A STUDY OF THE MORPHOLOGY
THE BLUE RIDGE ESKER AND CERTAIN RELATED
SEDIMENTARY CHARACTERISTICS

By

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CHAPTER I

INTRODUCTION

Statement of Problem

The purpose of this paper is to describe the characteristics and interrelationships of the topography and certain characteristics of sediments associated with the Blue Ridge, or Ackerson, Esker located south and east of Jackson, Michigan.[1] The following four basic questions were considered during the course of this study. (1) What is the topographic configuration and extent of the esker? (2) What can be determined regarding the formation of the Blue Ridge Esker from a study of the lithologic composition of esker pebbles and cobbles and an investigation of certain sedimentary characteristics within the feature? (3) Are there any associated features that are directly related to the esker such as tributary eskers or esker troughs, and what, if any, is their significance? (4) What was the nature of the glacial environment in which the esker was formed, and, more specifically, did the Blue Ridge Esker

[1] Hereafter, in this paper, the esker will be referred to as the Blue Ridge Esker. It was originally named the Ackerson Esker by F. Leverett but has since become known as the Blue Ridge.

form wholly, or in part, with a supraglacial, englacial, or subglacial stream?

Justification

A limited amount of previous work has been completed on the Blue Ridge Esker. F. Leverett appears to have been the only person to study the Blue Ridge Esker in detail, but since the publication of his work (Leverett & Taylor, 1915) additional data have become available for use in landform studies. For example, the use of topographic maps and air photos provide detailed information that was not available to Leverett. Also, exposures of related sediments are probably more numerous at this time and provide an important source for information regarding the internal characteristics of the feature. Hopefully this study will better help explain the distribution and formation of the Blue Ridge Esker and some of the related landforms in southeastern Jackson County.

Location of the Esker in Relation to the Interlobate Area

The Blue Ridge Esker is located mainly within an area of ground moraine southeast of Jackson (see Figure 1). Part of the esker, however, also extends into areas underlain by glacial outwash that are adjacent to the ground moraine. The outwash has been traced to the distal sides of the Kalamazoo Moraine of the Saginaw Lobe and the Mississinewa Moraine of the Huron-Erie Lobe as mapped by

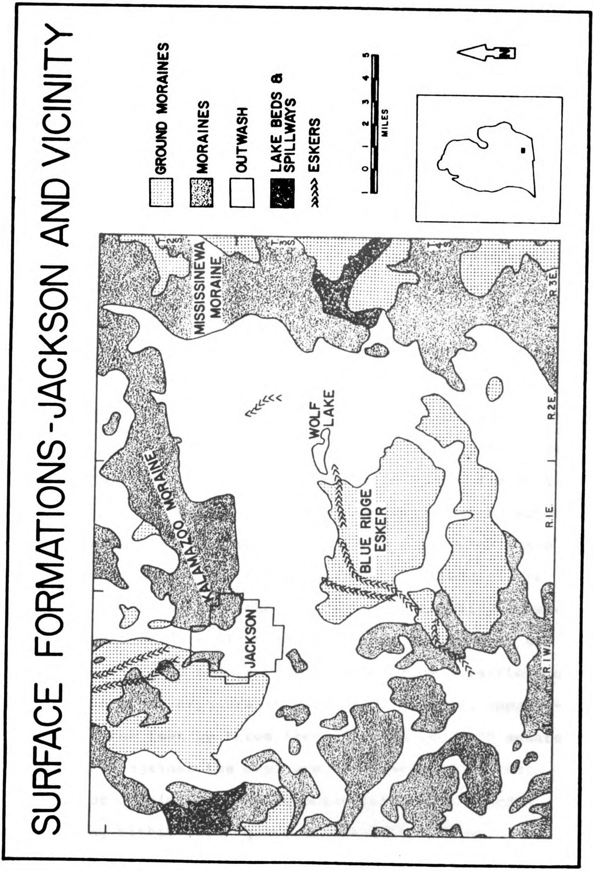

Figure 1 (after Martin, 1955).

Martin. Figure 1 shows that the esker is located approximately along the southwest extension of the trend of the interlobate area formed by these moraines (Leverett & Taylor, 1915).

Field Work

This investigation was primarily based on field work. The field work consisted of three main activities. First, the extent of the esker and adjacent landforms was mapped at a scale of 1:24,000 during the summer and fall of 1973. Air photos, U.S. Geological Survey topographic maps, and a soil survey map of the area were utilized in the mapping. Subsequently a field study of the esker and adjacent areas was undertaken to check the accuracy of the mapping and further refine the map. All except the most remote parts of the esker were observed in the field study.

Second, pebble and cobble samples were collected at six sites where exposures of sediments exist within the esker. The sites were situated along the trend of the feature to assure that the nature and variability of stone types could be determined for different sections of the feature. In situ stones were selected from a vertical or nearly vertical exposure at each site. A grid, approximately three feet by three feet, divided into 100 squares, was placed against the exposure, and the most central pebble or cobble was then selected from the sediments appearing within each square of the grid. If no appropriate-sized stone was found within a square, the sediments within that area of the grid were excavated until a stone was found. One hundred stones were collected at each site and were analyzed to determine their lithologic composition.

Third, observations were made at all suitable sites of sediment types and structures to provide information concerning the internal characteristics of the esker.[2]

Additionally, laboratory analysis was conducted and consisted of identifying the 600 pebbles and 600 cobbles collected at sites within the esker. Five categories were recognized in the classification of these stones: carbonate, igneous-metamorphic, siltstone and shale, sandstone, and others.

Review of Pertinent Literature

General Characteristics of Eskers

An esker, as defined by R. F. Flint (1971, p. 214), is "a long narrow ice contact ridge commonly sinuous and composed chiefly of stratified drift." According to Embleton and King (1968, p. 369), the sedimentary constituents of an esker ridge include much sand and gravel although R. F. Flint (1971, p. 215) notes that boulders and silt-sized material may exist in places. He further notes

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[2]Exposures that were being actively excavated were observed at several different times.

that most eskers are located in areas of low relief and generally trend parallel to the direction of the flow of the most recent glacier that existed in the area. J. K. Charlesworth (1957, p. 420) also states that eskers are often bounded by "narrow lateral moats or ditches," which are commonly referred to as esker troughs. Many authors believe that esker troughs are the result of subglacial stream erosion (Rieck, 1972).[3]

Early Contributions to the Esker Literature

Many authors have made important contributions to the literature concerned with eskers. W. Upham, one of the first, published numerous articles on the subject in the late 1800s and early 1900s (1876, 1893, 1894, and 1904 are a few examples). T. C. Chamberlain also authored publications concerned, at least in part, with eskers during approximately the same time period (1884, 1893, and 1894, for example). W. M. Davis (1892) described certain subglacial eskers in New England, while G. Stone (1899) probably drew increased attention to the feature when he published his major work on the eskers of Maine for the U.S. Geological Survey. F. Leverett, author of numerous studies of glacial geomorphology (for example, 1902, 1915,

[3]Whether or not eskers formed in subglacial, englacial, or supraglacial positions has probably been the most debated issue in the esker literature, and this topic will be discussed in greater detail in a later section of this paper.

1929, and 1932), mapped and described a number of eskers located in the Midwest.

G. DeGeer (1897), working in Scandinavia, proposed a theory for the formation of "beaded eskers," which, because of his research on these features, are today known as DeGeer Eskers.

Thus, by 1920 as a result of work by these and other authors many eskers had been described and mapped in various countries, and several theories concerning their origin had been proposed.

Recent Contributions to the Esker Literature

There are several authors of more recent publications who have made especially useful statements regarding eskers. R. F. Flint has published numerous articles concerning eskers in both North America and Europe (for example, see 1928, 1930, and 1932). J. K. Charlesworth (1957) devotes a small but significant part of his book to the study of eskers, and C. Embleton and C. King (1968) also summarize some of the more important esker studies in their book on glacial geomorphology. R. Sharp (1953) has published a definitive work in which the nature and origin of some eskers in North America are discussed.

Much research has been conducted on eskers in Scandinavia. Studies by A. Hellaakoski (1930), A. Matisto (1951), and especially K. Virkkala (1958), M. Okko (1962), and V. Okko (1957) are among the most important. Many of these authors have been particularly interested in studying the origin and transportation of eskerine sediments.

There has also been an increasing amount of study on eskers that are presently forming in connection with certain Arctic glaciers. For example, R. Price has completed numerous studies on the formation of eskers associated with Alaskan glaciers (for example, see 1964 and 1966), and J. C. Stokes (1958) has presented an interesting article on the formation of an esker in an ice tunnel of a glacier in Norway.

In 1972 R. Rieck completed a comprehensive review of existing literature on eskers in which the major publications and topics relating to the study of eskers have been identified. This is probably one of the most useful and helpful works in terms of organizing and summarizing the esker literature.

Mode of Esker Formation

It appears that the majority of studies dealing with eskers are concerned mainly with the mode of their formation. There has been some disagreement in the literature as to whether eskers form primarily within, below, or on the surface of the glacier ice. W. Upham (1891), for instance, proposed a supraglacial formation for eskers he studied because of the absence of overlying glacial till. He believed that if an esker formed subglacially it would be reasonable to expect that some type of ablation drift would be deposited on the esker surface as the glacier ice melted (p. 381). If no ablation drift existed on the surface of the esker, he assumed that it formed in an ice channel open to the sky. W. Crosby (1902) also favored the supraglacial formation of eskers. J. B. Woodworth (1894), on the other hand, found overlying till and boulders on the eskers he studied (p. 216) and used the same line of reasoning as that used by Upham to advocate a subglacial formation for these features.

J. K. Charlesworth (1957, pp. 426-28) has offered some criteria for determining whether eskers have formed subglacially or supraglacially. He states that supraglacial formation should be considered if there are few boulders to be found on the esker or if the esker becomes broader near its distal end, which signifies a widening of the supraglacial stream channel toward the margin of the glacier. He further indicates that supporting evidence for consideration of subglacial formation includes: a large amount of locally derived material within the esker, evidence that at least part of the esker flowed upslope, erratics and till existing on the top and sides of the esker, arched bedding within, and water-worn surfaces beneath the esker.

W. M. Davis (1892) favored subglacial formation of eskers and was one of the first workers to note the major problem with the supraglacial formation theory. This problem, often used as a basis to reject the supraglacial theory, involves the process of superimposing the esker sediments from a position on the surface of the glacier to the ground beneath the ice without severely disturbing the bedding and destroying the distinctive form of the esker. An additional problem with the supraglacial theory is that most glacial debris is carried near the base of the glacier rather than on its surface, and hence C. Embleton and C. King (1968, p. 371) point out that there is probably too little debris carried in supraglacial streams for an esker to be formed on the surface of the ice.

Some glacial geomorphologists now agree that most eskers probably formed in subglacial tunnels, but they do acknowledge the supraglacial and englacial formation of some eskers (Sharp, 1953; Embleton & King, 1968; and Flint, 1971, among others).

Glacier Conditions and Esker Formation

It is also believed by many authors that the ice associated with the formation of eskers must have been stagnant (Chamberlain, 1884; Davis, 1892; Sharp, 1953; Embleton & King, 1968; and Flint, 1971, among others). This interpretation is based on the conclusion that, if active ice movement were to occur after the formation of the esker, it is most probable that its topographic form would be destroyed. It is also doubtful that an ice tunnel, into which esker sediments are deposited, could form within active ice of a glacier.

Origin and Transportational Distance of Esker Sediments

A number of studies in Finland revealed that sediments comprising eskers located in that country appear to be mainly of local origin. A. Hellaakoski (1930), A. Matisto (1951), and K. Virkkala (1958) all concluded that material comprising eskers was derived locally for the most part. A. Matisto reported that the transportation maximum of the sediments in eskers he examined was about twenty kilometers and that the average distance that the eskerine material had been transported was ten to fourteen kilometers. A. Hellaakoski studied the Laitila Esker, which traverses an outcrop of the distinctive type Rapakivi granite. He observed that the distance from the exposure to the place where there was a maximum abundance of the Rapakivi granite within the esker was seventeen to twenty-four kilometers and that the first identifiable granite appeared in the esker at five to eight kilometers from the outcrop. K. Virkkala found that only about 40 percent of the sediments in the esker he studied had been transported over five kilometers. Thus, although there is some disagreement among these authors concerning the distance eskerine material has been transported, they do agree that many of the esker sediments are of local origin. Virkkala summarized the importance of his findings by stating that "The source areas of the gravel and stone material of the esker can be traced with rather great probability if the bedrock, the topography and the retreat of the inland ice are known with sufficient accuracy" (Virkkala, 1958, p. 103).

R. Rieck (1972, p. 74) also notes that of the studies he considered only one out of thirty-seven authors who stated an opinion concerning the provenance of esker sediments did not believe that the source of most eskerine material was local.

Previous Study of the Blue Ridge Esker

The only previous technical description of the Blue Ridge Esker was published by F. Leverett in 1915. In his study (p. 203) Leverett notes that the esker is situated very near the junction of the Saginaw and Huron-Erie lobes and terminates in a morainic spur about eight miles southeast of Jackson. He describes the esker as being "more massive" than the ordinary esker and having "an abrupt embankment-like appearance" (Leverett & Taylor, 1915, p. 203). He mentions that in places the esker is as much as an eighth of a mile wide and thirty to forty feet high. He also emphasizes that the sediments of the Blue Ridge Esker are much coarser than "normal esker material" (p. 203) and that it is not uncommon to find pieces of rock with longest dimensions that exceed two feet, although most of the boulders are of smaller size. Leverett offered the following theory to account for the formation of the Blue Ridge Esker: "Possibly it is the product of a combination of ice deposition with subglacial drainage, and this may account for the coarseness of its material and for its unusual size" (Leverett & Taylor, 1915, p. 203).

