Ken Pierce

Geomorphology and Quaternary Geology of the Owensboro Quadrangle Indiana and Kentucky

GEOLOGICAL SURVEY PROFESSIONAL PAPER 488

Geomorphology and Quaternary Geology of the Owensboro Quadrangle Indiana and Kentucky

By LOUIS L. RAY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 488

A study of an unglaciated area along the Ohio valley through which drained melt water and outwash from the continental glaciers

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

Library of Congress catalog-card No. GS No. 65-249

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

	Page
Abstract	1
Introduction	2
Purpose of study	4
Acknowledgments	4
Geographic setting	5
Physiography	5
Climate	13
Vegetation	14
Pre-Quaternary geology	16
Pennsylvanian System	16
Tertiary System	17
Pliocene	17
Luce Gravel	17
Lithology and structure	18
Age	19
Origin	20
Gravel deposits elsewhere along the Ohio valley	20
Geomorphic history	21
Post-Pennsylvanian—pre-Quaternary interval	21
General description of the region	21
Deep channel of the Ohio valley	22
Configuration	22
Age	24
Quaternary geology	24
Lowland deposits	24
Genesis of deposits in the bedrock valley	25
Pre-Wisconsin deposits	29
Wisconsin deposits	30
Quaternary geology—Continued	
Wisconsin deposits—Continued	
Pre-Tazewell deposits	30
Beds at Hubert Court	30
Flora and fauna and their climatic implications	32
Valley-train and related deposits of Tazewell age	34
Theory of valley-train origin	34
Tazewell valley train	35
Sand dunes	38
General features	38
Physical properties	40
Lacustrine deposits	41
Physical properties	44
Fauna and its environmental implications	45
Valley train and terrace of Cary age	46
Post-Cary alluvial history	49
Flood plain of the Ohio River	50
Hill-land deposits	54
Origin	56
Loess units	57
Nebraskan loess	59
Kansan loess	59
Loveland Loess	60
Farmdale Loess	62
Peorian Loess	63
Mechanical composition of loess deposits	65
Mineralogical composition of loess deposits	67
References cited	69

ILLUSTRATIONS

		Page
PLATE 1.	Geologic map of the Owensboro quadrangle	In pocket
FIGURE 1.	Index map	3
2–5.	Aerial photographs of—	
	2. Point bar opposite Owensboro, Ky	6
	3. Low (Cary) terrace	9
	4. High (Tazewell) terrace	11
	5. Sheet erosion	12
6.	Graphs of highest, mean, and lowest temperatures recorded at Evansville, Ind	14
7.	Graphs of precipitation at Evansville, Ind	15
8.	Section at Hubert Court	31
9.	Calcareous nodules from lacustrine deposits	45
10.	Crossbedded sandy conglomerate	49
11.	Laminated silty clay near Stanley, Ky	49
12.	Flooded areas of Owensboro quadrangle	52
13.	"Stone packings," or "rosettes"	54
14.	Aerial photograph of 1937 flood near Rockport, Ind	55
15.	Outcrop of loess in Bon Harbor Hills, Ky	56
16.	Calcareous nodule from Peorian Loess	65

TABLES

	Page
TABLE 1. Pollen from wood-bearing strata of beds at Hubert Court	33
2. Mechanical analyses of dune sand and an intercalated lens of loess	40
3. Mineralogical analyses of dune sand and an intercalated lens of loess	42
4. Mechanical analysis of typical lacustrine clayey silt of Tazewell age	44
5. Fauna of Wisconsin (Tazewell) age from the Owensboro quadrangle and adjacent areas	46
6. Mechanical analyses of loess, Owensboro quadrangle	67
7. Mechanical analyses of bedrock and loess deposits at section 1	67
8. Mineralogical analyses of loess, Owensboro quadrangle	68

GEOMORPHOLOGY AND QUATERNARY GEOLOGY OF THE OWENSBORO QUADRANGLE, INDIANA AND KENTUCKY

By Louis L. Ray

ABSTRACT

The Owensboro quadrangle, astride the broad Ohio valley near the head of the so-called alluviated valley section, lies south of the limits of continental glaciation. Because this section of the valley served as a drainageway for glacial melt water and debris, glaciations controlled the geomorphic history of the area during the Quaternary Period.

The pre-Quaternary geomorphic history has been reconstructed largely from regional studies, as evidence is lacking in the Owensboro quadrangle for determination of events during the long hiatus between deposition of the youngest bedrock of Pennsylvanian age and the development of the oldest landforms and Tertiary deposits still preserved. The so-called Lexington Plain of presumed middle Tertiary age is held to be older than any landforms now preserved in the Owensboro quadrangle. Destruction of this ancient surface by stream erosion during the Pliocene Epoch is interpreted as the causal factor in the development of the present bedrock topography in this area now covered by either a loess mantle or alluvial valley fill.

Successive surfaces of erosion of Pliocene age are represented along the ancient Ohio by a series of high-level gravel deposits resting on bedrock benches above the level of the present river and its tributaries, from the vicinity of Louisville, Ky., to Cairo, Ill. Altitudes of these deposits suggest a sequence of erosion stages that are interpreted to be the result of intermittent, possibly differential regional uplift of Pliocene age.

In the Owensboro quadrangle there is evidence for the last three of these erosional stages. The oldest is represented by a deposit of cherty gravel and sand similar to the Lafayette Formation (of former usage) on a bedrock bench about 400 feet above sea level. The name Luce Gravel is proposed for this gravel and sand which is correlated with similar deposits at increasingly higher altitudes upstream and at lower elevations downstream. The next stage, now buried by Quaternary alluvium, is represented by a bedrock bench at approximately 280–300 feet altitude. It has been recognized by contouring the bedrock surface beneath the alluvial valley fill. The bedrock floor of the valley, some 200 feet below the bench capped by the Luce Gravel and more than 100 feet below the present bed of the river, marks the final stage of stream entrenchment in bedrock, immediately before the lower Ohio valley became a drainageway for melt water and debris from the first continental ice sheet to invade the river basin.

During each invasion of the Ohio drainage basin by continental ice sheets, melt water and debris produced a valley train in the Owensboro area. During each withdrawal of the ice sheets when the Ohio drainage basin was ice free, valley-train deposits were dissected and partly removed by stream degradation. Because aggradation during glaciations exceeded interglacial degradation, alluvium has gradually filled the preglacial bedrock valley in the Owensboro quadrangle to a maximum depth of about 200 feet.

Valley-train deposits of the last glaciation, the Wisconsin, completely obscure all earlier alluvium within the valley. Evidence for the older valley trains of Kansan and Illinoian ages is found, however, in (1) the stratigraphic succession of genetically related loess deposits on hill lands adjacent to the valley and (2) in the direct association of the valley above Louisville, Ky., with glacial till of these glaciations. Only for the earliest glaciation, the Nebraskan, are both loess and glacial deposits unidentified.

The oldest deposits of Wisconsin age observed within the valley of the Ohio River in the Owensboro area consist of a unique stratigraphic succession of three beds of sandy and clayey silts that crop out beneath younger valley-train deposits of Tazewell age. Informally designated the beds at Hubert Court, they represent a sequence of events possibly of regional significance. The lowest bed consists of 6 feet of silty noncalcareous fine sand that is interpreted to be a deposit related to the closing phase of the formation of the earliest valley train of Wisconsin age, the Farmdale. The widespread occurrences of Farmdale Loess along the Ohio valley, resting directly on deeply weathered Loveland Loess of Illinoian age, indicate the presence of such a valley train, the earliest post-Sangamon event that can be determined from the loess stratigraphy.

The middle bed consists of 5 feet of laminated slightly calcareous fine sandy and clayey silt containing a few shells and layers of matted wood. Carbon-14 dating of the wood provides an age of approximately 23,000 years, suggesting that these beds may mark the period between a waning of the ice sheet of Farmdale age and the readvance of a later ice sheet into the Ohio drainage basin, upstream.

The youngest of the beds at Hubert Court, overlain by the coarser valley-train deposits of Tazewell age, consists of 7 feet of organic calcareous silty clay and fine sand that is thickly set near the top with a fresh-water fauna of small gastropods and bivalves. Carbon-14 dating of the deposits of Tazewell age along the Ohio as 18,500± years indicates that the uppermost of the beds at Hubert Court fits into an interval of less than 5,000 years' duration. It is tentatively suggested that the youngest of the beds is the result of the initial phase of alluviation of Tazewell age.

Following deposition of the beds at Hubert Court, the valley was flooded by glaciofluvial outwash from the most extensive ice sheet of Wisconsin age, the Tazewell. During aggradation along the main valley, which resulted in the highest and most widespread valley train, the mouths of small tributary streams were dammed by debris accumulating within the main valley; backwater sediments of clayey silt from the main valley and silts washed from adjacent hills filled the lower ponded

courses of the tributary streams almost to the level of the valley train.

At the time of maximum alluviation of the Ohio valley by the Tazewell valley train, low bedrock divides were buried and the river shifted its course. The course following the ancient bedrock channel south of the Bon Harbor Hills was abandoned in favor of a more direct course across the buried divide between the Bon Harbor Hills and the Rockport island hills. Upstream, the river was able to shift its course from its eastern valley wall to impinge against the bedrock at Rockport. Floodwaters frequently swept across the ancient buried bedrock divide that separated the drainage basins of Little Pigeon and Lake Drain Creeks, producing a diversion channel around the Rockport island hills. These floodwaters, debouching from the Lake Drain into the Little Pigeon valley through the narrow col at the north tip of the Rockport island hills spread unconfined across the broad Little Pigeon valley in a complex braided drainage pattern discernible today on the surface of the deposits of Tazewell age. At the same time, wind deflation carried finer sediments from the surface of the alluvium to the hill lands where they accumulated as a thick mantle of loess. Coarser sediments piled on and along the windward sides of the valley train, lacustrine flats, stream channels, and valley walls produced the sand dunes so widely scattered throughout the Owensboro quadrangle.

Retreat of the Tazewell ice sheet from the drainage basin of the Ohio River initiated a period of stream degradation with consequent dissection of the valley train and of the lacustrine deposits in the lower courses of the tributary valleys. The surface of these eroded remnants of deposits of Tazewell age now forms the extensive high terrace of the Owensboro area.

Resurgence of the continental ice sheet once again into the drainage basin of the Ohio during the succeeding time of Cary glaciation reversed the regimen of the river; degradation was supplanted by aggradation and a valley train again developed. Because of the limited expansion of the Cary ice sheet within the Ohio drainage basin, its valley-train deposits failed to refill the valley to the level of the earlier Tazewell deposits by some 15–20 feet. With the waning of the ice sheet of Cary age the drainage basin of the river above Owensboro became ice free, and the Wabash, a major tributary downstream, carried torrents of melt water from glacial Lake Maumee into the Lower Ohio. Degrading in its upper course and aggrading in its lower, the Wabash poured a mass of debris from its mouth into the valley of the Ohio below the Owensboro quadrangle. Unable to remove this debris, the Ohio was temporarily impounded at least as far upstream as the Owensboro quadrangle. During ponding, fine sands, silts, and clays were spread over the surface of the Cary outwash, producing the youngest deposits within the Owensboro quadrangle that can be correlated with glacial events.

As soon as the effects of the Cary ice sheet culminated on the Wabash, the Ohio River again became a degrading stream in the Owensboro quadrangle. Valley-train deposits of Cary age were dissected, leaving a low, and in places ill-defined, terrace rising only a few feet above the broad flood plain that marks the final episode in the geomorphic history of the river. Although several readvances of the continental ice sheet, such as the Mankato and Valders, occurred in post-Cary time, none appears to have invaded the drainage basin of the upper Ohio to produce effects that can be recognized in the Owensboro quadrangle. In post-Cary time the river has, through limited incision and lateral shifting, produced a broad flood plain marked by extensive point bars, especially well developed north of Owensboro where swell (scroll) and swale topography is prominent. The surface of flood-plain alluviation, as indicated by the high points on the scrolls, natural levees, and alluvial islands in the river indicate that the flood-plain surface is only a few feet below the frequently flooded terrace which was the surface of deposition during the Cary age. The flood plain is restricted to that area across which the river has shifted laterally in post-Cary time.

The loess mantle that blankets the hill lands of the Owensboro area is divisible into a stratigraphic succession of distinct deposits which are, from oldest to youngest: Kansan(?), Loveland, Farmdale, and Peorian. The Peorian Loess is considered to be of Tazewell age. Each loess deposit possesses characteristics by which it can be distinguished, is thickest and coarsest nearest the source areas, and has been subject to weathering of varying degrees of intensity before deposition of the next overlying deposit. In only one locality is the complete stratigraphic succession of possibly four loess deposits exposed although the three youngest crop out in many sections.

Mechanical analyses of the loess indicate wide variations in grain-size distribution resulting from alterations during development of profiles of weathering. The remarkable uniformity in grain-size distribution of the Farmdale Loess is in marked contrast to that of the older loess deposits, whose wide variations are the result of deep weathering and contamination of the basal part through mixing of particles derived from the underlying bedrock formations of sandstone and shale.

Mineralogical analyses of loess samples by X-ray and petrographic methods confirm differences resulting from degree of weathering and differing ages of the deposits. Mechanical and mineralogical analyses verify the sequence of loess units recognized in the field.

INTRODUCTION

The Owensboro 15-minute quadrangle comprises an area of approximately 236 square miles in the States of Indiana and Kentucky, from lat 37°45′ to 38° N. and from long 87° to 87°15′ W. (fig. 1) and includes the Rockport, Richland, Owensboro East, and Owensboro West 7½-minute quadrangles. The mean low-water stage along the north bank of the Ohio River was established as the north boundary of the Commonwealth of Kentucky when it became a State in 1792 (Douglas, 1930). When Indiana attained statehood in 1816, that part of the Owensboro quadrangle in Indiana had been subdivided by a system of coordinates into townships and sections, as directed by Congress on March 26, 1804. All Indiana localities discussed are cited according to this system of land subdivision. Approximately 151 square miles, or 63.5 percent, of the Owensboro quadrangle lies in Indiana. Of the 85 square miles in Kentucky, about 10 percent is covered by water of the Ohio River at normal pool stage.

Owensboro, county seat of Daviess County, is the fourth largest city in Kentucky, with a population of more than 40,000. A rapidly expanding industrial

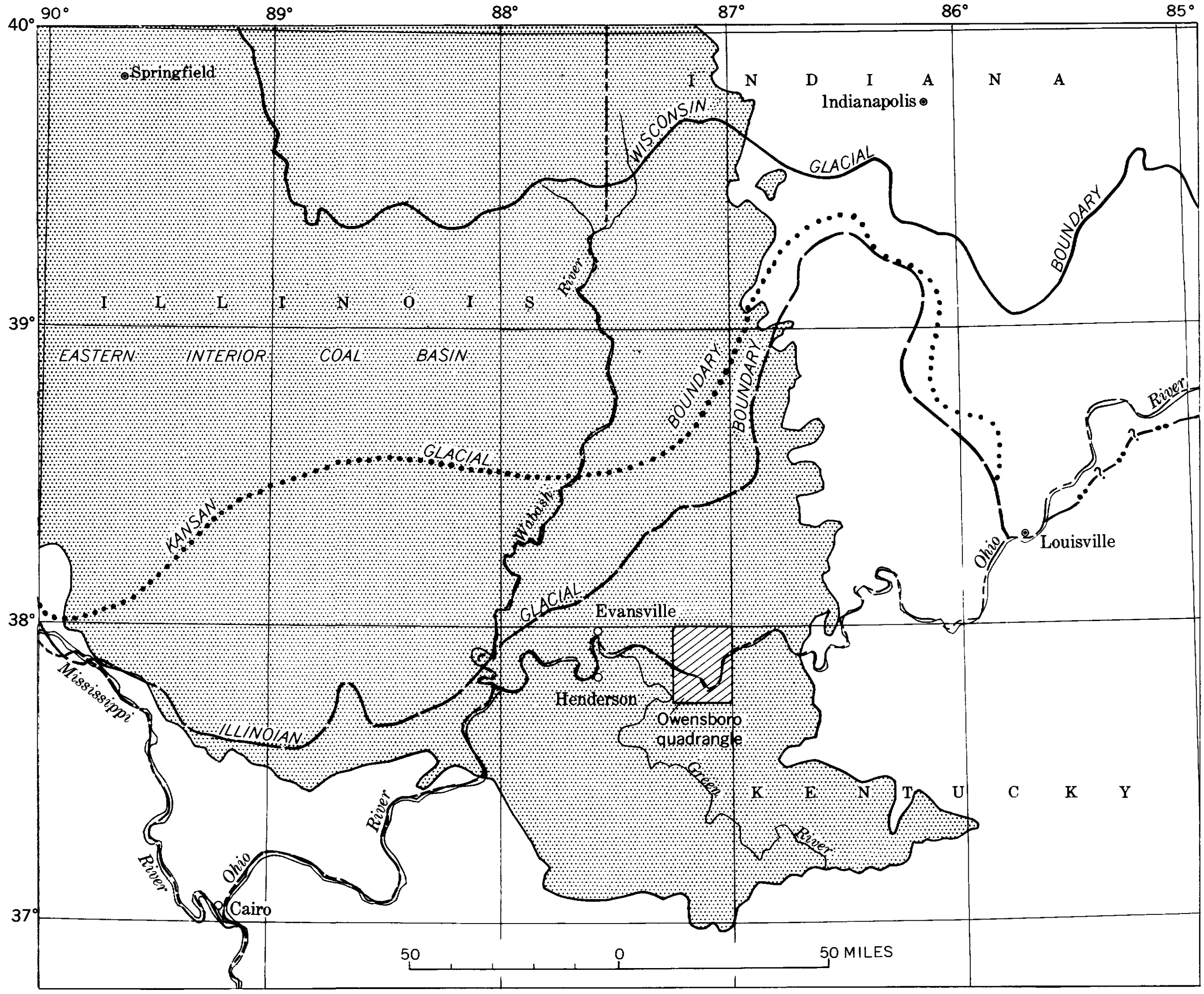

FIGURE 1.—Index map showing location of Owensboro quadrangle (pl. 1) relative to Eastern Interior Coal Basin and to boundaries of Kansan, Illinoian, and Wisconsin ice sheets.

and merchandising center on the left bank of the Ohio River, it is about 80 airline miles southwest of Louisville, Ky., and 30 miles southeast of Evansville, Ind. Rockport, county seat of Spencer County, with a population of almost 2,500, is the southernmost city of Indiana, about 140 airline miles southwest of Indianapolis and 29 miles east and south of Evansville. Except for industrial activities at Owensboro, the area is predominantly agricultural. Eureka, Hatfield, Richland, Sorgho, Stanley, and Thruston are small villages serving local communities.

The Ohio River has been the most important factor in the physical as well as cultural development of the Owensboro quadrangle. Serving first as a pioneer route of immigration, it was, during the 19th century, a major avenue of commerce and communication, as well as a political and cultural barrier, crossed only by ferries at several points from Rockport to Enterprise, Ind. Since 1938, when the Ohio River Bridge at Owensboro was opened to vehicular traffic, all ferries have been abandoned and the bridge is now the only direct means of communication between the Indiana and Kentucky parts of the area. Regulation of the river by dams, the establishment of the 9-foot channel in 1929, and the introduction of modern towboats and barges, has revitalized the volume of river-borne traffic, which had declined rapidly in the late 19th and early 20th centuries (Barton, 1957).

All distances along the Ohio River are given in river miles below Point Bridge, Pittsburgh, Pa., the zero mile established by the Corps of Engineers, U.S. Army.

The unglaciated sector of the Ohio valley between Louisville, Ky., and its confluence with the Wabash, in which the Owensboro quadrangle is located, comprises two distinct sections noted by the earliest travelers descending the river: the constricted valley section, in which the valley walls rise sharply above limited alluvial lowlands, and the broad alluviated valley section, where extensive lowlands are backed by low rounded hills. The Owensboro quadrangle lies just below the head of the broad alluviated valley section. James (1823, p. 39) noted the change at "the little town of Rockport, about 150 miles below the falls or rapids at Louisville * * *."

PURPOSE OF STUDY

The Ohio River valley has had a long and complex history, as yet only partly revealed by geologic investigations. Its history previous to the advent of the continental glaciers is fragmental and controversial. Its later history, intimately related to and correlated with the fluctuations of the Quaternary glaciers, has been deciphered largely by reconnaissance studies made before the many complex and uncertain aspects of the glacial history within the drainage basin of the river were recognized. Parts of the valley were glaciated and thus were directly affected by the continental ice sheets; parts outside the limits of glaciation were affected only indirectly. To understand the Quaternary history of the valley, events in both parts must be correlated and a unified overall picture developed.

In the belief that the history of the Ohio valley might best be understood by an initial detailed study of a small segment, followed later by regional studies, it was decided that the area selected should fulfill a threefold objective: (1) to provide a suitable central area with sufficient well-developed and diversified features to serve as a basis for broader regional interpretations of the development of the valley, as well as for correlation of events and deposits outside the limits of glaciation with the known glacial chronology; (2) to serve as a guide for planning and practical land utilization of the selected area through knowledge of its basic character; and (3) to stimulate interest in, and broaden knowledge of, the local area by providing a detailed picture of its development and the dynamic processes involved. Furthermore, basic data for terrain analysis are included in order to present as complete a picture as possible of the physical character of the present landscape.

The Owensboro quadrangle was selected for initial investigation because of its geographic location with reference to the areas occupied by the continental glaciers, and because of the diversity of its many well-developed types of Quaternary deposits that are intimately related to the glaciations. It was believed that this area would readily fulfill the first objective set forth for this study. Later reconnaissance studies by the writer along the middle and lower Ohio have justified this belief and indicate the regional validity of some correlations and conclusions reached; other conclusions await more extensive and detailed regional studies. It is hoped that this report fulfills the other objectives. In such an area of rapid urban and suburban growth and industrialization along the broad alluvial lowlands, care and judgment must be exercised in planning the use of the land, where hazards, not readily observable, may play a fundamental part in the local pattern of community welfare.

Field investigations consumed about 7 months during the years 1952, 1953, and 1954; the report was completed in 1959. Field studies consisted primarily of examination of the alluvial valley fill and the eolian deposits of the uplands in both natural and artificial exposures and hand-auger samples. Throughout large parts of the area the only exposures are in shallow roadcuts. In places, especially along the slopes marginal to the lowlands, these cuts may be deep, with almost vertical walls; elsewhere, they may be slumped and covered by vegetation. Contacts between the surficial deposits of Quaternary age and the underlying bedrock are rarely exposed.

Physiographic features were mapped with the aid of aerial photographs, at scales of approximately 1:20,000 and 1:40,000 (U.S. Dept. Agriculture, 1950), and 1:32,770 (U.S. Geol. Survey photographs GS-KY, 1950), on the standard topographic quadrangles at scales of 1:24,000.

ACKNOWLEDGMENTS

The writer is grateful to his colleagues of the U.S. Geological Survey who have visited the Owensboro quadrangle and offered suggestions. C. C. Nikiforoff, soils scientist, U.S. Department of Agriculture, spent several days in the Owensboro quadrangle in 1952, and his critical observations, questions, and approach to many problems provided a lasting stimulus. To M. M. Leighton, Chief Emeritus, Illinois Geological Survey, and consultant, U.S. Geological Survey, the writer is indebted for his astute and critical field observations, comments, and suggestions based on his long familiarity with Quaternary problems in the Middle West. Through field and office conferences with Dr. Leighton, local and regional problems have been critically reviewed and analyzed. The writer, however, assumes full responsibility for all statements presented in this report.

Basic data for subsurface contouring of bedrock beneath the alluvial valley fill were largely obtained

through the courtesy of F. E. Moran, petroleum engineer and geologist, Owensboro, Ky., who in 1954 generously made available his extensive collection of well logs. Additional information was supplied through the kindness of Wallace Damron, Damron and Garey, Owensboro, the Indiana Department of Conservation, Division of Oil and Gas, and the Ohio River Bridge Commission, Owensboro, Ky.

Fossil identifications were provided by P. E. Morrison, U.S. National Museum, and by Cornelia C. Cameron, U.S. Geological Survey. Identification of the flora of the beds at Hubert Court was provided by E. S. Barghoorn, Harvard University. Samples were collected and pollen of the beds at Hubert Court were identified by Grace Brush, U.S. Geological Survey. Carbon-14 age determinations of wood were made by Meyer Rubin; mechanical and mineralogical analyses of many samples from the Owensboro quadrangle and adjacent areas have been made by Paul D. Blackmon and Dorothy Carroll, all on the staff of the U.S. Geological Survey.

To these and to many others, especially local inhabitants of the Owensboro quadrangle, the writer expresses his appreciation for their cooperation and for much information that has been incorporated in this report.

GEOGRAPHIC SETTING

PHYSIOGRAPHY

The Owensboro quadrangle is in that part of the western Interior Low Plateau province designated "the Shawnee section" by Fenneman (1938).[1] In Indiana that part of the Shawnee section which includes the Owensboro quadrangle has been referred to by Malott (1922) as the Wabash Lowland; Shaw (1911; 1915a) proposed the name "Alluviated Valley section." These names suggest the two major landforms—the broad alluviated valleys and the dissected uplands of rolling to hilly terrain with gentle slopes and moderate relief.

Maximum relief in the Owensboro quadrangle is about 300 feet, from the normal pool stage of the Ohio River at 347 feet below Dam 46 at Owensboro to the summits of Coal and Fisher Knobs, which rise sharply to altitudes slightly above 640 feet. Only along the river bluffs and in the vicinity of the knobs is relief in short distances sufficient to provide sharply graded slopes.

Drainage is largely through sluggish creeks and sloughs directly to the Ohio River, except in the southwestern part where drainage heads about 1½ miles from the Ohio and flows for more than 30 miles through Katie Meadow Slough and Green River to reach the Ohio. Little Pigeon, the largest creek, rises in the unglaciated hills to the north (Fuller and Ashley, 1902) and empties into the Ohio a few miles beyond the west boundary of the Owensboro quadrangle.

Throughout most of the year all but the largest creeks are either dry or are a series of stagnant pools. Except on steepest slopes in the headwater reaches of a few creeks where bedrock crops out, all creeks flow on compacted clay or silt, rarely on sand or gravel. In places, creek beds are pebbly for short distances below road crossings because of contamination by local river gravel used for road metal. Along the larger drainage ditches or where creeks have been artificially deepened to provide increased runoff, there may be pebbly accumulations of limonite nodules and pipelike concretions derived from the heavy silty clay through which the channels have been cut. Extensive systems of drainage ditches and tiling throughout the lowlands have in places changed the direction of natural flow by cutting across almost imperceptible low divides. Swamps, bogs, and shallow ponds—characteristic features of the lowlands at the time of the first white settlers—have been drained, and the land reclaimed for agricultural use. Springs, except for a few intermittent seeps, are rare.

The winding Ohio River, 0.3–0.7 mile wide, flows for some 23 miles across the Owensboro quadrangle to cover an airline distance of 14.5 miles. Wide-radius bends and long reaches, backed by extensive alluvial lowlands, impart to the river a majesty not obtained upstream where the steep-walled constricted valley is characterized by more closely spaced short-radius bends. In the Owensboro quadrangle, four elongate alluvial islands lie between the main channel and the riverbanks, from which they are separated by shallow sloughs. A fifth, Little Yellow Bank (fig. 2), across from the mouth of Yellow Creek, has in recent years become tied to the right bank by alluviation of the shallow slough. (For comparison with present conditions, see U.S. Geol. Survey topog. quad., Owensboro (Ind.-Ky.), scale 1:62,500, 1901, repr. 1950.)

At Owensboro, the computed average flow of the Ohio is approximately 121,200 cfs (cubic feet per second) from the drainage basin of approximately 97,200 square miles (U.S. Geol. Survey, 1957, p. 522). Variations in flow discharge are great, but less apparent today than before the river was dammed to maintain a 9-foot channel. During low-water periods, when flow discharge and river level are low, the river is

[1] Flint (1928) originally distinguished this section and proposed the name "Shawnee Hill Section." In Illinois it has been termed "Shawnee Hills section" by Leighton, and others (1948).

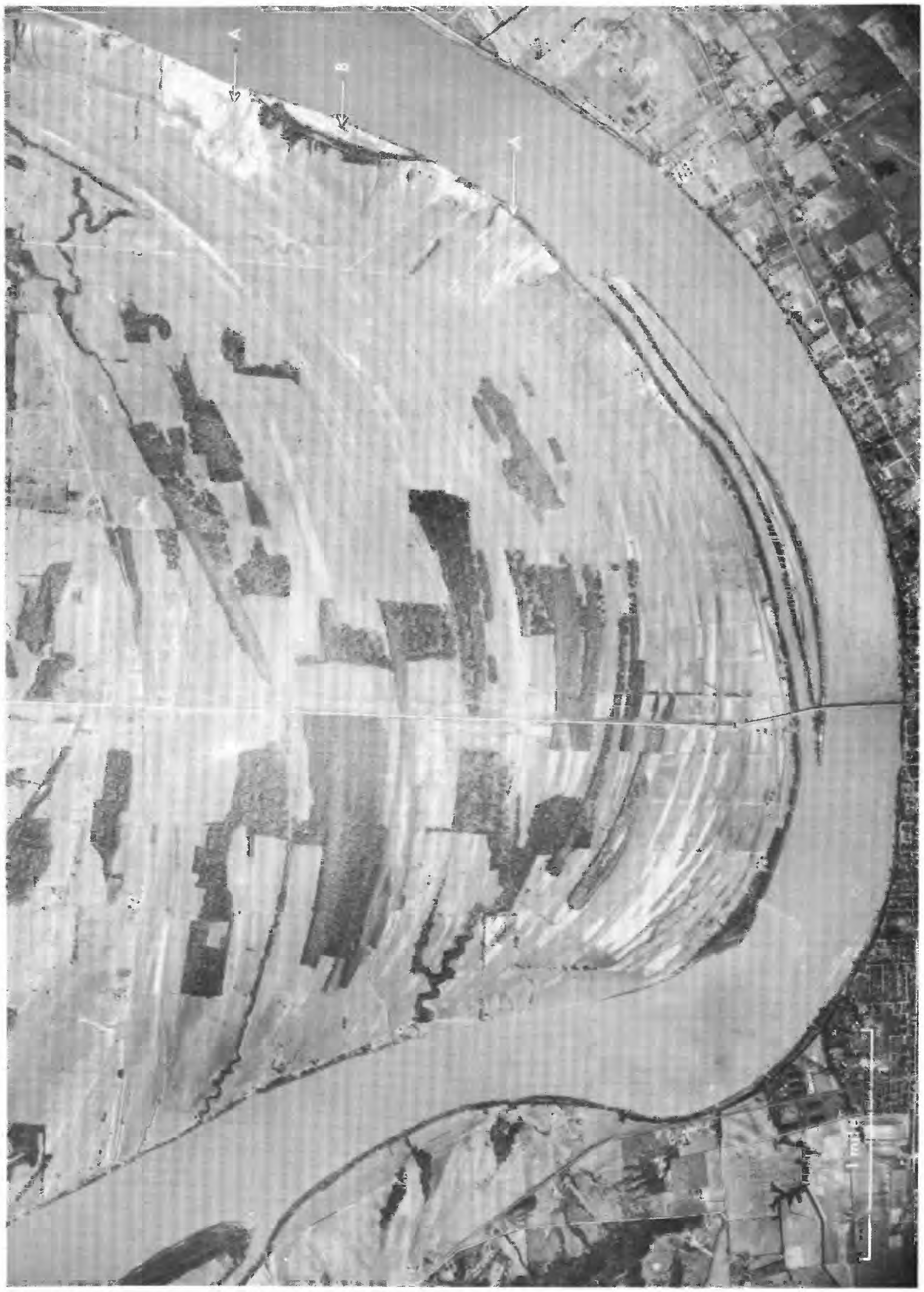

FIGURE 2.—Aerial photograph of point bar opposite Owensboro, Ky., showing well-developed swell (scroll) and swale topography. *A*, floodwater chutes leading away from river channel; *B*, land-tied island. U.S. Geological Survey, GS-KY, Nos. 1-128 and 1-129, Mar. 4, 1950.

regulated to prevent its dropping below a designated pool stage. Before cannelization, however, the mean low-water level at Owensboro is reported to have been about 341 feet, or some 17 feet below the present pool stage above the dam. The minimum river level, not recorded, was somewhat lower, for during low-water periods extensive sand and gravel bars spread from the riverbanks or appeared as islands at channel crossings. Frequently the river could be waded, and normal traffic of shallow-draft river boats was slowed and at times halted. Gould (1889, p. 590) noted that in 1838 or 1839 "there was but 16 inches of water in the channel at Rockport. This was an unusually low water year and all old boatmen on the lower Ohio will remember the difficulty of crossing the bar at Rockport * * *."

During the more spectacular periods of flood, flow discharges are greatly increased and river level rises appreciably, flooding vast areas of lowlands adjacent to the main valley and along the lower courses of tributary valleys. At the time of the greatest of all recorded floods in this area, January 28, 1937, the flow discharge was 1,210,000 cfs, or 10 times the average, and river level rose to a record crest of 394 feet at Owensboro, approximately 53 feet above the mean low-water level (U.S. Geol. Survey, 1957). In 1945, a flood with a calculated frequency of 14 years and a flow discharge of 842,000 cfs, reached a crest of approximately 383 feet (U.S. Geol. Survey, 1957). Similiar crests occurred during the floods of 1884 and 1913. During the floods of 1884, 1913, 1937, and 1945, overflow from the main river channel extended up the valley of Lake Drain, to the north and northwest of Rockport, and into the valley of Little Pigeon Creek, to rejoin the Ohio main stem some 15 miles below Owensboro (Veatch, 1898a), so that the triangular area of hilly uplands on which Rockport is located was completely surrounded by flood waters. Veatch (1898a, p. 269) reported that flood waters at the narrowest part of the channel between the Lake Drain and Little Pigeon valleys were 4 feet deep during the flood of 1884, and that they "flowed with such swiftness along the base of the bluff * * * that a man could not have stood upright in it." Similar reports for the flood of 1945 were given by local residents.

The extensive alluviated lowlands of the Owensboro quadrangle appear to the casual observer to be a monotonous flat of negligible relief. Closer inspection, however, reveals that in a vertical interval of less than 60 feet above the pool stage of the river, the lowlands are separable into three surfaces: (1) the present flood plain of the river and its tributaries, (2) a low terrace, and (3) a high terrace with genetically associated backwater flats at accordant altitudes in reentrants and the lower parts of creek valleys of the hilly uplands. The terraces are of late glacial (Wisconsin) age. The high terrace and lacustrine flats represent the maximum alluviation of the Ohio valley in this area and are of Tazewell age. The younger, low terrace is of Cary age. A similar sequence of terrace levels has been reported along the Ohio a few miles downstream in Henderson County, Ky. (Theis, 1922), and in the lower Wabash valley (Fidlar, 1948). Thornbury (1950) has shown the widespread distribution of the backwater lacustrine flats in the valleys of southern Indiana that are tributary to the Ohio.

The present flood plain of the Ohio in the Owensboro quadrangle is an irregular strip of alluvial lowland marginal to the river. Although it would appear that both its vertical and areal limits would be readily apparent, this is not so, for the problem of defining and delimiting a flood plain is highly complex and controversial. Despite many attempts to define a flood plain precisely and explain its development, no wholly satisfactory criteria have been reached (Wolman and Leopold, 1957). The situation was nicely summarized by Melton (1936, p. 593) when he stated that "Few surficial features are more complex than these elongate masses of alluvium, yet there are few whose immediate origin is more apparent." For purposes of terrain description, the flood plain is arbitrarily delimited and described herein; consideration of problems relative to it and to its origin are discussed under "Flood plain of the Ohio River" (p. 50).

In places the flood plain extends back from the river on both sides; elsewhere, it may occur on one side, the opposite alluvial bank rising to the level of either the low or high terrace. Riverbanks along the flood plain in general rise somewhat steeply, as much as 20 feet or more above pool stage of the river. Normally they are silty and sandy, covered by a tangled mass of vegetation, exposed roots, and drift. Numerous steplike microterraces, 2–14 inches high, interrupt the continuity of the slope. These are largely ephemeral, produced by wave action during lowering of the water level following the annual spring flood (Sundborg, 1956, p. 263). In contrast, where riverbanks are cut into terrace deposits, they are commonly vertical and largely barren of vegetation as a result of undercutting and slumping.

