VARIATIONS IN THE BOUNDARIES OF THE CHARLOTTE MORAINE IN INGHAM COUNTY, MICHIGAN, AS MAPPED BY F. LEVERETT AND H. MARTIN

AN ANALYSIS OF THE MAY PRECIPITATION GRADIENT IN SOUTHERN LOWER MICHIGAN

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SUPPLEMENTARY
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ABSTRACT

VARIATIONS IN THE BOUNDARIES OF THE CHARLOTTE MORAINE IN INGHAM COUNTY, MICHIGAN, AS MAPPED BY F. LEVERETT AND H. MARTIN

by

David Paul Lusch

The boundaries of the Charlotte Moraine in Ingham County are shown differently on four maps compiled by F. Leverett dated 1911, 1915, 1921, and 1924 as well as on three maps compiled by H. Martin, two of which are dated 1954 and 1955 and a third undated manuscript. The relationships between these delineations and topography, surficial sediments, drift thickness, and the bedrock surface configuration were examined in this study. The conclusions are that (1) both Leverett and Martin reinterpreted the extent of the Charlotte Moraine in Ingham County several times; (2) Leverett's 1921 large-scale map appears to be the most appropriate of the seven maps studied; (3) of the three maps by Martin studied, her 1954 map appears to be the most suitable; (4) the boundaries shown on Leverett's 1924 map and on Martin's 1954 map may have been generalized from Leverett's 1921 map; (5) both Leverett and Martin recognized the segmented nature of the Charlotte Moraine in Ingham County, but this is shown only on Leverett's 1921 large-scale map and on Martin's 1954 map; (7) it is suggested that the change in morphology of the Charlotte Moraine in Ingham County was a major contributing factor to the variations in the moraine borders shown on the maps of both F. Leverett and H. Martin.

VARIATIONS IN THE BOUNDARIES OF THE CHARLOTTE MORAINE IN INGHAM COUNTY, MICHIGAN, AS MAPPED BY F. LEVERETT AND H. MARTIN

By

David Paul Lusch

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To Claudia, my loving wife

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INTRODUCTION

The Charlotte Moraine has been recognized and mapped over an extensive area of the Lower Peninsula of Michigan (Leverett and Taylor, 1915; Martin, 1955). On the basis of topographic expression, Leverett concluded that the Charlotte Moraine is one of the most prominent in the southern part of the state (Leverett and Taylor, 1915, p. 30). But according to Leverett and Taylor (1915, p. 205), the borders of this moraine in Ingham County "...are very irregular both on the north and the south."

Frank Leverett compiled several maps of the surface formations of the Lower Peninsula of Michigan, four of which are dated 1911, 1915, 1921, and 1924. In addition to an undated blue-line print, Helen Martin constructed maps, published in 1954 and 1955, which show the glacial landforms in Ingham County. It is interesting to note that each of these seven maps delineates the Charlotte Moraine in south-central Michigan somewhat differently.

STATEMENT OF PROBLEM

The purpose of this study is to determine the nature and magnitude of the variations in the maps of the Charlotte Moraine in Ingham County by F. Leverett dated 1911, 1915, 1921, and 1924 and those of H. Martin dated 1954 and 1955 and including an undated manuscript map. The relationships between these various boundary placements and surface altitude, local relief, surficial sediments, drift thickness, and bedrock topography will also be evaluated and discussed.

JUSTIFICATION

Both Leverett and Martin reinterpreted the extent of the Charlotte Moraine in Ingham County several times. Most interpretations of the glacial geomorphology of an area are based, at least in part, on the mapping of the surface formations. It seems appropriate, therefore, to assess the importance of the variations between the seven maps compiled by Leverett and Martin. Such study may also lead to an understanding of the basis for their interpretations of this glaciated landscape and promote an increased awareness of the problems associated with mapping a landform unit such as a moraine.

REVIEW OF PUBLISHED LITERATURE

In a report on the surface geology and agricultural conditions of the Southern Peninsula of Michigan, Leverett (1912) recognized the Charlotte Moraine in southern Livingston, Ingham, and Eaton Counties and in northeastern Barry County. He interpreted it as representing the third major stillstand of the receding margin of the Saginaw lobe. He concluded that the meltwater drainage at this time was westward, parallel to the ice terminus, into Battle Creek, and thence southwestward into the Kalamazoo River. A map[1] showing the extent, character,

[1] This map, published at a scale of 1:1,000,000 and compiled by Leverett, is dated 1911 although it was distributed with this 1912 report.

and agricultural value of a variety of glacial landforms in the Lower Peninsula of the state was included in this publication.

Later in U.S. Geological Survey Monograph 53, Leverett and Taylor (1915, p. 30) noted that the Wisconsinan moraines in Illinois, Indiana, and Michigan were, "...concentrated in groups. Several moraines, closely crowded together, adjoin a few that are more widely spaced, and these in turn are succeeded by another closely crowded group...." They associated the Charlotte Moraine with the group in which "... all the bulky moraines of the southern half of the Southern Peninsula of Michigan are included" (Leverett and Taylor, 1915, p. 30). The large number of eskers which extend toward the proximal side of the moraine, as well as the character of the outwash and the pro-glacial drainage, indicated to them that the ice associated with parts of the feature was nearly stagnant (Leverett and Taylor, 1915, p. 204).

In their monograph Leverett and Taylor (1915, p. 205) describe the Charlotte Moraine in Ingham County as a single belt of morainic topography with very irregular proximal and distal borders. The texture of the drift associated with this feature is exceedingly variable: the low relief areas often consist of mounds of sand and gravel with a till covering, and the areas of higher relief are largely composed of ice-contact, glaciofluvial material (Leverett and Taylor, 1915, p. 206). The distribution of a variety of glacial landforms in the Lower Peninsula of Michigan is shown on a map included in this publication that was compiled by Leverett and Taylor (1915, Plate VII) and published at a scale of 1:1,000,000.

Another map compiled by Leverett, published in 1924 at a larger scale, shows the agricultural suitability of the surface formations of the Lower Peninsula of Michigan.

Helen Martin (1955) edited a map of the surface formations of the Southern Peninsula of Michigan which shows the Charlotte Moraine. In a report on Ingham County, Martin (1958, p. 1) associated this feature with "Halt II" of the retreating glacier front and explains that this was the second of four ice-margin stillstands in the area. She agrees with Leverett and Taylor that the ice at this time was probably stagnant and states that the bedrock at or near the surface by Mason and Williamston indicates that this ice contained only small amounts of drift (Martin, 1958, p. 2). A small-scale map of the glacial landforms of the county, compiled by Martin and dated 1954, was included in this publication.

BEDROCK SURFACE, DRIFT THICKNESS, SURFICIAL SEDIMENTS, AND TOPOGRAPHY OF SOUTHERN INGHAM COUNTY

Bedrock Surface

Except for a small area of northeastern Stockbridge and southeastern White Oak Townships, all of Ingham County is underlain by the Pennsylvanian Saginaw Formation, according to Vanlier, Wood, and Burnett (1973, p. 42). This formation, which is composed chiefly of sandstone and shale with small amounts of coal and limestone, is more than 400 feet thick in parts of the county and, according to L. David Johnson,[1] is underlain by the Bayport and Michigan Formations of late

[1]Contributor to Stratigraphic Succession in Michigan, Michigan Department of Conservation, Geological Survey, Chart 1, 1964.

Mississippian age.

The bedrock surface underlying the county is very irregular. This undoubtedly resulted, at least in part, from preglacial erosion and was probably made more complex as a result of the effects of multiple glaciations. It has been stated that a complex erosion surface was etched on the bedrock when "...damming of many of the streams by advancing glaciers caused reversals in the direction of flow of some" (Vanlier, Wood, and Brunett, 1973, p. 32). The general characteristics of this surface are shown in Figure 1. According to Vanlier, Wood, and Brunett (1973, p. 32),

> Most of the main preglacial streams flowed in a generally northwesterly direction, and many tributaries were at right angles to the main flow direction. The resulting somewhat rectangular pattern of the drainage system suggests that stream valleys formed in weakened zones along faults and joint systems in bedrock.

Although regionally the altitude of the bedrock surface within Ingham County tends to increase to the south (Vanlier, Wood, and Brunett, 1973, Plate 2), bedrock altitudes in the study area are higher in the western four townships. The highest surface, above 950 feet, exists near the common corner of Aurelius, Vevay, and Leslie Townships. The lowest bedrock altitudes, below 825 feet, are located in northwest Aurelius, northeast Ingham, and south-central Stockbridge Townships, as well as in the southeastern half of Leslie Township.

Drift Thickness

Within most of the study area, the drift varies from a few feet to more than 100 feet in thickness, but there is a tendency for the drift to thicken toward the east (Figure 2). In Aurelius and Vevay

