AN AERIAL PHOTOGRAPHIC STUDY OF THE GLEN LAKE - SLEEPING BEAR POINT AREA LEELANAU COUNTY, MICHIGAN

> Thesis for the Degree of M. S. MICHIGAN STATE UNIVERSITY Kenneth G. Johnson 1957

. •



. 1

!







#### AN AERIAL FHOTOGRAPHIC STUDY

## OF THE

#### GLEN LAKE - SLEEPING BEAR FOINT AREA

### LEELANAU COUNTY, MICHIGAN

Вy

#### KENNETH G. JOHNSON

#### A THESIS

Submitted to the School of Science and Arts of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Geology

1957

.

1-28-58

)

#### ABSTRACT

An aerial photographic study of the Glen Lake-Sleeping Bear Foint area in Leelanau County, Michigan shows that the area includes a horseshoe-shaped depression flanked on the west by a large dune complex.

The depression is divided into four parts on the basis of topographic configuration and origin of the features present. The divisions are:

- The portion of the depression occupied by Glen Lake.
- 2. The Day Hills which dominate the west central portion of the depression.
- 3. A low, flat area at the northern edge of the depression.
- 4. Morainic hills which rim the depression on the east, south, and southwest.

The southern third of the dune complex is a plateau which has developed on the northwestern end of the moraine extending northwest from the southwestern side of Glen Lake. Sand, which forms a high percentage of the material in the moraine, is swept northeast into an area of accumulation. The lee slope of the dune complex is encroaching on the Glen Lake depression.

#### ACKNOWLEDGMENTS

The writer wishes to express his thanks to Miss Helen M. Martin of the Geological Survey Division, Michigan Conservation Department, for suggesting the problem; to Mr. William L. Daoust, State Geologist, for his cooperation in making the aerial photos available; to Mrs. Jane E. Smith, Michigan State University, for her guidance and helpful criticisms during the pursuance of the study; to Dr. H. B. Stonehouse, Dr. W. A. Kelly, and Dr. J. W. Trow, all of Michigan State University, for reading the manuscript and suggesting suitable changes; to Mr. Richard Ernst for aid in obtaining field elevations; and to D. Nancy Johnson for typing the manuscript.

## TABLE OF CONTENTS

	Page
INTRODUCTION	1
Nature and Furpose of Study	1
Location and Extent of Area	3
Methods	4
THE GLEN LAKE DEIRESSION	5
Glen Lake	7
The Day Hills	9
The Bar Area	11
The Moraine Surrounding the Depression	14
THE SLEEFING BEAR DUNES	15
General	15
The Plateau and Associated Dunes	17
The Area of Accumulation	22
Origin of the Dunes	26
RECOMMENDATIONS FOR FURTHER STUDY	29
BIBLIOGRAPHY	32

.

## FIGURES

Figure		Page
1.	Index map showing location of the thesis	
	area.	3
2.	Photograph of the west arm of Glen Lake.	10
3.	Fhotograph of the west end of the bar area.	12
4.	Photograph of the Crystal River.	14
5.	Photograph of the lee slope of the Sleep-	_
	ing Bear dunes.	16
6.	Fhotograph of the Sleeping Bear and the	
	southern portion of the plateau.	20
7.	Photograph of a large blowout on the east	
	side of the plateau.	21
8.	Fhotograph of exhumed cedars in a blowout	
	on the east slope of the area of accumula-	
	tion.	25
9.	Fhotograph of blowout in area of accumula-	
	tion.	26.

## PLATES

## Plate

I	Form line map showing the topography of the Glen Lake depression.
II	Map showing vegetation cover and road system of the Glen Lake depression.

## III Topographic map of the Sleeping Bear sand dunes.

#### INTRODUCTION

Nature and Furpose of the Study

Extensive areas of sand dunes are found along the south and east coasts of Lake Michigan. As far north as Manistee these dunes are in the form of long foredune ridges backed by blowouts in dunes built previous to the present stage of dune formation. The older dunes evolved during the various glacial and early postglacial lake stages of the Lake Michigan Basin. They were subsequently anchored by vegetation and are now being dissected by wind erosion. The foredune ridges are a result of the action of waves and currents which deposit sand on the beaches, and onshore winds which sweep the sand from the beach and deposit it in long ridges paralleling the coast.