CHAPTER II

TOPOGRAPHY AND TRIBUTARY ESKERS

Topography

On the basis of morphology the Blue Ridge Esker can be divided into three segments, each of which has different characteristics. These three divisions will be referred to as the Northern, Middle, and Southern Segments.

The Northern Segment is that part of the esker that is located between Wolf Lake and the area between Ackerson and Cranberry Lakes where the topographic expression of the esker is less apparent and disappears altogether in the SE 1/4, Section 30, T. 3 S., R. 1 E. (see Plate I). This segment is approximately 3.7 miles long, trends in an almost straight east-west direction, and is characterized by its greater width, though this varies significantly. For example, the esker averages one-half mile in width but ranges from less than an eighth to about three-fourths of a mile in cross section. The topography adjacent to the esker has average elevations of approximately 990 feet above sea level. Maxium elevations of the esker crest exceed 1,030 feet in a few places within the Northern Segment, but for most of its length here the crest is between 1,020 and 1,000 feet above sea level. Thus, the esker crest is from approximately 10 to 40 feet above the adjacent land in the Northern Segment.

The Middle Segment of the esker extends from the approximate position of Greens Lake on the north to the Grand River to the south. This segment is approximately three miles in length and is generally narrower and has higher elevations than the Northern Segment and is slightly wider than the Southern Segment. The esker, in this section, is sinuous, trends in a southwesterly direction, and is generally about one-eighth of a mile in width. The altitude of the adjacent topography averages about 980 to 990 feet above sea level. Elevations along the crest of the esker in the Middle Segment exceed 1,050 feet in numerous places and are seldom lower than 1,030 feet except in the north near Greens Lake, where elevations are in most places slightly over 1,000 feet above sea level. Thus, the esker is as much as 50 feet above the adjacent topography along much of its length in this segment, and in some places its crest may be 70 or 80 feet higher than the topography nearby to the east or west.

The Southern Segment is separated from the middle portion of the esker by a lowland occupied by the Grand River. This shortest segment of the esker is approximately three miles in length. As in the Middle Segment, the esker is sinuous in plan and trends in a northeast-southwest direction. For most of its length in this segment the esker is quite narrow, being less than one-eighth of a mile in width at numerous places. Average altitudes of the adjacent topography to the northwest of this segment range from about 1,000 to 1,050 feet above sea level, while the land to the southeast averages only about 980 feet. Within this segment the crest of the esker attains its highest altitude of slightly more than 1,080 feet. However, for most of its length in this southern portion maximum altitudes associated with the crest of the feature are usually between 1,030 and 1,050 feet above sea level and are rarely below 1,030 feet except near the southwest terminus near Skiff Lake. Thus, the esker crest is as much as 100 feet higher than the adjacent topography to the southeast in at least one area, but throughout most of this segment its surface is about 50 feet or less above the adjacent land. However, the topography a short distance to the northwest is relatively high, and in this area the esker crest is often only 10 to 40 feet above the nearby land.

Profiles of the Esker and Adjacent Topography

Figure 2 represents a longitudinal profile of the Blue Ridge Esker and two similar profiles of the adjacent topography: one to the south and east and the other to the north and west of the esker. These profiles appear to represent a straight line; however, the reader should recognize that they follow the sinuous course of the esker.

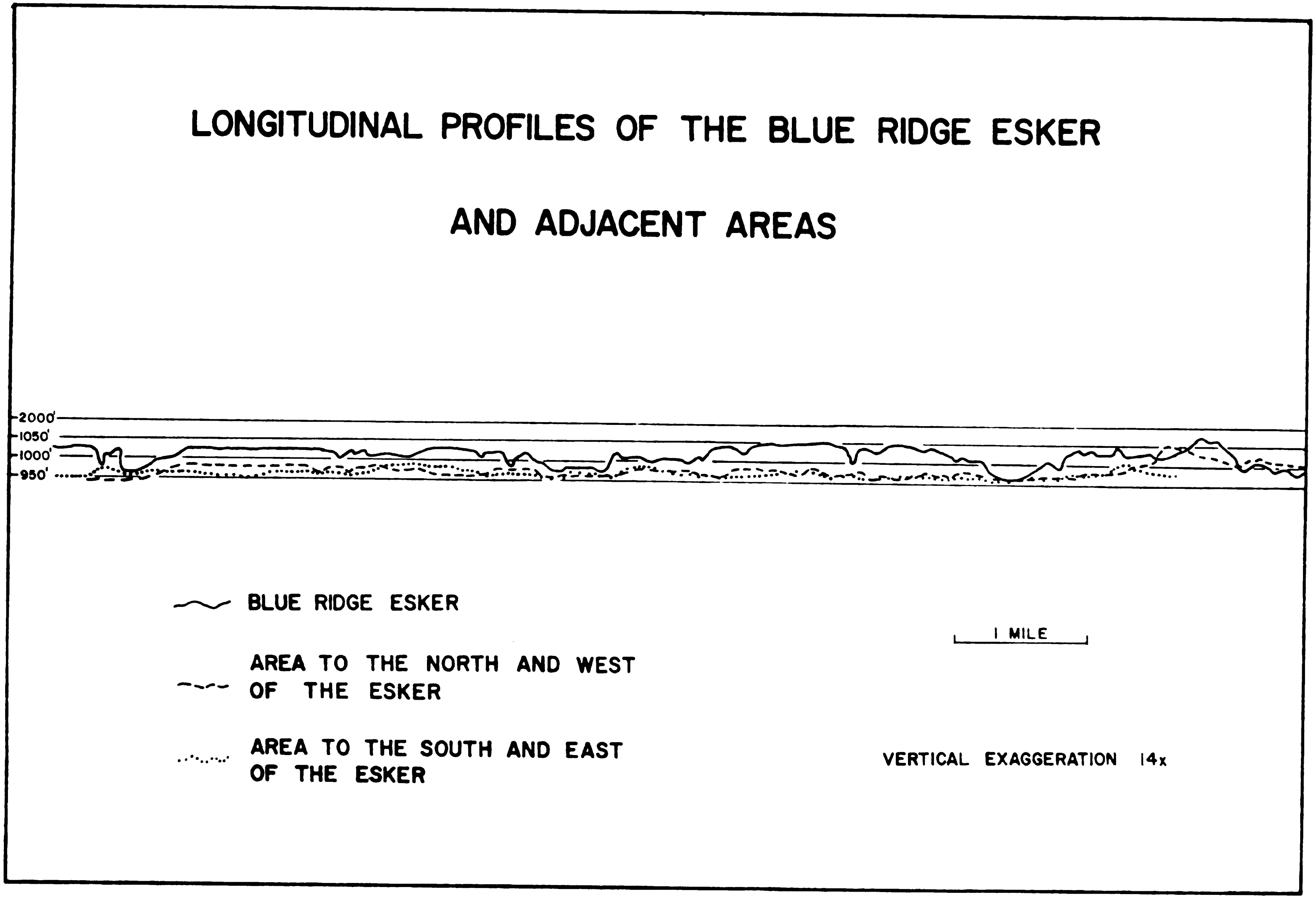
LONGITUDINAL PROFILES OF THE BLUE RIDGE ESKER
AND ADJACENT AREAS
2000'
1050'
1000'
950'
BLUE RIDGE ESKER
AREA TO THE NORTH AND WEST OF THE ESKER
AREA TO THE SOUTH AND EAST OF THE ESKER
1 MILE
VERTICAL EXAGGERATION 14x

Figure 2.

Although there are many variations, it is evident from the esker profile that altitudes along the crest of the esker generally tend to increase with increasing distance from the upstream (northeast) portion of the esker. The topography adjacent to the esker in many places also exhibits a slight increase in the same direction. This is especially true in the areas adjacent to the downstream (southwest) portion of the esker. This increase in elevation in all profiles indicates that the esker trends upslope in some places. Charlesworth (1957) notes that evidence of an esker trending upslope supports a theory of subglacial esker formation. Thus, if his interpretation is correct, this situation indicates a subglacial origin of the Blue Ridge Esker.

Topographic profiles of the esker also reveal that a relationship apparently exists between the degree of irregularity of the esker crest and the width of the esker. The crest is most irregular in the Southern Segment, where the esker is narrowest, and least irregular in the Northern Segment, where the feature is widest.

Figure 3 represents four profiles constructed at right angles to the trend of the Blue Ridge Esker and adjacent areas. The tranverses along which these profiles were constructed are shown in Plate I.

Profile A, which represents a typical cross section of the Northern Segment of the esker, shows that in this

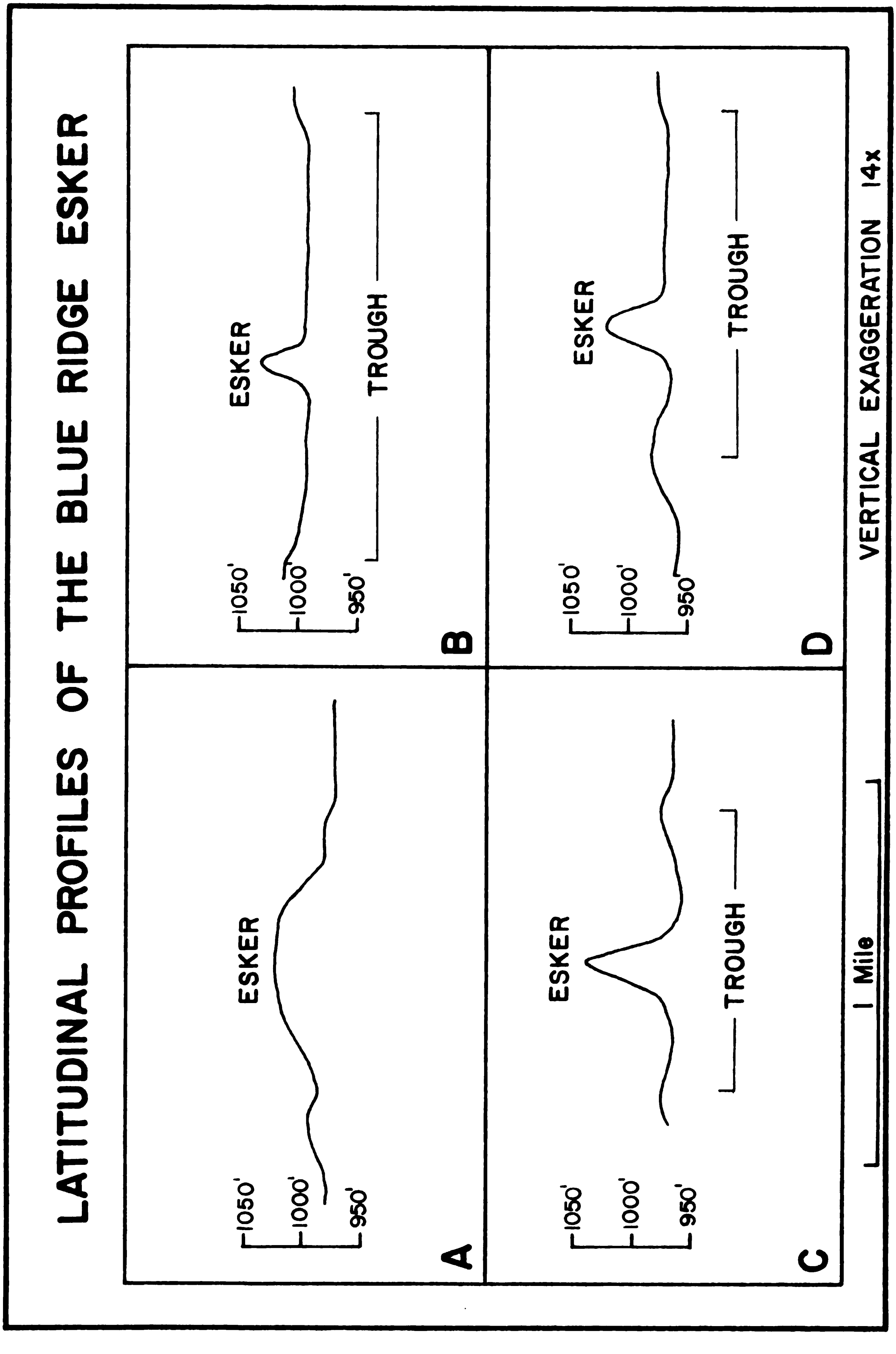
LATITUDINAL PROFILES OF THE BLUE RIDGE ESKER
A
1050'
1000'
950'
ESKER
B
1050'
1000'
950'
ESKER
TROUGH
C
1050'
1000'
950'
ESKER
TROUGH
1 Mile
D
1050'
1000'
950'
ESKER
TROUGH
VERTICAL EXAGGERATION 14x

Figure 3.

area the esker has relatively low crest elevations and is relatively wide.

Profile B is located downstream (southwest) from Profile A but also within the Northern Segment. In this area the esker is much narrower and smaller topographically, but its crest elevation is slightly higher than that of Profile A.

Profiles C and D are representative of the Middle and Southern Segments, respectively. In these areas the esker is not as wide (approximately one-eight of a mile) as at most places within the Northern Segment, but the altitude of the crest is about 1,050 feet, approximately thirty feet higher than the crest of Profile A.

It is apparent from Profiles B, C, and D that at some places the Blue Ridge Esker is bounded by an esker trough. Topographic map analysis and field study indicate that an esker trough exists along almost the entire length of both sides of the Middle and Southern Segments and about one mile of the southwestern portion of the Northern Segment of the esker. The surface of the trough is approximately ten to twenty feet lower than the average altitude of the adjacent land in most places, and it may vary from less than one-half mile to more than a mile in width.

