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GLACIAL FEATURES OF COOK COUNTY, MINNESOTA*

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ABSTRACT. Reliable evidence has been found for only two ice invasions of Cook County, although the glacial history of this area must have been much more complex. The Rainy lobe moved into the area from the north and covered the entire county during the Cary substage of the Wisconsin. It was succeeded by the Superior lobe which moved west-southwest along the Superior trough during the Mankato substage of the Wisconsin and covered a narrow belt along the southern margin of Cook County. These advances were not contemporaneous because Superior lobe red clayey till rests upon Rainy lobe brown sandy till, and red lake clays derived from the Superior lobe were deposited over areas earlier occupied by the Rainy lobe.

Lakes associated with these ice sheets have occupied parts of Cook County at the following times: (1) prior to or during early stages of the Rainy lobe advance, (2) during or shortly after recession of the Rainy lobe, (3) prior to or contemporaneous with advance of the Superior lobe, (4) during the climax and recessional phases of the Superior lobe, and (5) after all ice had disappeared from Cook County but still lay in neighboring regions.

Contrary to earlier reports, end moraines are not present in Cook County. The most obvious glacial deposits are principally irregular accumulations of sand and gravel formed in association with masses of stagnant ice isolated in low areas during recession of the Rainy lobe. Sixteen eskers, the largest 20 miles long, have been identified and mapped. The internal constitution and structure and the external form, orientation, and arrangement suggest that they were formed largely by streams flowing chiefly in ice tunnels but possibly to some extent in ice-walled gorges. The esker streams flowed directly on the subglacial floor in some places, and in others they were not more than 10 to 20 feet above the glacier's base. Wide gaps in esker ridges are thought to represent places where the streams flowed across still thicker ice, so that the deposits eventually became superglacial and were dispersed. The internal "anticlinal" structure of at least one esker is considered to be a primary depositional feature, but the exact mode of origin of this structure is not understood. Crude drumloid ridges were formed in southwestern Cook County by the Rainy lobe.

INTRODUCTION

GENERAL statement.—Cook County lay directly in the path of continental ice masses which repeatedly moved south out of Canada and west-southwest down the Superior trough during the Pleistocene. Its glacial history must have been long and complicated, but the complete record is not preserved.

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Evidence has been found for only two ice invasions, both of Wisconsin age.

The Rainy lobe (Elftman, 1898, p. 108) moved down from the north and covered all of Cook County. The exact age of this advance is not known, but it is unquestionably Wisconsin, most likely about middle Wisconsin (Wisconsin III or Cary). The Superior lobe (Leverett, 1929, p. 7) came from the east-northeast, followed the Superior trough, and covered only a narrow strip of land along the southern edge of Cook County. Its age is presumed to be late Wisconsin (Wisconsin IV or Mankato).

Judging from Leverett's map (1932, pl. 1), he attributes all the drift mapped in Cook County to the Superior lobe. This is clearly refuted by evidence cited in following pages which shows that the Mankato Superior lobe extended at most 5.5 miles north of the present Lake Superior shore. Furthermore, this evidence does not support the contemporaneous occupation of parts of Cook County by the Rainy and Superior lobes as formerly suggested by Elftman and Leverett, nor are the features in Cook County previously mapped as end moraines believed to be such.

This study constitutes part of a geological investigation of Cook County made largely by F. F. Grout, and sponsored by

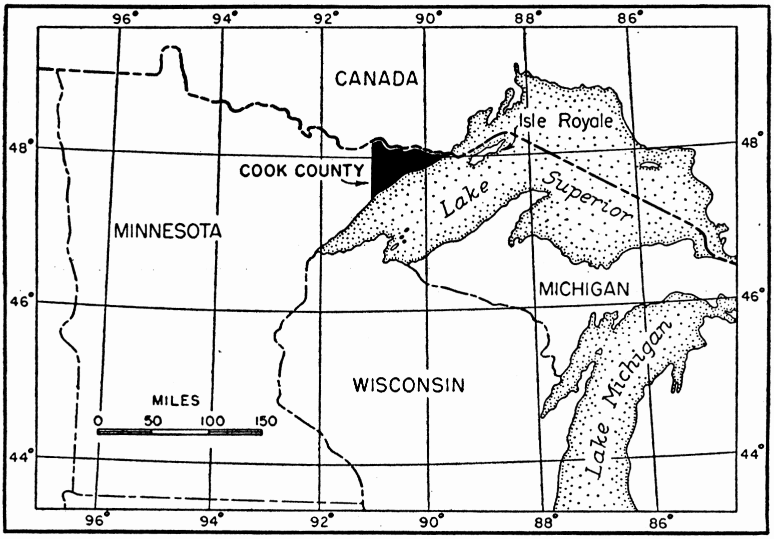

Fig. 1. Location map of Cook County.

the Minnesota Geological Survey. Appreciation is expressed for the aid, advice, and suggestions of Grout, G. M. Schwartz, and H. E. Wright. The Graduate School of the University of Minnesota provided funds for purchase of air photographs. Field work on the Pleistocene features of Cook County covered a period of approximately 3½ months in the summers of 1946 and 1947. Considering the size of the area and the vegetative cover, this must be classified as a reconnaissance study.

Physical setting.—Cook is the northeasternmost county (fig. 1) of Minnesota (47° 55′ N., 90° 30′ W.). Its triangular shape is determined by the eastward convergence of the Canadian border and the north shore of Lake Superior. About 17 percent of the total area of 1680 square miles in the county is said to be water-covered (Leverett and Sardeson, 1917, p. 50), but recent air photos suggest that this is an underestimate. The area is hilly, with local relief up to several hundred feet and altitudes ranging from 602 feet, the surface of Lake Superior, to 2230 feet in the Misquah Hills, the highest point in Minnesota. Were the water drained from Lake Superior, this figure would be increased nearly 1000 feet, and it is the total bedrock relief that is of principal significance in the glacial relations.

Physiographically, the county is divisible into three units: (a) the Coastal Hills along the shore of Lake Superior rising to elevations as much as 1200 feet above lake level within a few miles inland; (b) the Interior Upland, a rolling surface of slight relief lying north of the Coastal Hills at elevations between 1400 and 1900 feet with occasional ridges and groups of hills exceeding 2000 feet; and (c) the Northern Ridges and Valleys, or the Rove area, which features long lake-filled valleys at altitudes of 1500 to 1800 feet lying beside cliff-faced cuesta ridges in some instances almost 500 feet higher.

The bedrock of Cook County is wholly Precambrian, with Saganaga granite, Ely greenstone or Knife Lake series, Pokegama quartzite and Gunflint iron formation in the northwest; Rove formation slate, graywacke, and diabase in the north and northeast; largely Duluth gabbro with redrock differentiates and Keweenawan volcanics in the Interior Upland; and chiefly Keweenawan volcanics and red sedimentary beds, with diabase intrusives, in the Coastal Hills (Thiel, 1947, figs. 15-16).

The number of lakes in Cook County, excluding swamps, probably exceeds 1000. The deepest, aside from Lake Superior, is Saganaga Lake at 240 feet, and the largest lying wholly within the county is Brule Lake, which covers 4062 acres.[1] Several of these lakes have multiple outlets.

This is essentially a sparsely settled "wilderness" area with only a few roads and trails. It is covered by a dense second-growth forest of deciduous and coniferous trees with an undergrowth of other plants (Butters and Abbe). The available maps are small scale and planemetric only, but air-photo coverage is now available for the entire county.

GLACIAL EROSION

The principal effects of glacial erosion in Cook County are small markings on ice-scoured outcrops, including polish, striations, grooves, chattermarks, friction cracks and small joint-controlled excavations; and larger landscape features such as rounded outcrops, glacially scoured and plucked hills and ridges, and basins and valleys excavated in the bedrock. Only those erosional features useful in determining direction of ice movement are considered here.

Most Rainy lobe striations bear within 30° on either side of south (fig. 2). The various trends appear to reflect the influence of local topographic situations and were undoubtedly controlled to some degree by the direction of slope of the glacier's surface according to principles best presented by Nye (1952, p. 92). Striations show that flow within the Rainy lobe changed from a southerly to a southeasterly direction in the southern part of Cook County. This was probably due to the southeasterly slope of the land approaching the Lake Superior trough. Superior lobe striations show movement west-southwest down the Lake Superior trough, with a slight tendency to fan out northwestward onto the adjacent upland. This fanning probably expresses the control on direction of flow exerted by a relatively steep outward slope of the ice surface along the margin of the lobe.