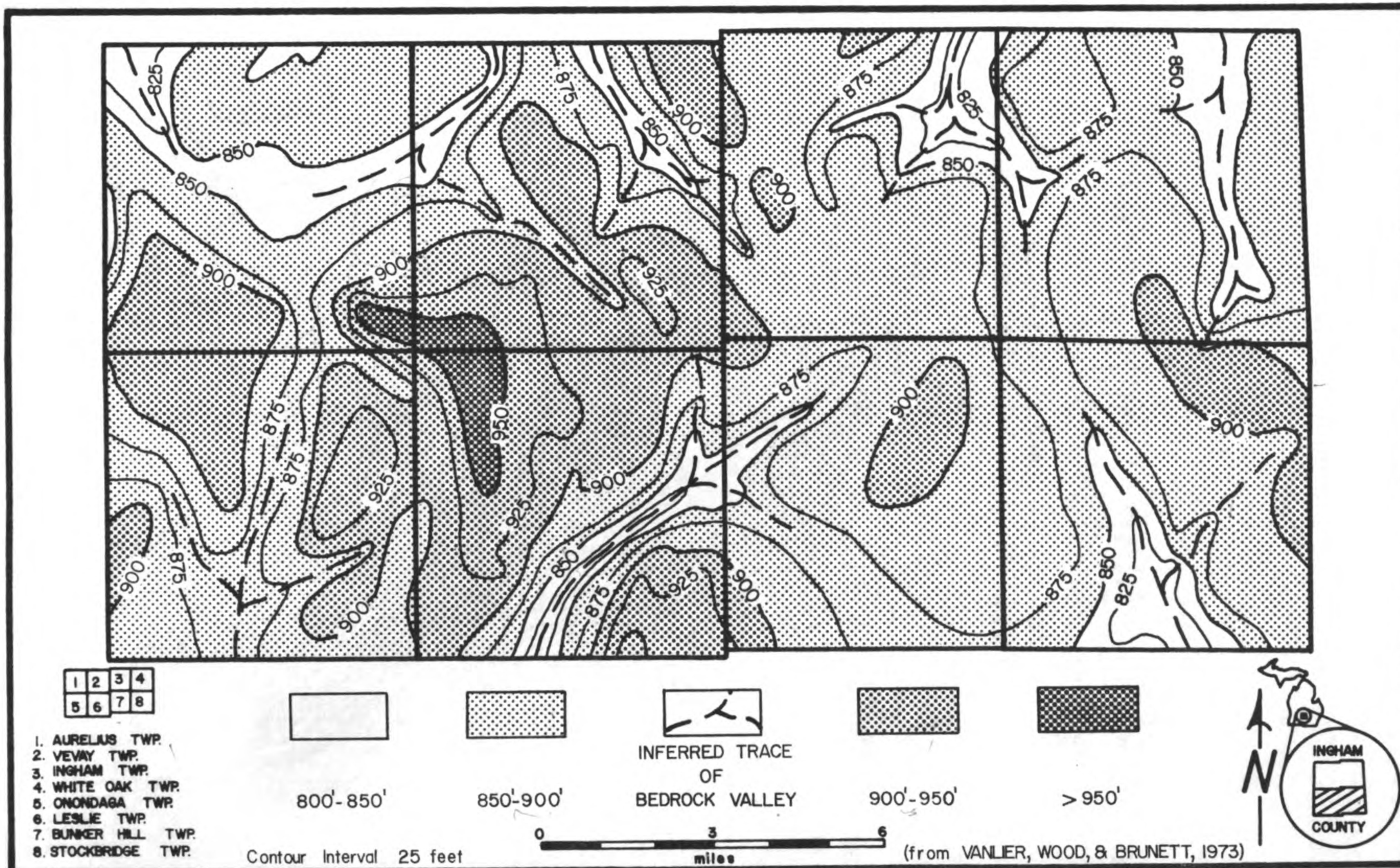

Figure 1. Bedrock surface, southern Ingham County

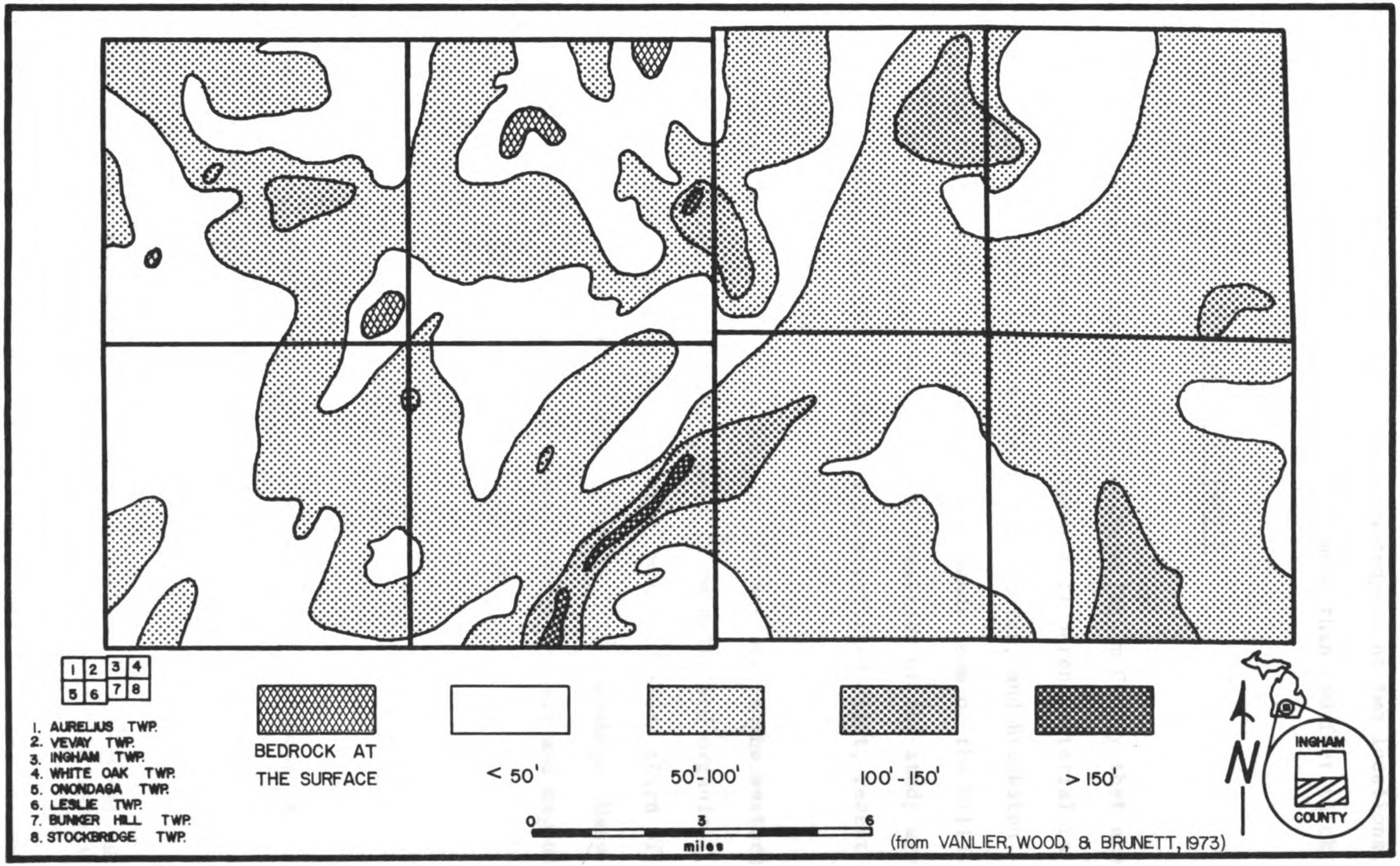

Figure 2. Drift thickness, southern Ingham County

Townships there are at least two bedrock outcrops. At two locations, in Vevay and Leslie Townships, the drift is more than 150 feet thick.

Surficial Sediments

The distribution of the soils in southern Ingham County that are most probably derived from a clayey or sandy till parent material is shown in Figure 3. These include the Miami, Conover, and Brookston loams of the Miami catena[1] and the Hillsdale sandy loam of the Hillsdale catena (Veatch, et al, 1941). In the remainder of the study area, the soils are thought to be associated with stratified drift, recent alluvium, or organic material.

In general, till is most extensive at the surface in the western half of the study area. To the east, stratified drift and organic material become more abundant, particularly in the southern third of Ingham Township and the northern half of Bunker Hill Township. Many of the organic deposits in the study area are somewhat linear and may be associated with glacial drainageways (Figure 4).

Topography

The surface altitudes of southern Ingham County are shown in Figure 5, which is based on U.S. Geological Survey topographic

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[1]The 1941 Soil Survey of Ingham County included in the Miami catena only the Miami, Conover, and Brookston loams. A newer soil-classification system (Schneider, Johnson, and Whiteside, 1967) includes the Celina loam in the Miami catena.

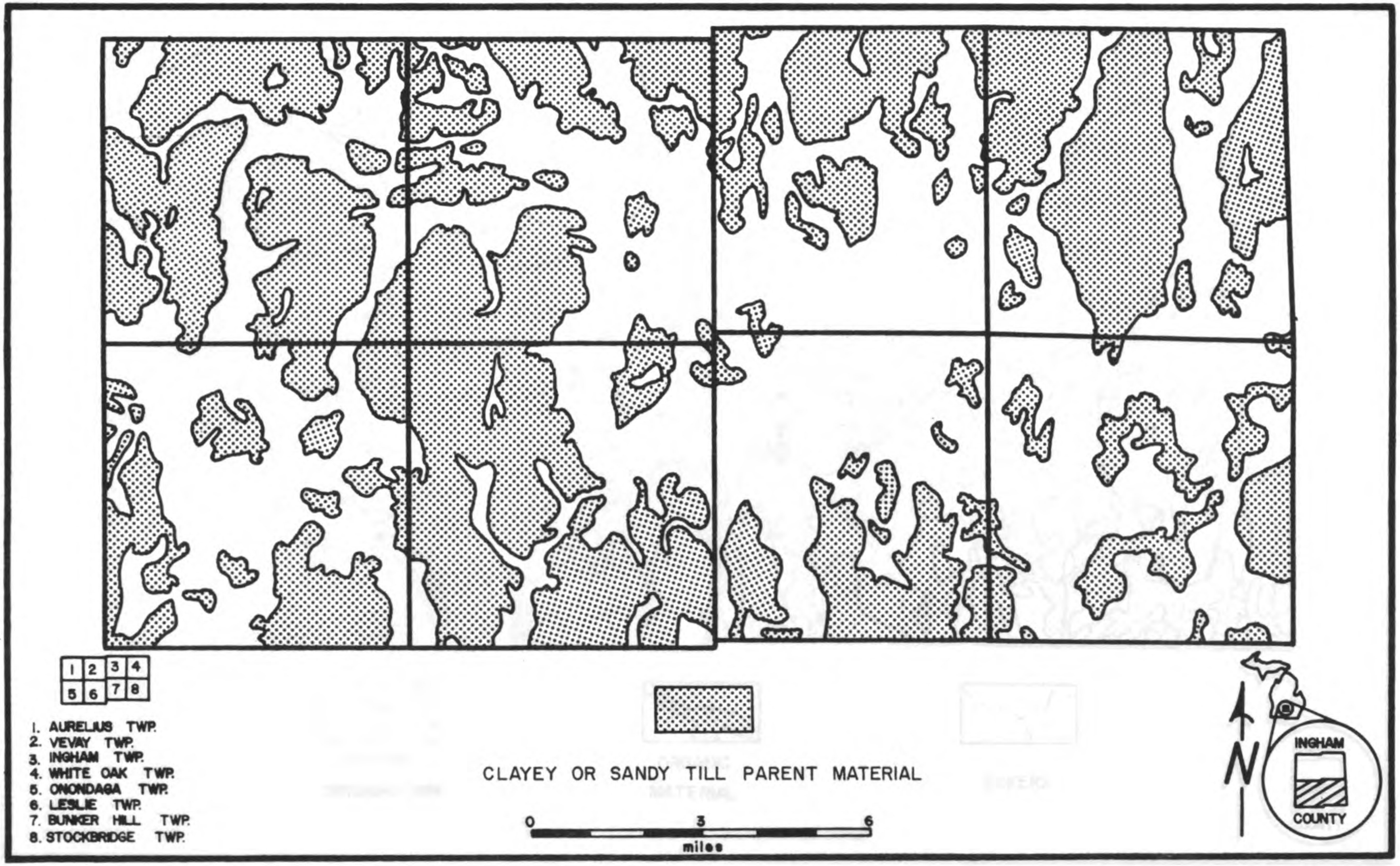

Figure 3. Clayey or sandy till parent material, southern Ingham County

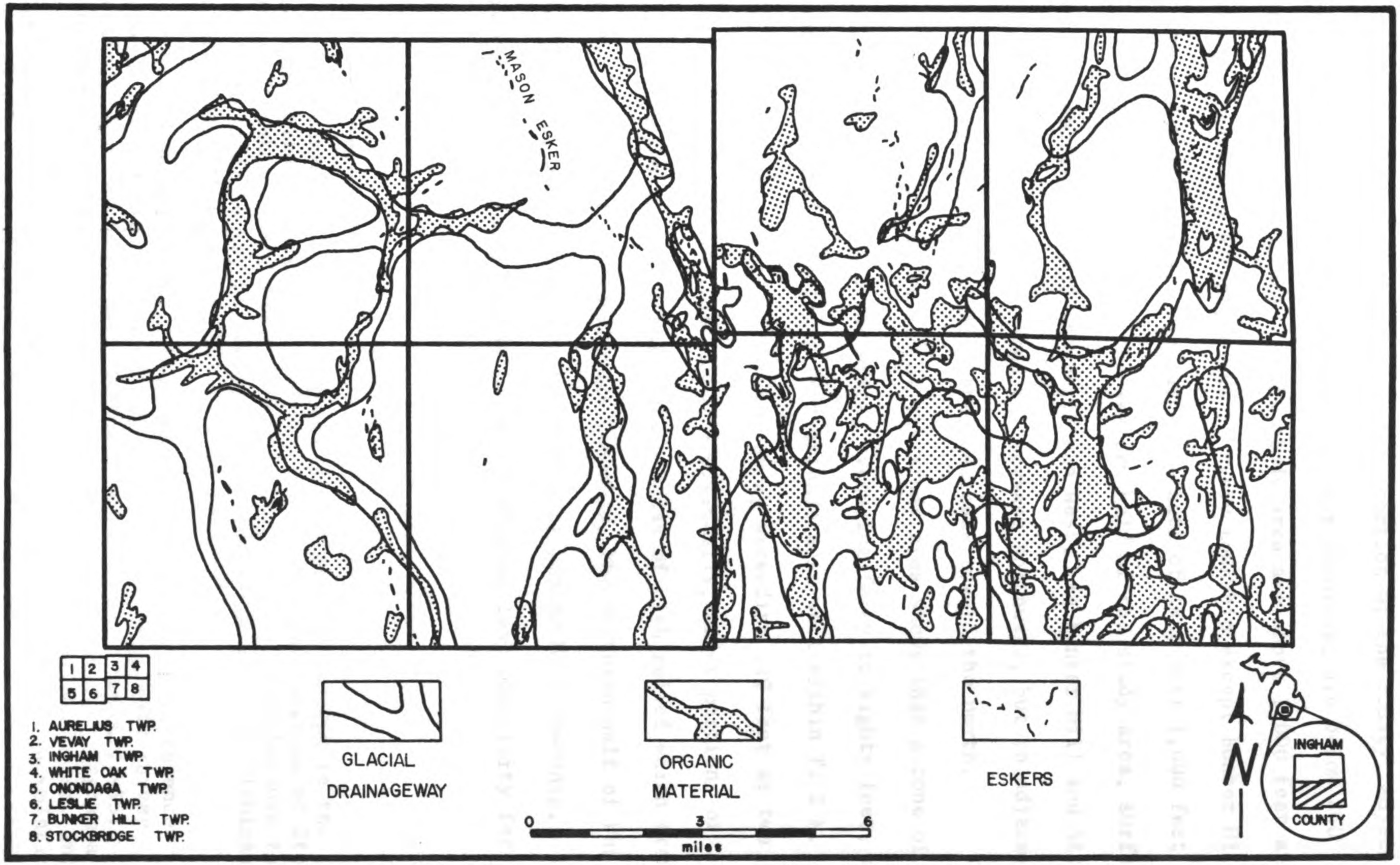

Figure 4. Glacial drainageways, organic material, and eskers, southern Ingham County