Low sandy ridges along the river margin of the flood plain appear to be low natural levees. These ridges are especially well developed on the right bank across from Owensboro and on the left bank across from Rockport; in both areas ridges are parallel to the inside of the river bend, contrary to the more normal position of natural levees on the outside of the bends. Ridge crests are broad and slopes are low, but steeper on the river side. Away from the river, slopes are so low that they are not readily distinguished except during flooding. In places the ridges are cut by small floodwater chutes leading away from the river. Through these chutes (fig. 2) floodwaters may move with sufficient velocity to scour a channel effectively and build low alluvial fans along the inner margin of the ridge. Foodwaters pouring through these channels follow the shallow swales on the flood plain and return to the main stem of the river downstream.

Upstream from Rockport, especially in the vicinity of the mouth of Honey Creek, a prominent, low, sharp-crested and steep-sided ridge parallel to the riverbank represents a true natural levee, in contrast to the lower broader segmented ridges parallel to the inside of the bends. Although its crest is discontinuous, no evidence of scour was observed at the low points and no alluvial fans have been developed away from the river and onto the narrow flood plain.

Back from the river margin, the flood-plain surface consists of a series of broad shallow swales and low swells, or scrolls (Melton, 1936), oriented more or less parallel to the configuration of the present river. The swells comprise the highest parts of the flood plain and are comparable in height to the highest altitudes of the alluvial islands within the adjacent river channel. In the vicinity of Owensboro (fig. 2), the altitude of Yellow Bank Island, the low ridge parallel to the riverbanks, and the swells of the extensive point bar are slightly above 380 feet. This is the upper limit of the flood plain, for it is the highest point of alluviation during the annual-biennial floods. The major part of the flood plain, however, is at a somewhat lower altitude.

Flood-plain relief between the crests of the swells and the creek bottoms is, in places, as much as 15 feet. Where creeks have been artificially straightened and deepened, relief may be somewhat greater. Relief on the flood plain is greater than that on either of the two terraces that rise above it along low escarpments or, in places, along long gentle slopes. Low escarpments are well developed northeast of Rockport, where State Highway 66 follows the margin of the lower terrace, and along Kentucky State Highway 331 northwest of the Bon Harbor Hills, where the road also follows the edge of the low terrace.

The lower parts of the flood plain are normally flooded at least once a year, and records indicate that it is wholly flooded on an average of every 2 years. During flooding it is commonly assumed that a thin deposit of alluvium is spread over the area. Local residents, however, report that the crests of the swells are neither subject to deposition nor erosion during flooding, but that swales may receive minor increments of alluvium. Thus, relief of the flood plain possibly grows less with each flood. If, on the other hand, the swells are stabilized, it may be an indication that the river is neither aggrading nor degrading, a conclusion suggested by observations of others (Johnson, 1936; Theis, 1922).

Soils on the flood plain are azonal fine sandy silts and silty clays. Sandy silt is characteristic of the swells, the low ridges along the riverbanks, and the alluvial islands. Where uncultivated, it may assume a bricklike hardness when dry, and prove highly resistant to erosion. Normally, however, the soil is well drained and easily cultivated. Surficial soil of the swales is largely sandy silt, grading downward at shallow depth to heavy clayey silt, and in places to plastic organic clay. Because of the higher organic content, soils of the swales may be somewhat darker than those of the swells; the poorer drainage make them less desirable for cultivation than soils of the swells.

Natural sloughs on the flood plain generally have been artifically deepened and straightened to provide maximum drainage. A fetid heavy dark-gray to black plastic clay containing masses of decaying vegetation and shells of water-loving mollusks is commonly exposed along their banks. Iron staining and small limonite concretions and tubules around plant remains may occur at depths of 3–5 feet.

The flood plain is normally considered to be excellent for farming. Where artificial regulation of the river has interfered with natural drainage by raising ground-water level and thereby reducing the rate of drainage in early spring, yield is said to be less than formerly. Dwellings are not situated on the flood plain, although barns are still common on the highest ground.

Some 10 feet above the level of the flood plain is the second bottom or low terrace of Cary age which is subject to less frequent flooding. Its surface is generally flatter and more monotonous than that of the flood plain. Relief of only a few feet is developed by a maze of shallow channels that cut across its surface. In places, these channels are readily apparent; elsewhere, they may be almost obliterated by alluvial fill and by surface wash resulting from cultivation, so that they are apparent only as tone patterns of the ground on aerial photographs (fig. 3). Surface soils are in places sandy, especially along the river where floods, such as that of 1937, deposited surficial sand (Mansfield, 1938). Normally the surface soil is a

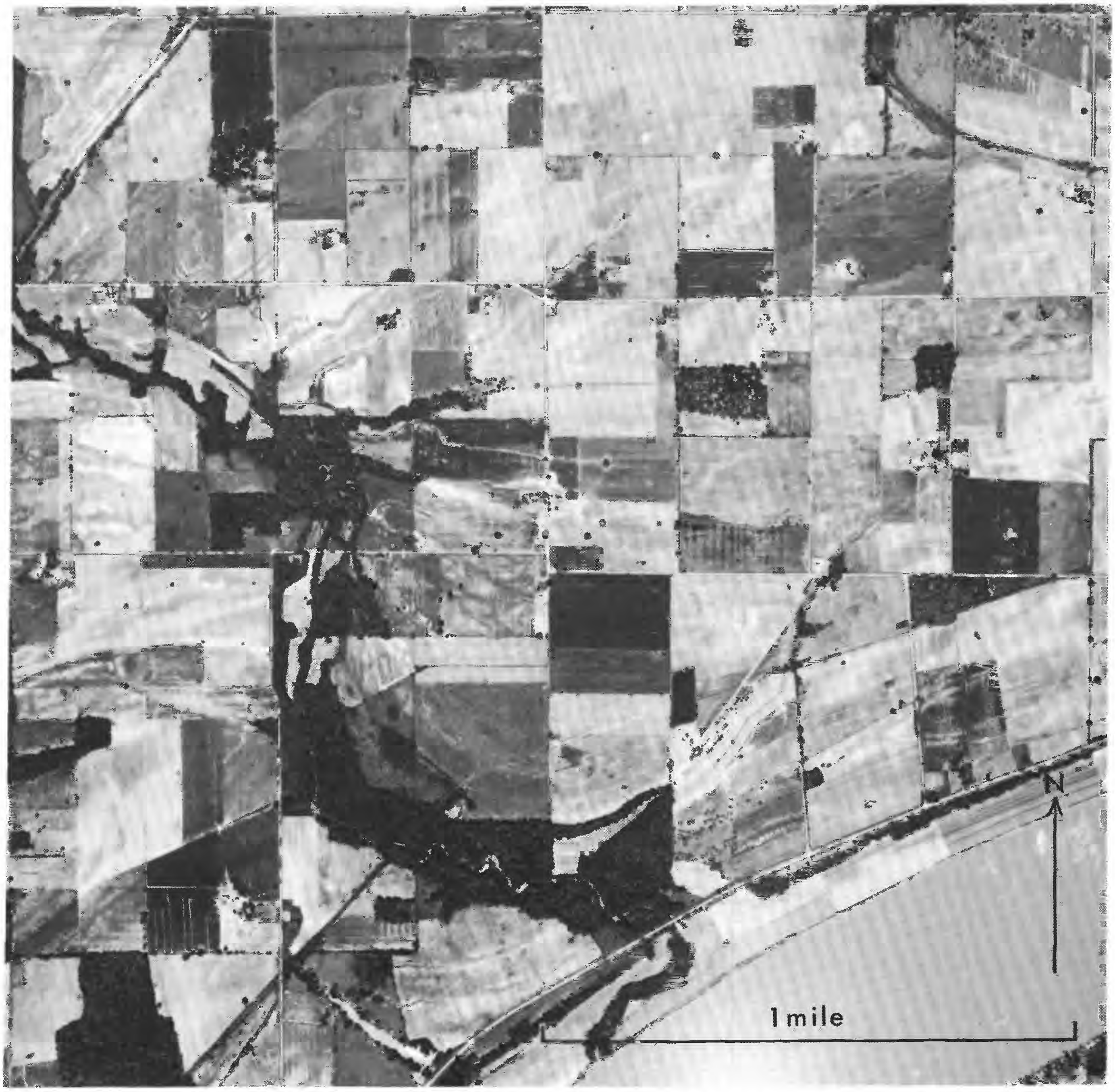

FIGURE 3.—Aerial photograph of low (Cary) terrace surface (secs. 1 and 12, T. 7 S., R. 6 W., and secs. 6 and 7, T. 7 S., R. 5 W.) modified by flood scour and entrenched by Honey Creek. Narrow flood plain adjacent to river, bounded by low terrace escarpment followed by Indiana State Highway 66. U.S. Dept. of Agriculture photograph, PMA, QX-1F-191, May 16, 1950.

light-buff or gray-brown to ashen-gray coarse silt or silty clay with a very weak soil profile. At depth along drainage channels, heavy clayey subsoils with concentrations of limonite concretions indicate former wet, swampy conditions. Along a few creeks, lenses of fine- to medium-coarse sand and pea-sized gravel are exposed under the superficial alluvium. Crumbly gray clayey "crawfish" soils are common in formerly swampy areas, that have been drained during the last century. Such soils occur along Lake Drain. Where soils have been artificially drained, they may be relatively heavy clays, poorly suited to cultivation after the original surficial humus is destroyed.

The low (Cary) terrace is especially extensive and characteristic to the north and west of the Bon Harbor Hills, in the western part of the Little Pigeon valley, and to the north of Rockport. Its gradient is so slight that it cannot be adequately measured. In the Owensboro quadrangle the average altitude of the surface of the low terrace is about 390 feet; however, like that of the flood plain, it rises slightly up the valleys of the tributary streams.

In places, the high (Tazewell) terrace rises sharply above the low terrace along generally well defined scarps as much as 15 feet high. Elsewhere, it may merge with the lower surface through long gentle slopes. Numerous braided channels cut across its surface, especially along the east margin of Little Pigeon valley (fig. 4). Where such channels predominate, the terrace surface may consist of isolated and slightly elevated areas separated by shallow swales 2–3 feet deep and as much as several hundred feet wide. With intense cultivation, the differences in relief may be almost obliterated and, like the swales on the low terrace, the channels may be largely traceable only by means of aerial photographs. A few of these channels have been flooded by backwaters in historic time.

The high (Tazewell) terrace surface is mantled by thick buff coarse silt and sand in which a youthful profile of weathering has been developed. Areas of low stabilized dunes commonly occupy areas between the shallow braided channels and are mantled by loess that is generally not more than 3 feet thick. Along the margins of the terrace, especially along the eastern wall of Little Pigeon valley and in the vicinity of Owensboro, dunes are well developed and their loess mantle may be as much as 10 feet or more thick.

Numerous reentrants into the hilly uplands are characterized by extensive flats at altitudes correlative with the high terrace level. At the time of settlement of the area many of these broad alluviated valley bottoms were poorly drained and supported scattered swampy areas, except along the slightly entrenched creeks where drainage was fair to good. Tiling and the deepening and straightening of creeks have largely obliterated the swamps. Only one small forested tract, locally known as "Black Slash," between the Southern Railway and Indiana State Highway 45 (sec. 23, T. 6 S., R. 6 W.) 2½ miles north of Rock Hill, indicates the original conditions of the valley floor. There a thick stand of timber grows on heavy dark organic silty clay, which is moist or boggy throughout most of the year. Underbrush is sparse, but near the forest margin, where the soil is better drained and sunshine can penetrate, underbrush is dense. Generally the flats are underlain by characteristic silty clays, leached to depths of 4–6 feet. Below the leached zone the clayey silts are calcareous and normally contain myriads of small calcareous nodules. The lacustrine origin and geologic history of these flats is discussed in detail on pages 41–46.

The broad lacustrine flat of Willow Pond covers an area of approximately 2 square miles. Its floor, at an altitude correlative with the high (Tazewell) terrace level in Little Pigeon valley, is separated from the valley by a double set of arcuate loess-covered sand ridges, in places more than 30 feet high. At the time of settlement of the country, Willow Pond Bed was so poorly drained that shallow stagnant water stood over much of the malaria-infested area. Ash, maple, and water oak are reported to have grown in profusion across the water-logged flat, but the trees were small. About 1880, Willow Pond Ditch was dug to drain the waters and open the land to cultivation. Intensive farming following drainage removed much of the humus from the black highly organic surficial soil, producing a light, ash-gray soil. The less intensive the cultivation, the darker the color of the soil.

The heavy dark-gray to black clayey silt surficial soil of Willow Pond Bed grades downward to heavier organic clay that is crumbly when dry and plastic when wet. Scattered shells and vegetable matter occur throughout the clay where exposed along drainage ditches. Along the margins of the flat, the clayey silt grades upslope into the buff-yellow silt of the loess-mantled hills. Where buff-yellow silty slope wash from the adjacent cultivated hills has moved over the gray clay, it can readily be discerned because of the marked color difference. Along the northeast margin of Willow Pond Bed, a low slightly arcuate loess-mantled sand dune, almost half a mile long, is readily observable from the air, but almost indistinguishable on the ground.

Prominent loess-mantled dune ridges associated with the high terrace level of Tazewell age are especially well developed in the southern part of the area. There they extend as single ridges or as a series of parallel ridges, from a few to several tens of feet high, from southwest of Owensboro through the city and to the northeast. The most prominent, reaching at one point a height about 50 feet above the general terrace level, extends as an almost continuous ridge, in places bifurcated, from the south edge of the mapped area at Pleasant Ridge Church, through the city and to the northeast for more than 5 miles along the terrace surface before mounting the bedrock valley wall north of Van Buren Creek, to continue for another 2 miles to the vicinity of Pup Creek. So striking is its topographic development and so apparently related to the configuration of the present river, this dune has been reported and illustrated by Leverett (1929) and Lo-

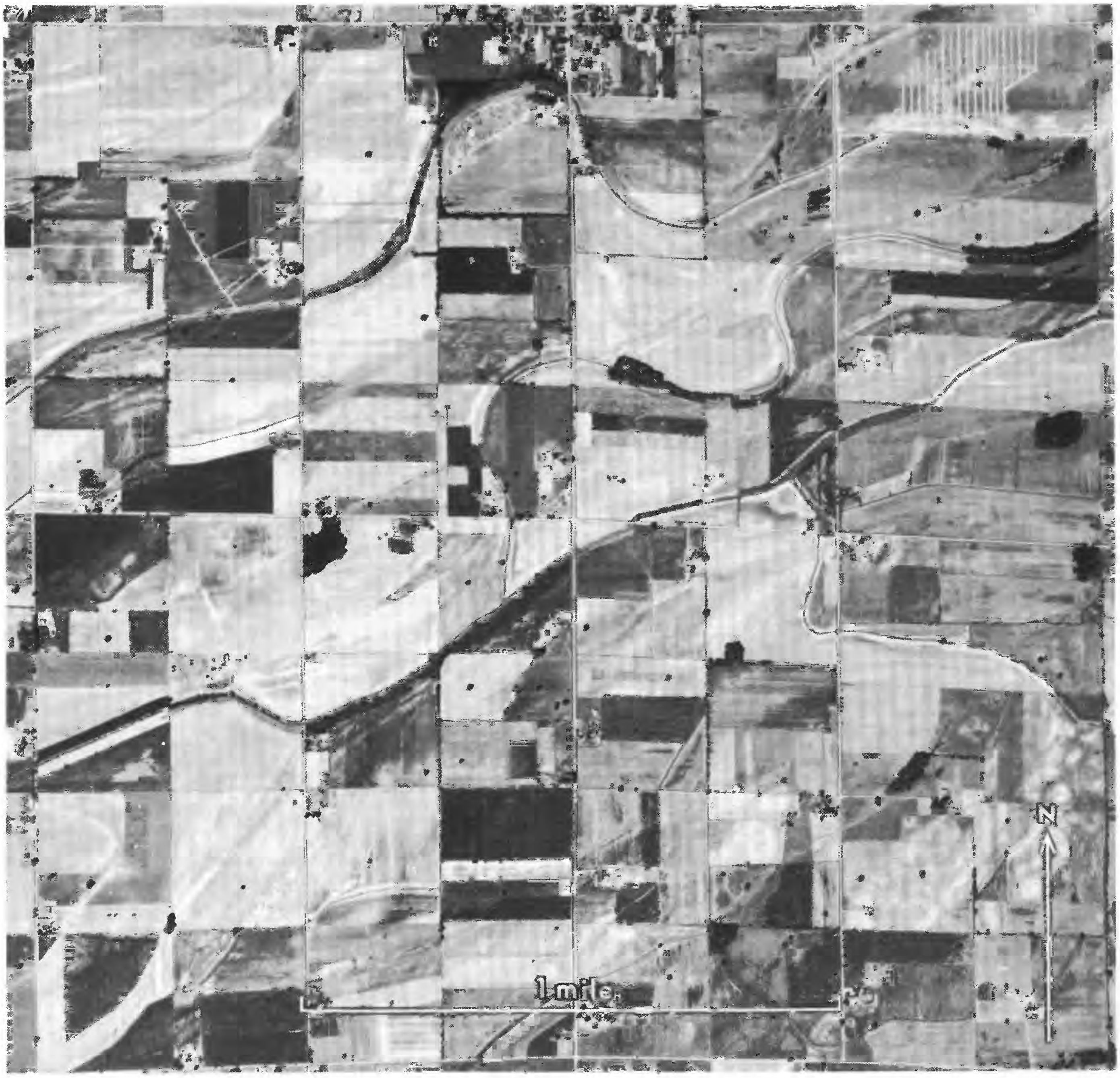

FIGURE 4.—Aerial photograph of secs. 2, 3, 10, and 11, T. 7 S., R. 7 W., showing surface of high (Tazewell) terrace with braided channels. Low sand dunes on terrace surface in lower right corner. U.S. Dept. of Agriculture photograph, PMA, QX-2F-67, May 16, 1950.

beck (1930, 1939) as a natural levee. However, its core of laminated dune sand, steep slopes, both facing and away from the river, its unusual height, its habit of splitting and uniting, and its continuation along the margin of the valley wall, high above river level, indicate its dunal character. Its origin, as well as that of the sand ridges enclosing the Willow Pond Bed and similar ridges elsewhere in the area, is associated closely with the river channel at a time contemporaneous with the development of the high Tazewell terrace, with which all dunes are associated.

In the lowlands, dwellings are located, wherever possible, on the high terrace, away from flood waters; channelways across the terrace surface are avoided as building sites. The relatively level and easily drained soils of the terrace make it one of the most valuable farming areas of the region. Some areas in the channelways, underlain by heavy organic clayey silts, are less desirable agriculturally because of the necessary treatments required for high productivity.

That land lying above the river flood plain and terraces is classed as hill lands, and is separable into two categories: the regional hilly uplands and two island-hills—the Bon Harbor Hills of Kentucky and the Rockport island hills of Indiana, named here for the city of Rockport at their eastern margin. Shaw (1911, p. 489) first proposed the term "island hills" for individual hills or groups of hills surrounded by low-lying deposits of lacustrine origin. The hills on which the town of Island, Ky., is located were suggested as the type. As used here, the term is applicable to any bedrock hill or group of hills surrounded by alluvium and isolated from the adjacent hill lands, and takes priority over the more restricted term, "valley braid core," as defined by Fidlar (1933, p. 140).

The regional hilly uplands near the Ohio valley are covered by a mantle of loess that is thickest adjacent to the broad alluviated valley and progressively thinner away from it.

Before deposition of the loess mantle and thick valley alluvium, the bedrock hills had greater relief, steeper slopes, and a more rugged aspect. Deposition of the mantle of eolian silt and sand has not only produced a more gentle terrain but added striking constructional features. In places along the windward margins of the hilly uplands, where the mantle of dune sand and thick loess has accumulated, it is not always possible to determine whether marginal hills have cores of bedrock or dune sand. Sharp gullies and bedrock outcrops are few, except where soil erosion is actively dissecting formerly cultivated slopes now abandoned or, near the summits of the Knobs, where steep slopes are graved by V-shaped gullies cut in bedrock and separated by equally sharp divides.

Broad alluviated valley bottoms within the hilly uplands have such low gradients that most creeks have been artificially deepened and straightened to provide adequate surface drainage. Normally, deposition of loess on hill slopes and subsequent slope wash have obliterated the sharp distinctions between valley wall and valley bottom. Similarly, the heads of small valleys merge with the gently rounded divides in shallow open theater-shaped depressions in which distinct drainage channels are lost.

Hilltops and ridge crests appear to form more or less accordant levels at 450–500 and near 550 feet; above this level the Knobs rise almost 100 feet higher. To the north, in the adjoining area, Fuller and Ashley (1902) termed the highest hills, comparable to the "Knobs," the "Rugged Uplands" and the hills 100–150 feet below the highest summits, the "Rolling Uplands." Theis (1922), in describing the terrain a few miles to the southwest of the Owensboro quadrangle, recognized a summit peneplain at 550 feet and rock terraces at 500 and 440 feet, each with associated gravel deposits. No gravel deposits were found at these altitudes in the Owensboro quadrangle.

Soils developed through long-continued weathering of the loess mantle of the hilly uplands generally consist of a well-drained noncalcareous grayish-buff silty surficial soil that has a maximum thickness of 8–10 inches. In cultivated areas appreciable amounts of surficial soil have been removed by sheet erosion without gullying. Much of this erosion appears to have taken place during the past half century, as there is no mention of it in the soil survey of the Indiana part of this area (Mangum and Neill, 1905). In places, especially on steeper slopes, the original surficial soil may be entirely removed, exposing the underlying darker orange- to reddish-yellow leached crumbly clayey silt (fig. 5). Such erosion is responsible for the thin layer of gray to buff surficial silt that overlies the dark-gray humic soil zone in the broad creek valleys. This dark humic soil, now at depths as much as 14 inches in valley bottoms, represents the surficial soil at the time the area was first settled and land put under cultivation.

At depths from 1 to 3½ feet the silty loessial soils are normally darker, clay enriched, oxidized, and leached.

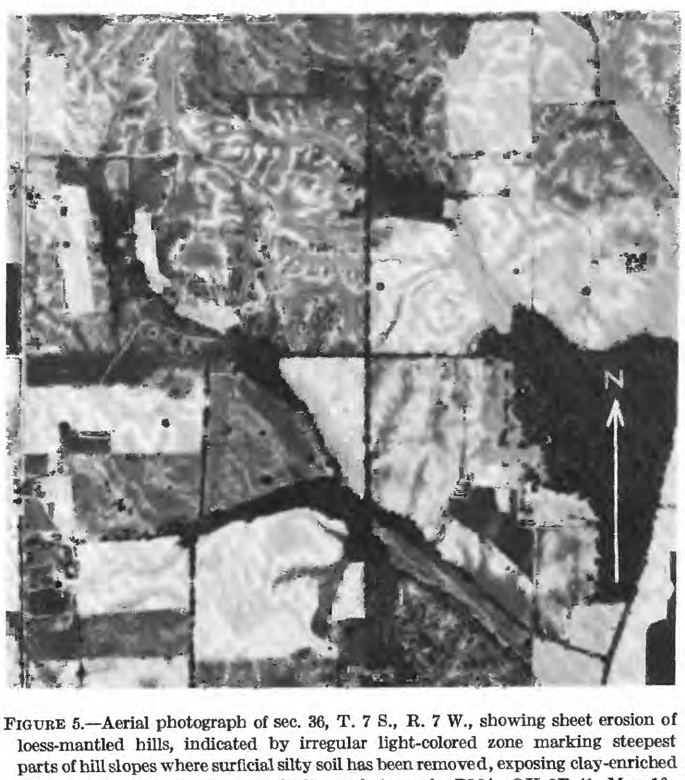

FIGURE 5.—Aerial photograph of sec. 36, T. 7 S., R. 7 W., showing sheet erosion of loess-mantled hills, indicated by irregular light-colored zone marking steepest parts of hill slopes where surficial silty soil has been removed, exposing clay-enriched zone below. U.S. Dept. of Agriculture photograph, PMA, QX-2F-41, May 16, 1950.

Adjacent to the broad alluvial lowlands, where the loess mantle is thickest, the clay-enriched zone grades through a leached and oxidized zone into porous, buff, oxidized, and calcareous loess. Where the loess mantle is thin, it may be oxidized and leached to bedrock. In places, as discussed in sections below (p. 57–63), older, compact, weathered, and noncalcareous loess may intervene between bedrock and the youngest loess mantle, on which the present soil is developed.

Rising to heights of 100–150 feet above the alluvial lowlands, the loess-mantled Rockport and Bon Harbor island hills break the monotony of the broad lowlands. Despite apparent similarities, they have somewhat different topographic aspects. The steeper slopes of the Bon Harbor Hills resemble those of the Knobs, for the steep narrow valleys are V-shaped in their upper reaches, and ridge crests, although rounded, are narrow. Slopes of the Rockport island hills are lower, valleys broader, and the general aspect similar to that of the adjacent uplands. The alluviated valleys, occupied by lazy creeks, are in marked contrast to the shorter steeper valleys of the Bon Harbor Hills. In the southwestern part of the Rockport island hills, where the loess is unusually thick, the topography has a distinctly dunal aspect, in part validated by a few scattered sections of thick dune sand below the surficial loess mantle.

Adjacent to the main river channel, slopes of the island hills are steep in many places, and scattered outcrops of bedrock are exposed where flood scour has removed the loess mantle and colluvium. At Rockport, where the present channel of the Ohio has undercut the hills, sandstone is exposed as a mural escarpment, in places capped by more than 20 feet of loess. Bedrock crops out locally below similar thicknesses of loess along the margin of the Rockport island hills to the south and west as far as the vicinity of Enterprise. Similarly, a few outcrops occur south of Lake Mill, where stream scour has oversteepened the valley wall. Bedrock crops out sporadically at the base of the Bon Harbor Hills from the point where the river impinges on them to the north and west for about 3 miles. There, some of the thickest loess sections are exposed. Along the west margin of the island hills, where protected from flood scour, bedrock is deeply mantled by dune sand and loess.

CLIMATE

In the present rigorous and variable continental climate of the Owensboro area precipitation is normally well distributed through the year. Summers are long, hot, and humid; winters, with relatively mild temperatures but penetrating dampness, are characterized by brief periods of intense cold. Spring is an unusually short season between the lingering cold of winter and the sudden onrush of early summer heat. Autumn seems to be longer because of the continuing summer warmth, punctuated by brief periods of cool, crisp weather. Day-to-day and year-to-year weather is highly variable, for the average temperatures are modified by sudden changes at all seasons—changes that bring periods of severe cold in winter and welcome and commonly short-lived relief from the excessively hot, muggy summer days and nights.

Local climatological data, summarized for Evansville, Ind. (U.S. Weather Bureau, 1954), 20 miles to the west, represent the local conditions throughout the Owensboro region (see also Visher, 1929, 1944). Data indicate long hot summers and mild winters, interrupted by brief periods of severe cold (fig. 6). The mean annual temperature of 56.9° F does not indicate the extreme temperature range from −23° F (February 1951) to 108° F (July 1952). Records for the period 1900–1953 show January to be the coldest month (mean temp 34.7°F) and July the warmest (mean temp 79.1° F).

Although rainfall is normally well distributed through the year (fig. 7), the amount may vary widely from year to year—from an annual maximum of 63.13 inches (1950) to an annual minimum of 25.60 inches (1930). The monthly maximum of 14.78 inches (January 1937) and monthly minimum of 0.01 inch (March 1910) are in startling contrast to the normal monthly rainfall average which is highest (4.29 in.) in March, and lowest (2.82 in.) in October, and to the maximum rainfall of 6.94 inches in 24 hours (October 1910). There are similar marked deviations in the average frost-free growing season of 210 days (Apr. 3 to Oct. 30), for extremes range from 169 to 250 days. Likewise, snowfall ranges widely from year to year with rarely more than a few inches falling at any one period and lasting no more than a few hours or days. No data are available to indicate the duration of frozen soil or depth of frost penetration during periods of subfreezing winter weather when a snow cover is absent. Occasionally, however, surface soil is frozen to depths of several inches for brief periods.

Floating ice pans and shore ice develop along the banks of the Ohio during cold spells in a normal winter, but the river is rarely frozen over (James, 1823). With breakup of river ice following periods of sustained intense cold, destructive "gorges" of ice blocks grind slowly downstream. These gorges, if immobilized by freezing together of the blocks, result in severe flooding upstream. The most spectacular ice gorge along this section of the Ohio occurred in 1917–18 and

768-324 O—65——2

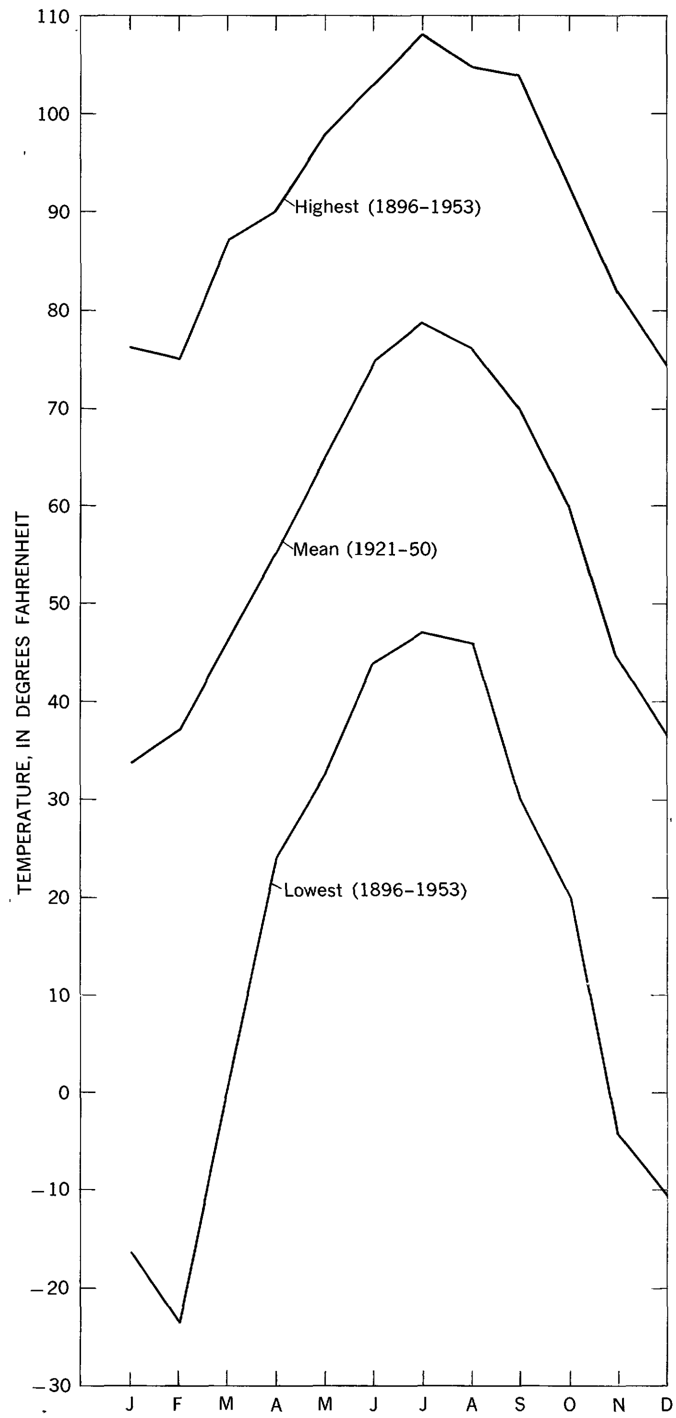

Figure 6.—Graphs showing highest, mean, and lowest temperatures recorded at Evansville, Ind. U.S. Weather Bureau, 1954.

has been described briefly by Albert Brand (in Henry, 1919).

Winds are predominantly from the south, with prevailing southwesterly winds in June and July and northwest winds in February. Occasionally gales or tornadoes are associated with thunderstorms. Winter blizzards of short duration are generally associated with passing cold fronts. During summer months, small convective "dust devils" are common. Where they move across plowed fields in dry weather, dust columns may be carried to heights of more than 100 feet. In aggregate, dust devils and the hot dry summer winds move vast quantities of pulverulent soil—so much so, that there are occasional periods when the atmosphere is sufficiently contaminated to materially reduce visibility and deposit thin layers of dust over the area.

No features that can be ascribed to perennially frozen ground or intense frost activity have been recognized in the Owensboro area, nor evidence found to indicate significant changes in plant assemblages that can be referred to climatic changes resulting from glaciation. It is suggested, therefore, that during periods of glaciation, the weather did not differ radically from the extremes of cold and wetness of today. Summers were probably equable and without the extreme high temperatures of the present. Periods of sustained winter cold were longer than those today, but lowest temperatures possibly were not materially below those recorded today. The warming south and southwest winds modified and turned aside the cold north and northwest winds, especially during summer. Interaction of these opposing air masses produced a higher precipitation at all seasons. During winter, a heavy blanket of snow protected the native vegetation and prevented deep freezing of the ground. Cold glacial melt water, coursing through the Ohio valley, may have cooled somewhat the adjacent areas; but in winter, when stream flow was reduced, rivers were probably frozen over and mantled with snow, thus having little influence on local weather. The weather throughout the year may have been similar to, but wetter than, that of northern Indiana and southern Michigan today. This conclusion is supported by the fact that the living representatives of almost all freshwater fossils occurring in the backwater lacustrine sediments of Tazewell age in the Owensboro area can be found in northern Indiana today (p. 45).

VEGETATION

The early explorers and pioneers, moving westward along the great natural highway provided by the Ohio River, had little interest in the primeval forest—a forest shortly to be swept away by the ax and fire of the homesteader. Only a few, such as J. J. Audubon (quoted by M. R. Audubon, 1897), "foresaw with great concern the alterations that civilization would soon produce along these delightful banks." Today the character of that undisturbed vegetation can be reconstructed only from early descriptions and the few remaining tracts of virgin forest. The many environmental changes produced by human activity, natural events, and plant disease have so altered the total environmental conditions that the modern plant assemblage probably differs appreciably from that extant at the time of the coming of the white man. Second-growth forests of today presumably bear little resemblance to the original forests of a century and a half ago, although their major elements may be the same.

No tract of virgin timber appears to have survived in the Owensboro quadrangle, but a few scattered great trees attest the size that once may have been common. The ardor of the early settler was such that the great forest of broad-leaf hardwoods was thoroughly eradicated. Hill lands were cleared and put under cultivation; lowlands were artificially ditched and tiled for more perfect drainage, with consequent modification of the natural habitats of the original plant communities, remnants of which now survive only along ditches and banks of small streams where the environment may bear some semblance to the natural undisturbed habitat. For example, the extensive cane breaks, recorded in such names as Caney Creek, are gone; only a few isolated struggling clumps of cane remain, as along Garrett Creek (sec. 9, T. 8 S., R. 6 W.). However, early descriptions of the area point out that "Here [a few miles above Owensboro] the cane begins to make its appearance on the banks of the Ohio, and from its ever-green foliage, it has a pleasant effect on the imagination, when all the surrounding vegetable matter is locked up in the winter's frost" (Cramer, 1818).

With the decline in agricultural use of the land and concentration only on that which is most productive, much of the poorer hill land has been allowed to revert to second-growth hardwood forests, predominantly of oak and hickory. Normally, sassafras, black locust, and sumac are pioneers on abandoned land, preceding reestablishment of oak, hickory, and other trees and shrubs.

Two distinct habitats for plants occur in the Owensboro quadrangle—the loess-mantled hill lands and the alluvial lowlands. The hill land forests have been variously classified (Braun, 1950; Deam, 1940; Shantz and Zon, 1924; U.S. Forest Service, 1949). Deam's designation, "Chestnut Oak Upland," is appropriate regionally; but in the Owensboro area, where relief is moderate, slopes gentle, and loessial soils deep, the higher ground is forested predominantly with beech, tulip, and sugar maple and the lower slopes with oak, hickory, elm, and sweet gum.

