concerning the term 'operational' is needed. Although it is technically possible to produce automatic recognition maps based upon spectral curves from the ERTS(I) data, these data would probably be useful only for scientific and historical, as opposed to operational (near real-time), functions. This is because the ERTS(I) satellite passes over a given area only once each 18 days, its data collection ability may be curtailed by cloud cover (e.g., Fig. 6) and finally because the delay between the time of satellite pass and data collection and its ultimate delivery to the investigator is presently in the neighborhood of 4-6 weeks. This latter problem may, however, be corrected in the future. For more isolated areas or where the immediacy of such information is pertinent, it may be compensated for by the acquisition of a data read-out apparatus operated by the investigators. This possibility is, however, very expensive and would be beyond the financial capabilities of most non-government organizations.

CONCLUSIONS:

The spectral reflections of several types of ice and in the same bands as the NASA ERTS(I) satellite have been presented and used, in a very basic way, to demonstrate their ability for interpretation of fresh-water ice conditions. The study situations are taken from the Great Lakes of North America. Snow covered ice, white ice, slush and water, two types of pack ice drained slush and open water are identified. However, the purpose of the paper is to present the nature of the problem of ice identification from a high altitude, medium resolution (approximately 91 m) satellite system rather than to present definite interpretation techniques. The problem is one which needs considerable additional study. Although all ERTS(I) bands are considered to be of importance in interpretation of the data, some bands, and combinations of bands, are of greater importance than others - which ones these are is dependent upon the nature of the problem to be investigated. At present, this type of work has limited utility for real time operational work (e.g., planning immediate ship movements) while the utility for scientific studies of ice distribution, movement and type identification, is much greater.

TABLE 1

ERTS-MSS Spectral Response

BAND	NDPF Band Code	Wavelength (Micrometers)
1	4	.5 - .6
2	5	.6 - .7
3	6	.7 - .8
4	7	.8 - 1.1

FOOTNOTES

(a) Data Users Handbook: Prepared for NASA, Goddard Space Flight Center, Greenbelt, 20771) by: General Electric, Space Division. Valley Forge Space Center. PO Box 8555. Philadelphia Pa., USA. 19101. Purchase Price $10.00

(b) NASA Earth Resources Survey Program Weekly Abstracts
Available from: U.S. Dept. Commerce. National Technical Information Service, 5285 Port Royal Road Springfield, VA. 22151

(c) Bendix Aerospace Systems Division, 3300 Plymouth Road, Ann Arbor, Michigan 48107

(d) EXOTECH, Inc. 1200 Quince Orchard Blvd., Gaithersburg, Md. 20760

(e) Gamma Scientific, Inc., 3777 Ruffin Road, San Diego, Calif. 92123

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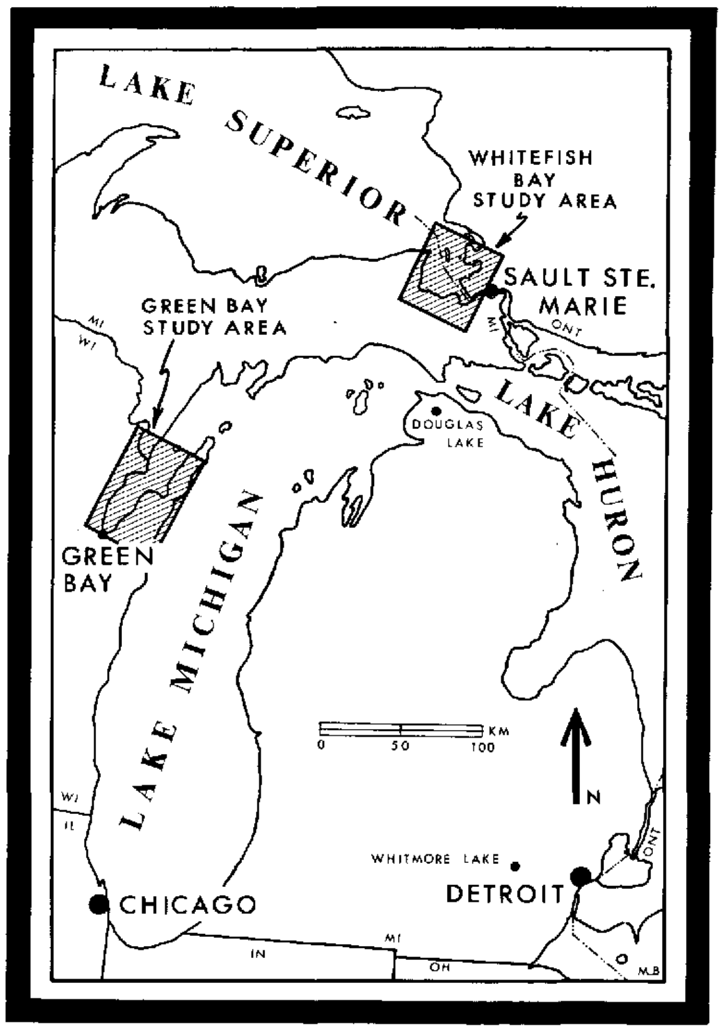