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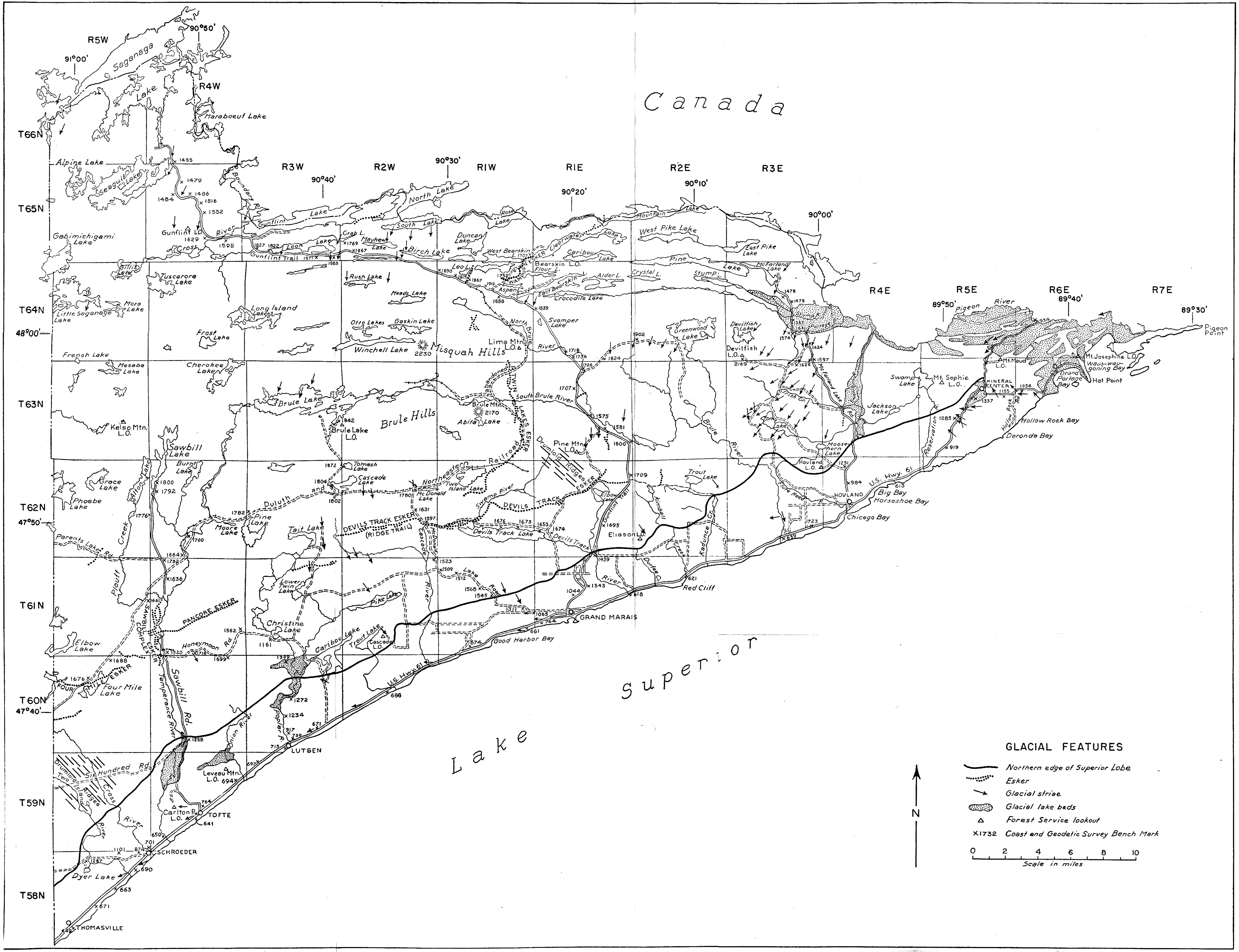
[1] Data on lakes kindly supplied by Professor Samuel Eddy of the University of Minnesota. An excellent publication on Minnesota lakes is also now available (Zumberge, 1952).



NOTE: SVAMPER LAKE (T. 64 N., R. 1 E.) SHOULD READ SWAMPER LAKE.

Fig. 2. Map of glacial features in Cook County.

Of the several types of friction cracks described by Harris (1943) only crescentic fractures were found in this region, an especially fine display being on an outcrop of Northern Light gneiss in the northeast arm of Saganaga Lake just north of Cook County. Many glaciated rock surfaces have joint-controlled scars, a few inches to one or two feet across and an inch or two deep, from which a mass of rock has been plucked. Most scars are defined by one joint plane dipping gently with or against the direction of flow and by one or more steep joints transverse to the direction of flow (fig. 3). Modification of these scars by glacier scour shows that they were formed beneath moving ice, or at least were overridden by it, and the asymmetry of scouring indicates the direction of ice movement.

Most of the prominent bedrock hills and ridges in Cook County show some degree of asymmetry related to glacial plucking and oversteepening on their lee slopes. Carlton Peak near Tofte has steep sides to both the south and west,

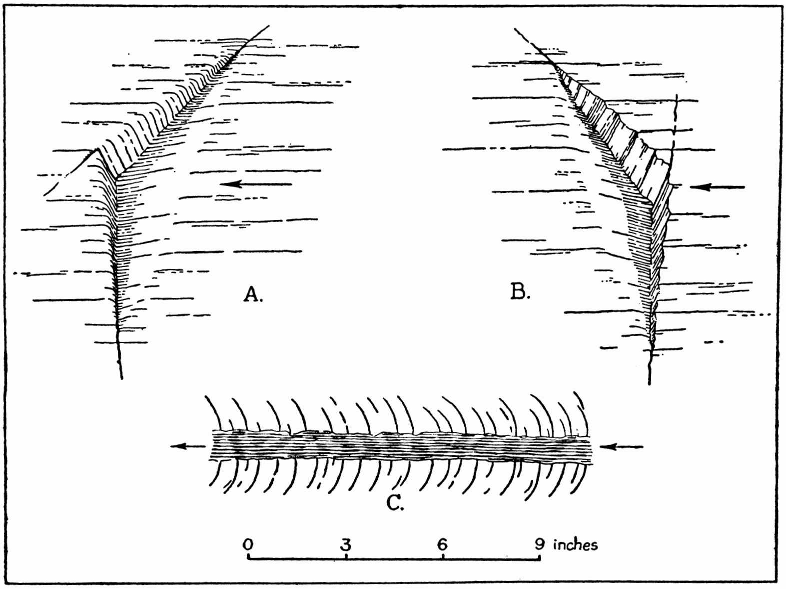


Fig. 3. Field sketches of minor features on glaciated bedrock surfaces. A—joint-controlled excavation with ice moving against gently dipping face. B—same with ice moving against gently dipping face. C—vertical view of glacial gouge and associated crescentic fractures. Arrows indicate direction of ice movement.

perhaps reflecting initial plucking by the south-moving Rainy lobe and later plucking by the west-flowing Superior lobe. Exceptions to the usual asymmetry are afforded by cuesta-like strike ridges underlain by massive diabase sills in the Rove area of northern Cook County (Grout and Schwartz, 1933; Zumberge, 1952, p. 24-30). Here rock structure is the predominant influence, and the steeper slopes of these ridges are to the north, facing against rather than with the direction of ice movement. This came about because glacier plucking and sapping of fissile sedimentary beds underlying the south-dipping diabase sills created or at least maintained a steep face to the north.

GLACIAL DEPOSITION

Brown sandy till (Rainy lobe, Cary or Wisconsin III).—The most extensive glacial deposit in Cook County is a discontinuous mantle of brown sandy till left by a south-moving ice mass which covered the entire county. Good exposures of this till can be seen along Sawbill road (T. 60 N., R. 4 W.), along Gunflint Trail south of Swamper Lake (T. 64 N., R. 1 E.), and along the abandoned right-of-way of the Duluth and Northeastern Railroad east and west of Sawbill road (Ts. 61 and 62 N., Rs. 4 and 5 W.).