The esker trough may be an especially significant feature because many authors consider its existence as indicative of subglacial esker formation (Rieck, 1972). Some workers propose that esker troughs are the result of glaciofluvial action, and thus they believe that if the esker stream was able to erode the trough it apparently flowed in a subglacial tunnel of the ice (Rieck, 1972, p. 40).

Tributary Eskers

There are apparently several tributary eskers to the Blue Ridge. One, referred to here as the Stony Lake Esker, is located to the east of the Middle Segment and joins the Blue Ridge in the NW 1/4, Section 6, T. 4 S., R. 1 E. (see Plate I). This esker originates as a topographic feature at least as far east as the center of Section 9, T. 4 S., R. 1 E. and extends in an east-west direction for a distance of about two and one-half miles. However, the esker is not continuous topographically but instead consists of a number of segments, the longest of which is only slightly more than one-half mile in length.

The topography adjacent to the esker segments averages between approximately 970 to 990 feet above sea level. The crest exceeds 1,000 feet in numerous places, and the highest elevations, more than 1,020 feet, exist within the largest segment. Thus, the crest of the Stony Lake Esker is about 20 to 30 feet above the adjacent land in most places, with the maximum being 40 feet.

A second related esker, known as the Wolf Lake Extension, is narrower than most parts of the Blue Ridge Esker and forms a relatively straight ridge that is two and one-half miles in length and is discontinuous in only a few places. Mapping indicates that it originates as a topographic feature just east of Norvell Road in the SW 1/4, NW 1/4, Section 15, T. 3 S., R. 2. E. (see Plate II).

The altitude of the topography directly adjacent to the Wolf Lake Extension averages approximately 980 feet above sea level, while altitudes along the crest of the esker often exceed 1,000 feet. Thus, this feature is usually about 20 feet or more above the nearby land. However, the Wolf Lake Extension is an impressive feature within the adjacent topography since much of its surface is not tree covered and, therefore, its linear form is strikingly displayed along much of its course.

The Grass Lake Esker is a tributary to the Wolf Lake Extension and appears to originate in the SW 1/4, NW 1/4, Section 4, T. 3 S., R. 2 E. (see Plate II). It extends in a north-south direction, is sinuous in plan, and is slightly more than two miles in length. The topographic expression of this feature terminates very near the Wolf Lake Extension in the SE 1/4, Section 17, T. 3 S., R. 2 E.

The altitude of the topography adjacent to the Grass Lake Esker averages about 980 feet above sea level while the crest of the esker is generally between 990 and 1,000 feet. Thus, in most places its crest is 10 to 20 feet above the adjacent topography, and it is topographically not as apparent as the eskers previously discussed.

Significance of Tributary Eskers and Their Spatial Distribution

The spatial pattern of the Blue Ridge Esker and its tributaries reveals that an extensive, relatively well-developed drainage system existed within the glacier during the final deglaciation of this part of Michigan. Eskers are also characteristic features of glacial stagnation. Therefore, if it is correct to assume that the Blue Ridge and its tributary eskers formed contemporaneously, the spatial distribution of these features suggests that ice stagnation was probably quite widespread in this area. Additionally, numerous kames, also indicative of ice stagnation, are located in various areas adjacent to the Blue Ridge Esker system.

Apparently large masses of ice became disassociated with the ice margin, whose position may have been retreating to the north and east. The stagnant ice became perforated with many cracks, holes, chambers, and tunnels into which much glacial drift was deposited by mass wasting and supra-glacial, englacial, and subglacial streams. Hence, instead of an assemblage of landforms that formed in connection with an ice margin that was associated with active ice that tended to retreat in an orderly manner, this area is characterized by ice-disintegration features such as kames and eskers. Flint (1971, p. 207) notes that "In such a situation not only is the locus of deposition of drift not concentrated at the glacier terminus, but the deposited drift assumes forms most of which are very different from those of end moraines." Thus, the Blue Ridge Esker and adjacent landforms were probably formed in an environment characterized by the slow melting of large masses of stagnant ice accompanied by the deposition over a large area of ice-contact glacially derived sediments.

CHAPTER III

STONE TYPES WITHIN THE BLUE RIDGE ESKER

Characteristics of Pebbles and Cobbles

Pebble and cobble samples were collected according to the methods described in Chapter I at five sites within the Blue Ridge Esker and at one site in the Wolf Lake Extension (see Plates I and II for the location of these sites). An identification of the lithology of the pebble and cobble samples (Table 1) reveals that carbonate pebbles are the most numerous, averaging close to 50 percent of the total pebbles collected at each site. Igneous-metamorphic rocks are second in abundance and comprise nearly 30 percent of the total pebbles. Shale and siltstone and other rock types make up the remaining fraction of the pebble samples. The samples of all sites appear to be uniform in that the percentage of pebbles of the various rock types is similar in all the samples except for site three, which has an abnormally high amount of carbonate rocks and lower percentages in all other categories, especially the igneous-metamorphic group.

The lithologic types of cobble size differ markedly from those described previously. The percentage of

Table 1.--Lithology of pebble and cobble samples collected from the Blue Ridge Esker, in percent of total stones collected at each site.

Pebble Sample Site Number	Carbonate	Igneous-Metamorphic	Siltstone and Shale	Sandstone	Other
One	53	37	. .	4	6
Two	40	36	5	15	4
Three	66	18	1	11	4
Four	40	31	1	26	2
Five	42	33	2	13	10
Six	48	33	6	9	4
Cobble Sample Site Number	**Carbonate**	**Igneous-Metamorphic**	**Siltstone and Shale**	**Sandstone**	**Other**
One	40	41	2	18	1
Two	29	50	2	19	. .
Three	45	40	1	13	1
Four	36	26	4	34	. .
Five	38	33	. .	28	. .
Six	41	28	2	29	. .

carbonate rocks averages only about 40 percent of all the cobbles collected, while there is only a slight increase in the percentage of crystalline rocks. The major difference is a marked increase in the percentage of sandstone cobbles, which comprise about 25 percent of the esker cobbles sampled.

Table 1 reveals that a marked change in lithology is evident between sites three and four in both the pebble and cobble fractions, although the former is not as apparent. The percentage of sandstone cobbles from site four is twice as much as that identified in the sample from site three. Site four has the largest percentage of sandstone cobbles in the esker, and this ratio tends to decrease slightly downstream from this location. It appears logical to conclude that somewhere between sites three and four a considerable amount of locally derived sandstone was introduced into the esker stream.

The data concerning the lithologic composition of the esker sediments do not support the conclusions made by Scandinavian authors regarding the origin and transportational distances of eskerine sediments. They found that esker sediments apparently are largely of local origin and probably have not been transported many kilometers. However, it was previously shown in this paper that approximately one-third of the pebbles and cobbles of the Blue Ridge Esker are of the igneous-metamorphic group. Obviously these crystalline rocks do not have their origin in southeastern Michigan. It also may be possible that some of the stones of other lithologic types are not of local origin.

On the other hand, the abundance of sandstone within the esker, especially the portion downstream from site three, supports the concept that local bedrock may be a source for a significant amount of sediment within eskers. This apparent contradiction with the findings in Scandinavia may be explained by the following:

1. The effects of multiple glaciation. Since there were at least three major stages of glaciation before the Wisconsinan, during which the Blue Ridge Esker was formed, it is entirely possible that a large percentage of the esker's igneous-metamorphic stones were derived from older drift within southeast Michigan, thereby accounting for the apparently large amount of crystalline stones within the feature.
2. The thickness of previous drift. If the previous glacial drift within the area was relatively thick, it is quite reasonable to conclude that the glacier ice may not have been able completely to penetrate the older drift and erode sediments from the bedrock below. Hence. there would be few, if any, local source areas of bedrock from which sediments may be derived, and this situation would cause the

percentage of non-locally derived material within the feature to be relatively high.

3. The characteristics of the bedrock surface. If bedrock exists near the surface in or adjacent to areas traversed by the esker stream, it seems reasonable to suggest that a relatively large percentage of sediments of this bedrock type may be present within esker sediments since the glacier ice may have readily eroded bedrock which was near the surface.

Thus, the effects of multiple glaciation, the thickness of the previous glacial drift, and the characteristics of the local bedrock surface are probably all significant factors in determining the amount of locally derived sediments within eskers.

Possible Origin of Locally Derived Sandstone Sediments

The origin of the increased amounts of sandstone between sites three and four may be related to the bedrock characteristics in the areas adjacent to the esker. Martin (1936) has mapped the bedrock immediately beneath the glacial drift in the Blue Ridge Esker area as sandstone. A drift-thickness map (Figure 4), constructed from approximately 400 well-log records for the area,[4] reveals that

[4]Well-log data, extracted from a map indicating the location and depth to bedrock of water and oil wells in Jackson County, was supplied by the U.S. Geological Survey, Lansing, Michigan.

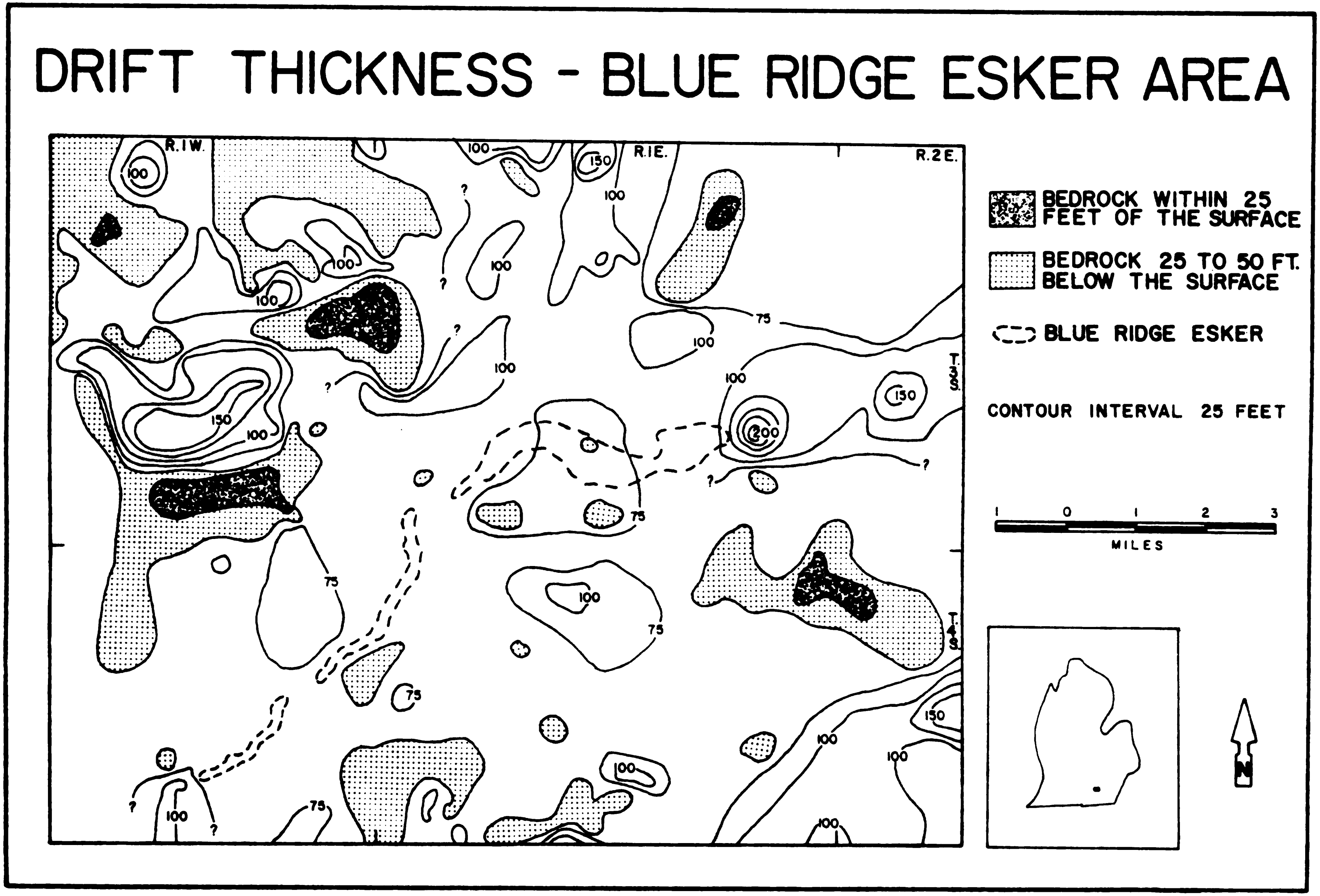
DRIFT THICKNESS - BLUE RIDGE ESKER AREA
BEDROCK WITHIN 25 FEET OF THE SURFACE
BEDROCK 25 TO 50 FT. BELOW THE SURFACE
BLUE RIDGE ESKER
CONTOUR INTERVAL 25 FEET
1 0 1 2 3
MILES
N
R.1W.
R.1E.
R.2E.
T.3S.
T.4S.

Figure 4.

sandstone bedrock exists at shallow depth beneath the surface within a part of the Northern Segment directly downstream from site three. This is indicated by a log for a well located within the NE 1/4, Section 28, T. 3 S., R. 1 E., which shows thirty-eight feet of sand, gravel, and boulders, probably associated with the esker, resting on bedrock.[5] Thus, it appears that the source for the increased amounts of sandstone between sites three and four is associated with an area of sandstone bedrock underlying a portion of the Northern Segment of the esker. Additionally, there are numerous other areas in the vicinity of the esker where sandstone bedrock exists close to the surface, and these may also have been source areas for some of the locally derived sandstone.

