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Implications of Photogeologic Linears in the South Long Lake Area, Alpena and Presque Isle Counties, Michigan

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IMPLICATIONS OF PHOTOGEOLOGIC LINEARS IN THE SOUTH LONG LAKE AREA, ALPENA AND PRESQUE ISLE COUNTIES, MICHIGAN

by

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IMPLICATIONS OF PHOTOGEOLOGIC LINEARS IN THE SOUTH LONG LAKE AREA, ALPENA AND PRESQUE ISLE COUNTIES, MICHIGAN

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There are numerous linear features in Alpena and Presque Isle Counties, Michigan, which are generally visible on aerial photographs. These photolinears trend in two general directions, northeast-southwest and northwest-southeast. These two sets are perpendicular to each other, and represent vector means of two fracture sets.

The development of the photolinears began in Early Devonian. Throughout its history, ground water flowed along underground channels connecting fracture intersections. This underground drainage network is responsible for many of the photolinears. Some of the photolinears can be attributed to Early Devonian ground water activity and subsequent collapse of the Salina Salt basin, and some are attributable to more recent ground water activity.

Some photolinears are the result of differential erosional resistance between different beds of rock, or the result of progressive stages of Pleistocene lakes.

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Finally, I would like to dedicate this manuscript to my wife Janette for her continued loving interest in the project.

Richard Elmer Kimmel

INTRODUCTION

This paper is concerned with several unusual photogeologic features observed in the Upper Middle Devonian Traverse Group of northern Michigan. The Traverse Group is composed of a sequence of marine shallow-water, gray to brown fossiliferous limestones and shales. The name "Traverse Group", was first proposed by Lane (1895). Douglass (1841) first named the group the "Little Traverse Bay Group," after exposures on the shore of Little Traverse Bay, Emmet County, Michigan.

In Alpena and Presque Isle Counties, the most complete section of the Traverse Group is exposed in a narrow band 10 to 15 miles wide. In this paper, the general stratigraphy of the Traverse Group will be reviewed, as well as the stratigraphy of each of the 11 individual formations in the Traverse Group. The stratigraphy will then be related to two well-defined sets of structural and topographic lineaments, which are generally visible on aerial photographs.

Geographic Location of the Area

The study area of this paper includes parts of northern Alpena and eastern Presque Isle Counties, Michigan. Alpena County is located in the northeastern corner of the lower peninsula, 100 miles southeast of the Straits of Mackinac, and 100 miles north of the Tri-Cities – Midland, Bay City, and Saginaw. Presque Isle County lies immediately north and northwest of Alpena County (Figure 1). The study of linears was made largely from photomosaics and individual aerial photographs of Alpena and Presque Isle Counties. The detailed geologic map included in this paper covers an area of 48 square miles, all but six of which lie in Alpena County. This area will be referred to as the South Long Lake area in this paper. The southern edge of the South Long Lake area lies approximately six miles north of the city of Alpena. The area extends approximately ten miles to the west and six more miles to the north (Figures 2 and 14). The dominant physical feature in the South Long Lake area is Long Lake.

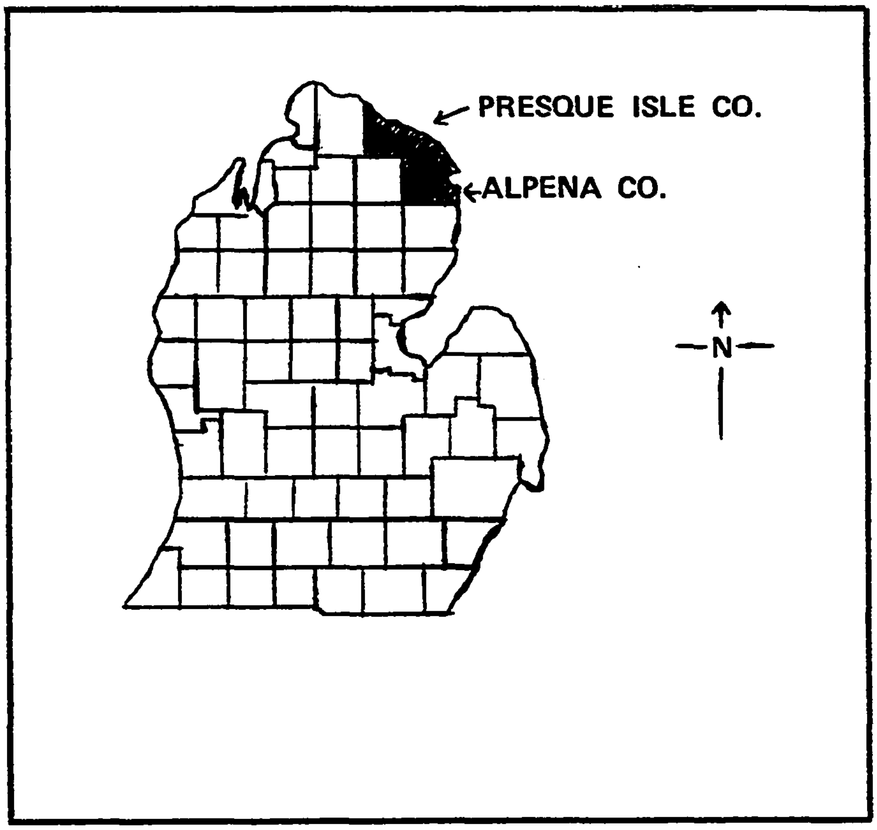


FIGURE 1. Location of study area.

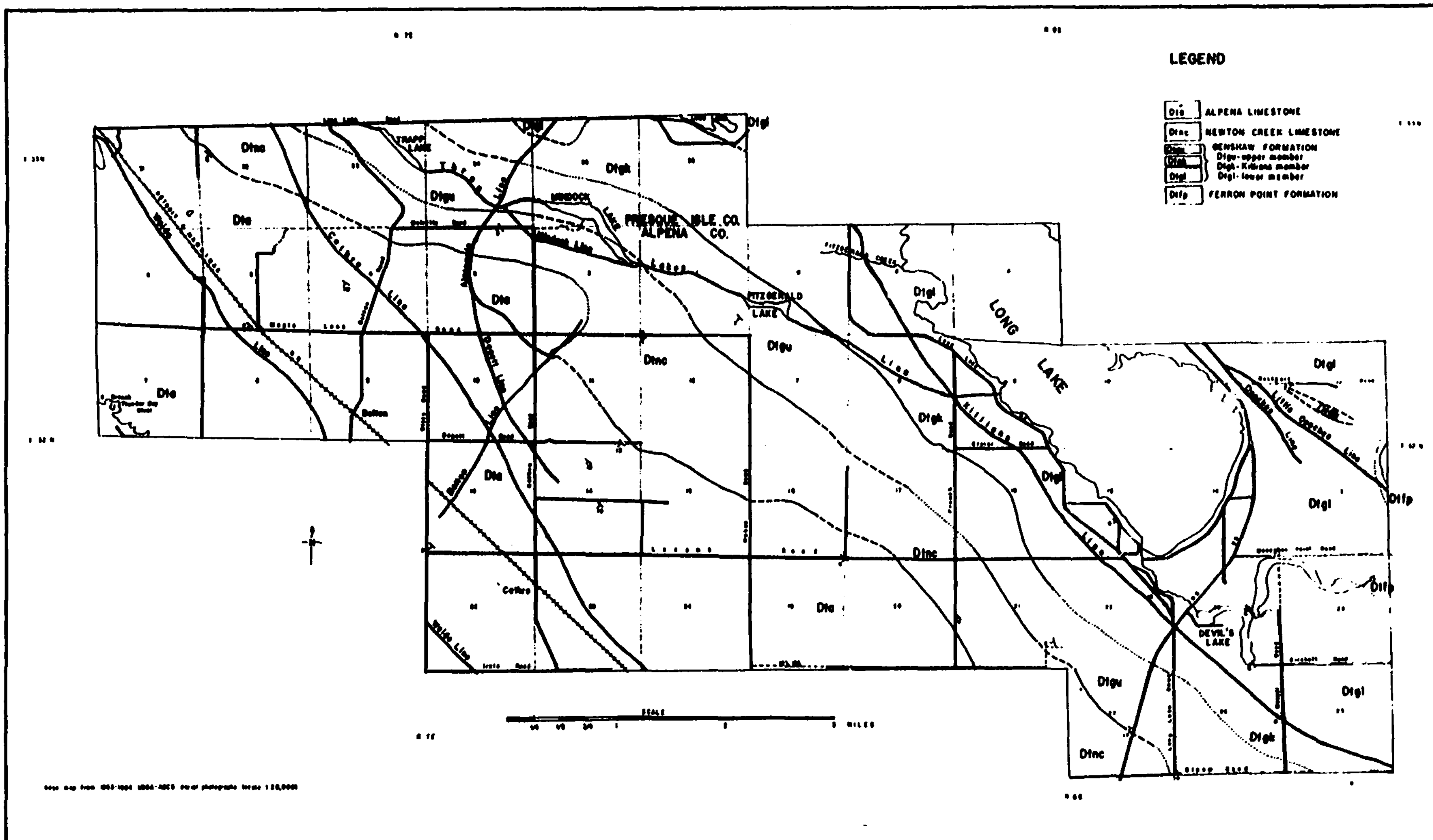


FIGURE 2. Bedrock geology of the South Long Lake area, Michigan

Geologic Position of Traverse Group

The Devonian column in Michigan is represented by approximately 6200 feet of sedimentary rocks, 830 feet of which belong to the Upper Middle Devonian Traverse Group (Dorr & Eschman, 1970). The Lower and Middle Devonian strata consist chiefly of carbonates and evaporites (Dorr & Eschman, 1970), while the Upper Devonian strata consist largely of shales and mudstones shed into the Michigan Basin from the Appalachians region (Dorr & Eschman, 1970).

The outcrop area of the Traverse Group of northern Michigan extends in a broad band from Alpena to Charlevoix, in the lower peninsula. There are three major areas of exposures, the Little Traverse Bay area in the west, the Onaway area of Presque Isle County, and an eastern area along the shore of Lake Huron (Kelly, 1949). The South Long Lake area lies in the third area. The Traverse Group of Alpena and Presque Isle Counties is overlain by the black Antrim Shale of Lower Upper Devonian age, and is underlain by the brownish-buff limestones of the Middle Devonian Rogers City Limestone of the Dundee Group (Ehlers & Kesling, 1970; Allan, 1972, personal communication).

Scope of Investigation

The purpose of this paper is to study several unusual photogeologic "linears" in the South Long Lake area, and to suggest origins of these features and the relationships of these features and the stratigraphy of the Traverse Group.

The Devonian rocks in the Alpena-Presque Isle County area have been studied in detail by several authors (Rominger, 1876; Lane, 1895; Grabau, 1901, 1902, 1903; Ver Wiebe, 1927; Pohl, 1930; Warthin & Cooper, 1935, 1943; Kelly & Smith, 1947). In more recent years, a number of karst features in the area began to attract major interest of geologists as well as laymen (Gregg, 1935; Kraemer, 1962; LaForest, 1970; Mahan, no date; Martin, 1958; Grand Rapids Press, 1957). The present writer believes these karst features are related to the photolinears.

Several of these karst features were studied in the South Long Lake area, and include sinkholes, disappearing streams, springs, solution cracks, and fracture zones. Many of these features are definitely related to two major sets of photolinears in Alpena and Presque Isle

Counties. These two sets trend predominantly northeast-southwest and northwest-southeast.

The photolinears are reflections of such surface and subsurface features as formational contacts, bedding planes, glacial and post-glacial shorelines, fracture zones, joints, and underground drainage channels. Ten of these photolinears have been named by the writer, and will be documented and interpreted in this paper. Some of them, it may be expected, have no apparent surface expression in the field, and therefore remain unexplained at this time.

A stratigraphic summary is included in the first part of this report. It is believed that the rocks of the Traverse Group in the area exert a definite control over these linear features, therefore the bedrock geology of the South Long Lake area has been mapped in detail (Figure 2).

The study of photolinears was begun in April of 1972. Photolinears were mapped on an acetate overlay of 1963-1964 uncontrolled aerial photomosaics published by the U. S. Department of Agriculture. The lengths and orientations of the photolinears were statistically studied.

The field investigations in the South Long Lake area were undertaken during the spring and early summer of 1972.

Previous Work

The Upper Middle Devonian Traverse Group of northern Michigan was first studied by Winchell (1871). He named the group the "Little Traverse Group", after exposures at Little Traverse Bay, Emmet County, Michigan. In 1893, Lane (1895) dropped the word "Little", and renamed the group the Traverse Group, due to exposures at both Grand Traverse and Little Traverse Bay. He defined the Traverse Group to include all strata below the "St. Clair black shales" (now known as the Antrim Shale), and above the Dundee Limestone.

Grabau (1901, 1902) divided the Traverse Group into four subdivisions, which he named, in ascending order, Bell Shale, "Long Lake Series", Alpena Limestone, and "Thunder Bay Series". The present equivalents of these named units will be discussed later. In a 1915 unpublished manuscript, Grabau redefined the Traverse Group of Alpena and Presque Isle Counties to include, in ascending order, a "Presque Isle Series" containing three members, an "Alpena Series", and a "Thunder Bay Series". The three members of the "Presque Isle Series" were named, in ascending order, Bell Shales, "Grand Lake Limestone", and "Long Lake Beds."

Pohl (1930) divided the Traverse Group of the northern part of the lower peninsula of Michigan into three units, which he named, in ascending order, "Gravel Point Stage", "Charlevoix Stage", and "Petoskey Formation". He believed his "Gravel Point Stage" to be the basal member of the Michigan Traverse Group.

Finally, Warthin and Cooper (1935) divided the Traverse Group of the Thunder Bay region (Alpena and Presque Isle Counties) into the Bell Shale, "Rockport Limestone", "Long Lake Stage" (consisting of Ferron Point Formation, Genshaw Formation, and "Killians Limestone"), Alpena Limestone "Stage", and "Thunder Bay Stage" (including Norway Point Formation, Potter Farm Formation, a covered interval, and "Partridge Point Formation"). Above their "Thunder Bay Stage" was another covered interval, followed by the Squaw Bay Limestone, which they believed should have been excluded from the Traverse Group.

The first appearance of the present divisions of the Traverse Group in Alpena and Presque Isle Counties is documented by Warthin and Cooper (1943), and includes, from the base upward, Bell Shale, Rockport Quarry Limestone, Ferron Point Formation, Genshaw Formation (consisting of lower, Killians, and upper members), Newton Creek Limestone, Alpena Limestone, Fourmile Dam Formation, Norway Point Formation, Potter Farm Formation Thunder Bay Limestone, and Squaw Bay Limestone (Figure 3). This is also the terminology of Ehlers and Kesling (1970), and that which will be adhered to in this paper.

The karst features in Alpena and Presque Isle Counties were observed as early as 1869, when Newton Winchell, brother of state geologist Alexander Winchell, studied them (Winchell, 1870; Martin, 1958). Since that time, they have been reported in almost all the papers which have appeared concerning the area. The sinkholes of Alpena County were interpreted by Ver Wiebe and Bergquist (1925) as having been produced by the dissolving action of ground water saturated with carbon dioxide. The rain waters so described percolate through joints in the limestone, and consequently widen them. In the same paper (Ver Wiebe & Bergquist, 1925), it is stated that 35 sinkholes had been mapped in Alpena County, including 14 sinkholes near the village of Leer in northern Alpena County.

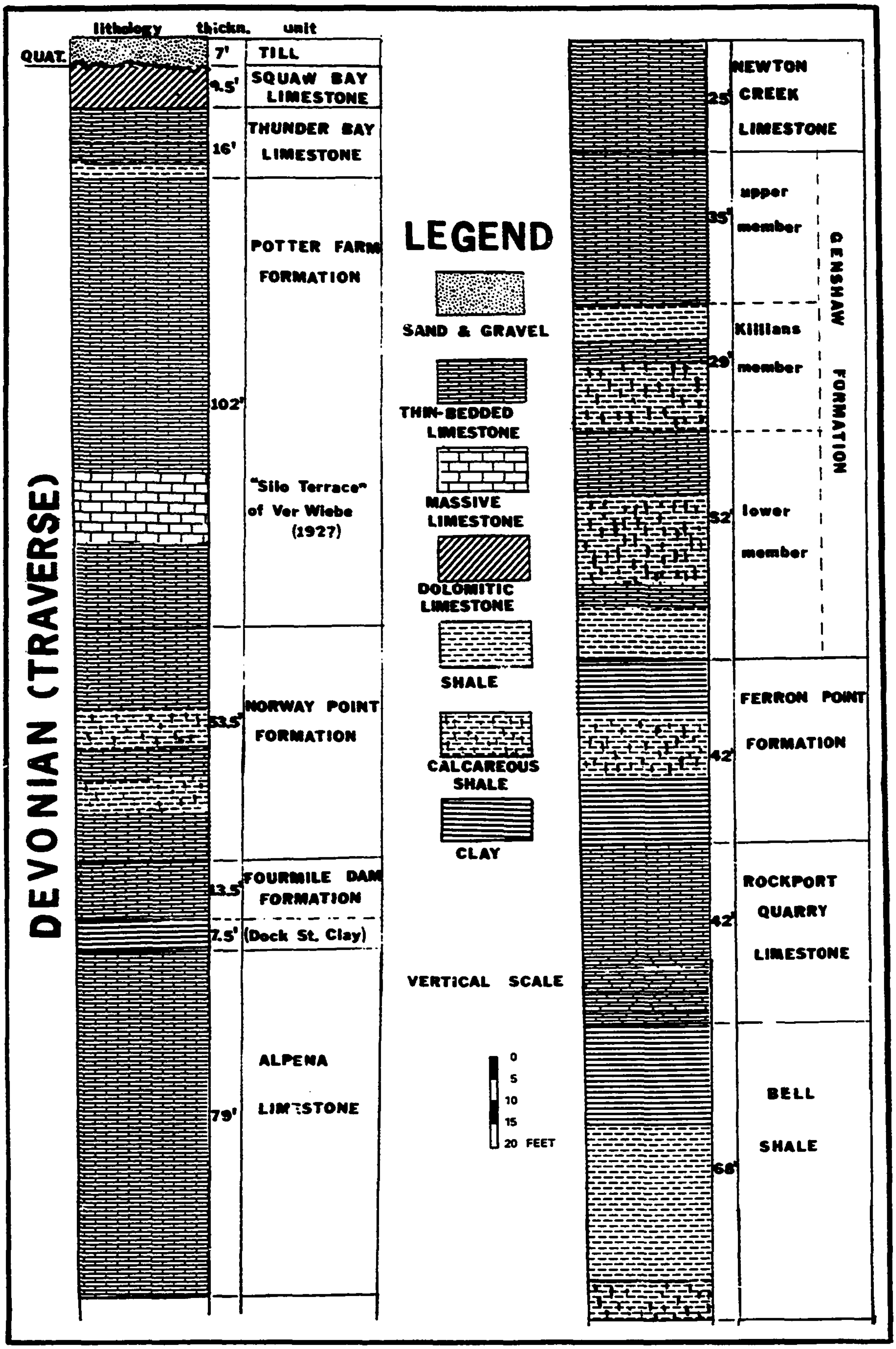


FIGURE 3. Stratigraphic column of the Traverse Group of Alpena and Presque Isle Counties, Michigan

Dewey (1961), in his report, accounts for nearly 300 sinkholes in Alpena County.

In the late 1950's and early 1960's, there was an increase in tourist attraction to the sinkholes of Alpena and Presque Isle Counties. Many citizens from the area speculated on the occurrence of a huge underground drainage network in the two counties. A Rogers City citizen, Art Poch, reported occurrences of huge underground caverns in the vicinity of Posen, south central Presque Isle County, and of trenches so deep that cattle were lost in them (Grand Rapids Press, 1957; Thomas, 1958; Martin, 1958; Mahan, no date; Kraemer, 1962). Mr. Poch's deep interest in these features led him to open a tourist park in the valley of Sunken Lake, one mile northeast of Leer, in section 32, T. 32 N., R. 6 E., Presque Isle County (Thomas, 1958). Mr. Poch named his park "Mystery Valley", and it opened on June 15th, 1958.

To date, no detailed geologic work has been undertaken to relate the numerous Karst features and photolinears to the stratigraphy of the Traverse Group in the area. This is the primary purpose of this investigation.

STRATIGRAPHY

The consolidated rocks of Alpena and Presque Isle Counties range in age from Lower Middle Devonian to Upper Devonian. The Lower Middle Devonian of the area is represented by the Dundee Limestone (Rogers City Limestone in Presque Isle County), the Upper Middle Devonian by the Raverse Group, and the Upper Devonian by the Antrim Shale in the east and the Ellsworth Shale in the west (Dorr & Eschman, 1970; Martin, 1956; Cooper et al., 1942). The present usage of the term "Traverse" for the Upper Middle Devonian rocks was proposed by Lane (1895) to include all strata above the Dundee Limestone and below the "St. Clair black shales" (now known as the Antrim Shale), in Alpena and Presque Isle Counties. The Traverse is divided into 11 formations, as described originally by Warthin and Cooper (1935, 1943) and redescribed by Ehlers and Kesling (1970). From the base upward, the 11 major divisions are Bell Shale, Rockport Quarry Limestone, Ferron Point Formation, Genshaw Formation, Newton Creek Limestone, Alpena Limestone, Fourmile Dam Formation, Norway Point Formation, Potter Farm Formation, Thunder Bay Limestone, and Squaw Bay Limestone.

Four of the eleven formations are exposed in the South Long Lake area. These are the Ferron Point, Genshaw, Newton Creek, and Alpena. In this section of the paper, each of the 11 formations will be individually described, with special emphasis placed on those formations which are exposed in the South Long Lake area.

Definition of the Traverse Group

The Traverse Group of the northern portion of the lower peninsula of Michigan was first studied by Douglass (1841). He named it the "Little Traverse Group", after exposures at Little Traverse Bay. He described it as a "series of thick-bedded magnesian buffish granular limestones underlying the Huron Group and overlying the Corniferous Group." (see Martin, 1956, sheet 1). Douglass believed his "Little Traverse" rocks to be the time-equivalent of the Hamilton Group of New York State.

A later study (Lane, 1895) in and south of the Little Traverse Bay area described exposures of "Little Traverse" strata in the Grand Traverse Bay area as well. Because of these findings, the word "Little" was dropped from the name of the group. The "Traverse Group" was then redefined to include "bluish calcareous shales and limestones or dolomites, 100 to 600 feet thick" (Lane, 1895). The extent of the Traverse Group was defined to include all the strata below the "St. Clair black shales", and above the Dundee Limestone.

In 1902, Grabau, of the Michigan Geological Survey, divided the Traverse Group into a "Long Lake Series", Alpena Limestone, and "Thunder Bay Series" (Grabau, 1901,1902). Grabau's units were again studied by Ver Wiebe (1927), who divided Grabau's "Long Lake Series" into three subdivisions, the lowermost being the "Rockport Limestone". In later studies (Kelly & Smith, 1947; Warthin & Cooper, 1935, 1943), this unit was renamed Rockport Quarry Limestone, after exposures at the Kelly Island Lime and Transport Company quarry at Rockport, northeastern Alpena County.

Pohl (1930) carried out further investigations into the stratigraphic succession within the Traverse Group. His studies were concerned mainly with the Little Traverse Bay section, in Emmet and Charlevoix Counties, Michigan. He proposed a threefold division of the Traverse Group, which included a basal "Gravel Point Stage", overlain by the "Charlevoix Stage" and the "Petoskey Formation".