Vegetation of the alluvial lowlands differs markedly from that of the hill lands, for the Owensboro quadrangle is almost coincident with the northeast limit of a flora that follows the valley lowlands from the lower

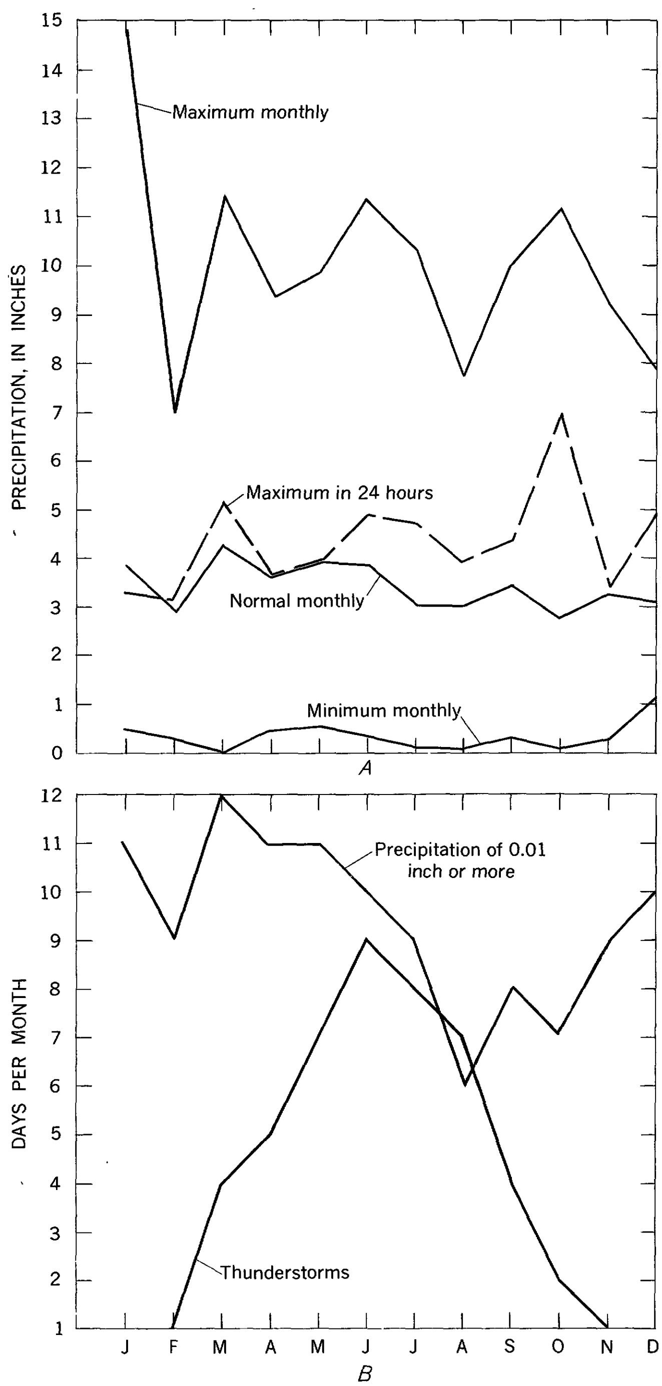

FIGURE 7.—Graphs showing precipitation at Evansville, Ind.: *A*, Maximum, minimum, and normal monthly precipitation, and maximum in 24 hours; *B*, number of days with 0.01 inch or more precipitation and thunderstorms per month. U.S. Weather Bureau, 1954.

Mississippi valley (Deam, 1940). Subtle differences in soil drainage largely account for the different plant assemblages within the lowlands. The riverbanks, lined with willow, cottonwood, and sycamore, are commonly almost impenetrable thickets because of tangled vines and creepers. The marshy and swampy sloughs and swales back from the river support moisture-loving trees, brushy undergrowth, and succulent grasses, sedges, and reeds. Bald cypress (*Taxodium distichum*), once common along Little Pigeon Creek, has disappeared, but it is still present a few miles downstream. The higher better drained soils of the alluvial lowlands, which once supported luxuriant growths of walnut, pecan, sugarberry, sycamore, and poplar, have been almost completely cleared. Johnson grass (*Sorghum halepense*) has recently become a troublesome weed, especially in the lowlands along the river where it chokes out other plants and inhibits cultivation.

The exact nature of the flora of the Owensboro area during periods when the continental ice sheets covered the land only a few miles to the north is not known. It has been held that in the Central States there were extensive migrations of plants to the south, in front of the advancing ice and, conversely, to the north as the ice disappeared. Thus, in the unglaciated areas south of the ice terminus, successive plant communities are presumed to have moved in and out in response to the waxing and waning of the glaciers. However, it is possible that the extent of such migrations and changes in the character of the floral assemblages have been exaggerated for areas along the southern limit of the continental glaciers in southwestern Indiana. The many problems and divergent opinions regarding plant distribution and migration, as effected by continental glaciation, have been carefully reviewed by Braun (1955), who points out that in the lower latitudes (38°–40° N.), conditions may have been such that the ranges of tolerance of many plant species were sufficient to permit survival near the glacier margins at the time of maximum ice advance.

Many of the more hardy and adaptable components of the flora in the Owensboro area appear to have remained throughout the periods of glacial advance and recession, so that the present flora may in many respects resemble that of the time when the ice terminus lay only a short distance to the north. This is suggested by the few components identified from an ancient flora in the alluvium of the Owensboro area (p. 32) and by the lack of any indications of a former rigorous periglacial climate. As prevailing winds were from the south and southwest, the climatic effects of the nearby ice masses were seemingly at a minimum (Bryan, 1928). The possibility is suggested that at the southern limit of continental glaciers in Indiana and Illinois, the ice may have been so deeply covered by ablation moraine that the more hardy plants could establish themselves directly on the supraglacial debris for some miles back of the ice terminus and that significant migrations of the total plant assemblage did not occur in areas immediately in front of the ice masses.

Since the disappearance of the glaciers, there have been without doubt migrations of those plants most sensitive to climatic and other environmental changes that are operative at all times. Minor components of the flora may have completely disappeared; others may have been introduced, only to disappear later if conditions became generally unfavorable before the modification of the environment by man. For lists of plants now growing in the Indiana part of the Owensboro quadrangle, reference can be made to the detailed report of Deam (1940).

PRE-QUATERNARY GEOLOGY

PENNSYLVANIAN SYSTEM

The Owensboro quadrangle lies near the southeastern margin of the broad shallow structural Eastern Interior Coal Basin[2] which comprises large parts of western Kentucky, southwest Indiana, and Illinois (fig. 1). Outcrops of bedrock of Pennsylvanian age are relatively few and inconspicuous because of the thick mantle of loess on the hill lands and the deep alluvial fill in the lowlands. At Rockport, however, a mural escarpment reveals massive coarse- to medium-grained friable crossbedded unfossiliferous[3] ferruginous sandstone. Elsewhere, bedrock consists of friable sandstone, shale, some coal, and thin limestone.

Early studies by Owen (1838, 1839) and by Mather (1839) roughly outlined the Eastern Interior Coal Basin and indicated that the strata in the Owensboro area dipped gently to the west at an angle so slight that it could be determined only through regional studies. Dips in general range from 15 to 45 feet per mile (Crider, 1913). The general lack of resistance to erosion of the Pennsylvanian strata and their westerly dip were recognized as significant factors in the development of the present landscape. Owen (1856, p. 183) called attention to the relationship of the

[2] Various names, such as Illinois Basin, Illinois Coal Basin, and Illinois-Indiana Coal Basin, have been used to designate the whole structural depression. The part in Kentucky has been called the Western Coal Field.

[3] Remnants of a single cast of *Lepidodendron*, about 4 feet long, locally referred to as a fossil snake, have been observable in the bluff at the south end of the Rockport escarpment for many years (Goodspeed Bros. & Co., 1885).

nonresistant beds stratigraphically above the massive sandstone exposed at Rockport to the broad valley of Little Pigeon Creek to the west, which developed along the belt of outcrop of the beds. Similarly, the marked change in character of the Ohio valley above the Owensboro area, noted as early as 1819 (James, 1823, p. 39–41), was shown to coincide with the change in bedrock character, from the resistant formations of Mississippian age upstream to the relatively nonresistant formations of Pennsylvanian age downstream. The areal extent of the alluviated valley region of low rounded hill lands and broad valleys coincides in general with the extent of the Pennsylvanian strata of the Eastern Interior Coal Basin.

TERTIARY SYSTEM

PLIOCENE

The only deposit in the Owensboro quadrangle assignable to the long interval between the youngest formation of Pennsylvanian age and the oldest deposits of Quaternary age consist of unconsolidated to poorly consolidated sand, gravelly sand, and gravel, the Lafayette Gravel of Veatch (1898a, b). That these clastic sediments mark the only deposits referable to this long interval gives them an importance, both locally and regionally, that is entirely out of proportion to their areal extent.

Throughout the Middle Western States, similar deposits, characterized by a "bronzed" cherty gravel, have been found and correlated with each other and with deposits in Eastern United States, the Gulf Embayment and along the Gulf and Atlantic Coastal Plains as a single unit, the "Lafayette Gravel." Unfortunately, as the widespread deposits are not readily datable, as depositional conditions differed widely from place to place, and as the deposits are scattered through a wide range of altitude, they are not easily fitted into a sequence of tectonic or environmental events.

The history of the recognition of the Lafayette Formation, its widespread acceptance with resultant confusions, and its final repudiation, have been reviewed by Rubey (1952, p. 66–67; see also Wilmarth, 1938, p. 1128–1129). In large part, its age, origin, and correlation are still not known; but studies by Potter (1955) of the gravel in the northern part of the Gulf Embayment have clarified some of the earlier confusions and paved the way for a rational understanding of its age and origin. Some of Potter's conclusions support those reached independently by the writer after examination of the deposits in the Owensboro quadrangle and elsewhere along the Ohio valley: the deposits are of preglacial, probably of Pliocene age, and are the result of "epeirogenic uplift rather than late Tertiary climatic change or eustatism" (Potter, 1955, p. 115).

The deposits in the Owensboro quadrangle fit the redefinition of the Lafayette Gravel by Potter (1955, p. 3):

> Lafayette gravel refers to a distinctive deposit found in the Central Lowland, Interior Low Plateau, Ozark Plateau province and the Mississippi embayment portion of the Coastal Plain province, that consists primarily of insoluble components: chert, sandstone, quartz, and quartzite pebbles, cobbles, and boulders associated with noncalcareous sand, silts, and clays, which in the aggregate are either stained or, less commonly, cemented by the oxides of iron and manganese * * *. In regions underlain by pre-Mesozoic rocks, the Lafayette gravel is commonly restricted either to the higher terraces of the more prominent streams, to abandoned channels of previous stream cycles, or to isolated exposures, which in the Central Lowland province, occupy positions on some of the highest and oldest erosion surfaces.

It is necessary to evaluate briefly the problem of the high-level gravel deposits in order to explain the physical character of the Owensboro quadrangle at the opening of the Quaternary period and to indicate some of the complexities related to the geomorphic history of the Ohio valley. With detailed regional studies, the high-level gravel deposits at widely differing elevations will eventually be grouped into a sequence of levels shown to represent Pliocene erosional stages in the development of the present landscape.

LUCE GRAVEL

Sand and gravel tentatively referred to the "Lafayette division of the Neocene" by Veatch (1898a, p. 270; 1898b, p. 264–265) crop out sporadically in the Owensboro quadrangle along the Ohio valley wall from a point about half a mile east of Enterprise, Ind., to a point about 3 miles to the west (Veatch 1898a, b; Fuller and Clapp, 1904, p. 6; Leverett and Taylor, 1915, p. 67–68; Fowke, 1933, p. 183–184; Thornbury, 1937, p. 90–94). Thin deposits of a distinctive sand and gravel lie directly on bedrock of Pennsylvanian age at altitudes near 390 feet; their upper surfaces are erosional and mantled with loess of Quaternary age. Good exposures occur where section-line roads cut through the valley wall and at small gravel pits along the valley wall. To these deposits near Enterprise, Luce Township, Ind., the name Luce Gravel is here given.

The areal extent of the Luce Gravel is poorly known and tentatively suggested by data from domestic water wells located back from the valley wall. These data indicate that the sand and gravel extend under the loess mantle for at least a mile north of the valley wall. According to local inhabitants, domestic wells tap water in "sandstone" and in an underlying "river gravel" encountered at shallow depths—that is, at altitudes between 390 and 400 feet—that are comparable to the altitude of the sand and gravel outcrops along the valley wall. Furthermore, in the eastern part of sec. 5, T. 8 S., R. 7 W., ravines cutting headward into the hills intersect for several hundred feet, at their lower ends, the sand and gravel, and the underlying bedrock, giving further indication that the deposits extend back from the valley wall an unknown distance. The upper ends of the ravines are cut only into the loess above the sand and gravel. This leads to the conclusion that the clastic deposits lie on a bedrock bench at an altitude near 390 feet and that this rock bench with gravel and sand cap represents an erosional surface related to the geomorphic development of the adjacent Ohio valley.

A somewhat restricted areal extent for this gravel is superficially indicated, on the other hand, by the fact that neither Jackson Creek nor Clear Creek transports gravel and neither appears to cut into the Luce or the underlying bedrock. Furthermore, the lack of gravel exposures around the base of the hills to the west and north was first noted by Veatch (1898a, p. 271), who intimated that the gravel had no areal extent away from the main valley wall and concluded that this was the result of the Little Pigeon valley having been cut after that of the Ohio. Another explanation more in keeping with the local data and geomorphic history seems to be warranted, for, following deposition of the Luce Gravel, the main Ohio valley was cut almost 200 feet deeper, leaving as an erosional remnant the sand-and-gravel-capped bench near Enterprise. Thus, it is possible that all the uplands south of Clear Creek and west of and including most of the Jackson Creek basin conceal an eroded bedrock bench at an altitude near 390 feet, on which there are eroded remnants of the Luce. Hills in this area, some of which are more than 490 feet high, are postulated to be composed entirely of unconsolidated Quaternary sand and silt overlying the Luce Gravel and to lack bedrock cores. The only direct field evidence for this belief occurs along the valley wall in the western part of sec. 5, T. 8 S., R. 7 W., where deposits of dune sand are exposed.

LITHOLOGY AND STRUCTURE

The Luce Gravel in part consists of noncalcareous and oxidized, medium to coarse, compact to poorly consolidated sand with thin clayey layers and some scattered gravel; intercalated lenses and stringers of gravel form transitional zones between the compact sand and gravel layers. Color of the sand ranges from grayish white through pale yellow and brilliant orange to a deep crimson red. In places the crimson red sands are mottled with grayish spots, presumed to indicate deoxidation around points of root penetration. The best and thickest exposures of the sand are in the westernmost part of the pit along the valley wall in sec. 4, T. 8 S., R. 7 W.; elsewhere the sand is thinner and contains more intercalated gravel.

Gravel consists of chert, jasper, vein quartz, hard sandstone, quartzite, and rarely quartz geodes. Normally, all chert particles and to a lesser degree other components, except the vein quartz, have a characteristic brown limonite stain, and are commonly referred to as "bronze cherty gravel." Where limonite-stained gravel has been exposed to surficial weathering for a period of years, the stains may be partly or wholly removed. Such bleached pebbles are generally not common in undisturbed outcrops (Potter, 1955, p. 31–32); but they were noted at the top of the gravel in the roadcut separating secs. 4 and 5, T. 8 S., R. 7 W., and in the zone of a perched water table where the gravel rests directly on a thick stratum of coal in the eastern part of sec. 4, T. 8 S., R. 7 W.

Rarely are the pebbles sharply angular; generally they are subrounded to rounded, with greatest diameter from 0.5 to 1.5 inches, although a few are 4 inches or more in diameter. As noted by Potter (1955, p. 29), the unstained vein quartz and quartzite pebbles are most rounded and similar in character to those in the basal Pennsylvanian conglomerates, suggesting that they are probably not of first-cycle origin (Theis, 1922, p. 99).

Within the gravel mass, iron and manganese oxides may cement horizontal layers of massive hard conglomerates as much as 18–24 inches thick. Cemented layers are well developed in a small abandoned gravel pit along the valley wall on the west side of sec. 2, T. 8 S. R., 7 W.

Most gravel exposures are too restricted or crop out too poorly to show the internal structure of the mass. In the eastern part of the abandoned pit (sec. 3, T. 8 S., R. 7 W.), however, where a vertical face 10–12 feet high has been developed during excavation, well-defined bedding with an imbricate structure is displayed. Bedding, indicating vigorous streamflow, is in part horizontal; in part dips are steeply to the west in the manner of deltaic topset and foreset beds. (See also Potter, 1955, p. 24). The undisturbed structure of the deposits indicates that there has been no slump or compaction due to leaching out of calcareous particles following deposition, thus leading to the conclusion that at the time of deposition the clastics contained only insoluble materials and were derived from residuum resulting from leaching of limestone bedrock and disintegration of conglomeratic sandstone upstream.

AGE

The exact age of the Luce Gravel is controversial. Veatch (1898a, p. 271), as previously noted, reached the conclusion that the deposits were of late Tertiary age and therefore "must belong to the Lafayette division of the Neocene." This age assignment, never generally accepted, led Fuller and Clapp (1904, p. 6) to compare deposits on a hilltop north of Princeton, Ind. (some 40 miles northwest of Enterprise), to which they assigned an Eocene(?) age and tentatively correlated the Irvine Formation of Campbell (1898), with the deposits near Enterprise, and to report that—

> Whether these gravels [that is, the Luce Formation], which certainly look much older than the oldest glacial deposits, are to be regarded as the result of a reworking, in late Tertiary or early Pleistocene time, of older Tertiary sediments, as Mr. Leverett has suggested, or as undisturbed later Tertiary deposits, as Mr. A. C. Veatch has urged, is a question that has not been fully answered.

Leverett and Taylor (1915, p. 67) were no more specific when they referred to the formation at Enterprise as "apparently redeposited from the preglacial gravels outcropping in the bluffs farther up the Ohio." Presumably they referred to the gravel deposits at Tell City, Ind., some 25 miles to the northeast, that are here correlated with those near Enterprise. Thornbury (1937, p. 92), following Leverett, suggested that they "are probably reworked Tertiary gravels," inferring that they might be of Quaternary age. Theis (1922, p. 95), Jillson (1950, p. 57), and later Potter (1955, p. 120–123) concluded, when considering the broader aspects of the problem of overall age of the so-called Lafayette Gravel, that they are Pliocene in age. Rubey (1952, p. 74) concluded for similar deposits in central-west Illinois, that they were "clearly post-Eocene, pre-Pliocene, and possibly late Miocene" on the basis of physiographic relations.

It is not possible to determine stratigraphically—because no fossils occur that are contemporary with the accumulation of the deposits—whether the Luce Gravel belongs to the latest Paleozoic, Mesozoic, Tertiary, or to that part of the Quaternary period antedating the deposition of the overlying loess. It can be suspected, without precise data, that it belongs to the younger part of this interval rather than the older, for obviously the sand and gravel were deposited after the close of the Pennsylvanian period, as they lie on a bench of Pennsylvanian bedrock that is some 250 feet below outcrops of the youngest strata of Pennsylvanian age on the uplands.

That deposition of the sand and gravel did not immediately precede the deposition of the overlying loess is indicated by the unconformable relationship and by the fact that the gravel appears to have been deeply weathered. It is believed, however, that the buried zone of weathering, first noted by Veatch (1898b), was developed on a thin loess and therefore is not related to the weathering previous to the deposition of the loess. On the other hand, Potter's suggestion (1955, p. 31) that the crimson-red staining of the sand and perhaps even the bronze staining of the gravel may have been the result of deep weathering of the sediments before burial appears acceptable.

Veatch (1898a, b) pointed to the lack of glacially derived particles in the formation as an indication of its preglacial origin, yet this negative approach signifies only that the depositing streams carried no glacially derived material and that no outwash from the continental glaciers had invaded the Ohio valley in this area at the time of deposition of the sand and gravel at Enterprise. Thus, the deposits are nonglacial, but not necessarily pre-Quaternary.

Until recently the Luce Gravel could be assigned only to a pre-Illinoian age, for the earliest continental glacier known to have supplied debris to this part of the Ohio valley was that of the Illinoian Glaciation. Recently, however, drift referred to the Kansan Glaciation has been found in the Ohio valley upstream from the deposits at Enterprise (Ray, 1957); therefore the minimum age of the gravel can now be extended to a pre-Kansan time. This still does not exclude a pre-Kansan Quaternary age for the deposits, as there is no established demarcation point in time by which the Tertiary can be precisely separated from the Quaternary in this region.

It has been pointed out that the Luce Gravel is one of a series of sand and gravel deposits on bedrock benches along the Ohio and its major tributaries. Furthermore, the bedrock bench on which the Luce rests is about 250 feet below the bedrock summit of the nearby Coal Knobs and almost 200 feet above the bedrock bottom of the Ohio valley. The Coal Knobs, the highest summits in the Owensboro quadrangle, appear to lie slightly below an old erosion surface of low relief (p. 21), the so-called Lexington-Highland Rim pineplain of Campbell (1898) for which a Miocene age has been suggested (Jillson, 1950). Thus, the Luce Gravel must be post-Miocene and preglacial.

If the Lexington-Highland Rim surface of low relief was completed by the close of middle Tertiary (Miocene) time, and the Pliocene was initiated by uplift which continued intermittently to the close of the Tertiary, it follows that the present topography is of post-Miocene age, and that the bedrock terrace and its gravel cap were developed during the period of subaerial erosion that culminated in the cutting of the deep bedrock channel of the Ohio, presumably before the advance of the earliest continental glacier of Quaternary age. The conclusion is reached, therefore, that the bedrock bench and the Luce Gravel are of Pliocene age and are the youngest deposits exposed in this area belonging to the series of gravel and sand formations capping bedrock benches that are related to the several Pliocene episodes of erosion. Although there is a bedrock bench younger than that capped by the Luce Gravel (p. 23; Theis, 1922, p. 93–94), data are lacking to prove that it had a gravel cap, for the terrace is deeply buried by Quaternary alluvium and is known only through well records and contouring of the bedrock surface beneath the valley fill (pl. 1). Because the bedrock bench near Enterprise possibly represents the fifth of seven postulated episodes of Pliocene erosion, to assign to it and to the associated Luce Gravel a Pliocene, presumably a late Pliocene age, appears to be justified.

ORIGIN

Veatch (1898a, p. 271), following the concepts of McGee (1891), suggested that the deposit near Enterprise was of estuarine origin, laid down in an arm of a great bay extending up the Ohio valley from the Gulf Embayment while the land was temporarily depressed. No indications of such an estuarine invasion or in the postulated subsidences and uplifts suggested by Veatch (1898b, p. 271–272, and fig. 9) have been found. To consider the origin of the Luce Gravel without considering, at the same time, the origin of similar deposits elsewhere in the region is hazardous and is not cogent, for, as has been indicated, the deposit near Enterprise is only one of the series of related deposits whose origin and subsequent history appear to have been virtually the same.

Attention has been called to the fact that the series of bedrock benches and associated gravels along the Ohio, downstream from Louisville, are closely related geographically to the present entrenched drainage and that the deposits are of fluviatile origin (Theis, 1922, p. 99–100; Malott, 1922, p. 133; Leverett, 1929, p. 13; Mayfield, 1934, p. 111–112; Jillson, 1950, p. 55; Potter, 1955) and rest on stream-cut bedrock benches. Axiomatically, the highest and oldest deposits are the most widespread geographically on isolated hilltops; the youngest and lowest are most closely related to present valleys. Deposits of each series progressively decline in altitude downstream. Although epirogenic uplift, climatic fluctuations, and eustatism have been considered possible explanations for development of the bedrock benches and their capping deposits, it is generally believed that simple uplift has been the mechanism by which they have been developed by the rejuvenated streams (Theis, 1922; Rubey, 1952; Potter, 1955). Only Theis, however, has suggested intermittent uplift to explain the several episodes of erosion.

By middle Tertiary time the Ohio valley in the Owensboro area appears to have been an erosional lowland of slight relief across which sluggish streams flowed in broad, shallow valleys. This surface, presumably the so-called Lexington Plain, was mantled by deep residuum, the product of long-continued weathering. Where bedrock consisted of siliceous limestones of Paleozoic age, the surface was deeply blanketed by residual chert and ferruginous clay; similarly, sandstones and conglomerates were deeply weathered. Streams were too sluggish to remove the thick accumulation of surficial insolubles.

With regional uplift at the close of the Miocene, streams were rejuvenated, downcutting initiated, and the residual blanket of insoluble material transported by stream action. Continued intermittent uplift and consequent stream rejuvenation resulted in the production of a series of bedrock benches capped by fluviatile deposits of sand and gravel. Gravel on the lower benches may have been incorporated at one time or another in the higher and older deposits, and may, as has been suggested, represent several cycles of erosion, transportation, and redeposition.

GRAVEL DEPOSITS ELSEWHERE ALONG THE OHIO VALLEY

Scattered deposits of the characteristic bronzed cherty, Lafayette-type gravel, ranging in altitude from 980 to 390 feet, have been examined along the Ohio valley from the vicinity of Louisville, Ky., to the mouth of the Wabash. Each consists of insoluble clastic material resting on bedrock. At many localities the gravel is cemented by iron and manganese oxides to form horizontal plates or layers of conglomerate.

Most outcrops are poorly exposed and slumped. Only where recent roadcuts have provided good exposures is a compact imbricate structure revealed, suggesting fluviatile deposition. Bedding is either horizontal or dips generally parallel to the flow of the present Ohio River. At no outcrop where a fresh surface is exposed were there indications that the deposits had slumped from higher positions or had been "reworked" in any sense other than by normal stream action. This does not mean, however, that some gravel may not have been in deposits at a higher altitude that were eroded by stream action and the gravel later redeposited downstream at a lower altitude. The deposits examined can be grouped into a distinct series on well-defined bedrock benches that slope gently to the west at gradients seemingly a little greater than the gradient of the present Ohio River.

Gravel deposits at a distance from the Ohio appear to be associated with the more important tributary valleys in which bedrock benches indicate an erosional history presumably correlative with that of the main stream. This association of the gravel with erosional levels on a regional basis is not a new concept and was considered by Theis (1922, p. 95) for the deposits in the Henderson, Ky., area. His conclusions for that area, based on recognition of a series of bedrock benches and on a regional concept of the geomorphic history were "that since the cutting of the 560-foot level the drainage has cut down in an intermittent manner to an elevation of about 500, 440, 390, and 300 feet above the sea. The levels from 560 to 390 feet, inclusive, are capped by places by the 'Lafayette' gravels." Jillson (1950), Rubey (1952), Potter (1955), and others reached the conclusion that the deposits were the result of Tertiary uplift of an erosional surface of low relief with consequent stream rejuvenation. Neither Rubey nor Potter, however, discussed the possibility that uplift may have occurred as a series of minor episodes of uplift and stream rejuvenation. Jillson (1950, p. 57) suggested that his studies along the Kentucky River indicated that "several stages of entrenchment are represented."

The deposits, here considered to be part of the Luce Gravel, are held to comprise a distinct formation of Pliocene age, related to a single stage in the entrenchment of the Ohio valley. The Luce Gravel dips downstream at an angle seemingly greater than that of the alluvial valley fill, and may not be exposed along the Ohio near its mouth where the gravel deposits represent older stages in the series of Pliocene events.

Similar gravel-capped rock benches at Tell City, Ind., some 25 miles to the northeast (Leverett, 1929, p. 13; Fowke, 1933, p. 178–179), and near Baskett, Ky., some 17 miles to the west (Theis, 1922, p. 53–54), are correlated with the Luce and indicate that it may have been widespread along the Ohio valley and that other remnants may be recognized elsewhere.

During incision of the bedrock valley of the Ohio to its lowest point, bedrock benches, like those at Enterprise, Tell City, and Baskett, must have been dissected and in large part destroyed. Later Quaternary alluviation of the main and tributary valleys to a maximum altitude of approximately 400 feet in the Enterprise area and the deposition of the associated loess concealed the dissected gravel-capped rock terraces. In the vicinity of Enterprise along the Ohio valley wall, the wall has been undercut by later river action, so that the older buried sand and gravel deposits are exposed.

GEOMORPHIC HISTORY

POST-PENNSYLVANIAN—PRE-QUATERNARY INTERVAL

GENERAL DESCRIPTION OF THE REGION

Throughout the Interior Low Plateaus province there is a singular lack of definitive evidence by which a sequence of events can be established for the interval between the deposition of the youngest formation of Pennsylvanian age and the deposition of materials correlative with the continental glaciers of Quaternary age. Insofar as known, this interval, estimated to be about 184 million years (Marble, 1950), was predominantly one of subaerial erosion—a time when the gross features of the present landscape were developed. Tangible clues for unraveling the geologic history consist primarily of relict landforms and widely scattered deposits of unconsolidated to poorly consolidated clastic sediments, such as the Luce Gravel.

Brief summary reviews of the regional history and sequence of events have been presented by Malott (1922) for Indiana, by McFarlan (1943) for Kentucky, and by Horberg (1950) for Illinois. Studies by Jillson (1950), Potter (1955), Wayne (1952), and others indicate the present state of knowledge of the geomorphic development of the Owensboro region.

Although it has been assumed that the Interior Low Plateaus province has been continuously subject to subaerial erosion since late Paleozoic time, there is no direct evidence by which Mesozoic events can be determined. No deposits or residual landforms are recognizable in the Owensboro quadrangle that can be assigned to this long interval (125 million years, Marble, 1950). On the basis of present knowledge it can be assumed only that the Owensboro region was probably subject to almost continuous subaerial erosion from the withdrawal of the Pennsylvanian seas to the close of the Mesozoic Era, and that the opening of the Cenozoic Era was marked by regional elevation of the resultant low-lying plain of slight relief. By the close of the Tertiary Period, some 59 million years later (Marble, 1950), the present gross landscape appears to have been largely outlined.

The oldest landforms of the Interior Low Plateaus province consist of upland flats, ridge crests, and hilltops that rise to roughly accordant summit levels. These have been interpreted as relicts of an ancient erosion surface to which Campbell (1898) gave the name "Lexington Plain." Where stream dissection has been especially active, there may be little indication of the former plain except a somewhat general accordance of scattered hilltops and cuestas. Malott (1922) correlated the Lexington Plain with the highlands (alt 900–1,000 ft) of southern Indiana, to the east of the Owensboro quadrangle. To the west, where the relatively incompetent sandstone and shale of Pennsylvanian age crop out, remnants of the Lexington Plain appear to have been removed by subsequent erosion or are too modified and poorly preserved for recognition. It has been suggested that farther west, in southern Illinois, the Lexington Plain may possibly be correlative with relicts of an old surface at an altitude of 700–800 feet on the Shawnee Hills (Fenneman, 1938; Leighton and Willman, 1949; Horberg, 1950). Gravel-capped hills in southwestern Indiana at altitudes of 600–650 feet have been provisionally considered remnants of the Lexington Plain (Fuller and Ashley, 1902; Fuller and Clapp, 1904), but present interpretations suggest that they are are younger and lie below the projected older surface. Likewise, the Coal and Fisher Knobs, highest points of the Owensboro quadrangle, with summits at 640 feet, are interpreted as lying below the Lexington Plain and to be remnants of a later stage of erosion.

The age of the Lexington Plain, tentatively assigned to the early Tertiary by Campbell (1898), has not been definitely determined but is assigned provisionally to the middle Tertiary (Miocene). This view has been supported by Flint (1941), who suggested that an erosional surface in the Ozark Plateau, believed correlative with the Lexington Plain, bevels the Wilcox Formation of Eocene age, and is probably of middle Tertiary age. Jillson (1950) has been more specific and assigned a late Miocene age to the Lexington Plain.

With completion of the Lexington Plain, most of the midcontinent east of the present Mississippi may have been a lowland of slight relief, in part sloping gently toward the Gulf Embayment to the southwest and in part to the present Great Lakes region to the north. Rivers, meandering through broad alluviated valleys, drained low hill lands. Where bedrock was siliceous limestone, thick deposits of residual chert and ferruginous clay developed on the low hills.

Factors causing dissection of the Lexington Plain and deposition of the present high-level gravel deposits have been the subject of much speculation. The terrain now consists of a series of widespread dissected gravel-capped erosional remnants and, near the major stream valleys, gravel-mantled bedrock benches. Change in climatic regimen, eustatic fluctuations of sea level, and differentially spreading upwarps have been proposed to explain the origin of the gravel. Similar gravel deposits elsewhere have been postulated to be of marine (McGee, 1891) or of glacial origin (Leverett, 1923). Theis (1922), Rubey (1952), and Potter (1955) reached the conclusion, however, that the gravel is fluviatile and was deposited by streams rejuvenated through uplift that terminated the relatively stable conditions under which the Lexington Plain was developed. Uplift, probably started at, or near the close of, the Miocene, possibly as late as early Pliocene time, and continued through the Pliocene Epoch. Presumably it was greatest to the east and least in the area of the Gulf Embayment to the west. Rejuvenated streams, reflecting the intermittent uplift, dissected the elevated Lexington Plain in a series of erosion stages for which the widespread gravel-capped bedrock benches along the major streams now provide tangible evidence.

DEEP CHANNEL OF THE OHIO VALLEY

CONFIGURATION

In the Owensboro quadrangle the bedrock valley of the Ohio has been filled with alluvium to a height slightly above 400 feet. Between that altitude and the pool stage of the river, a vertical interval of about 50 feet, the only bedrock exposed crops out sporadically beneath the alluvium along the riverbanks near the Bon Harbor Hills on the Kentucky side and, on the Indiana side, from the vicinity of Isaac Wright Drain to a point almost 2 miles below Enterprise (pl. 1). Below the level of the river there is no direct indication of the character of the bedrock configuration of the valley, except that which can be obtained through well records. Locally it is common knowledge that the valley wall beneath the alluvium is steep, because water wells, installed in valley fill within a few feet of the bedrock valley wall, penetrate several tens of feet without reaching shelving bedrock. Similarly, many oil wells, drilled in the alluvial lowlands, penetrate thick alluvium before encountering bedrock. This situation, common through the region of the broad alluviated valleys, indicates deep stream incision (Shaw, 1915a). In the Owensboro quadrangle, well logs indicate that the Ohio has cut a bedrock channel in places almost 200 feet below the maximum height of the later valley fill and to a maximum depth of almost 125 feet below the normal bed of the present river (pl. 1).

Elsewhere along the Ohio from Louisville to its mouth, well records indicate a deeply entrenched valley which continues into the Gulf Embayment and is comparable to the deep trenching of the Mississippi-Mahomet-Teays drainageway (Fisk, 1944; Horberg, 1945; Shaw, 1915a; Wayne, 1952), suggesting that this major stream possibly may have had a geomorphic history somewhat comparable to that of the Ohio.

At Louisville the configuration of the deeply buried bedrock channel has been contoured on the basis of

230 mi // 5 mile Owensbor 4 bore [illegible] necessary

records from deep wells, borings, and soundings (Guyton and others, 1944, fig. 3; MacCary, 1955). There, the lowest point mapped in the bedrock channel was 309 feet above sea level. In the Owensboro quadrangle oil-well data as of 1954 show that 3 wells encounter bedrock between 200 and 210 feet above sea level.[4] Theis (1922, p. 110) reported the lowest point in the bedrock channel near the mouth of the Wabash River to be about 200 feet above sea level. Confirmatory evidence of bedrock near 200 feet above sea level near the mouth of the Wabash is indicated by Fidlar (1948, pl. 3). Harvey (1956, p. 76) reports, however, that in the Henderson area "bedrock is at about 240 feet in the deepest places," suggesting that the deepest point in the valley may not have been indicated.

Near the head of the Gulf Embayment, at Ullin in the Cache Valley of Illinois, well data indicate the depth of the entrenched channel of the ancient Ohio to be slightly below 180 feet (Fisk, 1944, pl. 8A), a lowering of the channel by some 130 feet from the Louisville area. Data indicate an average gradient of approximately 4.3 inches per mile for the ancient deep channel, using as distance the present river miles. This figure may be compared with a slightly lower gradient of 3.4 inches per mile for the mean low-water gradient of the present river.[5]

The bedrock surface beneath the alluvial fill of the stream valleys in the Owensboro quadrangle (pl. 1) has been contoured from data largely derived from oil-well logs and bedrock outcrops. Reliability of the contouring is only fair to good, depending on the data available and interpretations and extrapolations of that data. Closely spaced wells, as in the area west of the Bon Harbor Hills, provided detailed information and a basis for checking. Commonly, well logs indicate only unconsolidated materials above bedrock and fail to differentiate between sand and sandstone, or mud, silt, and shale. Where unconsolidated materials and bedrock are not differentiated, interpretations were made between sand and sandstone, and mud and shale, on the basis of the regional relationships and adjacent wells. Where it was felt that data warranted, depth to bedrock was based on depths at which well casings were set or casing size was changed, for in general, drillers in this area report that casings are normally set within a few feet of the top of bedrock or that casing size is reduced when bedrock is encountered. The few wells where such interpretations were made probably fall within the accuracy of the 10-foot contour interval, so that slight deviations in depth do not necessarily change the overall configuration of the contours on the bedrock surface.