Brown is the prevailing color with minor and local variations to grayish, blackish, and reddish hues. The till is stony with a sandy matrix. Less than 5 percent has a matrix of clay or silt, probably obtained by local incorporation of lake deposits. Stones are composed of gabbro, intermediate and redrock differentiates of gabbro, diabase, taconite, jasper, iron formation, greenstone, granite, porphyritic granite, syenite, gneiss, schist, amygdaloid, felsite, rhyolite, basalt, basalt porphyry, quartzite, graywacke, red and white arkosic sandstones, and quartz-pebble conglomerate. The largest boulders are 15 feet in diameter. The till shows many compositional variations reflecting the nature of underlying or nearby bedrock. Near exposures of the Rove formation, for example along the road just south of McDonald Lake, it consists largely of fragments of argillite with some quartzite, graywacke, and diabase. On or near belts of redrock it is composed of redrock stones set in a sandy matrix of ground up redrock. Till in which 90 percent of the stones are redrock has been observed to grade within one mile to till in which 90 percent of the stones are Keweenawan volcanics.

The till is loose and uncemented in most exposures, displays considerable oxidation, and shows some decomposition and disintegration of rocks especially susceptible to weathering, chiefly the olivine gabbros and diabases. The soil mantle is thin, and its profile immature. Average thickness of the till probably does not exceed 15 feet, and in many places it is even thinner although wells suggest greater thicknesses in favorable spots (Thiel, 1947, p. 98-102). Along the old railroad grade northeast of Sawbill road are exposures of brown

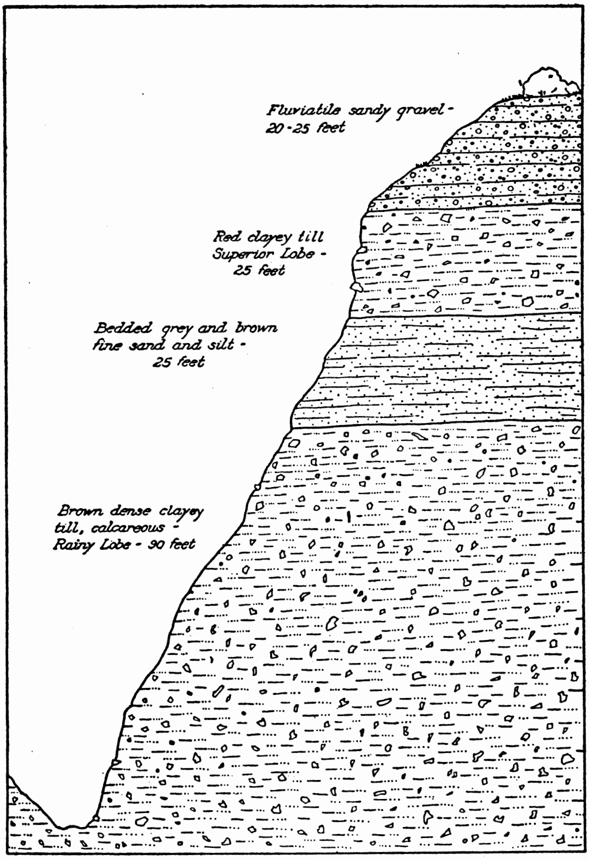


Fig. 4. Field sketch of drift section exposed in east wall of Brule River gorge just below Pothole Falls (south center of Sec. 22, T. 62 N., R. 3 E.).

sandy till 35 to 50 feet thick, and near Pothole Falls on Brule River (Sec. 27, T. 62 N., R. 3 E.) 93 feet of brown calcareous clayey till are exposed beneath sandy silts and red clayey till (fig. 4). This brown clayey till is provisionally included with the brown sandy till, although it might be older.

Leverett (1932, pls. 1 and 3) appears to attribute the brown sandy till to the Superior lobe, although Elftman (1898, p. 92-96, 108-109) had earlier attributed it to the Rainy lobe. Elftman's interpretation is considered correct for the following reasons: (1) Striations (fig. 2) associated with the brown sandy till trend mostly within 30° of north and south. That the movement was southward is shown by the asymmetry of glaciated bedrock hills, by minor joint-controlled depressions, by friction cracks, and most definitely by composition of the till. (2) Numerous exposures along the south edge of the county display brown sandy till underlying red clayey till.[2] This relation is somewhat obscured by red illuvial clay which has been carried down into the brown till from the overlying deposits, but it has been confirmed repeatedly, and in places glacifluvial beds (figs. 4 and 5) lie between the two tills. It is clear that the brown and red tills are two distinct deposits and that the brown till was formed by a south-moving ice mass, for which Elftman's (1898, p. 108) term, the Rainy lobe, is accepted. This advance probably occurred in the Cary (Wisconsin III) substage, but treatment of age relations is taken up following consideration of the red clayey till.

Both Elftman (1898, pl. 11) and Leverett (1929, p. 28-29; 1932, pl. 1) mapped end moraines in the area covered by the Rainy lobe. Careful restudy of the features so mapped shows that they are either bedrock ridges thinly mantled with till or accumulations of glacifluvial material developed in association with isolated bodies of stagnant ice. No definite end moraines were found in all of Cook County.

Red clayey till (Superior lobe, Mankato or Wisconsin IV).— The Superior lobe moved west-southwest along the Lake

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[2] This stratigraphic relation appears to have been discovered by Franklin B. Hanley whose work in Cook County was cut short by death in 1944. Hanley's field notes could not be located, but the caption on one of his lantern slides at the University of Minnesota identified red till resting on brown till in Cook County.

Superior trough and left a discontinuous mantle of red clayey till over a belt 3 to 5.5 miles wide on the southern margin of Cook County (fig. 2). This till is best preserved in the broad valleys of the Coastal Hills, and good exposures can be seen along Caribou Lake road (Sec. 11, T. 60 N., R. 3 W.), along U. S. Highway 61 at Poplar Cemetery 1.5 miles west of Grand Marais, along a road east of Poplar River (center of Sec. 21, T. 60 N., R. 3 W.), and on Gunflint Trail north of Grand Marais (Secs. 9 and 10, T. 61 N., R. 1 E.). Most of this till is red or pink, but in places near the base it is brownish pink and locally brown owing to incorporation of brown lake clay or brown sandy till. Younger red lake clay has been laid down over much of the area covered

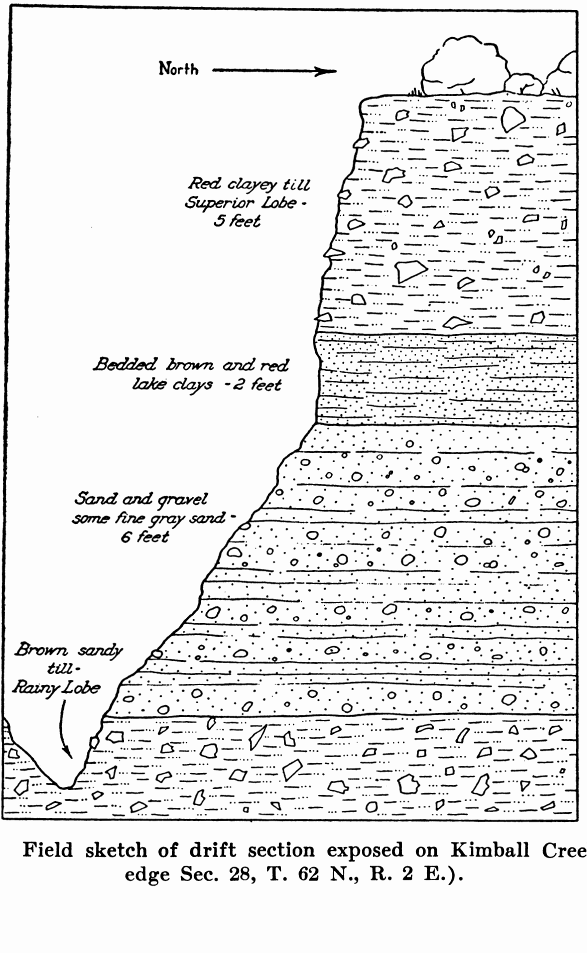

Fig. 5. Field sketch of drift section exposed on Kimball Creek (south edge Sec. 28, T. 62 N., R. 2 E.).

by the Superior lobe, and every exposure of red clay-rich material raises the problem of distinguishing between clayey till and lake clay. This is especially difficult where the lake clay has been affected by some mass movement.