By this time, Grabau had redefined his fourfold division into the "Presque Isle Series", followed in ascending order by the "Alpena Series" and the "Thunder Bay Series". The "Presque Isle Series" consisted of three members, the basal Bell Shales, the "Grand Lake Limestone", and the "Long Lake Beds" (Grabau, 1915).

An attempt was then made (Hake & Maebius, 1938) to establish statewide divisions within the Traverse Group. Seven divisions were thus established from well log studies, which divided the Traverse Group, in ascending order, into the Bell Shale, "Rockport Limestone", "middle shale and limestone", "middle massive limestone", "upper shale unit", and finally an overlying "transition zone."

The current division of the Traverse Group in Alpena and Presque Isle Counties first appeared in papers by Warthin and Cooper (1935, 1943). Grabau's "Long Lake Series" is now defined to include the Rockport Quarry Limestone, Ferron Point Formation, and Genshaw Formation. This section of the column is included within the "Rockport Limestone" and "middle shale and limestone" of Hake and Maebius (1938). Grabau's "Thunder

Bay Series" is redefined to include the Norway Point Formation, Potter Farm Formation, and "Partridge Point Series" (Warthin & Cooper, 1935). The "middle massive limestone" of Hake and Maebius (1938) includes this sequence, plus the Alpena Limestone. The "Partridge Point Series" of Warthin and Cooper (1935) was then again subdivided into a Thunder Bay Limestone and Squaw Bay Limestone (Warthin & Cooper, 1943).

A summary of Traverse Group correlations across the United States can be found in Cooper, et al. (1942). Generally speaking, the Traverse is belived to be time-correlative with the Hamilton Group of New York State, the basal Bell Shale being the time equivalent of the Levanna Black Shale of the Finger Lakes area (Cooper, et al., 1942). In eastern New York, the Hamilton consists of continental red beds (Chadwick, 1935). To the west, the Hamilton red beds grade into shales and sandstones (Delphi Station Formation through Geneseo Shale), then into the Levanna, Centerfield, Ledyard, Wanakah, Tichenor, Deep Run, Mentern, Kashong, and Windom shales and limestones. In northwestern Ohio, southwestern Ontario, and southeastern Michigan, much of this time-rock unit is absent due to non-deposition (Cooper, et al., 1942).

If the Hamilton and Traverse are time-equivalent, then the two areas of concern, Michigan and New York State, may have been connected by a strait in northern Ohio. However, south and west of the Michigan Basin, no equivalent strata have been found. This suggests that the Traverse-Hamilton seaway probably did not extend beyond this area, unless the strata were deposited and later completely removed by erosion. A more thorough study of the Upper Middle Devonian appears in Chadwick (1935) and Cooper, et al. (1942).

The top of the Traverse Group is represented by the top of the highest Devonian limestones in Michigan (Warthin & Cooper, 1943). Strata above the Traverse Group consist mainly of shales. The base of the Traverse, as presently defined, is marked by the base of the wide-spread gray-blue Bell Shale (Figure 3).

Descriptive Stratigraphy

Bell Shale

The lowermost member of the Traverse Group of Alpena and Presque Isle Counties has been named the Bell Shale by Grabau (1901, 1902), after exposures at the clay pits near the old town of Bell, southeastern Presque Isle County. In his study of the Churchill Well in Alpena, Grabau described a section believed to include the Bell Shale. This section is traversed by his units 15, 16, and 17 (Grabau, 1901, 1902). Unit 15 is a shale, unit 16 is a hard white limestone, and unit 17 is a blue shale.

The Bell Shale is inaccessible or covered throughout most of the two counties. There are no natural exposures of the Bell in the South Long Lake area. There are a few exposures in the northeastern corner of Alpena County, along Lake Huron, near Ferron Point, Presque Isle County, and at the abandoned Kelly Island Lime and Transport Company quarry at Rockport (Ehlers & Kesling, 1970). The only exposures studied by Grabau were those in the sides of the great "bottomless sink" near Ferron Point, Presque Isle County (Grabau, 1901, 1902).

Well log studies have shown the Bell to extend as far south as Allegan County, Michigan (Hake & Maebius, 1938). It attains its maximum thickness at Manistee County, on the west-central side of the lower peninsula. The southeastern extent of the Bell is in northwestern Ohio, where fauna identical to those from Grabau's (1915) redefined "Presque Isle Stage" have been found (Pohl, 1930). Its average thickness in Alpena and Presque Isle Counties is 68 feet (Figure 3). The Bell is characteristically a gray to blue, slightly calcareous shale, containing some pyrite. The fauna is typical of lower Hamilton species. Warthin and Cooper (1943) correlated the Bell Shale with the middle Skaneateles Shale of New York State. Its maximum thickness in Alpena and Presque Isle Counties is 80 feet. In the western part of the state, the Bell ranges from 40 to 100 feet thick (Pohl, 1930). In this area, it is included within "Zone 1" of Pohl (1930) "Gravel Point Stage." The exposures at Gravel Point are described as consisting of a dark brown to black, thin-bedded shaly limestone, containing abundant crinoids.

Rockport Quarry Limestone

The Rockport Quarry Limestone lies above the blue-gray Bell Shale in Alpena and Presque Isle Counties. It was originally described by Smith (1915) as the "Rockport Limestone", after exposures at the Kelly Island Lime and Transport Company quarry at Rockport, northeastern Alpena County.

Grabau (1901,1902) described the strata now known as the Rockport Quarry Limestone at his localities 37 and 19. At locality 37, he observed some ledges of rock on the southwest side of Grand Lake, Presque Isle County. Locality 19 was the great "bottomless sink" southwest of Ferron Point, Lake Huron. He described the strata exposed in this sinkhole as "fine-grained, homogeneous, smooth limestones, ... spotted by masses of calcite." (Grabau, 1902). Below these limestones were over six feet of bituminous shale with alum efflorescence, containing small branching species of the colonial coral Favosites. These strata make up the lower beds of Grabau's "Long Lake Series" (Michigan Geological Survey, no date).

According to Ver Wiebe (1927), the "Rockport Limestone" was the equivalent of unit no. 4 of the Churchill Well in Alpena. It consists of approximately 40 feet of very bituminous limestone, the upper 10 feet of which are buff-colored, fine-grained, and break with a blocky cleavage.

Like the underlying Bell Shale, the Rockport Quarry Limestone is fairly extensive throughout the Michigan Basin. In lithology, this formation is a very pure limestone in the Alpena-Presque Isle County area. It becomes locally dolomitic in Roscommon and Antrim Counties to the west and southwest. No equivalent strata had been discovered southwest of Lake and Montcalm Counties at the time of Hake and Maebius's (1938) study.

Exposures of the Rockport Quarry Limestone occur at two major localities in Alpena and Presque Isle Counties. The first, and type locality, is the now-abandoned limestone quarry at Rockport, previously described. At one time, this limestone formed a 16-foot natural bluff at this locality, but it has since been removed by quarrying operations (Warthin & Cooper, 1943). The second major exposure of the Rockport Quarry Limestone is in the vicinity of Ocqueoc Falls, west-central Presque Isle County. Both of these localities were visited by the writer. The rocks of the Rockport Quarry section are gray to brown, finely crystalline, micritic or sublithographic limestones, often styolitic, with limonite staining and occasional specks of yellow calcite. Pyrite is also common in the limestone, and, compared with other members of the Traverse Group, fossils are relatively rare. The strata at the abandoned quarry weather into blocky slabs. The rocks exposed at Ocqueoc Falls are somewhat darker in color, and more irregularly-bedded. The color of the strata are brown rather than gray.

At the Onaway limestone quarry, 10 miles northwest of Ocqueoc Falls, the Rockport Quarry Limestone is at least 50 feet thick. The black argillaceous facies, which is characteristic of the basal beds at the Rockport quarry and the exposed strata at Ocqueoc Falls, is absent here (Kelly & Smith, 1947). There are no known exposures of the Rockport Quarry Limestone in the South Long Lake area.

Ferron Point Formation

The Ferron Point Formation is the third formation of the Traverse Group, and consists of marine shales and clays, with some limestones (Figure 3). The formation was named for Ferron Point, on Lake Huron, southeastern Presque Isle County, but the type locality and best exposures are in the walls of the abandoned limestone quarry at Rockport, the same locality as the Rockport Quarry Limestone type section. At this locality, the Ferron Point consists of about 20 feet of poorly-exposed clays and shales, capped by 2 or 3 feet of argillaceous limestone. It contains an abundant coral fauna, most notably large heads of the colonial coral Hexagonaria sp.

The Ferron Point Formation was studied by Grabau (1901, 1902) and Ver Wiebe (1927). It was first recognized as a separate formation by Warthin and Cooper (1935). Previously, the Ferron Point was customarily included as part of Ver Wiebe's (1927) "middle member" of the old "Long Lake Series" of Grabau (1901, 1902).

The Ferron Point Formation was grouped by Hake and Maebius (1938) as part of their "middle shale and limestone", which consisted of shales, limy shales, muddy limestones, cherty limestones, and dolomites. This undifferentiated unit included the Ferron Point Formation as well as the overlying Genshaw Formation and Newton Creek Limestone of present usage. The combined unit is 190 feet thick in Alpena County, attaining a maximum thickness of 220 feet in the Saginaw Bay area, and thinning to not over 120 feet in Livingston County. In western Michigan, the combined unit is replaced by a massive unit of limestone and dolomite (Hake & Maebius, 1938).

Exposures of the Ferron Point Formation are uncommon. In the area around Afton and Onaway, Presque Isle and Cheboygan Counties, outcrops are rare, as they are in Alpena County. Exposures have been reported along Black Lake, Presque Isle County (Kelly & Smith, 1947). At this locality, the Ferron Point strata appear as soft light gray calcareous shales, interbedded with thin lenses of dense limestone, and very fossiliferous. Most of the exposures in Alpena and Presque Isle Counties are artificial, observed only in quarries, ditches, or pits. Only a small portion of the South Long Lake area (sections

13 and 24, T. 32 N., R. 8 E.) is underlain by the Ferron Point Formation (Ehlers & Kesling, 1970). This area was visited by the writer. No exposures are now present in these places. The only evidence suggesting formational contacts is thickly-vegetated lowlands bounded by small escarpments.

The best exposures of the Ferron Point Formation are above the Rockport Quarry Limestone in the walls of the abandoned Kelly Island Lime and Transport Company quarry at Rockport. The most conspicuous feature of the Rockport quarry exposures is the abundance of weathered-out Hexagonaria sp. heads, many of which are 7 to 8 inches in diameter, and some even larger.

Genshaw Formation

The Genshaw Formation is the thickest formation of the Traverse Group of Alpena and Presque Isle Counties, attaining an average thickness of 116 feet (Figure 3). The outcrop area is a northwest-trending belt 3½ to 4 miles wide. In current usage, the Genshaw is divided into three units, a lower member, the Killians Member, and an upper member. All three of these are exposed in the South Long Lake area (Figure 2).

The Genshaw was observed by Grabau (1901, 1902). He placed it near the top of the "Long Lake Series". The upper member of the "Long Lake Series" was described by Ver Wiebe (1927) and the Michigan Geological Survey (no date) as consisting of 80 feet of argillaceous limestones and shales. The formation was named by Warthin & Cooper (1935) after scabby exposures in the roadbed at the site of the old Genshaw School, on Monaghan Point Road, section 13, T. 32 N., R. 8 E. (Figure 2). For several years, there was debate as to the exact stratigraphic position of the Killians Member of the Genshaw. Some authors believed it to be a separate formation (Kelly & Smith, 1947; Warthin & Cooper, 1935), overlain by the Alpena Limestone or its equivalent. Warthin and Cooper (1943) then redefined the Killians as a member of the Genshaw Formation. The type locality chosen was an exposure on French Road, Alpena County, about one half mile south of the old Killians Resort and Long Lake (Figure 4).

Kelly and Smith (1947) estimated the thickness of the Genshaw as 116 feet in Alpena County, thinning in Cheboygan County to the west. In the Afton-Onaway area, six faunal zones have been described within the Genshaw (Kelly & Smith, 1947). The Lower Genshaw in this area is described as alternating dark gray shaly limestones and calcareous shales, with some black coloration.

FIGURE 4. Type locality of the Killians Member, Genshaw Formation, SE¼, NE¼, sec. 8, T. 32 N., R. 8 E.

The Killians Member is one of the few black units of the Traverse Group (Warthin & Cooper, 1943). It is a very conspicuous unit in outcrop due to its dark color, cuesta form, topography, and fossil content. Its contact with the lower Genshaw is marked by a prominent scarp, the Killians Line, along most of its length (Figures 2, 14). This scarp appears on aerial photographs as a linear, and will be discussed later in this paper.

Exposures of the Genshaw are quite numerous in the South Long Lake area. The lower Genshaw is typically exposed as a hard gray-blue or tan, crystalline limestone, in part argillaceous, containing numerous brachiopods and crinoids. The rock shows evidence of jointing at places, such as along the old Long Lake Road, just southwest of Long Lake Creek, in the SW¼, NE¼, section 22, T. 32 N., R. 8 E., where some long straight cracks have been observed in the strata, with evident cross-fracturing (Figure 33). These structures will be discussed in more detail later. At the same locality, the lower Genshaw is exposed in a drainage ditch, just off the road (Figure 5).

The lower Genshaw is very soluble, more than many of the other formations of the Traverse Group. At one outcrop of the lower Genshaw, at the south end of Devil's Lake, in the SW¼, SE¼, section 23, T. 32 N., R. 8 E., there are a number of cracks and holes in the strata. Some of these are 4 or 5 feet deep, and had snow in their bottoms, even after all the ground snow in the area had melted.

FIGURE 5. Lower Genshaw exposure along old Long Lake Road (hammer for scale), NE¼, NE¼, sec. 22, T. 32 N., R. 8 E.

The configurations of Devil's Lake, and the small unnamed lake connected to Devil's Lake on the north, have been attributed to structural control by joints (Poindexter, 1935). The present writer observed a spring at lake level at the bottom of a small ravine in the lower Genshaw at the south end of Devil's Lake. On the first visit to this locality, the creek was dry, and water could be seen bubbling through the rocks at the bottom. On subsequent visits, the creek was flowing, and the spring was obscured (Figure 6). Apparently, this spring is fed by ground water which percolates through the glacial till in the nearby topographically-high areas, and then finds its way to the lake through the numerous passageways within the lower Genshaw. In times of heavy rainfall, most of the water runs off the land through streams, and very little percolates into the ground. Therefore, the spring flow would be less than normal.

Most of the exposures of the lower Genshaw are found along the shoreline of Long Lake (Figure 7), since the lake lies completely within the outcrop area of the lower member of the Genshaw Formation. The configuration of Long Lake reflects the regional strike of the Traverse Group in the north. In the South Long Lake area, the lake trends somewhat oblique to the regional strike. This anomaly is still unexplained.

Above the lower Genshaw, and marked by the northeast-facing scarp of the Killians Line, is the Killians Member of the Genshaw, which consists predominantly of black

FIGURE 6. Lower Genshaw exposed in stream bed; south end of Devil's Lake, NW¼, NE¼, sec. 26, T. 32 N., R. 8 E.

FIGURE 7. Lower Genshaw exposed on shore of Long Lake, NW¼, NE¼, sec. 36, T. 33 N., R. 7 E.

FIGURE 8. Killians-lower Genshaw contact–French Road Cut, SE¼, NE¼, sec. 8, T. 32 N., R. 8 E.

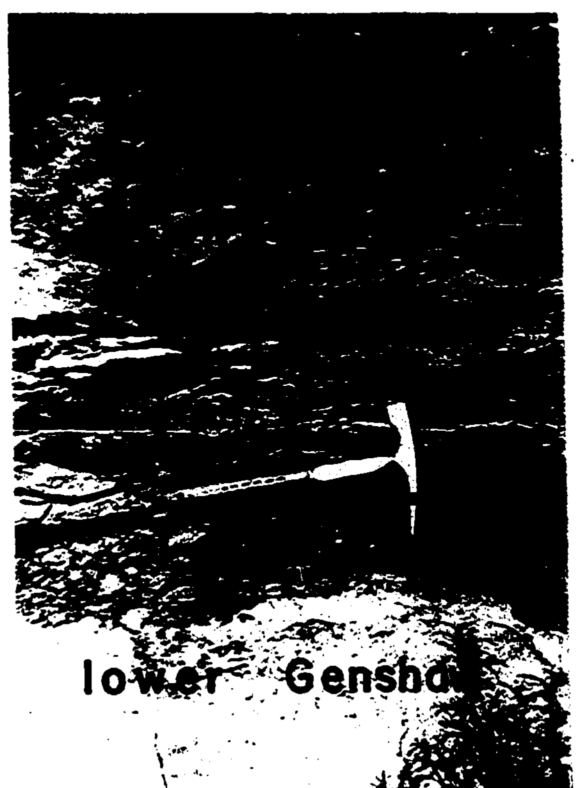


FIGURE 9. Close-up of the contact shown in fugure 8, SE¼, NE¼, sec. 8, T. 32 N., R. 8 E.

limestones. The contact is well-exposed in very few places. The most striking exposure of this contact is at the French Road cut, one half mile south of the site of the old Killians Resort, which was on the south shore of Long Lake (Figures 7, 8, and 9). The rock exposed here is a dark gray, almost black, somewhat argillaceous limestone, containing numerous fossils, predominantly crinoid stems and large corals up to several inches in diameter. The bedding is somewhat irregular, and there are shaly partings throughout.

The Killians is generally poorly-exposed. Locally it is exposed in roadbeds, as along Grover Road, in the S½, section 9, T. 32 N., R. 7 E., Presque Isle County. In much of the area, fragments of the underlying bedrock may be seen laying haphazardly in fields and timbered areas. These slabs were plowed up by the Pleistocene ice sheet, and are incorporated within the thin glacial cover in the area (Figure 10).

FIGURE 10. Typical occurrence of Killians Member, Genshaw Formation, NE¼, SE¼, sec. 26, T. 32 N., R. 8 E.

Exposures of upper Genshaw rocks in the South Long Lake area are even more scarce. The best exposures are found along the shores of Trapp, Mindock, and Fitzgerald Lakes. The lithology of the upper Genshaw is somewhat different than that of the lower member. The color of upper Genshaw rocks ranges from buff to blue-gray to dark gray. It is typically a hard, crystalline, fossiliferous limestone, and represents a transitional member between the Killians limestones and the overlying Newton Creek Limestone.

The upper Genshaw fauna is composed mainly of crinoid stems, corals and brachiopods. In some places, field observation alone is not sufficient to separate the upper Genshaw from the strata directly above or below it. Exposures along Trapp and Fitzgerald Lakes are characterized by a series of elongated cracks in the strata, some of them 5 or 6 feet deep. The origins and significance of these features will be discussed later in this paper.

Newton Creek Limestone

Above the limestones and shales of the Genshaw Formation in Alpena and Presque Isle Counties, is the Newton Creek Limestone, a relatively thin unit, averaging only 25 feet in thickness (Figure 3). The name Newton Creek did not appear as a recognized formation name until 1943 (Warthin & Cooper, 1943). Apparently, the Newton Creek was included with Grabau's (1901, 1902) "Long Lake Series". Hake and Maebius (1938) included the Newton Creek as the uppermost unit of the "middle shale and limestone."

The Newton Creek Limestone is named after Newton Creek, a small creek which flows across section 13, T. 31 N., R. 8 E., the section in which the Huron Portland Cement Company quarry is located, just east of the city of Alpena. This quarry is the type locality of the Newton Creek Limestone, as well as the overlying Alpena limestone.

According to the current interpretation, the Newton Creek Limestone of the Alpena-Presque Isle County area corresponds to the brown central beds of the "middle Traverse limestones" described by Warthin and Cooper (1935). The brown color is due to interstitial petroleum in the limestone. One of the diagnostic characteristics of the Newton Creek Limestone is the strong petroliferous odor it possesses when it is freshly broken.

The lithology of this limestone is consistent throughout Alpena County. It varies somewhat in Presque Isle County. In the South Long Lake area, the Newton Creek is a brown medium-to coarsely-crystalline fossiliferous limestone. The fauna includes chiefly corals, but occasional bryozoans and brachiopods are also found. In the Afton-Onaway area of western Presque Isle County and eastern Cheboygan County, Kelly and Smith (1947) have studied a unit believed to overlie the Killians, and named it the Koehler Limestone. What is now believed to be the Newton Creek Limestone equivalent in the area appears as a buff-colored limestone, whereas the Koehler is a gray, bedded, dense, sublithographic limestone, unconformably underlying the "Gravel Point crystalline" strata. However, in spite of this apparent incongruity, the Koehler is believed to represent, in part at least, the time equivalent of the Newton Creek Limestone in the Afton-Onaway area (Dorr & Eschman, 1970; Martin, 1956, sheet II). The Koehler is exposed only at two localities in the Afton-Onaway area: the Afton quarry, and the LeGrand quarry, near Onaway (Kelly & Smith, 1947).

The outcrop area of the Newton Creek Limestone in the South Long Lake area is a narrow northwest-southeast trending band, averaging one half mile in width. Its contact with the overlying Alpena Limestone is marked by a prominent scarp along most of its outcrop area. The most striking scarp associated with this contact appears in Long Lake Road, 1½ miles west of Bolton Road, in section 32, T. 33 N., R. 7 E., Presque Isle County. At this locality, the road drops about 30 feet at a prominent scarp. Just southeast of that locality, a sinkhole was observed on the contact. The scarp is somewhat lower at the sinkhole, perhaps only 15 or 20 feet (Figure 11). This scarp is probably due to differential erosional resistance of the upper strata of the Newton Creek and lower strata of the Alpena Limestone.

FIGURE 11. Newton Creek-Alpena contact marked by large scarp in NW¼, NW¼, sec. 32, T. 33 N., R. 7 E.

A number of sinkholes are localized along the Newton Creek-Alpena contact in the northern half of the South Long Lake area. In addition to the one west of Bolton, two other sinkholes were studied in the NW¼ of section 11, T. 32 N., R. 7 E. In section 14, same township, two sinkholes within the Alpena Limestone were studied less than one mile away from the Newton Creek contact. These sinkholes will be discussed in detail in a later section of this paper.

Alpena Limestone

The Alpena Limestone was named by Grabau (1901, 1902) as a replacement for the name "middle Traverse Limestone", also described by Grabau (1901). This limestone is quarried at the Huron Portland Cement Company quarry immediately north and northeast of Alpena, thus the name. Grabau observed the limestone as a coralline to hydrocoralline limestone, containing brachiopods and fenestellid bryozoans (Grabau, 1902). The name Alpena Limestone was retained through the years, and is still in use. These exposures were again studied by Ver Wiebe (1927), and the Michigan Geological Survey (no date), where the Alpena Limestone was described as being represented by the strata from the top of the Churchill well to the base of Grabau's (1901, 1902) "unit 6."

The Alpena Limestone was included as the basal member of the "middle massive limestone" of Hake and Maebius (1938), consisting of massive limestones and dolomites with varying amounts of chert.

The Alpena Limestone of the South Long Lake area is a massive or medium-bedded gray to white coarsely-crystalline limestone. It is fossiliferous, and contains many corals, brachiopods, and bryozoans. It is a biohermal limestone, and quarrying operations at the Huron Portland Cement Company quarry at Alpena often expose large bioherms. It is reported by Stumm (1969) that, at this quarry, any given bioherm may disappear within one year after it is exposed, as the walls are quarried away. The bioherms are lens-shaped and relatively thin. They represent Devonian coral reefs, thus the mound-like form. Stumm (1969) believed the convex base of these reefs were formed either by compression of overlying strata, or sinking of the mass into the unconsolidated substrata at the time of deformation.

In the Afton-Onaway area, the Alpena Limestone equivalent is included within the Gravel Point Formation of Pohl (1930) and Kelly and Smith (1947). It cannot be differentiated as a separate formation by field observation.