The wells are located on plate 1 as accurately as permitted by data available. Where altitudes of well heads were obviously in error, they were adjusted to conform with the base maps. Where data are scanty or lacking, as north and northeast of Owensboro, configuration of bedrock is interpretive.

Despite possible errors in the generalized contouring of bedrock, conclusions can be drawn that are significant to the understanding of the local and regional geomorphic history of the Ohio valley and the character of the preglacial terrain. Contouring of adjacent areas, especially the broad alluviated area to the south, southwest, and west will indicate configuration of the deep valley between the Ohio and Green Rivers (see Panther (Ky.), Reed (Ky.-Ind.), Spottsville (Ky.), and Sutherland (Ky.) topographic quadrangles), an area for which little data are available.

Contours (pl. 1) show that the ancient Ohio flowed in a broad, sinuous, deep, and presumably V-shaped valley, to which oversteepened tributary valleys were seemingly graded. No broad valley bottom is indicated from well logs; therefore it is assumed that the river was primarily engaged in downcutting immediately before alluviation. Narrows, like that east of Rockport, appear to show the influence of competent rock strata.

West and northwest of the Bon Harbor Hills and in the broad valley of Little Pigeon Creek, an extensive bedrock bench is indicated at an altitude between 280 and 300 feet above sea level. This bench, believed to represent a broad valley stage in the erosional history of the area, is about 100 feet lower than the rock bench capped by Luce Gravel (p. 17). The position of the bench suggests that it is probably correlative with a similar rock bench noted by Theis (1922, p. 93–95) in the Henderson area and elsewhere downstream, for he reported that many wells in the Henderson area reached bedrock at altitudes about 300 feet above sea level or about 100 feet above the deepest point in the bedrock valley bottom. This level, Theis believed, marked a definite bedrock bench concealed under the valley alluvium, intermediate between that capped by the Luce Gravel and the valley bottom. As no other erosion level has been recognized in this interval, the three youngest stages of pre-Quaternary

[4] Walker (1954, pl. 2) reports the channel bottom at Owensboro, Ky., to be at 255 feet above sea level. (See also Walker, 1957.)

[5] Average gradients determined for the ancient buried Mahomet-Teays Valley of Ohio, north-central Indiana and Illinois are considerably greater (Stout and others, 1943, p. 53; Horberg, 1945, p. 359; Wayne, 1952, p. 581), as they are calculated for reaches farther removed from the base level to which the Mississippi-Mahomet-Teays drainage was graded, and as the computed distance is presumably from point to point rather than in river miles. Roughly, the average gradient of the deep channel of the Ohio from Louisville to Cairo, based on a point-to-point distance, is approximately 7.8 inches per mile, a figure comparable to the 7 inches per mile obtained by Horberg (1945) for the average gradient of the Mahomet-Teays valley from Chillicothe, Ohio, to Tazewell County, Ill.

erosion recognized with some degree of certainty are (1) that which led to the development of the bedrock bench on which the Luce Gravel rests, (2) that which produced a bedrock bench along the river valley at an altitude about 100 feet lower, and (3) a final period of stream incision that produced the rock channel about 100 feet lower. These three erosion levels in the Owensboro quadrangle correspond to those noted by Theis and appear to have a regional extent that supports their validity.

At the time of formation of the 280- to 300-foot terrace, the main river channel may have been either to the north or south of the Bon Harbor Hills, for present data do not permit its position to be determined. Nor is it possible to assign any gravel to this level, for well records indicate no gravel that can be distinguished from the later alluvial fill which overwhelmed the terrace. It is possible that there may have been a series of stream piracies, broad meanders, and cutoffs, involving the ancient Green River as well as the Ohio, that may have produced a drainage history of great complexity that is not decipherable. It is strongly suspected that the Bon Harbor Hills may represent an ancient meander core similar in origin to but larger than, others along the Ohio and lower Wabash valleys.

AGE

On the basis of information available in the Owensboro quadrangle, it is not possible to assign an exact age to the completed deep channel of the Ohio. It is obviously younger than the Luce Gravel of Pliocene age and older than the alluviation of the valley by glacial outwash of Wisconsin age. Presumably lowering of the bedrock channel ceased with the alluviation of the valley by the oldest valley train of glacial origin, for it is unlikely that later erosion in interglacial time was of sufficient magnitude to remove the valley fill and permit resumption of extensive bedrock trenching in this area. Furthermore, eustatic shifts of sea level during waxing and waning of the ice sheets are not believed to have been of sufficient magnitude or duration to have effected the regimen of the river as far upstream as the Owensboro area. Walker (1954, p. 28) has suggested, however, that during the time of the Iowan ice sheet of Wisconsin age, the river "cut downward and removed most of the glacial outwash deposited in late Illinoian time, until it ran on or close to the deep bedrock channel," and that "the advance of ice and lowering of sea level in the Tazewell substage again set the river to deepening its channel." On the basis of theoretical considerations (p. 34–35), such speculations do not appear to be justified.

The first continental glacier definitely known to have invaded the basin of the Ohio was of Kansan age (Ray, 1957), but no outwash or valley train deposits related to that glaciation or to the following glaciation of Illinoian age have been identified. Deposits of each of these glacial stages probably have been in part removed by interglacial erosion, and the erosional remnants have been buried by the younger outwash deposits. It is also probable that at no time since the valley was occupied by the first valley train has the river been able to trench its bedrock channel in this area.

Since there is as yet no evidence that the oldest ice sheet, the Nebraskan, developed an outwash train in the Ohio valley, the time of channel cutting is concluded to be pre-Kansan and before the invasion of the valley by glacial melt water and debris. Furthermore, since it is not possible to determine the end of the Tertiary and the opening of the Quaternary Period in this region, except through the presence or absence of deposits either directly or indirectly related to glaciation, there is no evidence that the deep channel of the Ohio was completed in pre-Quaternary time. However, all lines of argument point to a preglacial origin, before the advance of the first continental glacier that poured outwash into the valley. It is concluded that, lacking specific data, cessation of downcutting by the Ohio in the Owensboro area ended the Tertiary (Pliocene) Period of river incision that resulted from intermittent uplift, and that the beginning of alluviation of the valley in response to the advance of the continental glaciers marked the opening of the Quaternary Period.

QUATERNARY GEOLOGY

LOWLAND DEPOSITS

The Quaternary deposits of the Owensboro quadrangle are divisible into two major groups—those that lie within the broad bedrock valley of the Ohio and its tributaries, and those that mantle the adjacent hill lands. Deposits of these groups are closely related genetically, for they are either directly or indirectly the products of glaciofluvial alluviation.

Because the Owensboro quadrangle lies beyond the limits of the glacial ice sheet (fig. 1), glaciofluvial material can have been introduced into the area only by the river as outwash originating upstream. The closest source was in the vicinity of Louisville, Ky., where ice sheets of both Kansan and Illinoian age debouched directly into the river valley. The terminus of the later ice sheet of Wisconsin age was more remote. Between Louisville and Owensboro a single tributary from the north, Blue River, briefly carried minor amounts of outwash into the Ohio valley from the glacier of Illinoian age (Thornbury, 1937, 1938). Although Walker (1957) has suggested that Salt River, tributary to the Ohio from the south, some 25 miles below Louisville, carried melt waters during part of the time of ice advance in Illinoian time, no evidence has been found in the lower Salt River valley that would substantiate this suggestion (Ray and others, 1946).

GENESIS OF DEPOSITS IN THE BEDROCK VALLEY

The deep alluvial fill in the lower valleys of the Ohio and Mississippi Rivers and their tributaries has been attributed to many factors. The factors involved are discussed as they appear to have affected the Ohio, especially in the Owensboro area, and some general conclusions are drawn.

Before the advance of the first great ice sheet of the Quaternary Period, the ancient Ohio below Louisville, Ky., flowed in a deep bedrock valley and was a relatively small stream with a drainage basin much smaller than that of the present. Headwaters of this ancient stream have been reported at various points upstream, but, for purposes of this study, it is sufficient to note that the restricted preglacial drainage basin of the Ohio was greatly enlarged as a result of disruption of the extensive preglacial Mahomet-Teays drainage basin and the diversion of much of its headwater drainage into the Ohio.

Where bedrock along the preglacial Ohio valley consists of relatively competent limestones of Mississippian age, the main and tributary valleys are constricted and steep sided; where bedrock consists of relatively incompetent shales and sandstones of Pennsylvanian age, valleys are open and have gently sloping side walls. Transition between these two valley types, just upstream from the Owensboro area, near the margin of the Eastern Interior Coal Basin (fig. 1), is readily apparent even though the valleys have been deeply alluviated.[6] Where valleys are broad and open, alluviation resulted in extensive valley bottoms that are the most distinctive topographic feature along streams of western Kentucky, southwestern Indiana, and Illinois. So impressive are they on topographic maps that Salisbury and Atwood (1908), presumably without field examination, interpreted them to be areas of maturity and old age in the cycle of stream erosion, failing to realize that their configuration was the product of alluviation.

[6] For comparison with the Owensboro area, see Alton (Ky.-Ind.), Leavenworth (Ind.-Ky.), and New Amsterdam (Ky.-Ind.) topographic quadrangles.

Although no data are available to indicate the regimen of the ancient preglacial Ohio, it is reasonable to assume that with a drainage basin smaller than that of the present, its average annual discharge was less. The increasing humidity and decreasing temperatures that produced a climate favorable for glaciation modified these conditions. With the advance of the first sheet and diversion of drainage of large areas of the preglacial Teays sytem into that of the Ohio, conditions were radically changed and the preglacial regimen of the lower course of the river was permanently destroyed. The successive waxing and waning of the ice sheets produced a series of environmental changes, each profoundly affecting the regimen of the river and its tributaries. These changes are reflected in the complex nature of the alluvial fill of the main and tributary valleys and in the genetically related loess deposits of the uplands adjacent to the valleys.

Early workers concluded that the thick alluvial deposits of the valleys could be readily explained by crustal deformation. Ashley (1903), for example, when considering the differences between the constricted valleys in the limestone areas of southern Indiana and the broad alluviated valleys of the Owensboro area, postulated downwarping with consequent alluviation in southwestern Indiana and adjacent regions, and relative uplift to the east. The hinge zone between these areas he placed near the margin of the Eastern Interior Coal Basin, where the Ohio leaves the area of competent formations of Mississippian age and enters the area of less competent formations of Pennsylvanian age (fig. 1). Citing Pigeon Creek (that is, Little Pigeon Creek of the Owensboro area), Ashley says (1903, p. 60).

> Pigeon Creek's broad bottoms are evidently due to the filling of sunken valleys * * * In brief, the area in which Pigeon Creek lies has evidently sunk below drainage level so that all the valleys have filled up until the streams have been raised so that they will run off again.

Shaw (1910), Theis (1922), Fowke (1925), and others rejected as untenable the role of crustal deformation as the sole, or even major, cause of valley alluviation. Although minor crustal disturbances are known to have affected the lower Ohio and Mississippi valley region during the Quaternary Period, they were not of sufficient magnitude to have resulted in the amount of alluviation here discussed.

Shaw (1910, 1915a), on the basis of his studies of alluvial deposits along the lower Ohio and along the Mississippi in southwest Illinois, concluded (1910, p. 153) that alluviation of the major valleys "was glacial and its form was essentially that of a valley train." He suggested that either delta extension or an increase in stream volume might account for the thick alluvial deposits. He could not critically evaluate the first suggestion and rejected it.

The concept of delta extension as the major cause of valley alluviation was, however, later elaborated by Malott (1919, 1922) and by Leverett (1921). Malott explained that through lengthening of the river by seaward growth of the Mississippi delta, as a result of the glacial debris transported to its mouth, aggradation was produced in the lower and middle courses of the main and tributary streams. He pointed out (1919, p. 29) that "If there should be ever so little extension of this delta seaward, there would necessarily be an adjustment of the entire graded portion of the stream to fit the extended stream, since the present load capacity of the stream is delicately adjusted to the grade," and that "the grade must be maintained, and any extension of the stream must result in the synchronous building up of the stream bed as far back upstream as the graded condition prevails." Cautiously, Malott noted (1919, p. 34) that although there has been differential uplift or tilting in the Mississippi valley, its effect was "not out of harmony with the principle of valley filling due to the extension of the Mississippi River by delta building." He suggested (1919, p. 23) that were the entire Mississippi valley area to be "moderately" depressed, the result would be valley cutting rather than filling because "the low grade of the lower Mississippi would be transferred into the interior regions * * *."

The theory of alluviation primarily through delta extension is based on the premise that by the lengthening of a stream, "graded" relative to its slope, there would be an adjustment of the graded slope through deposition, or as stated by Hack (1957, p. 63; also Lobeck, 1939), the channel slope of a stream may be decreased by the lengthening of its course, resulting in adjustment by deposition along the channel. According to Rubey (1952, p. 134), if the only factor affecting the stream is assumed to be channel lengthening, it might well be that the graded slope of the stream profile would be elevated by aggradation through its length "first near the mouth and then progressively upstream until the whole stream had been aggraded by an equal amount throughout * * *." No evidence has been found to indicate that aggradation of this type has taken place, and, as Rubey has shown, it is possible for a stream to adjust its channel cross section so that depression or elevation of the channel profile is not necessarily required for adjustment to an extension of the stream course. He says (1952, p. 134),

> if the slope is overflattened by drowning, by approach to base level, or by the building forward of a delta, the equilibrium between cutting and filling can be maintained most readily by deposition at the edges of the stream so that proportionate depth increases.

The major fallacy in Malott's argument (1919, 1922) for delta extension as the prime cause of alluviation was his failure to recognize and evaluate the vast amount of glacial outwash poured into the stream valleys and the resulting new conditions imposed on the stream regimen. Rubey (1952, p. 134) brought this factor into sharp focus, stating that the profile of a stream is "controlled by duties imposed from upstream, but the elevations at each point are determined by the base level downstream."

If the elevation at each point on a stream profile is determined by the base level downstream, it is obvious, following Rubey, that the process of channel lengthening through delta extension does not necessarily affect the elevation of the stream profile throughout its length, if base level remains constant. It is well known that base level was not constant during the Quaternary Period, but fluctuated in response to changing sea levels. Although there are divergent opinions as to the amount of sea level fluctuation, there is general agreement that sea level was depressed during glacial episodes, when vast quantities of water were locked in the great glaciers. Conversely, melting of the glaciers permitted return of water to the sea with consequent rise in sea level. Such fluctuations resulted in a variable factor affecting the Mississippi River system that was of much greater magnitude than delta extension or crustal deformation. To this a further complication was added in that during periods of glaciation and lowered sea level, the rivers were carrying an excessive load, and delta formation was presumably at a maximum. Similarly, when sea level was elevated during interglacial periods, delta extension was presumably at a minimum.

The cause of fluctuating sea level as the major factor in erosion and deposition along the lower Mississippi has been championed by Russell (1940, 1944) and Fisk (1944), who taking little cognizance of the "duties imposed from upstream," postulated a series of erosional and depositional periods corresponding to depression and elevation of sea level during the Quaternary Period. Glacial stages, when sea level was depressed, have been held by Fisk to be periods of valley erosion, and the time when sea level was rising, in response to deglaciation, has been interpreted to result in aggradation (Fisk, 1944, p. 69–70, fig. 77). If only the single factor of fluctuating sea level had affected the river, elevation or depression of the graded profile might, without a change of stream regimen, have produced the effects postulated by Fisk. However, the intimate association of the main stem of the Ohio-Mississippi system with the waxing and waning glaciers has imposed on the drainage system fluctuating conditions of such magnitude that all other factors are outweighed, and whatever changes may have been attributable to such factors are effectively concealed and not subject to analysis.

The conclusion is reached that the major valley alluviation along the Ohio in the Owensboro area was due mainly to conditions imposed from upstream, and that the effects produced by conditions downstream have been negligible insofar as can be determined. The two conditions imposed from upstream are first, volume of water, and second, amount and character of stream load; or, as Rubey (1952, p. 135) so aptly expressed it, "the graded slope at any point along a stream's course depends upon the volume of water and the amount and kind of load being carried there." Although it is the combination of these imposed conditions that results in the ultimate character of the stream at any point, it is necessary, for purposes of clarity, to consider each separately before attempting to analyze their combined results.

The volume of water passing through the Ohio valley in the Owensboro area depends on (1) area and character of the drainage basin upstream, (2) climatic conditions within the drainage basin, and (3) unusual dynamic events, such as the invasion of the drainage basin by glacial ice sheets.

By enlargement of the Ohio drainage basin, presumably at the time of the advance into the North Central States of the great Nebraskan glacial ice sheet, the volume of water that is gathered into the valley upstream from the Owensboro area has been materially as well as permanently increased. The volume of water was increased further by a general climatic shift from the presumably warmer and somewhat drier climate of the late Tertiary to the more humid and cooler climate of the glaciations and possibly some, if not all, of the interglaciations. Although the amount by which the increased drainage area and precipitation augmented the average annual discharge cannot be determined, it was probably appreciable and permanent. If only these two factors are considered, it would appear that the volume of water passing through the river channel at Owensboro might in all probability have been somewhat similar to that of today. However, the increased volume of water then carried by the river cannot be quantitatively ascertained, as the effects of glaciation cannot be singled out and divorced from the effects of the expanded drainage basin and the increased precipitation.

The third and most significant factor influencing the volume of water carried by the Ohio was the invasion of its drainage basin by glacial ice sheets. Although little is known of the general physical character and dynamic behavior of the great ice sheets in the lower latitudes, it is essential to consider what general effects their melt waters may have had on the volume of runoff from drainage basins which they invaded.

As soon as an ice sheet, moving from higher to lower latitudes, invaded a drainage basin which drained away from the ice margin, melt waters pouring from the ice front immediately increased basin discharge. The outward-sloping, peripheral zone of ablation of an advancing glacier (Demorest, 1942), of uncertain but assuredly a width of many miles, provided quantities of melt water runoff that were augmented, both directly and indirectly, by the effects of local precipitation on and marginal to the ice, especially during the summer.

When the advancing glacier overwhelmed the bedrock divide delimiting a preglacial drainage basin, the drainage basin was effectively enlarged by the inclusion of large sections of the zone of peripheral ablation of the glacier. This zone, perhaps as much as a hundred miles wide in the lower latitudes, sloped gently from the area of ice accumulation to the advancing, but melting, terminal margin. Supraglacial melt water moving down the sloping ablation zone and across the buried bedrock drainage divide into the preglacial basin radically increased summer discharge. Flooding, as a result of summer melting, provided a substantial seasonal fluctuation to the discharge of the drainage basin. As soon as alimentation decreased in the area of ice accumulation, in response to climatic amelioration, either through warming or decreased precipitation, or both, forward motion of the ice sheet was retarded. When forward motion was overbalanced by ablation, the glacier advance was halted and waning was initiated. At that moment there was presumably the maximum of clear ice exposed to ablation, and the maximum melt-water runoff was produced.

Once wasting of the ice was well established, the ice sheet grew thinner and less extensive areally; the zone of ablation expanded in width and the surficial ablation moraine grew thicker and more effective as an insulator, so that melting per unit of time was decreased. Width of the marginal zone of thick ablation moraine is speculative, but it may have been on the order of several tens of miles, possibly more. Although the influence of the ablation moraine-covered marginal zone on local climate and vegetation is likewise subject to speculation, it was probably of major importance, for not only did the ablation moraine protect the underlying ice from insolation, temperature fluctuations, and the effects of precipitation, but it also minimized the chilling effect of the ice mass on the local climate and weather (p. 13–14). A foothold for the hardier plant communities displaced by the advancing ice sheet may have been provided.

With thinning of the ice as the result of decreased alimentation and increased ablation, its movement would be reduced and stagnation would eventually occur in marginal areas so that the ice disappeared through downwastage in place. During ice wastage the amount of debris freed per unit of time increased. Meanwhile, regulatory effects of the deglaciated terrain played an increasingly greater role in minimizing the extremes of both flooding and low-water discharge from the drainage basin. The spongy water-saturated unconsolidated glacial debris mantling the terrain exposed by the waning glacier and the saturated outwash choking the drainageways, together with the disruption of preglacial drainage with the production of swamps and lakes, served to regulate streamflow long after the direct effects of the melting ice had vanished.

Although it is not possible to determine quantitatively the amount of increased annual runoff during glacial invasion of a drainage basin in low latitudes, it was perhaps manyfold. Maximum seasonal runoff occurred during summer months, especially following periods of heavy precipitation in the form of rain that increased surface melting of the ice. Daily fluctuations in runoff presumably had little effect on stream regimen except relatively near the ice margin. Maximum discharge of a torrential nature occurred for an unknown period immediately after the ice sheet had attained its greatest areal extent. Melt-water runoff as well as fluvioglacial outwash from the wasting ice remained at a high level until the ice had materially dwindled in areal extent, at which time the torrential effects of melt-water drainage began to taper and the volume of runoff, together with stream load, may have decreased in proportion to the areal extent of the ice within the basin. After complete disappearance of the ice, regulation of runoff within the basin by the absorptive quality of the unconsolidated glacial debris and by the disruption of drainageways and renewed vegetative cover tended to maintain a runoff level with lessened extremes of flooding or low-water flow than in preglacial time when drainage was well intergrated and there was less alluvial valley fill.

If the increased volume of water coursing through the Ohio valley during glacial periods had been the only changed condition imposed on the river, a regimen would have been established that might be analyzed on the basis of a single variable. Assuming the stream load to have remained constant, the increased discharge would act in the direction of reduction of the graded slope of the stream (Gilbert, 1877, p. 114). This was, however, not the case, for vast quantities of outwash of all grade sizes were carried from the ice fronts and extensive valley trains built. Because of the increased discharge and consequent increase in velocity, the capacity for transportation by the river was materially increased along the Ohio when the river was oversupplied with glacial debris. Although much detritus was deposited near the ice margin, especially at points of issue of subglacial streams, vast quantities were transported as far as the mouth of the river system and deposited in the expanding delta of the Mississippi.

Valley trains of the Ohio were somewhat steeper, especially near the ice margin, than either the present river flood plain or the preglacial bedrock valley floor. Thus, when river discharge, velocity, and its capacity for transportation were greatest, the channel slope was increased. Because of the overabundance of material available for transportation, the river was so excessively loaded that, as expected, greatest deposition took place upstream. Thus, there was a relative increase in channel slope upstream which increased the capacity of the stream, or as Rubey (1952, p. 130) has pointed out, the stream adjusted itself to its increased load by an increase in slope in order to provide increased efficiency for transportation.

Fluctuations in the capacity of the Ohio during waxing and waning of the glacial ice sheets, as well as seasonal fluctuations, produced a complexity of conditions. Complete adjustment of the river to the fluctuating conditions imposed on it was never fully attained, so that there was a constant change in regimen, the river cutting at times, filling at others, and modifying its channel, slope, and velocity to fit conditions momentarily imposed on it.

Between the times of glaciation, when the drainage basin was ice free, river volume and velocity decreased sharply. The river, however, flowing on alluvial fill, had available a ready supply of transportable material. Because of the increased channel slope, inherited from the valley train, the river was competent to erode, thereby increasing its velocity in an attempt to adjust to the new conditions. In general, river incision was, as expected, greater upstream and less downstream.

PRE-WISCONSIN DEPOSITS

Within the bedrock valley of the Ohio in the Owensboro area no alluvial deposits that can be assigned a pre-Wisconsin age have been identified. This does not mean, however, that such deposits were not at one time present, nor does it preclude the possibility that they are present today but are concealed by younger alluvium. This conclusion was tentatively reached by Leverett (1929).

No glaciofluvial deposits have been found in the Owensboro area above the level of the valley fill of Wisconsin (Tazewell) age. Along the valley walls where the oldest datable loess formation, the Loveland of Illinoian age, crops out, it rests directly on bedrock or on the Luce Gravel of Pliocene age at altitudes almost coincident with the level of the highest valley fill. This indicates that glaciofluvial deposits of Illinoian age and older either did not fill the valley to this level, or they have been completely removed by erosion before deposition of the loess of Illinoian age. Of these two possibilities, the former seems more probable and suggests that the volume of deposits of pre-Wisconsin age which occupied the valley was insufficient to fill it above the level of the deposits of Wisconsin (Tazewell) age. Such an interpretation is plausible because the upper 40–50 feet of valley fill now exposed is no older than Wisconsin age.

On the basis of indirect evidence and theoretical considerations, it is postulated that at least two, possibly three (Nebraskan(?), Kansan, and Illinoian) outwash trains of glaciofluvial debris occupied the valley in response to the pre-Wisconsin stages of glaciation. Whether remnants of these have survived below the surficial mantle of later alluvium is a question more difficult to assess, because interglacial stages were periods of stream erosion and there is seemingly no method by which the amount of valley fill removed can be determined. Furthermore, despite the fact that numerous wells have been drilled in the Quaternary valley fill, records permit no interpretations of the age relations of the materials at depth; nor can major discontinuities in Quaternary sedimentation be recognized, if they exist. In general, records of wells indicate only a thick surficial sandy silt overlying intercalated deposits of sand, gravel, gravelly sand, and clayey silt.

The extent of an ice sheet of Nebraskan age in the Ohio drainage basin is not known. However, if one accepts the postulate that integration of the present drainage basin was in large part the result of the first ice sheet, the Nebraskan, one must also accept the fact that some outwash debris was poured into the valley and that a valley train of unknown proportions resulted.

It is entirely possible that the valley train of Nebraskan age was small and occupied only the lower part of the deep bedrock valley. One may well question its hypothetical existence on the basis that if loess deposits are genetically related to valley trains, no exposures of loess have been found along the Ohio to which a Nebraskan age can be assigned. To this there are two possible explanations—first, that whatever loess may have been deposited has been removed by subsequent erosion; second, that because the valley train was small and confined within the deep inner bedrock valley, conditions were generally unsuited for the formation of extensive loess deposits.

Events during the the time of the Kansan ice advance are less obscure than during the Nebraskan, for the areal extent of the ice sheet of Kansan age within the drainage basin of the Ohio is gradually being outlined (Leverett, 1929; Ray, 1957; Flint and others, 1958; Wayne, 1958; Goldthwait and others, 1961). Although the ice sheet of Kansan age crossed the Ohio valley above Louisville, the adjustments of drainage that must have been produced are not known. The intimate relationship of the glacier of Kansan age to the valley downstream demands, however, that the valley served as a sluiceway for melt water ladened with outwash debris. On the basis of this relationship a valley train of Kansan age has been postulated (Ray, 1957) despite the fact that no remnants of it have been reported and that there is no direct evidence of its existence in the Owensboro area. Like the postulated valley train of Nebraskan age, the one that developed in response to the glaciation of Kansan age must have been largely confined within the deep inner bedrock valley of the Ohio and have had a relatively restricted surface area. Using the same negative evidence as before, it is assumed that the surface altitude of the valley train was lower than that of the Wisconsin (Tazewell).

One would expect that silt blown from the surface of a valley train of Kansan age would be lodged on the adjacent hill lands to form a loess mantle. With this in mind, special attention was given to the materials directly overlying bedrock in the Owensboro area in the hope that loess referable to a Kansan age would be found that would provide substantiating evidence for the postulated valley train. No such deposits were found, but in the adjoining Yankeetown quadrangle, a silt deposit crops out for a distance of some 300 feet along a roadcut across the nose of a low ridge (NE¼, SW¼, sec. 26, T. 6 S., R. 8 W.) that is tentatively referred to a Kansan age (p. 59).

768-324 O—65——3

The third, or Illinoian ice advance, was the most extensive to invade the drainage basin of the Ohio. At the time of its maximum advance it appears to have covered more area than did those of any other glacial stage and also, to the west in Illinois, reached the lowest latitude attained by the ice sheets in North America.

It was recognized long ago that ice of Illinoian age crossed the valley of the Ohio (fig. 1) and in places moved a few miles to the south of the river valley between Louisville and Cincinnati. Resultant readjustments in drainage along this particular sector of the front, like those along the ice margin of Kansan age, have in general not been determined, for, as Leverett (1929, p. 61) has suggested, "to the east of Louisville there seems to be no line of displaced Ohio drainage along or near the border of the Illinoian drift."

Although the terminus of the ice sheet of Illinoian age advanced to within about 18 miles of the northwest corner of the Owensboro quadrangle, the only material of glacial origin to reach the Ohio valley in the Owensboro area was brought in from upstream. Between the Owensboro and Louisville areas the only known stream draining from the ice front into the Ohio valley was the relatively small Blue River (Thornbury, 1932, 1937, 1950), whose contribution of debris must have been insignificant. The preponderant source of debris and melt water was in the vicinity of Louisville where the ice margin reached to the Ohio valley, so that there was direct association of ice-margin drainage and the main trunk of the Ohio River drainage.

Deposits assignable to an Illinoian age probably were of insufficient volume to have overwhelmed either the low bedrock divides across the present valley north of the Bon Harbor Hills, the bedrock bench to the east of Rockport, or the Lake Drain-Little Pigeon divide northwest of Rockport (pl. 1). It is probable, however, that the valley train caused ponding in the lower courses of the small tributary valleys so that they were filled with backwater sediments to depths for the most part comparable to the height of the main valley-train surface.

Because no deposits of an undoubted Illinoian valley train have been recognized, its existence may be challenged. This does not appear warranted, for there are numerous well-preserved deposits of Loveland Loess of Illinoian age along the walls of the Ohio valley from the Louisville area to its mouth (Leighton and Willman, 1950; Ray, 1957) that are genetically related to a valley-train source area (p. 56–57). Without such a source of silts, formation of the Loveland Loess deposits along the Ohio, especially between Owensboro and Louisville, would not be possible. The areal extent and thickness of the deposits indicate that the valley-train surface, from which the sediments were derived by deflation, must have been widespread.

During Sangamon time, following the disappearance of the ice sheet of Illinoian age and completion of the valley train, the regimen of the river was reversed and aggradation gave way to degradation. Meanwhile, the mantle of Loveland Loess on the hill lands was weathered and eroded. Where not completely removed by erosion, a characteristic profile of weathering was developed. By the close of pre-Wisconsin time the Owensboro area had a relief only slightly greater than that of today. Within the valley the river flowed on a bed of alluvium across a relatively broad alluvial plain in a course that carried it several miles to the east of Rockport and south of the Bon Harbor Hills. Terraces may have been developed along the river flood plain from the valley train of Illinoian age that were correlative in height with terraces developed from backwater deposits in the lower courses of the tributary valleys. The adjacent hill lands were in places stripped of their mantle of loess, and the exposed bedrock, largely sandstone and shale, was eroded almost as rapidly as it was weathered. With the onset of the ice sheet of Wisconsin age, conditions were radically modified and a new environment produced.

WISCONSIN DEPOSITS

PRE-TAZEWELL DEPOSITS

The oldest alluvial beds of Quaternary age recognized within the Ohio valley crop out along the riverbank at Owensboro beneath deposits of the valley train of Tazewell age. Because of age, stratigraphic position, and importance in determination of environmental conditions, these deposits are informally designated the beds at Hubert Court.

BEDS AT HUBERT COURT

The beds at Hubert Court are exposed for a distance of several hundred feet just downstream from the river end of Hubert Court in the eastern part of Owensboro (pl. 1). Some 18 feet of massive compact dark-gray clayey to fine sandy silt crops out from pool stage of the river (358 ft) to a point about 30 feet below the well-developed terrace marking the surface of the overlying valley train. Resistance of the beds to river undercutting is such that they form a narrow bench from which the overlying coarser unconsolidated valley-train deposits have been removed by erosion (fig. 8). The contact between these dissimilar deposits, marked by a spring zone, is pre-

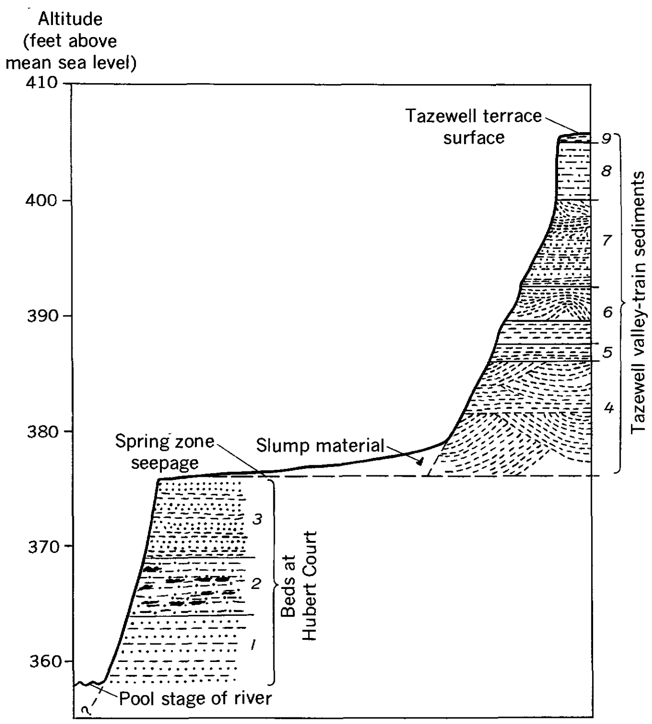

FIGURE 8.—Section showing beds at Hubert Court overlain by valley-train deposits of Tazewell age. Numbers refer to stratigraphic section below.

Section showing Tazewell valley-train deposits and beds at Hubert Court

	Feet
Tazewell valley-train deposits: - Sand	
9. Grayish-brown noncalcareous silty sand	1.5
8. Red-brown noncalcareous clayey silty sand; grades downward to sandy silt	5
7. Gray to yellow-brown stratified noncalcareous fine sand, silty and clayey sand; some staining and cementation by iron oxides. Basal layers a compact clay	7.5
6. Gray noncalcareous medium-fine unconsolidated sand, in part crossbedded; some concentrations of dark minerals and limonite concretions. Basal layer of dark-gray to brown plastic silty clay with greasy luster	5
5. Gray to dark-brown finely laminated plastic silty clay and yellow sand with clay pellets; much lensing of beds	1.5
4. Gray calcareous well-stratified and crossbedded medium-fine sand, in part stained and cemented by iron oxides. Much finely comminuted coal in coarsest sand layers	10.5
Beds at Hubert Court:	
3. Massive gray calcareous highly fossiliferous, fine-silty clay and fine sand; color, dark gray, black on surface (Silt)	7
2. Weakly calcareous compact finely laminated gray organic fine sandy and clayey silt; contains much woody material and some shells; color, dark gray, black on surface	5
1. Compact noncalcareous gray silty fine sand; color, dark gray, black on surface	6

sumed to be a disconformity, although it has not been observed because it is concealed by slumping of the unconsolidated coarse sands onto the bench.

Although superficially homogeneous, the beds at Hubert Court are divisible into three units (fig. 8): (1) a lower 6 feet of noncalcareous and nonfossiliferous, gray silty fine sand; (2) an intermediate 5 feet of organic, gray, laminated, and slightly calcareous fine sandy and clayey silt containing a few shells and layers of matted twigs, leaves, and woody fragments as much as several inches in diameter; and (3) an upper 7 feet of gray organic calcareous silty clay and fine sand that near the top is thickly set with a freshwater fauna of small gastropods and bivalves. The conspicuous black color of the outcrop is only superficial, for at a depth of 3–4 inches from the face of the exposure it fades to a dark gray (locally called "blue"), indicating that the surficial black color results from present-day oxidation of the contained humus.

The outcrop of the beds at Hubert Court is only a few hundred feet long. Attempts to determine their further extent along the riverbank were not successful because of riprapping and other protective measures taken to prevent undercutting and slumping along this residential-industrial area. The deposit, however, is assumed to be the 10- to 14-foot stratum of "blue potter's clay" reported (Inter-State Publishing Co., 1883, p. 260) to crop out 10–15 feet below the top of the riverbank "from 3 miles above to 2 miles below Owensboro." Extension of these beds back from the river is suggested by well records at Owensboro (Maxwell, 1954) in which "blue" and black muds and silts are reported at depths of 12–30 feet below the terrace surface of Tazewell age. Definite correlation of these silts with the beds at Hubert Court is not made, for similar "blue clay" along tributaries of the Ohio have been found to be Tazewell in age on the basis of carbon-14 dates (Rubin and Alexander, 1960, W–520 and W–645) and of depositional history.