FIGURE 1. LOCATION OF STUDY AREAS

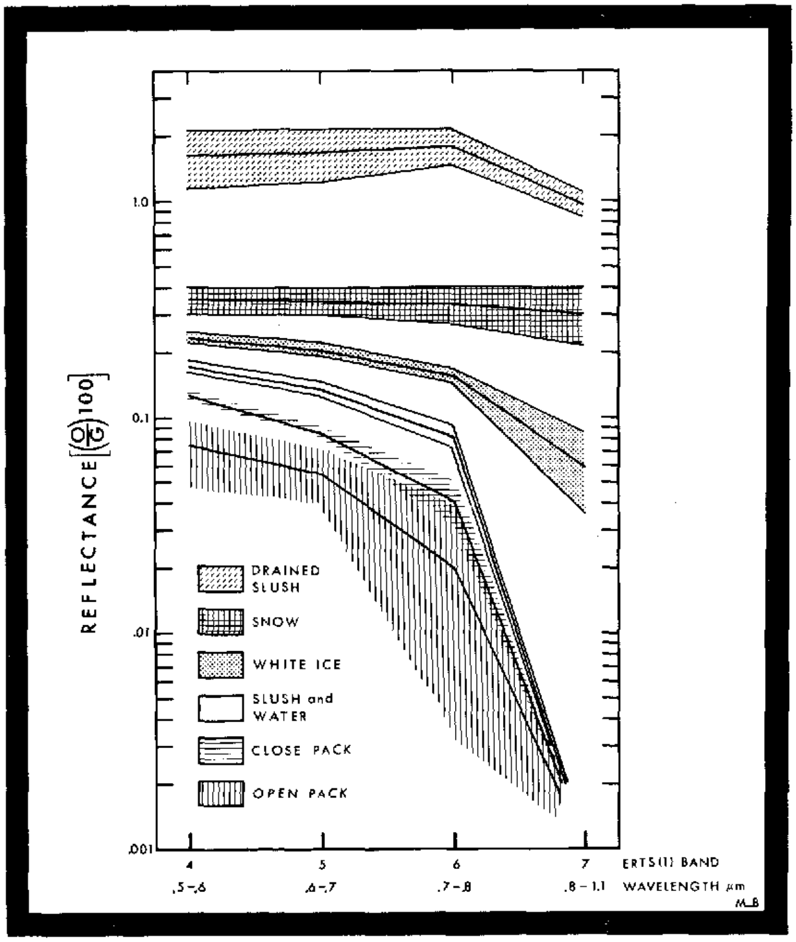

FIGURE 2. SPECTRAL RESPONSE FROM ICE AND SNOW SURFACES.
(See Text for Discussion.)