Comparison of the Lithologic Composition of the Blue Ridge Esker and the Saginaw and Huron-Erie Lobe Deposits

Kneller (1964) analyzed pebbles from glaciofluvial deposits in southeastern Michigan to determine whether their source was associated with the Saginaw or Huron-Erie Lobe. His data and findings provide a basis for differentiating such drift of the two glacial lobes.

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[5]It should be noted that there is some question as to the exact location of this well. The well-log record contains a poor, general description of the location. However, as plotted on the map supplied by the U.S. Geological Survey, this well is positioned immediately adjacent to a part of the Northern Segment of the esker.

The author has averaged Kneller's data on the lithology of these sediments for all samples collected in both the Saginaw and Huron-Erie deposits (see Table 2). Data concerning the pebble lithology of all six sites within the Blue Ridge Esker were also averaged and are shown in Table 2.

A comparison of the average pebble lithologies of the two lobe samples and the esker sample reveals several important relationships. First, the average percentage of igneous-metamorphic pebbles of the esker and the Saginaw Lobe samples are nearly equal, whereas the average percentages of this rock type in the Huron-Erie Lobe samples is much lower (7 to 8 percent). A similar relationship is also apparent when comparisons are made between the average for siltstone and shale. Percentages of stone types from the Saginaw Lobe samples and those of the Blue Ridge Esker are nearly equal; however, the Huron-Erie samples averaged nearly 8 to 9 percent more siltstone and shale.

Another significant relationship is revealed when the average amount of sandstone within the esker is compared with that associated with the two lobes according to Kneller. The two lobe samples average nearly the same percentage of sandstone, approximately 6 percent, whereas the average of all six sites within the esker was about twice this amount.

Two conclusions may be made regarding the relationships between the samples of glaciofluvial sediments from

Table 2.--Average lithology of pebble samples from lobe and esker samples in percent of total.

Sample	Carbonates	Igneous-Metamorphic	Shales and Siltstones	Sandstone	Other
Huron-Erie* Lobe	52.2	23.7	10.5	6.0	5.8
Blue Ridge Esker	48.1	31.3	2.3	13.2	5.1
Saginaw Lobe*	50.3	32.4	1.3	6.3	8.3

*Data averaged from Kneller, 1964.

the two lobes and those from the Blue Ridge Esker. (1) It appears that the lithology of the Blue Ridge Esker is more closely associated with that of the Saginaw Lobe rather than the Huron-Erie Lobe because the average number of igneous-metamorphic and siltstone and shale pebbles of the esker and the Saginaw Lobe samples were nearly equal, whereas the Huron-Erie samples of these stone types revealed differences of about 8 percent with the averages for the esker samples. (2) It may be concluded that a significant amount of sandstone was introduced into the esker stream from a local source because the average amount of sandstone within the esker was twice as much as that found within the two lobe samples according to Kneller.

Sedimentary Characteristics

Leverett in 1915 (Leverett & Taylor, 1915) reports that the size of the sediments comprising the Blue Ridge Esker, for the most part, appear to be relatively large. Although many exposures within the esker reveal mainly sand- and pebble-sized material, there are numerous beds of cobbles and boulders. Figure 6a is a photograph of a pile of discarded boulders in a gravel pit at site three. Figure 6b shows a boulder, within the same gravel pit, that was measured to be five and three-quarters feet by six feet by four feet. Boulders and cobbles were found in great abundance in all exposures examined in the esker. Several authors note that the presence of coarse material within

Figure 6a. Snow-capped boulders in gravel pit at site 3.

Figure 6b. Large limestone boulder in the gravel pit at site 3. Note the hat on the boulder for scale.

the esker sediments indicates that a swift current existed within the stream from which they were deposited (Carney, 1908; Reeves, 1920; and Embleton & King, 1968).

R. F. Flint (1971) and Embleton and King (1968) both believe that eskers are formed in contact with the glacier ice. Flint (1971, pp. 184-85) has recognized at least three criteria for the identification of ice-contact stratified deposits, all of which exist within the Blue Ridge Esker. These criteria are (1) abrupt changes and extreme range in grain sizes, (2) included bodies of till or flow till, and (3) collapse or slump structures within the sediments.

Abrupt changes in grain size and extreme range of sediment sizes were observed in all exposures examined in the Blue Ridge Esker except at site six, which was overgrown with vegetation. Figure 7 illustrates the abrupt change from cobble- and boulder-sized material to fine sand at site three.

A mass of flow till, approximately ten feet thick and twenty feet in length, was observed along a northwest-facing exposure in the esker at site five. Although till appears to overlie much of the esker sediments at site five, this mass apparently was deposited from above about ten feet into the esker sediments. Possibly during a late phase of deglaciation this till flowed off a mass of ice or fell from the roof of the ice tunnel into the esker sediments.

Figure 7. Abrupt change and extreme range in grain sizes in an exposure at site three. A small shovel and camera case are included for scale.

Slump and collapse structures (Figure 8) exist at site five within the northwest-facing exposure mentioned above. These features were formed when the supporting ice melted, allowing the sediments to slump or collapse. Displacement indicates that relative movement of two feet or more occurred at several places.

Except for the structures described above, no evidence of folding, faulting, or contorted bedding was observed at any of the sites examined in the Blue Ridge Esker. If the esker formed supraglacially or englacially and the esker sediments were superposed upon the surface by melting of underlying glacier ice, evidence of disturbed bedding should be abundant. Lack of such characteristics indicates that the esker probably formed at the base of the glacier ice.

Sedimentary characteristics also indicate that the esker stream flowed in a southwesterly direction. In every exposure examined in the esker, with the exception of site six, the most common bedding trends were associated with foreset beds dipping toward the southwest.

According to Mr. Ron Stevik (1973, personal communication), drilling to determine the subsurface extent of the sand and gravel at site five indicates that these sediments extend at least fifty feet below the working surface of the gravel pit, which is approximately at the same altitude as the topography adjacent to the esker. Exposures observed show that the esker sediments extend at

Figure 8. Slump structures in the gravel pit exposure at site five.

least ten feet below the surface and that, if the entire fifty feet of these subsurface sands and gravels are part of the esker, it would appear that in this area possibly less than one-half of the esker sediments are exposed topographically. If this interpretation is correct, it indicates that the esker formed subglacially because only such a stream would be capable of eroding a channel and depositing sediments below the level of the present land surface.

With the possible exception of site six, an average of four or five feet of ablation till overlies the esker sediments in all exposures. The till is very sandy, is buff-colored, apparently contains only small amounts of clay, and is very similar to the till that was observed within the esker sediments at site five. Apparently during the last phases of deglaciation varying amounts of ablation drift were deposited upon the surface of the esker. This resulted from either collapse of the overlying ice accompanied by the deposition of drift or slumping of glacial debris from adjacent masses of ice.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Topographic Expression and Extent of the Esker

The Blue Ridge Esker, which can be divided into three segments, extends for a distance of about ten miles within an area of till and outwash plain in southeastern Jackson County. The esker varies in width from well over a half mile in the Northern Segment to much less than one-eighth mile in the southern portion. Height above the adjacent topography varies from an average low of about thirty feet in the Northern Segment to average highs of about fifty to sixty feet in the Middle Segment. In one place in the southern portion the esker is slightly higher than 100 feet above the adjacent topography.

Additionally, it was observed that a relationship exists between the degree of irregularity of the esker crest and the width of the feature. Where the esker is wide (Northern Segment), the esker crest is least irregular, and where it is narrowest (southern portion), the crest is most irregular.

Certain Sedimentary Characteristics and Relationships

The sedimentary characteristics of the Blue Ridge Esker indicate several important relationships. First, the lithology of the glaciofluvial sediments of the esker is more closely associated with that of the Saginaw Lobe rather than the Huron-Erie Lobe. This suggests that the Saginaw Lobe contributed a greater amount of sediment to the Blue Ridge Esker stream.

Second, on the basis of the relative abundance of sandstone pebbles and cobbles within the esker, it was concluded that much of the sandstone sediments were derived locally from an area of bedrock located at shallow depth immediately underlying a part of the esker or from a number of areas in the vicinity of the esker where bedrock exists near the surface. Thus, it was suggested that, if bedrock is located near the surface in areas traversed by the esker, sediments of that bedrock type should be relatively abundant within the feature. If bedrock is not located near the surface, it probably is not an important source area for eskerine material.

It was also observed that as much as one-third of the esker sediments (crystalline stones) may have originated from a distant source, such as Canada. However, it was noted that much of the apparently non-local sediments may actually have been derived from older glacial drift in southeast Michigan.

Formation of the Esker

Sedimentary and topographic characteristics also indicate that the Blue Ridge Esker formed in a subglacial tunnel or crevasse of the ice. Sedimentary evidence supporting this conclusion includes (1) that in one place no more than one-half of the esker sediments are topographically expressed, and (2) that no disturbed bedding other than the slump structures at site five were observed. Topographic evidence includes (1) the apparent upslope trend of the esker along some part of its course, and (2) the location of the esker within an esker trough throughout much of the feature's length.

Deglaciation Environment

The nature and characteristics of the Blue Ridge Esker and its tributaries provide some basis for understanding the nature of the deglaciation environment in this area. The spatial distribution of these features suggest that a relatively well-developed drainage system existed within a large area of stagnant glacier ice. The declaciation process was characterized by the disintegration of the stagnant ice in place, accompanied by the deposition of ice-contact sediments and the formation of such features as eskers and kames.

Relationship of Findings to Previous Work

As a result of an examination of the morphology of the Blue Ridge Esker and its tributaries, it is possible to recommend several modifications of Martin's 1955 Map of the Surface Formations of the Southern Peninsula of Michigan.[6]

1. According to Martin (Figure 1) a tributary esker from the north joins the Blue Ridge Esker just north of the Grand River. This esker is portrayed as being approximately four miles in length and located to the west of the Blue Ridge. On the basis of this study the existence of such a feature is not verified. There are, however, several kames in this area which are arranged in a somewhat linear pattern.
2. Martin indicates that the Blue Ridge Esker extends about one and one-half miles to the southwest of Skiff Lake. The area to the south and southwest of Skiff Lake appears to be a complex maoranic area consisting of many small knobs, depressions, and ridges. However, none of these ridges is continuous for any considerable distance, and they do not appear to be connected with the Blue Ridge Esker. Observation of topographic maps and field work indicate that the southern terminus of the Blue Ridge Esker is located to the west of Skiff Lake rather than approximately one and one-half miles to the southwest as portrayed on Martin's 1955 surface formations map.

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[6]Figure 1 is based on this map.

3. Neither the Stony Lake Esker nor the Wolf Lake Extension are represented on Martin's 1955 map. The topographic expression of both eskers is apparent in the field, and hence it would seem appropriate to recognize these two eskers as part of the Blue Ridge Esker System on the Map of the Surface Formations of the Southern Peninsula of Michigan.

Suggestions for Further Study

Although it was determined that much of the esker sediments were probably contributed by the Saginaw Lobe it was not possible to state whether the esker formed at the interlobate contact or entirely within one of the glacial lobes that existed in the area. This question concerning the location of the formation of the Blue Ridge Esker remains unanswered and merits further study.

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LARGE NEGATIVE TEMPERATURE DEPARTURES AT LANSING, MICHIGAN, DURING SPRING AND THEIR RELATIONSHIP TO HUDSON BAY AIR MASSES AND MIDDLE LEVEL WIND FLOW PATTERNS

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INTRODUCTION

In Southern Michigan, spring is a season of quite variable weather often characterized by outbreaks of cold polar air or invasions of tropical air from the Gulf of Mexico. Although an outbreak of cold air may cause unpleasant weather, it can also have a more severe affect on the fruit growing and related industries of the state, especially if it occurs in late spring. For example, on May 18, 1973, a record minimum temperature of 25 degrees F. was observed at Lansing, while freezing temperatures occurred throughout much of the state, resulting in great damage to Southern Michigan vineyards, apple, and other fruit orchards.

Purpose

The purpose of this paper is to determine the paths taken by cold air masses that have caused large negative temperature departures from normal at Lansing, Michigan, during spring. More specifically, an attempt will be made to determine whether these air masses traverse the Hudson

Bay area before entering the Midwest. Since cold "pools" of air and their movement are easily identifiable on 850 mb. facsimile charts, these maps will be used to trace the paths of cold air masses at this low atmospheric level.

Upper and middle level wind flows, in general, are responsible for surface weather patterns and therefore this paper will also attempt to establish a relationship between the frequency of cold air mass invasions from the Hudson Bay area and average monthly tropospheric windflow patterns. Accordingly, the movement of cold air masses into the Lansing area during April, May, and June of 1972 and 1973 and the mean 700 mb. windflow patterns for these months will be examined.

Discussion of Middle Level Windflow Patterns and Their Relationship to Surface Temperatures

Air flow in the mid-troposhere in the westerly wind belt is wave-like in plan and forms a sinuous course about the earth. The position of these planetary waves has a great effect on surface temperatures because surface air masses interact with them and move in response to the associated flows. For example, if a strong ridge is located in Northwestern Canada and a deep trough downstream, "this flow pattern effectively deploys cold Arctic air masses southward over the continent" (Namias, 1953, p. 24). Similarly a southwesterly flow from a trough to a ridge advects warm air from a southerly source to the more northerly area of the ridge. Namias (1953, p. 25) summarizes the importance of the relationship between planetary waves and surface weather by stating: "It appears that, especially for time periods longer than a few days, the temperature of an area depends greatly upon the characteristics of the planetary wave pattern about one-half wave length upstream."