Normally the entire succession of beds cropping out below valley-train deposits might have been considered of Tazewell age and the lower beds interpreted to be backwater deposits of an aggrading valley train. Carbon-14 dating of the wood, however, has shown clearly that this is not true, for the clayey silts are some 4,000–5,000 years older than the overlying coarse valley-train sediments. The date of 23,150±500 radiocarbon years B.P. (Rubin and Suess, 1956, W–260) indicate a late Farmdale or immediately post-Farmdale age.

See w/ early Woodfordian
Farmdale
25-30,000

The tripartite division of the beds at Hubert Court poses a question concerning age and correlation of the

Not accurate?

various units. Are they to be considered a single stratigraphic unit or three distinct units? Their distinct physical characteristics have led to the conclusion that they indicate differing conditions of origin. Although their exact history has not been determined with certainty, it would seem that the lowest noncalcareous unit, separable from the overlying wood- and shell-bearing units on the basis of texture and the seeming lack of fossils, represents surficial deposits related to a valley train correlative with the closing stages of the Farmdale age alluviation. Existence of a valley train of Farmdale age with which the Farmdale Loess may be genetically associated is implied by the widespread deposits of Farmdale Loess along the Ohio valley from the Louisville area (Ray, 1957) to Cairo (Leighton and Willman, 1949). Despite the fact that no till referred to a Farmdale age has been described in the Ohio drainage basin upstream from the Owensboro area, post-Sangamon—pre-Tazewell loess (White, 1953) and till (Goldthwait, 1958) have been described in Ohio.

non-calc. leaching?

see J. Forsythe

If the lowest unit of the beds at Hubert Court is related to the Farmdale valley train, its surface was about 40 feet below that of the later Tazewell valley train. Confirmatory evidence for such blanketing of the Farmdale by the later Tazewell alluviation was found in an unusually fine exposure of loess and lacustrine sediments just west of the Owensboro quadrangle (Yankeetown quad., Ind.-Ky., SE¼, sec. 8, T. 7 S., R. 8 W.). There, recent cuts through a rock-cored loess-mantled hill and the surrounding lacustrine flat show the Farmdale Loess overlying the Loveland Loess that mantles bedrock. On the lower hill slope the Farmdale Loess is overlain by fossiliferous lacustrine silts to the height of alluviation of Tazewell age. Above, loess of Tazewell age overlies the Farmdale. The Tazewell age of the lacustrine silts has been determined by a carbon-14 date of 19,940±300 years B.P. (Rubin and Alexander, 1960 W–645) for wood obtained some 8 feet below the surface of the lacustrine flat. The lacustrine silts appear to merge imperceptibly with the thick fossiliferous Tazewell Loess that mantles the hill. Because the Farmdale Loess, so well exposed in this outcrop, must have been deposited on the hill slope above the level of its source area, the valley train, and above contemporary lacustrine backwater silts, the conclusion is unavoidable that the Farmdale valley train was below that of the overlying Tazewell lacustrine silts—an altitude comparable to the surface of the valley train of Tazewell age in the adjacent river valley.

Following deposition of the lowest unit of the beds at Hubert Court, the 5-foot intermediate unit of calcareous organic gray laminated silty fine sand and clayey silt was deposited. This unit is interpreted as a backwater deposit because of its wood and fossil content, which indicate a swamp environment. Whether it should be considered latest Farmdale or immediately post-Farmdale in age, cannot be determined.

The uppermost unit, consisting of 7 feet of calcareous silty clay and fine sand, thickly set with small fresh-water shells in its upper part, may represent either continued backwater deposition during the Farmdale-Tazewell interval or the earliest deposits of Tazewell age, unless they are interpreted as the product of alluviation of Iowan age. As no glacial deposits referrable to an Iowan age have been described in the Ohio drainage basin and as there is no conclusive evidence for loess of Iowan age along the Ohio above the Owensboro area, assignment of an Iowan age is not justified and it is believed that the sediments represent the earliest deposits of Tazewell age. This conclusion is reached on the basis that the earliest deposits of a valley train are of a finer grade size (p. 35).

FLORA AND FAUNA AND THEIR CLIMATIC IMPLICATIONS

Wood fragments collected at random from the clayey silts of the intermediate unit of the beds at Hubert Court were identified by Prof. E. S. Barghoorn, of Harvard University. Of the seven identifiable fragments, four were oak (*Quercus*) of the black-red oak type (*Erythrobalanus* group) that grow in the area at present; two of these fragments, possibly from the same large tree, were of such size that growth rings showed no distinguishable curvature. The other specimens of oak seemed to be from very large trees having evenly spaced and suppressed growth rings—that is, about 15 per centimeter of radius. Of the remaining specimens, two were of sycamore (*Platanus*), presumably from a single relatively large tree, and one was a large grapevine (*Vitis*) with crowded growth rings. Both specimens of sycamore were stem wood of a rapidly growing tree with widely spaced growth rings, in contrast to those of the oaks.

The lack of specimens of woody plants other than those growing in the area today is arresting, especially in view of the carbon-14 age determination for the material and the fact that wood recovered in southwestern Ohio is entirely coniferous, dominantly spruce (Burns, 1958). In his analysis of the forests of Wisconsin age in Ohio, Burns suggests (1958, p. 223) that close to the advancing ice of the glaciers, where the climate was "almost subarctic," there was a narrow zone of coniferous, largely spruce, forest on areas of glacial outwash. No clue is given as to the possible width of this periglacial zone of coniferous forest postulated for Ohio because no wood of comparable age has been identified beyond the glacial boundaries. Burns' suggestion that the coniferous forest occurred on areas of glacial outwash leads to the speculation that well-drained uplands near the glacier margin may have retained patches of deciduous forest. The likelihood of preservation of an upland flora would be so limited that its presence may be entirely lost. The possibility that just beyond the narrow zone of coniferous forest, especially in the lower latitudes and slightly more remote from the ice sheets, deciduous forests may have maintained themselves virtually undisturbed is suggested by the flora of the beds at Hubert Court, whose geographic position leads to the conclusion that it was outside the periglacial coniferous forest zone. The fact that no woody fragments from the beds showed evidence of abrasion to suggest stream transportation before deposition, indicates that the wood was locally derived. The conclusion is reached that the woody material was deposited in a swampy area at or near its point of growth, and that the general aspect of the local vegetation at that time was similar to that of the present (p. 14–16) in which sycamore and grapevine are common along the riverbanks and oak trees flourish on the adjacent higher and better drained ground.

Realizing the anomalous character of the woody material, Grace S. Brush, of the U.S. Geological Survey, in 1956 collected and studied six evenly spaced samples from bottom to top of the organic silt to determine its pollen content. Her identifications (table 1) indicate an assemblage of plants still living in the area and show that only a few types are foreign to the present flora. Pine and spruce pollen, identified in all samples, represent coniferous trees not otherwise identified in the area. The presence of coniferous pollen and lack of coniferous wood can be explained by one of two assumptions: (1) that with further sampling, pine and spruce wood might be found, or (2) that the pollen was introduced into the deposit from afar, either by wind or water transportation. This latter assumption appears to be the most reasonable, for a few of the coniferous pollen grains were somewhat eroded but the most were not. This fact suggests that some had been transported and eroded by the river and that the uneroded grains had been transported by eolian action. Also, it suggests that the climate had not been sufficiently disrupted by the waxing and waning of the glacier to seriously modify the local plant community.

TABLE 1.—*Pollen from wood-bearing strata of beds at Hubert Court*

[Collected and analyzed by Grace S. Brush. Samples at intervals of approximately 10 inches from top to bottom of unit]

Species	←Top					Bottom→
	Pollen sample in percent					
	1	2	3	4	5	6
Pinus (pine)	57.7	50.0	66.7	74.1	60.6	61.1
Picea (spruce)	9.6	34.6	23.6	23.1	35.8	27.8
Alnus (alder)	.9	3.0	.6	1.0	1.1	3.0
Betula (birch)	.9	4.2	.6	------	.6	.3
Quercus (oak)	1.3	3.0	6.7	.9	.6	6.1
Polygonum (knotweed)	5.2	------	------	------	------	------
Cuperaceae (sedge)	------	.2	------	------	------	------
Gramineae (grass)	3.9	2.8	------	------	------	------
Artemesia (sagebrush)	.5	.9	------	------	------	------
Platanus (sycamore)	------	------	------	------	.6	.6
Rosaceae (rose)	.5	------	------	------	.3	------
Vitis (grapevine)	------	------	------	------	------	.3
Nymphea (water lily)	.5	------	.6	------	------	------
Lycopodium annotinum (club moss)	------	.3	------	------	------	------
Sphagnum (moss)	.5	.5	------	------	------	------
Dryopteris (fern)	------	.2	------	------	------	------
Herbaceous forms	2.6	------	------	------	------	------
Fungi	10.2	Many	------	------	------	------
Unidentifiable	5.6	------	1.2	1.0	------	.3
Total	99.9	99.7	100.0	100.1	99.6	99.5

The fauna of the Hubert Court beds supports the conclusions reached by study of the flora. Cornelia C. Cameron, of the U.S. Geological Survey, who examined the beds at Hubert Court in 1953, has identified the following:

Land gastropods:
- *Carychiuum exiguum* (Say)
- *Stenotrema hirsutum* (Say)
- *Vertigo ovata* (Say)

Fresh-water gastropods:
- *Amnicola limnosa* (Say)
- *Fossaria parva* (Lea)
- *Gyraulus circumstriatus* (Tryon)
- *Helisoma* sp.
- *Valvata tricarinata* (Say)

Fresh-water pelecypod:
- *Pisidium* sp.

This faunal assemblage provides supporting evidence for the conclusions reached by study of the flora, for they are forms normally found in damp woods or swamps on flood plains. The fresh-water forms indicate an environment that was no warmer, perhaps somewhat cooler, but not notably different from that of today. Thus, evidence furnished by both fauna and flora of the Hubert Court beds suggests that during late Farmdale time the normal belt of southwesterly winds was not displaced, but continued to flow into the area to sustain a relatively moderate temporate climate. As long as the belt of prevailing southwesterly winds were predominant in the Owensboro area, the climate was not rigorously "periglacial," and no major change in the biota, as represented by the identified specimens, appears to have occurred. This does not mean, however, that winters may not

BL-Pd interglacial
Reminiscent of
Two Creeks!

have been somewhat colder and more snowy and summers cooler and wetter than at present, but that the overall climatic modification as the result of glaciation was insufficient to change radically the general character of the biota. Statistically, the average temperatures and precipitation may have been shifted toward a cooler and wetter climate, but the extremes of cold and wetness may not have been appreciably greater than those of today (p. 13).

Climatic modifications resulting from nearness of the ice front in the lowest latitudes can be minimized. The narrowness of the belt of coniferous forest marginal to the southern glacier terminus (Burns, 1958) and the distribution of congeliturbates in relation to the glacier ice (Frye and Willman, 1958) support the belief that the lower the latitude, the narrower and more ineffective was the zone of rigorous periglacial climate. Perhaps the rigorous climate did not extend much farther than the zone of ablation moraine-covered ice, where a fluctuating narrow, but for the most part permanent cold front, marked by cloudy rainy weather, was marginal to the ice sheet. It may have been in this particular zone, especially on poorly drained ground, that the coniferous forests existed, advancing and retreating with the waxing and waning of the glaciers. South of this peripheral cold and wet zone the relatively warm southwesterly winds may have maintained a climate, as in the Owensboro area, not too dissimilar to that of the present.

Conflicting views are suggested by evidence of widespread displacement of certain components of the flora during the time of the Wisconsin ice advance (Sears, 1948). The presence of northern plants in southern States, for example *Picea glauca* (Brown, 1938), led to a belief in widespread migration of plant species in response to drastic climatic fluctuations and to the development of "refuges" for less mobile components of the flora. The interpretation made here tends to nullify the need for such drastic disruption of the flora beyond the ice margin and to suggest that, especially in Eastern United States, migration occurred largely in areas marginal to the ice and along certain favorable routes, such as stream valleys carrying glacial outwash and melt water, coastal plain areas newly exposed by lowered sea levels, and mountain highlands where slight climatic changes are important in modifying the environment. In such areas competition to the migrating species would be at a minimum and the new environments particularly favorable. Elsewhere, in the lower latitudes climatic changes resulting from glaciation may have had little effect on the overall environment, which tended to support the stable plant communities.

VALLEY-TRAIN AND RELATED DEPOSITS OF TAZEWELL AGE

Deposition of the beds at Hubert Court was presumably followed by incision of the valley fill by the Ohio and its tributaries. This relatively brief period of erosion took place in an interval unfavorable to glaciation during which the pre-Tazewell (Farmdale) ice sheet in the drainage basin of the Ohio receded an unknown distance before a reversal of conditions resulted in glacial resurgence within the basin. At its position of maximum advancement the succeeding Tazewell ice sheet was the most extensive of Wisconsin age in the Ohio basin. On the basis of the carbon-14 dating of woody material from the beds at Hubert Court and from nearby deposits of Tazewell age, the time interval between the 2 periods of glaciation cannot have been greater than about 5,000 years and perhaps may have been as brief as 1,000–3,000 years.

During this interstadial time, before the effects of the advancing Tazewell ice sheet became apparent in the Owensboro area, the Ohio valley can be pictured as an alluviated bedrock trough in which the river and its tributaries had cut channelways into the valley train of Farmdale age. Although the width and depth of the river channelway and its flood plain cannot be reconstructed, it was without doubt less extensive than that of today. Presumably, the river followed its ancient bedrock channel along the east valley wall in the latitude of Rockport and to the south of the Bon Harbor Hills.

THEORY OF VALLEY-TRAIN ORIGIN

Before considering the development of the valley train of Tazewell age, the best preserved in this part of the Ohio valley, it is necessary to understand the principles underlying the origin and growth to completion of an ideal valley train resulting from continental glaciation in the lower latitudes. To avoid complication, let such an ideal valley train be developed in a preglacial river valley whose basin has been invaded by a continental ice sheet, so that normal preglacial degradation had been supplanted by glacial aggradation.

When a drainage basin is invaded by a continental ice sheet, a change in the regimen of the river results through increase in volume because of melt water from the ice and an increased load because of glacial debris carried from the ice terminus. The river, incapable of transporting the vastly increased load, inevitably aggrades, first in the immediate vicinity of the source of the load and later throughout the valley as conditions favoring deposition move with wavelike progression downstream. Near the source of the debris, the coarsest material is deposited with a consequent building up of the streambed so as to increase the gradient and velocity of the stream as it attempts to readjust its regimen to a point where it has the capacity to handle the newly imposed load. The finer debris, generally carried farther from the source, is deposited downstream as the velocity and competence of the stream decrease. Gradually this readjustment of the stream to its new regimen through increasing its gradient and velocity by deposition moves downvalley, so that the locus of deposition for each particle size tends to move downvalley, producing a graded profile at an altitude above that of the normal preglacial river. The finer grade size sediments deposited first may be in part swept forward, so that the earlier deposits may be supplanted later by those of increasing coarseness.

If the source point of the melt waters and debris remains virtually at one position and the volume remains constant for a sufficient period, the stream gradient becomes stabilized for these conditions when its competency reaches a point at which it is just capable of transporting its load throughout the valley. The gradient would be increasingly less downvalley because of reduction in grade size of the load, partly as a result of erosion of the particles during transportation. Such a gradient for the adjusted river would permit it to transport the load imposed on it with neither net deposition nor erosion, a condition of equilibrium in work capacity. Such an ultimate "poised" condition is only theoretical, for the stability assumed is not expectable in nature. This is especially true in a glacier stream in the lower latitudes where such an equilibrium could not be maintained because of the glacier fluctuations as a result of its inherent instability with its environment and because of the relatively minor daily and major seasonal fluctuations imposed on the drainage stream in response to normal daily and seasonal changes in weather conditions.

During growth of the valley train to the point of theoretical stabilization at the time of maximum extension of the ice sheet within the drainage basin, aggradation along the river's course would ideally have taken place in zones that slowly moved downvalley—zones related to the grade size of the deposited sediments, the coarsest nearest the source, the finest farthest removed. As each zone was supplanted by the next coarser, through stream readjustment to increased gradient resulting from deposition, presumably finer materials would be swept forward, so that a vertical section of sediments comprising the valley train at any one point would not be expected to show finer sediments at the bottom and coarser near the top, but the reverse in the completed depositional cycle. Coarser sediments deposited nearer the source would show, it is believed, a lenticular structure and crossbedding not found in deposits of the finer grade sizes farther removed from the source and downvalley for, at the point where the coarser materials were being deposited, the river was subject to greater fluctuations in its capacity for transportation and deposition and tended to continually shift its channel. Farther downstream, where finer material was being deposited, fluctuations in stream volume would be smoothed in some degree to produce a relatively even flow, so that the stream capacity would be for the most part constant and deposition would tend to be largely in relatively extensive horizontal beds.

With disappearance of the ice sheet from the drainage basin, a reversal of the waves of sedimentation zones based on grade size of the sediments would be expectable. The locus of deposition of finer sediments would move upstream with a decrease in volume of melt water and load, and finer materials would be deposited on coarser, which the river was no longer competent to move. Such sedimentation would prevail until either the river became stabilized, which would be relatively unlikely, or until, with the disappearance of the effects of the glacier ice, there would be a change from stream aggradation to degradation with consequent incision of the valley train. Thus, at the surface of the ideally developed valley train one would expect to find the finest materials, grading downward to coarser, crossbedded, and lenticular deposits at depth.

This concept of the origin of the mantle of finer over coarser grained sediments is at variance with the postulates of Fisk (1944, 1947), Walker (1957), and others that the fine-grained sedimentary mantle is the product of deposition along rivers whose gradient was lessened by rising sea level during glacier waning. Walker (1957, p. 12) in his interpretation of the Ohio valley separates the fine-grained surficial alluvium from the underlying coarser deposits by an erosion surface. He further states that the fine-grained alluvium represents normal nonglacial sediments deposited because of rising water along the Mississippi due to a late glacial rise in sea level.

TAZEWELL VALLEY TRAIN

In the Owensboro region the Tazewell valley train along the Ohio is represented by extensive terrace remnants that are in places mantled by dunes (fig. 4; pl. 1). This prominent terrace level, especially widespread at Owensboro, marks the maximum alluviation of the valley and provides a flood-free site for the larger part of the city. Reconnaissance tracing of terrace remnants upstream to Cincinnati indicates that this is the same terrace level identified by Fenneman (1916) as the outwash of the maximum ice advance of Wisconsin age that is, the Tazewell. The terrace surface, rising from about 405 feet at Owensboro to about 540 feet at Cincinnati, has an average gradient of approximately 5.6 inches per river mile as compared with the present average mean low-water gradient of about 4 inches for the same stretch of river. Downstream from Owensboro to the mouth of the Cumberland River the terrace surface descends at an average gradient of approximately 4.2 inches per river mile, as compared with an average gradient of the mean low-water level of the present river of about 3.6 inches. These figures indicate a very low extended hyperbolic gradient.

The Tazewell terrace of the Ohio valley was found to be correlative with the highest terrace of the Wabash valley. This, the Shelbyville terrace of Fidlar (1948), was traced upstream and shown by him to be a valley train associated with the Shelbyville moraine, marking the maximum advance of the Tazewell ice sheet in the Wabash valley. Thus, on purely physiographic correlations, there seems to be little doubt as to the age of the highest terrace level in the Owensboro area. Fortunately, the correlations of Fenneman and Fidlar can be confirmed by the carbon-14 dating of two samples of woody material from correlative silt deposits in small valleys tributary to the Ohio both above and below Owensboro (Rubin and Alexander, 1960, W–520 and W–645). These dates (18,520±500 and 19,940±300 yr B.P.) substantiate the validity of the earlier physiographic correlations and confirm the Tazewell age for the alluviation represented by the highest terrace.

The character of the Tazewell valley-train deposits cannot be readily determined in the Owensboro area. Because of the thick fine-grained surficial sediments on the terrace, gravel pits have not been opened either on or along its margin, which is normally so slumped that natural exposures are not present. In general, the fine-grained surficial sands and silts range in thickness from 10 to 25 feet or more in the Owensboro area; thus coarser sands and gravels reported at depth in well records are completely concealed. This situation, common throughout this sector of the Ohio valley, was reported by Leverett (1929, p. 71), who found that gravel occurs only rarely at the surface.

Upstream from the Owensboro area, where gravel pits have been opened in the Tazewell valley train, the writer has found that the average grade size of the largest gravel tends to grow progressively, though slowly, coarser, but that the predominant size is ¼–½ inch, locally termed "pea gravel." Erratic boulders from 18 inches to 3 feet in diameter rarely occur in the gravel deposits as far from the source of the outwash as the Owensboro area. In general, the gravel is well rounded, but the coarse crossbedded sands are commonly angular. The fine gravel and coarse angular sand are in many places loosely packed with no matrix of finer materials filling the voids between the particles. Both coarse- and fine-grained crystalline particles are abundant in the gravel, together with limestone, vein quartz, chert, and fine-grained quartzite. The larger particles, 4 inches or more in diameter, are generally less well rounded than the smaller. Cobbles and small boulders, generally of quartzite, can be found in almost every pit, but they are rare. Small particles of coal, some well rounded, are not uncommon; many beds of coarse sand contain finely comminuted coal particles that are troublesome in commercial utilization of the sand.

A single exposure of the materials underlying the upper part of the Tazewell valley train in the Owensboro quadrangle occurs in the Hubert Court section (fig. 8; pl. 1). There, in a 30-foot section above the pre-Tazewell beds, are exposed fine-grained silts and sands overlying somewhat coarser crossbedded sands with a few clayey layers. No typical gravel is observable in this shallow section. Gravel exposed at depth in pits on the lower and younger terrace, may in all probability be in part reworked gravel of the Tazewell, or perhaps, earlier valley trains.

Despite the fact that numerous wells have been drilled through the Tazewell valley train to bedrock, little direct information has been obtained from the records on which to base a stratigraphic sequence or from which the character of the deposits can be deduced. Normally the wells penetrate surficial yellow (oxidized) silts, gray silts (unoxidized), and fine sands or silty sands to depths ranging from a few to as much as 25 feet or more. At greater depths well logs indicate alternating beds or lenses of coarse sand and gravel and sandy gravel, with sporadic beds or lenses of "mud," silt, and fine sand. Commonly, but not always, gravel is reported to rest directly on bedrock. In general, there is no method by which one can distinguish Tazewell from earlier alluvium in the deep bedrock channel, and it is suspected that the alternating deposits of various grade sizes indicate differing conditions of deposition related to not one but several periods of valley alluviation.

With gradual accretion of the outwash of Tazewell age along the broad Ohio valley and consequent overtopping of earlier alluvial deposits, a broad alluvial plain was developed. At that time the low bedrock

good point

divides between Lake Drain valley, and Little Pigeon valley, northwest of Rockport, and between the Bon Harbor Hills and the Rockport island hills were overwhelmed so that, possibly for the first time, there was a continuous expanse of glaciofluvial outwash surrounding both island hills. Likewise, alluvium spread across the entire valley east of Rockport, burying the bedrock prominence that had deflected the river against the east valley wall. Similar alluviation isolating hill lands to produce island hills has been described from the Wabash valley (Fidlar, 1948), where such islands are unusually numerous.

The aggrading surface of the valley train can be pictured as a broad expanse of water-logged alluvium of grade sizes ranging from silt and clay through sand and gravel to occasional boulders. The river is believed to have been a network of shallow rapidly shifting channelways in which the swiftly flowing water was actively aggrading in some places while eroding in others. Because of constant variations in the stream regimen there was little or no stability of the many channels, nor of their capacity. Doubtless the surface of alluviation had a relief of several feet.

In its overall character, the aggrading valley train of the Ohio can be considered in its geomorphic expression and origin closely akin to the sandurs of Iceland (Hjulström, 1953, 1956). If the aggrading valley train is considered to be a grossly attenuated sandur, with a completed cycle of development through waxing and waning of the glacier in the drainage basin of the Ohio, the characteristics described by Hjulström in the development of this "supra-aquatic delta" have been somewhat modified. However, during the period of active development, as observed in Iceland by Hjulström (1956, p. 337)—

> everything is moving. The water is flowing, the water-stage is rising and falling, the banks and islands are eroded and new islands are being formed. From day to day the drainage pattern changes although the main features are almost always the same.

On the surface of an actively aggrading valley train with its high water table, rapidly shifting channels, and sporadic flooding, it is likely that even in the lower latitudes, as in the Owensboro area, the larger part of the surface would have been inhospitable to forest growth. Only the highest and best drained parts might support trees and shrubs for a temporary and precarious existence. Elsewhere, vegetation may have been scanty with only semiaquatic plants, such as marsh grass, reeds, and sedges, growing in areas of relative stability. However, above the height of flooding, on the hill lands where the ground was well drained, a typical forest vegetation, similar to that of today, presumably was able to maintain itself.

During aggradation, when the network of channels shifted continually across the extensive alluvial flats, rapid lateral erosion occurred wherever the stream impinged on valley walls. Interfluves between small valleys tributary to the main Ohio were trimmed back, and valley margins smoothly planed with the production of low bedrock bluffs. This type of erosion of valley walls is especially well shown in the bluffs at Rockport, along the northern part of the Bon Harbor Hills, and in the vicinity of Lake Mill, along the channelway northwest of Rockport. In contrast, along broadly alluviated tributary valleys, like those of Honey and Hurricane Creeks, the interfluves are uneroded and in part buried by alluvium correlative with that of the main valley train. The segment of the Ohio valley wall east and northeast of Owensboro, to the vicinity of Van Buren Creek, like that of the smaller tributary valleys, shows little evidence of lateral stream erosion, the valley wall indicating only burial by alluviation. This fact suggests that during the period of Tazewell valley-train formation the valley wall was either protected from major river erosion or that major stream erosion occurred before completion of Tazewell aggradation and that aggradation at the close of Tazewell alluviation buried the smoothly planed lower part of the valley wall. The latter explanation seems the most plausible.

During the long period of waning glaciation in the Ohio drainage basin, conditions were slowly changed in the Owensboro area, and a new regimen was gradually imposed on the river. Although aggradation continued, materials were of finer size, as indicated by the character of the sediments in the Hubert Court section (fig. 8). A relatively homogeneous mantle of clay, silt, and fine sand, as much as 30 feet or more thick, was spread over the entire valley train. It is the surface of this fine alluvium that marks the upper limit of the valley train, the remnants of which constitute the Tazewell terrace. Insofar as can be determined from the remnants of this terrace along the present river valley, the surface was for the most part a smooth plane of alluviation, perhaps in large part the result of overbank deposition during periods of flooding. Such flooding must have been relatively common because of the vast amount of stream fluctuation in response to fluctuating weather conditions.

Conditions, however, were not the same in the Little Pigeon valley part of the ancient diversion channel, where the alluvial surface is marked by a complex network of braided stream channels (pl. 1) whose origin can be only tentatively explained. As features of the landscape these channels may be readily overlooked by the casual observer on the ground, for in general they are only 1–3 feet deep and from a few tens to several hundreds of feet wide. On aerial photographs they are readily distinguished by tonal differences and the effects of erosion along channel margins (fig. 4). Although cultivation has tended to obliterate these very minor features, they are well recognized by the local farmers because the slight elevation of the interfluves permits more rapid drainage and consequent drying than in the channelways. Likewise, soils of the channelways tend to be somewhat more clayey than those of the higher fine-grained sandy silts of the interfluves.

Periodic flooding along the main channel of the Ohio during the time of glacier waning and final aggradation of the Tazewell valley train were such as to divert floodwaters through the Lake Drain channelway into Little Pigeon valley, to rejoin the main Ohio valley southwest of Hatfield. In all probability, floodwater deflected from the main channel into the funnellike Lake Drain valley had, when compared with that of the main channel, a slightly elevated surface resulting from the minor hydraulic head produced by deflection of the waters into the constricted valley. At the same time, velocity of the deflected floodwater was decreased and its capacity reduced proportionately. On passing through the constriction between the tip of the Rockport island hills and the hill lands to the north (sec. 31, T. 6 S., R. 6 W.), the floodwaters, suddenly released, debouched with force through a maze of self-imposed shallow braided channels in the broad valley of Little Pigeon Creek to produce an anomalous stream channel pattern (pl. 1) not recognized elsewhere. Fisk (1944, 1947) has shown, however, that there are areas of similarly braided channels in the broad alluvial valley of the lower Mississippi.

Commonly a braided stream pattern is ascribed to an overloaded stream; yet this explanation does not fit Little Pigeon valley, for if overloading was the major cause of the braided stream pattern, one would expect to find a braided channel pattern in the main Ohio valley. Studies by Leopold and Wolman (1957, p. 50) indicate that, contrary to the general belief, "braiding is not a consequence of aggradation alone." A reconstruction of the aggradation characteristics of the Little Pigeon valley shows that overloading was not the cause of braiding of the channel, as suggested by Fisk (1944, 1947) for the braided channel patterns in the lower Mississippi valley.

If one considers the regimen of the floodwaters of the Ohio as they moved from the main river valley, first into the funnellike, constricted Lake Drain valley and then into the broad Little Pigeon valley, it can be seen in the Lake Drain valley, where velocity was slightly reduced, the capacity of the floodwaters would be decreased and the load reduced. As the water poured through the constriction at the head of the Lake Drain valley, its velocity would be somewhat increased and, as a consequence, the stream would be underloaded rather than overloaded. Such a condition would seemingly be ideal for erosion and transportation by the stream. This, however, did not happen, as there is no indication of major stream erosion at this time. Furthermore, since the base level of the Little Pigeon valley waters was determined by the height of the alluvium in the main Ohio valley southwest of Hatfield, the gradient was too low to permit entrenchment by the underloaded floodwaters.

To maintain its equilibrium, the diverted floodwaters were splayed into numerous shallow braided channels, which reduced their capacity through dissemination of energy by channel adjustment, as suggested by Rubey (1952). Once braided channelways had become established, they appear to have been relatively stable, as indicated by the fact that many islands separating the braided channels support low sand dunes (pl. 1). Leopold and Wolman (1957, p. 53) likewise note that the stability of the braided channel pattern "suggests that rivers with braided patterns may be as close to quasi-equilibrium as are rivers possessing meandering or other patterns."

The fine-grained silty and sandy alluvium mantling the coarser sands and "pea gravel" found at depth is relatively thin when compared to the thickness of the fine alluvial mantle in the main Ohio valley. This suggests that either the Lake Drain-Little Pigeon diversion channel was not so frequently flooded as the main Ohio valley toward the close of the time of aggradation or that the floodwaters were able to move more material through the channelway and back into the main Ohio valley. Sufficient evidence is not available to provide a definite choice.

SAND DUNES

GENERAL FEATURES

Genetically related to the Tazewell valley train are the dunes that are conspicuous topographic features in the Owensboro quadrangle. Less well developed dunes are associated with the Tazewell valley train elsewhere, but at no point are dune forms as extensive as in the Owensboro area where they occur as groups of low irregular hummocks or well-defined ridges 10 miles or more in length (pl. 1, fig. 4). In general, dunes are located on the Tazewell valley train, banked against the valley walls, or are perched on bluffs marginal to the main valley. The two most conspicuous dunes are the elongate ridges trending northeast along the west side of the Rockport island hills (Sand Ridge) and those extending from southwest of Owensboro through the city, to the northeast on to the bluff overlooking the river valley. All dunes are mantled by loess from a few to as much as 15 feet or more thick. In many places the loess mantle is so thick that, unless there are deep artificial cuts, the sand core is not exposed, and the dune can be recognized only on the basis of its topographic form.

That dunes should be so well developed in this region is expectable because a ready source of material was amply provided by the extensive surface of the Tazewell valley train across which winds could sweep with little topographic interference. Deflation was therefore active, as the broad alluvial flats were relatively free of a stabilizing vegetative cover and, although the valley fill had a high water table, its surface was sufficiently dried by evaporation to permit transport of surficial particles by wind action.

That all dunes related to the Tazewell terrace have a core of sand, sometimes with interbedded lenses of compact silty sand, and a mantle of loess would seem to indicate two distinct periods of eolian deposition resulting from either a change in the character of the source material or in the transporting power of the winds. Furthermore, because the base of the sand core has not been observed for those dunes on the alluvial surfaces, it is suspected that the base is below the upper surface of the valley train and is either on or near the surface of the coarser materials at depth rather than on the upper surface of the finer alluvium. In other words, the present dunes were initiated either just before, or, more likely, when aggradation of coarser detritus was being supplanted by that of finer silts and sands. Similarly, the loess that invariably mantles the dunes would be largely the product of the final period of alluviation before the regimen of the river had been shifted from aggradation to degradation. Once aggradation ceased, the surface of the valley train would become stabilized by vegetation and the source of material for deflation would be destroyed.

Assuming this general mode of origin for the dunes, it would follow that their position and orientation was largely a product of conditions at, or immediately following, the period of maximum glacier advance within the Ohio drainage basin. Dunes on the valley-train surface were later surrounded and partially buried by the fine-grained alluvium that represents the last period of Tazewell aggradation and the major source for the eolian silt mantling the dunes.

It has been pointed out (p. 33) that winds in the Owensboro area were dominantly from the southwest throughout glacial and interglacial episodes, much as they are today. The orientation of the dune elements, however, raises the question as to the direction of the winds to which they owe their origin, for most can only have been the product of winds blowing from the northwest inasmuch as they are largely to the southeast of the source areas of the sand. This seeming contradiction is, however, more apparent than real, for dune formation is believed to be largely the result of the strongest seasonal winds whose direction did not coincide with the dominant annual wind direction. During the period when the sand cores of the dunes were initiated, cold drying strong winter winds from the northwest were much more common than today, when they are predominant only in February (p. 14). At the time of maximum glacier extension, winter winds would have swept from the northwest across the broad aggrading valley trains when streams were at their lowest level, and the maximum surface area was available for deflation. Whatever vegetation may have gained temporary foothold on the valley-train surface, it was also least effective as a deterrent of deflation during the winter.[7]

As aggradation decreased and constant shifting of the channels was less rapid, vegetation gained a foothold along the low banks of the main river channels. Such concentrations of vegetation acted as natural traps for windblown sand. Where channels shifted slightly to the windward, a series of low dunes developed, the largest where the stream was stable for the longest period of time, as in the area just northeast of Owensboro where a series of low dunes mark brief halts in the shifting stream channel. These minor dune ridges lie within the protection of the major dune ridge that rises to a height of more than 50 feet above the surrounding valley-train surface. Likewise, in the valley of Little Pigeon Creek, the bifurcated Sand Ridge marks two episodes in the shifting position of the stream from a nodal point in the SW¼ sec. 14, T. 7 S., R. 7 W. Here, parallel dune ridges to the northwest of the main Sand Ridge appear to mark later positions of the stream channel.

Along the base of the east wall of Lake Drain valley, dunes have been banked by northwest winds sweeping through the constricted passage from the Little Pigeon valley. These same winds, deflected by the topography, are presumed to have built the dunes

[7] Péwé (1951, p. 399) has noted that deflation in Alaska is greatest from valley-train surfaces in summer and is inhibited by ice and snow during winter months. In the latitude of Owensboro it would appear that ice and snow were less important in determining the amount of deflation.

bars with
horizontal lamination
Not primarily dunes

that extend northwest from Rockport along the south margin of the valley.

The thickest deposits of eolian sand may occur at the western tip of the Rockport island hills where conditions for accumulation of windblown sand and silt were ideal. Although no borings are available to indicate thickness of the unconsolidated mantle of sand and silt, it is believed that sand, accumulated on the bench of Luce Gravel, may possibly be as much as 60 feet or more thick and that the loess mantling the sand may be in places as much as 30 feet or more thick. Slumping along the steep valley wall, undercut by later river erosion, effectively conceals the character of the deposits composing the hills of this area, yet the topographic form of the hill lands strongly suggests a dunal origin with a thick blanket of loess.