quadrangles.[1] The lowest areas in this portion of the county, adjacent to the Grand River in northwestern Aurelius Township, are below 850 feet. The highest surfaces in the study area are above 1,000 feet and, although limited in extent, exist in every township except Bunker Hill and White Oak Townships. The largest tracts of land over 1,000 feet are in Leslie Township. In the western half of the study area, surface altitudes decrease toward the north and west. In Bunker Hill and Stockbridge Townships altitudes tend to increase northward, but in adjacent Ingham and White Oak Townships they decrease toward the north.

A relief map (Figure 6)[2] of the study area shows that a zone of considerable topographic variation, averaging forty to eighty feet, is generally confined to a tract that extends east-west within T. 2 N. The largest local relief within the area, exceeding 120 feet at two places, also exists in this tier. Additionally, major portions of Onondaga and Leslie Townships contain areas of high relief which trend north-south. Most of Stockbridge Township, the northern half of White Oak Township, and the eastern two-thirds of Bunker Hill Township, however, have surfaces of low relief, averaging less than forty feet.

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[1]The contour interval on this map is fifty feet except in the southern third of White Oak Township and the northern portion of Stockbridge Township, where the 960 foot contour line is shown because the U.S. Geological Survey has mapped these areas (Fowlerville, Michigan quadrangle) with a twenty-foot contour interval.

[2]Relative relief was determined by the arithmetic difference between the highest and lowest contour line values in each survey section. Similar techniques have been used by G.-H. Smith (1935), E.H. Hammond (1964), and B. Zakrzewska-Borowiecki (1974). Ingham and Bunker Hill Townships contain less than thirty-six square miles, and the altitudes in each partial survey section were used in calculating the relief of the adjoining section to the east.

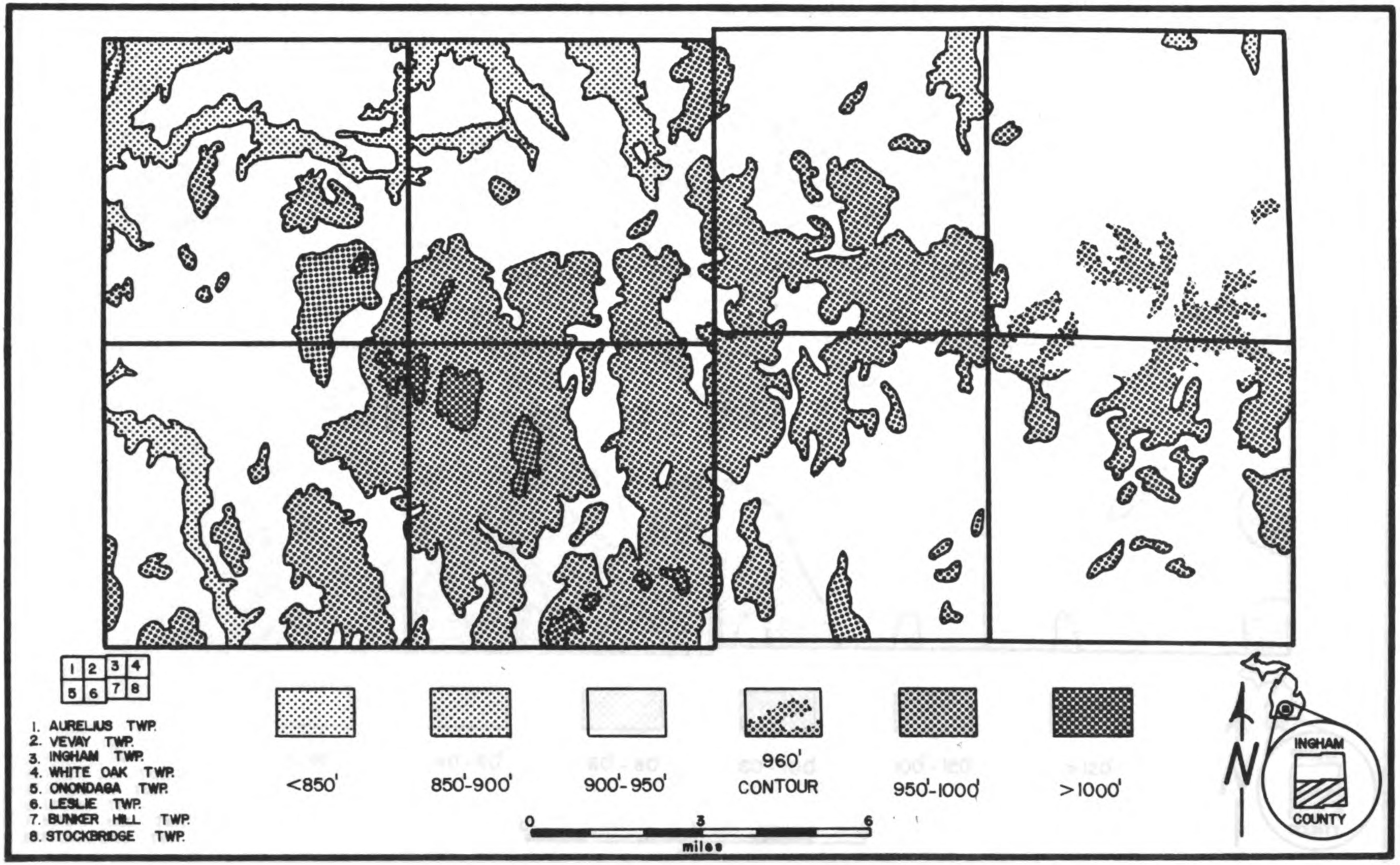

Figure 5. Surface altitude, southern Ingham County

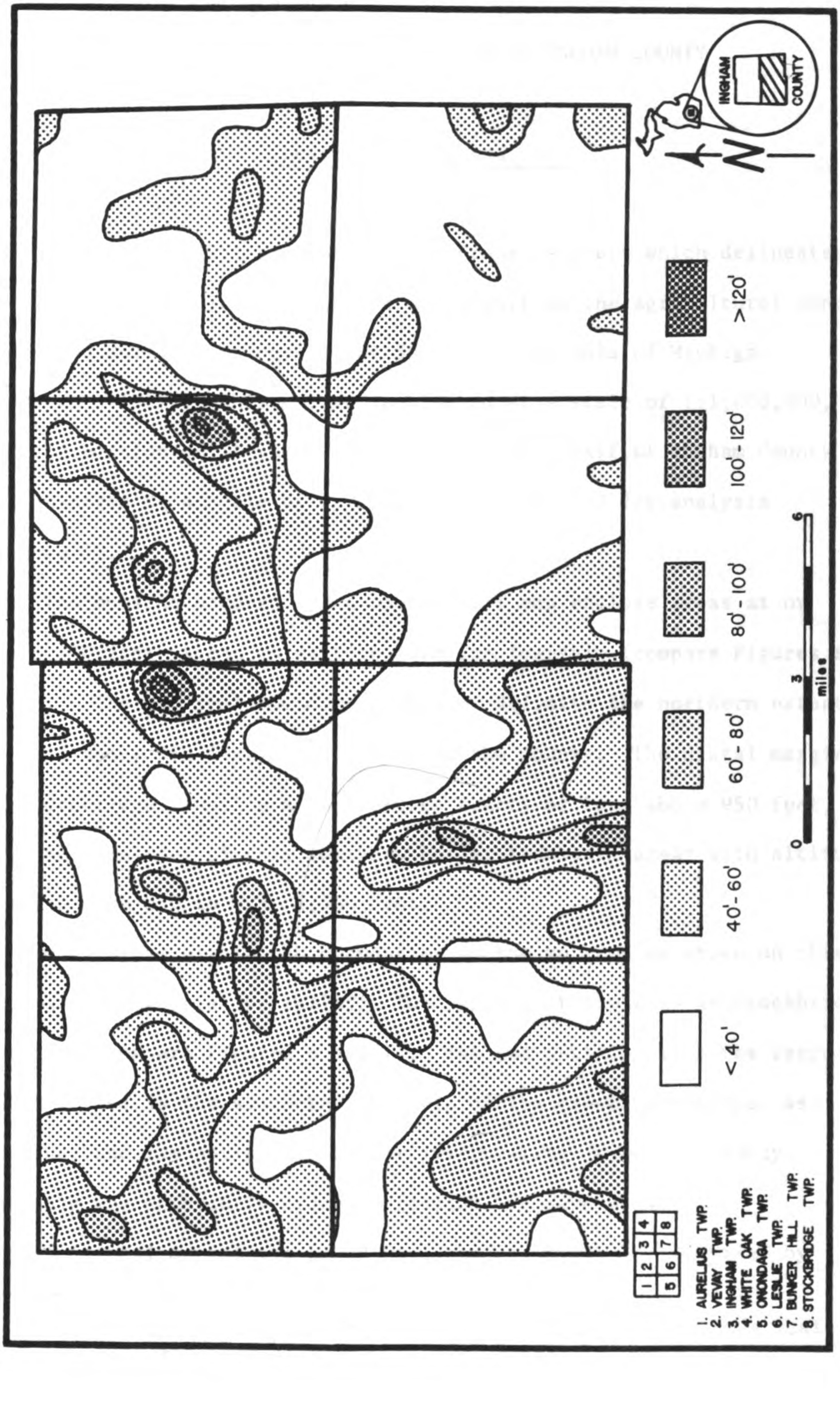

Figure 6. Relative relief, southern Ingham County

MAPS OF THE CHARLOTTE MORAINE IN INGHAM COUNTY

Leverett, 1911 and 1915

A map dated 1911 and compiled by Frank Leverett which delineates the Charlotte Moraine accompanied his report on the agricultural conditions and surface geology of the Southern Peninsula of Michigan (Leverett, 1912). This map was published at a scale of 1:1,000,000, and the portion of it which shows the southern half of Ingham County was enlarged to a scale of approximately 1:167,000 for analysis (Figure 7).[1]

The moraine borders shown on the 1911 map enclose areas at or above 900 feet except in western Aurelius Township (compare Figures 5 and 7). The proximal boundary generally delimits the northern extent of land above 950 feet in this part of the county. The distal margin in Stockbridge Township also encloses tracts of land above 950 feet, but the remainder of this southern border transects areas with altitudes ranging from 950 to over 1,000 feet.