In the average or "normal" upper air flow, planetary troughs and ridges generally occupy the same longitudinal positions from month to month since many of these waves are produced by fixed earth features such as coastlines (Sutcliffe, 1951) or mountain barriers (O'Connor, 1963). However, the position of mean troughs and ridges do change from season to season and the actual waves assume atypical positions rather frequently during any particular time period. "The abnormal longitudinal positioning of planetary waves is one of the basic factors producing abnormal weather over large areas and long periods of time" (O'Connor, 1963, p. 1009). Even if the troughs and ridges are in their mean positions "an abnormally northerly latitude of the air flow in the ridges, or southerly flow in the troughs, will be associated with unusual and sometimes extreme weather conditions" (O'Connor, 1963, p. 1009). Thus, sharp inter- and intra-monthly variations in the mix of air masses normally affecting a region can result.

Discussion of Ice Conditions Over Hudson Bay and the Formation of "Hudson Bay" Air Masses

Partly because of the extreme environment and the obvious difficulties of empirical observation, very little information is available concerning ice conditions over Hudson Bay and the associated modification, if any, of the overlying air masses. It has been suggested (Harman, 1968) that a relationship may exist between the depth and extent of ice cover on Hudson Bay and the degree of air mass modification that results. Forward (1956) thought the amount of snow cover determined the ice thickness attained on the Bay. However, as of yet there has been a lack of information concerning these two variables. Nevertheless, several studies have been completed describing the yearly ice conditions on the Bay as well as the formation and movement, during spring, of the so-called "Hudson Bay" air masses.

Hudson Bay is a large water body covering approximately 300,000 square miles in Northeastern Canada (Lamont, 1949). Because of the shallowness of the Bay and the relatively low salinity and vertical stability of its waters, combined with its high latitude, large areas of pack ice develop over the surface of the Bay (Forward, 1956). Ice cover approaches 100 percent by late January and the ice normally does not begin to break up until late May (Forward, 1956). By late June the ice is broken into small and medium sized floes but not until about July 10 are large areas of open water observed. In some years large quantities of pack ice may persist until late August.

Snow cover in the interior of Canada has usually melted by early May (Harman, 1968) while Hudson Bay is largely covered by ice through June. Thus, this large ice covered surface may act as an important heat sink during the spring season. This has lead some meteorologists to consider Hudson Bay as a likely location for the formation of cold anticyclones during spring (Klein, 1957; Johnson, 1948). Cold air masses that appear to develop in association with, or be modified by, Hudson Bay during the spring season, therefore, have been referred to as Hudson Bay air masses.

Bowie and Weightman (1917) were among the first meteorologists to recognize the occurrence of Hudson Bay air masses in spring. They noted that these air masses occurred less frequently than other types of anticyclones but most frequently in May. They were described as very slow moving anticyclones that usually resulted in a change to much colder weather.

Namias (1953) stated that warm periods in the spring were usually terminated by Hudson Bay highs, defined as slow moving anticyclones from the Hudson Bay area. He also noted that periods of warm weather during this time of year were seldom broken by air masses moving in from the west.

Klein (1957), in a study of the major tracks of anticyclones in North America, noted that the land-water temperature contrast is very pronounced during May and that these thermal differences are mainly responsible for an increase in the anticyclonic frequency over Hudson Bay, James Bay, and the Great Lakes during this period of the year. Because of these thermal contrasts a higher frequency of anticyclones is observed in central Canada than in the western part of the country in the spring.

Johnson (1948) specifically studied anticlyclogenesis in eastern Canada during spring and noted that the Hudson Bay area becomes a favored site for the development of anticyclones partly because of the stabilizing effect of the very cold surface temperatures of this region. He observed that, "During periods in which blocking is effective over North America the resulting decrease in zonal flow favors the development of cold low level anticyclones in the area where radiational cooling is greatest. In the spring months this is the region of Hudson Bay" (Johnson, 1948, p. 54).

In a study of negative temperature departures from normal at Urbana, Illinois, Harman (1968) noted that a large percentage of departure days in May and June appeared to be associated with air masses that passed near Hudson Bay before invading the Illinois area. Additionally, it was found that the percentage of departure days caused by these air masses increased "with an increase in the magnitude of the departure" (Harman, 1968, p. 12). He also noted the need for further research on the problem of the role of Hudson Bay on the modification and development of these so-called Hudson Bay air masses.

In summary, it appears that during spring Hudson Bay may serve as a source area of cold air and be a favored site for anticyclonic development. However, it also seems apparent that troposheric windflow patterns may play an important role in determining whether or not this cold air is advected southward into the Midwest.

INVESTIGATIVE HYPOTHESES

Two main hypotheses will be investigated in this paper. First, a high percentage of the large negative temperature departures from normal recorded at Lansing, Michigan, during spring should be the result of the invasion of cold air masses that passed over or near Hudson Bay before entering the mid-Michigan area. Second, a relationship should exist between mean monthly long wave positions and the frequency of cold air mass invasions from the Hudson Bay area. For example, if the mean monthly air flow is of a zonal nature, the frequency of Hudson Bay air mass penetrations in the Midwest should be relatively low. However, if the mean flow pattern was characterized by a strong mean ridge in central Canada and a deep trough in the Midwest, the frequency of cold air mass invasions from the Bay area should be relatively high.

DATA SOURCES

The observed mean daily temperature at Lansing for all days in the months of April, May, and June of 1972 and 1973 were obtained from Climatological Data-National Summary, while the Michigan Weather Service provided the normal mean temperatures for these dates. Data concerning the daily temperatures recorded throughout Canada at 850 millibars and the movement of cold air masses at this level were extracted from the National Meteorological Center daily facsimile maps. Information concerning mean monthly air flow patterns at the 700 mb. level was obtained from Monthly Weather Review.

PROCEDURES

Mean monthly 850 mb. isotherm maps of January, February, April, and May of 1972 and 1973 were constructed for Canada from temperature readings at twenty-seven stations throughout the country. This task was undertaken to determine whether Hudson Bay exerts a detectable cooling influence on the air temperatures at low altitudes in central and eastern Canada. These isotherm maps were then compared to the mean monthly 700 mb. air flow charts for the same periods to determine the possible influence of long wave positions on low altitude temperatures in Canada.

Next, the observed surface mean daily temperatures at Lansing for April, May, and June of 1972 and 1973 were obtained from Climatological Data and compared to the normal mean for all days in these months. All dates of negative temperature departures from normal of 10 degrees F. or more were recorded. Although there were 29 such days during the study period, many of these departures occurred on consecutive days. Hence, some consecutive departure days were grouped together and were considered to be the result of a single air mass invasion. (The validity of this procedure was checked during a subsequent portion of the study and was found to be acceptable.) In all, there were 16 days or groups of days that appeared to be the result of separate air mass invasions.

After the large departure days had been recorded, the 850 mb. facsimile maps were examined to determine the paths of the cold air masses which apparently caused these negative departures. Maps of the departure days as well as those of the several preceding days were examined and the center (or coldest part) of the cold air mass was plotted on a map. Only air masses actually affecting Michigan were plotted. For example, on several occasions a large cold air mass moved southeast or east across Hudson Bay while a lobe or tongue of this cold air moved out from the center of the air mass and pivoted around it to the south, apparently in relation to the mid-level flow. When this pattern occurred the center of the cold air lobe that passed over or near Michigan was plotted rather than the center of the large cold air mass itself. The points plotted on the map were then connected and the line that resulted was considered to represent the trajectory of the center of the cold air mass. These paths were then plotted on a single map for each spring month and compared with the mean monthly 700 mb. charts for the same period to determine whether a relationship existed between air mass movement and mean middle level air flow patterns.

RESULTS

The tracks of movement of the cold air masses that caused large negative temperature departures from normal at Lansing, Michigan, during the spring months of 1972 and 1973 (Figures 1 through 4) were generally north-south, with most of the cold air masses passing over or near Hudson Bay before entering the Midwest.[1] Almost all of these air masses originated directly over Hudson Bay or to the northwest of it and moved across Canada in a southerly or southeasterly direction toward the Great Lakes. After reaching this general area they appear to have curved northeastward toward New England or Newfoundland in response to middle and upper level windflow patterns.

The mean air flow of May, 1972 (Figure 5) was primarily zonal and only one outbreak of a cold air mass

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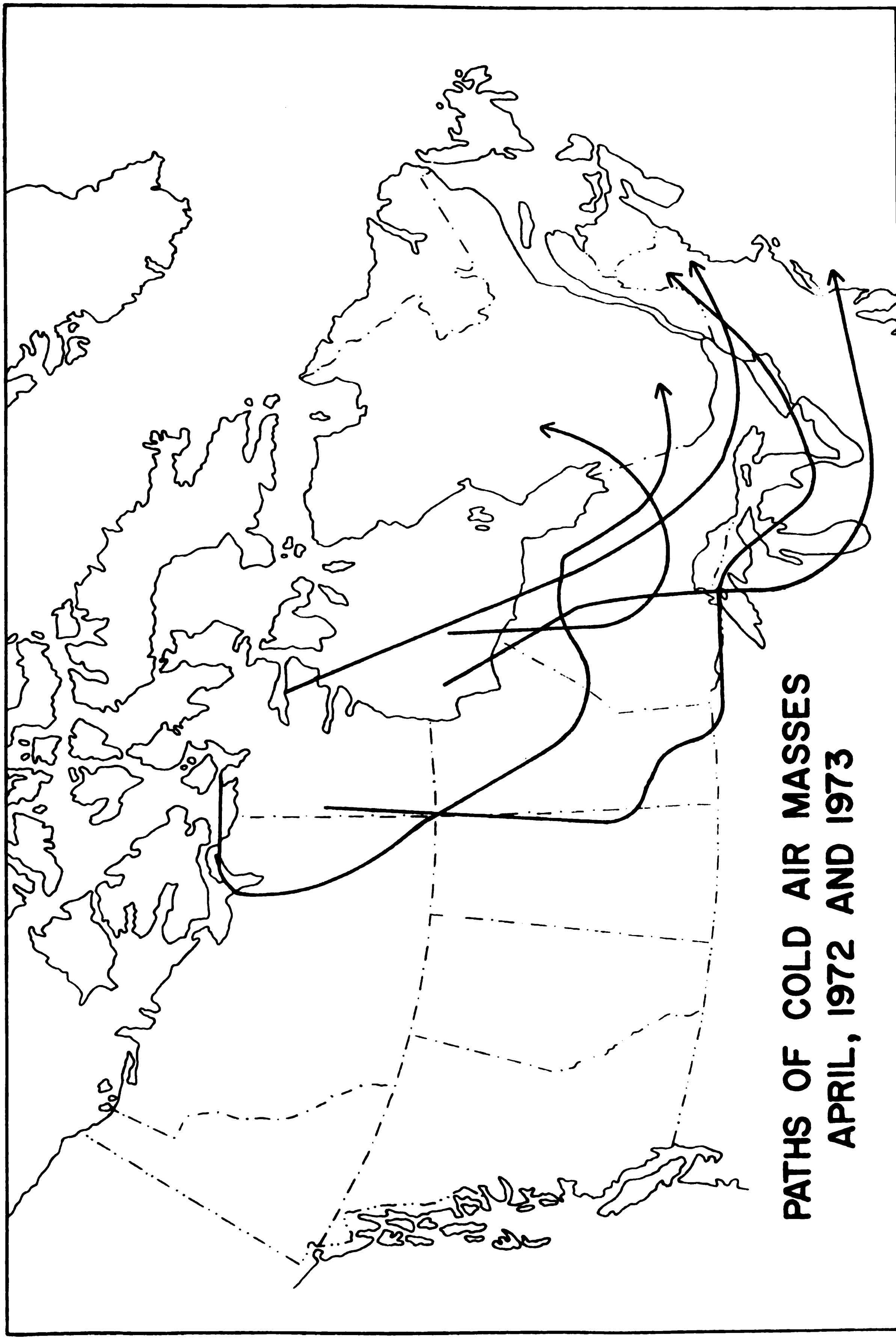
[1] One departure day in May and one in June were not included in the study because they were thought to be the result of precipitation rather than of qualities inherent in the air mass.