PHYSICAL PROPERTIES

Sand from the dune cores are dominantly fine grained (table 2) and subangular. Relatively few grains are rounded and frosted, presumably because they were transported relatively short distances from their source areas and were not shifted by wind action for a time sufficient to produce the characteristics generally ascribed to dune sand. The paucity of coarse sand in all samples suggests that there was little coarser material available for deflation at the time of dune formation, supporting the belief that the period of dune formation was one of waning rather than waxing glaciation. Some confirmatory evidence, suggesting a general uniformity in grade size of the sand available for deflation in the Owensboro quadrangle, comes from analyses of two samples of dune sand of similar age and origin upstream. The sample from Harris Church (Cloverport, Ind.-Ky. topographic quadrangle), about 40 river miles upstream from Owensboro, is dominantly (56.2 percent) fine sand; 75 river miles farther upstream, at Kinder Cemetery (Rock Haven, Ky.-Ind., topographic quadrangle) the dominant grade size is that of medium sand (65.9 percent). On the basis of this limited data it would appear that the dominant size of the dune sand is a reflection of the dominant size available from the local valley-train source area. That such deposits are coarser upstream and nearer their source is expectable.

At several places,[8] layers and lenses of silty sand to loesslike silt are intercalated in the dune sands. In general, such layers are compact and tend to retain moisture; thus they resist slumping, and form conspicuous surficial bands in pit walls. Analysis of one such calcareous loesslike silt layer (table 2) shows the material to be comparable to the normal calcareous loess of the area, indicating that the material represents variations expectable during normal deposition of dune deposits.

The dune sands are relatively similar in mineralogical composition (table 3), but differ markedly from the mantling loess deposits (see p. 67–69). In general, the heavy-mineral content of the sand fraction is higher (from 0.6 to 5.6 percent) than that of the loess. It is characterized by an abundance of blue-green amphibole—generally with a brown amphibole, probably common hornblende—ilmenite, occasionally a little magnetite, a pyroxene near diopside in optical properties, hypersthene, garnet, and tourmaline. Tourmaline, generally well rounded, zircon, and rutile

[8] 1. Sand pits on Sand Ridge near junction of Indiana State Highways 66 and 161.
2. Sand pit along secondary road, 0.5 mile east-southeast of Pup Creek bridge on U.S. Highway 60.
3. Roadcut, 0.4 mile southeast of U.S. Highway 60, along secondary road between Yellow and Pup Creeks.

TABLE 2.—*Mechanical analyses of dune sand and an intercalated lens of loess*

[Analyses by P. D. Blackmon. n.d., not determined: Tr., less than 0.1 percent]

Sample	Location	Distribution, in percent by weight, for indicated grain size, in phi units														Type of material
		Gravel	Sand					Silt					Clay			
		−2 to −1	−1 to 0	0–1	1–2	2–3	3–4	4–4.5	4.5–5	5–6	6–7	7–8	8–9	9–10	10+	
150256	Sand pit, 800 ft south of Kentucky State Highway 54. ¾ mile west of junction with State Highway 81.	0	0	0	4.0	57.0	26.2	4.6	0.7	0.6	0.3	1.2	0.2	1.2	4.0	Weathered dune sand.
150242	Stream cut through sand dune, NW¼, sec. 9, T. 7 S., R. 6 W.	0	Tr.	.3	22.5	39.3	14.1	5.9	2.0	1.9	2.1	.1	.2	2.2	9.4	
150243	do	0	0	.4	35.1	41.1	11.2	2.3	.9	1.5	1.7	1.3	2.2	n.d.	n.d.	Unweathered dune sand.
150257	Roadcut through dune, 0.6 mile northeast of confluence Van Buren and Yellow Creeks.	0	0	0	3.7	41.6	23.0	7.7	5.5	7.5	4.1	2.0	2.4	n.d.	n.d.	
150273	Sand pit, NE¼NE¼, sec. 12, T. 7 S., R. 7 W	0	0	Tr.	6.5	46.2	25.2	2.0	5.0	5.9	3.0	2.3	1.2	1.4	1.2	
150274	Sand pit, NW¼NE¼, sec. 21, T. 7 S., R. 7 W	0	0	.3	20.3	28.6	23.8	10.5	6.5	3.0	2.4	.6	.5	.7	2.8	
150260	Sand pit along secondary road, 0.5 mile east-southeast of Pup Creek bridge on U.S. Highway 60.	0	0	0	7.1	51.5	18.6	6.4	2.7	7.3	1.5	1.8	.7	n.d.	n.d.	
150261	do	Tr.	Tr.	.1	.4	5.1	6.3	12.9	21.4	34.7	11.0	1.1	.9	1.3	4.8	Loess lens in dune sand.

are present only in very small amounts. The silt and clay fractions contain mainly quartz and a small amount of feldspar (table 3). In the unleached samples, dolomite is the most abundant carbonate; calcite may occur only in traces or be lacking. In the leached clay fractions, kaolinite and mica are equal or nearly equal; in the unleached, mica content is slightly greater.

LACUSTRINE DEPOSITS

At altitudes comparable to the altitude of the Tazewell valley-train surface, there are in the Owensboro quadrangle extensive alluvial deposits of clayey silt and silty clay whose surfaces form broad flats and terraces in valleys tributary to the Ohio and to the Lake Drain–Little Pigeon channelway. The developmental history of these features provides a unique check on interpretations of the regional geologic history; by means of wood and shells recovered from the sediments, data on age and local environment can be obtained.

Although Rafinesque (1819) had suggested lakes in the Ohio valley, the first significant reports on the ancient lakes and lacustrine deposits did not appear until almost a century later when Shaw (1911, 1915a) described them in valleys tributary to the Ohio and Mississippi Rivers in southern and western Illinois. According to him (1915a, p. 150), clayey and silty deposits in the lower parts of valleys tributary to the Mississippi and Ohio "accumulated in lakes produced by valley fillings on the master drainage lines of the region." In essence, aggradation of master drainage streams by valley trains dammed tributary valleys at their mouths, ponding those that were unable, because of lack of a sufficient sedimentary load, to keep pace with aggradation in the main valleys. Although he did not specifically dicuss the source of the lacustrine silts and clays, Shaw apparently considered them to be the result of slackwater deposition of finer sediments derived from the glacial debris aggrading the main drainage lines.

Malott (1922), Theis (1922), Thornbury (1937, 1950), and Fidlar (1948) have described lacustrine deposits in valleys tributary to the Ohio and Wabash and, in general, have followed Shaw in relating them to aggradation of the major river valleys. They have not been, however, in complete agreement as to the fundamental causes of this aggradation (p. 25–28). The lacustrine deposits now generally dissected and represented by terrace remnants in each tributary valley rise in accordance with the increasing altitude of the valley train surface upstream, as pointed out by Shaw (1915a) and Thornbury (1950). Reconnaissance studies indicate that the altitude of the lacustrine flats increases from about 350 feet at the mouth of the Cumberland River to about 540 feet at Cincinnati, Ohio, about 500 river miles upstream. Shaw (1915a, p. 147–148) notes that lacustrine deposits increase in altitude from 345 feet near Cairo, Ill., to 650 feet at Galena, Ill., some 400 miles up the Mississippi River. On the basis of these figures it would appear that the average gradient of the Mississippi River valley train is approximately twice that of the Ohio. However, if river miles are used along the Mississippi so as to be comparable to the Ohio, the ratio is reduced to about 1.4.

The upper surface of the lacustrine deposits is seemingly almost horizontal, although there is a tendency in many places for it to be slightly higher at the mouth of the tributary valley, as noted by Theis (1922). Where streams have dissected the lacustrine flats, the surface is commonly separated, near the mouths of the tributary valleys, from the flood plains of the present streams by distinct low scarps. Upstream, the terrace scarps disappear as the flood plains gradually rise to merge imperceptibly with the lacustrine surface (pl. 1). At the lateral margins of the lacustrine flats the sediments merge in very gentle slopes with the silt-mantled valley walls, so that it is rarely possible to delimit the precise boundaries of the lacustrine valley fill. Because the lacustrine beds merge through a transition zone with the eolian loess mantling the valley walls, it is suggested that colluvium is relatively negligible except where slope wash has been accelerated by the activities of man.

A few shore features have been described. Shaw (1915a, p. 147) called attention to a few "beautifully developed and well-preserved beach ridges" near Madisonville, Ky., and Malott (1922, p. 249) has noted beaches and bars south of Richland City (Lake) in the Owensboro quadrangle. The latter have been shown to be dunes developed on the surface of the Tazewell valley train (p. 38–40; pl. 1). Examination of the features near Madisonville show that they are prominent terraces of gravel, possibly comparable to the Luce Gravel and are not beach ridges.

In the Owensboro quadrangle no features have been seen that could be ascribed to shore processes. As pointed out by Shaw (1915a, p. 147), shorelines in the ponded tributary valleys must have constantly fluctuated in response to fluctuations of the aggrading rivers of the main valleys, so that there was no position of stability for a time sufficient to develop normal shoreline features. As the lacustrine sediments were dominantly silt and clay, shorelines must have been swampy morasses with a vegetative cover of reeds and sedges, so that during periods of low water, wind-

TABLE 3.—*Mineralogical analyses of dune*

[Analyses by P. D. Blackmon and D. Carroll. P, present; A,

Sample	Location	Heavy minerals in fine sand fraction: Percentage by weight of total sample	Ilmenite	Amphibole, blue-green [1]	Amphibole, brown [2]	Pyroxene	Hypersthene	Garnet	Tourmaline	Epidote	Zoisite	Rutile	Zircon	Staurolite	Sphene	Sillimanite
150256	Sand pit: 800 ft south of Kentucky State Highway 54, ¾ mile west of junction with State Highway 81.	5.4	P	A	P	P	P	P	P	P	P	P	P	----	----	----
150242	Stream cut through sand dune: NW¼, sec. 9, T. 7 S., R. 6 W.	1.8	P	A	P	P	P	P	P	P	P	P	P	----	----	----
150243	do	.27	P	A	P	P	P	P	P	----	----	P	P	P	----	----
150257	Roadcut through dune: 0.6 mile northeast of confluence Van Buren and Yellow Creeks.	4.0	P	A	P	P	P	P	P	P	P	----	P	----	----	----
150273	Sand pit: NE¼NE¼, sec. 12, T. 7 S., R. 7 W.	2.4	P	A	----	P	P	P	----	P	----	P	----	----	----	----
150274	Sand pit: NW¼NE¼, sec. 21, T. 7 S., R. 7 W.	3.5	P	A	P	P	P	P	P	----	----	P	P	----	P	P
150260	Sand pit along secondary road: 0.5 mile east-southeast of Pup Creek bridge on U.S. Highway 60.	.6	P	A	P	P	P	P	P	P	----	P	P	----	----	----
150261	do	3.5	P	A	P	P	P	P	----	----	P	P	P	----	----	----

[1] Metamorphic type. [2] Probably hornblende.

blown silty clay was deposited along the margin of the lacustrine flats as well as on the adjacent valley walls. Under such conditions, whatever shore features might have developed, they would have been ephemeral, and deposits of lacustrine origin would have merged without appreciable change in character with eolian deposits.

Alluvial backwater deposits at the mouths of many tributary valleys are slightly higher than those of the upvalley lacustrine flats; some valley mouths are blocked by loess-covered sand dunes. Others show no indication of unusual sedimentation, and there is no discontinuity between sedimentation in the main and tributary valleys. Although local conditions must be considered in any attempt to explain the greater height of sediments at valley mouths, it must be borne in mind that the features now observable are those present at the close of the period of deposition, and that some features may have been initiated at an earlier time than others.

The broad low valley-mouth alluvial ridges appear to have been formed in much the same way as natural levees along river channels and are here termed "valley-mouth levees." When the aggrading river channel lay adjacent to the valley mouth, backwaters spread during periods of flooding from the main to the tributary valleys and, as would be expected, deposited the greatest load at the mouth of the tributary valley. Continued periodic deposition, so long as the river channel remained in the same position, would build broad low alluvial ridges. These would aid in preserving shallow lakes in the basins along the lower courses of the tributary valleys. In general, material of the valley-mouth levees would be only slightly coarser than that deposited in the lakes for, during the final stages of valley-train aggradation, the river load was largely of finer grade sizes. In times of flood, coarser materials transported by the river were moved only along the channels and were not carried into the tributary valleys.

Where the river channel of the main valley lay far from the mouths of tributary valleys, no unusual deposition would be expected at the valley mouth. For this reason, valley-mouth levees are most common along those stretches of the Ohio where the valley is constricted and channels were unable to move far from the tributary valley mouths (see Alton, Ky.-Ind. topographic quadrangle).

The best example of a valley-mouth levee in the Owensboro quadrangle is at the mouth of Honey Creek valley, about 4 miles north-northeast of Rockport (pl. 1). There the valley mouth is partly blocked by a broad alluvial mass that rises slightly above the general level of the lacustrine flat within the valley. The

sand and an intercalated lens of loess

most abundant mineral present; Tr., trace less than 0.1 percent]

Silt fraction (parts in 10)					Clay fraction (parts in 10)													
Quartz	Feldspar	Dolomite	Calcite	Mica	Montmorillonite	Vermiculite	Mica	Vermiculite-montmorillonite mixed	Vermiculite-mica mixed	Mica-vermiculite-montmorillonite mixed	Mica-montmorillonite mixed	Mica-vermiculite-chlorite mixed	Kaolinite	Quartz	Dolomite	Calcite	Feldspar	Type of material
9	1	-----	-----	-----	-----	<1	3	-----	-----	1	-----	-----	2	3	-----	-----	-----	
9	1	-----	-----	-----	Tr.	3	2	Tr.	2	-----	-----	-----	2	1	-----	-----	-----	Weathered dune sand.
5	1	3	1	Tr.	-----	1	4	Tr.	-----	-----	-----	-----	2	2	1	Tr.	-----	
6	1	2	1	-----	1	-----	3	-----	-----	-----	1	Tr.	2	2	1	-----	-----	
5	1	3	Tr.	-----	-----	1	3	-----	1	-----	-----	-----	1+	2+	1	Tr.	-----	Unweathered dune sand.
5	2	2	-----	-----	-----	1	2	-----	1	-----	-----	-----	1	4	1	-----	Tr.	
6	1	2	1	-----	-----	-----	3	-----	-----	-----	1	-----	1+	3	1+	Tr.	Tr.	
4	1	3	1	-----	-----	-----	3	-----	-----	-----	2	-----	1+	3	1	-----	-----	Loess lens in dune sand.

normal situation is complicated, however, by two bedrock "islands" that rise as loess-covered prominences above the general level of the alluvium at the valley mouth. These prominences seemingly represent a continuation to the southwest of the hill land bedrock ridge which, before almost complete burial by alluvium, constricted the mouth of Honey Creek valley. Alluviation in the lee of this bedrock ridge during times of flooding may have materially aided the normal process of levee building at the valley mouth. A water well drilled on this valley-mouth levee (NW¼ SW¼, sec. 36, T. 6 S., R. 6 W.) is reported to have passed through 25 feet of surficial "clay" underlain by 53 feet of "mud" with no indication of either sand or gravel. Such a thickness of fine-grained sediments appears to be indicative of the nearness of the deep bedrock channel of the Ohio to the tributary valley, and, as discussed below (p. 44), of more than a single period of alluviation in the tributary valleys.

Where tributary valleys were so oriented that sand might be blown from the valley-train surface into them, dunes commonly obstruct the valley mouths. Willow Pond is an excellent example of a small valley blocked by dune ridges across its mouth. Here drainage was impeded by alluviation in Little Pigeon valley so that much of the impounded basin was marshland surrounding an open pond that existed until construction of the Willow Pond Ditch in the mid-1870's. Marginal areas, however were sufficiently dry to support the development of very low dunes, composed largely of coarse silt and fine sand.

Local residents report that wells sunk in the Willow Pond Bed encounter shells, logs, and other vegetative debris to a known depth of approximately 65 feet. If this depth of fill is entirely related to the Tazewell valley-train aggradation, it indicates the minimum thickness of Tazewell alluviation, for which no figures are available in the main Ohio valley.

The largest area of ponding in the Owensboro quadrangle lies between the bedrock valley wall of the Ohio and the great dune ridge that extends to the northeast through Owensboro. Here, ponding as the result of Ohio valley alluviation occurred first in the valleys of Van Buren and Yellow Creeks before development of the great dune ridge. At that time the main river channel followed closely the base of the bedrock valley wall. Along this channel margin the dune ridge on which Yellow Creek Church is sited was developed. At one time this discontinuous dune ridge presumably blocked the valley mouths of the small creeks. Later, the channel of the Ohio shifted from the valley wall to a new position nearer the axis of the bedrock valley. The left bank of the channel in its new position is now marked by the great dune ridge, so that the surface of the valley train, between the valley wall and the dune ridge, became an area of impounded drainage and marshy ground. Occasionally flooded by backwaters, it was presumably an area occupied by a shallow, perhaps intermittent, lake in which silty clays of both eolian and fluviatile origin were deposited. So similar are these deposits that, despite their different origins, it is not possible to distinguish one from the other; nor is there sufficient data to indicate the thickness of these sediments over the coarser valley-train deposits at depth.

All observable lacustrine deposits in the Owensboro quadrangle are assigned a Tazewell age. The existence of older lacustrine deposits at depth is, however, not only possible, but highly probable, for similar lacustrine deposits in tributary valleys were probably developed in response to the production of pre-Tazewell valley trains. Whether these pre-Tazewell lacustrine deposits in tributary valleys were removed by subsequent erosion, before the Tazewell sedimentation, is not known, but it is likely that some remain concealed at depth. If so, the thickness of lacustrine deposits is not a measure of the amount of Tazewell alluviation.

PHYSICAL PROPERTIES

The lacustrine deposits where least weathered are bluish-gray to gray calcareous clayey silts (table 4). In places they are structureless; elsewhere, there are indications of laminated horizontal bedding. Concentrations of clay and silt rarely give an appearance of varves. Where weathered, the color may be light brown, buff, light yellow, or ashen white. Commonly outcrops are mantled by myriads of calcareous nodules weathered from the lacustrine deposits just below the zone of surficial leaching. A few rare limonite concretions occur on the weathered surface. Fresh-water fossils are infrequent, except at a few localities.

Where well exposed in deep cuts, the lacustrine silts show a remarkably developed profile of weathering; the zone of leaching ranges to depths of 3 to more than 6 feet below the surface, averaging about 5 feet.[9] The surficial zone, in general about 8–12 inches thick, consists of a structureless compact noncalcareous silt from which the clay fraction has been largely removed by illuviation. Through an ill-defined transitional zone, the surficial zone merges with an underlying zone 2–4 feet thick that breaks into hard subangular to angular particles that are small and dicelike at the top but as much as 1.5–2 inches in diameter below. These particles are coated by thin clay skins. In the lower few inches of this zone, where particles become indistinct, the material effervesces slightly with dilute hydrochloric acid, indicating incomplete leaching.

TABLE 4.—*Mechanical analysis of typical lacustrine clayey silt (sample 152551) of Tazewell age*

[Analysis by P. D. Blackmon. Locality, NW¼SE¼ sec. 8, T. 7 S., R. 8 W., Yankeetown (Ind.-Ky.) quadrangle]

Distribution, in percent by weight, for indicated grain size in phi units

Gravel	Sand (0.5 percent)					Silt (80.8 percent)					Clay (18.7 percent)		
−2 to −1	−1 to 0	0–1	1–2	2–3	3–4	4–4.5	4.5–5	5–6	6–7	7–8	8–9	9–10	10+
0	Tr.	Tr.	Tr.	0.1	0.4	1.3	16.3	42.7	15.9	4.6	3.2	1.5	14.0

Below this zone the clayey silts are calcareous. Commonly the upper 2 feet or so is high in clay, presumably from the introduction of illuvial clay particles carried downward from the overlying zones. Its top is generally marked by a heavy concentration of small (generally less than 0.5 in. in diameter) irregular knobby calcareous nodules, here termed "popcorn" nodules because of their superficial resemblance to popcorn on the weathered surface (fig. 9, top). The clayey zone is generally compact, except for films of calcite; rarely, horizontal plates of calcium carbonate as much as 0.25 inch thick and 8 to 10 inches long may occur as in the railroad cut in the NE¼NE¼, sec. 35, T. 6 S., R. 6 W. Below the clay-enriched zone, the compact calcareous silts commonly contain smooth rounded calcareous nodules (fig. 9, bottom), which, where flattened, tend to have their long axes parallel to the fine laminations of the clayey silt matrix. The differences in shape of the nodules suggest that the popcorn nodules are secondary, owing to redeposition of the carbonates leached from the surficial zones, and that the rounded ones below are primary, or syngenetic with the deposition of the lacustrine silts.

Rarely, near the mouths of valleys, small pebbles of quartz, chert, jasper, and quartzite may be scattered in the deposits; no igneous pebbles have been found. These pebbles are assumed to have been washed in from the main valley during periods of unusual flooding.

Thornbury (1950, p. 17) has pointed out that whereas the percentage of calcium carbonate in the lacustrine sediments generally decreases upvalley, in the larger valleys the "highly calcareous" deposits may extend for several miles back from the main valley "sluiceway" that was the source of the sediments. Furthermore, he states that, "This is particularly noticeable in the case of the lacustrine plain in Little

[9] Fidlar (1948) noted the average depth of leaching in the Wabash Valley to be about 52 inches; Thornbury (1940) estimated the average depth of leaching in the contemporary till to be about 51 inches. It is estimated that the average rate of leaching is approximately 3.5 inches in 1,000 years in the Owensboro area.

FIGURE 9.—Calcareous nodules from lacustrine deposits of Tazewell age. Irregular nodules (top) are typical "popcorn" nodules of secondary origin. Smooth nodules (bottom) are of primary origin; found largely below "popcorn" nodules.

Pigeon Creek, where the lake deposits are highly calcareous for a distance of more than 15 miles from the Ohio River." Whereas in general the calcareous material seems to decrease upvalley from the valley mouth, this seems to be the result of thinning of the deposits to a point at which they are completely leached. Also, the lowering and final disappearance of the terrace scarps upstream, where lacustrine deposits merge imperceptibly with the normal noncalcareous flood-plain deposits of the streams, complicates the determination of the original character of the lacustrine sediments at depth, so that it is not always possible to critically evaluate the amount of calcium carbonate originally present. It appears reasonable to believe that all backwater lacustrine sediments were calcareous at the time of deposition, but that the thickness, leaching, and flood-plain alluviation at the head of the lakes provide a false impression of the amount of calcareous material originally present.

In Little Pigeon valley, calcareous lacustrine clayey silt was not deposited 15 miles back from the main stem of the Ohio River, as suggested by Thornbury, for at the time of its deposition the Lake Drain-Little Pigeon channelway held an alluviating stream. Thornbury's map (1950, fig. 3) indicates his belief that the entire Lake Drain-Little Pigeon channelway and its tributary valleys were occupied by a glacial lake rather than by the diversion channelway (pl. 1). North of the Owensboro quadrangle, where Little Pigeon Creek is tributary to the diversion channelway, there is an extensive lacustrine flat separated from the channelway by a prominent terrace scarp that extends almost completely across the valley (Fuller and Ashley, 1902; Veatch, 1898a, b). These lacustrine sediments, at an altitude comparable to those at Bullocktown, are calcareous at depth and contain the characteristic zone of popcorn nodules for a distance of several miles north of the terrace scarp, whose position seems to have been almost coincident with the margin of the valley train in the Lake Drain-Little Pigeon channelway.

FAUNA AND ITS ENVIRONMENTAL IMPLICATIONS

Shells were collected at only four localities in the Owensboro area from the clayey silts of the lacustrine beds of Tazewell age, for in general the lacustrine deposits are not highly fossiliferous. Nearshore deposits along Jackson Creek, tributary to the main Ohio valley, are represented by two collections; the Willow Pond Bed, tributary to Little Pigeon channelway, is represented by a single collection. By far the best collection from the standpoint of abundance and variety of specimens comes from a locality 1¼ miles west of the Owensboro quadrangle in a small unnamed tributary to the Little Pigeon channelway.

Woody material has not been recovered from the lacustrine deposits in the Owensboro quadrangle, although wood is commonly reported to have been encountered in the digging of wells on the lacustrine flats. Wood recovered from lacustrine deposits near Yankeetown, 4¼ miles west of the Owensboro quadrangle, has been assigned a Tazewell age on the basis of a carbon-14 date of 19,940±300 years B.P. (Rubin and Alexander, 1960, W–645).

The faunal assemblage (table 5), with the exception of a few land gastropods, believed to have been washed into the lacustrine basins, consists of freshwater forms whose habitat is either that of shallow water or marshy flood plains with a cover of decaying vegetation. The habitat of only one species, *Helisoma truncata*, is that of relatively deep, open water. The recovery of this shell from near the center of Willow Pond Bed suggests that at that locality there was a relatively deep, permanent body of open water. At other sites the fauna does not demand that the shallow

TABLE 5.—*Fauna of Wisconsin (Tazewell) age from the Owensboro quadrangle and adjacent areas*

[Fossils in clayey silt identified by J. P. E. Morrison, U.S. National Museum, and in loess by Cornelia C. Cameron, except as noted]

Genus and species	Locality								
	Lacustrine clayey silt				Loess				
	1	2	3	4	5	6	7	8	9
Land gastropods									
Allogona profunda (Say)									X
Anguispira alternata (Say)						X	X	X	X
Discus cronkhitei (Newcomb)				X			X	X	X
Euconulus fulvus (Müller)								X	
Gastrocopta armifera (Say)					X			X	
Hawaiia minuscula (Binney)		[1] X		X					
Helicodiscus parallelus (Say)								X	
Hendersonia occulta (Say)							X	X	X
Polygyridae (immature)							X		
Retinella electrina (Gould)	X	[1] X							
identata (Say)								X	
rhoadsi (Pilsbry)								X	
Stenotrema barbatum (Clapp)								X	X
fraternum (Say)				X				X	
hirsutum (Say)						X			
Succinea avara (Say)		[2] X		X		X			
avara vermeta (Say)								X	
sp	X	X							
Strobilops labrinthica (Say)								X	
Triodopsis multilineata (Say)						X			
tridentata (Say)					X				
Vallonia gracilicosta Reinhardt(?)								X	
Vertigo gouldi (Binney)								X	
modesta (Say)								X	
nylanderi (Sterki)								X	
Fresh-water gastropods									
Amnicola lacustris (Pilsbry)	X	X							
limosa (Say)	X	X							
limosa porata (Say)				X					
Cincinnatia integra (Say)				X					
Fossaria exigua (Lea)	X			X					
modicella (Say)	X	X		X					
obrussa (Say)				X					
parva (Lea)	X	X		X					
Gyraulus circumstriatus (Tryon)	X	X		X					
parvus (Say)	X	X		X					
Helisoma anceps (Menke)				X					
campanulatum (Say)	X			X					
truncata (Miles)			[2] X						
Physa gyrina (Say)	X	X							
elliptica (Lea)			[2] X						
sp				X					
Planorbula armigera (Say)			[2] X						
Pomatiopsis lapidaria (Say)	X	[1] X		X					
Probythinella lacustris limafodens Morrison		X		X					
Stagnicola caperata (Say)	X	X		X					
elodes (Say)	X	X		X					
exilis (Lea)	X	X	X						
Valvata sincera (Say)	X	X		X					
tricarinata (Say)	X	X		X					
Fresh-water pelecypods									
Anodonta cf. *A. grandis plana* (Lea)				X					
sp	X								
Musculium securis (Prime)(?)	X	X							
Pisidium cf. *P. abditum* Haldeman	X	X							
compressum laevigatum Sterki(?)				X					
variabile Prime(?)	X	X		X					
ventricosum Prime(?)	X	X							
sp			[2] X						
Sphaerium occidentale Prime(?)				X					
sp			[2] X						

[1] Identified by Morrison and Cameron. [2] Identified by Cameron.

Localities:
1. Clayey silt in cut bank of Jackson Creek, NE¼NW¼, sec. 3, T. 8 S., R. 7 W.
2. Clayey silt in shallow ditch at intersection of county roads, SW. cor., sec. 35, T. 6 S., R. 7 W.
3. Clayey silt of Willow Pond Bed along Willow Pond Ditch, NW¼SW¼, sec. 24, T. 7 S., R. 7 W.
4. Interbedded silty clay and clayey silt along small tributary of Little Pigeon Creek, SW¼NE¼, sec. 11, T. 7 S., R. 8 W., Yankeetown quad.
5. Roadcut through loess at east end of Main St., Rockport, NW¼NE¼, sec. 26, T. 7 S., R. 6 W.
6. Roadcut through loess mantle of sand ridge, about 700 ft southwest of U.S. Highway 60, 1.4 miles west of junction with Kentucky State Highway 144.
7. Loess at abandoned strip coal mine at extreme northeast margin of Bon Harbor Hills, Ky. (See section 4, p. 61.)
8. Loess of hillside cut at Warrick Plant of the Aluminum Co. of America, E½SE¼, sec. 8, T. 7 S., R. 8 W., Yankeetown quad.
9. Loess of deep roadcut on south side of Indiana State Highway 66, NW¼SW¼, sec. 1, T. 7 S., R. 9 W., Newburgh quad.

lakes were permanent bodies of open water, but suggests that some may have been marshy flats surrounding ponds constricted during periods of dessication. Lime secreting algae (*Chara*) in the sediments at locality 4 indicates, however, that that particular site, like that of Willow Pond, was never completely dry. It is suspected that the high content of silt in the waters poured from the major valleys into the tributaries may have inhibited the growth of some of the more common types of pearly fresh-water pelecypods.

In general, most species identified from the lacustrine deposits continue to live in this region today under suitable ecologic conditions, indicating that the climate at the time of lacustrine deposition was not unlike that of the present. A definite northern climate affinity, however, is indicated by *Valvata sincera*, *Stagnicola caperata*, and *Stagnicola elodes*, whose present habitat is 200–300 miles to the north. Even these, however, do not suggest a climate radically different from that of the present.

VALLEY TRAIN AND TERRACE OF CARY AGE

Terrace remnants, commonly poorly defined, occupy a position intermediate in altitude between the Tazewell terrace and the flood plain of the present river (Lee, 1916; Theis, 1922). These are erosional remnants of a once-continuous valley train of Cary age, whose surface may have been modified by the effects of the Maumee torrent that coursed down the Wabash valley from Glacial Lake Maumee during recession of the ice sheet of Cary age (Fidlar, 1948). How far upstream the affects of the torrent were felt in the Ohio valley is not known, but it may have reached as far as the Owensboro quadrangle, about 100 river-miles above the confluence of the rivers. Thus, the geomorphic history of the Cary terrace in the Owensboro area may be more complex than that of the earlier Tazewell terrace and is closely associated with the geomorphic history of the Wabash valley.

In the Owensboro quadrangle the uneroded surface of the Cary terrace is about 10–12 feet above the level of the flood plain and 10–15 feet below that of the Tazewell terrace. Only rarely does a well-defined scarp separate the two terrace levels; commonly they are separated by gentle slopes. In many places the Cary terrace is barely distinguishable from the flood plain, except on the basis of its slightly higher altitude and differences in surface configuration. Shallow channels provide a low relief slightly greater than that of the Tazewell terrace surface and less than the relief of the broadly undulating river flood plain. Interfluves between channels in places assume streamlined shapes, as in the area northeast of Rockport (pl. 1;

fig. 3). The streamlined pattern in the constricted Lake Drain valley and upper part of the Little Pigeon valley changes to a dominantly meandering pattern in the lower Little Pigeon valley. West of the Bon Harbor Hills these two pattern types are intimately associated (pl. 1).

Unlike the Tazewell terrace, whose surface lies above the highest flood waters in the Owensboro area, the Cary terrace is frequently flooded and supports no sand dunes. Northeast of New Bethel Church (sec. 6, T. 7 S., R. 5 W.), however, its surface is extremely sandy and a few low sandy prominences rise to a height of 400 feet. Lack of dunal topography leads to the belief that these sandy areas are not the result of eolian action, but more likely are floodwater deposits.

There is relatively little observable difference between the surficial material of the Cary terrace and that of the present river flood plain, nor is it possible to differentiate the surficial materials comprising the Cary and Tazewell terrace deposits. Only a few exposures in the Cary terrace reveal the character of the sediments at depth. In the Little Pigeon valley at a depth of 5–7 feet, coarse noncalcareous sands and fine "pea" gravel occur. These tend to be open, although in places they are in part cemented by limonite. Gravel is largely cherty but includes some quartzite and crystalline rock. No exposures are such that direct comparison can be made between undoubted Cary and Tazewell valley-train deposits. General impressions are that in composition they are similar, but that the younger deposits contain a larger percentage of finer grained components, expectable because of the greater distance to their source—for the advance of the ice sheet of Cary age into the Ohio drainage basin appears to have been far short of that of the Tazewell—and because they may be reworked from older deposits upstream. Larger particles in deposits of Cary age may be locally derived from the older Tazewell deposits. Sandy silts overlying the coarser gravelly beds of the Cary valley train are commonly well oxidized and mottled with limonite stains. Frequently numerous small concretions and pipes of limonite, formed about rootlets, are concentrated in well-defined zones in the sandy silt, indicating swampy or boggy conditions. These sandy silts, normally yellow, grade upward in many places through a buff-colored zone into an ashen-white silt, believed to owe its color to oxidation of the surficial humus, following drainage and cultivation of the land.

Rarely, as in a gravel pit temporarily opened at Rock Hill (NW¼ NE¼, sec. 2, T. 7 S., R. 6 W.), is relatively coarse gravel exposed below the terrace surface. There, a few pebbles with diameters as much as 4 inches occur in crossbedded layers intercalated with coarse sand and fine gravel; the whole sequence is separated from the overlying finer material by a 4-inch gravel layer well cemented by limonite. The general appearance of this material suggests that the gravel may be part of the eroded Tazewell valley train, beneath a thin deposit of Cary age.

Where creeks have cut shallow channels into the mottled sandy silt of the Cary terrace surface, their beds may be very irregular because of cavernous, or vuggy, pockets eroded in the seemingly massive silt. These pockets represent the removal of the original unoxidized gray silt, or, more likely, of a deoxidized silt filling crayfish holes developed long ago on the boggy flats. In places creek beds appear to be gravelly because of the concentration of vast numbers of limonite pellets eroded from the banks and bottoms. These features all point to a long-continued swampy environment following deposition of the sediments. For this there is ample evidence in historic time, for much of the surface of the Cary terrace was poorly drained and swampy in the early 19th century and is dry now only because of extensive tiling and the construction of drainage ditches.

The sandy silt layer on the Cary terrace surface is, in general, 3–6 inches thick. Its lower boundary is transitional with an underlying clay-enriched zone 10–12 inches thick that is somewhat crumbly, breaking into irregular particles 1 inch or more in maximum diameter. Below these is a sandy silt, oxidized and in part or wholly leached, that commonly merges at depths of 5–15 feet with the underlying silty gravelly sand assigned to the Cary valley train. Where cultivated, the surficial sandy silt may appear to be calcareous because of the use of "lime" as fertilizer.[10]

The average thickness of the Cary valley-train deposits is not known. Persumably, the base lies below the pool stage of the river and is not directly observable, nor can these deposits be distinguished from the earlier Tazewell deposits in available well records. However, considering the relatively brief period available for degradation during the Tazewell-Cary interval, and the fact that the amount of debris carried by the river was much less than in Tazewell time, it can be assumed that deposits of the Cary valley train are of relatively small volume and thickness.

With recession of the Cary ice sheet, river regimen and valley train aggradation were modified along the

[10] Care should be taken in soil sampling throughout the Owensboro area to be certain that surficial deposits have not been contaminated by the use of powdered or finely crushed limestone as fertilizer. Continued use of "lime" may result in an accumulation of calcium carbonate at depths adjacent to the zone of plowing.

Wabash and Ohio Rivers. In the upper Ohio drainage basin, the areal extent of the Cary ice sheet was so limited that only a minor recession was necessary to free the drainage basin of ice and establish a nonglacial regimen for the river. However, as pointed out by Fidlar (1948), recession of the Cary ice sheet in the drainage basin of the Wabash was complicated by the development of Glacial Lake Maumee, which acted as a settling basin. Clear water was for a time poured as a "torrent" from the lake through a spillway into the Wabash River (Fidlar, 1948; Thornbury, 1958). Along the upper Wabash valley, the torrent was competent to erode; but downstream its competence decreased, and at some undetermined point above the river mouth, the Wabash, flowing at a lower gradient and overloaded by debris from erosion upstream, changed from a degrading to an aggrading stream. That the surface of this, the Maumee terrace of Fidlar, is aggradational in the lower Wabash valley is attested by its mantle of silt and fine sand and by sand dunes, none of which would be expectable on an erosional surface such as postulated by Fidlar. With continued recession of the ice in late Cary time, a lower outlet to Lake Maumee was uncovered, diverting the waters from the Wabash basin. At that time the surface of the deposits in the lower Wabash valley was neither the surface of the Cary valley train nor an erosional surface produced by the Maumee torrent, but an aggradational surface correlative with an erosional surface upstream that had been cut below the valley train developed by outwash from the Cary ice sheet. Such a history is suggested by the findings of Wayne and Thornbury (1951) in the upper Wabash valley.