Exposures of the Alpena Limestone in the South Long Lake area take a variety of forms. It is exposed in several sinkholes, such as those in section 14, T. 32 N., R. 7 E. The best natural exposure of the Alpena Limestone in the South Long Lake area is at the old Bolton quarry, just north of Maple Lane Road, in the south-central part of section 5, T. 32 N., R. 7 E. (Figure 12). Most of the exposures of the Alpena

FIGURE 12. Alpena Limestone exposed at old Bolton quarry, sec. 5, T. 32 N., R. 7 E., Alpena County

Limestone in the South Long Lake area consist of scabby exposures in roadbeds, or as slabs laying on the ground in ditches and fields. The average thickness of the Alpena Limestone is 79 feet (Figure 3), and the maximum width of the outcrop belt in the South Long Lake area is approximately three miles.

Fourmile Dam Formation

The Fourmile Dam Formation is generally considered to be the lowermost formation of Grabau's (1902) "Thunder Bay Series", and the base of the upper Traverse strata. The lowermost 7½ feet of the Fourmile Dam Formation has been named the Dock Street Clay, after exposures in a test well on Dock Street, in the city of Alpena (Grabau, 1901, 1902). For many years, the Dock Street Clay was considered to represent the uppermost interval of the Alpena Limestone. Ver Wiebe (1927) designated the top of the middle Traverse as the point where the lithology changes from a calcareous shale (Dock Street Clay) to a crystalline hard limestone. The current usage of the name Fourmile Dam was introduced by Warthin and Cooper (1943), from exposures at the foot of the Alpena Power Company's Fourmile Dam, on the Thunder Bay River four miles upstream from Alpena.

West of Alpena and eastern Presque Isle County, the Fourmile Dam Formation loses its distinction as a separate unit. In the Afton-Onaway area, its equivalent is included within the Gravel Point Formation of Pohl (1930) and Kelly and Smith (1947). Further south in the Michigan Basin, the Fourmile Dam Formation equivalent is included within the "middle massive limestone" of Hake and Maebius (1938).

There are no exposures of the Fourmile Dam Formation in the South Long Lake area, and very few exposures anywhere. The nearest exposures are 3 or 4 miles from the South Long Lake area, at the type locality.

Norway Point Formation

The Norway Point Formation is the fourth unit below the top of the Traverse Group in Alpena and Presque Isle Counties. The Norway Point was undifferentiated and included as part of Grabau's (1901, 1902) "Thunder Bay Series" for many years. It was not recognized as a separate formation until Warthin and Cooper (1935) named it after exposures at the base of the Alpena Power Company's Norway Point Dam, on the Thunder Bay River approximately five miles upstream from Alpena. In the western part of the state, as well as in the Afton-Onaway area, the Norway Point strata are included within the "Gravel Point Stage" (Pohl, 1930; Kelly & Smith, 1947). In central Michigan, these strata are included within the "middle massive limestone" of Hake and Maebius (1938).

The top and bottom of this formation are not visible at the type locality. The thickness of the exposed strata of this formation has been measured as 45 feet at the type locality (Warthin & Cooper, 1943). These strata were deposited on the irregular, somewhat biohermal surface of the underlying Fourmile Dam Formation. The Norway Point Formation is presumed to be the youngest Michigan formation with definite Hamilton faunal affinities (Warthin & Cooper, 1943), and is probably the time equivalent of the lower Wanakah Shale of the Ludlowville Formation of New York State.

The Norway Point Formation is not exposed in the South Long Lake area. The nearest exposures are along Haken Road south of the area, and at the Fourmile and Norway Point Dams on the Thunder Bay River. At these localities, it is exposed as a blue-gray, fissile calcareous shale, relatively free of fossils, and emitting a sulfur smell when efforvesced in dilute hydrochloric acid.

Potter Farm Formation

The Potter Farm Formation of Alpena County consists of over 100 feet of crinoidal limestones and gray calcareous shales. It is one of the units of Grabau's (1902) "Thunder Bay Series", or "upper Traverse limestones". For many years, it was not recognized as a separate formation. Ver Wiebe (1927) stated that one of the beds within the "Thunder Bay Series" formed a terrace on the farm of Fred Potter, near Alpena. This was a bed of massive limestone, and was referred to as the "Silo Terrace." The only other exposures now known as the Potter Farm Formation were described in the vicinity of Orchard Hill, a structural dome north of Long Rapids (Michigan Geological Survey, no date).

The Potter Farm Formation was named by Warthin and Cooper (1935) for the exposures on Fred Potter's farm, described by Ver Wiebe (1927). The type locality for the Potter Farm is located on private property along the south shore of the Thunder Bay River, north of Alpena, at the site of the old Potter farm.

The thickness of the Potter Farm Formation in Alpena County is reported by Warthin and Cooper (1943) to be 68 to 74 feet. Ehlers and Kesling (1970) reported it as being somewhat thicker (Figure 3). The Potter Farm, combined with the overlying Thunder Bay Limestone, are the approximate equivalents of the "Petoskey Formation" of Pohl (1930). Correlation with the Devonian of New York State has been found to be difficult (Warthin & Cooper, 1943).

There are no exposures of any of the upper Traverse strata in the South Long Lake area. The writer visited a few exposures along the south side of the Thunder Bay River northwest of Alpena, near the type locality. The exposed rock at these localities is a gray, somewhat argillaceous limestone, which weathers buff yellow, and contains numerous bryozoans and crinoids. At these localities, the Potter Farm is exposed in two small ledges 1 or 2 feet high, over which small overflow creeks flow into the Thunder Bay River. Along the dirt road leading from the river to highway M–65, there are a few low roadcuts on the west side of the road, in which Potter Farm strata are also exposed.

Thunder Bay Limestone

The name Thunder Bay as the name of a unit of the upper Traverse Group was first introduced by Grabau (1901, 1902). His "Thunder Bay Series", or "upper Traverse shales and limestones", included all the strata above the Alpena Limestone. The rocks of this series, which crop out at Partridge Point and Stoney Point, on Lake Huron, were first described in a report by the Michigan Geological Survey (no date), then redescribed by Warthin and Cooper (1935) as the "Partridge Point Series". Warthin and Cooper (1943) divided the "Partridge Point Series" into two smaller units, the Thunder Bay Limestone and the Squaw Bay Limestone. The observed strata consisted of irregularly-bedded limestones and fossiliferous calcareous shales. The east shore of Partridge Point, south of Alpena, was chosen as the type locality. At this locality, the strata form small ledges along the shore, and in the fields to the northwest.

In Alpena County, the type locality is one of the few places that either of the two members of Warthin and Cooper's (1935) "Partridge Point Series" are exposed. The entire sequence is only about 25 feet thick (Figure 3). The outcrop belt is no more than one half mile wide. Exposures are found only in south central Alpena County, south of Alpena. There are no exposures of either the Thunder Bay or Squaw Bay Limestones in the South Long Lake area.

The writer did not visit the type locality of the Thunder Bay Limestone. A description of its lithology can be found in Ehlers and Kesling (1970).

Squaw Bay Limestone

The Squaw Bay Limestone represents the uppermost unit of the Traverse Group of Alpena County. The formation was named by Warthin and Cooper (1935) after exposures on the south shore of Partridge Point, on Squaw Bay, Lake Huron. The Squaw

Bay Limestone and the underlying Thunder Bay Limestone were considered to be part of the "Partridge Point Series". Hake and Maebius (1938) recognized the Squaw Bay as a separate unit, the uppermost unit of the Traverse Group. It is a fine-grained, light brown, dolomitic limestone. Some workers (Hake & Maebius, 1938; Warthin & Cooper, 1943) have stated that, in earlier days, oil has been produced from this formation. Characteristic fossils in this limestone include goniatite cephalopods. Because of these occurrences, Warthin and Cooper (1943) believed the Squaw Bay to have the closest faunal affinities with the Genundewa Limestone of New York State.

In the Afton-Onaway area, the Squaw Bay equivalent has been named the Beebe School Formation by Kelly and Smith (1947). This formation is believed to overlie the Gravel Point Formation, which was named by Pohl (1930) for exposures in the Little Traverse Bay area.

The exceptional purity of the Squaw Bay Limestone suggests a period of subsidence following deposition of the "upper shale unit" of Hake and Maebius (1938). This "upper shale unit" probably includes some beds of the Thunder Bay Limestone, as well as some from the Squaw Bay Limestone.

The top of the Squaw Bay Limestone represents the top of the Traverse Group of Alpena County. The Traverse is overlain by the Antrim Shale in the Little Traverse Bay area. The Antrim Shale is believed to represent a major tectonic event in the Appalachians region, a result of which was the deposition of vast quantities of black mud into the Michigan Basin from the Appalachian highlands (Dorr & Eschman, 1970).

Surface formations

Above the Devonian rocks in Alpena and Presque Isle Counties is a thin veneer of glacial drift, averaging 7 feet thick (Figure 3). Numerous glacial landforms have developed in these Pleistocene deposits in Alpena and Presque Isle Counties, which resulted from Wisconsin glaciation. Martin (1955) mapped end moraines as well as ground moraines throughout most of the area. In a band parallel to the present Lake Huron shoreline, she mapped sand lake beds as well as several glacial and postglacial shorelines. Figure 13 is a reproduction of Helen Martin's map of Alpena and Presque Isle Counties.

Several individual glacial landforms in the two counties have been described by Ver Wiebe and Bergquist (1925), Poindexter (1931), Dorr and Eschman (1970), and Dewey (1961). Ver Wiebe and Bergquist (1925) recognized seven kames in Alpena County, the largest of which is a 70– to 80–foot high conical hill south of Lachine, in section 19, T. 30 N., R. 7 E. They also recognized numerous glacial and postglacial shorelines from the Algonquin and Nipissing stages of Lake Huron, as well as several sand dunes believed to be wind-blown from the Nipissing stage. Poindexter (1931) made reference to kames, eskers, moraines, till plains, shorelines, deltas, sand bars, spits, and sand dunes in Alpena County.

The major glacial feature in Alpena and Presque Isle Counties is the Cheboygan morainic system (Martin, 1955; Dorr & Eschman, 1970). This moraine is not well-developed in northern Alpena or eastern Presque Isle County. The best development of the Cheboygan end moraine is in the area west of Ossineke, southern Alpena County. In Presque Isle County, it can be studied in the Millersburg area.

In the South Long Lake area, Martin's (1955) map shows predominantly lake beds, both sand and clay. The only significant area of ground moraine is in Presque Isle County just west of Trapp Lake (Figure 13). The present writer observed a considerable amount of sand and clay in the South Long Lake area, associated with relatively flat topography. A few isolated areas of what is believed to be wind-blown dune sand were visited, in addition to several gravel pits, generally found in topographically-high areas. The material observed in the gravel pits ranges from fine sand to boulders 1 to 2 feet in diameter. Outwash material was not found anywhere in the South Long Lake area. A general term for the surface deposits in the area is "sandy till." In most of the area, Traverse bedrock has been incorporated into the till, some blocks attaining a diameter of 1 to 2 feet. Local occurrences of granitic erratics were also observed.

Due to the thinness of the drift in the area, many subsurface features can be studied with reasonable accuracy on aerial photographs. Whatever the cause of the photolinears described in the next section of the paper, they will have a definite expression in the surface material of the area. In many instances, this overlying material will collapse and fill in cracks previously developed in the bedrock. In many parts of Alpena and Presque Isle Counties, the glacial cover is less than one foot thick. In

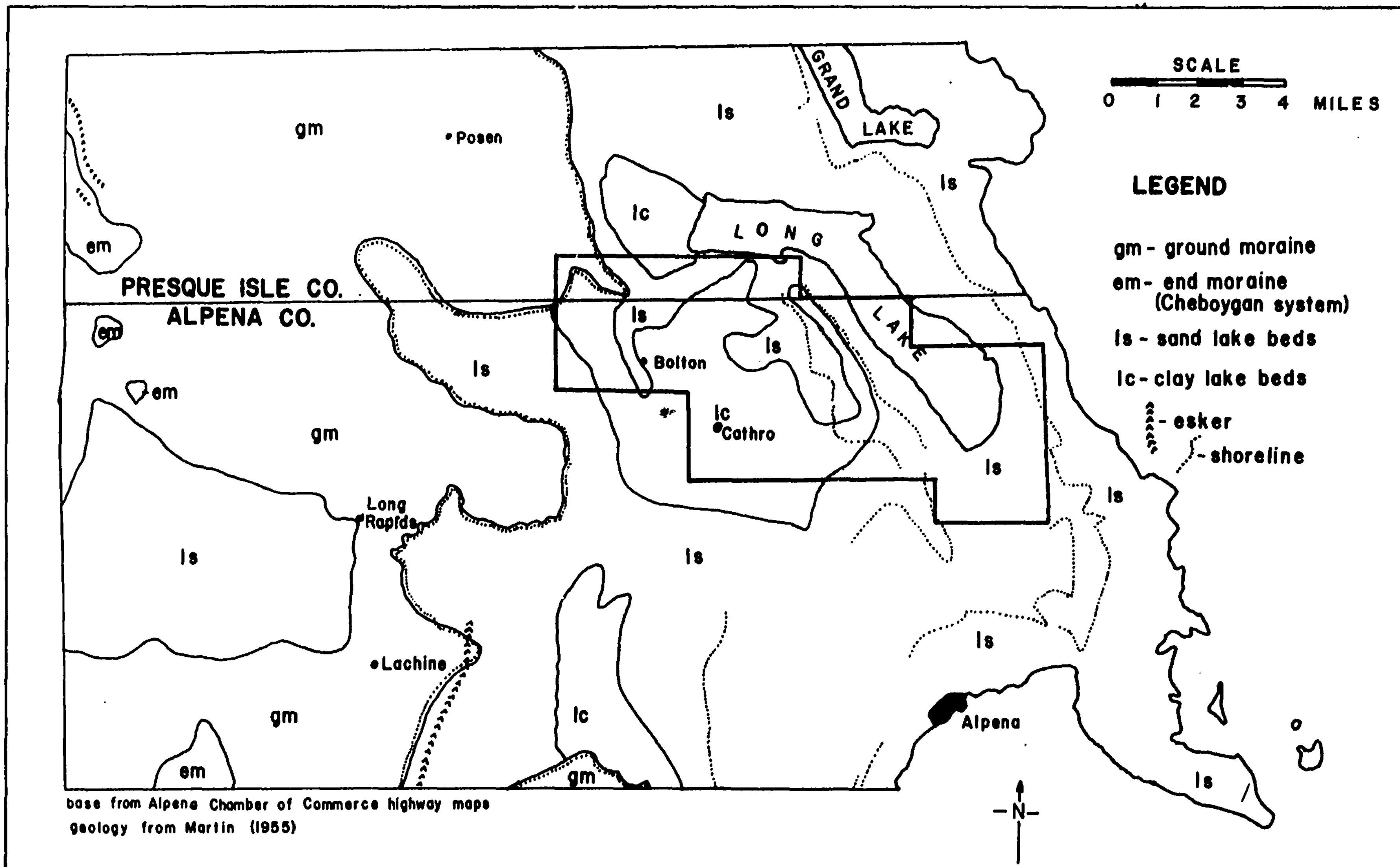


FIGURE 13. Surface geology of the South Long Lake area and vicinity

these places, linear features in the surface deposits, which are visible on aerial photographs, are a direct reflection of the subsurface features. These features are not always readily apparent in the field, and it is often a case of "not being able to see the forest through the trees."

Glacial and postglacial shorelines are of special importance in the patterns of photolinears in Alpena and Presque Isle Counties. Several of these shorelines were mapped by Martin (1955). The present writer found at least five more in the South Long Lake area, which were previously unmapped. These will be discussed in a later section. Most of these shorelines represent successive stands of the Algonquin stage of Pleistocene Lake Huron. This stage existed in late Wisconsin time, after the Two Creekian interstadial event. As the Valders ice sheet advanced across the Michigan Basin, lake levels became higher (Dorr & Eschman, 1970). The resulting high-level Lake Algonquin drained to the south. It should be noted that an earlier, north-draining Lake Algonquin existed prior to the Two Creeks interstadial event. It can be reasonably assumed that the shorelines in the South Long Lake area are the results of the later Algonquin stage, since there are no younger deposits on top of these shoreline ridges. In the Ossineke area, however, Ver Wiebe and Bergquist (1925) accounted for several ridges and terraces of the post-glacial Lake Nipissing stage. Lake Nipissing is believed to have resulted from a change in the outlet level from that of a previous postglacial stage (Dorr & Eschman, 1970). The change in outlet level was probably a result of isostatic rebound.

PHOTOLINEARS

The South Long Lake area, Alpena and Presque Isle Counties, Michigan, contains many karst features in addition to a large number of topographic and structural "photolinears", which are genarally visible on aerial photographs. These photolinears can be attributed to various origins. Definite relationships most likely exist between these linear features and the ground-water features in the area, as well as the rocks of the Traverse Group, and those which underlie the Traverse Group. In this section of the paper, these features will be described, their occurrences examined, in an attempt to put them into a proper perspective such that some definite statements can be made concerning their origins and significance in the total geologic framework of the area.

The photolinears were mapped on aerial photomosaics published by the U. S. Department of Agriculture–Stabilization and Conservation Service (ASCS). The writer visited the field in the spring of 1972, and studied several of these features.

Definitions and Descriptions of Linears

Humble Oil Company (1961) defined a "linear" as "any natural straight or smoothly curved line evident on an air photo." Two major types of linears (photolinears) are recognized: 1) a geologic fracture trace, and 2) a geologic lineament. A fracture trace is a photolinear which extends across the earth's surface continuously for less than one mile. A lineament extends continuously or discontinuously for at least one mile (Lattman, 1958). These features take on many forms when studied on aerial photographs. Some of these are topographic scarps, soil bands, vegetation lines, straight segments of streams, and lines of ponds or lakes. Expressions of large-scale lineaments also have many forms. Hobbs (1904) listed four occurrences which produce these large-scale features. These are 1) ridge crests or boundaries of highlands, 2) drainage lines, 3) coastlines, and 4) geologic boundaries, such as the Fall Line of the Atlantic Coastal Plain.

Fracture traces are believed to represent local bedrock joints and fractures, whereas lineaments seem to indicate major fracture zones (Lattman, 1958; Lattman & Matzke, 1961). Other features which have been known to produce photolinears are schistosity in metamorphic areas, shrinkage cracks, permafrost and solifluction patterns, wind erosion, glacial striations, drumlins, ice-crevasse fillings, beach ridges, and terrace scarps (Humble Oil, 1961). Both types of photolinears are present in the South Long Lake area. They have varied forms and origins. Many photolinears have no apparent surface expression, but show up only on aerial photographs. In contrast, some linear features have been observed in the field, but have no associated photographic traces. Most of the linears in the South Long Lake area appear as scarps in roads which become low ridges away from the roads. The scarps which appear as photolinears vary from 4 to 5 to as much as 30 to 40 feet in height.

There are two preferred orientations of photolinears in northern Alpena and eastern Presque Isle Counties. The mean azimuths of these two sets were calculated as 47^{o} and 133^{o} (N 47^{o}W and N 43^{o}E). These orientations are believed to represent two of the four principal directions of earth fracture suggested by Blanchet (1957). These four principal directions of earth fracture are products of a combination of internal and external stresses on the earth.

Photolinears are abundant throughout Alpena and Presque Isle Counties, particularly in the South Long Lake area (Figure 14). Ten of these are especially conspicuous, therefore each of them will be studied in detail. From east to west across the South Long Lake area, these lines have been named by the present writer as: Little Opechee Line, Opechee Line, Killians (Long Lake) Line, Three Lakes Line, Mindock Line, Bolton Line, Dagett Line, Algonquin Line, Cathro Line, and Weide Line (Figure 2). Of these ten photolinears, eight trend northwest-southeast, one trends northeast-southwest, and the tenth one (Algonquin Line) trands generally north-south, but has an eastward bend at the north and south ends. Of the eight that trend northwest-southeast, only four are parallel to the regional strike, which is approximately N 50^{o}W in the South Long Lake area. Only one of those, the Killians Line, is believed to represent a formational contact.

Methods of Study

Photolinears of Alpena and Presque Isle Counties were mapped on U. S. Department of Agriculture aerial photographs, using methods described by Humble Oil (1961), Blanchet (1957), Gross (1951), Lattman (1958), and Lattman and Matzke (1961). It was suggested to the author by Straw (1972, personal communication) that a linear study in Alpena and Presque Isle Counties would be a practical approach to a geological investigation of the area. Four aerial photomosaics were obtained from the U. S. Department of Agriculture. The photography of Alpena County was flown in October 1963 by Malcolm Aerial Surveys, Roanoke, Virginia. Presque Isle County was flown by the same firm on July 4th, 1964. One immediately-apparent problem was that the photography taken in the summer may not show as much detail, since the trees in the area were in full leaf then and minor subtleties in the ground expression of the photolinears may be obscured.

When the mosaics were carefully looked at and studied, there were indeed many visible photolinears. More photolinears were observed in Alpena County than in Presque Isle County, since the summer vegetation shown in the Presque Isle County mosaics did in fact obscure much of the detail.

The photolinears were traced onto an acetate overlay with a grease pencil. This was done in four subareas, each subarea representing that area covered by a single photomosaic. A composite of the subareas was used to generate a photolinear map (Figure 14). As the photolinears were being mapped, a tally was made of their average compass bearings, expressed in degrees east or west of north. Their maximum discernible lengths were also tallied. A preliminary conclusion at that time was that there are two principal orientations of the photolinears, those being northeast-southwest and northwest-southeast. Blanchet (1957) stated that the earth is fractured in four principle directions. If the photolinears are reflections of these four fracture trends, it becomes puzzling why only two directions appear in the Alpena-Presque Isle County area photolinears, and why there is no significant development in either the north-south or east-west directions.

After the photolinears were mapped, bar graphs were drawn showing the percentage of trends in each ten degrees of azimuth (Figures 15, 16, 17, 18). The distribution of photolinear trends in the entire study area was also graphed (Figure 19). Rose diagrams were then drawn for all the subareas (Figures 20, 21, 22, 23), as well as one for the entire area (Figure 24). The data produced by the photolinear study were summarized by descriptive statistics.