Many areas within the boundaries of the moraine as shown on this map have a low relative relief. The largest of these is in Stockbridge Township (compare Figures 6 and 7). The two sections with the largest local relief in the southern two tiers of the county are mapped as moraine, and the noticeable border irregularity in eastern Vevay Township was apparently drawn to include one such area.

A glacial map of the Lower Peninsula of Michigan, compiled by

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[1]To facilitate comparison, all maps are drawn at the same scale and show only the Charlotte Moraine boundaries.

Leverett and published at a scale of 1:1,000,000, is included as Plate VII in a monograph he co-authored with Frank B. Taylor (Leverett and Taylor, 1915). The part of this map which depicts the Charlotte Moraine in Ingham County has been enlarged to a scale of approximately 1:167,000 and is shown as Figure 8.

According to this map by Leverett, in Vevay and White Oak Townships the proximal border of the feature is somewhat coincident with the 950 or 960 foot contour line (compare Figures 5 and 8). In Aurelius Township this northern boundary encloses small areas with altitudes between 950 and 1,000 feet. In the remainder of the area, the altitude of the proximal and most of the distal border varies.

The relative relief of the areas shown as moraine on this 1915 map is extremely variable (compare Figures 6 and 8). This is particularly evident in Vevay Township, where tracts of subdued terrain are mapped as moraine to the exclusion of an area of very rugged topography, whereas in Ingham Township the proximal border protrudes northward to include an area of high relief. Major portions of the feature within White Oak, Stockbridge, and Bunker Hill Townships have small variations in altitude, but in the western four townships the borders generally enclose tracts of moderate to high relief.

The surficial drift within the western moraine boundaries shown on both the 1911 and 1915 maps is largely till, but to the east stratified drift and organic material are more abundant (compare Figures 3, 7, and 8). The segmented western half of the feature shown on these maps contains several linear organic deposits which may represent glacial drainageways (compare Figures 4, 7, and 8).

The bedrock surface is relatively high and overlain by comparatively thin drift within the western moraine borders shown on Leverett's 1911 and 1915 maps (compare Figures 1, 2, 7, and 8). The feature shown in Aurelius Township on the 1911 map includes two locations where bedrock is exposed at the surface. The remainder of the moraine shown on these maps is underlain by drift which tends to thicken toward the east in conjunction with a general decrease in the altitude of the bedrock surface.

Leverett, 1921 and 1924

Several 1921 U.S. Geological Survey 15-minute topographic quadrangles, on file at the Michigan Geological Survey,[1] show the glacial landforms of southern Ingham County as mapped by Leverett.[2] Figure 9 shows the Charlotte Moraine boundaries from these maps reduced to a scale of approximately 1:167,000.

The surface formations mapped by Leverett on these quadrangles are identified by colors. The more prominent topographic features such as moraines are shown with bright colors, and plains are represented by more subdued colors.

> This system has been elaborated sufficiently to bring out drift structure as well as topography. For example, for topography a moraine is given a red color, an outwash gravel a brown color, and a till plain a blue color, while for structure a gravelly part of a moraine has a brown color rubbed over the red, while the clayey part has a blue color over the red (Leverett, 1913, p. 586).

Portions of the moraine boundaries shown on Leverett's 1921 maps

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[1] I wish to acknowledge the generous help given by Mr. R.E. Kimmel, Geologist, Michigan Geological Survey, in making these maps available to me.

[2] These quadrangles are dated and bear the signature of Frank Leverett.

are closely associated with the surface altitude of this part of the county (compare Figures 5 and 9). Generally, only areas above 900 feet were mapped as moraine, and in places the borders coincide with the 950 foot contour line. The feature shown in central Vevay Township becomes very narrow along a north-facing slope. In northeastern Stockbridge Township, an area with altitudes of 950 to 1,000 feet is not mapped as moraine, and in northeastern Onondaga and northwestern Leslie Townships two of the largest tracts above 1,000 feet are shown as till plain.

The moraine boundaries on these maps enclose, for the most part, areas of moderate to high relief (compare Figures 6 and 9). Some low-relief surfaces are included as part of the feature, notably in White Oak Township. In Aurelius Township a tract of low relief appears to account for the discontinuity shown in the moraine.

A map of the surface formations of the Southern Peninsula of Michigan, compiled by Leverett in cooperation with Frank B. Taylor and others, was published in 1924 at a scale of 1:750,000. This map shows not only the distribution of the glacial formations but also assesses their general agricultural suitability. Figure 10 is an enlargement of the Charlotte Moraine borders in southern Ingham County as shown on this map.

The moraine boundaries on the 1924 map generally enclose areas which have altitudes above 900 feet (compare Figures 5 and 10). Only a few small portions of the borders coincide with the 950-foot contour line. The remainder of both the proximal and distal boundaries has altitudes of 950 to 1,000 feet.

Most of the feature shown on this map has a surface of at least moderate relief (compare Figures 6 and 10). The two sections having

the largest local relief in southern Ingham County are mapped as moraine in Vevay and Ingham Townships. Small areas with low relief are enclosed by the moraine borders in Aurelius and Vevay Townships, and larger areas of low relief are included in White Oak Township.

Till is the most abundant surficial sediment within the eastern and western parts of the moraine shown on both the 1921 and 1924 maps. The central areas of the feature shown on these maps are composed at the surface of till, stratified drift, and organic material (compare Figures 3, 9, and 10). A few linear, organic deposits segment the moraine in Aurelius and western Vevay Townships.

Most of the feature shown on Leverett's 1921 and 1924 maps is underlain by relatively thick drift on a bedrock surface of moderate altitude except in southwestern Aurelius Township, where the moraine includes an area of thin drift supported by a high-altitude, low-relief bedrock surface (compare Figures 1, 2, 9, and 10). The distal portion of the feature in Vevay Township shown on the 1924 map is also underlain by thin drift and a relatively high bedrock surface.

Martin, 1954, 1955 and Undated Manuscript

A map compiled by Helen Martin and dated 1954 shows the Charlotte Moraine in Ingham County. This map was published at a scale of approximately 1:262,000 and, as mentioned previously, was included in a short report on the geologic history of Ingham County (Martin, 1958). Figure 11 shows part of this map enlarged to a scale of about 1:167,000.

The moraine borders shown on this 1954 map enclose areas with altitudes of more than 900 feet except for two small tracts in western

Aurelius and northeastern Vevay Township (compare Figures 5 and 11). The proximal boundary, in places, is somewhat parallel to but lower than the 950-foot contour line. In Aurelius, White Oak, and Stockbridge Townships the borders tend to enclose small areas with altitudes between 950 and 1,000 feet. The remainder of the distal margin transects areas above 950 feet. In Vevay Township the moraine is shown as a narrow strip extending along a north-facing slope. This is similar to Leverett's 1921 map. The moraine as shown in Aurelius, Vevay, and Ingham Townships contains, for the most part, areas of at least moderate local relief (compare Figures 6 and 11). The moraine is shown as discontinuous in Aurelius Township in the vicinity of a low-relief tract. Extensive areas within the borders of the feature in White Oak and Stockbridge Townships have low relative relief.

Helen Martin edited the Map of the Surface Formations of the Southern Peninsula of Michigan, which was published in 1955 at a scale of 1:500,000. This map was based on the research of I. Russell, F. Leverett, W. Sherzer, S. Bergquist, F. Terwilliger, H. Martin, and others. The principle sources of data for the Ingham County area were the manuscript maps by Frank Leverett drawn on U.S. Geological Survey topographic quadrangles (Martin, 1955). Figure 12 is an enlargement of the Charlotte Moraine borders in Ingham County as shown on Martin's 1955 map.

The surface altitudes of the moraine as shown on this map are above 900 feet except in northeast Vevay and southwest Aurelius Township (compare Figures 5 and 12). The proximal boundary, in many places, delimits the northern extent of tracts with altitudes between 950 and 1,000 feet. The distal border appears to transect several areas above

950 feet. The moraine boundaries shown on the 1955 map enclose, for the most part, surfaces of at least moderate relief (compare Figures 6 and 16). In the east-central portions of both Vevay and Ingham Townships the feature has a considerable amount of local relief, but much of the moraine shown in White Oak Township has low relative relief. Two small tracts of low relief are included within the moraine borders in Aurelius and Vevay Townships.

A manuscript map, believed to have been compiled by Helen Martin,[1] on file at the Michigan Geological Survey, shows the surface formations of Ingham County at an approximate scale of 1:127,000. The southern half of the map was reduced to a scale of approximately 1:167,000 for analysis (Figure 13).

Most of the moraine shown on this manuscript map is above the 900-foot contour line except for a small area in northeast Vevay Township (compare Figures 5 and 13). The proximal boundary generally delimits the northern extent of tracts above 950 feet and in Vevay Township coincides, in part, with the 950-foot contour line. The distal border is less well correlated with surface altitude and usually transects areas 950 to 1,000 feet above sea level. In southern Vevay Township the extent of the feature is limited to a narrow north-facing slope.

The moraine boundaries in Vevay, Ingham, and eastern Aurelius Townships commonly enclose surfaces of moderate local relief (compare Figures 6 and 13). Large portions of the feature shown in White Oak, Stockbridge, and western Aurelius Townships have low relief. Not all

[1]R.E. Kimmel, personal communication.

of the high-relief area in eastern Ingham Township was included within the moraine boundaries.

On all three of the maps by Martin which were studied, till is the most abundant surficial sediment within the moraine boundaries shown in Aurelius, western Vevay, and south-central White Oak Townships. The surface of the feature shown in other parts of the study area on these maps is composed of till, stratified drift, and organic material (compare Figures 3, 11, 12, and 13). Several linear organic deposits, which are probably associated with glacial drainageways, transect the moraine shown on Martin's 1954 and 1955 maps and her undated manuscript map, especially in Aurelius and Vevay Townships (compare Figures 4, 11, 12, and 13). The moraine discontinuity shown in southeastern Vevay Township on the 1954 map coincides with a trough containing organic material and several segments of the Mason Esker.

Somewhat thin drift supported by a relatively high bedrock surface underlies the moraine shown in southwestern Aurelius Township on all three of the maps by Martin which were studied. Bedrock is exposed at the surface in several places in this part of the county, and some of these outcrops are included by Martin within the moraine, notably on her 1955 map. The remainder of the feature shown on these maps is underlain by drift which tends to thicken toward the east in conjunction with a general decrease in the altitude of the bedrock surface (compare Figures 1, 2, 11, 12, and 13).

CONCLUSIONS

Both Leverett and Martin reinterpreted the extent of the Charlotte Moraine in Ingham County several times. Little has been published about the methods that either used to map glacial landforms, but it is known that it was not unusual for Leverett to modify his previous interpretations. In his notebook No. 274 Leverett states (p. 80, July 11, 1921),

> Some of the mapping of moraines and till plains in parts of the Mason and Lansing quadrangles traversed by this highway [presumably the road from Leslie to Lansing] seem to need revision for the map which Mr. Smith has which purports to be a copy of mine has the color for moraine in places where the surface looks like till plain, and for till plain where there is considerable undulation, enough to suggest moraine topography.

Some of these revisions were necessary because the original interpretations were done without the aid of topographic maps.

Although Leverett changed some of his interpretations, subsequent maps were not always more detailed. Both the 1911 and 1915 maps were published at the same small scale, but the moraine boundaries in southern Ingham County shown on the later map are probably less appropriate than those of the 1911 map. The borders of the 1915 map enclose more extensive areas of low altitude and relief as well as tracts of thin drift or rock outcrops. Other areas of moderate or considerable relief at higher altitudes, which are underlain by relatively thick drift, were not shown as moraine on this map. These differences are most pronounced in Aurelius and Ingham Townships. It is curious that the boundaries of the 1911 map appear more appropriate, considering that they were drawn to illustrate a report on agricultural conditions, whereas the 1915 map was included in a monograph on the Pleistocene of

Indiana and Michigan.