In its typical form the till is compact and contains 60 to 80 percent red clay, both as matrix and as discrete fragments. Sandy and stone-rich facies are rare. Most are 0.5 to 4 inches in diameter, but some attain 2 feet. The most abundant rock types are rhyolite, basalt, redrock, diabase, greenstone, granite, gneiss, white and red arkosic sandstone, conglomerate, and a little cream-colored limestone. The only stones lithologically distinct from those in the brown sandy till are the limestone and a dense uniform greenstone, both of unknown source. Fragments of Keweenawan sandstone, conglomerate, basalt, and rhyolite are considerably more abundant than in the brown sandy till.

At Big Bay and on Poplar River the red clayey till is calcareous. On the crest of a well-drained ridge along Poplar River it is leached of carbonates to a depth of 2.5 feet. In general, the visual weathered zone on the till is only 16 to 18 inches thick, consisting of 6 to 12 inches of dark humic soil underlain by brownish oxidized material. The modest depth of alteration may reflect both the impervious nature of the till and a relatively short interval of weathering.

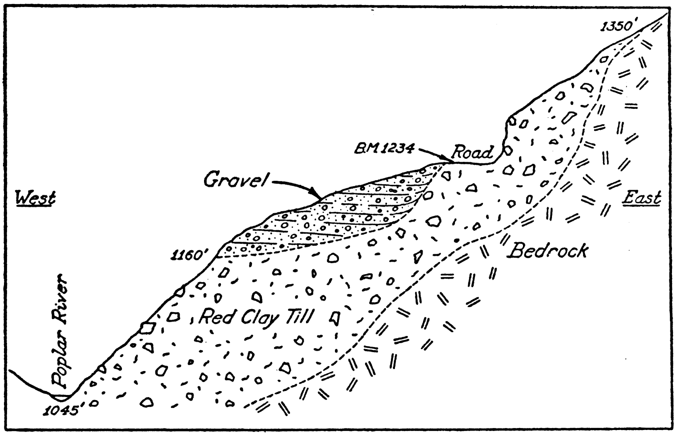

Fig. 6. Interpretative sketch of relations on Poplar River suggesting a thick till filling in a preglacial rock gorge (south center of Sec. 21, T. 60 N., R. 3 W.).

PLATE 1

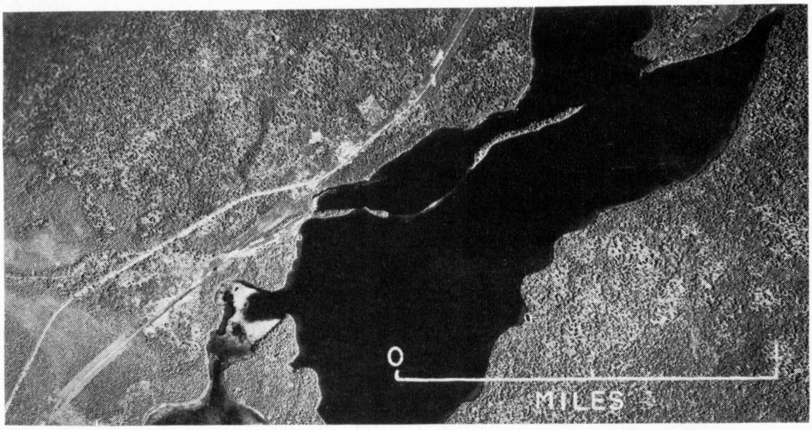

Fig. 1. Fourmile esker in Fourmile Lake (T. 60 N., R. 5 W.). Top is north. U. S. Forest Service air photo.

Fig. 2. "Anticlinal" bedding in Wampus esker near West Bearskin Lake (NW. ¼ Sec. 1, T. 64 N., R. 1 W.). Material is largely coarse sand and fine pebble gravel.

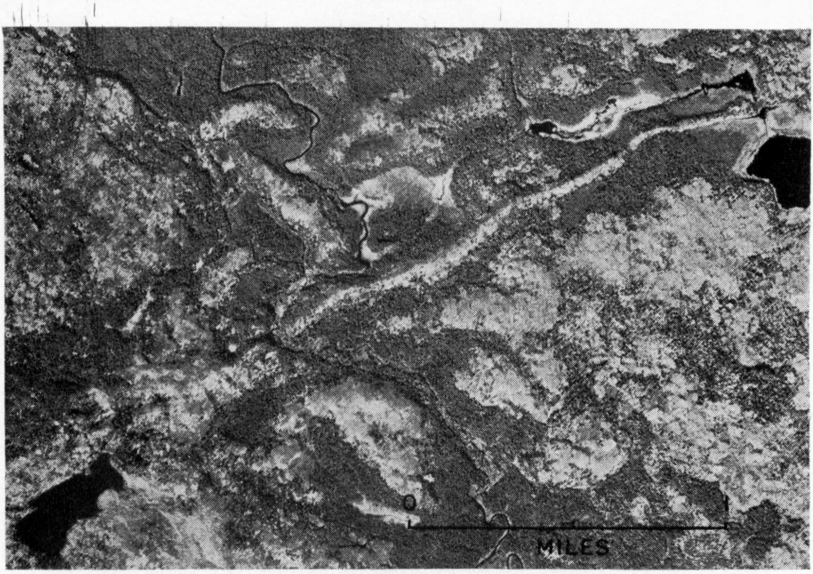

Fig. 1. Pancore esker between Pancore and Missouri lakes; Poplar River in middle (T. 61 N., R. 4 W.). Top is north. U. S. Forest Service air photo.

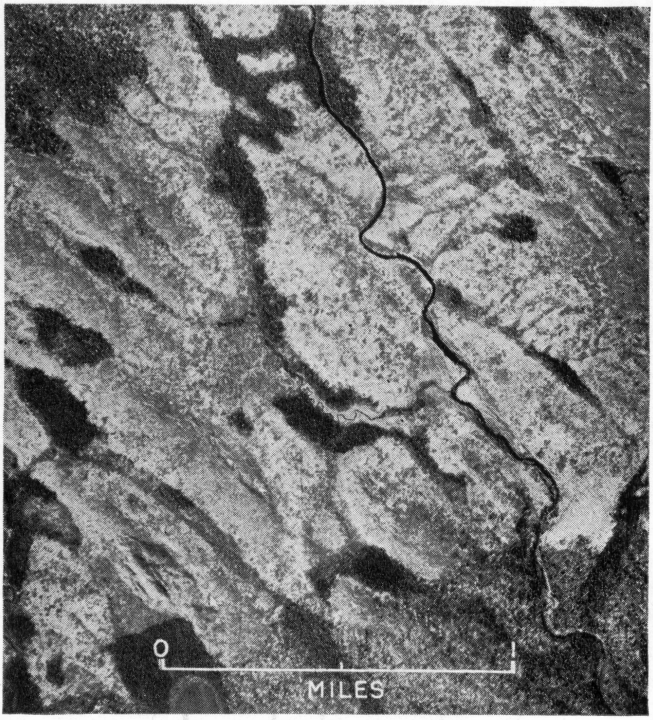

Fig. 2. Drumloid topography along Cross River in T. 59 N., R. 5 W. Top is north. U. S. Forest Service air photo.

In most exposures, the red clayey till is 5 to 15 feet thick, but locally as much as 25 feet is seen, and somewhat greater thicknesses are recorded in some wells (Thiel, 1947, p. 98-102). Along Poplar River (Sec. 21, T. 60 N., R. 3 W.) the exposures and relations depicted in figure 6 suggest that a preglacial rock gorge was filled to a depth of 200 to 250 feet by red clayey till.

The lack of sharp topographic features on the Superior lobe till is probably due to its high content of clay which gives great mobility when wet and facilitates spreading into low inconspicuous forms. The topography, composition, and thickness of the till deposits northwest of Grand Marais (Sec. 15, T. 61 N., R. 1 W.) are more suggestive of an end moraine than any other accumulation in Cook County, but even so they do not constitute a convincing example of such a feature.

Age of glaciations.—The abundant lakes, the freshness of the glacial forms, especially those composed of glacifluvial materials, and the lack of deep or advanced weathering preclude an age greater than Wisconsin and favor mid-Wisconsin or younger for the two drifts in Cook County. The distribution of Cary (Wisconsin III) drift farther south indicates that Cook County could hardly have escaped being glaciated during this substage, and similar relations suggest that it could have been partly or completely overrun by Mankato ice. H. E. Wright (1952) has collected evidence farther west and south in Minnesota indicating Cary and Mankato advances of both the Superior and Rainy lobes. Ruhe (1952, p. 400, fig. 2) shows all of Cook County as covered by Mankato ice, but this appears to be an unsupported generalization.