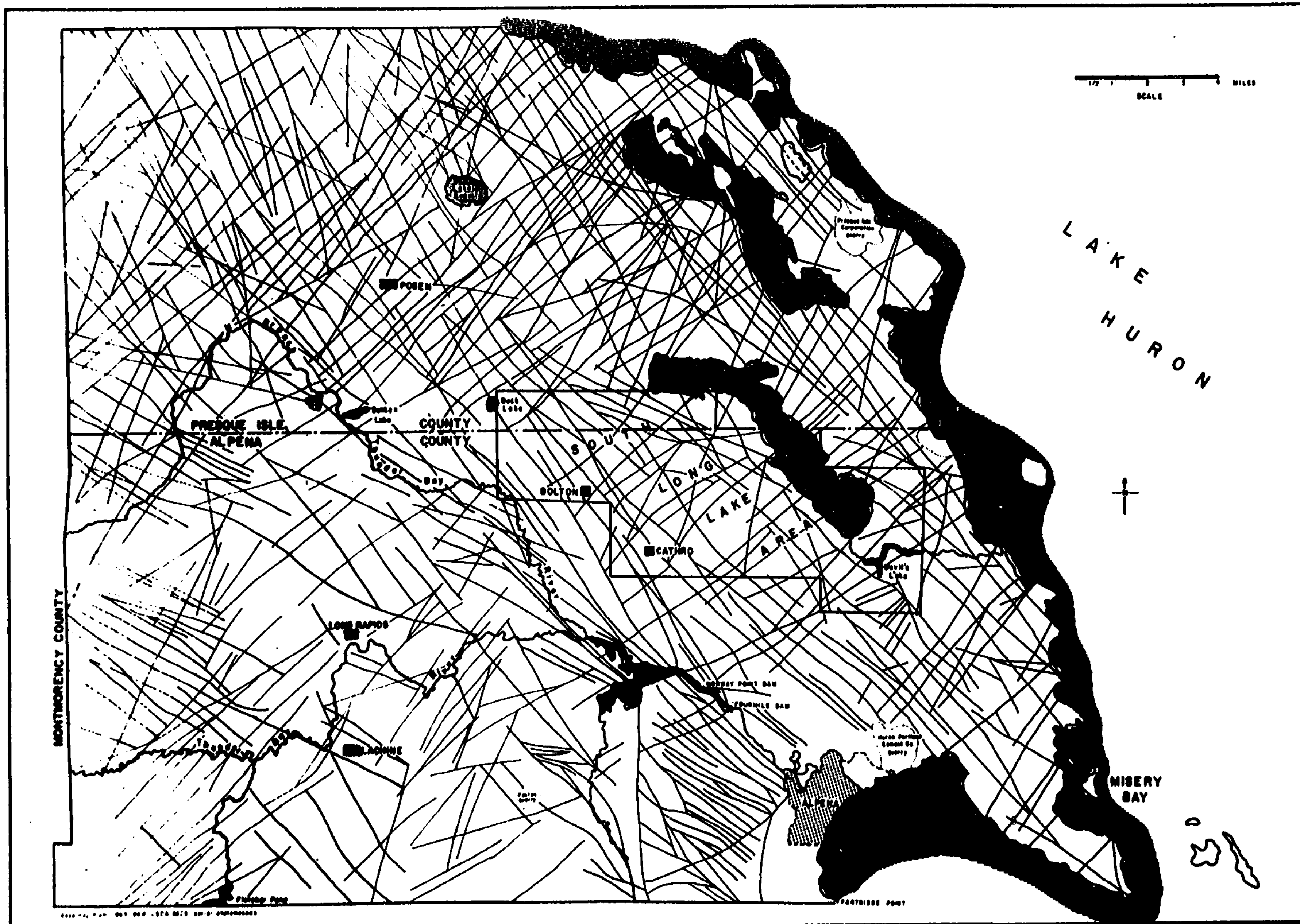


FIGURE 14. Photolinears in northern Alpena and eastern Presque Isle Counties, Michigan

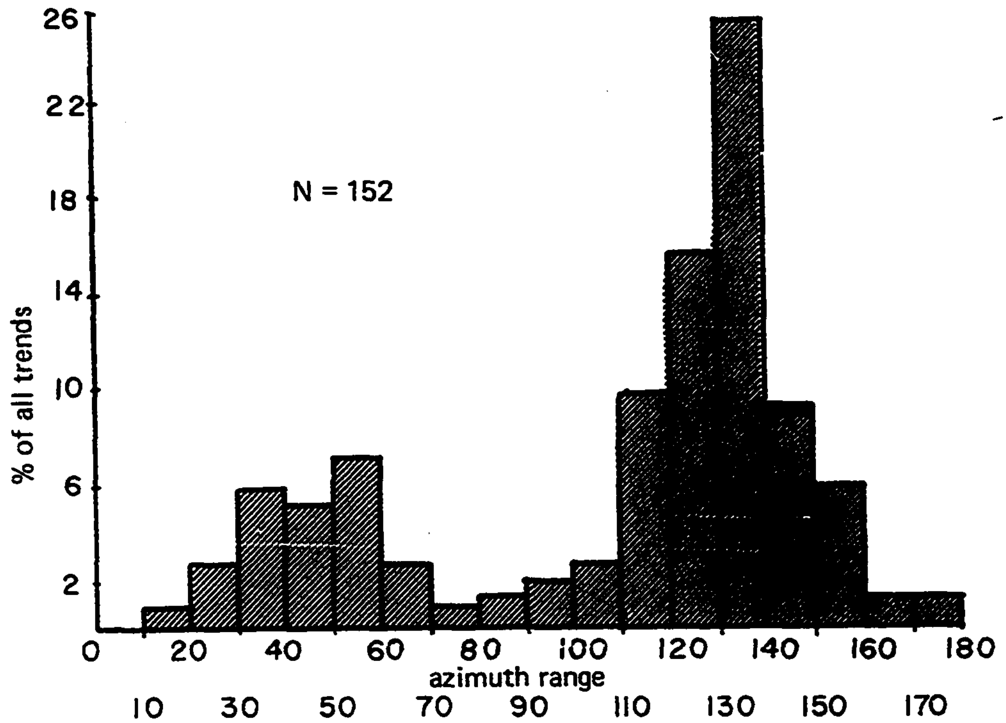


FIGURE 15. Orientations of photolinears in subarea I (northeast Alpena County)

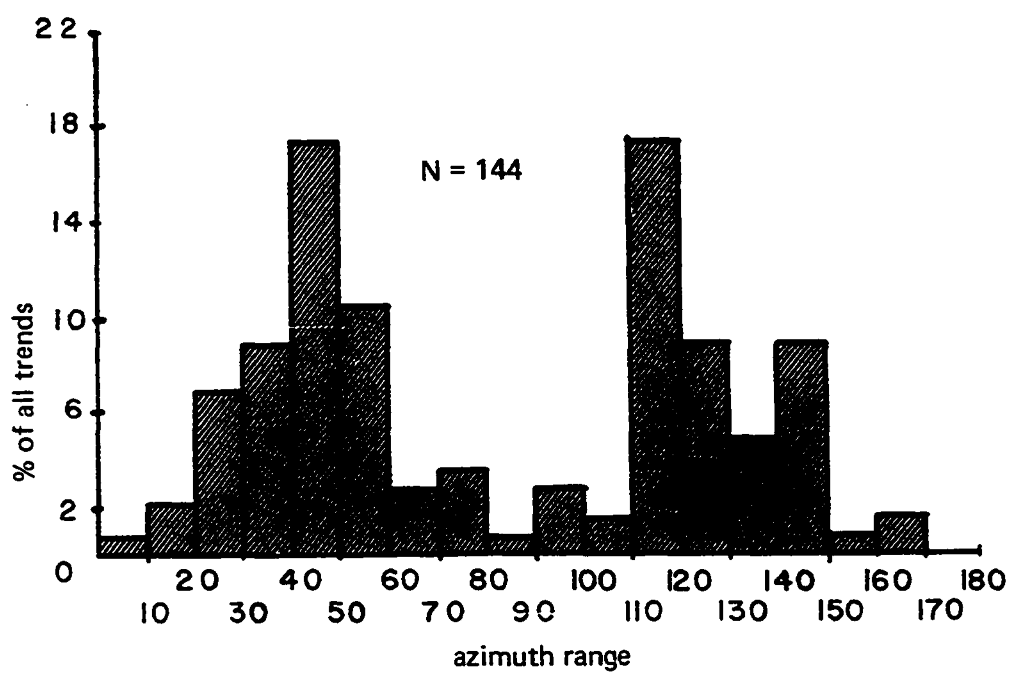


FIGURE 16. Orientations of photolinears in subarea II (northwest Alpena County)

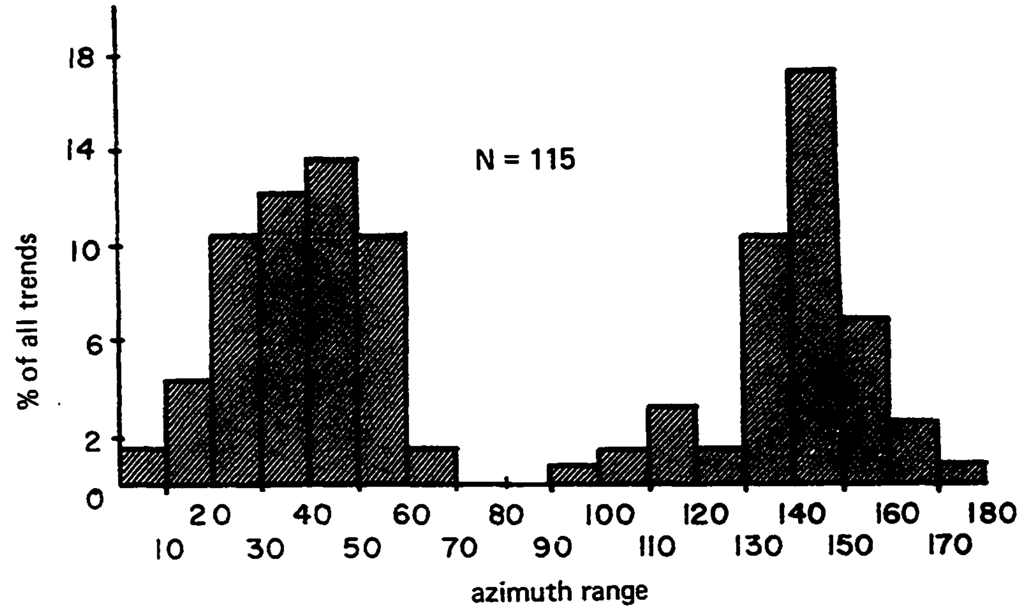


FIGURE 17. Orientations of photolinears in subarea III (easternmost Presque Isle County)

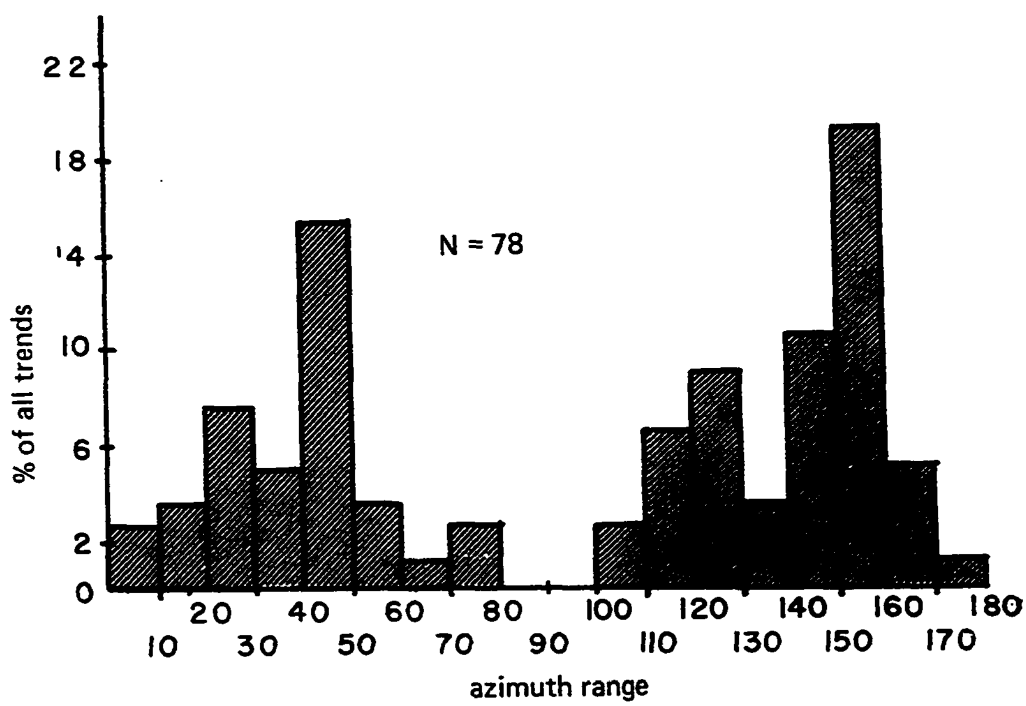


FIGURE 18. Orientations of photolinears in subarea IV (east central Presque Isle County)

Statistical Analysis

A major part of the study of photolinears in Alpena and Presque Isle Counties involved calculation of several statistical parameters, in an attempt to determine if any statistical relationships exist between the photolinears throughout the study area. The linears were mapped in four adjacent subareas within the total area, which consists of the northern half of Alpena County and the eastern third of Presque Isle County (Figure 14). Subarea I is here defined to include that area of northern Alpena County which appears on sheet no. 4 of the 1963 ASCS-USDA photomosaic of Alpena County. Subarea II is defined to include the area of northern Alpena County which appears on sheet no. 1 of the same set of photomosaics. Subarea III is that portion of eastern Presque Isle County covered by sheet no. 1 of the ASCS-USDA 1964 photomosaics of Presque Isle County. Subarea IV is defined to consist of the area which appears on sheet no. 5 of the same project.

Two variables were tested against themselves and each other, using the integrated statistics program written by the staff of the Western Michigan University computer center, and programmed for a Digital Equipment Corporation PDP-10 timesharing computer. The two variables tested by this program were compass azimuth and length (in miles) of the photolinears. It was hypothesized that a relationship might exist between these variables.

It was conclusively shown that there are two major sets of photolinears in the study area, these trending toward mean azimuths of 42.8° for the northeast-southwest set, and 132.9° for the northwest-southeast set. These two azimuths are 90° apart. The northwest-southeast set roughly parallels the regional strike of the strata in the area, and the longest photolinears are in this set (Figure 25).

Each of the two sets of photolinears was analyzed within each subarea, and again within the entire area (Table 1, appendix i). Each variable, azimuth and length, was analyzed separately. Within each subarea, it can be seen that each set of photolinear azimuths has a relatively symmetrical distribution, with skewness coefficients ranging from –.940 to +.293. Skewness is a measure of symmetry about the mean. The closer a skewness value approaches zero, the more symmetrical is the distribution.

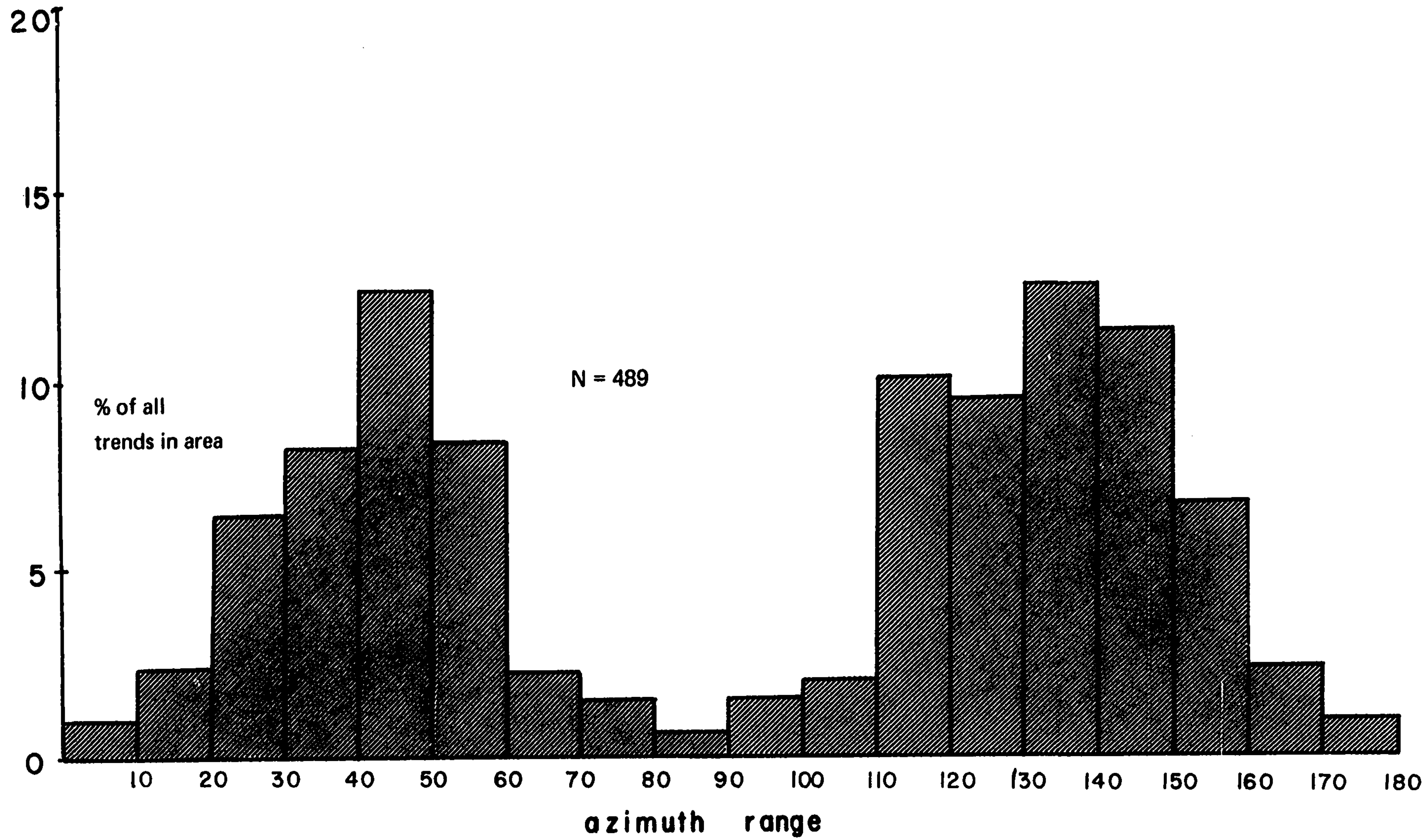


FIGURE 19. Orientations of photolinears in northern Alpena and eastern Presque Isle Counties