Of the four maps by Leverett which were studied, the 1921 moraine borders seem to be the most suitable because they outline, for the most part, areas of somewhat thicker drift at higher altitudes having at least a moderate amount of local relief. This is the only one of four maps by Leverett which shows the Charlotte Moraine in Ingham County as a discontinuous feature. Such an interpretation is supported by topographic and surficial sediment data. The suitability of Leverett's 1921 boundaries appears related, in part, to the large scale of the topographic maps on which they were based.

The boundaries shown on Leverett's 1924 map are very similar to those of his 1921 map, particularly in the western half of the study area, which suggests that they may represent a cartographic reduction of the earlier map. Such reduction and the accompanying generalization may account for the less irregular nature of the 1924 boundaries and also the depiction of the moraine as a continuous feature. Although this map is less detailed than the 1921 map, it is the most suitable of the three small-scale maps by Leverett.

The differences between the three maps by Martin are small in comparison with the variations between the four maps by Leverett. The borders shown on Martin's 1954 map appear to be the most appropriate of the three because much of the area outlined has both moderate to high altitude and relief and is underlain by relatively thick drift. Additionally, this map shows the Charlotte Moraine in Ingham County as a series of morainic segments, which seems consistent with the topographic and surficial sediment data.

Martin's 1955 moraine borders do not appear as suitable as those

of her 1954 map primarily because of the proximal border placement in Ingham and White Oak Townships and the location of the distal boundary in Stockbridge Township. This map shows the moraine as a continuous feature, and although this may be the result of its somewhat smaller scale, it is less appropriate. The borders on the 1954 and 1955 maps are very similar, especially in the western half of the study area. The two easternmost morainic segments in Aurelius Township, shown on the 1955 map, appear to be worthy additions.

The moraine boundaries shown on Martin's manuscript map are less suitable than those of either the 1954 or 1955 maps because of the extreme southern position of the proximal boundary in Ingham Township. This map also shows the Charlotte Moraine as a continuous feature, which appears to be inconsistent with the data. No morainic segments are shown in Aurelius Township on the manuscript map, which suggests that it may have preceded the 1954 map.

There is little similarity between any of Martin's maps and the 1911 or 1915 maps by Leverett. There is, however, a striking similarity between the borders on Martin's 1954 map and those on Leverett's 1921 maps. The moraine boundaries on Martin's 1954 map are not as irregular as those on Leverett's 1921 maps and may have been reduced and generalized from them.

Many of the small morainic tracts shown on Leverett's 1921 maps proximal to the moraine were not shown on Martin's 1954 map. Four moraine segments are shown on Martin's 1954 map in Vevay Township, but on Leverett's 1921 maps only two segments are shown. The easternmost moraine discontinuity shown by Martin in Vevay Township seems to be a worthwhile addition because it corresponds to a linear organic deposit which contains several esker segments. The central discontinuity is shown by both authors and represents a linear lowland containing some organic material, but the westernmost one, shown only by Martin, coincides with the valley of Sycamore Creek and contains few organic deposits.

The numerous boundary changes which can be seen on these maps of the Charlotte Moraine by Leverret and Martin illustrate the difficulty associated with the mapping of certain glacial landforms. One of the problems recognized by Leverett (1913, p. 584) was that "In the field one is forced to draw upon every available line of evidence to support his mapping, because of the incompleteness of the exposures." Even with the aid of air photographs and topographic maps, Flint (1955) noted that it was not always possible to differentiate between ground moraine and end moraine because the end moraine may grade imperceptibly into a till plain.

One model of deglaciation proposes that the orderly retreat and periodic stillstand of an ice front will result in a landform sequence of outwash plain, moraine, till plain. This model is undoubtedly valid for many glaciated areas but may be inappropriate where large areas of the ice stagnated and ablated in situ. On the basis of topographic, surficial-sediment, drift-thickness, and bedrock-surface data, it appears that the Charlotte Moraine in southwestern Ingham County is a segmented, somewhat amorphous, ridge-like accumulation of moderately thick drift with till being the most extensive surficial sediment. The topography of southwestern Aurelius Township, which has been mapped as moraine, should probably not be included as part of the Charlotte Moraine because it includes several bedrock outcrops and is underlain by thin drift and a high bedrock surface.

In the southeastern part of the county, the feature appears to be a complex of high-relief, glaciofluvial deposits, including many eskers, kames, linear drainageways, and some localized till bodies. This assemblage of landforms indicates that ice stagnation may have been the dominant mode of deglaciation in this area. It is interesting to note that, with the exception of Leverett's 1911 and 1915 maps, both Leverett and Martin show the Charlotte Moraine in southwestern Ingham County on all their maps which were studied in much the same position and form. The feature in this part of the county appears to be a recessional moraine, except in southwestern Aurelius Township, where its topographic expression is largely the result of a high bedrock surface. In the southwestern part of the county, where the ice was probably stagnant, the moraine delineations are much more dissimilar.

The Charlotte Moraine in Ingham County is here recognized as grading from a more typical recessional moraine in the west into a complex ice-stagnation feature in the east. It is suggested that this change in morphology was a major contributing factor to the variations in the moraine borders shown on the maps of both F. Leverett and H. Martin.

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ABSTRACT

AN ANALYSIS OF THE MAY PRECIPITATION GRADIENT
IN SOUTHERN LOWER MICHIGAN

by

David Paul Lusch

Precipitation in southern Lower Michigan during May, 1964-74, decreased eastward noticeably. Facsimile surface weather maps and published climatological data were used to establish whether this precipitation gradient was associated with more frequent and/or more intense precipitation in southwestern Michigan. Additionally, the feasibility of employing facsimile data with national coverage to the study of a meso-scale climatological problem was evaluated. The conclusions are that (1) the greater precipitation receipts in southwestern Michigan during May, 1964-74, resulted from larger daily precipitation totals, rather than frequencies; (2) Montana and southern Great Plains cyclones were the most frequent synoptic types associated with precipitation in southern Lower Michigan during May, 1972-74; (3) the majority of this precipitation appears to have been the specific result of cold or occluded front passage; (4) the amount of precipitable moisture in the lower troposphere, measured by dew point temperatures, was greater in southwestern Michigan during May, 1972-74; (5) the facsimile surface weather maps maintained by the Department of Geography, Michigan State University, are of only limited value for meso-scale climatological studies.

AN ANALYSIS OF THE MAY PRECIPITATION GRADIENT IN SOUTHERN LOWER MICHIGAN

By

David Paul Lusch

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INTRODUCTION

Mean annual precipitation in the Southern Peninsula of Michigan decreases from southwest to northeast (Figure 1), but mean monthly precipitation distributions vary considerably (Niedringhaus, 1966). Brunnschweiler (1962) has shown that the heaviest precipitation in the Southern Peninsula of Michigan for the period 1931-52 fell in the southwest during winter, the south during spring and the northwest during fall. Although vernal precipitation tends to generally decrease northward (Figure 2), during May it decreases eastward noticably in southernmost Michigan (Figure 3). The purpose of this study is to determine whether this west-to-east gradient of May precipitation is associated with more frequent and/or more intense precipitation in southwestern Michigan. Because facsimile surface weather maps and published climatological data available at Michigan State University will constitute the only source of data, a secondary aim of this study is to determine the feasibility of employing facsimile data with national coverage to investigate a climatological problem of meso-scale.

REVIEW OF LITERATURE

Heavy precipitation in Michigan is usually associated with the frontal activity of frequently recurring cyclones. In April, for example, the greatest amounts of daily precipitation are generally associated with the passage of cyclonic storms generated in Montana and