Sand deposits along the northeast shore of Lake Michigan are, in general, not found in the forms which are characteristic of those on the southeast shore. According to Leverett (1915), the Manistee moraine of the Fort Huron morainic system wraps around the western end of prominent ridges which are oriented transverse to the shore, and appear as headlands along the north-

east shore of Lake Michigan. Glacial ice readvanced into the lowlands between these transverse ridges and consequently the moraine makes a series of loops as it crosses the lowlands between the ridges. The alternation of lowlands separated by morainic ridges gives this part of the Lake Michigan coast an interrupted character which prevents extensive linear development of sand dunes parallel to the coast.

An interesting acolian depositional feature of the northeastern Lake Michigan coast is the perched dune. Some of these dunes rest on Nipissing and Algonquin beaches and are in an elevated position relative to the present lake level. Others are "perched" on high morainic bluffs adjacent to the shore. Fuller (1918) described the perched dunes of the Beaver Islands and South Fox Island. Dow(1938) investigated the origin of the perched dunes of the Manistee Moraine. Both writers briefly described the dunes of Sleeping Bear Foint in southwest Leelanau County. In 1926 Waterman described the Sleeping Bear dunes in his discussion of the ecology of the Glen Lake region.

The primary purpose of the present study is to map and describe the Sleeping Bear dunes and to discuss their origin and evolution. In addition, the Glen Lake depression is described because of its close association with the dunes.

#### Location and Extent of

#### the Area

The Glen Lake-Sleeping Bear Point area is located in southwest Leelanau County of Michigan's lower peninsula. It is approximately five miles north-northeast of the town of Empire and twenty miles northwest of Traverse City.

The area is bordered on the west by Lake Michigan, on the north by Sleeping Bear Bay and Manitou Passage, and on the east and south by morainic hills which rise abruptly from the shores of Glen Lake.



# LOCATION MAP

## FIG. 1

#### Methods

In the pursuance of this study, an emphasis was placed on laboratory work in the form of aerial photographic interpretation of the area and reliance on aerial photogrammetry for all mapping.

The photographs used were provided by the Conservation Department of the State of Michigan. They were taken with an  $\delta.25$  inch focal length camera at a flying height of 10,788 feet; the resulting scale being 4 inches to the mile.

At the beginning of the study a thorough interpretation of the photography was made. By this means, the physiography of the area was studied and specific locations were outlined where field reconnaissance would be necessary for an understanding of their relation to the gross physiography.

Since no large scale base maps of the Glen Lake-Sleeping Bear Point area were available, the next step was the compilation of a planimetric base map from aerial photography. Abrams mechanical triangulators were used to provide horizontal control by radial line plot. A vertical sketchmaster was used to transfer planimetric detail from the photos to the base sheet. The resulting map was compiled at the same scale as the photographs.

One week was devoted to a field reconnaissance of the area. At this time elevations were taken with a

Wallace and Tiernan barometric altimeter.

After the reconnaissance was completed, a Fairchild Stereocomparagraph was used to sketch formlines on the base map of the Glen Lake area. Although the formlines are not accurate enough to be considered contours, it is felt that they give a realistic picture of the topography of the Glen Lake depression. The same base was used to compile a map showing the road system and vegetation cover of the Glen Lake area.

The Sleeping Bear dune area was contoured with the stereocomparagraph after the effects of tip and tilt were removed from the vertical control point parallax readings by means of correction graphs. McNeil (1950) states that the smallest contour interval which can be used in contouring with the stereocomparagraph is 1/250th of the flying height of the aircraft which took the photography. The smallest usable contour interval in the case of the photography used in this study was 45 feet.