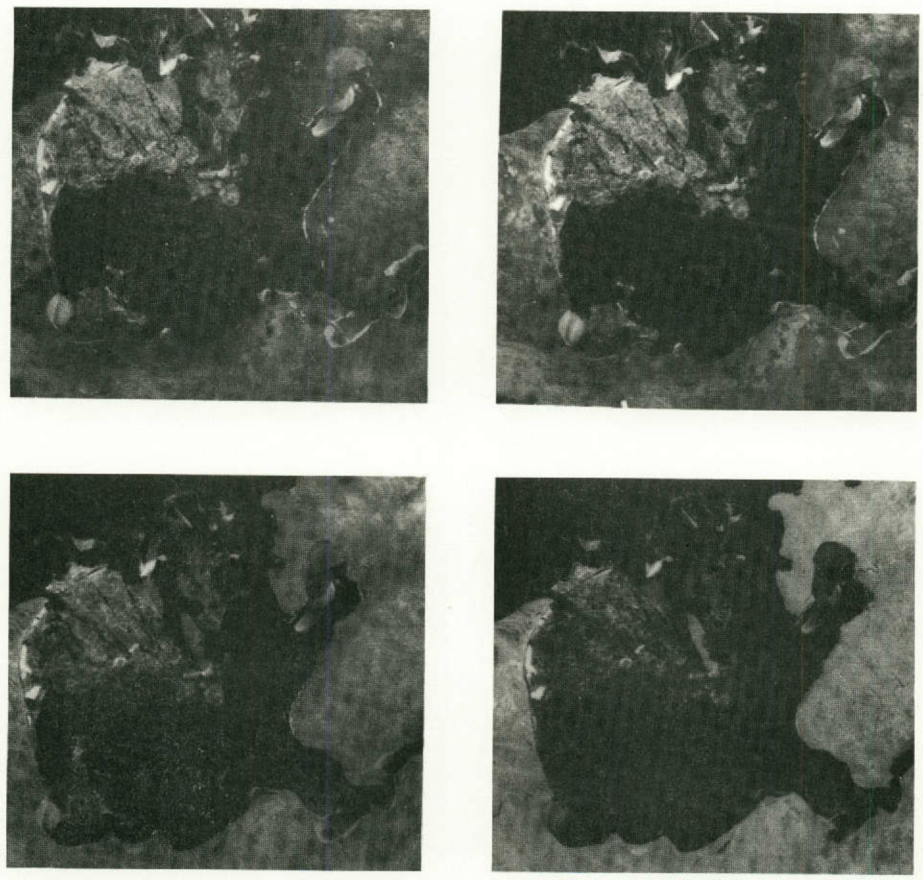

FIGURE 3. ERTS(I) IMAGERY. Whitefish Bay, MI. 29MAR73. Scene 1249-15582. (UL Band 4; UR Band 5; LL Band 6; LR Band 7.)

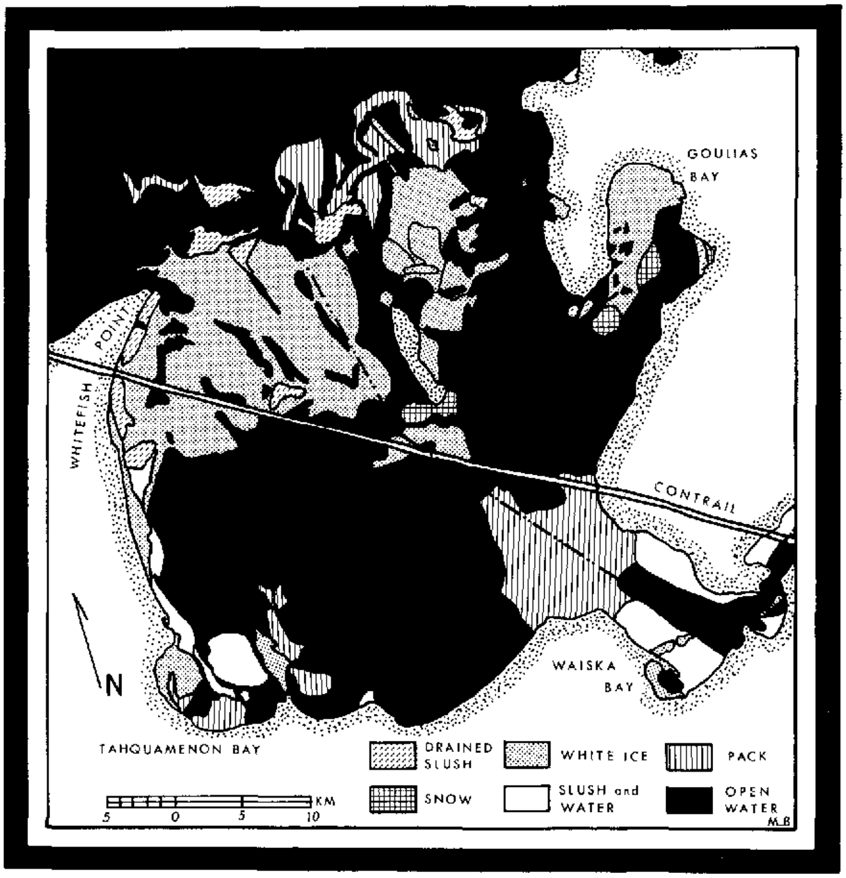

FIGURE 4. INTERPRETATION OF ERTS(I) IMAGERY FOR WHITEFISH BAY, MI. Scene: 1249-155582.