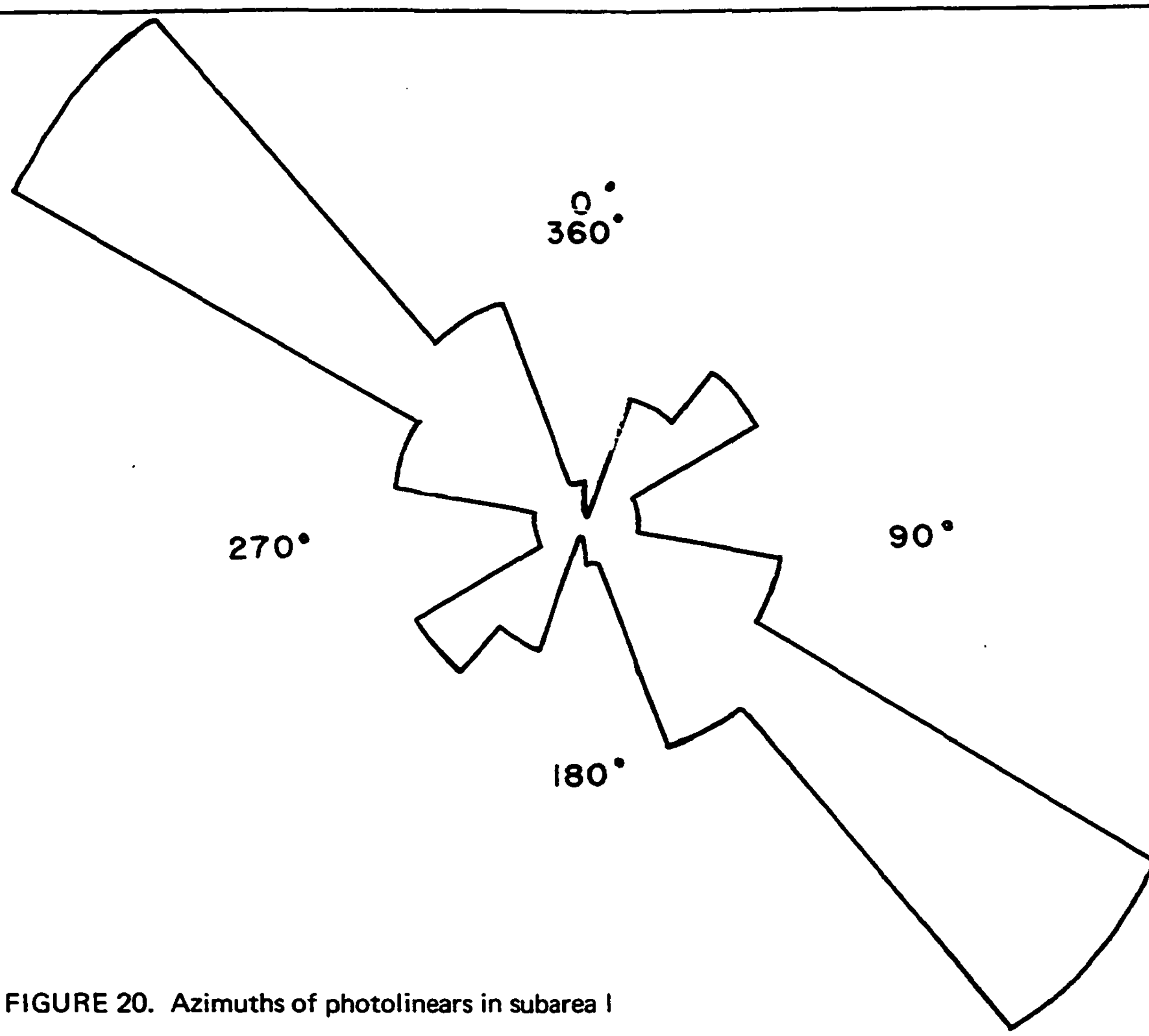


FIGURE 20. Azimuths of photolinears in subarea I

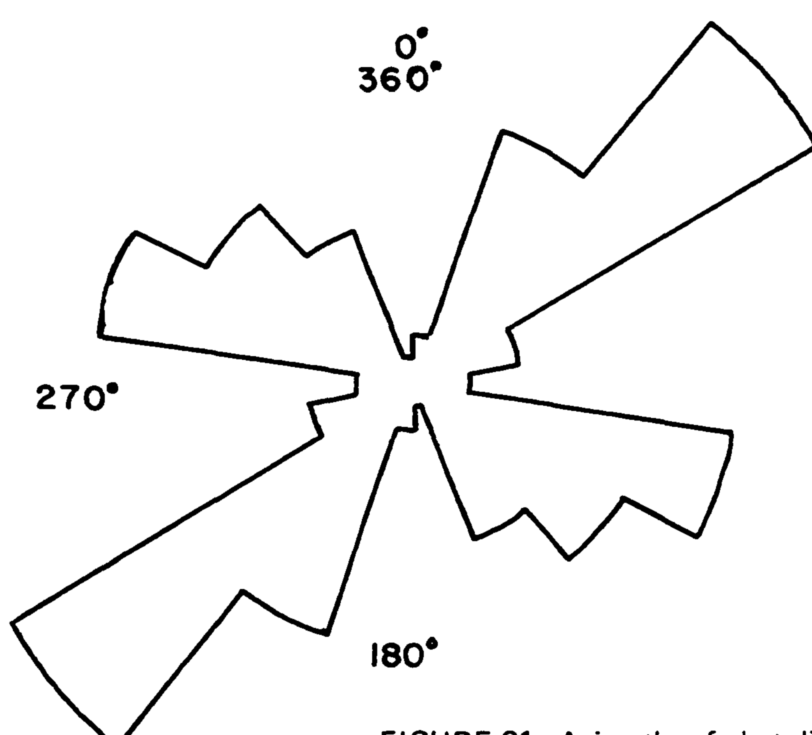


FIGURE 21. Azimuths of photolinears in subarea II

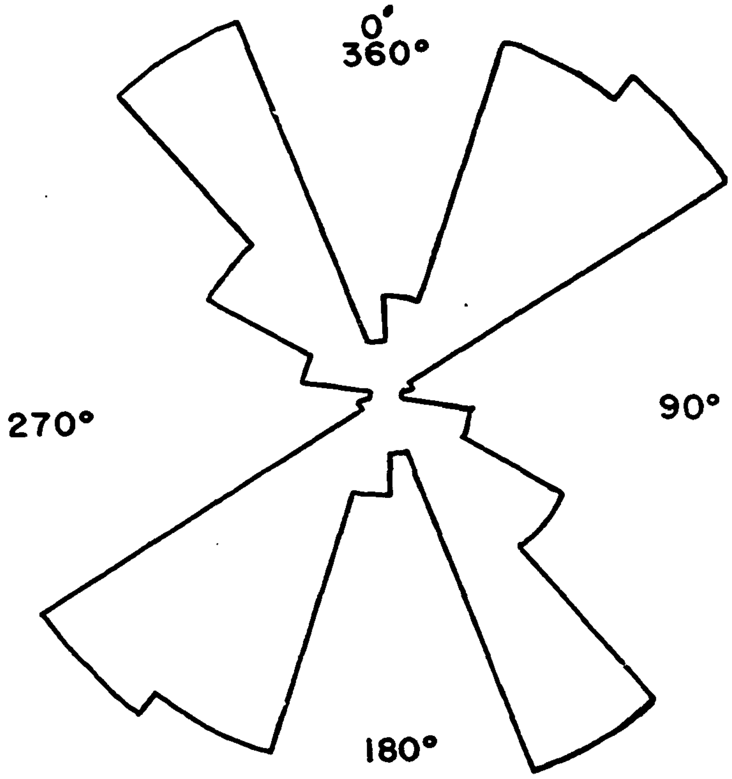


FIGURE 22.
Azimuths of photo-linears in subarea III

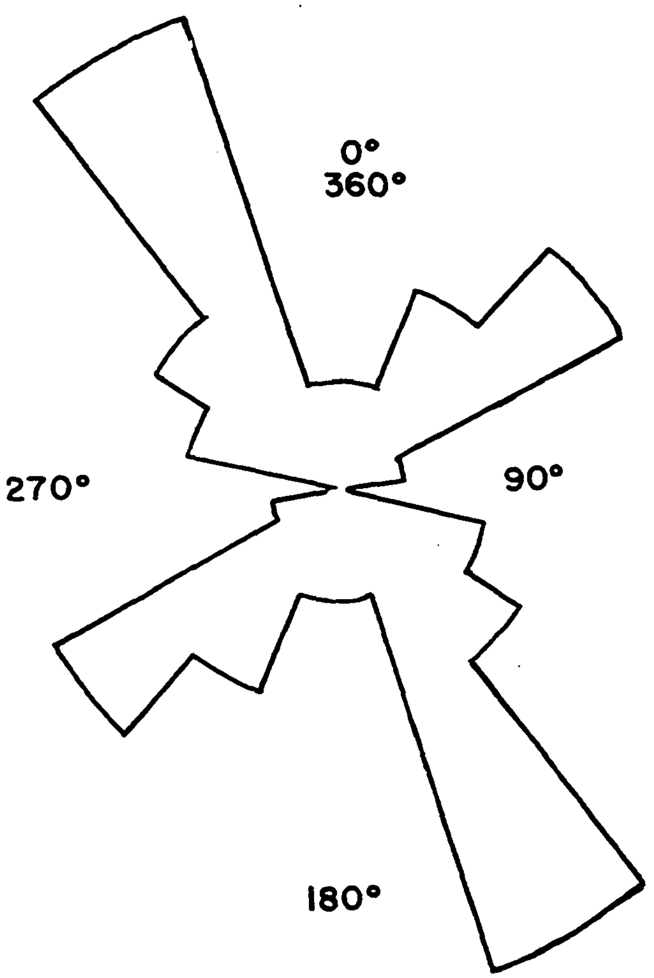


FIGURE 23.
Azimuths of photo-linears in subarea IV

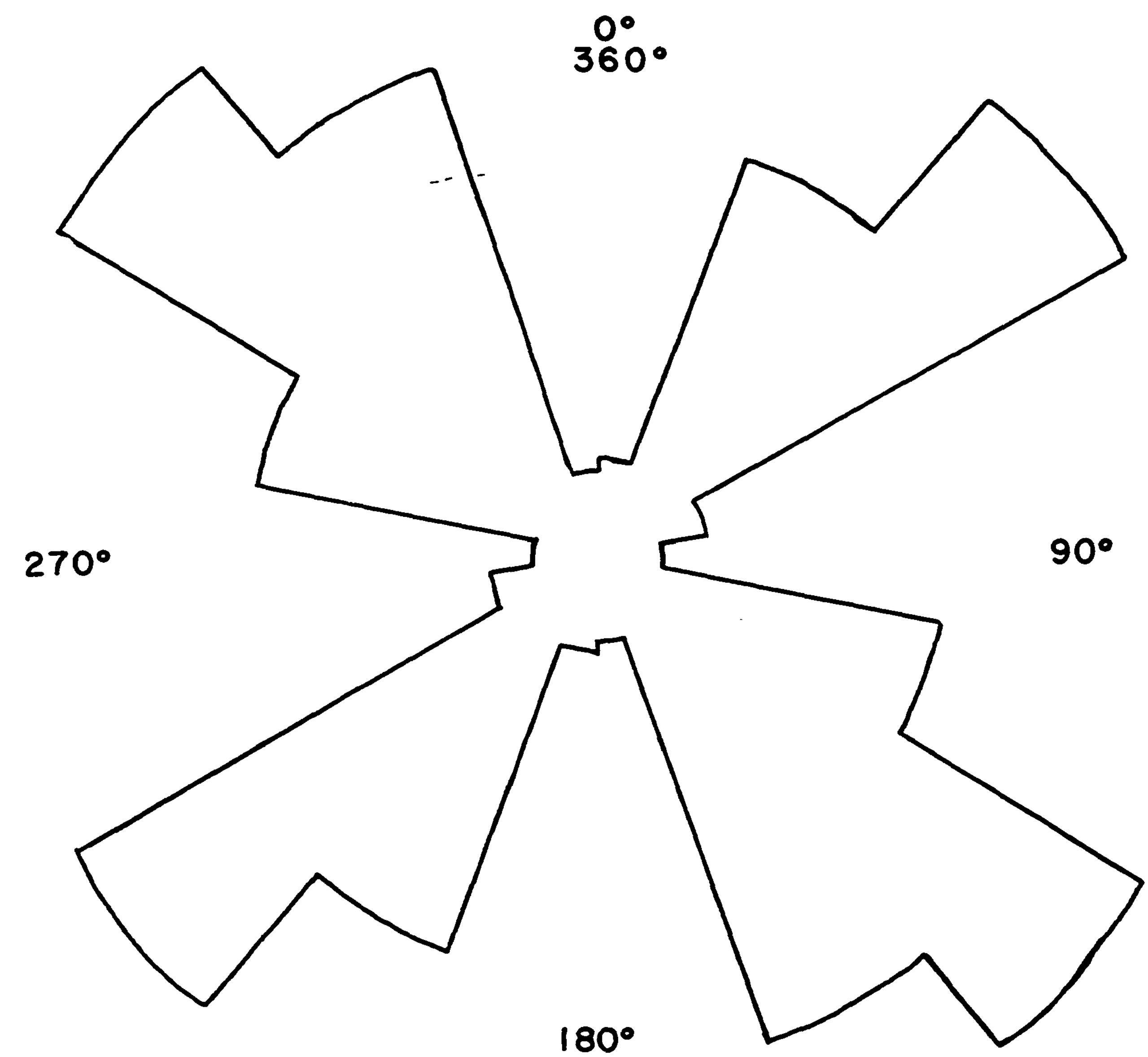


FIGURE 24. Azimuths of photolinears in northern Alpena and eastern Presque Isle Counties

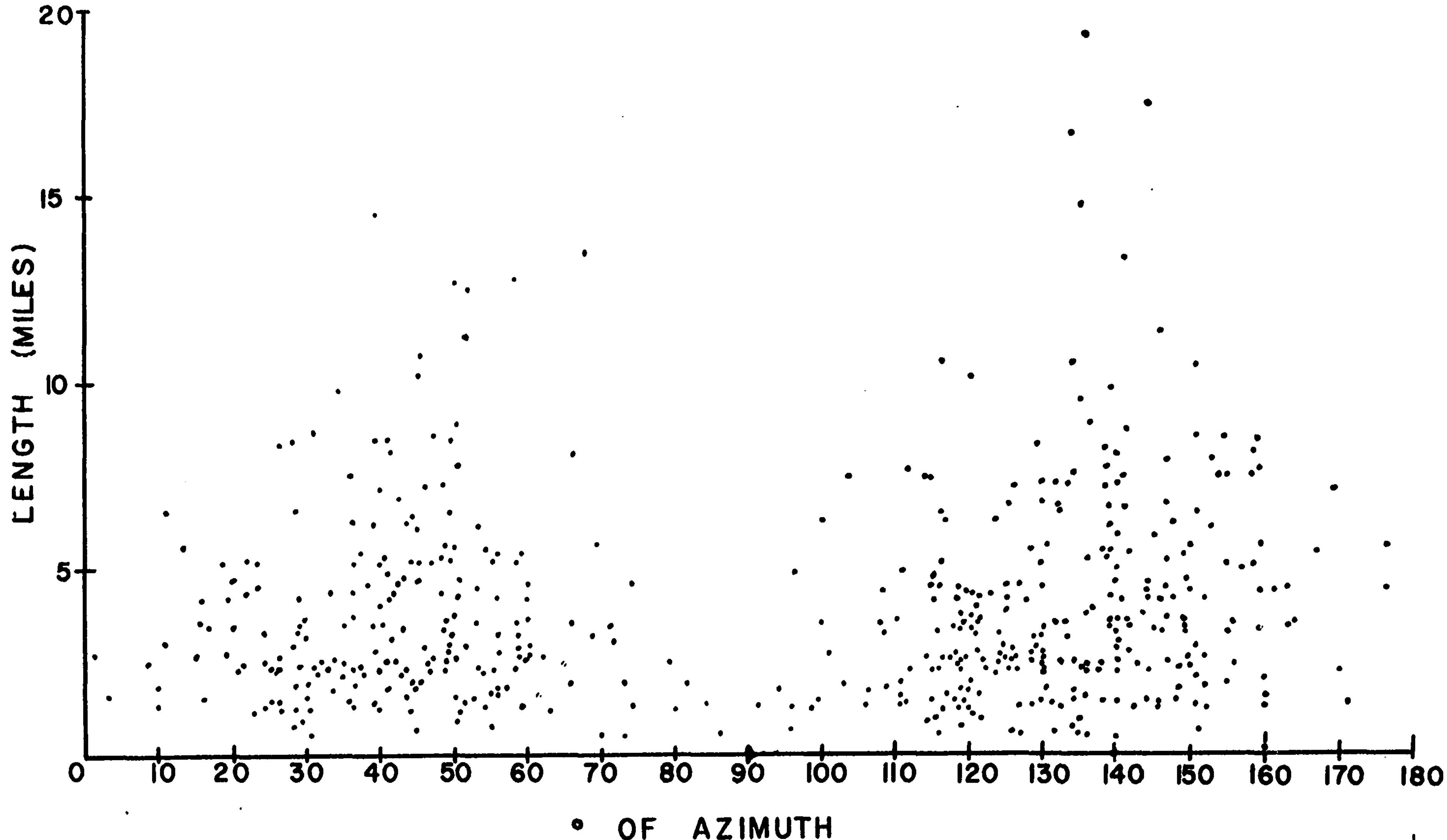


FIGURE 25. Scatter plot showing lengths of photolinears vs. azimuths in northern Alpena and eastern Presque Isle Counties

More asymmetry and shift away from the mean is shown by the bar graphs for lengths associated with each set of photolinears (Fig. 26, 27, 28, 29, 30). All skewness values associated with the length variable are positive, and range from .117 to 2.734. In figures 26 through 29, it should be noticed that there are not as many photolinears in the 0-1 mile range as one would expect from the general trend of the graphs. This is probably due to the fact that, on the relatively small-scale mosaics from which the data were taken, many of the very short photolinears would not be noticed, especially if they are obscured by vegetation. Assuming this to be the case, it appears that the exceptionally skew distribution of the lengths represents some sort of logarithmic function, the relative abundance of the photolinears in each set being related to the lengths in each set by a logarithmic equation.

The average length of the photolinears in the northeast-southwest set is 3.86 miles, with a maximum of 14.64 miles. The average length of the photolinears in the northwest-southeast set is 4.05 miles, with a maximum of 19.33 miles. The longest photolinears in the study area belong to the northwest-southeast set, which is roughly parallel to strike in some areas.

Variance around the means for each variable was also calculated. The standard deviation (σ in Table 1, appendix i), and the variance (σ^2 in Table 1, appendix i), indicate considerably more spread about the mean azimuth than about the mean length.

After the basic statistics were analyzed, the hypothesis that a relationship exists between azimuths and lengths of photolinears was tested. Using the Western Michigan University statistics program, correlation coefficients were determined (Table 2, appendix i).

The correlation coefficients ($\underline{r}$ in Table 2, appendix i) obtained indicate that, statistically, there is no relationship between the length variable and the azimuth variable. An $\underline{r}$ value of 1.00 indicates perfect correlation, and generally speaking, an $\underline{r}$ value of greater than 0.500 indicates significant correlation. However, for a large population, an $\underline{r}$ value of less than 0.500 can be significant. The value $\underline{r}^2$ is the coefficient of determination. This value shows how much of the variation of one variable can actually be attributed to the second variable.

After it was determined that no easily-defined relationship exists between the two variables, each variable was again studied and compared to itself in each subarea as well as the entire area. To compare means of the two variables, t-tests were run. A t-test is a