#### THE GLEN LAKE DEPRESSION

During the Wisconsin stage of the Fleistocene epoch the Lake Michigan Basin was occupied by glacial ice. Changes in climate and hence nourishment for the ice sheet caused the lobe alternately to extend southward

and retreat northward in the basin.

Beach lines above the present shore of Lake Michigan mark the levels of the ice-marginal lakes which occupied the basin at this time. The earliest of these lakes has been called Lake Chicago. The level of Lake Chicago rose and fell with advance and retreat of the tongue of ice and the consequent uncovering or covering of drainage outlets of higher or lower elevation. Although in its later stages Lake Chicago extended northward nearly to the Straits of Mackinac, the beaches which it built have been preserved only in the southern half of the basin.

The ice eventually retreated north far enough to allow the union of the waters of the Michigan, Superior, and Huron Basins. The extensive lake which resulted has been called Lake Algonquin.

The history of the Glen Lake depression prior to the formation of Lake Algonquin is obscure. The hills enclosing the depression and the Day Hills in the west central portion of the depression are part of the Manistee moraine. Hough (1953) correlates the Manistee moraine with the Mankato till of northeastern Wisconsin. Radiocarbon dating indicates that Mankato maximum glaciation occurred 11,000 years ago (Flint and Deevey, 1951).

During Algonquin time, the waters of this large icemarginal lake invaded the Glen Lake depression. The

entire depression, with the exception of the hill mass in the west central portion, was covered by the waters of a bay. "The highest Lake Algonquin stage was terminated either by a downcutting of one of its southern outlets or by diversion of its discharge to a new, lower outlet made available by recession of the glacial ice dam (Hough, 1953)." A beach below that of Lake Algonquin marks the level of Lake Nipissing in the northern Lake Michigan Basin.

The Glen Lake depression may be divided into four distinct parts on the basis of both topographic configuration and origin of the features found there. The divisions are:

- The portion of the depression occupied by the waters of Glen Lake.
- 2. The Day Hills which dominate the west central portion of the depression.
- 3. The low, generally flat area which fringes Sleeping Bear Bay at the north edge of the depression.
- 4. The morainic hills which rim the depression on the east, south, and southwest.

#### Glen Lake

Two thirds of the area within the depression is occupied by Glen Lake. The lake is divided into an east

arm and a west arm by a narrows where the moraine which borders the lake on the south lies in close proximity to the Day Hills in the west central portion of the depression. The east arm, the larger of the two, is nearly circular in outline and has an area of approximately seven square miles. The west arm extends northwest from the narrows for a distance of two and one quarter miles and measures one mile across at its widest point.

The only stream flowing into the lake is a small creek which rises on the slope of the moraine one half mile south of the east arm. The waters of Glen Lake drain north through Fisher's Lake and then to Sleeping Bear Bay via the Crystal River.

The level of Glen Lake, while field work was being conducted in August of 1957, was 594 feet above sea level. The level of Lake Michigan is variable around 578 feet above sea level, depending on the season and amount of precipitation. Scott (1920) found the Glen Lake level to be 17 feet above that of Lake Michigan.

The waters of Glen Lake are held in this elevated position by a succession of Algonquin baymouth bars which occupy the northeast fringe of the depression.

The Lake Algonquin level is represented in the depression, at an elevation of 615 feet above sea level, by a beach which closely follows the present shore of Glen Lake. The beach is best developed around the east

arm of the lake where wave action was undoubtedly more vigorous than in the smaller, more protected, west arm, and when viewed on photography or in the field is obvious on the northeast and southeast shores. Roads have been built on the beach along the northwest, northeast and southeast shores of the east arm of Glen Lake, and along the north and west shores of the west arm. One mile south of Glen Arbor, State Highway 22 crosses a triangular shaped remnant of the beach.