At the confluence of the Wabash and Ohio during the Maumee torrent, debris was poured into the Ohio valley, choking it and building into it a deltalike mass of debris. Because of its lower gradient and capacity, the Ohio was incompetent to move the debris spewed from the Wabash.[11] Above the confluence of the rivers, the Ohio appears to have been ponded temporarily, so that degradation by the river, normally expectable because of its nonglacial regimen, was inhibited and aggradational deposits mantled the valley-train surface with silty and clayey alluvium. How much the surface may have been elevated by alluviation in the Owensboro area is not known, but it is believed to have been relatively insignificant. Not until the waters of Lake Maumee were diverted from the Wabash valley did the Ohio become wholly freed of the influence of Cary glaciation. At that time, presumably, degradation once again supplanted aggradation along the river.

During aggradation and ponding of the Ohio the flood plain was swampy and boggy, probably so well covered by vegetation that there was no opportunity for deflation to produce sand dunes like those along the actively aggrading lower Wabash valley. No loess deposits assignable to the Cary age have been found in the Owensboro quadrangle.

Flood scour produced patterns of streamlined interfluves and crevasselike breakthroughs on the surface of the Cary terrace after degradation had been initiated by the Ohio. Floodwaters periodically pouring through the Lake Drain-Little Pigeon channelway scoured channels with streamlined interfluves, for where floodwaters were constricted, velocity was increased and scouring was at a maximum. Beyond the mouth of the constricted channelway, floodwaters deployed freely in the northern part of the Little Pigeon valley, so that scouring was at a minimum and the meandering course of Little Pigeon creek was relatively unmodified. The creek, unable to reduce its gradient because of the local base level imposed on it by the Ohio, appears to have meandered widely across the sandy silty alluvium of the Cary depositional surface, shifting its channel laterally and building low swells on point bars within its meanders (pl. 1). Because the highest points on the low swells are about the same altitude as the remnants of the terrace surface, it appears that post-Cary degradation has not only been slight but has been long continued.

During Cary time the Ohio appears to have followed a course along its eastern valley wall in the vicinity of Rockport and along its north valley wall in the vicinity of Owensboro. As the ancient channel south of the Bon Harbor Hills had been abandoned between Tazewell and Cary time, the river flowed between the Bon Harbor Hills and the Rockport island hills. A spillway, presumably occupied by floodwaters, followed the ancient channelway south of the Bon Harbor Hills and into the Green River valley west of the mapped area. Streamline interfluves indicate the effectiveness of flooding and scour through this now-abandoned channel (pl. 1).

A unique section is exposed below the level of the Cary terrace along the left bank of the Ohio in the vicinity of the navigation light about 1.5 miles northeast of Stanley, Ky. There a succession of alluvial deposits are revealed whose history is uncertain. Jutting into the water and extending from 4 to 6 feet above

[11] The character and magnitude of this effect of the Wabash on the Ohio were first brought to the attention of the writer by M. M. Leighton, who pointed out in the field, exposures in Posey County, Ind., just above the mouth of the Wabash, where deltaic sediments were deposited by waters from the Lake Maumee torrent pouring upstream into the ponded Ohio valley.

pool stage of the river (347 ft) are outcrops of an iron-stained coarse highly crossbedded poorly but variably cemented dark sandy conglomerate of valley-train origin (fig. 10). Pebbles of well-rounded chert, vein quartz, and rarely, crystalline rock are generally less than half an inch in diameter; the coarse sand grains are sharply angular. Although poorly cemented, the sandy conglomerate is sufficiently resistant to river erosion—in contrast with the unconsolidated alluvium cropping out elsewhere along the riverbanks—to inhibit lateral channel shifting. The overlying beds have been undercut by river erosion during periods of high water, so that there is a poorly defined bench that marks the irregular surface of the sandy conglomeratic beds. On this bench sandy alluvium is now being deposited and blocks of overlying beds have slumped, partly obscuring the irregular contact.

Above the sandy conglomerate and below the thick surficial deposits of silty sand is an 8- to 10-foot succession of beds; it consists of relatively unconsolidated sand in the basal 2–4 feet, overlain by finely laminated bluish-gray calcareous clay with fine sandy or silty partings, closely resembling varves (fig. 11). It is not certain whether these beds and the underlying sandy conglomerate represent continuous deposition or are separated by an unconformity, although the latter is the most likely.

The surficial deposits of this section consist of 10–14 feet of massive silty sand that shows little evidence of stratification and only an incipient soil profile. Leaching of calcareous material from the upper 6–7 feet of the material and its redeposition at depth have produced, however, a zone of secondary calcareous plates and nodules just above the impervious laminated silt and clay. The nodules occur as knobby, irregular masses, commonly spiny, with maximum diameters of 4 inches. The irregularly shaped calcareous plates, which may be as much as half an inch thick, are horizontal and may indicate vestiges of horizontal bedding within the seemingly structureless deposit.

FIGURE 10.—Crossbedded sandy conglomerate of Tazewell(?) age cropping out along riverbank near Stanley, Ky., at pool stage of river.

FIGURE 11.—Laminated silty clay cropping out in riverbank above crossbedded sandy conglomerate near Stanley, Ky. Note mattock for scale.

The age and areal extent of these beds are not known. It is possible that they are of Cary age and that the conglomerate represents valley-train deposits overlain by deposits related to the ponding of the Ohio. The character of the outcrop along the riverbank however, suggests that the deposits overlying the sandy conglomerate may represent a channel deposit on the Cary terrace. It is possible that the sandy conglomerate may represent valley-train deposits of Tazewell age, although its general aspect indicates that it is more likely of Cary age. If so, the overlying sand, laminated silty and fine-sandy clays, and the silty sands may be either the result of ponding of the Ohio at the time of the Maumee torrent or possibly a somewhat later filling of a channel cut in the Cary terrace. If the sandy conglomerate is of Cary age and its upper surface is erosional, this latter suggestion is most likely. Furthermore, the surficial material, although leached, does not appear to be as weathered as is the normal surficial material of the Cary terrace. Without further data no definite conclusions can be drawn, but it is suspected that the sandy conglomerate is of Cary age and that the overlying material is a channel filling on the Cary terrace that may possibly represent somewhat later, post-Cary deposition.

POST-CARY ALLUVIAL HISTORY

Although waning of the ice sheet of Cary age did not mark the close of the Wisconsin period of glaciation, its withdrawal from the drainage basin of the Ohio appears to mark the end of direct association of the river with continental glaciation, for the two later ice sheets, the Mankato and Valders, are not known to have extended into the drainage basin. Thus, from the time of withdrawal of the Cary ice sheet to the present, the regimen of the river in the Owensboro quadrangle has been for the most part nonglacial.

Many attempts have been made to separate a Recent Epoch from the glacial on both natural and artificial bases, but the separation has not been adequately determined and is the subject of continuing controversy (Morrison and others, 1957; Cooper 1958; Leighton, 1958a). Attempts to subdivide the Recent Epoch so as to develop a chronology based largely on climatic fluctuations recorded by various geologic and biologic events have not met with unanimous approval.

In the Owensboro quadrangle no chronology has been developed by which a Recent Epoch is separable from the glacial according to criteria used elsewhere, nor is it possible to develop locally a sequence of post-Cary events. For this reason a single time unit, the post-Cary, is used here to encompass the interval since the regimen of the river became nonglacial. It should not be construed, however, that during the post-Cary interval there have been no variations in geomorphic and biologic events as the result of climatic fluctuations, but rather that such events have not been recognized or are not at present locally decipherable. It is believed that whatever climatic fluctuations there may have been were relatively slight and that extremes of temperature and percipitation were no greater than those recorded at present during unusually cold or wet years (p. 13–14).

The exact time of withdrawal of the Cary ice sheet from the upper Ohio drainage basin, or from that of its tributary the Wabash, has not been determined other than that it is presumed to have occurred during the retreat of the ice sheet from its position of maximum extension, about 14,000 years B.P., and before readvance of the succeeding Mankato ice sheet to its position of maximum extension, about 12,400 years B.P. During this interval the regimen of the Ohio was modified and aggradation was supplanted by degradation, initiating what appears to be the final event of the river's geomorphic history in the Owensboro area, the development of the flood plain.

FLOOD PLAIN OF THE OHIO RIVER

The final event of the Ohio River's geomorphic history is the development of its present flood plain through degradation to a surface closely approaching stabilization (Johnson, 1936). Rapid at first, degradation is believed to have diminished as the river approached a graded condition until at present it appears to be negligible in the Owensboro area where river activity is now seemingly confined to lateral channel shifting.

Degradation was initiated by the nonglacial river regimen operating under conditions and principles previously described (p. 25–28). Presumably, entrenchment was at first more important than lateral channel shifting. Later, as entrenchment brought the river closer to a grade where it was just competent to transport its load during bankful stages, lateral channel shifting became dominant, as indicated by the present configuration of the river channel and the character of its flood plain.

At the beginning of the regimen of degradation, the main river channel entered the Owensboro quadrangle at a point about a mile south of its present position. Flowing to the southwest, it skirted the southeast tip of Rockport island hills, then, swinging in a wide-radius curve to the west, it flowed north of the Bon Harbor Hills and west for some 3 miles along the scarp now followed by Kentucky State Highway 331. Swinging to the northwest in a great arc across the mouth of Little Pigeon valley from the southwest tip of Rockport island hills, it left the quadrangle about 2.5 miles to the north of its present channel.

River incision, accompanied by the development of the present flood plain, has been so slight that higher floodwaters continue to spread over the Cary surface of alluviation, in places scouring and reducing it to such an extent that today it is not everywhere possible to dinstinguish between the flood plain and the modified surface. Where uneroded remnants are preserved on the Cary surface, as in the elongate ridges rising to heights of slightly more than 390 feet across the river from Rockport, weakly developed zonal profiles of weathering of the surficial alluvium indicate their relative age, for modern flood-plain soils are azonal.

Adjacent to the original Cary surface of alluviation, areas that have been lowered by river scour, or reduced to the level of the flood plain, although lacking zonal profiles of weathering, are classed as Cary terrace and not flood plain (pl. 1) in the belief that since the beginning of river entrenchment and flood-plain development the river channel has not moved across these areas. Material underlying the eroded remnants of Cary terrace have not been reworked by river action since they were deposited. Reduced remnants of the Cary surface of aggradation are separated in places from the river flood plain by flood-scoured sloughs and low scarps; elsewhere, they may merge

Good

with the flood plain so that the boundary is indefinite, the surface being indistinguishable in the field either on the basis of altitude or character of weathering of the surficial alluvium. This condition is well illustrated in the vicinity of Enterprise where the original surface of Cary alluviation has been reduced by flood scour to the approximate level of the flood plain; but since initiation of post-Cary river entrenchment and flood-plain development, the main river channel has not moved laterally across the area, which is a bedrock bench thinly mantled by alluvium. Outcrops of bedrock along the riverbank indicate that the area is rock defended and that lateral shifting of the river channel is inhibited, although floodwaters spread over it almost every year.

This seeming arbitrary distinction between terrace and flood plain is based on genesis rather than height. The flood plain of the river in the Owensboro area is here defined as the alluvial surface that has been constructed largely by lateral accretion of channel deposits along the shifting river and perhaps by overbank deposition during flooding. This definition follows in general that suggested by Leopold and Wolman (1957), in that it is the area covered by floodwaters on an average of once every 1–2 years. Records show that with a frequency of 2 years, floodwaters reach an altitude of 381.8 feet at Owensboro (384 ft at Rockport)—the altitude of highest flood-plain alluviation. Higher floodwaters (fig. 12) may cross higher parts of the Cary terrace, apparently scouring along sloughs and rarely depositing fine sandy sediments, as reported by local residents. No such scouring or deposition has been reported on the higher parts of the flood plain, although it is possible that some deposition in sloughs and along riverbanks accompanies almost every flood.

The question can be raised as to whether these parts of the Cary terrace interpreted as reduced by flood scour may not be the result of overbank deposition and thus a part of the body of the present flood plain. Despite the fact that there is no distinction in profile development between the azonal soils of the reduced terrace remnants and those of the flood plain, and that there may be no appreciable difference in their general height above the level of the river, those areas mapped as Cary terrace (pl. 1) are held to have been reduced by flood scour and so located that in post-Cary time the river channel has not moved across them. This conclusion is based on the geographic position of such terrace remnants in relation to the laterally shifting river, the pattern of the shallow surficial sloughs, which is in general unrelated to that of the flood plain, and the fact that local residents report no widespread deposition on the flood-plain surface after flooding—a conclusion reached by Wolman and Leopold (1957). It is possible, however, that minor amounts of surficial alluvium may result from overbank deposition during floods greater than the normal 1- to 2-year floods that delimit the height of modern flood-plain alluviation. Such overbank deposition during the flood of 1937 is reported by local residents to have resulted in a thin mantle of sand on the Cary terrace surface in a few scattered localities. The general impression is that during floods of sufficient magnitude to cover the Cary terrace, scouring by floodwaters is far more important than deposition.

That the flood plain itself may be subject to some deposition in swales is suggested by archeologic findings in the adjacent Yankeetown topographic quadrangle. There, along the riverbank in secs. 16, 21, and 22, T. 7 S., R. 8 W., several ancient fire pits with burned clay pellets, charcoal, and rock have been found at depths ranging from 7.4 to 10.95 feet below the surface of the flood-plain alluvium (Curry, 1954). It is suggested, however, that this may be the result of deposition in swales on the flood plain during lateral channel shifting and development of the point bar rather than deposition on an aggrading flood-plain surface.

The amount of lateral shifting and flood-plain development by the river is readily apparent at each bend and is especially well displayed in the point bar across from Owensboro. There the river has moved almost 3 miles to the south in post-Cary time, cutting into the older alluvium of the left bank and building a point bar with characteristic swell (scroll) and swale topography (fig. 2). Continued channel shifting to the south is inhibited at present by the relatively competent beds, at Hubert Court, by the bedrock of the Bon Harbor Hills, and by artificial riprapping of the bank. This has constricted the channel, so that in times of flooding, overbank flow pours across the point bar in an attempt to develop a shorter channel by streaming through crevasselike breakthroughs in the low alluvial ridge along the east margin of the point bar. This low ridge, extending from the tip of Rockport island hills to the vicinity of the Bon Harbor Hills, is composed of sandy alluvium and probably has been developed by overbank deposition, possibly during the waning phases of flooding when coarser material that moves out of the channel is trapped in vegetation marginal to the river. Along the west side of the point bar no such ridge has developed, because there the flood waters rejoin the main river channel after having presumably lost their load. Although the product of overbank deposition, the ridge is not a true

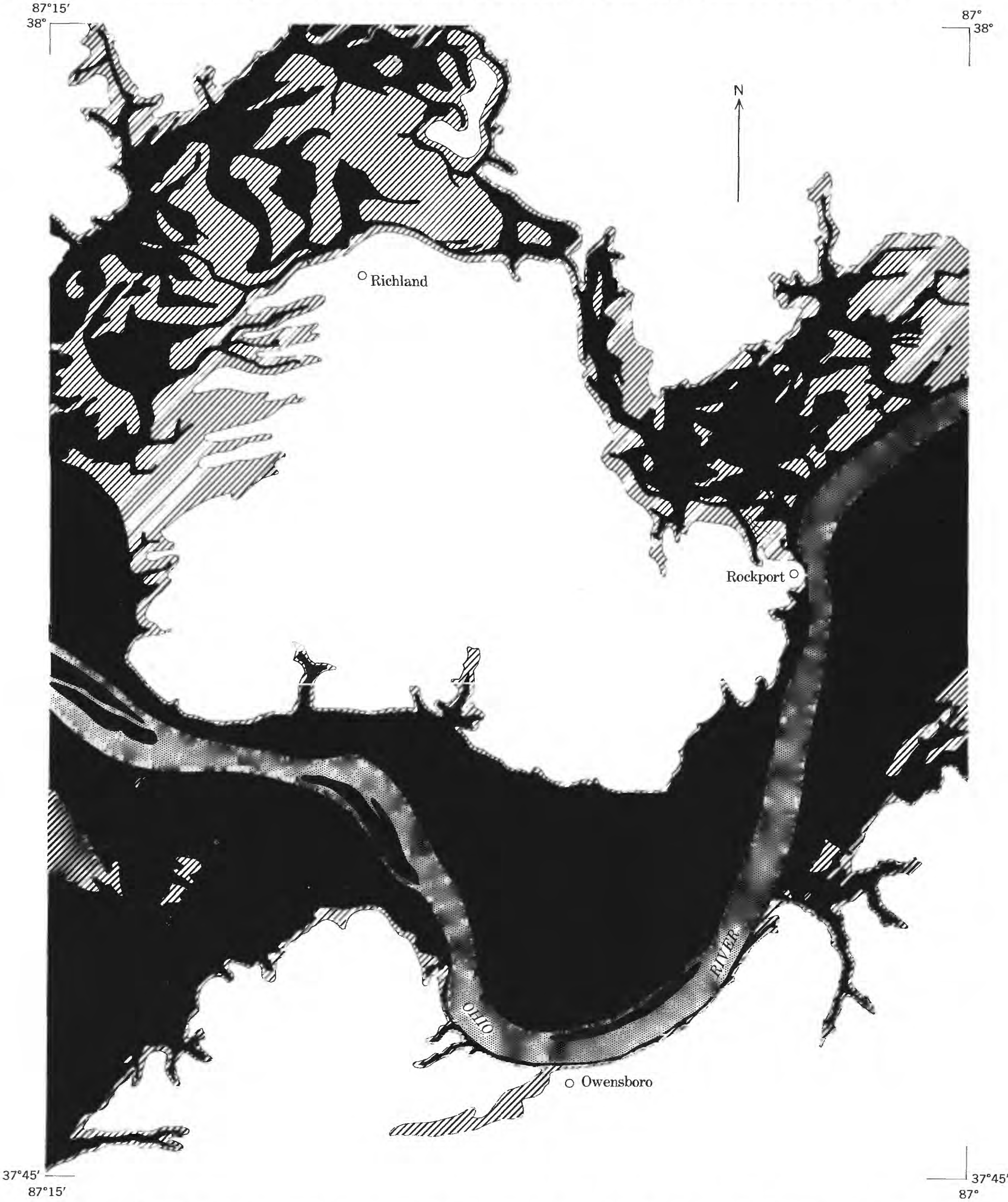

FIGURE 12.—Owensboro quadrangle, showing extensive areas covered by floodwaters in 1884 and 1913 (solid black), and in 1937 (diagonal lines). The 1937 flood is the greatest of record. Data from U.S Army Engineers.

natural levee, as defined by Leopold and Wolman (1957), for it follows the convex rather than the concave bank of the river. The belief that it is a natural feature rather than one artificially imposed rests on the fact that it was apparently well developed before the white man entered the Ohio valley.

The low ridge of sandy alluvium fringing the concave riverbank northeast of Rockport is a well-defined natural levee. Rising almost to the height of the nearby Cary terrace, it is separated from the terrace scarp by a conspicuous slough that carriers floodwaters parallel to the main channel. Across the river, on the convex Kentucky bank, is a sandy alluvial ridge similar in origin to that of the point bar across from Owensboro. Here, deflection and constriction, of the river by the bedrock outcrops at Rockport cause floodwaters to escape from the main channel and flow in a more direct course to the southwest along the margin of the reduced Cary terrace. Crevasselike breakthroughs are common. Where the river is unrestricted, as in the reach below the point bar across from Owensboro, no typical natural levees have been built along the outside of the river bends.

Elongate islands occur on the convex bank at bends of the river opposite points where channel depth is greatest. Each island is separated from the riverbank by shallow sloughs, and each rises to the height of flood-plain alluviation. With continued shifting of the river channel, each island will eventually become landtied, as is Little Yellow Bank (p. 5). The exact mechanics for development of these islands, which seemingly form the swells of the point bars, is not thoroughly understood. It is suggested that the islands are initiated by deposition of gravel bars following breakthroughs of overbank floodwaters across the point bars. At that time, floodwaters following the main channel at the apex of the point bar would suddenly be decreased, and deposition would take place where previously there had been the deepest scour. It has been reported (Matthes, 1941; Schultz and Cleaves, 1955) that during periods of flooding, the thread of maximum velocity of a river tends to shift from the concave to the convex side of the river bend. The sudden decrease of floodwaters causes a shifting of this thread of maximum velocity toward the concave side of the bend, producing rapid deposition of coarser material on the convex. Such islands are believed to grow by lateral accretion and perhaps some overbank deposition in times of average seasonal floods. Once landtied, the islands become swells on the point bars, and therefore, should have buried cores of coarse alluvium that represent the original gravel bar by which they were initiated.

At Owensboro, the deepest point of the river channel along the left bank is 319 feet, slightly more than 60 feet below the surface of the alluvial Yellow Bank Island and the flood-plain surface. This indicates a thickness of more than 60 feet of alluvial flood-plain clay, silt, sand, and gravel. Since depth of scour at times of maximum flooding is not known, it is not possible to determine the actual thickness of alluvium now in the process of stream transportation. It is reasonable to believe, however, that the gravel and probably a large part of the sand and silt now being moved by the river are derived locally from earlier alluvium of valley-train origin and that an appreciable amount of the finer silt and clay carried into the main stream by tributaries is derived from erosion of loess deposits of the hill lands. In general, gravel is not apparent in exposures of the sandy, silty, and clayey alluvial deposits that mantle the flood-plain surface. Scattered stringers or thin lenses of fine gravel indicate that coarser material is being moved and occurs at depth, as indicated by well records and by dredging operations along the river channel. The surface soils of swells on point bars are sandy silt; the soils of the swales are heavy, silty, humic clays, commonly with a fetid odor, and iron staining from rapid oxidation of organic ferrous oxides.

Before canalization of the river, extensive sand bars were exposed at low water along the convex banks of the meanders; since canalization, they are submerged below the pool stage of the river. Formerly, when extensive sand bars were developed, a slight rise of river level would float dry surface sand from the bars and carry it slowly downstream (McKelvey, 1941).

A unique feature along the riverbank at Enterprise is a small area of textured soil or "stone packings" (Troll, 1958). There a small outcrop of shale of Pennsylvanian age weathers to produce a platy rubble that is concentrated on a sandstone outcrop just above pool stage of the river (fig. 13). The rubble fragments, as much as 4 inches in maximum length and one-quarter of an inch thick, are clustered edgewise around blocks of sandstone or small willows, with a rosettelike pattern similar to those described by Gregory (1930) and Rozanski (1943) and considered to be formed by differential freezing and thawing in a fluctuating water-soaked environment. Normally such features are not associated with an environment like that of the Owensboro area and, if ancient, might

FIGURE 13.—"Stone packings," or "rosettes," of tabular shale fragments along the river margin at Enterprise, Ind. These frost-formed features are developed under present climatic conditions.

be referred to a rigorous so-called periglacial climate. This however, is not so, as these features are being actively developed under the present climatic conditions.

Normal 1- to 2-year floods along the Ohio cover the extensive flood plain but cause little damage or inconvenience. Some great floods, however, may do extensive damage and isolate Rockport island hills by pouring through the Lake Drain—Little Pigeon channelway (figs. 12, 14). At least four times (1884, 1913, 1937, and 1945) floodwaters with reported high velocity have poured through this channelway.

The greatest of all floods in the Owensboro area, that of 1937, rose to a crest of 394 feet on the right bank at Owensboro (Grover, 1938), about 10 feet above the upper surface of flood-plain alluviation. This flood, however, did not reach to the surface of the Tazewell terrace, nor did it flow through the broad depression in that surface from Owensboro, south of the Bon Harbor Hills, to Green River valley. Mansfield (1938) reported that not only was this the greatest flood of historic time, but that it probably had never been exceeded in certain sections of the valley since the development of the present flood plain. He found that flood deposits were generally thin and composed of clayey silts and sands, commonly interlaminated. He noted a great similarity in mechanical composition between the loess of the hill lands and the river silts deposited by the flood, thus leading to the conclusion that much of the debris transported by the river had been carried into it by tributary streams eroding the adjacent loess-mantled hill lands.

Since the coming of the white man into the Ohio valley, significant changes that have affected the river have been brought about. With the widespread removal of the forest cover and cultivation of hill lands, runoff has been accelerated with consequent increased erosion of the unprotected land surface (fig. 5), so that more water and more debris are carried to the river in brief intervals. Artificial drainage of the alluviated lowlands through tiling and ditching has likewise increased runoff by destroying the extensive marshes and swamps that were important regulators of surficial drainage. Regulatory dams, constructed to maintain a suitable navigational channel at periods of low water, have affected natural conditions, for through failure of the river level to drop below a given pool stage, a larger body of ground water is maintained at all times in the alluvium than would be under natural conditions. At periods of natural low water, large quantities of ground water would be drained from the now permanently saturated alluvium into the stream, providing a reservoir capable of replenishment at times of high water. Thus, the alluviated lowlands no longer act as a gigantic sponge, absorbing flood and rain waters, and then permitting their slow return to the main channel. As a result, it is possible that floods are now somewhat higher and of shorter duration than under natural conditions. It is suggested that during present-day flooding the river carries a greater load than under natural conditions, but that its competence remains virtually unchanged.

HILL-LAND DEPOSITS

The widespread mantle of windblown silt, or loess, that blankets the hill lands of the Owensboro quadrangle is separable into a stratigraphic sequence representing at least three distinct units.

As used here, the term "loess" designates a nonstratified relatively homogeneous eolian silt deposit composed largely of particles of silt and some clay and fine sand. Units of the sequence of loess deposits have demonstrable regional distribution and characteristic properties by which they can be correlated with, or separated from, other units on the basis of age relations. They are distinct units, but as they are not mappable individually, they are not regarded as formations. So continuous is this loess mantle that bed-

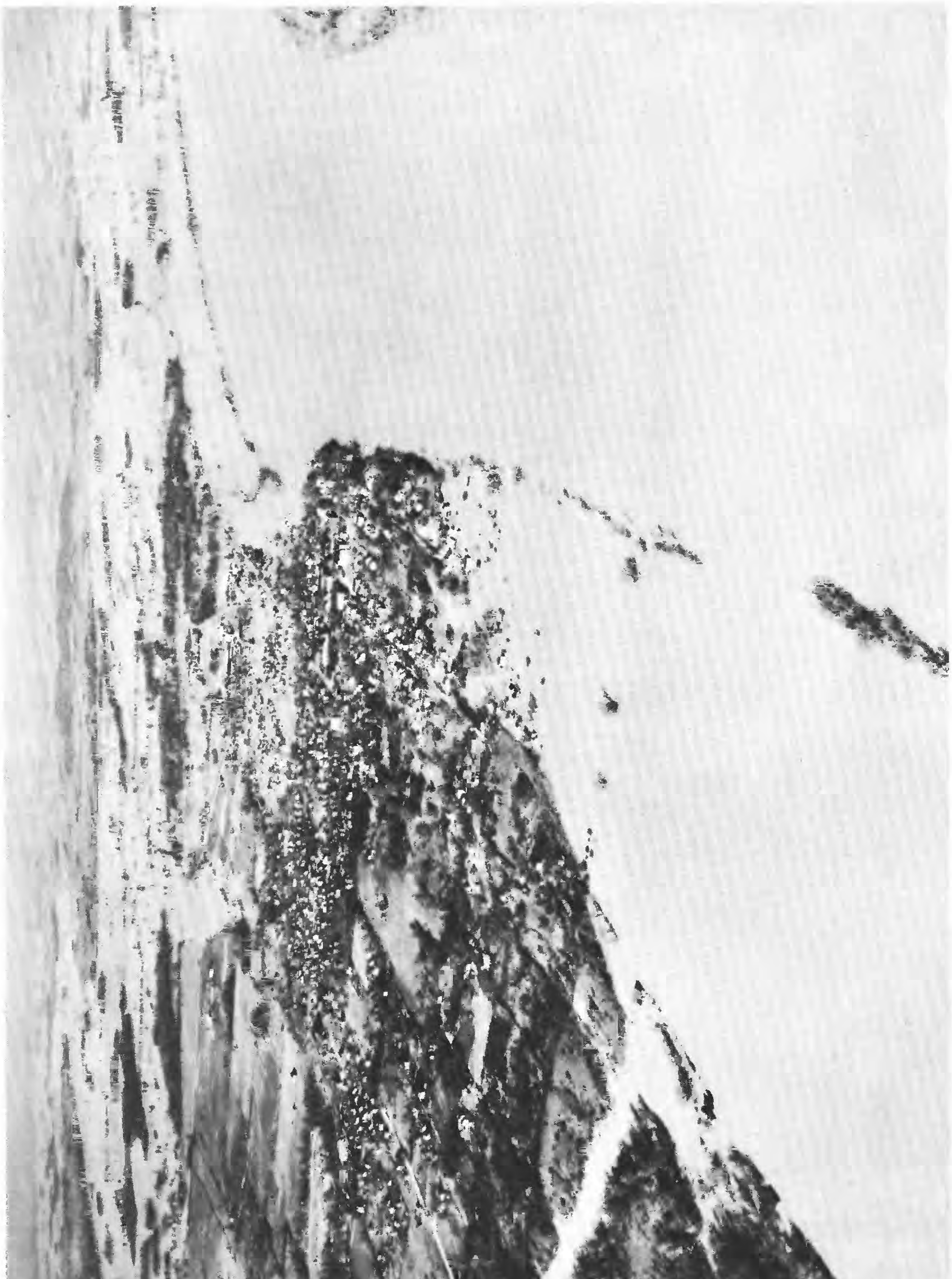

FIGURE 14.—Aerial photograph of Ohio valley at Rockport, Ind., during flood of 1937. Note tree-lined riverbanks in foreground, and in background, floodwaters flowing across Cary terrace to Lake Drain-Little Pigeon channelway in left background. Commercial photograph; source not known.

rock is exposed only in a few bluffs, in roadcuts, and in excavations; even the highest summits of the Coal Knobs are mantled by several feet of loess. Steep slopes just below the summits are thinly veneered, and bedrock is normally concealed except in the steepest ravines, where erosion is most active, or adjacent to coal mines, where erosion has been artificially stimulated.

The most casual inspection of the Owensboro area will show that on hill lands closest to the alluvial river lowlands the blanket of loess is thickest; away from the alluvial lowlands the loess grows progressively thinner. Unusually thick loess mantles the Bon Harbor Hills and is especially well exposed along abandoned quarry walls of an open-pit coal mine on the northeast side (fig. 15). The apparent thickness of the loess may be, in places, grossly exaggerated where exposed sections are not perpendicular to the underlying rock surface, or where loess mantles sand dunes so deeply that their topographic expression is obscured or lost. Thinner loess deposits, commonly from 3 to 5 feet, mantle hills farthest from the main river valley in the northeastern and northwestern parts of the area.

In artificial exposures the loess shows a tendency to stand with vertical faces of remarkable, but characteristic, stability. Slumping, however, is common and slumped blocks of loess several feet in diameter,

FIGURE 15.—Outcrop of loess overlying bedrock at abandoned coal mine at northeast margin of Bon Harbor Hills, Ky. (See section 4, p. 61.) *A*, Loveland Loess; *B*, Farmdale Loess; *C*, Peorian Loess.

separated from the face of the exposures along vertical fractures, have built up accumulations that reestablish a stable slope. Slumping of thick exposures appears to have been initiated through failure of damp powdery calcareous relatively unweathered loess at the bottom of the exposures to support the overlying leached and compact mass in which the vertical fractures develop. Where well-drained at depth, slumping does not occur as readily.

ORIGIN

For many decades the origin of loess was a problem that evoked much controversy. Many diverse origins were postulated, revised, combined, and debated through a welter of scientific papers (for a generalized historical summary, see Scheidig, 1934, and Thornbury, 1937). Two theories of origin, an aqueous and the now generally accepted eolian, were final contenders for ultimate approval, being either vigorously supported, cautiously approved, or assiduously avoided.

In southwest Indiana, where loess deposits are extensive, an early attempt was made to solve the problem of origin by separation of the surficial deposits of silt, sand, and some intercalated gravel into two categories—a marl-loess and a common, or bluff, loess (Fuller and Ashley, 1902; Fuller and Clapp, 1903, 1904). The two categories were distinguished largely on physical and chemical character and topographic position of the deposits. Stratified deposits of calcareous silt, sand, and gravel, reported at altitudes of 500 feet above sea level, were designated marl-loess and considered to be of dominantly aqueous origin. The common, or noncalcareous and nonfossiliferous bluff, loess on the higher hills was assigned a dominantly eolian origin. Where both types are present, the conclusion was reached that both modes of origin were in part responsible for the deposits. Thus, despite division of the deposits into two distinct types, there resulted in effect a combined theory of aqueous-eolian origin that failed to satisfy the field conditions.

E. W. Shaw (1915b) in his review of the loess problem in southwest Indiana showed that those deposits that could be classed as true loess were wholly of eolian origin and that most of the so-called marl-loess was not loess, but dune sand or water-laid deposits associated with valley alluviation. Furthermore, he pointed out that aqueous deposits did not occur above the level of the highest alluviation of the valleys, but that dune sand of two or more ages, assigned to the so-called marl-loess, occurs both near the valley bottoms and on the bluffs and hill lands adjacent to the river valleys. The dune sand he rightly interpreted to be intimately associated with eolian loess deposits. The relatively homogeneous bluff loess was shown to be, contrary to the earlier reports, calcareous at depth and to contain shells of air-breathing mollusks.

Following Shaw's keen analysis and resolution of the loess problem in southwestern Indiana, the development of the concept of the profile of weathering in surficial deposits (Leighton and MacClintock, 1930), and the accumulation of a wealth of data from detailed studies elsewhere, the eolian theory of origin for loess has become generally accepted.

A few writers (Russell, 1944; Fisk, 1944) reject an eolian origin. Russell (1944) proposed a "loessification" theory of origin for the deposits of the lower Mississippi valley, suggesting that the loess there is a colluvial deposit resulting from reworking of older backwater deposits. Although it is not the purpose of this study to argue the validity of the eolian origin of loess, it is implicitly believed that loess of the Owensboro quadrangle is of eolian origin and is genetically related to the glaciofluvial valley trains of the Ohio from which the silt was blown on to the hill lands.

The source area of sediments comprising loess deposits in the Owensboro quadrangle was largely the relatively barren valley-train surface, from which the finer grained constituents were removed by deflation and deposited on the adjacent hill lands. During progressive upbuilding of the valley trains by the aggrading river, stabilizing vegetation was inhibited and a continuous source of sand, silt, and clay-sized particles was exposed to wind action.

Although deflation could take place during any season when winds were of sufficient velocity to pick up and transport fine-grained particles and when the surface of the source areas was sufficiently dry, it is thought that maximum deflation took place during the fall, before winter ice cemented and snow blanketed the source areas. During the fall and winter the volume of melt water was less than during summer months, and winds, then dominantly from the northwest, were competent to pick up and transport clouds of fine sand, silt, and clay. During spring and summer, winds were dominantly from the southwest and were capable of deflation only when the surface of the source area was sufficiently dry. Despite the high water table of the valley trains, surficial drying would allow deflation. Such drying permitted deflation as successive thin surficial layers of fine-grained particles were removed to permit drying of the layer below. Spring was in all probability the season of minimum deflation, largely because it was the period of increasing volume of melt waters and perhaps because winds, largely from the southwest, may have been less competent and rainfall greater, so that the surface of the source area remained moist.

Clouds of fine-grained particles carried by deflation from the source area [12] were widely deposited on hill lands to form loess. As expectable, coarser particles, especially those of sand size, were dropped first; finer particles were carried to greater distances.

Thickness of loess deposits depended primarily on two factors other than nearness to the source area: first, amount of material available for deflation, and second, relation of area of deposition to source area and wind direction. Where valley-train source areas were broad, loess deposits are thicker than where the source area was limited. The first relation is well shown between Owensboro and Louisville, for where the Ohio valley is constricted and the source area limited, loess deposits are proportionately thin. Where the valley is wider and the source area was more extensive, loess deposits are proportionately thicker. Where deposits are alined with the wind direction most competent for deflation, they are thickest on the lee side of a valley train and thinner on the windward side. If these factors are combined, unusually thick deposits may accumulate, as at the southwest corner of Rockport island hills; there the thickest loess in the Owensboro quadrangle appears to have accumulated on the leeward side of the extraordinarily broad expanse of the valley-train source area.