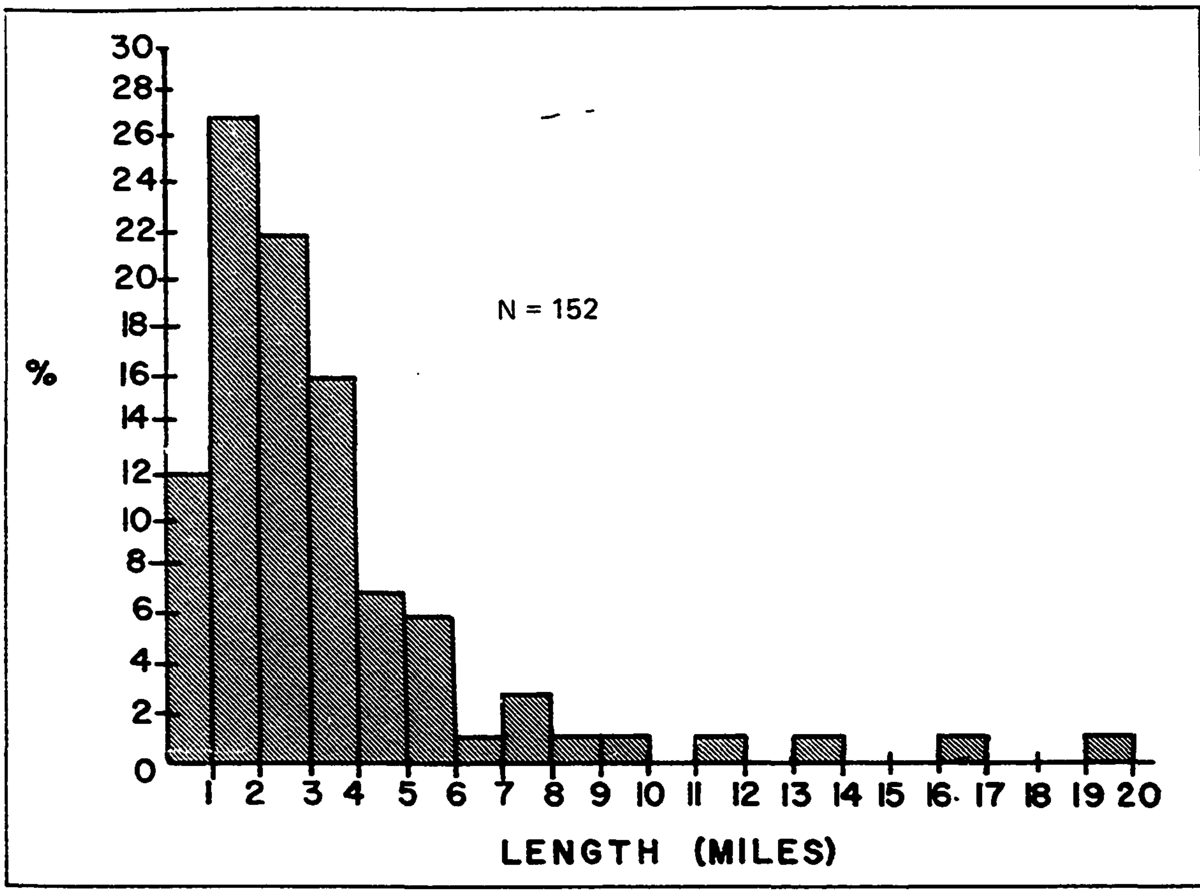


FIGURE 26. Lengths of photolinears in subarea I

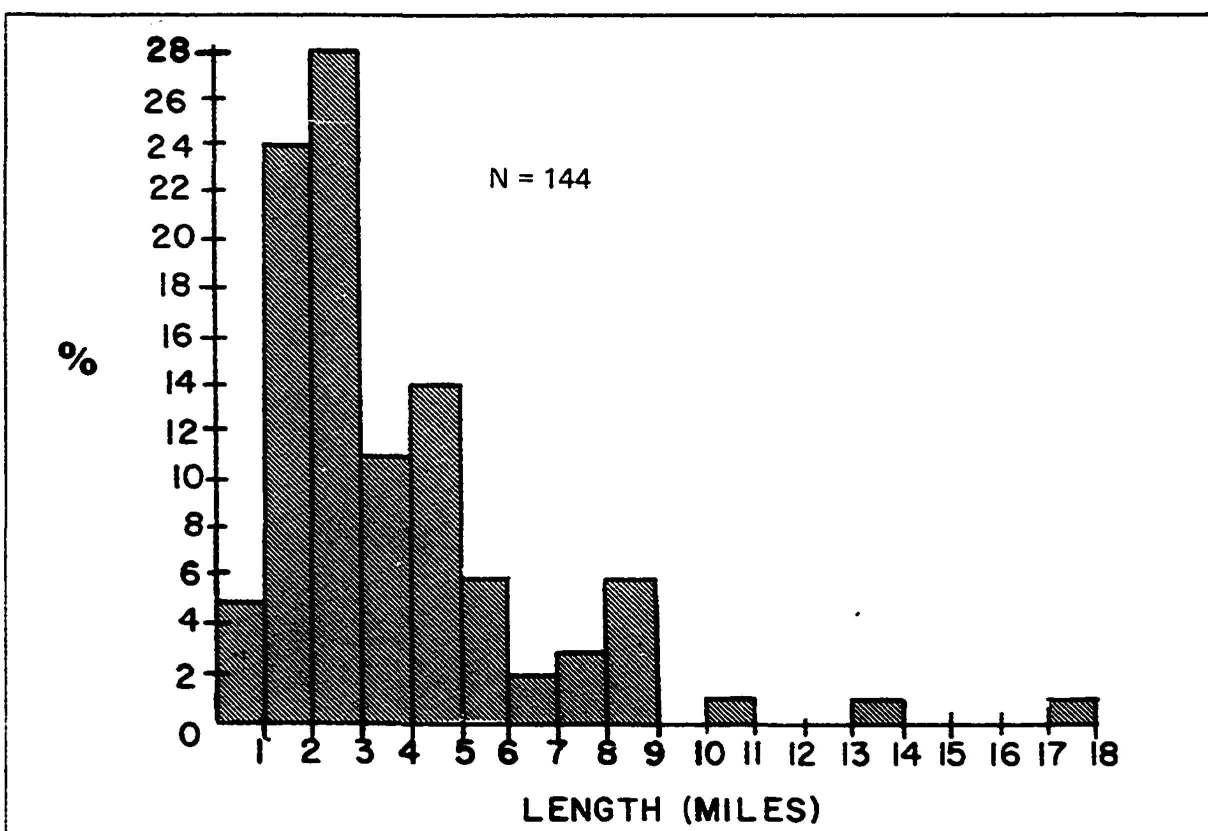


FIGURE 27. Lengths of photolinears in subarea II

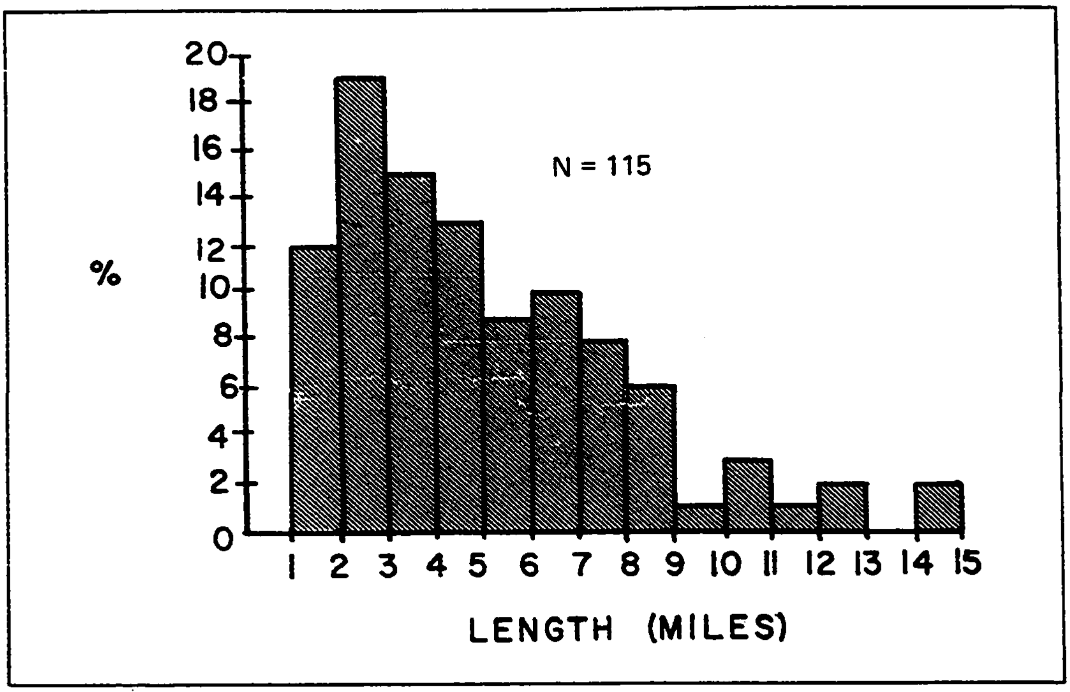


FIGURE 28. Lengths of photolinears in subarea III

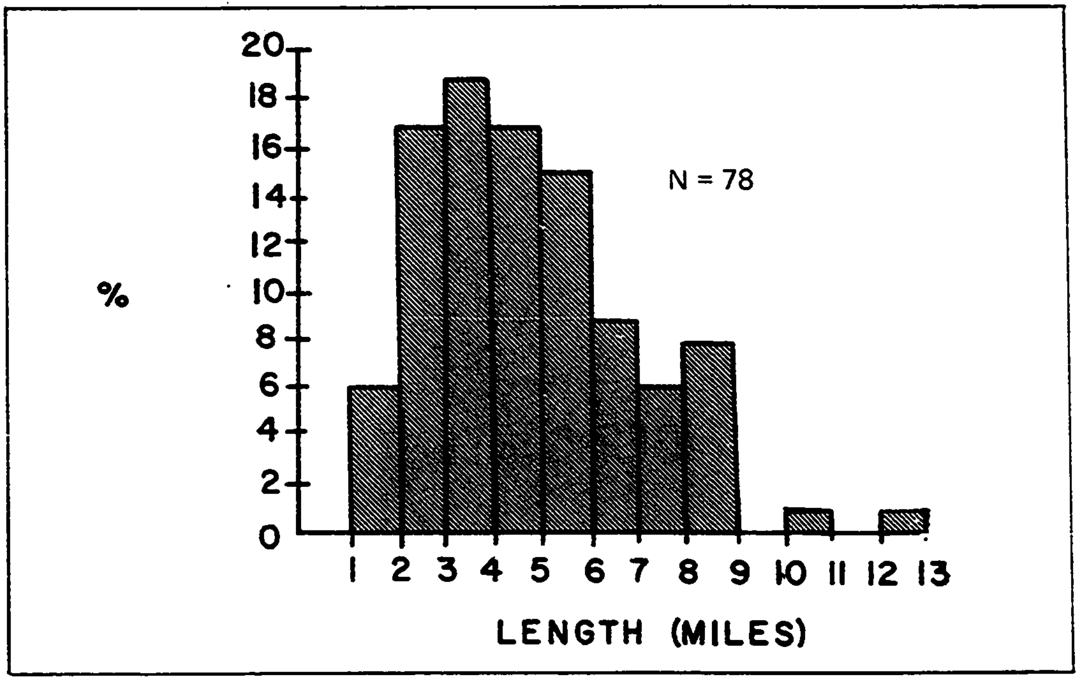


FIGURE 29. Lengths of photolinears in subarea IV

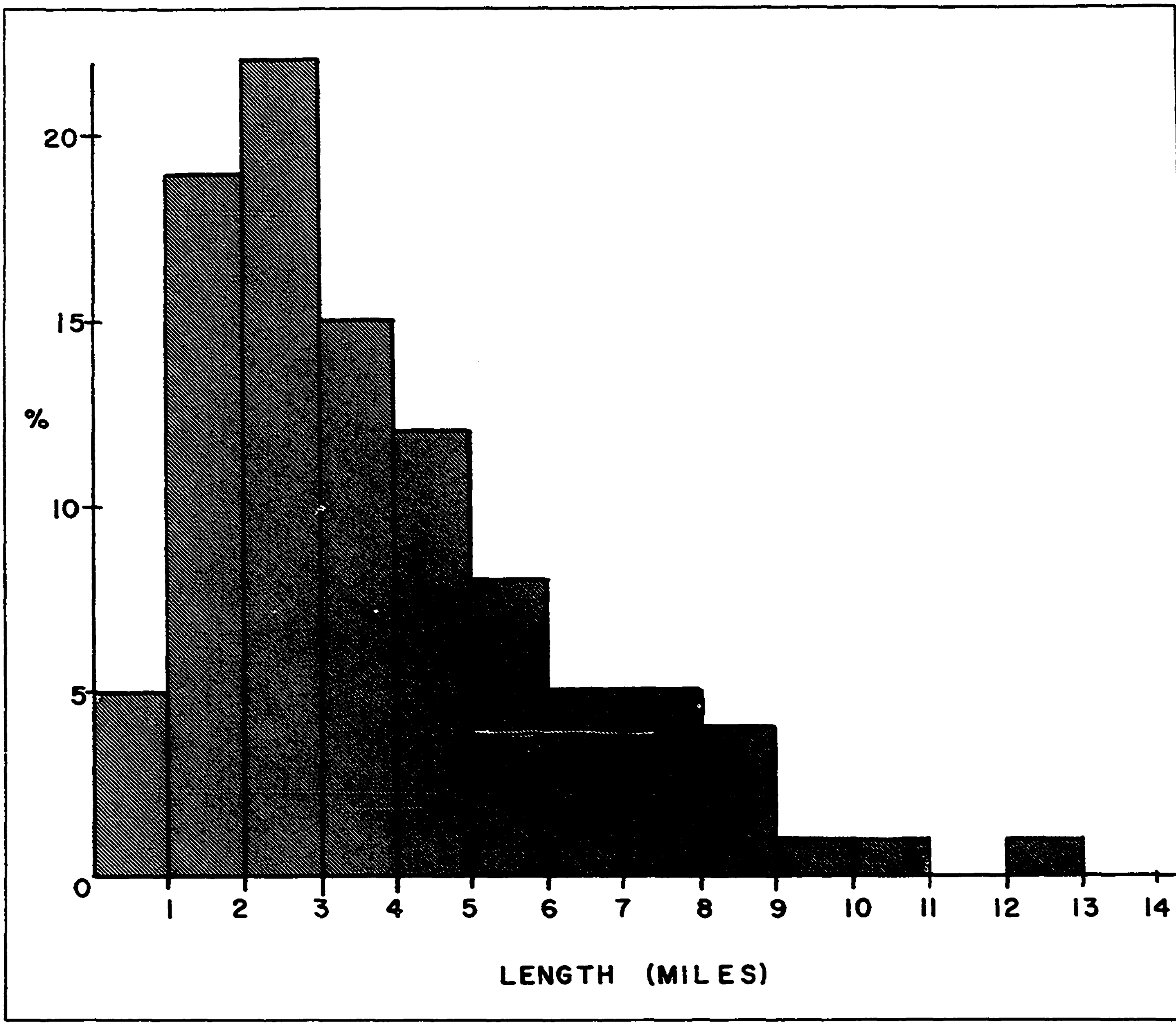


FIGURE 30. Lengths of photolinears in northern Alpena and eastern Presque Isle Counties

statistical measure used to show significance between means. The *t*-value is defined as:

$$t = \frac{X1 - X2}{\sigma\sqrt{1/N1 + 1/N2}}$$

where X1 and X2 are the means to be treated; N1 is the number of observations from which X1 was calculated; and N2 is the number of observations from which X2 was calculated. The standard deviation (σ) is defined as the quantity:

$$\sigma = \sqrt{\frac{(N1xS1^2) + N2xS2^2)}{DF}}$$

where N1 and N2 are the same as in the previous equation. S1 and S2 are standard deviations of each variable to be compared. DF is the number of degrees of freedom. This quantity is here defined to be the total number of observations minus two.

Most of the *t*-values were calculated from the Western Michigan University statistics program. However, due to the input format of this program, it was necessary for the writer to write a small program to calculate the *t*-values for some sets of data. In this program, the means, standard deviations, and N-values are input (Appendix ii).

After the *t*-values are known, their significance levels must be determined. Using another branch of the computer statistics program, a probability value was determined for each given *t*-value (Tables 3 and 4, appendix i). The probability (*p*) is expressed as a decimal number between 0 and 1.000. We established the null hypothesis that there is no significant difference between the means being tested, and set the level of probability for accepting or refuting the null hypothesis. In this study, it was arbitrarily decided that .0100 would be the break point for accepting or refuting the null hypothesis. A *p* value of .0100 indicates that there is one chance in one hundred that the two distributions being compared were drawn from the same parent set. If the *p* value is greater than .0100, it is concluded that no significant difference exists between the two means. The greater the *p* value, the greater is the chance that the two distributions came from the same parent set.

Most *p* values for the azimuth variable are greater than .0100 (Table 3, appendix i). One anamalous set is the northwest-southeast set in subarea II. It appears that this set of azimuths is significantly different from the others. This may be due to the fact that the strike of the strata in subarea II changes significantly from that in other areas. If these photolinears are controlled by the strike of the underlying bedrock, one would expect to find this difference in subarea II. Even in the South Long Lake area, which traverses both subareas I and II (Figure2), it is evident that the strike is different in the western and eastern portions.

Also within the northwest-southeast set, there appears to be a difference between the photolinears in subarea I and those in subareas II, III, and IV, but not those in the entire area. Again, this could be due to a change in strike of the strata..·

t-tests were also run on the length variable (Table 4, appendix i). Most p values support the null hypothesis, however, there are a few exceptions. In this study, an apparent difference in mean lengths, signified by a p value of less than .0100, seems to exist between those subareas in Alpena County (I and II) and those in Presque Isle County (III and IV). The photolinears in Presque Isle County appear to possess generally longer lengths than those in Alpena County. This is most likely due to the fact that the aerial photographs of Presque Isle County were taken in the middle of summer, while those of Alpena County were taken in October. In the middle of summer, the full leaf conditions of the trees probably obscured most of the shorter photolinears, thus making only the longer ones visible. Since only the photolinears which were discernible on the aerial photographs were mapped, this would explain the longer mean length associated with the photolinears of Presque Isle County, yet no significant difference between the mean azimuths.

It is concluded from the statistical study that there are two major sets of photolinears in Alpena and Presque Isle Counties, and that both sets are prominent throughout the area. There is a northwest-southeast set and a northeast-southwest set, and these are approximately 90° apart. The longest photolinears are found in the northwest-southeast set. There is no significant relationship between the mean azimuths and the mean lengths of the photolinears.

Photolinears of the South Long Lake Area

About 50 easily recognizable photolinears are present in the South Long Lake area, and they can be attributed to a variety of origins. Many of these photolinears were observed in the field. In this section of the paper, ten of the most significant photolinears in the South Long Lake area will be individually discussed. These photolinears are mapped in figure 2.

Opechee and Little Opechee Lines

The Opechee and Little Opechee Lines traverse sections 11, 12, and 13 of T. 32 N., R. 8 E. (Alpena township). This area is in the extreme northwestern portion of the South Long Lake area. These photolinears were named after the Opechee Grocery at the intersection of Rockport Road and U. S. 23, section 11, T. 32 N., R. 8 E. The bedrock in this area is the lower member of the Genshaw Formation. The *Killians Member of the Genshaw* is scabbily exposed along a power break about a quarter of a mile northeast of the Little Opechee Line, in section 12, T. 32 N., R. 8 E.

The most dramatic exposure of the Opechee Line appears as a scarp in Rockport Road, a couple hundred feet east of the junction with U. S. 23. This scarp is about 15 feet high, and several gravel pits have been dug on top of it.

The Little Opechee Line appears on aerial photographs as an almost-obscured lineation of trees. It crosses a power break in section 12, T. 32 N., R. 8 E., as a low ridge 5 to 6 feet high. Small sand and gravel pits have been dug into the ridge at this location.

The Opechee Line is expressed on aerial photographs as a distinct soil tone alignment, which is lighter-toned than the surrounding area. The light soil tone appears on top of the ridge. Both of these lines are believed to represent various stages of glacial lake shoreline, probably the Algonquin stage of glacial Lake Huron (see pp. 31). This conclusion is based chiefly on the occurrence of sand and gravel in the pits along these ridges, and an absence of bedrock. The materials in the gravel pits include limestone as well as glacial erratics. The cover of glacial material in the South Long Lake area varies from 0 to approximately 5 feet in thickness. The wall of the gravel pit on top of the Opechee Line is at least 20 feet high. This and the ridge-like expression of the feature suggest that it is a shoreline, and not merely a thicker-than-normal sequence of till. The absence of crossbedding and sorting implies that this is not an esker or a kame feature. Also, the fact that the Opechee and Little Opechee Lines diverge from a common hinge point, suggests that these photolinears represent two successive glacial lake levels, rather than some other type of feature. The strike of these photolinears is not coincident with the regional strike of the Traverse Group, which rules out the possibility of these photolinears representing formational contacts.

Killians Line

The Killians Line is a major northwest-southeast photolinear in the South Long Lake area. It extends completely through the area, but is not always recognizable in the field. In the area adjacent to Devil's Lake, sections 23 and 26, T. 32 N., R. 8 E., this line appears on aerial photographs as a tonal alignment of vegetation. In the field, the line appears as a low scarp. The most notable exposure of this photolinear is at the point where it was named, that being a power break on Wessel Road, about one mile south of the Earl Dubey gravel pit, which is at the point where the road across the Narrows bridge joins Wessel Road. The power break crosses Wessel Road halfway across the eastern line of section 23, T. 32 N., R. 8 E. (Figure 2). It was believed that this scarp represents the contact between the lower member of the Genshaw Formation and the more resistant Killians Member.

This photolinear can be traced almost completely through the South Long Lake area. It appears as a scarp along most of its length. At the type locality of the Killians Member, on French Road (Figures 4, 8, 9), the same scarp appears. In the area north of Fitzgerald Creek, section 5, T. 32 N., R. 8 E., the scarp also appears at the contact between the lower member of the Genshaw and the Killians Member. It is thus hypothesized that this particular photolinear results from differential erosional resistance between the two rock units.

The contact between the Killians and the upper member of the Genshaw appears locally as a scarp, ridge, or other linear feature. One such occurrence is along French Road, about one half mile south of the Killians type locality, where this contact is marked by a small cuesta which crosses the road.

Three Lakes Line

The most unusual feature in the South Long Lake area is the Three Lakes Line. This is a relatively sinuous photolinear which weaves across the South Long Lake area in a west northwest-east southeast course (Figure 2). The name comes from a string of three lakes, Trapp, Mindock, and Fitzgerald, all of which lie along this line. These three lakes trend traverse to strike throughout the area, and the line appears on aerial photographs locally as a tonal alignment or a valley. The linear alignment of Fitzgerald Lake is quiet apparent (Figure 31). Between these lakes, the Three Lakes Line appears as a continuous valley, 50 to 60 feet deep and one quarter of a mile wide. The inlets and outlets of the lakes are occupied by streams at only a few places. At the north end of Trapp Lake, the inlet has apparently been dry for many years, since there is now an apple orchard in the valley, and two wooden buildings which are at least 50 years old.

On the line between sections 34 and 35, T. 33 N., R. 7 E., this valley is occupied by a small inlet into Mindock Lake. The creek is only one foot deep, and there were fish swimming in it at the time of the writer's visit. At the other end of Mindock Lake, between Mindock and Fitzgerald Lakes, the valley is again dry, even during the wet season, and it supports a thick growth of pine trees. East of Fitzgerald Lake, the physical expression of the Three Lakes Line changes from a valley to a scarp. Eventually, this scarp cuts across section 8, T. 32 N., R. 8 E., and crosses French Road at its junction with the Killians Line.

The pattern of lakes and creeks along this photolinear suggests that this particular photolinear may be a result of some type of ground-water solution along zones of weakness. As the winter snow was melting in the area in April of 1972, the writer observed several disappearing streams in the vicinity of Trapp Lake. These streams began in high ground to the southwest of Trapp Lake, and apparently flow toward the lake and disappear into a zone of ravines in the ground. The owner of Trapp Lake, Don Trapp, tells a legend (1972, personal communication) that, in the logging days, loggers would run their lumber

FIGURE 31. Fitzgerald Lake, which lies along the Three Lakes Line, NE¼, SE¼, sec. 1, T. 32 N., R. 7 E.

into nearby Sunken Lake, and the logs would "disappear", only to come to the surface again in Misery Bay, Lake Huron, 10 to 15 miles away. This drainage network will be studied in detail later in this paper.

The Three Lakes Line probably does represent, in part at least, the surface expression of an underground drainage network. The strike of this photolinear does not coincide with the regional strike of the bedrock. During the writer's visit ot the area, many small linear solution features within the Genshaw Formation were studied. Along the old Long Lake Road, near the south end of Long Lake, some of these features were found in the lower Genshaw strata (Figures 32, 33). These features appear as linear depressions in the rocks, with apparent cross-fracturing. The same type of features were also observed at the top of the south bank of Fitzgerald Lake (SE¼, sec. 1, T. 32 N., R. 7 E.)

FIGURE 32. Linear solution feature in lower Genshaw strata, NE¼, NE¼, sec. 22, T. 32 N., R. 8 E.

FIGURE 33. Cross-fracturing in jointed strata of Genshaw Formation, NE¼, NE¼, sec. 22, T. 32 N., R. 8 E.

Three banks of all three of these lakes display an unusual "stair-step" structure (Figure 34). The low parts of this "stairstep" structure are represented by elongated ravinelike depressions 4 to 5 feet deep, similar to those described above, only slightly larger. In cross-section, they have the appearance of slump blocks. This was hypothesized, but later shown not to be the case, since the outline of a slump block probably would not possess such straight sides. From photointerpretation alone, these features have the appearance of faults. The very straight southwestern shore of Trapp Lake and the apparently down-faulted lake basin give the appearance of recent faulting activity. However, the writer could not find any conclusive field evidence that any of these lakes are fault phenomena. There appear to be no displaced strata, and slickensides and anomalous dips which would be associated with faulting are lacking.

The Three Lakes Line was most likely produced over a zone of weakness in the underlying limestone. There are probably sinkholes in the beds of all these lakes through which the water drains. Fall aerial photography of these lakes shows that they dry up somewhat during the dry season, in late summer and early fall. Most of the water probably drains underground, thus explaining the valleys with no streams flowing

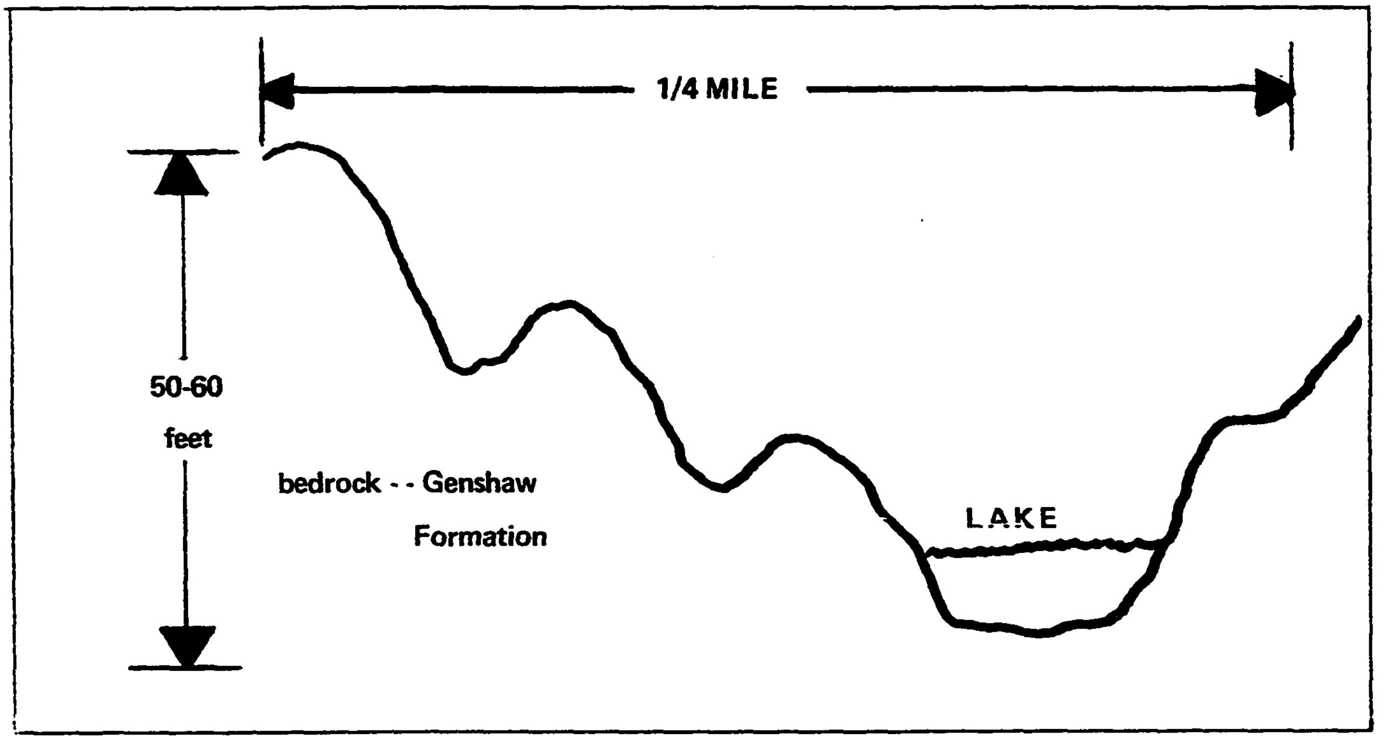


FIGURE 34. Cross-section of "stairstep" structure along the Three Lakes Line

through them. This situation is similar to the drainage system at Devil's Lake, sections 23 and 24, T. 32 N., R. 8 E. According to Martin (1958) and the Michigan Geological Survey (no date), the outlet from Long Lake into Long Lake Creek drains into a large sinkhole in the creek bed during the dry season, and flows through Devil's Lake and the lake connected to Devil's Lake on the north during the wet season. These two lakes have been attributed to the enlargement of limestone joints by ground water solution (Poindexter, 1935; Martin, 1958; Michigan Geological Survey, no date). The present writer believes the Three Lakes Line have a similar origin.

Mindock Line

This photolinear is a branch of the Three Lakes Line. It appears on aerial photographs as an arcuate alignment of vegetation extending from the southeastern end of Mindock Lake to the northwestern end. In the field, this photolinear appears as a small ravine throughout most of its length. Along Cathro Road, just south of its intersection with Mellville Road (See Figure 2), the Mindock Line appears merely as a low rise in the road. This rise also appears on Melville Road just west of the intersection.

The Mindock Line represents either a slump feature, or another solution feature such as those associated with the Three Lakes Line. There are no creeks or lakes associated with the Mindock Line. The scarps which mark this line face northeast, which would be expected if the block outlined by the Mindock and Three Lakes Lines is a slump block. On the other hand, the linear depression along the southeastern portion of this line seems to be a feature similar to those associated with the Three Lakes Line. Solution could account for the scarp features which cross the roads at the localities previously described. The individual scarps may represent edges of solution valleys. Most of the bedrock along the Mindock Line is covered, the only exposures being occasional scrapings in the dirt roads where road graders have scratched the bedrock.

Algonquin Line

The Algonquin Line can be traced from Long Lake Road, section 35, T. 33 N., R. 7 E., southeast to a sinkhole in section 11, T. 32 N., R. 7 E. This photolinear is unusual because it is curved rather than straight. It is easier recognized on individual aerial photographs than on photomosaics. Its ground expression is quite consistent, and throughout its sinuous course, it appears as a ridge ranging in height from 6 to 7 feet to about 15 feet (Figure 35).

This particular feature was first observed many years ago, when VerWiebe and Bergquist (1925) classified it as a former shoreline of the Algonquin stage of glacial Lake Huron. The sinkhole in the NW¼, section 11, T. 32 N., R. 7 E., is believed to be a re-entrant along this ancient shoreline.

The present writer agrees with the interpretation that the Algonquin Line is a former shoreline. It is similar to the Opechee and Little Opechee Lines in that there are numerous gravel pits dug into the ridge. The topographic expression of the Algonquin Line is also an indication that it is a shoreline. It stands 6 to 7 feet higher than the adjacent lowlands along the ridge. It does not follow the underground drainage network in the area, therefore probably cannot be attributed to ground water activity. Also, the fact that the Algonquin Line is a ridge (positive feature) and not a depression (negative feature), would seem to indicate an origin by some process other than ground water activity. This photolinear is not parallel to the predominant joint sets in the area

FIGURE 35. Algonquin Line at Melville Road, SW¼, SE¼, sec. 34, T. 33 N., R. 7 E.

also. Based on all these observations, it is concluded that the Algonquin Line is in fact a Pleistocene shoreline, from the Algonquin stage of glacial Lake Huron.

Dagett Line

The Dagett Line is a photolinear which extends south about 2½ miles from its junction with the Algonquin Line in section 3, T. 32 N., R. 7 E. It is barely visible on individual aerial photographs taken at the scale of 1:20,000, and not visible on photomosaics. For this reason, the Dagett Line does not appear on figure 14. It is included in this discussion because it forms a prominent linear scarp which can be observed in the field. It is named from its best exposure, that being a large 20-foot scarp in Dagett Road, section 10, T. 32 N., R. 7 E., just west of Cathro Road (Figure 2).

On individual aerial photographs, the Dagett Line appears as a discontinuous, somewhat curvilinear tonal alignment. In the field, it forms a scarp throughout most of its length.