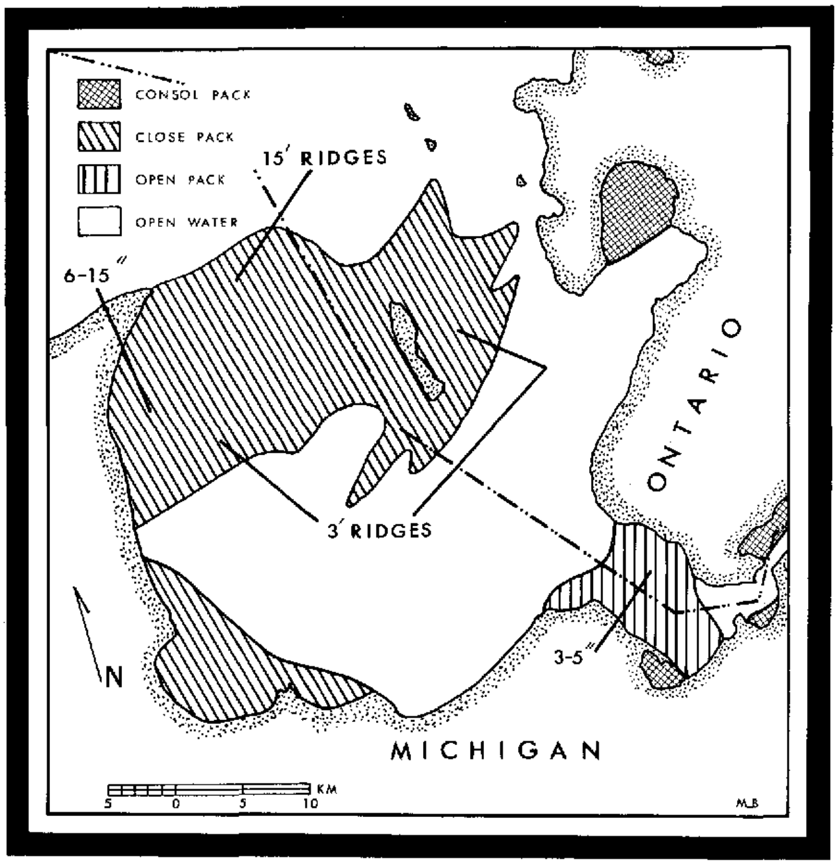

FIGURE 5. ICE ON WHITEFISH BAY, MI. 28MAR73. (SOURCE: U.S. Lake Survey, Detroit, MI.)

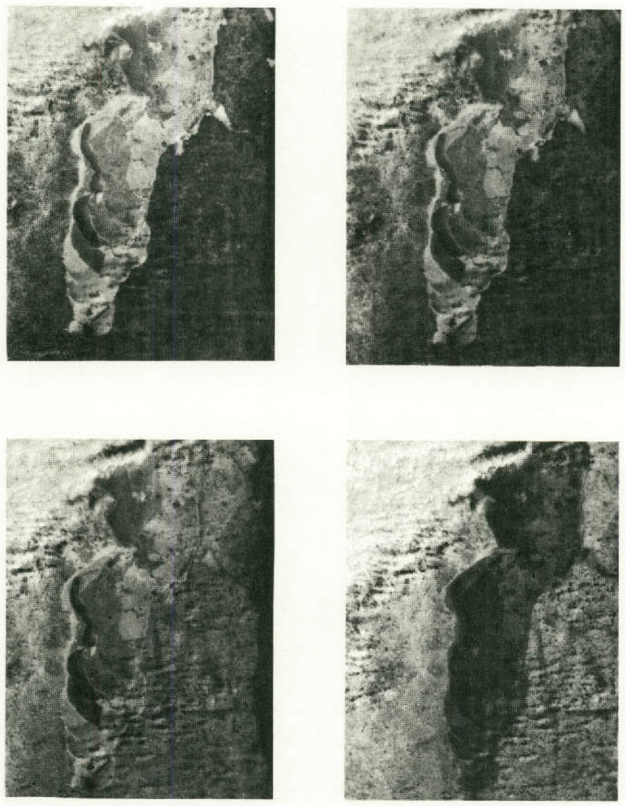

FIGURE 6. ERTS(I) IMAGERY. Green Bay, WI. 05FEB73. Scene: 1197-16095. (UL Band 4; UR Band 5; LL Band 6; LR Band 7.)