PATHS OF COLD AIR MASSES
APRIL, 1972 AND 1973

Figure I

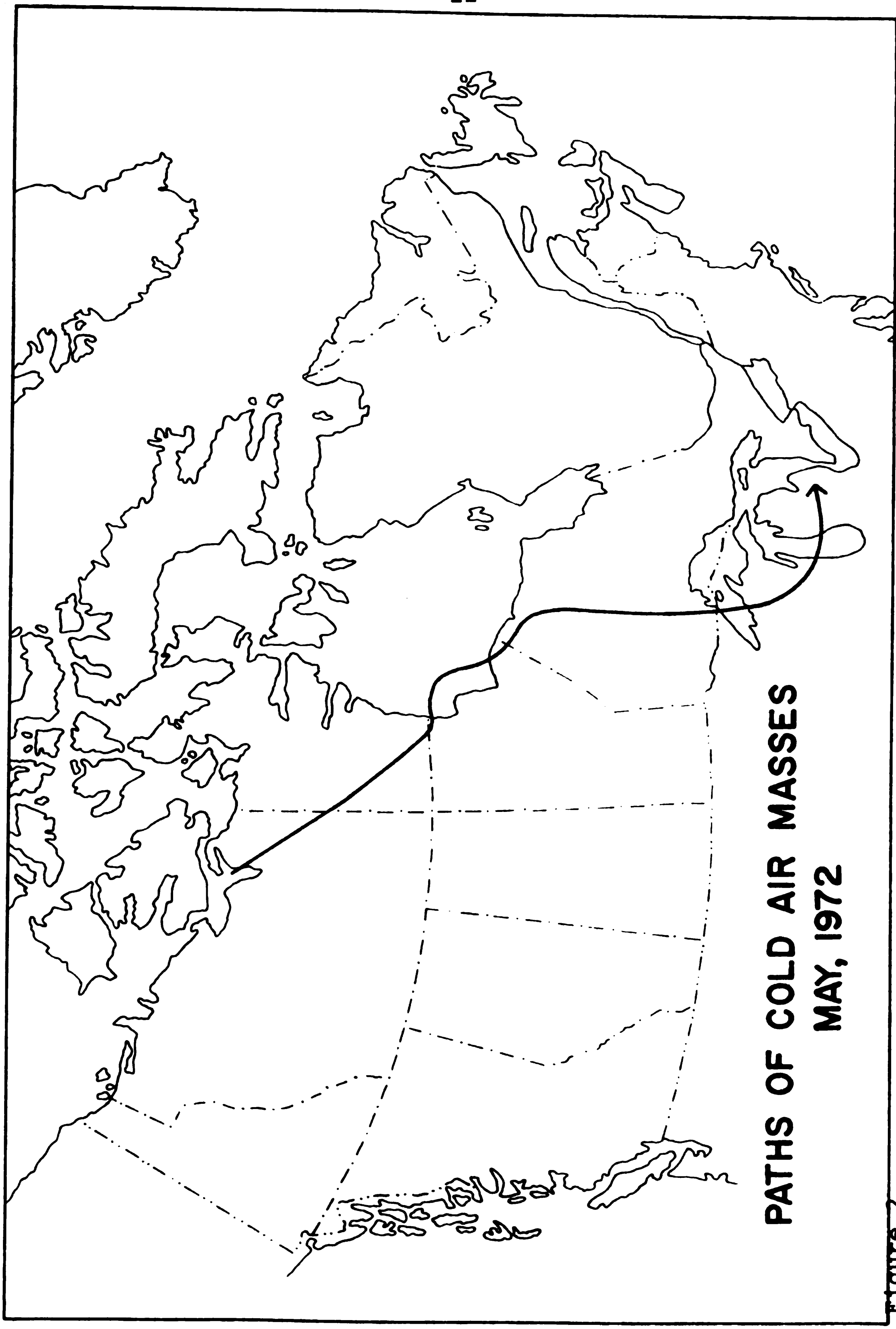
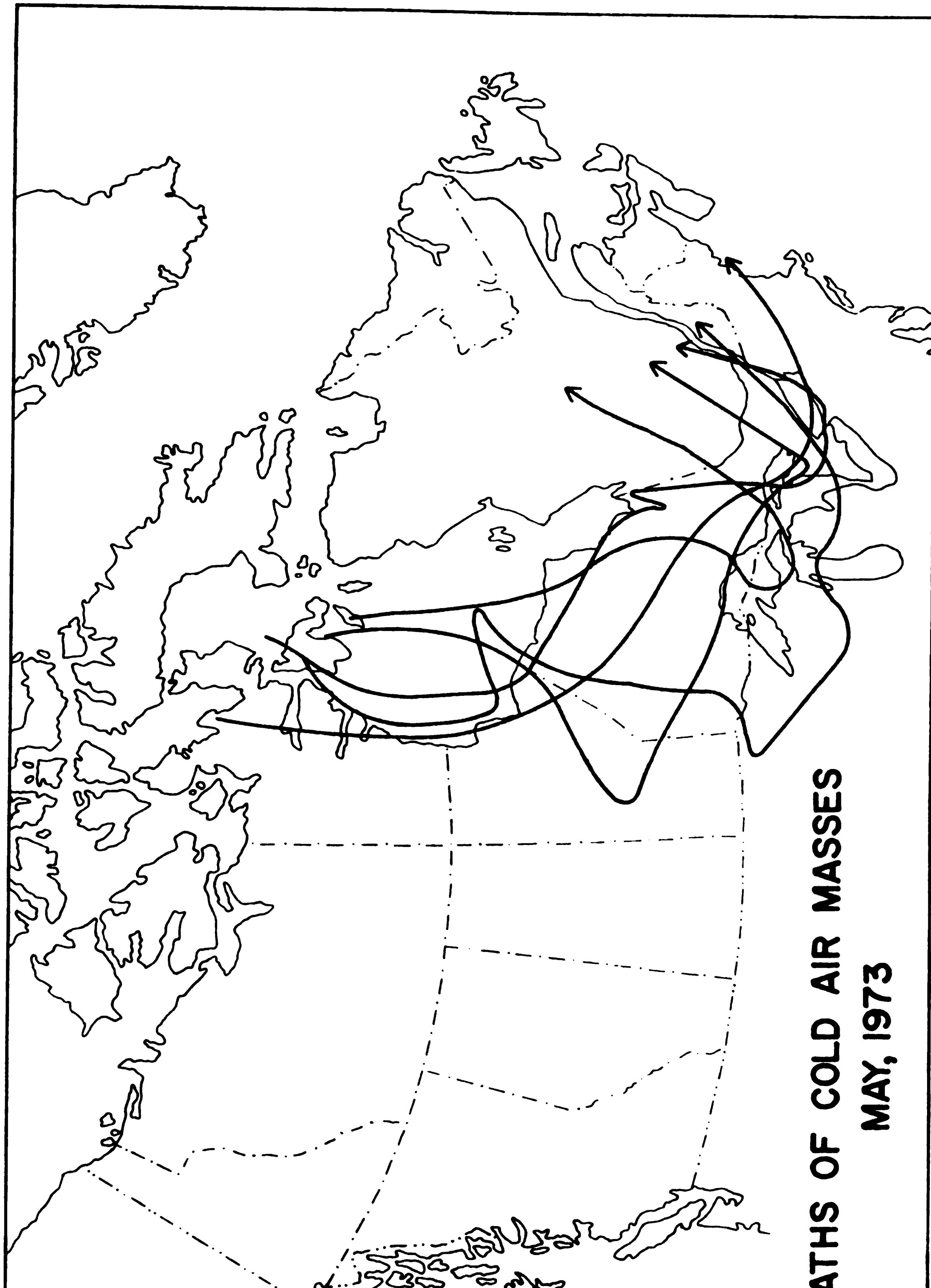


Figure 2



PATHS OF COLD AIR MASSES
MAY, 1973

Figure 3

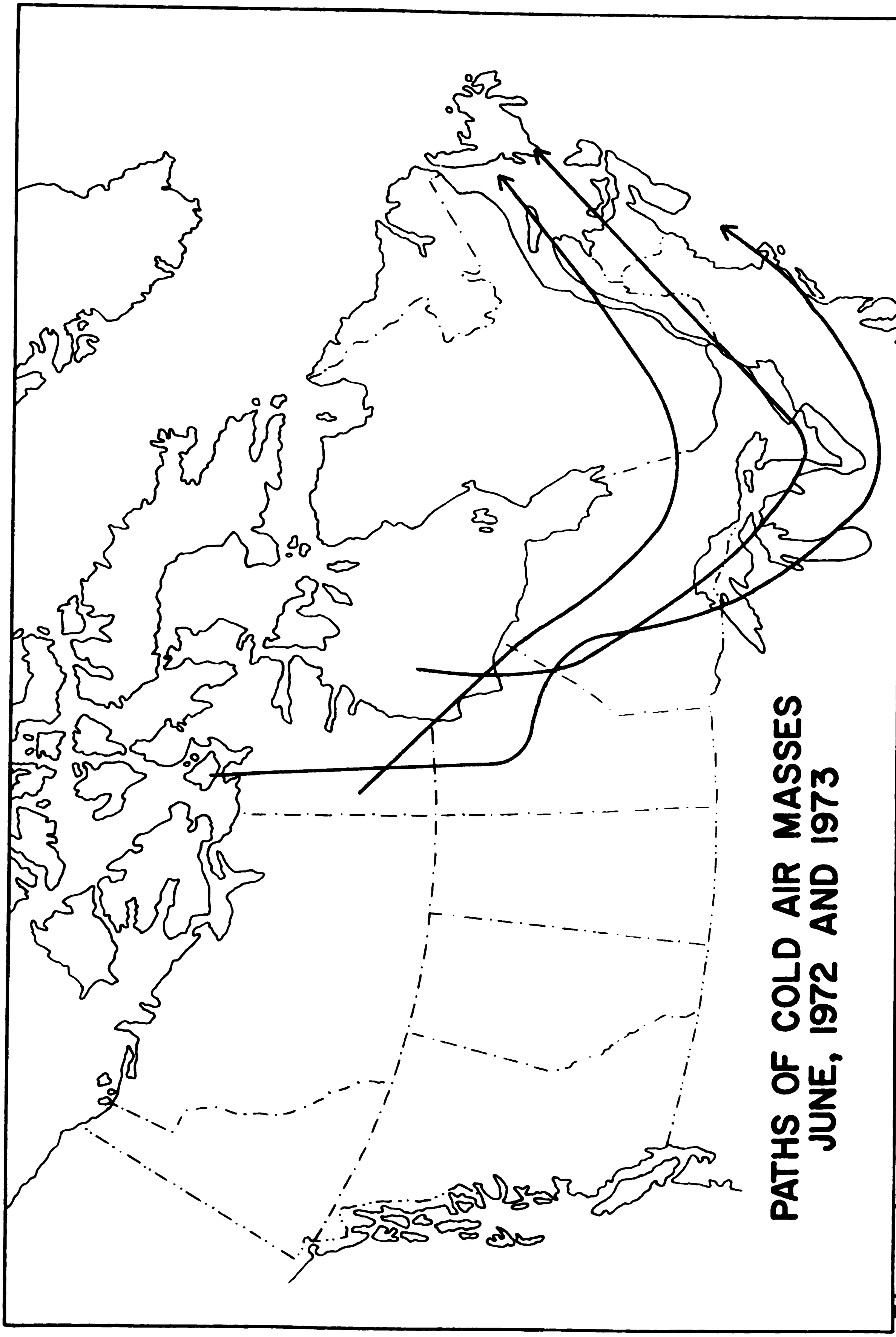


Figure 4

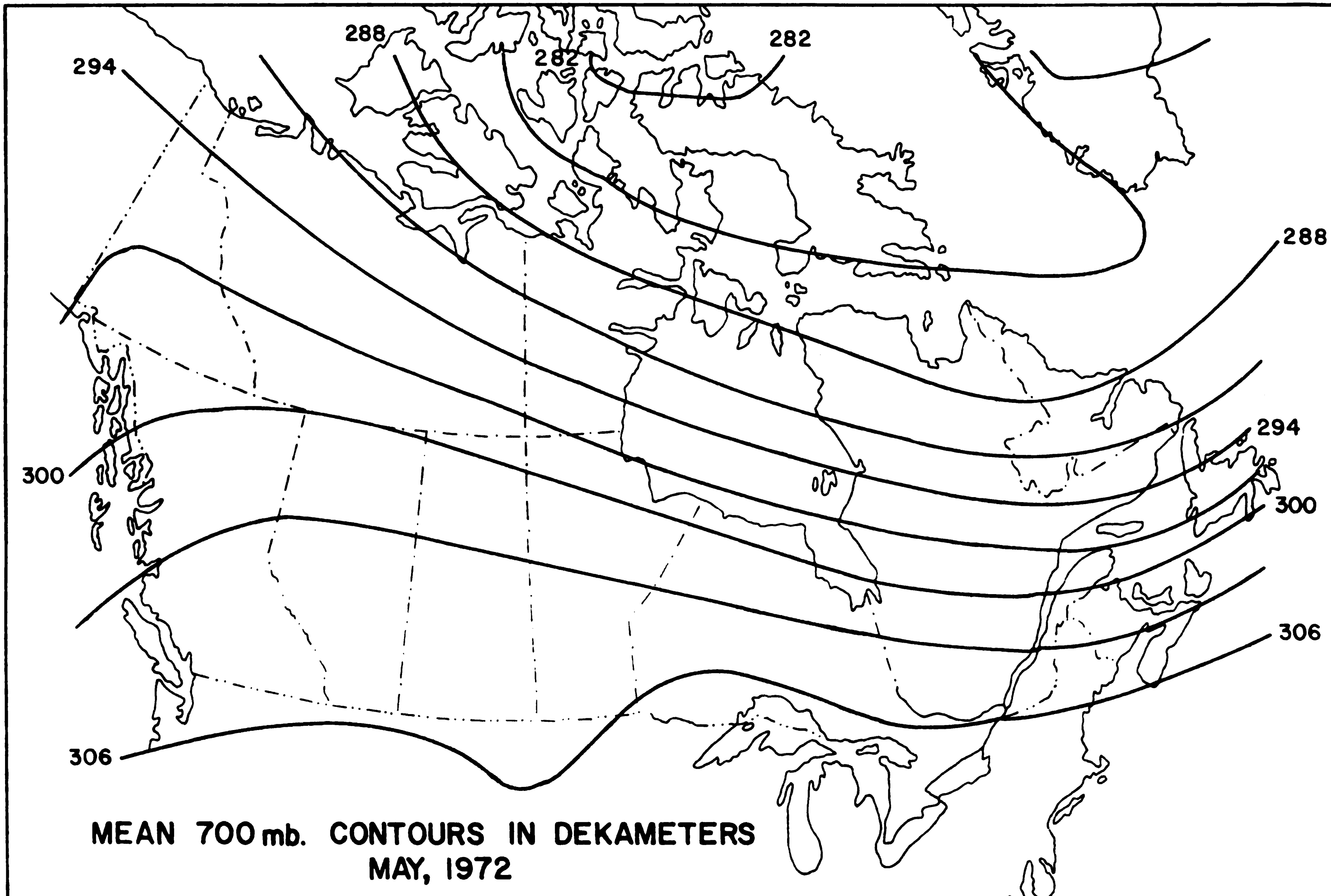


Figure 5 (Source: <u>Monthly Weather Review</u>, August, 1972).

from the Hudson Bay area occurred. However, May, 1973, exhibited a markedly different mean longwave pattern (Figure 6). A mean ridge was located immediately west of Hudson Bay in northern Canada while a deep trough was centered over the Midwest. This pattern evidently led to the repeated deployment of cold air from north central Canada, across Hudson Bay, and into the Midwest. Five such cold air masses can be recognized. Hence, it would appear that longwave positions are of great importance in determining whether cold air from north central Canada and the Hudson Bay area will move into the Midwest.