#### The Day Hills

A high, densely forested hill mass is situated in the west central portion of the depression. The hills rise to an elevation of 953 feet above sea level threequarters of a mile southwest of Glen Arbor. The mass is highest along its northern edge where a bluff slopes precipitously to the low area bordering Sleeping Bear Bay. The south side slopes less steeply to the west arm of Glen Lake. A spur projects west from the northwest side of the mass, decreasing in width as it approaches the lee side of the Sleeping Bear dune complex. The bluff which characterizes the north slope of the Day Hills extends west along the north side of the spur.

The bluff is the result of the erosive action of the waves of Lake Algonquin. The lower slope was sub-

jected to the full force of waves which developed in catchment areas far out in the lake. The wave-cut bluff which resulted was probably not much steeper than that which we find today because a dense vegetation cover has prevented erosion and consequent destruction of its face.

When the waters of Lake Algonquin invaded the Glen Lake depression, the Day Hills became an island. At this time two channels provided access to the depression, one, approximately two miles wide, east of the hill mass and one west of the spur. The western chancl is now covered by the Sleeping Bear dune complex. Its extent, therefore, is unknown.



Figure 2. View of the west arm of Glen Lake from the area of accumulation.

The Day Hills are covered by a dense deciduous forcst. The only open areas in this forest are the grasscovered remains of a golf course which was constructed on the D. H. Day estate some years ago. A network of unpaved roads provides access to the area.

#### The Bar Area

A succession of Algonquin bars parallels the shoreline of Sleeping Bear Bay and constitutes a record of the withdrawal of the waters of Lake Algonquin from the Glen Lake depression. The bars extend from the foot of the moraine which borders the depression on the east, westward to Sleeping Bear Foint. This low, generally flat area is widest immediately north of the east arm of Glen Lake, narrows to less than half a mile just west of Glen Arbor, and widens slightly westward toward the dunes covering Sleeping Bear Foint.

The eastern third of the bar area is poorly drained, with small patches of marshy ground, some of which are covered by a dense growth of tamarack. This area concists of baymouth bars built during the time the waters of Lake Algonquin occupied the depression and during the lowering of the lake to Nipissing level.

The western two-thirds of the bar area is slightly higher, and has had a somewhat different origin than the east third. Here bars were not built in the shallow

entrance to a bay, but adjacent to a steep bluff which was being cut by wave action. They are now protected from wind erosion by a covering of vegetation, and the high moraine and sand dunes which shut out the prevailing southwest winds. In places, however, blowouts of limited extent have developed in the west third of the bar area. Gravel has been uncovered in some of these blowouts and probably represents coarse bar material which had been eroded from the bluff. The overlying sand was deposited in low dune ridges which backed the beach as it moved lakeward during the lowering of Lake Algonguin to Nipissing level.



Figure 3. View of the west end of the bar area from the area of accumulation.

The wave action which formed the bluff along the north side of the hill mass and spur was also responsible for the formation of a wavecut terrace at the base of the bluff. Although the terrace extends from a point approximately one half mile southwest of Glen Arbor westward nearly to the east slope of the dune complex, it is best seen in its west half where the land has been cleared and orchards planted. The terrace is composed of three levels. The highest is 605 feet above sea level, the lowest approximately 600 feet. Just east of the road junction where State Highway 109 turns east toward Glen Arbor, the combined width of the three levels is approximately 100 yards.

At the east edge of the bar area the Crystal River flows in broad meanders northwest toward Sleeping Bear Bay. The course of the stream is controlled by the orientation of the bars.

The western third of the bar area is covered by stands of evergreens, poplars, and grass. The eastern two-thirds is densely forested with hardwoods.



Figure 4. View of the Crystal River east of Glen Arbor

The Moraine Surrounding the Depression

The moraine which encloses the Glen Lake depression forms a bluff where it extends southwest along the east shore of Sleeping Bear Bay. At Frospect Hill the moraine turns south and closely follows the shore of the east arm of Glen Lake. South of the west arm of Glen Lake the moraine lies farther from the lake shore, but is closer to the shore where it trends northwest toward the Sleeping Bear dunes. A gravel plateau, partially Covered by sand dunes, composes the northwest end of the moraine. This plateau constitutes the southern third of the Sleeping Bear complex.