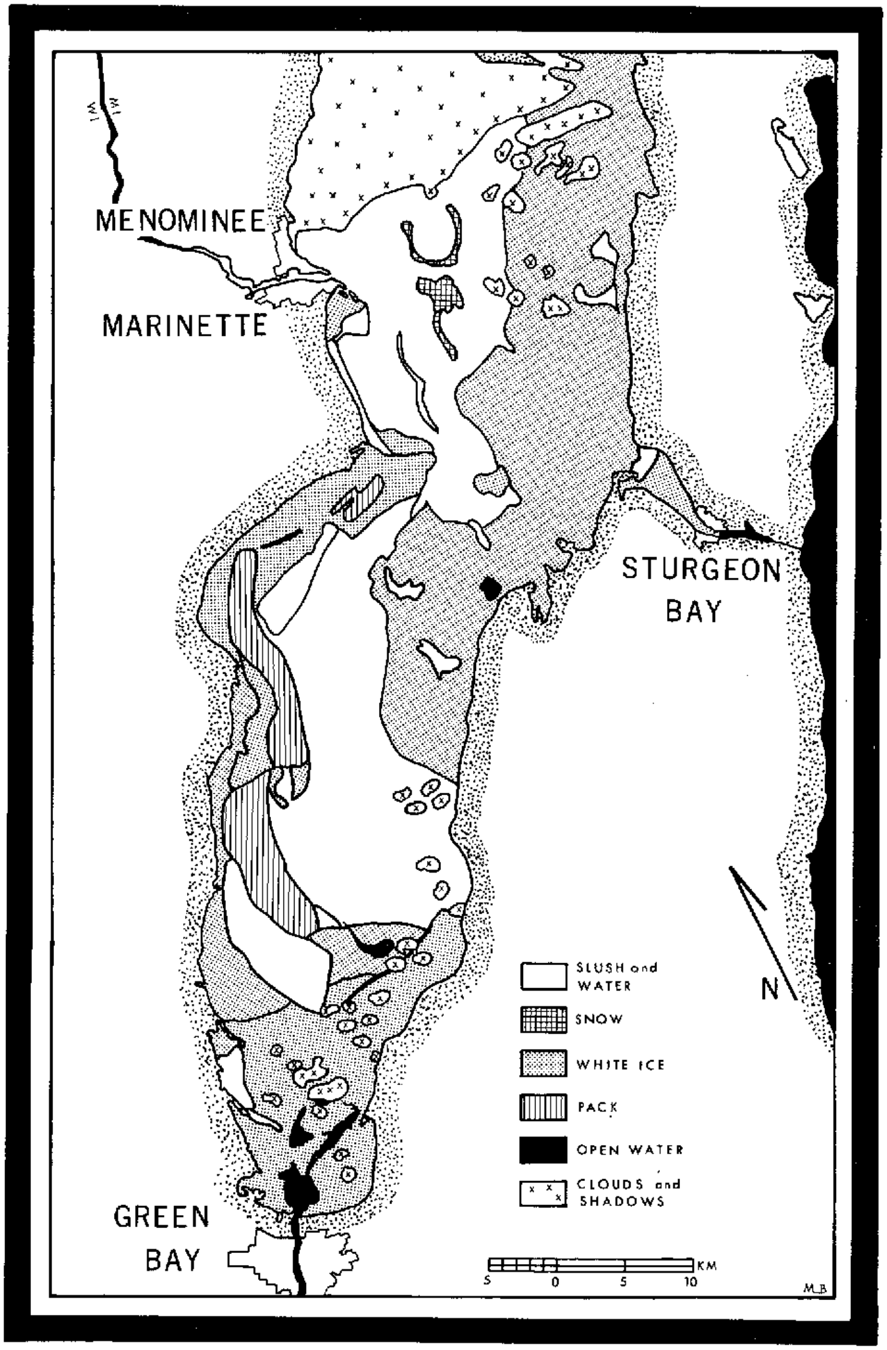

FIGURE 7. INTERPRETATION OF ERTS(I) IMAGERY FOR GREEN BAY, WI. Scene: 1197-16095.