In May, 1972, when the mid-level air flow was primarily zonal (Figure 5), the Michigan area experienced average monthly temperatures of about 3 degrees F. above normal (Figure 7). Parts of northern Minnesota averaged as high as 9 degrees F. above the monthly mean. Apparently during much of this month mild air from the Pacific was advected across the Midwest by the predominantly zonal wind flow. May of 1973, on the other hand, was colder than normal in most of the Midwest (Figure 8). Mean monthly temperatures were at least 3 degrees F. below normal in Michigan and Wisconsin. During much of this month when a northern Canadian ridge and a Midwestern trough were characteristics of the mean flow pattern, cold Arctic air was advected from northern Canada across Hudson Bay and into the Midwest. These different patterns strongly suggest that the number of Hudson Bay air masses reaching

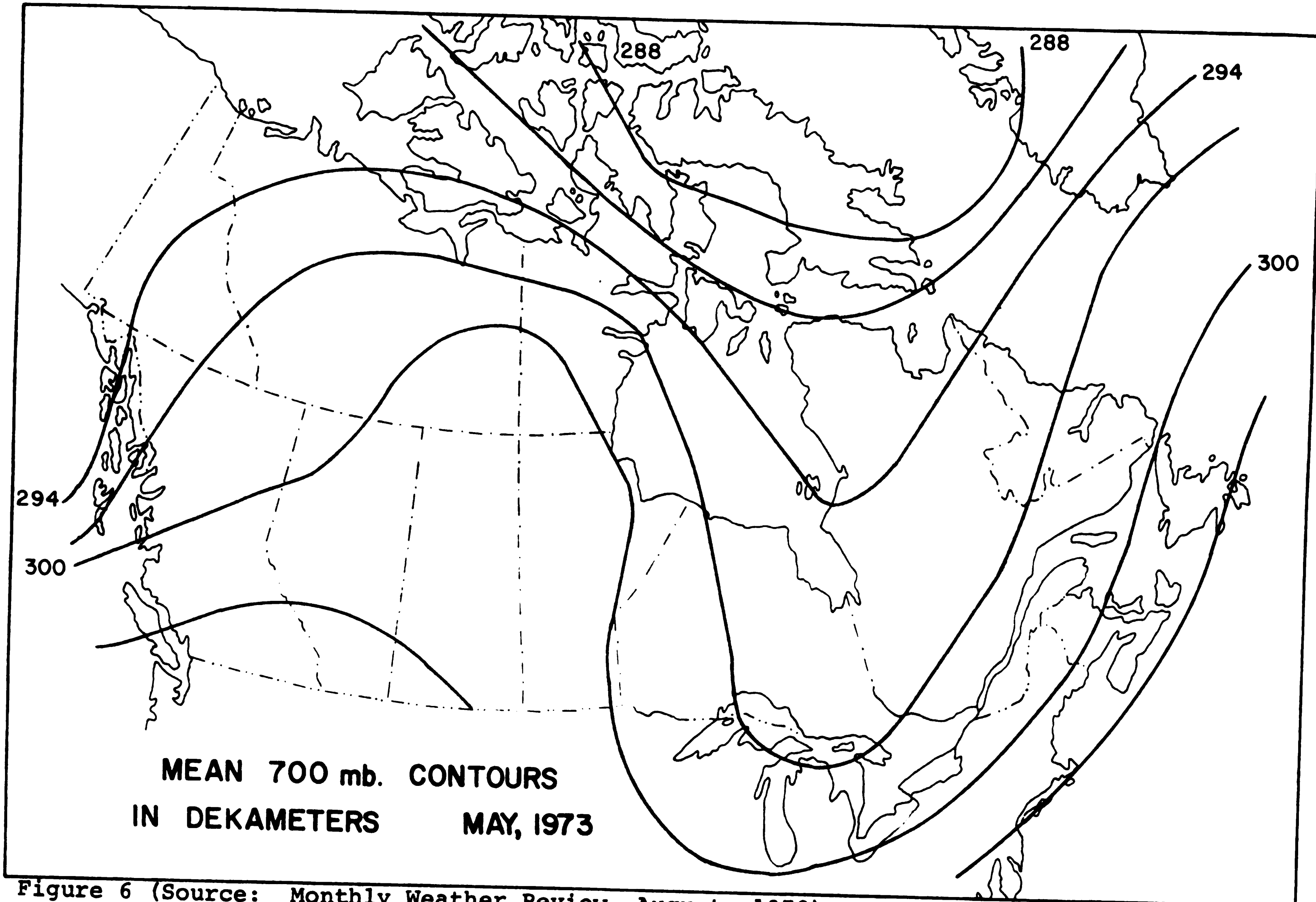


Figure 6 (Source: Monthly Weather Review, August, 1973).

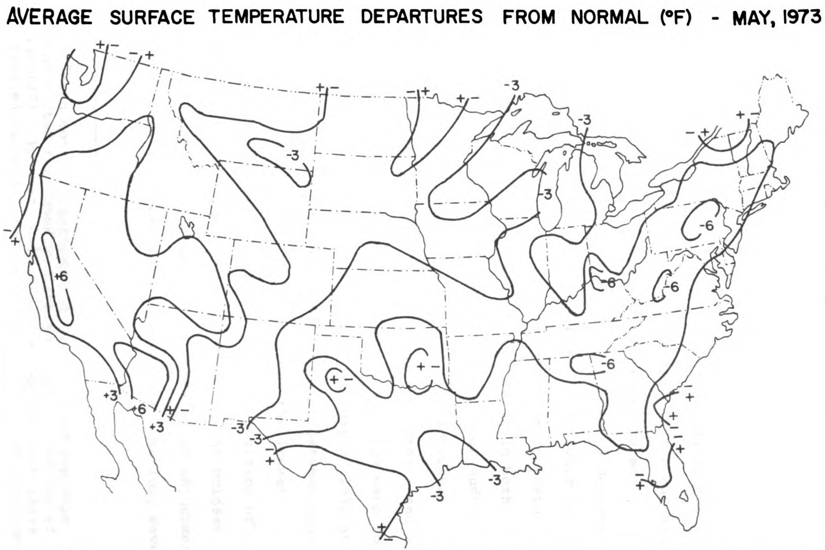


Figure 8 (Source: Monthly Weather Review, August, 1973).

the Midwest is a response primarily to variations of mean longwave positions.

Effects of Hudson Bay on Low Level Temperatures in Canada

The mean monthly isotherm maps of Canada at the 850 mb. level would appear to indicate that Hudson Bay has little effect on low level atmospheric temperatures (Figures 9 and 10).[2] Although Figure 9 reveals a depression of temperature in the area around Hudson Bay, Figure 10 shows that the coldest 850 mb. temperatures in southern Canada are found well to the east of the Bay. In both figures the lowest mean temperatures are north of Hudson Bay, suggesting a relationship with the mean longwave position as evident on the 700 mb. charts (Figures 5 and 6). Mean monthly 850 mb. isotherm and 700 mb. air flow maps for the months of January, February, April, and May of 1972 and 1973 all exhibit a close spatial relationship between mean pressure height and temperature, such that the lowest temperatures in southern Canada lay near the position of the planetary trough. Hence, the location of the coldest air at the 850 mb. level appears to be less of an adjustment to surface conditions than to the position of the long wave trough.

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[2]Mean monthly isotherm and 700 mb. windflow maps were constructed for January, February, April, and May of 1972 and 1973. However, only those of May for both years are presented since all the maps exhibit the same relationship.

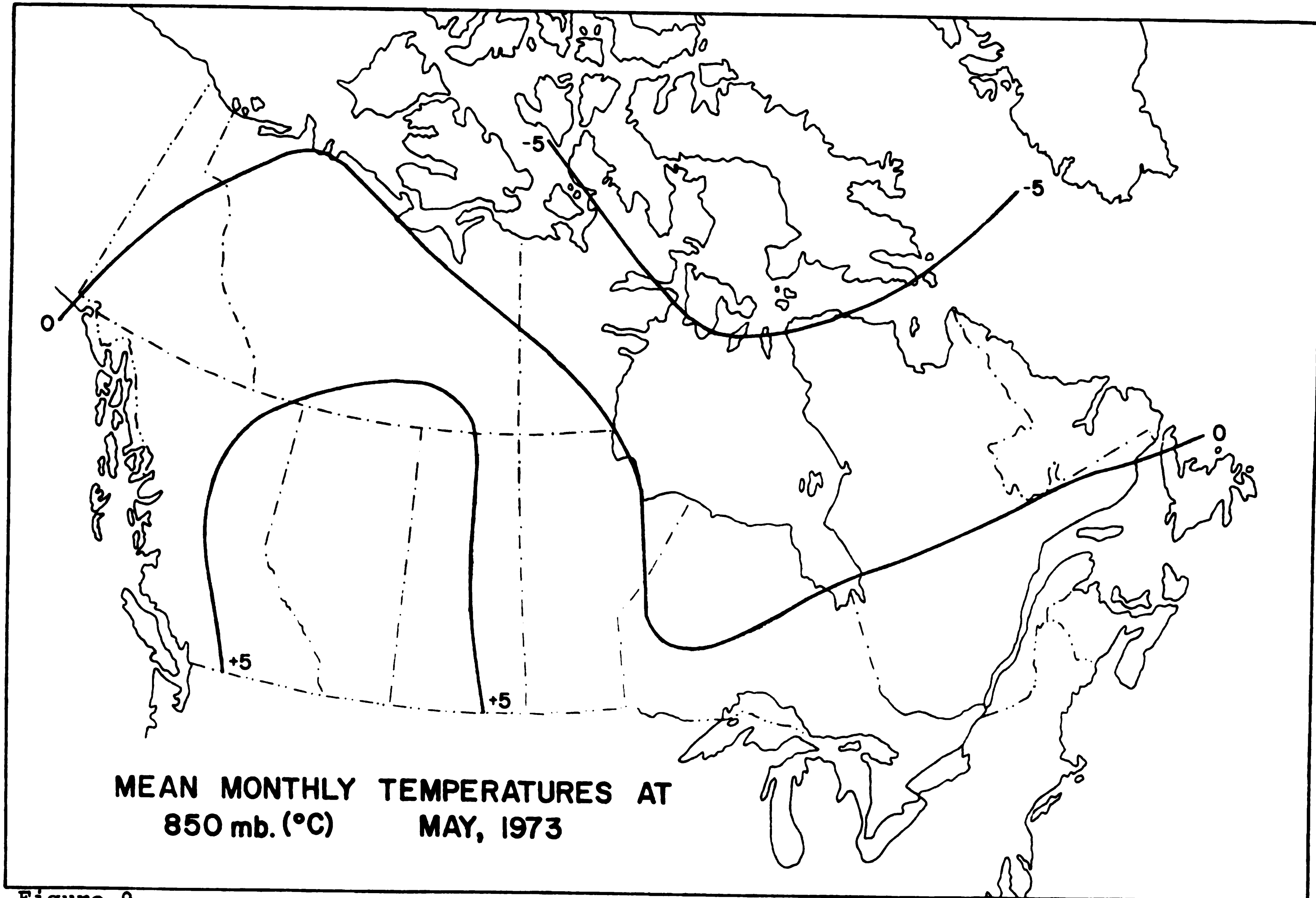
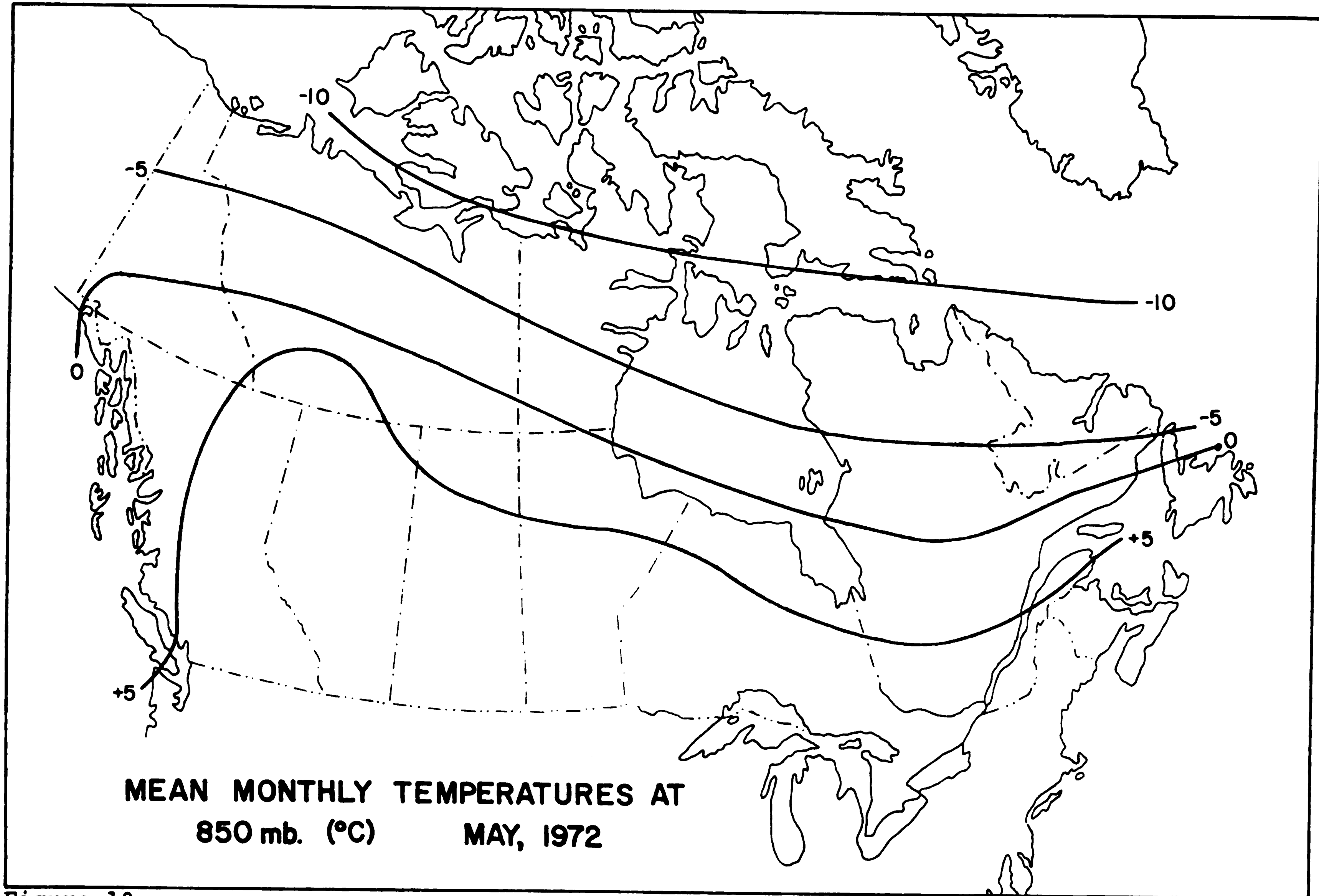