Even though the red clayey till overlies the brown sandy till, both might be either Cary or Mankato. However, the preferred interpretation assigns the brown sandy till to the Cary and the red clayey till to the Mankato. This interpretation hinges on the interval of time between deposition of these two tills, a point on which the local evidence is indicative but not compelling. It is as follows:

No perceptible evidence of weathering has been found on the brown till where overlain by red till, but considerable incorporation of brown material in the basal red till suggests glacial erosion along this contact, and Thwaites (1943, p. 136) could find little evidence of weathering between Valders

(Mankato) and Cary till in Wisconsin. Weathering at this contact would be decisive, but under these circumstances its absence is not fatal to the preferred interpretation. More positive evidence is furnished by red lake clays, derived from the Superior lobe, which were deposited over an area in northern Cook County formerly occupied not only by the Rainy lobe but also by a lake receiving debris from that lobe as it shrank. The Rainy lobe must have receded north of the Canadian border before the Superior lobe was in a position to shed meltwater and debris into this area, the basins of the Pigeon and Stump rivers.

These relations suggest that the culminating phases of the two ice lobes were not closely contemporaneous. The Cary-Mankato interval appears to have been relatively brief in Iowa, southern Minnesota, and the Dakotas (Flint, 1950, p. 1461; Ruhe, 1952), and it was probably even shorter in areas closer to the center of glaciation, such as Cook County, because of the shorter time between the waning and waxing phases of successive glaciations. H. E. Wright (personal communication) and associates have obtained evidence farther west in Minnesota suggesting that ice which deposited the brown sandy till in Cook County was distinctly earlier than other ice masses considered to be Mankato on independent evidence. For these reasons a Cary age is favored for the brown sandy till in Cook County. Leverett (1929, p. 21, 38-39) has assigned a Mankato date to the red clayey till in Cook County largely on the basis of regional studies, and nothing incompatible with this dating has been discovered during the present work. If these age assignments are correct, evidence for a Superior lobe of Cary age (H. E. Wright, 1952) has not been found here, and behavior of the Rainy lobe in relation to Cook County during Mankato time remains unknown.

Glacial lake deposits.—Parts of Cook County have been occupied at various times by extramarginal glacial lakes which received meltwater and debris from the ice. Their former existence is demonstrated primarily by beds of red clay, locally calcareous and in some places resting upon older beds of brown non-calcareous clay and silt. Such lake deposits are exposed principally in the valleys of the Stump, Swamp, and Pigeon rivers; the Mineral Center region; the lower valleys of the

Poplar, Onion, and Temperance rivers; and in areas immediately bordering Lake Superior (fig. 2).

In the broad flat valley of Stump River 1 to 2 feet of red clay rest with sharp contact on brown clay layers interbedded with silt in a manner faintly suggestive of varves. Total thickness of the brown beds is not known, but it is at least several feet. Around the margins of this valley the brown beds rise to 1415 feet altitude, but the red clay attains only 1385 feet. Red clay beds extending up to 1385 feet altitude on Swamp River and its tributaries were deposited in an arm of the same lake that flooded Stump River. Exposures and excavations on Swamp River were too shallow to show whether these red beds are also underlain by brown lake deposits.

The water body occupying the valleys of the Stump and Swamp rivers was named Lake Omimi by Elftman (1898, p. 104), but Leverett (1929, pl. 2) considered it to be part of Lake Duluth. The interpretation favored here is that these valleys were flooded at two different times, the brown beds being deposited in a body of water nourished by the Rainy lobe, namely Lake Omimi, and the red beds originating in a later lake dammed and fed by the Superior lobe. This second lake was not part of Lake Duluth, however, for that water body did not rise to a level high enough to flood Stump River (Sharp, 1953, p. 116). The nature of the dam impounding Lake Omimi is not known, but it may have been a detached and stagnant mass of Rainy lobe ice somewhere along the Pigeon River. It seems unlikely that the Superior lobe formed the dam because the generally sharp contact between the red and brown beds suggests that red material was not being contributed to the lake while the brown beds were being deposited.

Much of the lower Pigeon River-Grand Portage region is covered by lake deposits. Not all parts of this region shown on the map (fig. 2) as lake beds have been visited in the field, but their elevation, appearance on air photographs, and relation to areas known to be underlain by lake beds favor this interpretation. About 200 yards south of Pigeon River on U. S. Highway 61, at 980 feet altitude, 20 feet of red clay overlie with sharp contact 30 feet of brown silty clay. Southward along U. S. 61 the red clay decreases in thickness and rises to 1400 feet. As on Stump River, the brown silty clays are attributed to an earlier lake nourished by the Rainy lobe and the red clay to a later lake receiving debris from the Superior lobe. The considerable thickness of red beds at the Pigeon River locality is probably due to additional deposition in a succession of lakes marginal to the Superior lobe, including Lake Duluth and stages of Lake Algonquin.

Mineral Center (T. 63 N., R. 5 E.) is situated in a broad basin covered with at least 7 feet of red lake clay. This clay is massive to poorly bedded, and contains calcareous nodules as well as occasional stones and patches of sand. Since the upper limit of these clay beds, 1350 feet, is above any known or postulated level of Lake Duluth in this vicinity, they are assigned to a somewhat older lake held at a higher level along the margin of the Superior lobe. The water body at Mineral Center appears to have been independent of the lakes on Stump and Pigeon rivers.

In the southwestern part of the county, lake beds are exposed in the valleys of Poplar, Onion, and Temperance rivers on the northern side of the Coastal Hills (fig. 2). For the most part these accumulations are thin and consist entirely of red clay, but at Oxbow Camp on Temperance River (Sec. 33, T. 60 N., R. 4 W.) the 50 feet of red clay exposed contains interbeds of fine brownish sand and silt near the top. The upper limit of lake beds is 1309 feet on Poplar River, 1250 feet on Onion River, and 1240 feet on Temperance River. These elevations are above known or postulated shorelines of Lake Duluth at these places (Sharp, 1953, p. 116), so the deposits are attributed to marginal lakes formed when the valley mouths were dammed by the Superior lobe. Meltwater carried red debris north into the lakes which must have attained their maximum extent after some recession of the ice had occurred, for the beds lie largely in areas formerly covered by the Superior lobe. The brown sand and silt near the top of the Temperance River section were probably reworked from Rainy lobe drift.

The land immediately bordering Lake Superior was submerged by Lake Duluth and its successors, and within this area are scattered deposits of red lake clay up to 10 feet thick.

The high content of red lake clay in Superior lobe till indicates that the ice moved over areas mantled by lake beds older than any red beds discussed so far, and on Kimball

Creek is an exposure (fig. 5) showing 2 feet of red clay beneath red clayey till. Such clay beds may have been deposited in a proglacial lake related to a receding ice mass such as Martin's (1932, p. 453-457) Lake Rouge or Lake Sioux or Murray's (1953, p. 153) Lake Keweenaw which formerly occupied the Superior basin. However, there is no proof that the beds on Kimball Creek were not deposited in a smaller lake bordering the advancing Superior lobe. Clay-rich phases of the Rainy lobe till also suggest incorporation of earlier lake beds, and brown silty clays are exposed beneath the brown till along Gunflint Trail just south of Devils Track River.

From the above, it appears that late Pleistocene glacial lakes occupied parts of Cook County at the following times: (1) prior to or during the early stages of the Rainy lobe advance, (2) during or shortly after recession of the Rainy lobe, (3) prior to or contemporaneously with advance of the Superior lobe, (4) during the climax and recessional phases of the Superior lobe, and (5) after all ice had disappeared from Cook County but still lay in neighboring regions (Lake Duluth et al.).