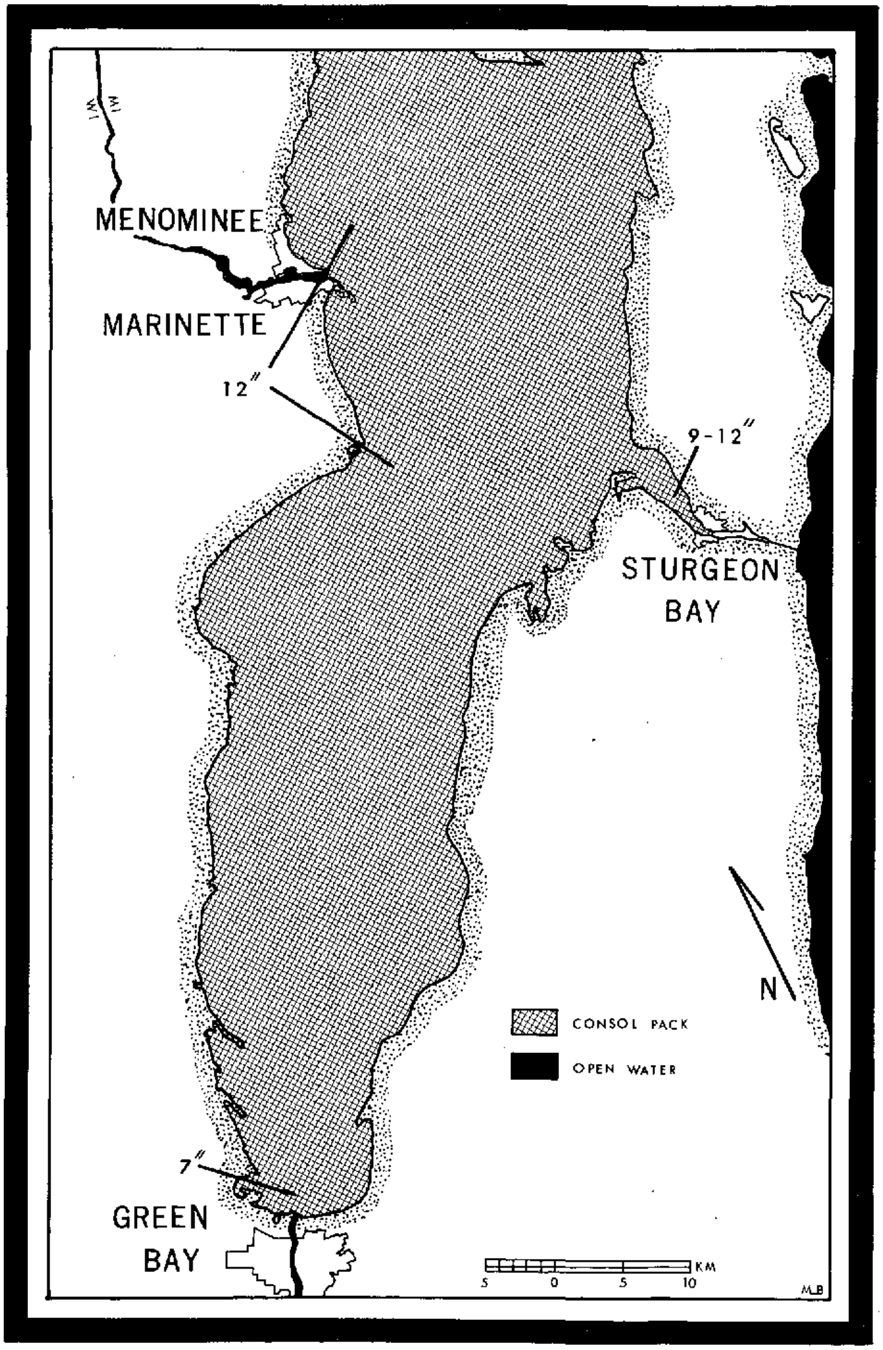

FIGURE 8. ICE ON GREEN BAY, WI. 05FEB73. (SOURCE: U.S. Survey, Detroit, MI.)