#### THE SLEEPING BEAR DUNES

General

Dow (1938) states that of 20 sections in Glen Arbor township, 10 are composed of sandy till. Leverett (1911) records a similar high percentage of sand in his soil studies of townships of western Benzie County. According to Dow some of the morainic bluffs along the northern Lake Michigan shore are composed of such a high percentage of sand that early geologists described them as wind-blown deposits. The moraine which extends northwest toward Sleeping Bear Foint from the southwest side of Glen Lake has this characteristic high percentage of sand. The composition of the moraine and its exposure to the prevailing southwest winds provide two requisites which are essential for the development of aeolian activity: a source of material and wind of generally constant direction and velocity sufficient to move the material. The presence of these requisites on the west flank of the Glen Lake depression has resulted in the formation of the Sleeping Bear dunes.

The Sleeping Bear dunes border Lake Michigan south from Sleeping Bear Foint for a distance of six miles. The dune complex is widest in its northern half where

•

its longest east-west dimension measures a mile and a quarter. It becomes narrower southward until it "pinches out" against the shore just north of North Bar Lake.

The area of aeolian activity is referred to as a complex because it consists of two closely related, but distinctly separate parts. The southern third of the complex is a gravel, capped plateau which lies an average of 325 feet above the level of Lake Michigan. Portions of the plateau are covered by sand dunes. An extensive sand accumulation lies north and northeast of the plateau. The accumulation is encroaching on the Glen Lake depression to the east.



Figure 5. View of the lee slope of the Sleeping Bear Dunes from the top of the spur west of the Day Hills.

#### The Plateau and Associated Dunes

The morainic plateau which constitutes the south third of the area of aeolian activity is triangular in plan view. The longest side of the triangle trends north-south along a precipitous bluff which follows the Lake Michigan shore. The shorter sides of the triangle are approximately equal in length and trend northeast and southeast from the ends of the bluff.

The northwest portion of the plateau consists of a surface of lag gravel and cobbles. The material shows the wide range of composition and size which is characteristic of moraines. In this area the finer material has been carried away by the action of the wind. Gobbles and gravel which remain have been polished and faceted by the bombardment of wind-blown sand and many excellent ventifacts have developed. Dow(1940) has described the ventifacts of the Sleeping Bear dunes. He concluded from a study of the orientation of the windfaceted cobbles that the prevailing wind is from the southwest.

The morainic bluff which marks the west edge of the plateau ranges from 320 to 375 feet high. It rises from the narrow beach at its base at an angle of approximately 32° near its south end. The slope angle increases to approximately 38° near the north end. The bluff is cut

by numerous gullies, a few of which extend half way down the bluff face. Most of the gullies, however, extend approximately one quarter of the way down to the beach. The gullies provide accessways for sand which blows up the bluff from sand lenses farther down the slope. Long, low ridges of loose sand extend northeast onto the plateau from the tops of the larger gullies. The material which gains access to the plateau through the smaller gullies generally is not of sufficient quantity to accumulate in elongate ridges at the west edge of the plateau. This is not to say, however, that in the course of time considerable quantities of sand do not move from the bluff face to the plateau surface via the smaller gullies.

The accumulations of sand in the gullies and the sand ridges which extend onto the plateau from their upper ends make the gullies the most obvious channels by which sand gains access to the plateau. However, sand does move up the bluff along its entire length. A low ridge of sand extends along the top of the bluff. It ranges from a few to several feet in height, and exhibits a "smoking crest". Here the sand which has moved up the bluff comes to rest temporarily before it begins its movement northeastward across the plateau.

Although the velocity of the wind which blows on-

not likely that much, if any, material is blown up the bluff from the beach. The force of the wind decreases noticeably from the top of the bluff to the beach. Here, of course, the velocity requirement for transportation of sand up the bluff is greatest. Dow (1938) thinks that it is probable that some sand does move up the bluff from the beach, but very slowly.