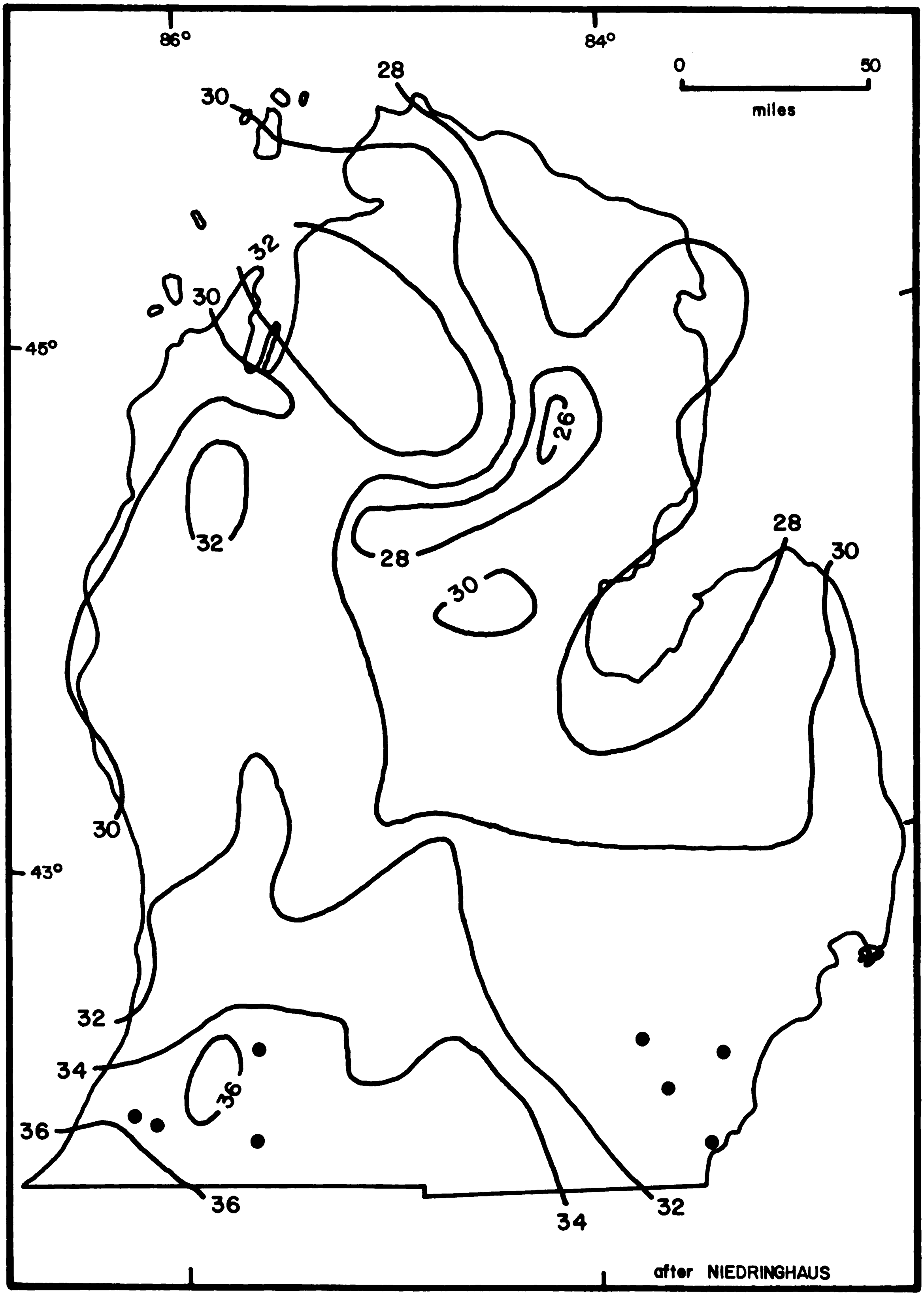

Figure 1. Mean annual precipitation (inches), 1931-1960

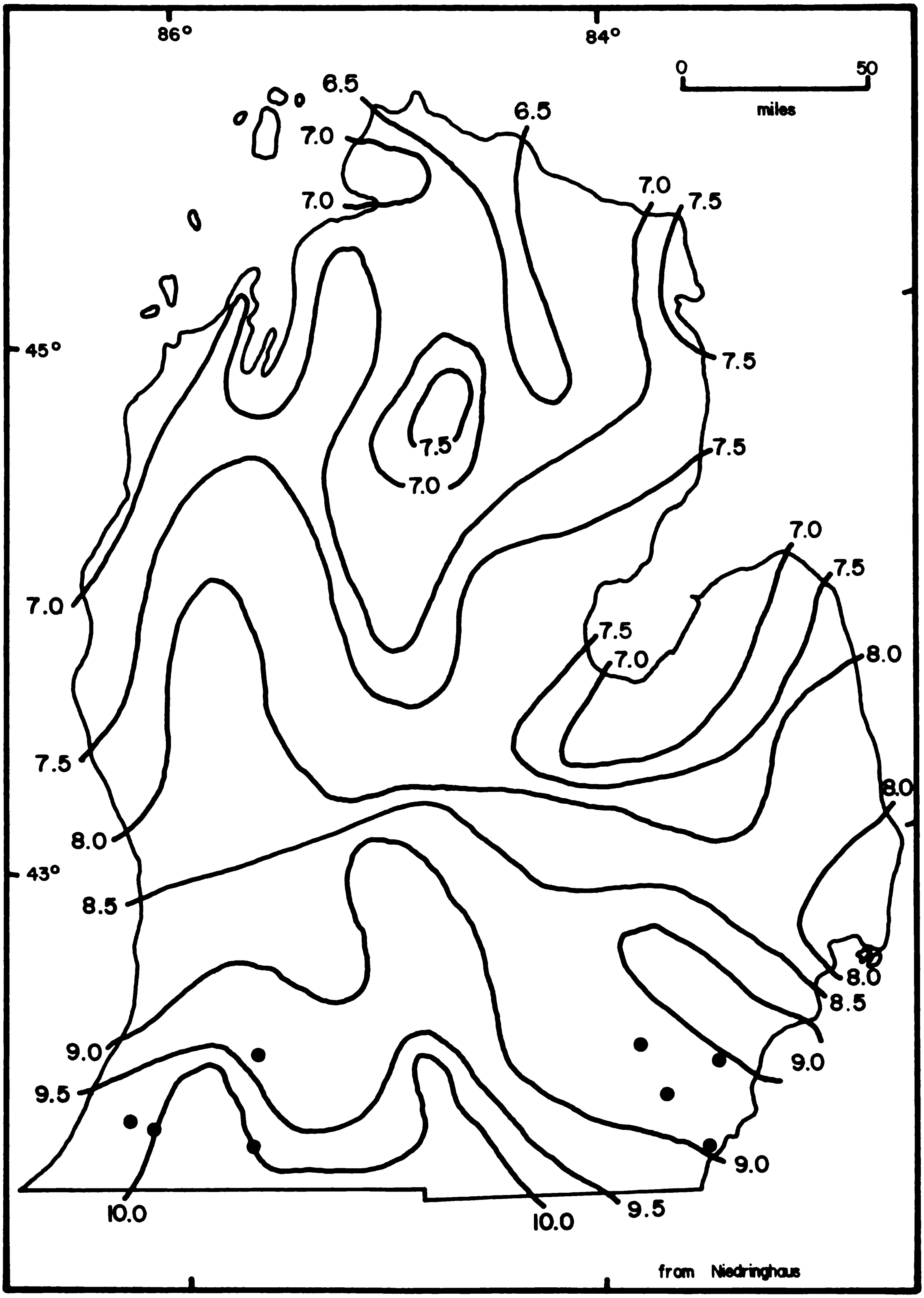

Figure 2. Spring precipitation (inches), 1931-1960

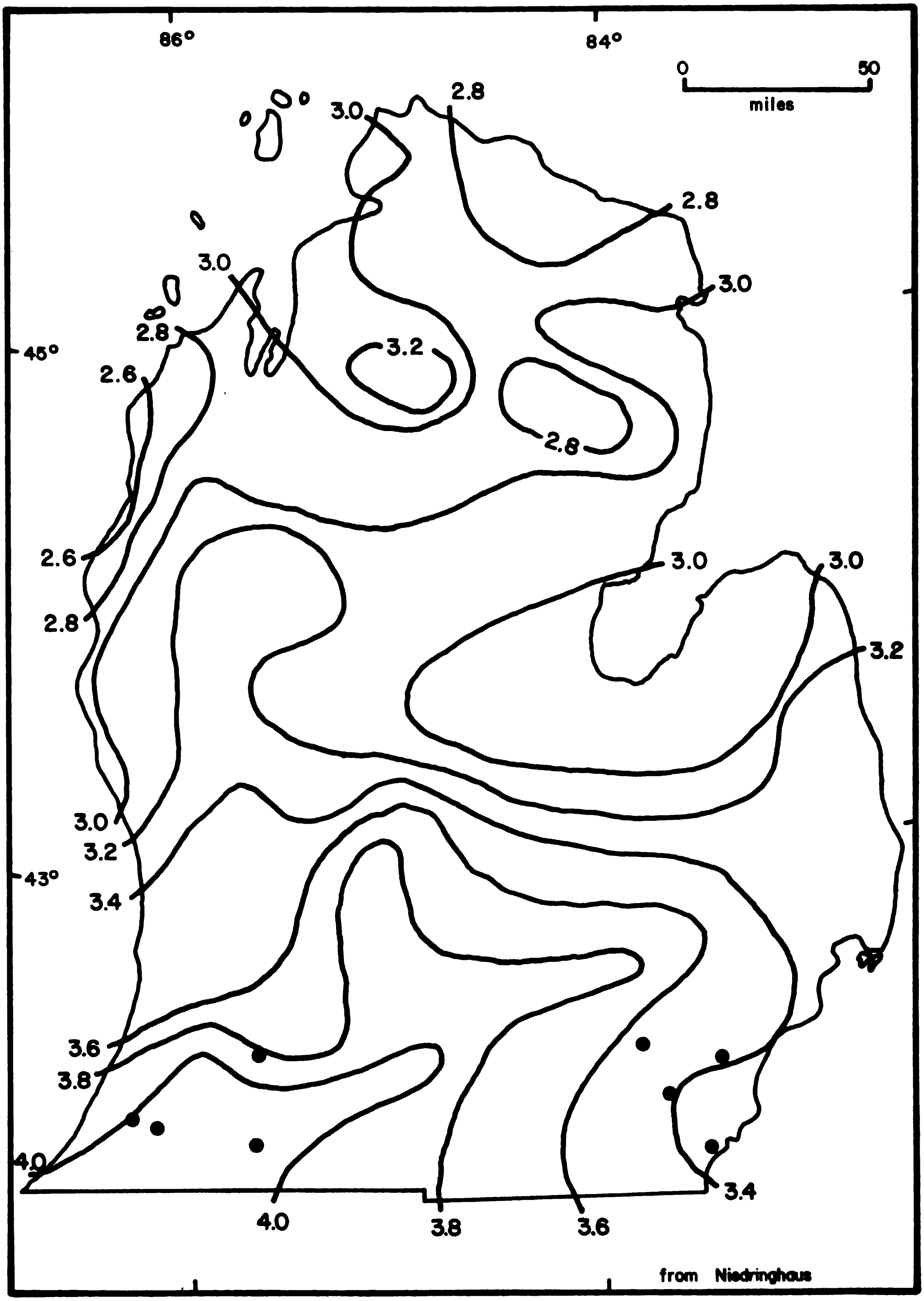

Figure 3. May precipitation (inches), 1931-1960

the southern Great Plains (Hodgins, 1960). During May, the Montana cyclogenetic area becomes less active and lows developed in central Alberta frequently affect Michigan. These Alberta lows usually pass just north of Lake Superior, whereas the southern cyclones generally move northeast across the Lower Peninsula of Michigan (Klein, 1957).

Brunnschweiler (1962) has shown that May is the period of maximum precipitation in southeastern Michigan, and May and June the period in the southwestern part of the state. He concluded that the major genetic factor in seasonal precipitation variations is the frontal activity along the migrating polar front during spring and fall.

Niedringhaus (1966) differentiated the southwestern area of Michigan on the basis of both mean annual and mean May precipitation and suggested that the atmospheric moisture content over the eastern Lower Peninsula is somewhat lower than over the west. He also investigated the relationships between mean monthly precipitation and distance from a Great Lake according to prevailing wind direction, latitude, and elevation, and noted that May had the lowest coefficient of multiple determination (.249), indicating that these three variables could account for only about 25 percent of the variation in May precipitation. According to Niedringhaus, the peninsular nature of Michigan may be one of the most important factors associated with these unexplained precipitation variations. The land bridge which connects the Lower Peninsula to the continent allows maritime tropical (mT) air masses to enter southern Michigan without first passing over the surface of a Great Lake. Throughout much of the year, the Lakes are cooler than, and have a stabilizing effect on, the air masses which are advected over them. Thus, southernmost Michigan has a higher degree of "land control" than the rest of the Southern Peninsula when air masses enter the state from the south.

METHODS

The daily measurable precipitation (.01") receipts during May, 1964-74, at eight southern Lower Peninsula stations were obtained from Climatological Data and analyzed to establish whether the May precipitation gradient results from more intense or more frequent precipitation in southwestern Michigan. The southeastern Michigan region was represented by Ann Arbor, Detroit Metropolitan Airport, Monroe Sewage Plant, and Willis, whereas the southwestern area was represented by Dowagiac, Eau Claire, Kalamazoo State Hospital, and Three Rivers (Figure 4). Not only are these stations located within the zonal May precipitation gradient, but they are also distributed somewhat evenly within the southwestern and southeastern areas. The statistical significance of the precipitation differences between these two regions was determined using a difference of means test.

Facsimile surface weather maps for most days in May, 1972-74, are on file at the Department of Geography, Michigan State University. These maps, supplemented when necessary with those of the Daily Weather Maps, Weekly Series, were used to identify the dominant synoptic weather types for those days when both southwestern and southeastern Michigan received at least .01 inches of precipitation. These weather types were classified according to the system developed by Hodgins (1960). The frequencies of these synoptic weather types were computed for days when the southwestern Michigan precipitation receipts exceeded those of