The appearance of the Dagett Line, on both individual aerial photographs and in the field, is much like that of the Algonquin Line. It is hypothesized that this photolinear and the Algonquin Line, when considered together, represent two temporary stands of glacial Lake Algonquin. In other words, both the Algonquin Line and the Dagett Line are Pleistocene shorelines.

Bolton Line

The Bolton Line is relatively faint on both aerial photomosaics and on individual aerial photographs. However, in the field, it appears as a scarp along Dagett Road, a soil tone alignment in section 10 of T. 32 N., R. 7 E. (Maple Ridge Township), and a ridge connecting two sinkholes in section 11, T. 32 N., R. 7 E. The sinkhole described by Ver Wiebe and Bergquist (1925) as a re-entrant in a glacial shoreline lies at the intersection of the Bolton Line and the Algonquin Line.

This particular photolinear clearly belongs to the northeast-southwest set. It does not possess the features characteristic of Pleistocene shorelines which are associated with the Dagett, Algonquin, Opechee, and Little Opechee Lines. The trend of the Bolton Line does not follow the hypothesized regional underground drainage trend, which would rule out its being formed by ground water activity like the Three Lakes Line.

In section 11, T. 32 N., R. 7 E., two sinkholes lie along the Bolton Line. This suggests that ground water solution may be a significant factor to the origin of the Bolton Line. However, it is more likely that this major northeast-southwest set of photolinears results from some form of jointing. Therefore, the regional patterns of jointing in the area must be taken into consideration (Figure 33). The localization of sinkholes within the northeast-southwest set of photolinears and the absence of solution cracks indicates that ground water does not play a significant role in the development of the northeast-southwest set of photolinears. In addition to this, the trend of the underground drainage network is northwest-southeast rather than northeast-southwest.

If the Bolton Line is controlled by joints or fractures, sinkholes may be associated with the weaker parts of the system, especially in an area with an extensive subterranean drainage network such as Alpena and Presque Isle Counties. It is believed that the Bolton Line represents in part a fracture zone or a joint system. The sinkholes along this photolinear probably occur in the weaker areas, perhaps points where joints or fractures intersect.

Cathro Line

The Cathro Line is a major photolinear in the South Long Lake area. It belongs to the northwest-southeast set of photolinears, and can be traced from section 24, Maple Ridge township (T. 32 N., R. 7 E.) a few hundred feet east of the Detroit and Mackinac Railroad grade on the south border of the South Long Lake area, northwest all the way to Long Lake Road, section 32 of Krakow township (T. 33 N., R. 7 E.), Presque Isle County.

In the field, the casual observer would miss this line, but it appears on aerial photographs as a continuous alignment of vegetation and soil tones. The locality at which the Cathro Line was named is approximately one half mile north of the settlement of Cathro. At this locality, a distinct line (approximately .04 inches wide on a 1:20,000 scale aerial photograph) appears as a band of unusually light soil tone. A ground check revealed only a low linear area crossing a cornfield. South of this particular area, the Cathro Line appears on aerial photographs as an alignment of vegetation which parallels the railroad grade for a short distance.

The exact origin for this line could not positively be determined by field evidence alone, due to the lack of visible features associated with it. The lack of ground expression most likely indicates that the Cathro Line is older than the other photolinears. At one time, there may have been distinct topographic features along this line, such as scarps or valleys, which have since been removed by erosion or filled in by younger deposits. The immense length and continuous expression of the Cathro Line across the South Long Lake area may suggest an origin related to differential resistance to erosion between the beds of the Alpena Limestone. This theory must be rejected, however, since the Cathro Line also traverses the outcrop area of the Newton Creek Limestone, and it is not parallel to the strike of the underlying strata. The Cathro Line lacks the sinuous trend and gravel and sand deposits associated with the Pleistocene shorelines. It may follow a portion of the underground drainage system in the area, but field evidence to support this statement is lacking. It is also possible that this line, like the Bolton Line, represents control by joints. A possible origin of the Cathro Line will be suggested later in this paper.

Weide Line

The final photolinear upon which individual attention will be placed has been named the Weide Line, from a ridge which crosses Maple Lane Road at the farm of Rudolf

Weide (section 6, T. 32 N., R. 7 E.).

The Weide Line is expressed as a sinuous ridge of sand and gravel. It can be traced from Duck Lake, at the northwest corner of the South Long Lake area, to a ridge on Irwin Road, near the southwestern corner of the South Long Lake area. Mr. Weide (1972, personal communication) reports that this ridge can be followed all the way to the town of Harrisville, on Lake Huron, 30 miles south of Alpena.

This photolinear is also believed to be a shoreline from a Pleistocene lake, probably also the Algonquin stage of Lake Huron. There are no solution features on top of this ridge as there are in the bedrock areas near the ridge, and it is a topographic high composed of sand and gravel. At one time, the county highway department quarried gravel and sand for road fill from a pit on Mr. Weide's property, on the east edge of this ridge. There is also a water well on the ridge, in the Weide's back yard, which draws water from a depth of 48 feet. It is reported that the well "never runs dry" (Weide, 1972, personal communication). Two other wells on Mr. Weide's property, only about 200 feet east of the Weide Line, draw water from depths exceeding 100 feet. Apparently, the material which composes the ridge is excellent aquifer material, probably sand and gravel throughout its volume.

It is believed that the Weide Line, like some other photolinears in the South Long Lake area, is a shoreline from glacial Lake Algonquin.

Other photolinears

The ten photolinears just discussed were chosen as the ten most significant photolinears in the South Long Lake area, but they do not represent a sample of all the linear features, or even all the geologic conditions responsible for these features. There are many more linear features visible on photomosaics or individual photographs of the South Long Lake area. Not all of these can be observed in the field, and likewise, not all linear features in the area have expression on aerial photographs.

The most common photographic expression of these features are alignments of soil or vegetation tones. In the field, most of the photolinears appear as scarps or cuestas, which are most prominent where they cross roads. The typical field appearance of photolinears is shown in Figure 36.

FIGURE 36. Unnamed minor photolinear south of Fitzgerald Lake, SE¼, SE¼, sec. 1, T. 32 N., R. 7 E

Many of the photolinears with anomalous trends can be attributed to Pleistocene shorelines, as has been shown. Others are definitely formational contacts, such as the Killians Line. In section 31, T. 33 N., R. 7 E., the Newton Creek-Alpena contact crosses Long Lake Road at a dramatic 50-foot scarp.

Many of the photolinears were produced by ground water solution of the underlying limestone bedrock, as shown by their association with sinkholes and other karst features. Some of the photolinears are probably also attributable to collapse of soluble strata below the Traverse Group, such as the Salina Salt (Upper Silurian), which is several hundred feet below the surface in Alpena and Presque Isle Counties. The agent most significantly responsible for the formation of the photolinears is the regional pattern of jointing in the Alpena-Presque Isle County area.

Origins of Photolinears

There are two major sets of photolinears in Alpena and Presque Isle Counties, Michigan. Within each set, photolinears of many origins can be found. There is certainly no single, all-inclusive explanation for the photolinears.

Some of these features probably represent control by joints or fractures in the bedrock. According to Blanchet (1957), the earth is fractured in four principal directions, and this fracturing is due to both internal and external stresses on the earth, such as earth tides, changes in radial acceleration of the earth, or a gradual decrease in the rate of rotation of the earth. In an earlier study (Hobbs, 1904), made in the Atlantic Coastal Plain, it was found that, in undisturbed areas, the two prominent sets of joints intersect each other at right angles. In the same study, it was found that some of the major lineaments observed were not continuous lines, but rather a zigzag pattern composed of many smaller lines perpendicular to each other, the resulting azimuths being actually the vector sum of the two sets of perpendicular joints or fractures.

It is very likely that many of the photolinears in Alpena and Presque Isle Counties result from a similar pattern of jointing. The two sets of photolinears lie at right angles to each other, much like Hobbs' (1904) lineaments. At many localities in the field, a definite pattern of cross-fracturing and jointing was observed on a small scale, such as at the locality shown in Figures 32 and 33. Similar features were also studied on the south bank of Fitzgerald Lake and at the south end of Devil's Lake. It has been stated by various workers (Poindexter, 1935; Michigan Geological Survey, no date) that Devil's Lake and the small lake connected to Devil's Lake on the north are controlled by joints. If this theory is valid, it can plainly be seen from the map (Figure 2) that the two major joint orientations in this area are north-south and east-west. The resultant vectors of these two orientations coincide with the azimuths of the two major sets of photolinears in the area. In limestone areas, such as Alpena and Presque Isle Counties, the intersection of two joints is a favorable condition for the development of ground water solution channels (Ver Wiebe & Bergquist, 1925). If the area is abundantly jointed or fractured, these linear solution features can develop between joint intersections.

The presence of a vast underground drainage network in northeastern Michigan is responsible for many of the photolinears. Detailed descriptions of the ground water features will be included in the next section of this paper. Most of the drainage in this portion of the Michigan Basin flows generally eastward toward Lake Huron. This includes both surface and underground drainage. The limestones of the Traverse Group are very soluble. This property, in addition to the climate of the area and the pattern of jointing, suggests the presence of conditions favorable to underground solution of the limestones.

If much of the drainage in Alpena and Presque Isle Counties is subterranean, favorable conditions for development of sinkholes and lakes along underground drainage channels probably exists. These conditions are believed to exist along the Three Lakes Line (see page 55).

In addition to the present underground drainage network, an early Devonian drainage network is believed to have existed. Evidence of this has been found at several localities north of the Alpena-Presque Isle County area. The outcropping rock in the Mackinac Straits area is the Mackinac Breccia. This formation, described in detail by Landes (1944, 1945, 1959), is composed of broken fragments of limestones and shales from the Bois Blanc, Detroit River, and Dundee Formations, all of which are pre-Traverse. Landes (1945) attributed this formation to the collapse of the underlying soluble evaporites of the Upper Silurian Salina and Pointe Aux Chenes Formations. A similar theory has been proposed for the cave breccias of Carlsbad Caverns, New Mexico (Lee, 1925).

The thickness of the Salina Salt under Alpena County is approximately 1200 feet (Landes, 1945). Although the salt-bearing strata are several hundred feet below the surface, some of the blocks of the Mackinac Breccia are several hundred feet in diameter (Landes, 1945, 1959). If any sediments were later deposited over these huge caverns produced by salt basin collapse, then the upper layers of these sedimentary units would most likely reflect the configuration of the surface of the collapsed salt basin below. The maximum known thickness of the Mackinac Breccia in the Rogers City area, northeastern Presque Isle County, is over 1000 feet (Landes, 1945). These great thicknesses suggest that huge underground salt caverns existed several hundred feet in depth. The salt was leached out by ground water during the middle Devonian. The Mackinac Breccia is composed of broken fragments of the Dundee and Detroit River Formations, but free from fragments of the Traverse Group. This indicates that the salt basin collapse must have occurred after deposition of the Detroit River and Dundee Formations, but before deposition of the Traverse Group (Landes, 1945, 1959).

A modern prototype of this early Devonian system is believed to have produced the Three Lakes Line. The only differences are the direction of flow of the subterranean water, and the lithology. Soluble rocks associated with the Three Lakes Line are limestones, while those associated with the Mackinac Breccia are evaporites, predominantly salt and gypsum.

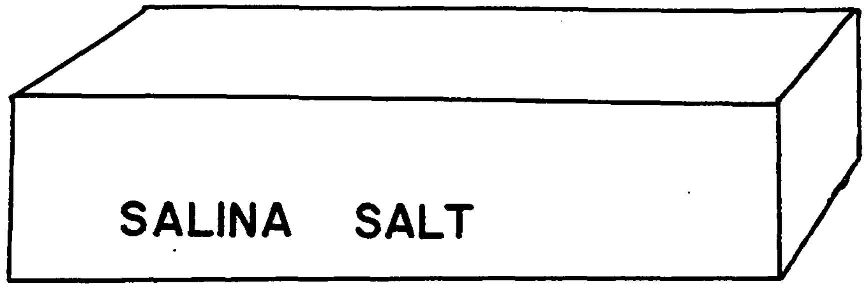
Some of the photolinears in Alpena and Presque Isle Counties are believed to have been produced by this early Devonian salt basin collapse. Figure 37 illustrates this process. This mechanism is believed to have been responsible for the formation of the Cathro Line.

Some of the most prominent photolinears of Alpena and Presque Isle Counties were produced by relatively simple geologic conditions. There are two major types, and both of these can be observed in the South Long Lake area. These photolinears are attributable to formational contacts and Pleistocene shorelines. The Killians Line is an excellent example of a photolinear produced at a formational contact. These features result from differential resistance to erosion between certain beds within the Traverse Group. The huge scarp on Long Lake Road previously described (sec. 32, T. 33 N., R. 7 E.) is another such photolinear. This scarp is part of a photolinear which marks the contact between the Newton Creek Limestone and the Alpena Limestone. In the South Long Lake area, numerous scarps and ridges are associated with differential erosion between beds of the various formations. These ridges expose resistant ledges in the roadbeds where road graders have scraped the roads.

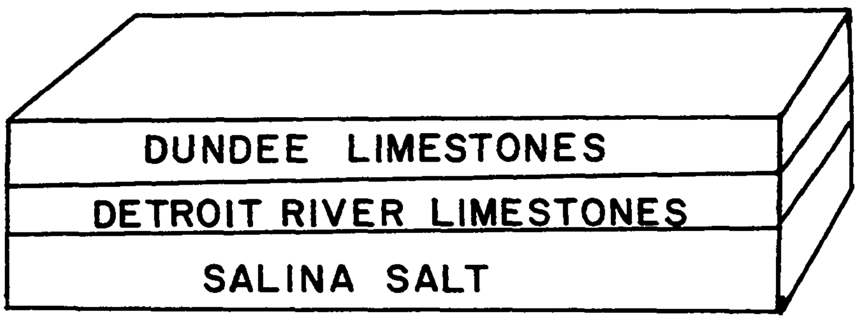
At least four photolinears in the South Long Lake area have been attributed to Pleistocene shorelines. In Alpena and Presque Isle Counties, these features have a unique topographic expression. They appear as sinuous ridges of sand and gravel, which stand topographically above the lower areas around them. Most of them, at one time or another, have been excavated for building materials.

The most important geologic factors involved in the formation of photolinears in Alpena and Presque Isle Counties are ground water solution associated with the underground drainage system, and jointing in the limestone bedrock.

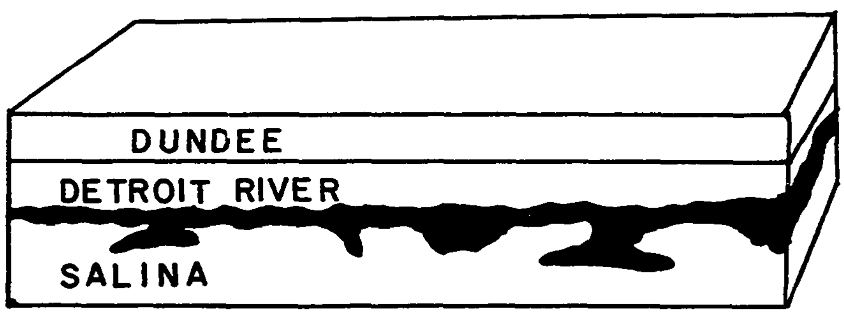
The collapse of the Salina Salt is probably third in importance to the formation of photolinears, after jointing and ground water solution. If 100-foot deep caverns were leached out of the salt by an ancient underground drainage system, then all the rocks subsequently deposited in the area could easily collapse into these caverns. Many of the photo linears in Alpena and Presque Isle Counties which appear as small ravines and cannot otherwise be explained, are very possibly an indirect result of the lower Devonian collapse of the Salina Salt basin along former subterranean channelways.



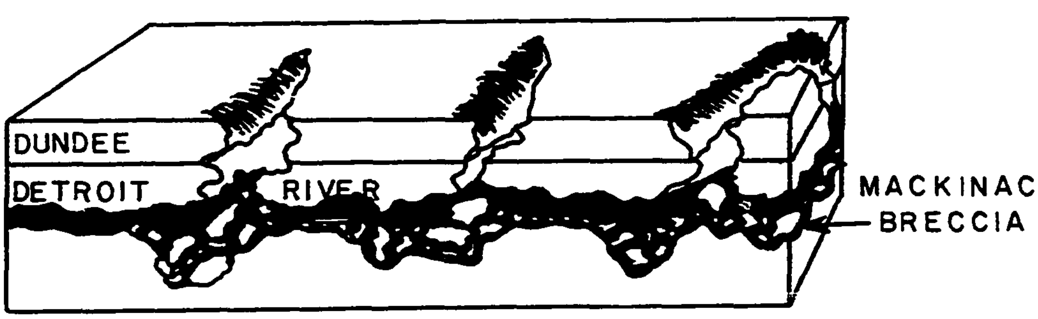
1. Deposition of Salina Salt



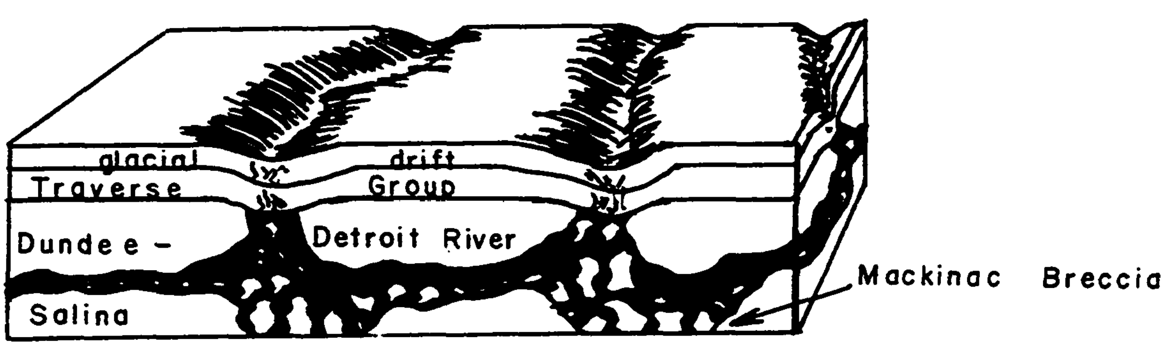
2. Deposition of lower Devonian formations



3. Ground water leaching of Salina Salt



4. Formation of Mackinac Breccia by collapse of overlying strata



5. Filling of older cracks and crevasses by younger formations

FIGURE 37. Development of photolinears by salt basin collapse.

It is concluded that the photolinears of Alpena and Presque Isle Counties are the results of several distinct conditions. The strike of the bedrock in the area is generally northwest-southeast. The strata display abundant cross-fracturing and jointing, which is most likely the result of tectonic deformation of the Michigan Basin during the Paleozoic Era. Due to the thinness of the glacial cover in Alpena and Presque Isle Counties, the bedrock joint patterns greatly affect the appearance of the landscape, and many photolinears have probably developed along planes of joint intersections.

The underground drainage system, which will be discussed in more detail later in this paper, also has considerable influence on the landscape. Solution channelways develop in beds of the most soluble strata, predominantly rocks of the lower units of the Traverse Group, especially the Genshaw Formation. These channelways usually develop in areas where joint planes intersect.

Significance of Photolinears

The study of photolinears of Alpena and Presque Isle Counties is the first step in the reconstruction of the geologic and tectonic history of the area. The thinness of the glacial cover in Alpena and Presque Isle Counties makes the bedrock relatively accessible for study.

After deposition of the Silurian evaporite basin (which consists mainly of salt and gypsum), this portion of Michigan was elevated above sea level. According to Landes (1945), the uplift in Alpena and Presque Isle Counties took place after the deposition of the Detroit River Group, but before deposition of the Dundee Limestone. The Salina Salt basin began to collapse at this time, due to leaching of the salt by ground water. Accompanying the salt leaching was the formation of the Mackinac Breccia. The overlying strata were probably deposited in cracks formed by the solution of the underlying strata (Figure 37).

The Michigan Basin began to subside then, and internal tectonic stresses built up, probably at right angles to each other. These stresses, combined with the continuing effects of ground water, most likely gave rise to the two major sets of photolinears, which coincide with the lines of intersection of joints and fractures produced by tectonic deformation of the basin.

As time progressed, the Middle and Upper Devonian strata were deposited on the pre-Traverse topography, probably still filling in the crevasses produced by the collapse of the Salina Salt basin. After the area was again lifted above sea level, in the late Paleozoic, the continuing forces of erosion tended to level the landscape. Where resistant layers of rock were encountered, cuestas and scarps formed, which locally appear as photolinears.

The climate changed from arid to humid between the late Silurian and the present time. In the more recent geologic past, the majority of the sinkholes probably developed, as the mean annual rainfall increased. The underground drainage network which we now observe probably also developed in the recent past. This is indicated by the freshness of the solution scarps and linear valleys, such as those along the Three Lakes Line.

The photolinears attributable to Pleistocene shorelines were created within the past one million years. The events represented by these photolinears are relatively insignificant to the total geologic history of the area, but they are responsible for many of the more obvious photolinears observable on aerial photographs.

GROUND WATER AND KARST FEATURES

Alpena and Presque Isle Counties are noted for their unusual ground water features. These include sinkholes, disappearing streams, and disappearing lakes. Through the years, reports of these features have furnished undoubted evidence of a vast underground drainage network. Some authors (LaForest, 1970; Michigan Tourist Council, no date; Grand Rapids Press, 1957) believed that there is a vast underground cavern system in Presque Isle and Alpena Counties. The present writer believes that these features are related to the photolinears.

Surface Drainage

In Alpena County, there are very few through-flowing surface streams. Most of Alpena County is drained by the Thunder Bay River and its tributaries. This particular drainage basin ranks 9th in size among the primary river systems in the lower peninsula (Wisler, 1925). However, its effective surface drainage area is decreased due to the amount of drainage which flows underground.

Speculation on the presence of an underground drainage network dates from at least 1892. These early reports were documented almost a century later by Dewey (1961). At the supposed outlet of this underground network, Misery Bay, there is one area of the bay which never freezes over in the winter. Many reports (Noble, 1965; Grand Rapids Press, 1957; and others) tell of warm puffs of air coming from this spot, which is believed to be a large sinkhole.

The eastern portion of Presque Isle County also lacks a well-integrated surface drainage system. The major stream is the North Branch of the Thunder Bay River. In the western part of the county, there are considerably more streams and lakes, and many of the lakes are associated with sinkholes. The two major streams are the Ocqueoc and Rainy Rivers, both of which flow to the north.

Rainy River is part of the Black-Rainy River drainage basin. This river is part of a system which drains 1594 square miles in six counties (Melhorn, 1947). Many sinkholes, disappearing lakes, and disappearing streams are associated with this drainage system in western Presque Isle County.

The source of the Ocqueoc River is in the central portion of Presque Isle County, and the river flows to the northwest. This particular river is believed to flow underground along part of its course (Martin, 1958; Michigan Tourist Council, no date). There are also sinkholes associated with this river.

Karst Features of Alpena and Presque Isle Counties

Sinkholes

By 1925, at least 32 sinkholes had been studied in Alpena County (Mahan, no date; Michigan Geological Survey, no date; LaForest, 1970). More recent estimates (LaForest, 1970) have accounted for 200 or 300 sinkholes in the county. In the South Long Lake area, at least ten sinkholes have been studied by the present writer. Presque Isle County is known for large sinkholes also. A classic example of a large sinkhole is near Shoepac Lake, in the southwestern part of Presque Isle County. The depth of Shoepac Lake is approximately 20 feet. A giant sinkhole, only 500 feet east of the lake, extends to a depth of 90 feet below lake level (Martin, 1958). The present writer visited this sinkhole. It appears to be at least 120 feet deep, perhaps more, and perhaps one half mile in diameter. This sinkhole supports a thick growth of vegetation. To date, no outlet has been discovered. Poindexter (1935) used photogeologic and field studies to show that, at one time, Shoepac Lake did have an outlet into Rainy River, which has since been captured by outflow. Upon closer examination, however, Poindexter's study showed this not to be the case. As a result, Poindexter's new (1935) theory stated that this sinkhole is a "valley sink."