At the top of the bluff, approximately midway between its north and south ends, an isolated sand accumulation rises 70 feet above the plateau surface. This remnant of what was once a larger dune is called the Sleeping Bear. After the recession of the glacial ice from the Michigan Basin, isolated stands of cedars were able to gain a foothold on the moraine west of the Glen Lake depression. One of these stands grew at the present location of the Sleeping Bear with some of the trees reaching a height of over 35 feet. Sand moving up the bluff and across the plateau was trapped by the cluster of vegetation. As the sand deposit grew the cedars were buried and sand which blew over the crest of the dune fell into a wind shadow on its lee side. It is probable that the dune did not develop at the edge of the bluff, but that the bluff at that time lay farther to the west. The constructive phase of the development of the Sleeping Bear may have ended because of a decrease in wind velocity or a shift in wind direction. Whatever the

reason for the cessation of deposition, it is probable that vegetation stabilized the dune at this time.

The destructive phase of dune development was initiated when a prevailing southwest wind pattern was established. As the wind blew against the exposed face of the dune a hollow was formed. Sand blown from the hollow accumulated on its leeward rim. The Sleeping Bear is now a blowout surrounding the cedars which have been exhumed at its center. The north and east slopes are covered by arborvitae, calamovilfa, sand cherry, and grasses (Dow, 1938).



Figure 6. View of the plateau and the Sleeping Bear dune from the southern end of the Sleeping Bear dune complex. -Sand dunes occupy the eastern and southern portions of the plateau. The highest dunes are found at the south end where they rise to an elevation of over 1050 feet above sea level. Some dunes along the east edge of the plateau are over 950 feet above sea level. The prevailing southwest winds of the area are reflected in the large number of blowout and elongate blowout dunes which trend northeast across the plateau surface.

\_ \_

25.0

2

Figure 7. View of a large blowout on the east side of the plateau.

Although large dunes are found on the east and south portions of its surface, the plateau, viewed in total aspect, is a source area rather than an area of deposition.

#### The Area of Sand Accumulation

The northern two-thirds of the Sleeping Bear dune complex is occupied by a massive sand accumulation which is moving east into the Glen Lake depression. Dow (1936) refers to these deposits as semi-perched dunes. This portion of the complex is an area of dominant deposition. The activity here contrasts with that on the plateau to the south where sand is being removed and blown northeast into the area of accumulation. The prevailing southwest winds have removed sand from the northeast side of the plateau and deposited it in a broad, rather elongate mass which trends northeast from the plateau. Several extensive depressions on the plateau immediately windward of the sand accumulation have been scoured by wind action.

The highest elevations in the area of accumulation are found in its southeast portion where one dune rises to over 850 feet above sea level. Elevations decrease gradually northward toward Sleeping Bear Foint. They decrease more abruptly northwestward to a low area, 2300 yards long and 650 yards wide, which borders Lake Michigan. The elevation of this low area averages 25 feet above the level of Lake Michigan with several depressions less than 20 feet above lake level. This

area was covered by the waters of Lake Algonquin. It is probable that the depressions represent terraces and beaches of Lake Nipissing (Waterman, 1926).

Aerial photos show a concentration of blowout dunes on the plain and on the slopes which rise from the plain toward the east side of the area of accumulation. These blowouts, like those on the plateau, trend northeast. Many of them contain cedar stands which have been exhumed by the action of the wind. The material from the blowouts has been transported northeast toward Sleeping Bear Foint and has collected in a broad dune. the top of which rises to over 700 feet above sea level. The vigorous action of the wind on this exposed dune is exhibited in the broad wind ripples which trend northwest across its surface and in the rapid burial of poplars on its lee slope. A narrow, somewhat lower dune extends northeast from the main mass.

The northwest side of Sleeping Bear Foint consists of a shallow, bowl-shaped depression approximately 200 yards in diameter. The dunes mentioned above form the southwest and southeast flanks of the depression, and a low dune ridge separates it from the beach which borders Lake Michigan on the northwest. The floor of the depression is at about the same level or slightly below the level of Lake Michigan. This relationship to

Lake Michigan along with the internal drainage attendant with its configuration has caused the depression to be moist throughout most of the year and even to support a small pond during periods of heavy rain and high lake level. Grasses, and some poplars and scrub pine cover the floor of the depression.