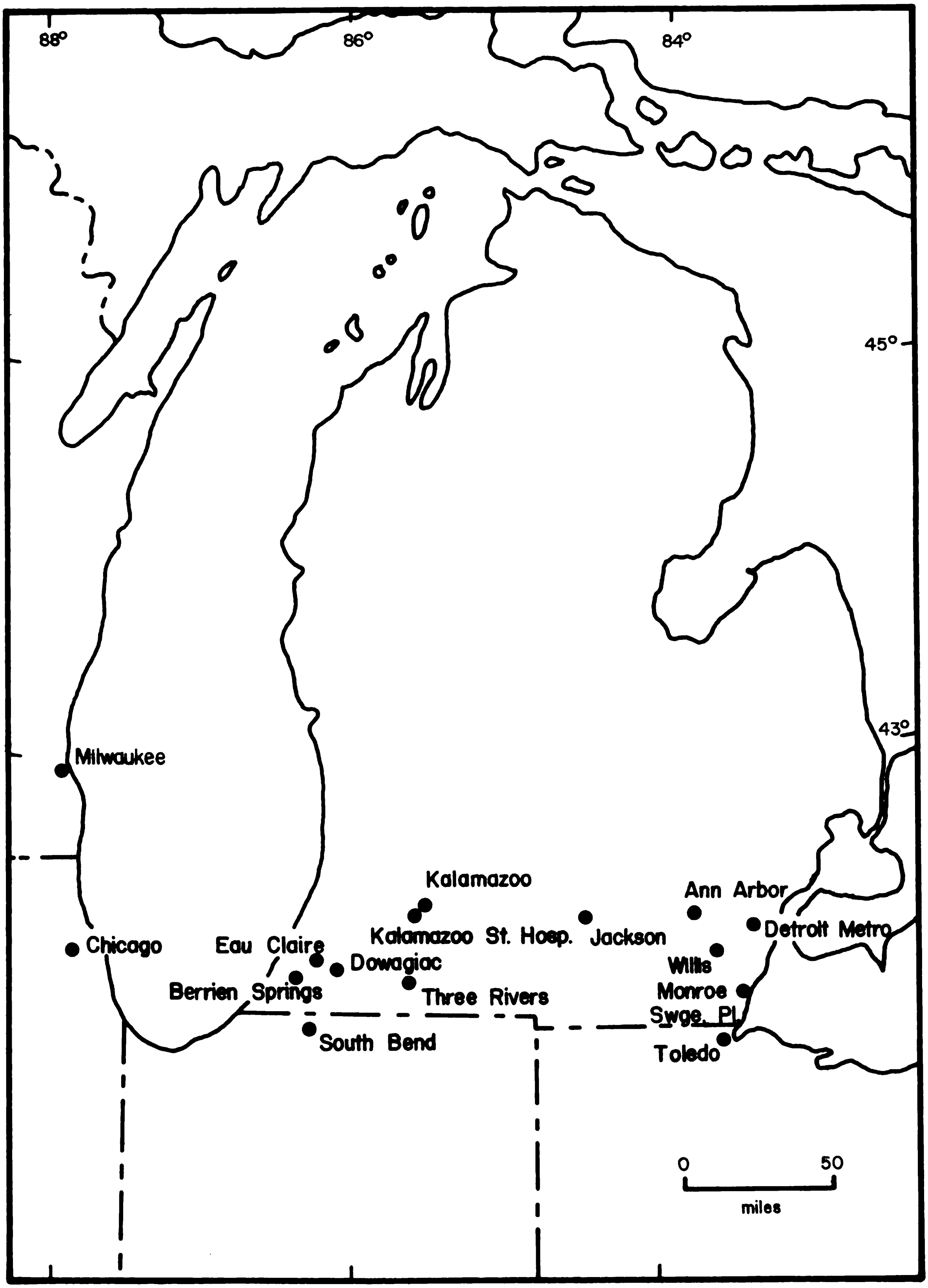

Figure 4. Location of reporting stations

the southeastern area, and for days when southeastern Michigan received more precipitation than the southwest area. Also determined from these maps were the frequencies and types of fronts associated with this measurable precipitation.

The dew point temperatures of air masses may be used as indexes of the amount of moisture present within them. The mean dew point temperatures just prior to the passage of a cold or occluded front, computed from the facsimile maps and the Daily Weather Maps, Weekly Series, were compared for the southern Lake Michigan and western Lake Erie regions for days when both southwestern and southeastern Michigan received at least .01 inches of precipitation but the southwestern precipitation receipts exceeded those of the southeastern area. Milwaukee, Chicago, and South Bend represented the southern Lake Michigan area and Detroit Metropolitan Airport, Jackson Airport, and Toledo represented the western Lake Erie region (Figure 4).

Unstable conditions may be induced by ground radiation heating the lower atmosphere and increasing the environmental lapse rate, particularly in midafternoon when maximum daily temperatures generally occur. The precipitation associated with the passage of cold fronts or mid-tropospheric short waves at such times, therefore, may be enhanced. Since the zone of lifting associated with the cold front is much narrower than that of a mid-tropospheric short wave, the timing of its passage may have an important influence on the distribution of precipitation intensities. Published hourly precipitation data are available for Berrien Springs and Kalamazoo in southwestern Michigan and Ann Arbor and Detroit Metropolitan Airport in the southeastern part of the state (Figure 4). These data were analyzed to determine the timing of maximum precipitation on days in May when both southwestern and southeastern Michigan received at least .01 inches of precipitation but the southwestern area received more.

RESULTS

The precipitation receipts for May, 1964-74, were determined for southwestern and southeastern Michigan (Table 1). In this eleven year period the stations in southwestern Michigan received a total of 4.33 inches more precipitation than the southeastern region, a mean annual difference of 0.39 inches of precipitation. These data were analyzed using a difference of means test with twenty degrees of freedom. The null hypothesis, that no significant difference exists between the mean annual precipitation receipts of these two areas, was rejected at the .05 level indicating that these precipitation differences would be expected to occur by chance only five times in 100 years.

During May, 1964-74, when at least .01 inches of precipitation fell at one station in both southwestern and southeastern Michigan, the total precipitation of the southwestern area exceeded that of the southeastern part of the state by 9.32 inches, a mean annual difference of 0.85 inches. On days when measurable precipitation fell in only one area, however, southeastern Michigan received 1.58 inches more precipitation than the southwestern region, a mean annual difference of 0.14 inches (Table 2).

Table 1

AMOUNT AND DISTRIBUTION OF PRECIPITATION
IN SOUTHERN LOWER MICHIGAN, MAY, 1964-74

	PRECIPITATION DISTRIBUTION						TOTAL MAY PRECIPITATION	
	Total precip. for days when SW Mich. precip. total exceeded SE Mich. precip. total		Total precip. for days when SE Mich. precip. total exceeded SW Mich. precip. total		Total precip. for days when only one area received ≥ .01" precip.			
YEAR	SW Mich. receipts	SE Mich. receipts	SW Mich. receipts	SE Mich. receipts	SW Mich. receipts	SE Mich. receipts	Southwestern Michigan	Southeastern Michigan
1964	3.99"	1.14"	3.25"	6.24"	.39"	.06"	7.63"	7.48"
1965	5.26"	1.83"	1.16"	4.62"	.60"	.69"	7.02"	7.14"
1966	13.46"	8.26"	.08"	.17"	1.45"	.00"	14.99"	8.43"
1967	5.39"	2.93"	.83"	1.28"	.12"	2.58"	6.14"	6.79"
1968	3.72"	2.00"	4.62"	21.04"	.69"	1.98"	9.16"	25.10"
1969	7.05"	2.84"	5.56"	13.12"	.40"	.24"	13.01"	16.20"
1970	12.78"	7.53"	2.47"	5.29"	.32"	.91"	15.57"	13.73"
1971	5.83"	1.10"	1.81"	5.84"	.85"	.87"	8.49"	7.81"
1972	6.84"	4.07"	4.02"	7.27"	.02"	.03"	10.88"	11.37"

Table 1 (cont'd.)

YEAR	PRECIPITATION DISTRIBUTION						TOTAL MAY PRECIPITATION	
	Total precip. for days when SW Mich. precip. total exceeded SE Mich. precip. total		Total precip. for days when SE Mich. precip. total exceeded SW Mich. precip. total		Total precip. for days when only one area received ≥.01" precip.			
	SW Mich. receipts	SE Mich. receipts	SW Mich. receipts	SE Mich. receipts	SW Mich. receipts	SE Mich. receipts	Southwestern Michigan	Southeastern Michigan
1973	22.39"	7.84"	2.99"	4.67"	.15"	.16"	25.53"	15.89"
1974	13.19"	4.48"	6.76"	10.57"	1.58"	.63"	21.53"	15.58"
					1964-74 TOTAL		139.95"	135.62"
					MEAN		12.72"	12.32"

Table 2

MAY PRECIPITATION TOTALS, 1964-1974

Precipitation Distribution	SW Michigan	SE Michigan
Southwestern and southeastern Michigan each receive $\geq$ .01" of precipitation	133.45"	124.13"
$\geq$ .01" of precipitation in one area to the exclusion of the other	6.47"	8.15"

The measurable precipitation which fell in both southwestern and southeastern Michigan on forty-four days in May, 1972-74, appears to have been associated with several different types of synoptic disturbances. These weather types are shown in Figure 5, which also depicts the area of genesis and subsequent trajectory of the cyclonic types. On over half of the days, the precipitation was associated with cyclones which developed in either Montana or the southern Great Plains (Table 3).

On those days when cyclones generated in Alberta were the dominant synoptic type, southwestern Michigan usually received more precipitation than did the southeastern part of the state. On days when Colorado lows affected Michigan, more precipitation fell in southeastern Michigan compared to the southwestern area.

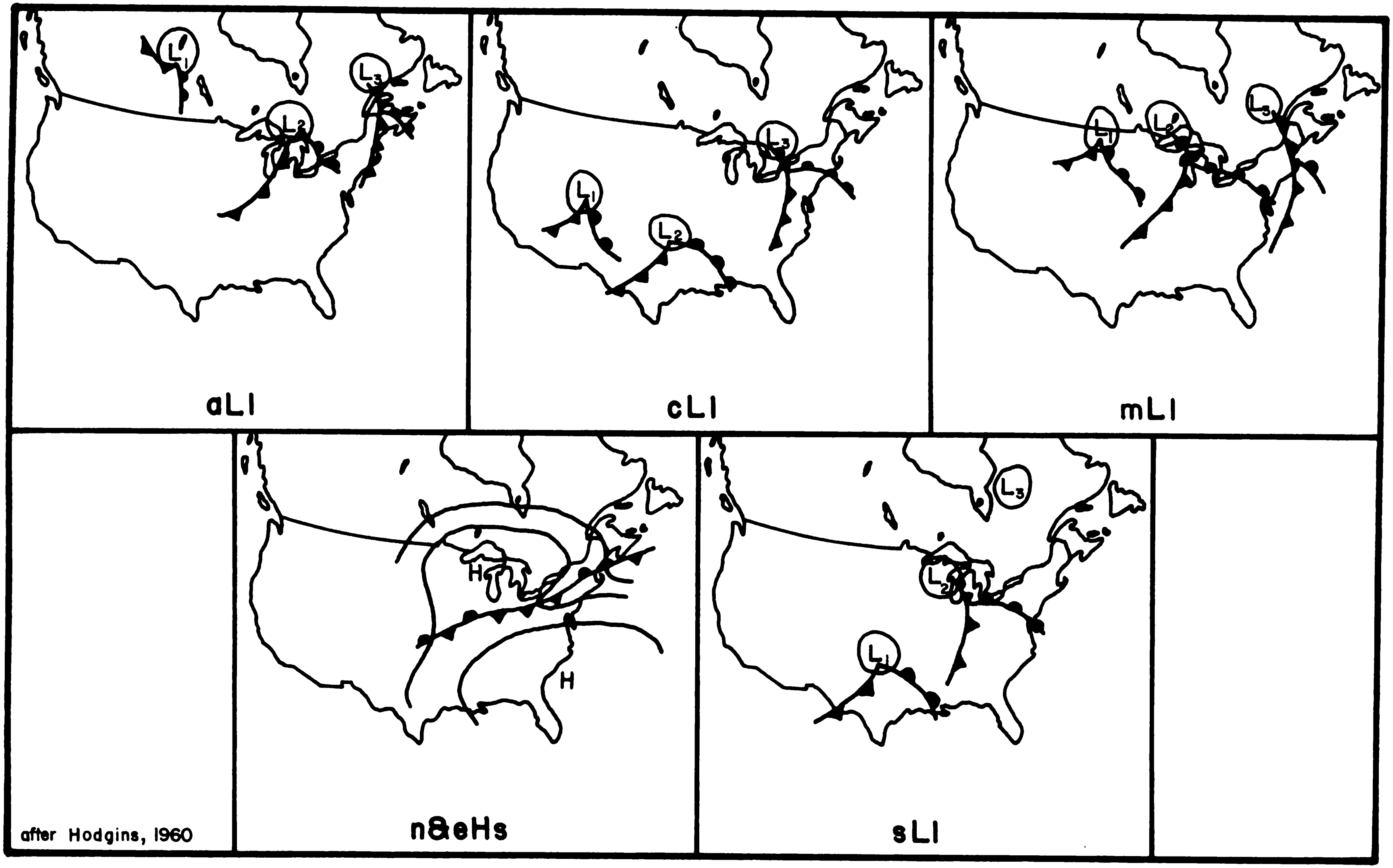

Figure 5. Synoptic types

Table 3

FREQUENCY OF SYNOPTIC TYPES PRODUCING PRECIPITATION IN SOUTHERN LOWER MICHIGAN DURING MAY, 1972-74, ACCORDING TO PRECIPITATION DISTRIBUTION

Synoptic Type*	SW Mich. precipitation total exceeds SE Mich. precipitation total		SE Mich. precipitation total exceeds SW Mich. precipitation total	
	frequency (days)	percent of total	frequency (days)	percent of total
Alberta low through the Great Lakes Region (aLl)	5	22	1	5
Colorado low through the Great Lakes Region (cLl)	0	0	4	19
Montana low through the Great Lakes Region (mLl)	6	26	8	38
Highs north and east of the Great Lakes Region (n&eHs)	4	17	1	5
Southern low through the Great Lakes Region (sLl)	7	31	4	19
no dominant pattern	1	4	3	14
	23	100	21	100

*see Figure 5

On eighteen of the twenty-three days in May, 1972-74, when measurable precipitation fell in both southwestern and southeastern Michigan but the precipitation of the southwestern area exceeded that of the southeastern region, frontal activity appears to have been involved.