In the South Long Lake area, there are many features which are believed to be "valley sinks" of this type. These features appear as northwest-southeast trending depressions which usually extend northwest from sinkholes, thus reflecting the trend of the underground drainage. The most prominent such feature in the South Long Lake area can be found in section 14, T. 32 N., R. 7 E. (Figure 38). The trend of these solution valleys, or "valley sinks" parallels the trend of the small solution features which are located south of Fitzgerald Lake, as well as those which were observed at the south end of Devil's Lake.

FIGURE 38. Solution valley associated with a sinkhole, N½, sec. 14, T. 32 N., R. 7 E

FIGURE 39. Sinkhole along Newton Creek-Alpena contact, NW¼, NW¼, sec. 32, T. 33 N., R. 7 E

Most of the sinkholes in the South Long Lake area are located within the outcrop belt of the Alpena Limestone. This limestone is very permeable and very soluble, due to its exceptional porosity and purity. It is a relatively thick unit (Figure 3), and crops out in a wide band in the South Long Lake area. In the northwestern part of the South Long Lake area, at least two sinkholes have been studied in the vicinity of the Newton Creek-Alpena contact. One of these is just north of Long Lake Road, in the SE¼, section 30, T. 33 N., R. 7 E. Another sinkhole is located in the NW¼, section 32, T. 33 N., R. 7 E. (Figure 39). These holes were formed at the contact of two beds with differential erosional resistance. The Newton Creek Limestone is more resistant than the Alpena Limestone, as indicated by the large down-section facing scarp associated with the contact. This led to the development of a natural low area at the base of the scarp, into which ground water could flow and consequently dissolve the soluble Alpena Limestone.

In section 11, T. 32 N., R. 7 E., another sinkhole is associated with the Alpena-Newton Creek contact (Figure 40). It is reported by local residents (1972, personal communi-

FIGURE 40. Sinkhole just southwest of Maple Lane-Cathro intersection, N½, NW¼, sec. 11, T. 32 N., R. 7 E.

cation) that, during the spring of 1970, this sinkhole backed up after an exceptionally heavy winter snow. As a result, the intersection of Maple Lane and Cathro Roads (figure 41), one quarter of a mile away, was flooded until the end of June that year. The roads were closed all spring due to the 7-inch inundation.

FIGURE 41. Maple Lane—Cathro intersection—this intersection flooded in 1970 by a sinkhole backup

SE¼, SE¼, sec. 3, T. 32 N., R. 7 E.

This phenomenon is relatively common in Alpena and Presque Isle Counties. Sinkholes become plugged by a few different mechanisms. During storms, logs and debris may fall into the sinkholes and consequently plug up the outlets. Also, as streams flow into the hole, they carry sediment with them, and the result may be that the hole will become temporarily plugged up. Minor rockslides can also produce this. In some cases, even human debris thrown into the sinkholes can cause a plug-up.

In some places near Leer, northern Alpena County and south-central Presque Isle County, and in one sinkhole north of Cathro (Figure 42), man has utilized sinkholes as repositories for his trash. This is a very dangerous, unsafe condition. In some areas of Presque Isle County, most of the ground water supply comes from the underlying limestone. In the town of Posen, eastern Presque Isle County, there was a serious epidemic of hepatitis in 1959. This epidemic has been attributed to widespread contamination of wells (Wilcox, et al., 1961). This epidemic was caused by wells and cisterns being dug too close together, and so shallow that percolation of ground water through the limestone contaminated the entire area.

In areas like Cathro, this problem can also become serious. Most of the water supply in this area does not come from wells at the present time, since modern treatment plants have been built between Cathro and Alpena. Some stock water in the South Long Lake area, however, still comes from wells. Data on the effects of ground water on cattle in the South Long Lake area are unavailable.

Aside from the sinkholes, there are known holes in the bottoms of some of the disappearing, or "drying-up", lakes. These individual features will be described in the following sections of this paper. It is believed that the bottoms of Trapp, Mindock, and Fitzgerald Lakes contain sinkholes.

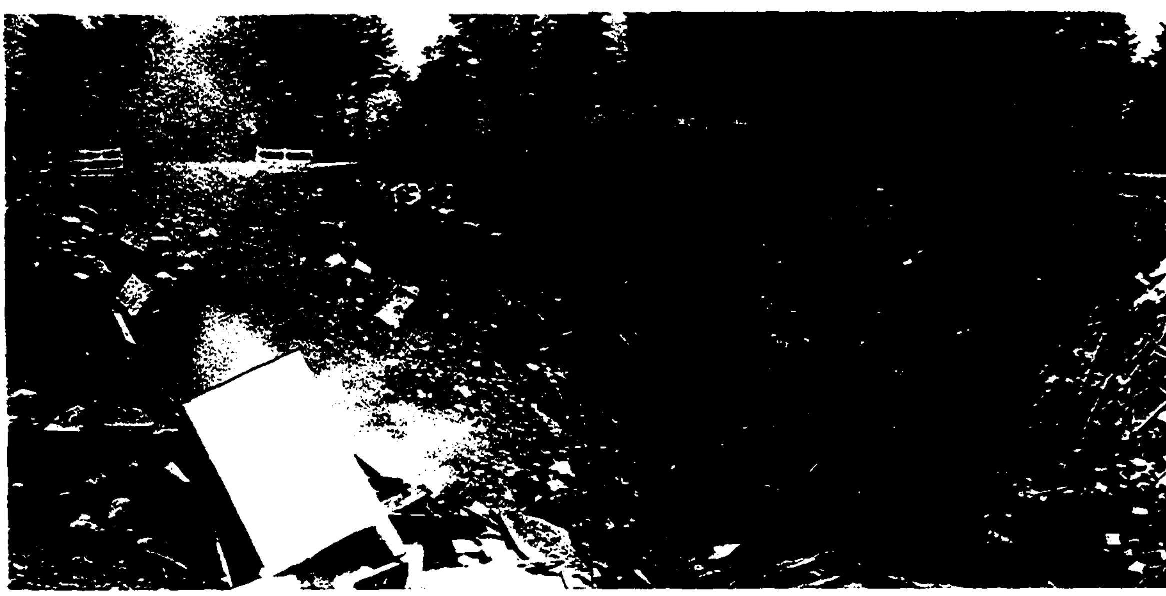


FIGURE 42. Cathro village dump—very poor usage of a sinkhole, NW¼, NW¼, sec. 14, T. 32 N., R. 7 E.

Devil's Lake

Devil's Lake is a small joint-controlled lake in section 23, T. 32 N., R. 8 E., Alpena township, in the South Long Lake area. It is connected to another unnamed lake to the north by a small connecting strip of water called "The Narrows". These two lakes are fed by Long Lake Creek, which is the natural surfact outlet of Long Lake. In the spring and early summer, Long Lake Creek is at a high stage, and these two lakes consequently fill up to a depth of 20 to 35 feet. In the late summer and early fall, these lakes become almost dry, and sinkholes can be observed in their beds (Michigan Geological Survey, no date).

Local reports (1972, personal communication) say that, during the wet season each year, all the drainage from Long Lake goes to Lake Huron via these two lakes and the Narrows. During the dry season, the drainage from Long Lake drains into sinkholes in the bed of Long Lake Creek, and then flows underground toward Lake Huron.

Devil's Lake is believed to lie along the same underground drainage system as the other disappearing lakes and streams in Alpena and Presque Isle Counties, such as Sunken Lake and Rainy Lake. Poindexter (1935) believed that the water which enters Lake Huron at Misery Bay comes totally from Devil's Lake.

The most significant feature of Devil's Lake and the lake to the north of it, is the shape of the two lakes. If these two lakes are controlled by jointing, this suggests a possible explanation for the pattern of photolinears. It is believed that the two prominent sets of photolinears in Alpena and Presque Isle Counties coincide with the vector means of the two joint sets to which the trends of these two lakes are parallel. These two sets of joints are at right angles to each other (see page 62).

Rainy Lake

Rainy Lake is located in southwestern Presque Isle County. It is one of the most unusual karst features in the two counties, as it "flushes" itself every few years and disappears. The subterranean drainage of this lake flows into a long sinuous ravine in the lake bottom, as reported by Gregg (1935) and Dorr and Eschman (1970). This ravine is visible when the lake is dry. It is believed to lead to some large sinkholes, and eventually to underground channelways.

It is reported by the Michigan Tourist Council (no date) that Rainy Lake was dry in 1894, 1925, and 1950. When Rainy Lake is not dry, the natural drainage from the lake flows north from Rainy River to Black Lake (Melhorn, 1947). Normally, Rainy River is a productive trout stream. The trout breed in Rainy Lake. During the years when Rainy Lake is dry, there are surprisingly no dead trout found in the lake, as would be expected. The fish reappear, however, when the lake fills up again (Gregg, 1935).

Another story reports that, in the logging days of the early 1900's, timbermen wanted to float logs down the Rainy River from Rainy Lake to Black Lake. Immediately before this was to be done, the lake dried up. Consequently, the loggers built a railroad in the dried-up bed. As soon as the railroad was completed, however, the lake again filled up with water (Gregg, 1935).

Rainy Lake disappears and reappears when a large sinkhole in the bottom of the ravine in the lake bed becomes plugged with sediment, then subsequently becomes unplugged. When it is plugged, the lake is full. When the sediment is carried away from the plugged sinkhole by the continuing action of ground water, the lake drains through this sinkhole and subsequently dries up (Dorr & Eschman, 1970).

Rainy Lake is significant to this study in that it offers further evidence for a major underground drainage system in Alpena and Presque Isle Counties. This drainage normally flows eastward toward Lake Huron, The source of the underground drainage network is at least as far west as Onaway, Presque Isle County, and perhaps even further to the south and west (LaForest, 1970). This has to be a relatively large subterranean system in order to accommodate all the drainage from Rainy Lake, which covers a surface area of approximately one half a square mile.

There are a number of sinkhole lakes and sink valleys in this part of Presque Isle County, including the 120-foot deep sinkhole to the east of Shoepac Lake. The Traverse Group strata in this part of the county consist mostly of highly-soluble Alpena Limestone, the ratio of limestone to shale being greater than 4:1 (Michigan Geological Survey, 1972). The solubility of the strata is probably a major factor in the development of the postulated underground drainage system.

There is a drainage divide in this part of Presque Isle County. The streams originating on the west side of the divide, such as the Rainy and Ocqueoc Rivers, flow northwest toward Black Lake, while the streams originating on the east flank of the divide flow to the east or southeast, toward Lake Huron. The North Branch of the Thunder Bay River is one such stream in the southeast-flowing group.

Sunken Lake—Mystery Valley

Mystery Valley is located just four miles west of the northwest corner of the South Long Lake area, in sections 32 and 33, T. 33 N., R. 6 E., Presque Isle County. It is believed to be a sink valley (Thomas, 1958; Mahan, no date). Older reports term it a "rift valley" (Michigan

Geological Survey, no date). Half of Mystery Valley is occupied by Sunken Lake.

Speculation that Mystery Valley is a sink valley dates back to the lumbering days of the early 1900's. It is reported that, when the lumberers would run their logs down the North Branch of the Thunder Bay River, the logs would get caught at a sinkhole, and the water would consequently back up into the valley, since its drain was plugged.

Evidence for a subterranean drainage system was first noted by Winchell (1870), when he observed that Sunken Lake had no surface outlet, and the complete drainage of the lake seemed to "disappear" under a limestone ledge. To prevent all the lumber from getting lost in what appeared to be a giant sinkhole, the loggers built a diversion dam just above Sunken Lake, to divert the water from the river away from the valley of Sunken Lake.

Through the years, local residents as well as geologists have accepted the theory that Sunken Lake is a major entry point into a vast underground drainage system known to exist in Alpena and Presque Isle Counties.

Sunken Lake is also a disappearing lake, similar to Rainy Lake. The Michigan Tourist Council, in an undated press release, tells of an attempt one year to beautify the floor of Mystery Valley, after the lake had failed to appear the previous summer. The property owners believed the lake to be gone for good, so they planted flowers in the valley. After the garden was planted, the lake reappeared the next year, and the beautiful garden was gone. .

The name "Mystery Valley" was given to the area by Arthur Poch, a citizen of Rogers City, Presque Isle County. He bought some property in the valley in the 1950's, during the dry year. It is reported (Kraemer, 1962; no date) that Mr. Poch's valley began to "fill up with cold clear water, which emerged from cracks in the ground." Within one month, the lake was 40 feet deep and one half mile long. By October of that year, the lake had again vanished.

Summary of Karst Features

Alpena and Presque Isle Counties are noted for their numerous karst features. Most reports state that these features are related to a vast underground drainage network. In some areas of Presque Isle County, caverns have been discovered. Some reports (Martin, 1958; Kraemer, 1962) tell of vast underground caverns in Presque Isle County. These huge chambers were entered by way of small sinkholes in the ground several feet above the caverns. In one cave in Posen township, just northwest of the South Long Lake area, an actual underground stream was discovered, plus numerous stalactites, stalagmites, and even an underground waterfall (Kraemer, 1962; Kraemer, no date; Kuehner, 1972, written communication). Similar caverns were found in other parts of the two counties (Grand Rapids Press, 1957; Martin, 1958).

It is concluded that the source of the underground drainage network is at least as far west as Rainy Lake. This system extends southeast toward Misery Bay, Lake Huron. The Thunder Bay River and its northern tributary are the surface expressions of this system. When water level is down, and lakes and sinkholes are not plugged with sediment, the lakes drain into the underground drainage network. In the wet season (spring and early summer), meltwater from winter snows carries a large volume of sediment into these sinkholes, and makes it easier for the sinkholes to become plugged up. When this happens, lake levels rise, and sinkholes back up. There are probably only a few major underground channelways in the area. As time progresses, these channels enlarge, especially at joint or fracture intersections. In time, this type of ground water solution can produce a collapse of the overlying strata, and the result appears on aerial photographs as some type of linear feature.

CONCLUSIONS

Alpena and Presque Isle Counties, Michigan, are underlain by rocks of Lower and Middle Devonian age, which consist chiefly of limestones and shales. Most of the area is underlain by sedimentary rocks of the Traverse Group. A narrow band parallel to the Lake Huron shore in northern Presque Isle County is underlain by the Rogers City Limestone and older Dundee rocks.

Due to the selective permeability and solubility of these limestones, an extensive ground water network has developed, which is controlled largely by the regional pattern of jointing in the bedrock. The two major joint sets in this area trend north-south and east-west. The two major sets of photolinears are oriented at mean azimuths of 43° and 133°, and these mean azimuths are 90° from each other. The mean azimuths of the photolinears are coincident with the vector means of the two major sets. Joints are natural passageways for water, and where they intersect, ground water flows underground between the joint intersections and into the underground drainage network, which flows east until the base level is reached. In this area, the base level is the mean level of Lake Huron.

A vast underground drainage network is present in Alpena and Presque Isle Counties. This system is believed to flow to the southeast. In part, it parallels the surface course of Thunder Bay River and its tributaries. It is fed through the numerous sinkholes and karst features by meltwater from the winter shows, as well as from the normal annual rainfall in the area. Major inlets to the underground drainage network are sinkholes associated with Rainy Lake, Sunken Lake, Trapp Lake, Mindock Lake, Fitzgerald Lake, and Devil's Lake, plus numerous sinkholes in the Alpena Limestone, for instance those around Leer, Alpena County, and those in the South Long Lake area associated with the contact between the Alpena Limestone and the Newton Creek Limestone.

The underground drainage system closely parallels the northwest-southeast system of joint intersections, and extends along zones of weakness within the rocks of this area. Continuous ground water solution along these zones causes collapse of the overlying strata, and features develop which appear as photolinears on aerial photographs. Close examination of Figure 14 reveals that two subsets are present within the northwest-southeast set of photolinears. One subset trends east-southeast, whereas the other trends in a more southerly direction.

The subset which trends east-southeast probably includes the photolinears produced by the present underground drainage network. The subset which trends in the more southerly direction is probably the result of an early middle Devonian underground drainage system. During the early Devonian, hundreds of feet of Salina Salt existed near the surface of the earth in Alpena and Presque Isle Counties. As the Detroit River sea withdrew after deposition of the early Devonian strata, the land was elevated and ground water is thought to have flowed to the south-southeast, and to have leached out large amounts of Salina Salt. As the salt was leached out, the result was a series of large linear ravines or canyons in the surface of the earth. These openings were filled in by collapsed overlying strata as the ground water continued to dissolve salt, gypsum, and limestone. Many of the resulting caverns were large enough to warrant designating the collapsed fill material as a separate formation—the Mackinac Breccia. All subsequent rock layers were deposited in the ravines and canyons, their resulting topography containing linear features along trends of the former ravines and canyons.

Most of the remaining photolinears in the South Long Lake area are thought to be either Pleistocene shorelines or bedding plane features such as formational contacts. Although they are not due to fracturing or collapse of the bedrock, these features are important to the geology of the area, and they account for some of the more impressive photolinears in the area.

Suggested Future Work

The photolinear study of Alpena and Presque Isle Counties is only the first step in reconstructing the geologic history of the area. The next step is to determine the nature of the folding and fracturing of this unique part of the Michigan Basin. Thin-section work would be especially useful in a study such as this. Samples of the bedrock of the Traverse Group could be taken from different areas of Alpena and Presque Isle Counties, and the textural petrofabrics could be studied for patterns of crystal strain and deformation. More detailed thin-section work on each formation of the Traverse Group could possibly give clues to explain the localization of certain karst features in each unit. Finally, the glacial geology of the area could be studied in more detail by taking till samples from the various gravel pits and shorelines, such as the Algonquin Line or the Opechee Line. Till petrology could be studied, and perhaps a more detailed glacial geochronology of this area could be hypothesized.

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APPENDIX I

TABLE 1. Summary statistics for each set of photolinears within each subarea

	NE-SW SET							NW-SE SET						
	subarea	mean	median	mode	skew-ness	σ	σ^2	subarea	mean	median	mode	skew-ness	σ	σ^2
azimuths	1	47.27°	47.00°	28.00°	.094	16.20	262.59	1	131.13°	130.00°	130.00°	.293	14.3	204.4
	2	45.00°	45.00°	48.00°	.040	15.15	229.65	2	124.66°	121.00°	115.00°	.134	15.8	250.9
	3	34.35°	40.00°	39.00°	–.245	14.17	200.70	3	139.94°	141.25°	140.00°	–.940	14.8	220.1
	4	38.88°	42.00°	48.00°	–.114	17.79	316.47	4	141.83°	147.00°	147.00°	–.469	18.7	850.8
	total	42.82°	43.00°	48.00°	–.040	15.77	248.78	total	132.94°	133.00°	130.00°	–.032	16.7	280.3
lengths	1	2.93	2.42	1.38	2.68	2.23	4.99	1	3.32	2.52	1.38	2.73	2.98	8.85
	2	3.40	2.73	1.87	1.06	2.08	4.33	2	3.69	2.86	2.66	2.49	2.91	8.49
	3	4.93	4.18	1.28	1.12	3.11	9.67	3	5.00	4.29	6.73	1.08	2.79	7.79
	4	4.06	3.37	2.86	2.03	2.46	6.03	4	5.31	5.10	6.53	0.12	1.87	3.48
	total	3.86	3.01	2.86	1.59	2.61	6.80	total	4.05	3.45	1.38	1.86	2.88	8.29

all lengths are given in miles

TABLE 2. Coefficients of correlation and determination

NE-SW SETS					NW-SE SETS				
subarea	mean length	mean azimuth	r	r^2	subarea	mean length	mean azimuth	r	r^2
1	2.93	47.27°	.086	.0073	1	3.32	131.13°	.145	.0210
2	3.40	45.00°	−.019	−.0003	2	3.69	124.66°	.259	.0670
3	4.93	39.35°	.187	.0349	3	5.00	139.94°	−.097	−.0094
4	4.06	38.88°	.147	.0216	4	5.31	141.83°	.134	.0179
total	3.86	42.82°	.033	.0010	total	4.05	132.94°	.203	.0412

all lengths given in miles

TABLE 3. Significance between mean azimuths determined by t-tests

	NE-SW SETS					NW-SE SETS					
Subarea	1	2	3	4	total	1	2	3	4	total	Subarea
1 (t=)	.0000	−.7539 (p=.452)	−2.631 (p=.010)	−2.119 (p=.038)	−.903 (p=.367)	.0000	−2.817 (p=.005)	3.626 (p=.000)	3.861 (p=.00)	1.001 (p=.318)	1 (t=)
2 (t=)		.0000	−2.254 (p=.026)	−1.837 (p=.069)	−1.043 (p=.298)		.0000	5.381 (p=.00)	5.243 (p=.00)	6.792 (p=.000)	2 (t=)
3 (t=)			.0000	−.1413 (p=.888)	1.562 (p=.119)			.0000	.5544 (p=.581)	−2.806 (p=.005)	3 (t=)
4 (t=)				.0000	1.306 (p=.193)				.0000	−3.237 (p=.001)	4 (t=)
total (t=)					.0000					.0000	total (t=)

all probabilities are based on 2-tailed tests

TABLE 4. Significance between mean lengths determined by t-tests

	NE-SW SETS					NW-SE SETS					
Subarea	1	2	3	4	total	1	2	3	4	total	Subarea
1 (t=)	.0000	1.125 (p=.263)	3.560 (p=.001)	2.066 (p=.042)	2.134 (p=.034)	.0000	.8206 (p=.413)	3.441 (p=.001)	4.172 (p=.000)	2.244 (p=.025)	1 (t=)
2 (t=)		.0000	3.465 (p=.001)	1.444 (p=.152)	1.844 (p=.066)		.0000	2.493 (p=.014)	3.308 (p=;001)	0.924 (p=;356)	2 (t=)
3 (t=)			.0000	−1.397 (p=.166)	−2.715 (p=.007)			.0000	.6273 (p=.532)	−2.191 (p=.029)	3 (t=)
4 (t=)				.0000	−.403 (p=.687)				.0000	−2.831 (p=.005)	4 (t=)
total (t=)					.0000					.0000	total (t=)

all probabilities are based on 2-tailed tests

APPENDIX ii

Fortran IV Program to calculate t-values

```
C       T-TESTS
        REAL M1, M2, N1, N2
24      TYPE 4
        ACCEPT 10, M1, SD1, N1
        TYPE 5
        ACCEPT 10, M2, SD2, N2
        SIGMA=SQRT (((N1*(SD1**2))+(N2*(SD2**2)))/(N1+N2-2))
        SN= (1/N1)+(1/N2)
        TVAL=(M1-M2)/(SIGMA*(SQRT(SN)))
        WRITE (5,12) TVAL
        ACCEPT 11, I
        IF (I.EQ.1) GO TO 24
        CALL EXIT
4       FORMAT (1X, 23H ENTER M1, SD1, and N1,/)
10      FORMAT (F6.3, F5.3, F3.0)
5       FORMAT (1X, 22H ENTER M2, SD2, and N2,/)
12      FORMAT (1X, 23H THE VALUE OF THE T IS, F6.3,///
       11X, 42H TO CONTINUE, TYPE 1 -ANYTHING ELSE TO EXIT,/)
11      FORMAT (I)
        END
```

explanation:

M1 —— mean of the first variable
M2—— mean of the second variable
SD1— standard deviation of the first variable
SD2— standard deviation of the second variable
N1—— no. of samples from which M1 was calculated
N2—— no. of samples from which M2 was calculated
TVAL–t-value