The high sand ridge which constitutes the east edge of the area of accumulation is moving east into the Glen Lake depression. Stands of hardwoods along the west side of the depression are being buried by the sand. Fence lines erected a relatively few years ago now disappear into the advancing lee slope of the sand mass. Approximately a mile and a quarter south of Sleeping Bear Point, a road, which parallels the east edge of the dune complex, has been cut off by the encroaching sand. The lee side of the area of accumulation has a slope of approximately 32, the characteristic angle of repose of dry, loose sand.

Two large blowouts lie along the east edge of the sand mass. The larger of the two, approximately half way between Sleeping Bear Foint and the south end of the area of accumulation, lies at the northeast end of a longitudinal dune which extends northeast from the plateau. The smaller blowout lies immediately to the north in an area which has been stabilized by vegetation.

Cedar stands buried by the advance of the sand, have been exhumed at the centers of the blowouts.



Figure 8. View of exhumed cedars in a blowout on the east slope of the area of accumulation.

Throughout both the area of accumulation and the plateau vegetation has been able to gain a foothold in areas which are protected from the wind. Some of the patches of grass, vines, and poplars are now situated in exposed locations and must have evolved at times when they were more protected. In places the vegetation has stabilized the dunes. Thin layers of organic material uncovered in some of the blowouts indicate previous periods of dune stabilization.



Figure 9. View of a blowout in the area of accumulation.

Origin of the Dunes

Fuller (1918) and Dow (1938) have offered theories of origin to explain the development of the Sleeping Bear dunes.

Fuller divided the dunes of northern Lake Michigan into two groups, lacustrine dunes, and terrestrial dunes. He considered the lacustrine dunes as: "being formed from sand thrown upon the shore by the waters and then caught up by the wind, carried inland, and piled in characteristic mounds and ridges." The lacustrine dunes are of

two types: beach dunes developed on the existing beach; and perched dunes developed on substrata elevated some distance above the beach. He envisaged terrestrial dunes as being: "formed from sandy material deposited by the action of ice and water about the margin of the Fleistocene ice sheet and afterwards worked over by the wind". He classifies the dunes of the Sleeping Bear complex as terrestrial in origin. Although the findings of this study generally support Fuller's designation of the Sleeping Bear dunes as terrestrial dunes, the divisions of the classification proposed by him are so broad that they have little practical value.

Dow, after studying the perched dunes found along the western edges of the Manistee moraine, proposed the following arbitrary classifications:

- Type I Sand of beach origin---accumulation due to wind action.
- Type II Sand of beach origin---accumulation due to wind action accompanied by shore recession.
- Type III- Sand derived from morainic drift.
- Type IV Sand of combined beach and morainic origin.

Dow includes the Sleeping Bear dunes under his Type IV classification.

The observations made during the present study warrant a theory of origin essentially the same as that offered by Dow. The only point of possible disagreement would be whether or not sand is transported from the beach to the plateau via the high, steep bluff at the southwest edge of the complex. Even this point is a purely academic one, for Dow pointed out that he considered the rate of sand movement from the beach to the plateau to be very slow. He clearly states that the Type IV perched dunes of the northern Lake Michigan shore are composed of material derived mainly from the sandy moraines of the area.

The origin and development of the Sleeping Bear dune complex may be summarized as follows: The high percentage of sand in the moraine which extends northwest from the southwest side of Glen Lake provides a source of material. The prevailing southwest wind which strikes Sleeping Bear Point and the shore south of the point is of sufficient velocity to act as a transporting medium.