Irregular glacifluvial accumulations formed in association with stagnant ice.—Deposits of glacifluvial material with extremely irregular topography cover parts of central and northern Cook County. The most accessible are along Sawbill road (T. 61 N., R. 4 W.), at the west end of Devils Track Lake (T. 62 N., R. 1 W.), in the vicinity of Elbow Lake (T. 62 N., R. 1 E.), and in some of the northern valleys, particularly near Leo, Hungry Jack, Aspen, Flour, West Bearskin, and Clearwater lakes (Ts. 64 and 65 N., Rs. 1 W. and 1 E.). These deposits stand out in the landscape and on air photos because of their topographic peculiarities, and in the past some of them were mapped as end moraines (Elftman, 1898, pl. 11; Leverett, 1932, pl. 1). As shown in the following discussion this interpretation is considered erroneous, and similar accumulations in other areas likewise have caused confusion (J. W. Goldthwait, 1938; Mannerfelt, 1938).

In grain size the glacifluvial materials range from sand to boulders, and the stones are the same as in the brown sandy till. Bedding, sorting, and rounding of particles range from poor to good, and in most places the deposits are clearly waterlaid. Locally a layer of bouldery unbedded detritus containing erratics up to 15 feet in diameter mantles the glacifluvial deposits. This mantle is generally thicker and coarser than a slopewash or a lag concentrate, and it is probably composed of superglacial detritus dumped onto the glacifluvial beds from nearby higher masses of ice.

Topographically the glacifluvial materials form a complex of swells and swales, knobs and kettles, and short ridges without consistent trend, pattern, or character. The ridges bifurcate, intersect, broaden or thin, and change direction abruptly. Some of the knobs are strung together as beaded ridges. The local relief is 20 to 50 feet and slopes are steep, mostly 20 to 30 degrees. Lowland areas are the favored topographic setting for glacifluvial accumulations.

The origin of these deposits is pictured as follows. As the waning Rainy lobe thinned by down-melting (Ahlmann, 1938, p. 337; Flint, 1942) masses of ice lying in lowland areas became isolated from the main body owing to the relatively strong relief of the subglacial floor. These isolated masses stagnated and wasted away in situ. A heavy cover of superglacial debris developed and was moved about on the extremely irregular surface that seems to characterize most masses of stagnant ice. Both ponded and running water were abundant, and drainage from nearby slopes and outwash from other ice masses probably brought considerable debris to these areas. The volume of material seems too large to have come solely from the stagnant ice.

Eventually, the ice melted away completely in a few places, and here the deposits were laid down in their final resting place upon the ground. Such spots were probably originally small, irregular in outline, largely unconnected, and partly or wholly enclosed by walls of ice. As wastage continued they became larger, even more irregular, and were integrated to some degree with each other. Eventually, as the ice grew thinner and the deposits thicker, or at least more concentrated, large masses of ice were completely buried in debris. Subsequent melting of these buried masses caused collapse and slumping of the overlying and bordering deposits. The knobs, swells, and ridges of the present topography therefore represent areas where the ice disappeared first and the thickest deposits accumulated, and the swales and kettles represent areas where ice lingered longer and the deposits were thinner. The ridges were formed in elongated depressions which may have been controlled to some degree by structures in the ice.

The suggestion has been made that some glacifluvial deposits resembling those in Cook County are of subglacial origin (Ver Wiebe, 1927, p. 177; Andersen, 1931, p. 613; Priehäusser, 1938, p. 109). According to this concept deposition occurs under thin stagnant ice that is essentially afloat in its own melt-water, and the topography developed is supposedly a cast of the bottom of the overlying ice mass. The large volume of the Cook County deposits, their sharp topographic forms with slopes at the angle of repose, and the lack of internal structures conformable to the supposedly molded forms suggest that this mode of origin does not apply here. Thwaites (1943, p. 106) was also unsuccessful in finding indications of a subglacial origin for similar deposits in Wisconsin.

Eskers.—The sixteen eskers mapped in Cook County are grouped largely in two belts, one extending west-southwesterly to the western edge of the county, and a second extending southward from the Canadian border and almost joining the first (fig. 2). Without much imagination these two belts and most of the component eskers within them could be joined into a single stream-like system. Notable eskers are Fourmile (pl. 1, fig. 1), Pancore (pl. 2, fig. 1), Devils Track (fig. 7), Twin

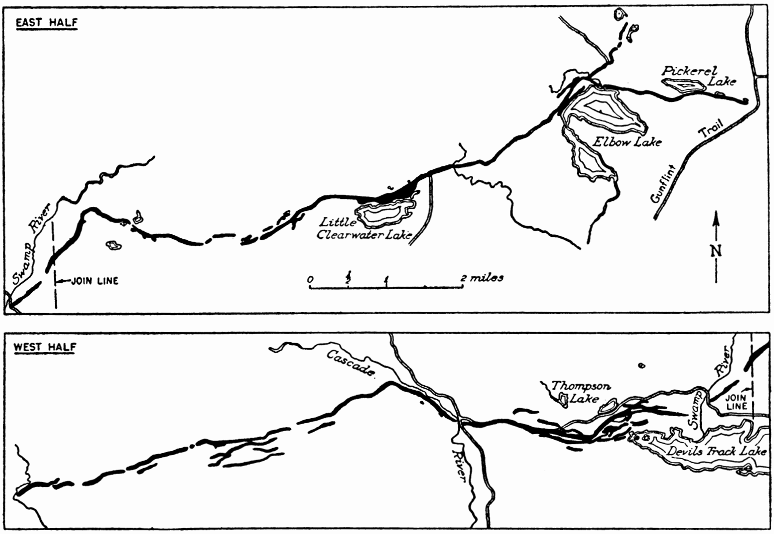

Fig. 7. Map of Devils Track esker.

Lake (fig. 8) and Wampus (fig. 9). No Cook County eskers are situated on or cross topographic eminences, and none was found in areas covered by the Superior lobe. Those of the west-southwest belt trend almost at right angles to the direction of movement within the Rainy lobe, as indicated by nearby striae, and thus provide an exception to the generalization that eskers are usually parallel to the direction of glacier flow (Flint, 1947, p. 151).

Gravel is the major constituent of Cook County eskers, but sand is abundant in the matrix and locally composes individual beds. In places Wampus esker consists largely of fine to coarse sand with a little pebble gravel (pl. 1, fig. 2). Boulders up to 4 feet in diameter are embedded in the esker deposits, and larger boulders, some 15 feet across, are scattered about on the surface. A structureless mantle of bouldery detritus, 2 to 3 feet thick, on the crests and slopes of many Cook County eskers looks like ablation debris deposited from overlying or nearby ice. Similar mantles in other areas have been interpreted as a slopewash or lag concentrate (Brown, 1931, p. 476).

Stones in the esker gravel are subangular and their wide range in composition indicates that they have been derived in large part if not wholly from Rainy lobe ice or the brown sandy till. Eskers are usually composed of reworked ice-carried debris (Trefethen and Trefethen, 1944), and there is no indication here that much of the material was derived by direct erosion of the bedrock by the esker-forming stream (Hershey, 1897, p. 244). Sorting and bedding are poor except in a few layers of pebbly gravel and of sand. Small-scale cross bedding was observed, but larger deltaic foresets are lacking. The pseudo "anticlinal" structure characteristic of many eskers is shown here in a few instances. Mostly it appears to be related to surficial slumping or creep, but Wampus esker shows an internal "anticlinal" structure which is not the product of surficial processes (pl. 1, fig. 2).

Most Cook County eskers are 20 to 30 feet high, some attain 50 feet, and a few are 80 to 90 feet high. Lengths of 0.5 to 3 miles are usual, but Twin Lake esker is at least 10 miles long, and Devils Track esker can be traced with confidence for 20 miles. Side slopes range from 20° to 35°, depending upon material, and asymmetry in cross section is not uncommon. The steeper slope is not consistently on the same side in neighboring eskers or in different places on the same esker. The internal bedding of Wampus esker in one locality dips 34° west and 25° east, roughly conformable with its external form. Air photos and field observations suggest that the steeper

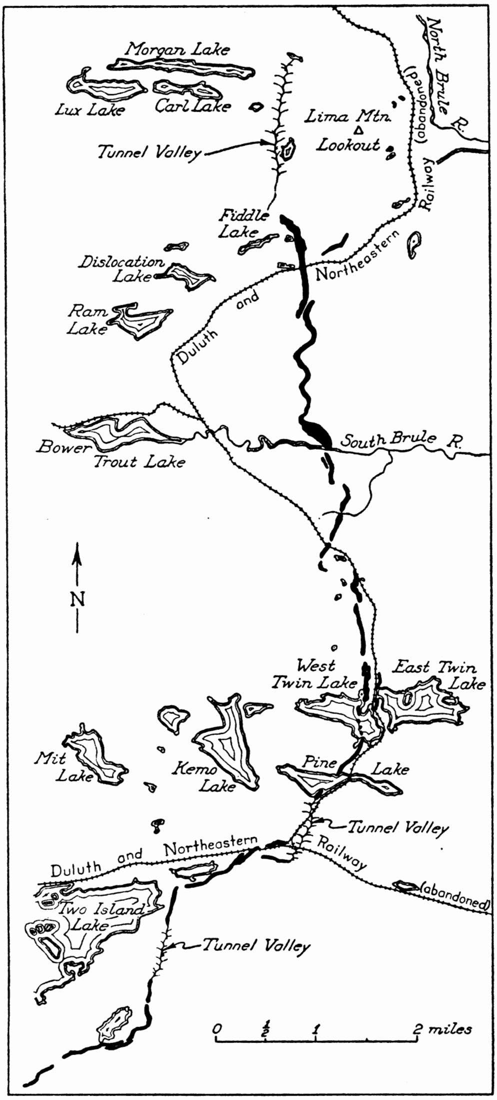

Fig. 8. Map of Twin Lake esker.

side marks a tendency toward lateral shifting by the esker-forming stream, for it is located largely on the outsides of curves.