The frequency of the various frontal types was as follows:

Frequency (Days)	Percent of Total	Frontal Type Associated with Precipitation
8	44	cold front
3	17	warm front
2	11	stationary front
4	22	occluded front
1	6	both warm and cold fronts
18	100	

The precipitation patterns and intensities are generally somewhat similar for cold and occluded fronts, and it is interesting to note that these two frontal types accounted for almost two-thirds of the precipitation occurrences.

On twenty-one days in May, 1972-74, both southwestern and southeastern Michigan received at least .01 inches of precipitation but the southeastern region received more than the southwestern area. On sixteen of these days, the precipitation appears to have been associated with frontal activity. On half of the days when more measurable precipitation fell in southeastern Michigan compared to the southwestern part of the state, the precipitation appears to have been associated with cold or occluded fronts.

The frequency of the various frontal types was as follows:

Frequency (Days)	Percent of Total	Frontal Type Associated with Precipitation
5	31	occluded front
4	25	warm front
3	19	cold front
2	12.5	stationary front
2	12.5	both warm and cold fronts
16	100	

In summary, the cumulative precipitation receipts during May, 1964-74, of the southwestern Michigan stations exceeded those of the southeastern stations by a statistically significant amount. On days when both of these areas received measurable precipitation during this period, the cumulative receipts for the southwestern area were greater, but on days when only one of the two areas received at least .01 inches of precipitation the southeastern Michigan precipitation totals were greater. Cyclones generated in Montana and those from the southern Great Plains were the dominant synoptic types associated with precipitation during May, 1972-74. The majority of this precipitation appears to have been the specific result of cold or occluded front passage.

Variations in the amount of precipitable moisture available in the two study areas just prior to the passage of a cold or occluded front could result in precipitation differences between them. Dew point temperature may be used as an index of the amount of atmospheric moisture present. On twelve days during May, 1972-74, when southwestern Michigan received more precipitation than the southeastern area, it appears to have been largely the result of either cold or occluded fronts. On eight of these days, for which adequate dew point temperature data were available, the mean dew point temperature for the southern Lake Michigan region was 55^{o}F. On one of these eight days, the mean dew point temperature was the same for both areas. For the remaining seven days the mean dew point temperature of the southern Lake Michigan region exceeded that of the western Lake Erie region by as much as 40^{o}F.

Hourly precipitation data were available for ten of the twelve days in May, 1972-74, when measurable precipitation resulting from cold or occluded fronts fell in both southwestern and southeastern Michigan but the southwestern precipitation receipts were greater. The diurnal timing of the maximum precipitation receipts was extremely variable. The only obvious pattern was that on eight of the ten days the southwestern area received the bulk of its total daily precipitation prior to the southeastern region. On only two of the ten days did the southeastern area receive the bulk of its daily precipitation prior to the southwestern region.

DISCUSSION OF RESULTS

The differences between the May, 1964-74, precipitation totals for southwestern and southeastern Michigan (Table 1) are statistically significant. The results of the difference of means test indicate that such differences would be expected to occur by chance only five times out of 100. Thus, they must have some sort of a physical basis.

On days when only one of the two study areas received measurable precipitation during May, 1964-74, the cumulative precipitation receipts of the southeastern Michigan stations were greater than those of the southwestern Michigan stations (Table 2). During this period, measurable precipitation fell only in southwestern Michigan on thirty-five days, whereas it fell only in the southeastern area on thiry-three days. Since both mean annual and mean May precipitation are slightly greater in southwestern Michigan (Figure 1, Table 1), that which falls in southwest Michigan when both areas receive measurable precipitation (Table 2) must offset this pattern. Hence, the eastward decrease of total May precipitation in southern Lower Michigan detected in this study for 1964-74 must have been the result of higher precipitation intensities, rather than frequencies, in southwestern Michigan.

Cyclones generated in Montana or the southern Great Plains were the most frequent synoptic types associated with precipitation during May, 1972-74, in southern Lower Michigan (Table 3). According to Niedringhaus (1966), Montana lows are the most frequently recurring cyclonic type in Michigan. Cyclones generated in the southern Great Plains which pass through the Great Lakes region, on the other hand, are markedly concentrated in the spring and are closely related to the April-June precipitation maximum observed in much of the midwest. This cyclonic activity is due, in large part, to the configuration of the westerlies during spring when upper tropospheric long wave troughs are frequently centered over the Great Plains placing Michigan under the influence of moist, unstable southwesterly flow. Surface cyclones, supported by upper tropospheric short waves, migrate northeastward through this system and are, therefore, "steered" across the Great Lakes region in spring. The vertical movements of air associated with these troughs are intensified at this time of the year by the strong zonal index which results from the accentuated baroclinic zone along the northward migrating polar front.

The measurable precipitation associated with the passage of cyclones originating in both areas during May, 1972-74, was greater in southwestern Michigan (Table 3). The heaviest precipitation produced by the southern cyclones "...usually occurs just northwest of the path of the center of the low..." (Hodgins, 1960, p. 66) and the track of these storms often trends northeast across the Lower Peninsula of Michigan (Klein, 1957). As both of these systems move to the east or northeast and begin to occlude, the inflow of warm, moist air is interrupted and the thermal contrast across the fronts lessens as the warm air mass becomes diluted. Thus, the precipitation produced by these lows tends to diminish as they move across the state, possibly accounting for the concentration of precipitation in southwest lower Michigan.

On more than seventy-five percent of the days when precipitation fell contemporaneously in southwestern and southeastern Michigan during May, 1972-74, it appears to have been related to frontal activity with the cyclonic centers passing north of the study area. On days when more precipitation fell in southwestern Michigan, almost two-thirds of it was associated with either cold or occluded fronts. These two frontal types accounted for only half of the days when heavier precipitation fell in southeastern Michigan. Thus, a tendency existed during May, 1972-74, for cold or occluded fronts to produce more precipitation in southwestern Michigan than in the southeastern part of the state.

Maritime tropical air masses, advected northward by way of the Mississippi River valley, are a principal source of atmospheric moisture for the Lower Peninsula of Michigan and usually enter the state from the southwest. These air masses may provide more moisture for the southwestern Michigan area if soon after they enter the state they are cut off from their source area by a rapidly eastward-moving cold or occluded front or are diluted by vertical or horizontal mixing.

Dew point temperatures just prior to the passage of a cold or occluded front, which are indexes of the amount of moisture in the air, were compared for the two study areas. On twelve days in May, 1972-74, measurable precipitation resulting from cold or occluded fronts fell in both areas but southwestern Michigan received more than southeastern Michigan. On eight of these days, for which data were available, the mean dew point temperature for the southern Lake Michigan region was 55°F., whereas it was 53°F. for the western Lake Erie region. This pattern indicates that the heavier precipitation in southwestern Michigan may have been the result of more available atmospheric moisture in this part of the state. This inequitable distribution of atmospheric moisture in southern Lower Michigan is probably the result of rapidly moving cold or occluded fronts which progress eastward faster than the currents of moist air they are displacing and accordingly intersect them before they overspread the state. The resulting differences in precipitable moisture appear to have been a major factor in the establishment of the west-to-east precipitation gradient in southern Lower Michigan during May, 1972-74.

Cold or occluded fronts which pass through an area during the middle or late afternoon, when somewhat unstable conditions produced by lower atmospheric warming often prevail, may promote heavier precipitation than similar frontal passages at other times of the day. Although data on the actual time of frontal passage are not available at Michigan State University, the timing of these passages can be estimated by observing the temporal distributions of precipitation receipts published in Hourly Precipitation Data. These distributions were extremely variable for the ten days during May, 1972-74, when more precipitation resulting from cold or occluded fronts fell in southwestern Michigan and hourly precipitation data were available. This variability suggests that frontal passage timing is relatively unimportant in establishing the May precipitation gradient in southern Lower Michigan.

SUMMARY AND CONCLUSIONS

Precipitation totals for southwestern and southeastern Michigan during May, 1964-74, differ significantly. Since only five percent of these differences could be accounted for by chance, they are evidently the result of a complex of meteorological mechanisms. During this period, the greater receipts in southwestern Michigan resulted from larger daily precipitation totals, rather than frequencies.

Cyclones generated in Montana or the southern Great Plains were the most frequent synoptic type associated with precipitation during May, 1972-74, in southern Lower Michigan. Although Montana lows frequently pass over the Great Lakes region throughout the year, similar passages of cyclones generated in the southern Great Plains are markedly concentrated in the spring and are closely related to the April-June precipitation maximum observed in much of the midwest. The majority of the measurable precipitation which fell in southern Lower Michigan during May, 1972-74, appears to have been the specific result of frontal activity, particularly cold or occluded fronts, associated with these passing cyclones.

The amount of precipitable moisture in the lowermost part of the atmosphere, as measured by dew point temperatures, was greater in southwestern Michigan during May, 1972-74. During this period, the precipitation produced by Montana or southern Great Plains cyclonic systems diminished as they moved east or northeast across the state. Increased precipitable moisture and associated heavier precipitation appear to have been favored in southwestern Michigan at least partly because these cyclonic systems often occlude as they move across the state, a process which interrupts the influx of moist air from the south and diminishes the thermal contrasts across the fronts through time. This inequitable distribution of atmospheric moisture and the related pattern of heavy precipitation were probably major factors in the development of the west-to-east precipitation gradient in southern Lower Michigan during May, 1972-74.

Results of this study indicate that frontal passage timing is relatively unimportant in establishing the May precipitation gradient in southern Lower Michigan in May. Although late afternoon cold or occluded front passages can promote heavier precipitation than similar passages at other times of the day, particularly in summer, the prevailing upper tropospheric conditions over much of the midwest during spring seem to provide sufficient instability so that heavy precipitation can result irrespective of the timing of frontal passage.

The conclusion that the well-developed precipitation gradient in southern Lower Michigan during May, 1972-74, resulted largely from an inequitable distribution of precipitable moisture in this part of the state which favored heavier precipitation in southwestern Michigan can be accepted only tentatively because of the small sample size used in this study. Continued research involving a larger sample population over a longer period of time will be necessary before this factor can be more conclusively evaluated.

Although estimation of the amount of precipitable moisture by dew point temperature is a valid technique, to be more appropriate this information is needed just prior to frontal passage. Because such facsimile data are generally transmitted at three or six hour intervals, they are not always applicable. Thus, the difficulty in obtaining a valid measurement of the amount of precipitable moisture available just prior to frontal passage is a factor limiting this type of study.

The facsimile surface weather maps maintained by the Department of Geography, Michigan State University, are of only limited value for meso-scale climatological studies for several reasons. Continuous daily coverage is not available and individual station information is often either difficult to read or missing altogether. Additionally, these facsimile maps do not provide hourly synoptic data which are useful for this type of study.

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