Figure 9



MEAN MONTHLY TEMPERATURES AT
850 mb. (°C) MAY, 1972

Figure 10

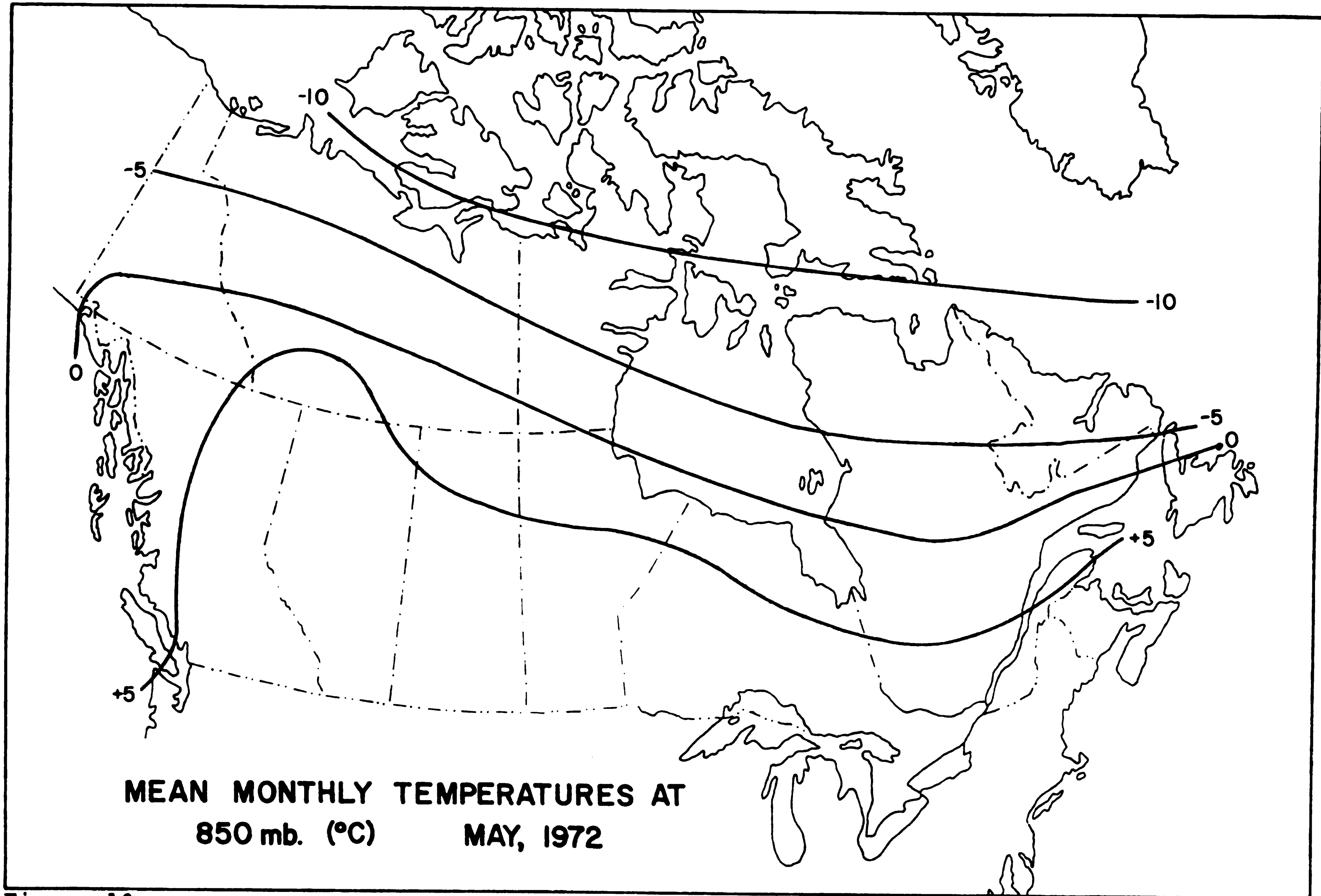


Figure 10

CONCLUSIONS

Most large negative temperature departures from normal observed at Lansing, Michigan, during spring, 1972 and 1973, were the result of cold air masses that previously passed over or near Hudson Bay. Furthermore, it appears that in order for these outbreaks of cold air to occur, upper and middle level wind flow patterns must be favorable. More specifically, conditions are conducive for the advection of cold air into the Midwest if a planetary ridge in north central Canada and a deep trough in the Midwest are present. Such flow also favors the development of anti-cyclones in the Hudson Bay area since it lies in the region of the planetary wave where negative vorticity advection and subsidence are occurring. These cold air masses are then "steered" into the Midwest by the circulation aloft.

Although 850 mb. isotherm maps of Canada failed to show a cooling influence of Hudson Bay on the lower atmosphere during spring, such an influence may exist at lower levels of the atmosphere or at the surface. An examination of surface temperatures during spring might prove more useful than readings taken at 850 mb., which may be too high to be affected by the radiation budget of the Bay.

The effect of Hudson Bay on air masses lying directly over it appears to be an area that needs further study. Since air to the north of the Bay (at 850 mb.) is actually colder than the air overlying Hudson Bay, and is usually advected across its surface during outbreaks of cold air masses to the Midwest, Hudson Bay probably does not act to chill the air to lower temperatures, but may prevent this air from warming as it moves south. Hence, air masses passing to the west of Hudson Bay might modify faster and therefore be warmer when they reach the Midwest than air that passes over Hudson Bay. However, further research on this topic is needed.

Suggestions

Since examination of temperatures at 850 mb. did not reveal obvious relationships to the Bay, construction of surface isotherm maps of Canada for the spring months might reveal whether Hudson Bay does exert a cooling influence on the surrounding area. Furthermore, a study concerning the degree of modification of air masses over Hudson Bay during spring as compared to the modification of air masses from western Canada may prove helpful in understanding the role of Hudson Bay as a climatological agent.

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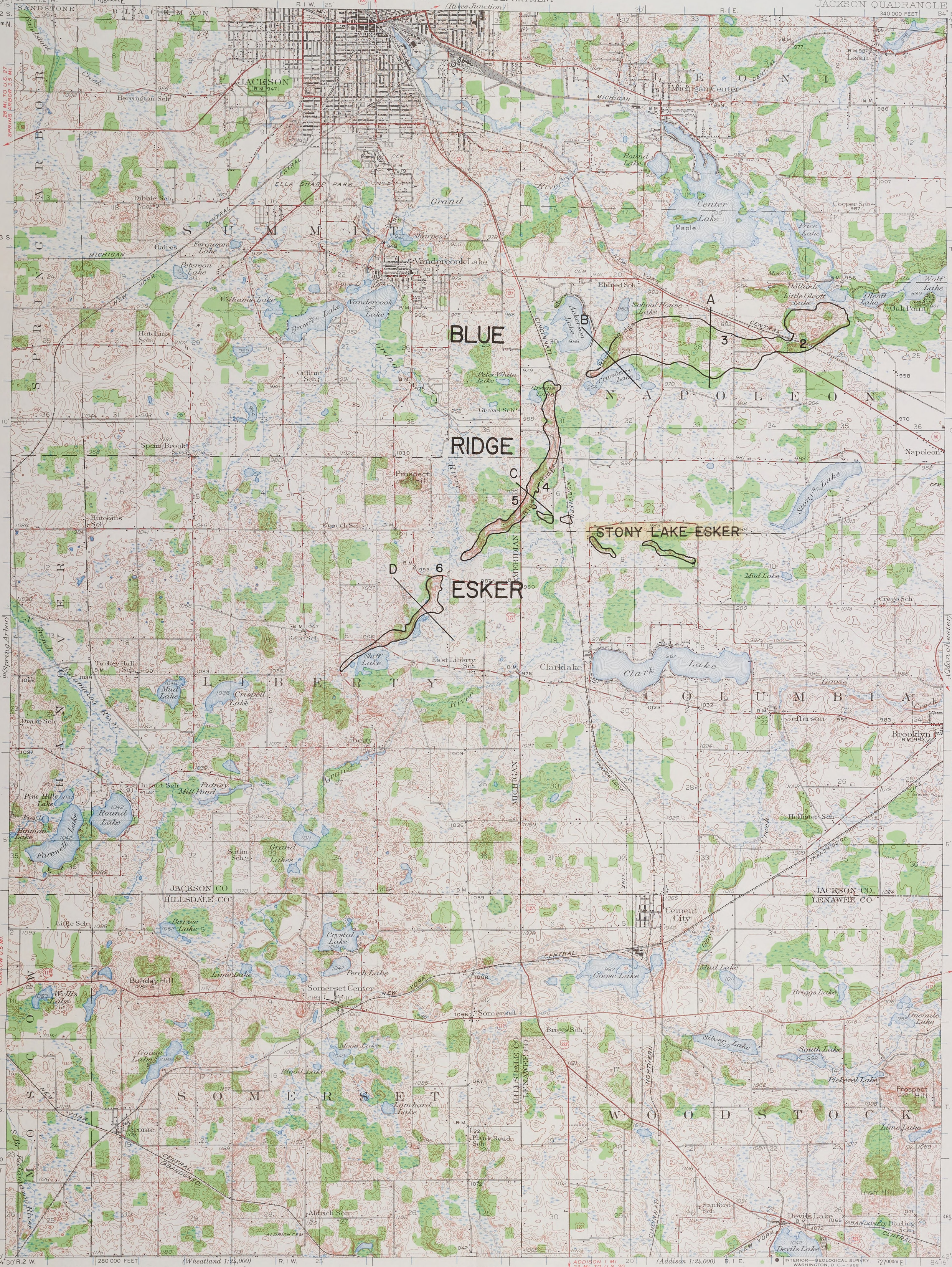
608
THS
plate I

PLATE I

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF MICHIGAN
REPRESENTED BY THE
STATE HIGHWAY DEPARTMENT

MICHIGAN
JACKSON QUADRANGLE



Topography by W.S.Gehres, F.L.Whaley, Kostka Mudd, A.W.Plushnick, E.J.Fennell, R.K.Kenerson, H.J.Owen, M.M.Stambaugh, LeGrand Smith, and R.Courtney
Surveyed in 1930 and 1935

ROAD CLASSIFICATION

Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
U. S. Route — State Route

APPROXIMATE MEAN DECLINATION, 1935

SCALE 1:62500

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

FOR SALE BY U. S. GEOLOGICAL SURVEY, WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1968

Polyconic projection. 1927 North American datum
10,000-foot grid based on Michigan (East) rectangular coordinate system
1000-meter Universal Transverse Mercator grid ticks, zone 16, shown in blue

JACKSON, MICH.
N4200-W8415/15

1935

PLATE II

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MICHIGAN
STATE HIGHWAY DEPARTMENT
CHARLES M. ZIEGLER
STATE HIGHWAY COMMISSIONER

MANCHESTER QUADRANGLE
MICHIGAN
15 MINUTE SERIES (TOPOGRAPHIC)

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Culture and drainage in part compiled from aerial photographs taken 1938 and 1940
Topography by plane-table methods 1947-1948

Polyconic projection. 1927 North American datum
10,000-foot grid based on Michigan coordinate system, east zone
1000-meter Universal Transverse Mercator grid ticks, zone 16, shown in blue

UTM GRID AND 1948 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:62500

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, WASHINGTON, D. C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1972

ROAD CLASSIFICATION

HARD-SURFACE ALL WEATHER ROADS	DRY WEATHER ROADS
Heavy-duty — 4 LANE 6 LANE	Improved dirt
Medium-duty — 4 LANE 6 LANE	Unimproved dirt

Loose-surface, graded, or narrow hard-surface

U. S. Route — State Route

MANCHESTER, MICH.
N4200—W8400/15

1948

AMS 4168 II—SERIES V762

Pocket has:
2 Plates

PLATE I

113
6?8
THS
Plate I