Wind blowing onshore from Lake Michigan has swept sand from the plateau and deposited it over a broad area to the northeast. Farts of the plateau are now capped by a surface of lag-gravel. Lenses of sand are exposed on the face of the bluff which marks the west edge of

the plateau. Gullies extending down the bluff serve as accessways through which sand moves to the plateau surface. Long ridges of sand extend from the upper ends of the gullies onto the plateau. The wind also transports sand up the bluff along its entire length. This sand accumulates at the top of the bluff in a low ridge. It is improbable that the wind has a velocity sufficient to transport sand from the beach to the plateau via the bluff face.

Sand dunes cover much of the plateau surface. These deposits consist of material which is migrating northeast across the plateau and which will eventually become a part of the sand mass in the area of accumulation. The plateau and the bluff at its western edge constitute the source area of the Sleeping Bear dune complex.

The northern two-thirds of the complex is an area of deposition. The east slope of the sand mass in this portion of the complex is advancing eastward into the Glen Lake depression.

#### RECOMMENDATIONS FOR FURTHER STUDY

Aerial photographic interpretation provides a means of studying the surface features of the land in a frac-

tion of the time required for a comparable ground survey. During World War II and the Korean Conflict the armed forces were quick to recognize the value of aerial photography for rapid evaluation of unfamiliar terrain. Fhotographic interpretation was developed to a high degree by trained specialists.

The peacetime applications of photographic interpretation are now being developed. For example, the distinct patterns shown on aerial photography by vegetation cover, and glacial and geomorphic formations make these features particularly adaptable for aerial survey. Frecise interpretation is dependent on a thorough understanding of the forms studied and field work may be required where a detailed evaluation is made.

Accurate planimetric and topographic maps may be compiled by photogrammetric methods more rapidly than by ground survey. However, characteristics of the available photography and capabilities of the instruments used to compile the maps place limitations on the topographic detail which may be shown on the maps. The flying height of the photography used in this study and the relatively simple instrument used for contouring allowed a minimum contour interval of 45 feet. Consequently the blowouts in the dune complex do not show on the topographic map of the Sleeping Bear dunes.

During every aerial photographic survey, problems are encountered and limitations are recognized. Improved techniques and methods consequently evolve. It is suggested that aerial photographic interpretation in its present stage of development offers an accurate, rapid, relatively inexpensive means of studying the surface features of the land, and that each survey which is conducted contributes to the overall development of photographic interpretation.

#### BIBLIOGRAFHY

- Dow, K. W. (1938) The origin of perched dunes on the Manistee moraine: Papers Mich. Acad. Sci., Arts, and Letters, Vol. 23, pp. 427-440.
- ----- (1940) Some examples of ventifacts from Sleeping Bear Point, Leelanau County, Michigan: Fapers Mich. Acad. Sci., Arts, and Letters, Vol. 25, pp. 473-476.
- Flint, R. F. and Deevey, E. S., Jr. (1951) Radiocarbon dating of Late-pleistocene events: Am. Jour. Sci., Vol. 249, pp. 257-300.
- Fuller, G. D. (1918) Some perched dunes of northern Lake Michigan and their vegetation: Trans. Ill. Acad. Sci., Vol. 11, pp. 111-122.
- Hough, J. L. (1953) Fleistocene chronology of the Great Lakes region: O. N. R. project report, 108 pp.
- Leverett, F. (1911) Surface geology and agricultural conditions of the southern peninsula of Michigan: Ann. Report Mich. Geol. and Biol. Survey, Pub. 9, Ser. 7, 144 pp.
- Leverett, F. and Taylor, F. B. (1915) The Fleistocene of Indiana and Michigan: U. S. Geol. Survey, Mon. 53, 529 pp.
- McNeil, G. T. (1950) ABC's of photogrammetry, part 1, fundamentals: published by author, 125 pp.
- Scott, I. D. (1920) Inland lakes of Michigan: Ann. Rep. Mich. Geol. Survey, Pub. 30, Ser. 25, 383 pp.
- Waterman, W. G. (1926) Ecology of Glen Lake and Sleeping Bear region: Fapers Mich. Acad. Sci., Arts, and Letters, Vol. 6, pp. 351-375.

.

1

: ·



Pocket has: 3 plates

!