Most of these eskers are irregular in plan. Neither the nearly straight 2-mile stretch of Pancore esker (pl. 2, fig. 1) nor the symmetrical meandering curves near the north end of Twin Lake esker (fig. 8) are typical. Some single ridges bifurcate and reunite thus inclosing a deep, steep-sided depression, a habit well shown by some Canadian eskers (Lang, Bostock, Fortier, 1947, A 4218-32). Single ridges also locally give way to a braided or reticulate network of ridges or to irregular glacifluvial deposits with knob and kettle topography. At curves some eskers display several subparallel ridges as though the esker stream underwent a succession of lateral shifts. This is not universal nor are subparallel ridges limited to curves. Stream-like tributary branches also exist, for example, on Devils Track esker at Elbow Lake (fig. 7) which, unless it is a barbed junction, indicates that the esker stream flowed westward. The Sawbill assemblage, consisting of an irregular arrangement of short subparallel esker ridges of north-south and east-west trend, is best termed an esker complex.

Stream-cut channels interrupting the course of an esker were found only along Twin Lake esker (fig. 8), which displays narrow gorges cut 10 to 30 feet into low bedrock prominences in three places along its course. These appear to have been formed by the same stream that built the esker, and in some areas they are known as esker valleys or tunnel valleys (Andersen, 1931, p. 616). Devils Track is the only Cook County esker with an extensive marginal fosse or esker trough.

The origin of eskers has been long debated, and many aspects of the problem remain unsettled. It is clear that the various features to which the name esker has been applied were not all formed in exactly the same way. Deposition by streams of glacial meltwater in intimate association with the ice is accepted as the principal mechanism. However, the details of the process and the various conditions under which it operates are not yet agreed upon.

According to one concept, deposition occurs at the mouth of a stream debouching into ponded water at the margin of the ice. As the ice front recedes a succession of elongated delta segments is built and joined together to form an esker (DeGeer, 1910, p. 243-245; W. B. Wright, 1914, p. 41-43; Flint, 1947, p. 153). In Scandinavia associated varves are said to show that each delta segment is an annual deposit, and experiments (Hanson, 1943, p. 451-452) suggest that esker-like forms can be built in this manner. Accumulation at the margin of a receding ice front without benefit of ponded water has also been advocated (Hershey, 1897, p. 244; Trowbridge, 1914, p. 216).

In the United States a generally favored concept has been one of deposition from heavily laden streams flowing in tunnels beneath stagnant or relatively inactive ice. Deposition is variously attributed to overloading, to choking of the mouth of the stream by proglacial deposition (Russell, 1893, p. 240-242), to an opposed gradient on the glacier's floor (Chadwick, 1928, p. 926), and to ponding of water beneath the ice (Andersen, 1931, p. 613-614; Flint, 1930, p. 628-629; Lewis, 1949, p. 318; Meier, 1951, p. 293). Minor compressional deformation of the esker deposits suggests that the ice forming the tunnel need not have been entirely inactive (Flint, 1942, p. 130-131).

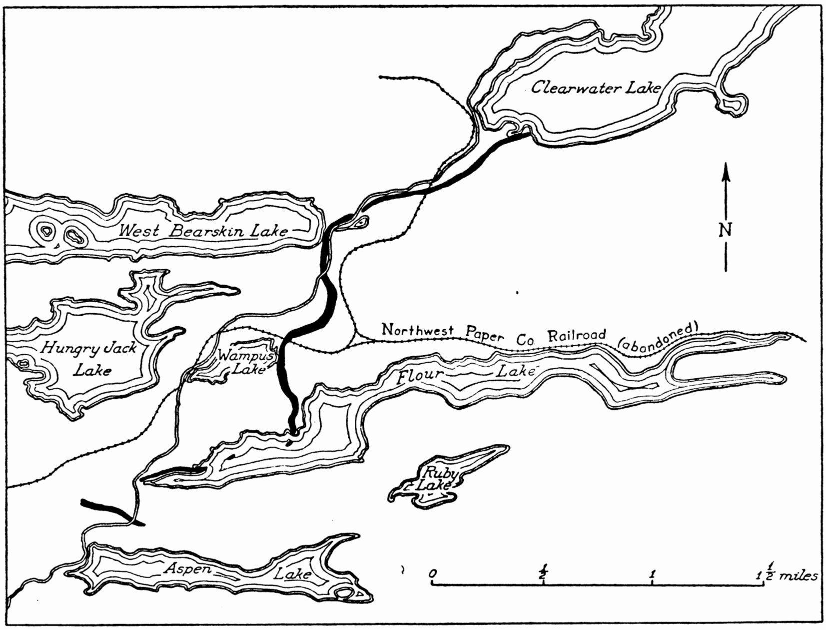

Fig. 9. Map of Wampus esker.

The formation of eskers by englacial (Alden, 1925, p. 54) or superglacial streams (Winchell, 1884, p. 668-669; Crosby, 1902) has not been widely accepted, although Hartshorn (1952) feels that some eskers associated with the Malaspina Glacier may have had a superglacial origin. The difficulty here lies in transferring superglacial or englacial accumulations to the ground without seriously altering or destroying them, a problem to be considered in more detail shortly. Wilson (1939, p. 126-127) proposes that certain Canadian eskers were formed by streams, initially superglacial, which cut their channels through the thin edge of an ice sheet and reworked the debris in and at the bottom of the ice. This type of esker is formed in an ice-walled gorge open to the sky and is supposedly built headward as the ice front recedes. Open ice-walled gorges are also favored by others (Dryer, 1901, p. 128; L. Goldthwait, 1939, p. 114-115), and often the evidence does not permit one to distinguish between deposits originating in subglacial tunnels and open ice-walled gorges (Thwaites, 1943, p. 110).

Eskers associated with existing glaciers throw some light on the problem of origin, and Washburn's (1941, p. 222) fine photograph of an esker extending outward from the Woodworth Glacier, Alaska, furnishes the following information although confirmation by study on the ground is needed: (1) The ice front has receded in normal fashion without evidence of stagnation in the immediate vicinity of the esker, although isolated bodies of stagnant ice have been left in nearby areas. (2) Erosional channels cut in the ground moraine between the end of the esker and the present ice edge appear to have been formed by the same stream that built the esker but not necessarily at the same time. (3) Braiding and bifurcation of the esker occurs at curves and in places where its course makes a large angle with the direction of ice flow, suggesting that the channel was displaced by stream erosion or by glacier movement. (4) Deposition of the esker appears to have been related to the building of an ice-contact outwash fan at an earlier stabilized position of the glacier front and to have occurred at the same time. (5) Progressive deposition of the esker along a receding ice front seems unlikely, in view of the lack of any outwash whatsoever on the surrounding ground moraine.

It seems clear that deposition of this esker must have taken place in an ice tunnel or ice-walled gorge at or almost at the bottom of the glacier. A subglacial tunnel is favored to some degree by the lack of any ice-walled gorge of comparable extent in the present glacier. Eskers associated with existing glaciers in the Wind River Mountains (Meier, 1951, p. 293) and in Norway (Lewis, 1949, p. 318) are also attributed to deposition in subglacial tunnels. Origin of Cook County eskers is now considered in the light of the above discussion.

The features of all Cook County eskers are similar enough so that great differences in the mode of origin seem unlikely. The possibility that the eskers of the west-southwest belt were formed as kame-like ice-contact deposits strung laterally along the margin of an ice sheet is not supported by any known evidence except their orientation, and it is opposed by lack of any external form or internal structure consistent with such an origin. Accumulation in successive segments along an ice front receding east-northeasterly also seems unlikely since independent evidence for an ice front of proper orientation receding in that direction is lacking. Although the west-southwest belt of eskers does not occupy a conspicuous lowland, it does lie north of and parallel to the higher Coastal Hills, suggesting that topographic control of subglacial drainage determined its orientation.

Accumulation of Cook County eskers in ice-walled gorges or in ice tunnels is suggested by: (1) the stream-like patterns with tributary branches; (2) the bifurcated, reticulated, and braided arrangements; (3) the multiple subparallel ridges at curves; (4) the orientation of the transverse asymmetry; (5) the localization in lowland areas; (6) the rock gorges along the course of Twin Lake esker; (7) the local heavy mantle of coarse ablation debris; and (8) the steep reverse faults in one esker suggesting mild compression by slightly active ice. However, the "up-hill down-dale" course of some eskers, frequently cited as proof of accumulation in subglacial tunnels, is not found in Cook County.

If the above features are accepted as indicating deposition in ice gorges or tunnels, then one must ask whether the streams flowed wholly on the subglacial floor, or wholly or in part upon ice somewhat above the bottom of the glacier. This introduces the problem of transferring a superglacial or englacial accumulation to its final resting place on the ground without seriously modifying or entirely destroying its external form and internal structure. In the instance of deposits formed close to the bottom of a thick glacier such a transfer may be possible because these deposits can be let down upon the ground by basal melting before surface ablation brings them into the superglacial environment. Basal melting of a temperate glacier (Ahlmann, 1948, p. 66) occurs at a rate of about 1/4 inch per year. Surface ablation of bare ice may easily be as much as 10 to 20 feet a year, but a thick debris mantle can reduce this to a few inches or even less. Thus, an englacial deposit a few feet above the base of a glacier, several hundred feet thick, may have a chance of becoming subglacial before the surface of the glacier is lowered enough to make it superglacial.

However, suppose it becomes superglacial, what are the possibilities of transferring this or any other superglacial deposit in a relatively undisturbed state to a resting place upon the ground? If the mantle of superglacial debris is of such homogeneity in character and thickness that the ice surface is lowered uniformly by ablation, and if basal melting is also uniform, superglacial accumulations may arrive on the ground in a relatively undisturbed condition. Most studies of stagnant glaciers have emphasized the great differences in surface ablation from place to place, the chaotic topography, and the constant shifting of the superglacial debris. However, on the stagnant margin of the Malaspina Glacier and upon other stagnant Alaskan glaciers, a superglacial mantle of sand and gravel has attained stability sufficient for spruce trees to have taken root and to have attained an age of at least 100 years. Melting of the ice beneath this mantle must be so uniform that no tilting of the trees or serious damage to their roots results. The rate of surface melting here may be of the order of an inch, more or less, per year, and the underlying ice in most places is at least 50 to 100 feet thick. However, even these relatively stable tree-covered superglacial accumulations are not likely to reach the ground in an unaltered state, as they are currently being destroyed by the back-melting of ice faces and cliffs moving outward from the margins of ponds and stream channels cut in the ice. These observations suggest that it is possible for surface ablation to be relatively uniform, but if the underlying ice is more than perhaps 20 feet thick, it would seem that the long period of time, literally centuries, required to melt the ice allows considerable opportunity for other processes to come into action and to destroy the original form of the superglacial accumulations. Preservation of superglacial eskers underlain by no more than 10 to 20 feet of ice appears to be within the realm of possibility under favorable conditions.

Some features of Cook County eskers suggest that at least in places the streams forming them flowed over ice. One such feature is the irregular longitudinal profile of most eskers. They have marked peaks and saddles and are more undulatory than normally expected of undisturbed stream beds. Such undulations might conceivably be formed in a subglacial tunnel if the deposits were molded against an irregular ceiling, but it is easier to picture them as the product of deposition on an irregular floor of thin ice which subsequently melted away allowing some differential settling of the deposits.

More significant in this connection are the wide gaps in some esker ridges. Some gaps are clearly the result of post-depositional erosion, but many are wide, flat-floored, and show no evidence of erosion either by later transverse streams or by the esker stream itself. The suggestion is offered that these gaps represent reaches where the esker stream was underlain by ice so thick that surface ablation eventually brought the deposits into a superglacial position where they were subsequently destroyed.

The origin of the internal "anticlinal" structure displayed by some eskers is a baffling problem. In those instances where the structure is clearly surficial, it is probably the product of the surface slump and creep characteristic of most ice-contact surfaces. Where it extends deeply into the esker something more than surficial modification is indicated. In some instances the structure is probably primary rather than secondary, but no satisfactory mechanism has yet been proposed for depositing these beds with an initial anticlinal form. Perhaps this may occur in a subglacial tunnel partly filled with debris and being slowly enlarged by melting of the walls, or, if eskers are molded against the base of thin stagnant ice essentially afloat, as suggested by Andersen (1931, p. 612-616), the anticlinal structure may represent successive episodes of molded deposition as the overlying ice was floated progressively to a higher and higher position. It is also possible that large-scale settling of a deposit filling a wide U- or V-shaped channel cut in ice is involved. This last mechanism is attractive because of simplicity, but the considerable elongation required in the uppermost beds suggests that small normal faults or thinning of the beds should be apparent. The best example of anticlinal bedding in a Cook County esker (pl. 1, fig. 2) shows no thinning of the beds and displays only steep faults, some of which have reverse displacements. This suggests that the structure is a primary depositional feature, but the exact mechanism involved in its origin remains a mystery.

In summary, Cook County eskers are thought to have been formed by streams flowing in ice-walled gorges or ice tunnels, mostly the latter, located directly on the subglacial floor in some places and no more than 10 to 20 feet above the glacier's base in others. Gaps in eskers are thought to indicate spots where the underlying ice was still thicker, so that the deposits subsequently became superglacial and were destroyed. The ice surrounding or enclosing the eskers was relatively inactive but not all of it was entirely stagnant.

Drumloid ridges.—In westernmost Cook County along the Six Hundred Road (T. 59 N., R. 5 W.) is a series of short parallel ridges trending about S. 45° E. (pl. 2, fig. 2). They are 10 to 25 feet high, 0.5 to 0.75 mile long, up to 0.25 mile wide, round-topped, equally blunt at both ends, and separated by wide swales. Some of the minor ridges lie on the flanks of larger ridges. These features occupy a broad lowland along Cross River where brown sandy till is the only material seen, but exposures are shallow. An area northwest of Elbow Lake (Sec. 5, T. 62 N., R. 1 E.) has similar but less conspicuous forms bearing roughly S. 50° E.

The first thought was that the ridges must be bedrock thinly mantled with till and that their orientation reflects a structural control. However, no exposures of bedrock have been found in the area, and the ridges are discordant to any known structural trend in this part of the county. Subsequent discovery of glacial striations bearing S. 35° E. about 8 miles to the northeast of the Cross River area suggests that the ridges are parallel to the direction of flow in the Rainy lobe. The drumloid ridges in the Elbow Lake region are also thought to have a similar relation to flow direction, although striations

1 to 2 miles north bear almost directly south. This divergence is attributed to the local topography, with Pine Mountain lying between the ridges and the striations, and 6 miles southeast are Rainy lobe striations trending southeasterly, nearly parallel to the ridges.

"Drumlinized" landscapes in Canada (Armstrong and Tipper, 1948, p. 287-293; Lang, Bostock, and Fortier, 1947) are striking similar, so the hypothesis is advanced that the Cook County features are primarily ridges of till deposited beneath the Rainy lobe as it moved in a southeasterly direction. Lack of deep exposures requires that this remains a hypothesis rather than a conclusion because somewhat similar features have been carved in bedrock by deep glacial scouring (Smith, 1948, p. 508-513). The term drumloid ridge is used because these features lack the asymmetrical longitudinal profile and stream-lined form usually attributed to ideal drumlins.

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