It is generally held that wind-transported particles were trapped and stabilized by the vegetative cover of the hill lands. Without such a stabilizing mantle, deposits would have been constantly shifted and redeposited by wind action to positions of relative stability determined by the local topography. Since evidence of such redeposition is rare, it can be assumed that there was a vegetative mantle. The effectiveness of the vegetative mantle as a trap for windblown deposits is well illustrated today along the Tanana Valley near Big Delta, Alaska, where wind-transported silts are accumulating. There, trees and shrubs are so mantled by silt that clouds of "dust" are dislodged as one pushes through the vegetation.

LOESS UNITS

Scattered outcrops of a well-defined sequence of loess units occur along the Ohio Valley beyond the limits of glaciation, from the vicinity of Louisville, Ky. (Ray, 1957), to Cairo, Ill. (Leighton and Willman, 1949, 1950). Where most complete, the succession consists of three distinct units: the Loveland Loess of Illinoian age and the Farmdale and Peorian

[12] For excellent illustrations of this process in action, see Péwé, 1951.

Loesses of Wisconsin age. At two places along the Ohio, however, a deeply weathered silt, interpreted as loess of Kansan age, has been observed to underlie typical Loveland Loess. Although this pre-Loveland Loess has not been found to crop out in the Owensboro quadrangle, one occurrence is only 3½ miles west of the mapped area.

Each loess unit has distinctive characteristics by which it can be distinguished at the outcrop; each is widespread adjacent to the Ohio valley, maintaining its general characteristics not only along the Ohio but along the Mississippi (Wascher and others, 1948; Leighton and Willman, 1949, 1950). In the upper Mississippi River valley some of these loess units are interbedded with glacial tills (Horberg, 1956; Leighton, 1926) and can be dated in terms of the sequence of glacial events.

Where loess is exposed to weathering, a zonal profile of weathering is developed (Leighton and MacClintock, 1930; Leighton, 1958b). Ideally, it consists of five zones, grading from a highly altered surficial zone (zone 1) to unweathered parent material (zone 5) at depth. The most complete profile of weathering, though not the most advanced, can be observed best in the youngest and thickest loess (Peorian) that blankets the hill lands of the Owensboro quadrangle. Older units commonly have incomplete profiles, in large part due to erosion between intervals of loess deposition. The zones as they are ideally developed in the Peorian Loess of the Owensboro quadrangle are as follows:

1. *Zone of eluviation.*—The surficial zone, where undisturbed, is normally about 8–10 inches thick and is deeply weathered and altered. Just below the humic surface litter the zone has a gray color; below, the color changes to light grayish brown. In this zone all carbonates have been removed by leaching, and the less stable primary silicates have decomposed to secondary clay minerals and oxides of iron. These clays have been in large part removed by eluviation, that is, they have been transported downward by rainwater. Only the most stable silicate minerals have withstood alteration. In general, this zone is a porous loose silt with a tendency toward an indistinct platy structure.

2. *Zone of illuviation.*—This zone, commonly 1.5–2.5 feet thick, is, like zone 1, highly altered by weathering; but it is characterized by a distinctive crumbly structure and by a high clay content, in part introduced by downward movement of clay from the overlying zone 1 and in part by clay derived through weathering of silicate minerals in place. The color may range from reddish brown, especially vivid when wet, through orange to yellow brown or bright yellow. A sticky "gumbo" when wet, the clay-enriched silts tend to dry to a hard, compact mass separated by many small shrinkage cracks into irregular or dicelike particles commonly coated with thin skins of colloidal clay that may impart a greasy sheen. Normally the skin is darker than the interior of the particles; thus the color in outcrop may appear to be a reddish brown, whereas the true color of the mass may be a yellow brown of lighter hue. Particles are smallest, one-quarter of an inch or less, at the top of the zone of illuviation, but they increase with depth to 1 inch or more at the poorly defined base of the clay-enriched part.

3. *Oxidized and leached zone.*—Commonly 6–10 feet thick, the oxidized and leached zone is indistinctly transitional from the deeply weathered overlying zone of clay illuviation. Here, however, silicates are relatively unaltered, but all carbonates have been removed by leaching. Iron oxides derived from weathering impart to this zone a generally characteristic buff to light-yellow color; small iron oxide concentrations are present in places and may form thin coatings in root canals. In general, silt of this zone is compact but friable, tending to stand in vertical walls of relative stability. In places, widely spaced vertical joints are parallel to the surface of the exposures, leading to the belief that vertical jointing, commonly held to be characteristic of loess, may be of secondary origin and related to wetting and drying of the exposed surface.

4. *Oxidized and unleached zone.*—The contact between zones 3 and 4 cannot always be observed readily in the outcrop but it is defined as the surface to which leaching of carbonates has penetrated from above. Average thickness of this zone cannot be determined in the Owensboro area, for even where deposits are thickest, oxidation has penetrated to the base of the deposit. Loess of this zone is light buff to yellowish and less compact than the overlying zones. Fossils and nodules of secondary calcium carbonate are characteristic. Diffusion banding by iron oxides may in places be prominent, especially around calcareous nodules and fossils. Exposures of this zone are commonly damp and moss covered.

5. *Zone of unaltered parent material.*—Although loess in the Owensboro area is not sufficiently thick to preserve unaltered parent material below the depth of weathering, the general character of the original silt is presumed to have been closely related in physical properties to that of zone 4. The original soft loose powdery silt with light- to blue-gray color was readily oxidized to the characteristic buff-colored silt zone 4.

Commonly, profiles are incomplete, for surficial erosion may have removed the upper zones; or where the original deposit was thin, weathering may have penetrated through the entire section, so that the lower zones may be in part or wholly destroyed. Where loess accumulation was so slow that weathering took place during deposition, the zonal profile would be likewise incomplete. Smith (1942) has shown that leaching of carbonates from thin loess deposits during slow accumulation in areas remote from the source of the sediments may account for the fact that in many profiles zones 4 and 5 are lacking. Other factors being equal, the longer the period of weathering, the thicker and better developed the profile. Because of climatic differences, deposits lying far south of the limits of glaciation have been more deeply weathered than those closer to the glacial boundary. Leighton and Willman (1950) noted that degree of weathering, as indicated by depth of leaching and oxidation, is appreciably greater along the lower Mississippi valley than in northern Illinois.

NEBRASKAN LOESS

No deposits of loess of Nebraskan age have been found along the Ohio valley. By inference, however, it is believed that a valley train related to an ice sheet of Nebraskan age possibly may have occupied the Ohio valley in the Owensboro area (p. 29), but it is unlikely that any loess developed as a result of deflation of silts from such a valley train has been preserved in this area.

KANSAN LOESS

The fact that the Ohio valley was overridden by the ice sheet of Kansan age (Ray, 1957)[13] and served directly as a drainageway for melt water and outwash debris suggests that a valley train of Kansan age developed along the Ohio valley in the Owensboro area, although no evidence for it has been observed. On the basis of genetic relationship between valley trains and loess deposits, it was suspected that where conditions were favorable, deposits of Kansan loess might be found (Ray, 1957).

Late in 1957 such a deposit of pre-Illinoian silt was found in an exposure just west of the Owensboro quadrangle (section 1). This section consists of a weathered compact reddish silty clay that is believed to represent loess of Kansan age resting on deeply weathered shale of Pennsylvanian age and overlain by compact slope wash. Above is the typical succession of later loess deposits of Illinoian and Wisconsin ages. The exposure is a roadcut some 500 feet long that is cut through the nose of a ridge adjacent to strip coal mines. Unfortunately the strip-mining operations have destroyed much of the local topography, so that similar sections may have been destroyed or covered by spoil.

SECTION 1.—*New roadcut (1957) through nose of ridge for access to strip coal mines, NE¼SW¼ sec. 36, T. 6 S., R. 8 W., Yankeetown, Ind.-Ky. quadrangle*

[For mechanical analyses of samples, see table 7]

	Feet
Peorian Loess:	
Buff-yellow noncalcareous and oxidized; top disturbed by strip mining and in places covered by spoil. (Sampled 2 ft above base.)	6+
Farmdale Loess:	
Light-brownish-buff compact noncalcareous silt with gray veining; flakes along partings parallel to surface; minute iron oxide pellets that smear on cut surface. (Sampled 3 ft above base.)	7±
Loveland Loess:	
Dark red to deep orange in upper 12–15 in.; deeply weathered; compact clayey silt, crumbling to irregular particles as large as 1.5 in. maximum diameter; veinlets of iron oxides; sharp break with lower dark chocolate-colored less weathered silt that is mantled by angular fragments of iron oxide-cemented particles from above. (Sampled about 15 in. from top and 8 in. from bottom.)	4±
Slope wash:	
Light- to dark-red; extremely compact and in part iron oxide-cemented fragments of ironstone and some sandstone flakes of local derivation that are oriented parallel to old land surface. Weathers to well-defined ridgelike prominence; weathered fragments in lower part	2±
Kansan loess:	
Pinkish-brown compact deeply weathered silt with dark-red clay coating irregular particles; in places, cracks filled with grayish clay; tends to be vesicular. Develops gentle slope on outcrop in contrast to steep slope of overlying slope wash. (Sampled about 1 ft above base.)	2±
Bedrock (silty shale of Pennsylvanian age):	
Upper 2 ft dark red with black iron-oxide staining; deeply weathered and original shaly structure destroyed. Very clayey; dry surface develops polygonal shrinkage cracks; breaks to irregular masses with thin clayey coatings; heavy and sticky when wet. (Sampled about 1 ft below top.) Grayish-green clayey silt with evidence of original bedding in lowest 1.5 ft; in part oxidized and iron stained along bedding planes. (Sampled about 10 in. below top.)	3+

In the center of the exposure the deposits follow the configuration of the underlying bedrock, producing the semblance of an anticline; at the outer limits of the exposure the older deposits are truncated by the successively younger overlying deposits. The profile of weathering developed on the bedrock at the base of the section appears to be the product of nonglacial (Aftonian) time. During the nonglacial Yarmouth time the Kansan loess was weathered, eroded, and

[13] Compare Flint and others (1945) with Flint and others (1958) for recent reinterpretation of age of glacial deposits along the Ohio valley between Louisville, Ky., and Cincinnati, Ohio.

partly removed from the lower ridge slopes. The upper slopes were stripped of their loess mantle, and bedrock was exposed to weathering and erosion. Small platy ironstone fragments, weathered and incorporated in weathered colluvial silts, produced a mantle of wash on the lower slopes that protected the uneroded Kansan loess beneath. The platy ironstone fragments of slope wash tend to be oriented parallel to the surface of the underlying weathered loess mantle and to the configuration of the bedrock of the ridge core. At the outer margins of the exposure they are truncated, and bedrock is mantled by younger loess deposits. The ironstone fragments, bound together by a compact silty matrix and in part cemented by iron oxides, are extremely resistant to erosion and have protected the underlying Kansan loess. It is possible that elsewhere remnants of similar weathered silt, to which a Kansan age can be assigned, are deeply buried and truncated by overlapping younger loess deposits, so that they are not exposed in the average artificial excavation.

LOVELAND LOESS

Along the Ohio valley from the vicinity of Louisville, Ky., to Cairo, Ill., are scattered outcrops of three stratigraphically distinct loess deposits (Leighton and Willman, 1949, 1950; Ray, 1957). The oldest, the Loveland Loess of Illinoian age, normally rests on deeply weathered bedrock; its upper surface is sharply delimited by a well-developed postdepositional profile of weathering imposed during the nonglacial Sangamon time, that is, before deposition of the overlying loess of Wisconsin age. Where the Loveland Loess is thin, it may be difficult to distinguish the deeply weathered loess from weathered fine sandy or shaly bedrock, as noted by Wascher, Humbert, and Cady (1948). This is especially true where weathered fragments of bedrock were incorporated in the basal part of the loess during its deposition. Where the loess is relatively thick, the profile of weathering developed in it can be distinguished from that developed in bedrock before deposition of the loess, as reported at the Medora section near Louisville (Ray, 1957).

At eight localities in the Owensboro quadrangle deeply weathered silt of the Loveland Loess crops out (sections 2–9). Thickness ranges from slightly less than 1 foot to about 7 feet. Regional distribution, delimited above and below by well-developed profiles of weathering, is demonstrated by its presence along the Ohio River. The similarity in character of the deposit and of the profiles of weathering in it to those along the Mississippi, as well as its stratigraphic position, provides ample evidence that these loess deposits along the Ohio are correlative with the Loveland Loess along the Mississippi beyond the limits of glaciation. The deposits beyond the limits of glaciation have been correlated with the pro-Illinoian loess of the glaciated upper Mississippi valley (Leighton and Willman, 1950), thus directly relating them to the sequence of glacial events.[14]

SECTION 2.—*Deep roadcut at valley wall along west side of NW¼ SW¼ sec. 9, T. 8 S., R. 6 W.*

	Ft	in
Peorian Loess:		
Gray silt below surficial humus	0	6–8
Red-brown compact deeply weathered clayey silt; crumbles to irregular particles	2	0
Buff-yellow silt; leached and oxidized	8–10	0
Grayish-buff calcareous, fossiliferous silt with calcareous nodules as much as 4 in. in maximum diameter; limonitic diffusion banding in lower part around fossils and minute calcareous nodules. (See table 6, loc. 6.)	6–8	0
Farmdale Loess:		
Grayish-brown compact silt; flakes parallel to surface of exposure; upper contact marked by slight overhanging cornice of Peorian Loess. (See table 6, loc. 6.)	4	0
Loveland Loess:		
Crimson-red crumbly silty clay		10–12
Red compact silty clay; grades to yellow brown at depth; scattered sand drains and deeply weathered sandstone fragments in lower part	5	0
Covered	5	0
Sandstone bedrock	10	0

SECTION 3.—*Deep cut, now obliterated, on secondary road in Bon Harbor Hills, 1 mile northwest of road junction with Kentucky State Highway 331 and 400 ft northwest of bridge over unnamed creek*

	Ft	in
Peorian Loess:		
Gray silt underlying surficial humus	0	8–12
Orange-yellow clayey silt; crumbles to irregular particles; deepest color on surface of particles	2	6
Buff-yellow powdery silt; oxidized and leached; basal few inches weakly calcareous and with a few calcareous nodules. (See tables 6, 8, loc. 3.)	10–13	0
Farmdale Loess:		
Light-brownish-gray silt with specks of carbonaceous matter; hard and compact; flakes parallel to surface of exposure; upper contact marked by slightly overhanging cornice of Peorian Loess; basal few inches stained red by contamination with underlying Loveland Loess. (See tables 6, 8, loc. 3.)	4	6

[14] The term "pro-Illinoian loess" is applied because the loess occurs in an unweathered state below the overriding Illinoian till.

SECTION 3.—Continued

	Ft	in
Loveland Loess:		
Dark crimson-red crumbly silty clay. (See tables 6, 8, loc. 3.)	1	0
Reddish-brown to brownish-yellow compact silty clay with buff-gray silt veins as much as ¼ in. thick. (See tables 6, 8, loc. 3.) Lower part sandy with platy fragments of weathered sandstone oriented parallel to underlying bedrock	4	0
Sandstone bedrock	1+	0

SECTION 4.—*Northeast margin of Bon Harbor Hills, 500 ft east of abandoned open-pit coal mine and 600 ft south of Louisville and Nashville Railroad tracks*

	Ft	in
Peorian Loess:		
Gray silt underlying surficial humus	0	8–10
Orange-yellow clayey silt; compact, but crumbles to irregular particles with surficial red color	2.5–3	0
Buff-yellow silt; oxidized and leached	4–5	0
Buff-yellow calcareous fossiliferous silt; many calcareous nodules, some containing fossils; nodules in lower 2 ft in large part elongate with axes (as much as 10 in.) horizontal	15–18	0
Farmdale Loess:		
Light-brown silt; compact, but tends to flake parallel to surface of exposure; upper contact marked by slightly overhanging cornice of Peorian Loess; nonfossiliferous but many secondary calcareous nodules	4	0
Loveland Loess:		
Crimson-red silty clay; original character almost obliterated		10
Bedrock:		
Shale of Pennsylvanian age; upper part weathered and stained from overlying thin Loveland Loess	8	0

SECTION 5.—*Northeast margin of Bon Harbor Hills, 350 ft west of abandoned open-pit coal mine and about 200 ft south of Louisville and Nashville Railroad tracks*

	Ft	in
Peorian Loess:		
Buff-yellow silt; upper part inaccessible; lowest few feet fossiliferous, powdery, with unusually large calcareous nodules, many elongate with axes (to more than 3 ft) horizontal	20±	0
Farmdale Loess:		
Brownish-buff compact unfossiliferous noncalcareous silt; flakes parallel to surface of exposure; top marked by slightly overhanging cornice of Peorian Loess. (See table 6, loc. 7.)	3–4	0
Loveland Loess:		
Dark crimson-red crumbly silty clay		10
Dark-red on surface of deeply weathered compact silt that breaks to irregular particles (1–2 in. in diameter); lower part brownish to chrome-yellow and gray with red stains along partings; fragments of underlying weathered shale incorporated in basal few inches. (Sample 3 ft below top; see table 6, loc. 7.)	5–7	0

SECTION 5.—Continued

	Ft	in
Bedrock:		
Shale of Pennsylvanian age; upper part weathered and disturbed	12+	0

SECTION 6.—*Roadcut through hilltop on U.S. Highway 60, Bon Harbor Hills, 2.7 miles west of Owensboro city limits*

	Ft	in
Peorian Loess:		
Buff-yellow silt on steep vegetation-covered slope	10–12	0
Farmdale Loess:		
Light-yellow-brown compact noncalcareous silt; vertical exposure	3–5	0
Loveland Loess(?):		
Red to yellow-brown silty clay with incorporated fragments of weathered bedrock; deeply weathered and crumbly		12–15
Bedrock:		
Micaceous sandstone and shale of Pennsylvanian age	6–8	0

SECTION 7.—*Roadcut along west side of NW¼SW¼ sec. 4, T. 8 S., R. 7 W.*

[See Veatch, 1898a, p. 267; Thornbury, 1937, p. 90, sec. 55]

	Ft	in
Peorian Loess:		
Gray surficial silt and humus	0	6–8
Bright-yellow clayey silt; crumbles to irregular particles	3	6
Buff-yellow silt; leached and oxidized	10	0
Grayish-buff loose powdery weakly calcareous silt; a few fossils; diffusion banding in lower part; 1–3 in. dark-brown (humic?) zone with some limonite staining about 2.5 ft from top	7	0
Farmdale Loess:		
Brownish-gray compact nonfossiliferous silt with large secondary calcareous nodules; flakes parallel to vertical surface of exposure; upper contact marked by slightly overhanging cornice of Peorian Loess	4–5	0
Loveland Loess:		
Gray silt with rusty mottling; weakly calcareous (secondary calcite)		10
Crimson-red crumbly clayey silt with scattered gravel incorporated from underlying formation	1	2
Luce Gravel:		
Gray compact silty sand with scattered chert gravel	3	0
Bronzed cherty well-rounded gravel with noncalcareous sandy matrix	5	6

SECTION 8.—*Roadcut along west side of SW¼NW¼ sec. 2, T. 8 S., R. 7 W.*

[See Veatch, 1898a, p. 265–267; Thornbury, 1937, p. 93]

	Ft	in
Peorian Loess:		
Gray surficial silt and humus	0	6–8
Reddish-brown clayey silt; crumbles to irregular particles with surficial reddish-brown color; interior of particles yellow brown	2	6
Brownish-yellow silt, grading at depth to compact buff-yellow silt; noncalcareous; faint indications of stratification	8–10	0

SECTION 8.—Continued

	Ft	in
Farmdale Loess:		
Orange-yellow clayey silt mottled with black; grades downward to grayish-brown compact silty clay with veins of gray silt; pellets of iron oxides	5	0
Loveland Loess:		
Red clayey silt mottled with black; scattered pebbles of chert, sandstone, and ironstone	4	0
Luce Gravel:		
Red sand and clay flecked with white	2–3	0
Covered	8	0
Well-rounded bronzed chert gravel, in part cemented to conglomerate by iron oxides; base not exposed	6	0

SECTION 9.—*Adjacent sand and gravel pits, 250 and 600 ft east of west side of SW¼NW¼ sec. 3, T. 8 S., R. 7 W.*

[See Veatch, 1898b, p. 264–265; Thornbury, 1937, p. 92–94, sec. 56]

West Pit

	Ft	in
Peorian Loess:		
Orange-yellow clayey silt that crumbles to irregular particles; underlain by buff-yellow silt, weakly calcareous in basal part	15	0
Farmdale Loess:		
Brownish-buff compact silt; weakly calcareous (secondary calcite) with secondary calcareous nodules	2	0
Loveland Loess:		
Red to orange-yellow noncalcareous sandy silt; 2-in. zone at base with scattered gravel	3	0
Luce Gravel:		
White to orange-yellow massive poorly consolidated sand with scattered gravel; upper 3 ft deeply weathered to crimson red; rounded gravel of bronzed chert, jasper, vein quartz, sandstone, and silicified fossils (crinoid stems) at base	15–20	0
Coal seam of Pennsylvanian age	1	6

East Pit

	Ft	in
Undifferentiated loess:		
Buff-yellow silt; crumbly red silty clay at base; poorly exposed and slumped	12	0
Luce Gravel:		
Yellow fine compact sand with clay balls as large as 6 in. in diameter; gray silt veins	8–10	0
Bronzed chert gravel; well rounded, with scattered gravel of jasper, vein quartz, sandstone and silicified fossils (largely crinoid stems); in places well cemented by iron oxides. Bedding in part horizontal, in part dips steeply to west; gravel surface irregular, in places sharply delimited, elsewhere intercalated with overlying sand	10–12	0

The history of the Loveland Loess in the Owensboro quadrangle is relatively simple. With development of the Illinoian valley train and consequent deposition of silts deflated from its surface on to the adjacent hill lands, the weathered bedrock outcrops were eventually blanketed with loess. During the early stages of deposition, weathered bedrock fragments were incorporated in the basal silt deposits through the mixing action of slope wash, the action of burrowing animals (Savage, 1915), and root disturbance. Infiltration of silt between particles of slope wash has produced the appearance of mixing in places. Generally the zone of mixing is less than a foot thick; only rarely does loess above the basal layer contain fragments of local bedrock.

Thickness of Loveland Loess in the Owensboro quadrangle at the close of deposition is not known. Following loess deposition, a period of uninterrupted weathering and erosion was initiated that lasted throughout the nonglacial Sangamon time until deposition of the overlying loess of Wisconsin age began. During this long erosion interval much of the Loveland Loess presumably was removed; where thin or where conditions were especially favorable for erosion, it was completely removed and the denuded bedrock again subjected to weathering and erosion. Where the loess was of sufficient thickness to be only partly removed by erosion, deeply weathered remnants remain, for as erosion progressively removed material from the top, weathering was able to attack progressively lower parts of the deposit. Under such conditions, the profile of weathering moved steadily downward. Sections of Loveland Loess in the Owensboro quadrangle lack zone 1 at the top and zones 4 and 5 at the bottom of the profile of weathering, for in all exposures leaching and oxidation have penetrated through the thickest deposit (section 5).

FARMDALE LOESS

Throughout the unglaciated Mississippi and Ohio valleys a loess of distinctive character, the Farmdale of Wisconsin age, overlies deeply weathered Loveland Loess or rests directly on weathered bedrock; rarely it overlies relatively fresh bedrock (Leighton and Willman, 1950; Ray, 1957). Remarkable for the regional constancy of its physical character, the Farmdale Loess was first recognized by M. M. Leighton in 1920 and referred to as "Late Sangamon loess" (Leighton, 1926). Renamed the Farmdale by Leighton (1946), the loess was assigned to the earliest Wisconsin age on the basis of its relatively slight alteration by weathering when compared to the profiles of weathering of Sangamon age.

The Farmdale Loess is a homogeneous compact oxidized silt that is noncalcareous in the Ohio valley. Ranging from a dark cocoa brown to a light grayish brown, it has, in places, a distinctly pinkish cast, in contrast to the color of the underlying and overlying deposits. At some localities, minute specks of powdery carbonaceous(?) material are scattered throughout the deposit. The Farmdale Loess ranges in thickness from about 3 to 5 feet and averages about 4 feet.

The strong profile of weathering developed on the Loveland Loess provides a sharp and readily distinguishable contact between the Loveland and the overlying Farmdale Loess (sections 2–9). Where the Farmdale Loess rests directly on bedrock of Pennsylvanian age (section 10), the approximate contact is in general recognizable, although the exact contact may be transitional and obscured by mixing of the basal few inches of loess with weathered bedrock and slope wash.

The source of the sediment composing the Farmdale Loess in the Owensboro quadrangle was a valley train of Farmdale age that marked the first advance of ice sheets of Wisconsin age into the Ohio drainageway basin after the long nonglacial Sangamon time. Deflation from the valley train spread a silt blanket over the adjacent deeply weathered countryside; this blanket was thickest near the source area, thinning with distance.

SECTION 10.—*Roadcut along west side of SE¼SE¼ sec. 31, T. 6 S., R. 6 W.*

[See Thornbury, 1937, p. 89–90, sec. 53]

	Ft	in
Peorian Loess:		
Grayish-buff silt under surficial humus	0	6–8
Brownish-yellow clayey silt; crumbles to irregular particles	2	0
Buff-yellow poorly compacted silt; oxidized and leached	7	0
Buff-yellow powdery weakly calcareous fossiliferous silt. (See tables 6, 8, loc. 5.)	5	0
Farmdale Loess:		
Grayish-brown noncalcareous silt; a few secondary calcareous nodules; sandy in lower part	4	0
Sandstone:		
Reddish-brown weathered, and decomposed sandstone of Pennsylvanian age	2	0

Presumably the Farmdale Loess was originally calcareous, for primary carbonates have been reported in these deposits along the lower Mississippi valley (Leighton and Willman, 1950). Its present leached condition throughout the Ohio valley can be explained in one of two ways. First, it can be assumed that a normal profile of weathering was developed in it between the time of its deposition and the deposition of the overlying younger loess, and that the present oxidized and leached Farmdale Loess represents only zone 3 of the profile of weathering. If this is true, zones 1 and 2 have been completely removed by erosion from all deposits and weathering was sufficient to destroy zones 4 and 5. Such an explanation does not appear probable, for had this been true, it would be expected that at some place evidence of zones 1 and 2, or 4 and 5, would be found. Furthermore, the limited time represented by the intrastadial period between deposition of the Farmdale and the overlying loess appears too short for production and subsequent selective erosion of such a well-developed profile of weathering. Therefore, a second interpretation is proposed.

Smith (1942) in his study of the Peorian Loess of Illinois has shown that loess on the uplands, far from the source areas where deposition was slow, was leached of its primary carbonate particles during deposition. Belief that the relatively thin Farmdale Loess along the Ohio was leached during its slow deposition appears to be far more justified than the alternate belief in the formation and subsequent erosion of the profile of weathering. Under this second hypothesis the thin Farmdale Loess may represent for the most part the uneroded thickness of the original deposit. That it should be thin is reasonable when the postulated glacial invasion of the Ohio drainage basin is presumed to have been of relatively limited areal extent, not yet clearly recognized nor outlined by field investigations.

If leaching accompanied deposition of the Farmdale Loess, removal of calcareous particles would be accompanied by shrinkage of the deposit through settlement of the residual particles. During movement of the particles, positions of stability occupying the least volume would be acquired, resulting in a tight, compact mass of leached silt.

The fact that at no locality in the Owensboro quadrangle has a surficial humic zone or a true zone of illuviation of the profile of weathering been found at the top of exposures of the Farmdale Loess indicates that the interval between its deposition and that of the overlying loess was relatively brief. Leighton and Willman (1950, p. 603) have pointed out that in the upper Mississippi valley the profile of weathering on the Farmdale is also very youthful and records only a brief interval.

PEORIAN LOESS

The youngest loess deposit, the Peorian, forms an almost continuous blanket on the hill lands of the Owensboro quadrangle to depths ranging from an observable maximum of more than 20 feet along the Ohio valley bluffs to a minimum of about 3.5 feet recognizable at greatest distances from source areas. This loess, with characteristic properties, is typical of the Peorian Loess described elsewhere in the Midwest, beyond the limits of the Tazewell ice sheet of Wisconsin age (Leighton, 1931; Smith, 1942). Along the Ohio valley it occurs from the vicinity of Louisville (Ray, 1957) to Cairo (Wascher and others, 1948; Leighton and Willman, 1949, 1950).

In the vicinity of Louisville, Ky. (Ray, 1957), this loess has been termed Tazewell rather than Peorian on the basis of its association with the Tazewell valley train. However, in western and southern Illinois the Peorian Loess consists of two units of Iowan and Tazewell ages. So closely associated are they in time and so similar are they in character that they can be separated only in glaciated areas where the basal part, the Iowan Loess, rests beneath glacial deposits of Tazewell age on which rests the Tazewell Loess. Beyond the limits of glaciation of Wisconsin age the two deposits merge into one inseparable unit, the Peorian Loess (Leighton and Willman, 1950).

In the belief that no loess of Iowan age occurred in the Ohio valley, Ray (1957) termed the surficial loess mantle Tazewell, indicating that it was wholly related to the Tazewell valley train. Later studies, especially along the Ohio below the mouth of the Wabash, led to the belief that such specific identification of the entire loess deposit with only the Tazewell valley train is not prudent even though no evidence of an Iowan valley train or loess of Iowan age has been identified. Therefore, the more specific correlation has been abandoned in favor of a less specific identification through correlation with the Peorian Loess of southern and western Illinois, especially along the Mississippi valley. Until it can be definitely demonstrated that no ice of Iowan age invaded either the drainage basin of the upper Ohio or that of the Wabash (see Thornbury, 1958), it is ill advised to limit the youngest loess solely to the Tazewell age. It is suggested, however, that the loess along the Ohio above the mouth of the Wabash is probably wholly of Tazewell age and that below may consist of inseparable deposits of both Iowan and Tazewell ages—the Peorian. Because no means have been found as yet for identifying the two closely related loess units of the seemingly homogeneous deposit, and because of the possibility that there may be a valley train of Iowan age along either or both the Ohio and Wabash valleys that is buried under the later Tazewell valley-train deposits, the youngest loess is termed the Peorian. Insofar as can be determined, however, the Peorian Loess of the Owensboro quadrangle is genetically related only to the Tazewell valley train.

Commonly, sand lenses and thin layers are intercalated with Tazewell Loess along valley walls, and all sand dunes are loess mantled, as illustrated by exposures along Sand Ridge. It is believed that, in general, the pattern of loess deposition was similar to that of earlier periods. Thus, earlier deposits, subject to weathering and erosion, have been obliterated locally from areas where they were thin and are generally expectable only where mantled by thickest deposits of Peorian Loess.

The Peorian Loess mantle was deposited above the surface of the valley train and lacustrine flats of Tazewell age, from altitudes of about 400–640 feet. There is no evidence of lacustrine silts above the level of the Tazewell source areas, although Thornbury (1937) held that in places in the Owensboro quadrangle, loess at altitudes well above 400 feet either rests on older lacustrine silt or is silt of lacustrine origin. He cites (1937, p. 89–90) a roadcut at the northernmost point of the Rockport island hills (see section 10) which he interpreted to be "lake silts deposited in the ponded waters of Little Pigeon Creek." There he reported 6–6.5 feet of leached brown silt overlying 10–12 feet of loose friable nonfossiliferous calcareous silt resting on 1–2 feet of brownish-red crossbedded sandstone at an altitude of 420–440 feet.[15] The lower silts, he noted, were sandy toward the bottom and contained secondary calcium carbonates. Examination of this section has led to the conclusion that the upper leached part comprises zones 1, 2, and 3 of the profile of weathering developed on Peorian Loess along a steep slope. The lower "calcareous" part consists of about 5 feet of oxidized and unleached Peorian Loess (zone 4) from which a common loess fossil (*Hendersonia occulta* Say) has been recovered. Silt of the lowest 4 feet is more compact and leached, containing only secondary calcium carbonate derived from leaching of the overlying silts. This is typical Farmdale Loess resting on weathered bedrock.

Along the margins of the Ohio valley, where the Peorian Loess is thickest and well drained, the profile of weathering has well-developed zonation (sections 2, 4, and 7). Where sections are sufficiently thick for zone 4 to occur, the base of the Peorian is separable with ease from the underlying Farmdale Loess on the basis of its lighter color, loose texture, and its unleached condition. In many outcrops the compact dry Farmdale Loess may spall parallel to the face of the outcrop in layers from ⅛ to ½ inch thick, and the overlying Peorian Loess may jut over the contact by as much as 3 inches to form an irregular cornice. Away from the source area where the Peorian Loess is thin, separation of the two deposits may be difficult to impossible either on the basis of field character or on laboratory analyses. Smith (1942, p. 149) has pointed out that unless the Peorian Loess is at least

[15] Recent topographic mapping (pl. 1) indicates that the base of the section is approximately at 405 feet.

75 inches thick, the underlying Farmdale cannot be separated from it by field methods.

Commonly, nodules of secondary calcite derived from leaching of the overlying material are scattered throughout zone 4 of the Peorian Loess or concentrated at the base of the deposit, just above the contact with the underlying compact and relatively impervious Farmdale Loess. At some localities calcareous nodules are surrounded by aureoles of bright yellow to rusty limonitic diffusion banding. Along the northeast margin of the Bon Harbor Hills (sections 4 and 5), calcareous nodules of unusual size and shape occur in an 18- to 24-inch zone just above the base of the Peorian Loess (zone 4). There, some nodules are irregular in shape; others tend to resemble doubly-terminated stalactites whose long axis lies parallel to the contact (fig. 16). One nodule, weathered from the loess, was more than 3 feet long and had a maximum diameter of about 10 inches. Normally the surfaces of these secondary calcareous concretions are irregular, knobby, or spiny. A few enclose shells of mollusks.

Exposures of loess in the hill lands are seldom of sufficient depth to extend through the oxidized and leached zone (zone 3), but zones 1 and 2 are well exposed and readily recognizable in shallow roadcuts. Zones 1 and 2 tend to produce gentle slopes on weathering; zone 3 tends to develop a relatively stable vertical face.

The rolling loess-mantled hill lands are marked by differences in soil color that can be observed best in the spring when the damp soil has been freshly plowed and is not obscured by plant cover. The top and lower slopes of the hills are commonly light grayish buff, the color of zone 1 of the profile of weathering. Along the upper part of the slopes, at the point of maximum convexity and therefore greatest soil erosion, sheet wash commonly has removed zone 1 and the lower darker orange-yellow clayey silt of zone 2 is exposed (fig. 5), indicating the amount of sheet erosion since removal of the natural vegetative cover in the early 19th century. When cultivated, zone 2 is sticky and gumbolike when wet, hard and cloddy when dry, and lacking in fertility, in contrast to that of the loose mellow silts of good tilth of zone 1.

FIGURE 16.—Calcareous nodule from base of Peorian Loess. Bon Harbor Hills (section 5). The nodule developdd just above the contact with the compact Farmdale Loess with its long axis (10 in.) horizontal and parallel to the contact.

MECHANICAL COMPOSITION OF LOESS DEPOSITS

Loess is composed largely of silt-sized particles but includes minor amounts of clay and sand. Mode of origin, areal relationship between source and place of deposition, and especially alteration of deposits through weathering are factors that have affected the grain-size distribution of the particles. Each factor must be appraised for each sample in order to interpret fully the results of mechanical analyses. Without such appraisal, mechanical analyses of individual samples, whether from a single loess section or from regionally scattered sections, are of relatively little significance and comparisons may be misleading. So important is the influence of weathering in altering grain-size distribution within a single vertical section of loess that the zone of the profile of weathering (p. 58) from which the sample came must be known for correct interpretation of analyses. Direct comparison for correlation and evaluation can be made only between samples obtained from the same zone of the profile of weathering.

Because loess of the Owensboro quadrangle is of eolian origin, it is expectable that through comparison of the least altered samples (zone 4), both sand and clay particles will occur with the predominant silt-sized fraction in proportions that vary with the geographic position of the deposit relative to the source area. Theoretically coarser particles should occur in deposits nearest the source area; with increasing distance there should be progressive diminution in particle size and in thickness of the deposit—a general relationship noted by Leverett (1899), Krumbein (1937), and Smith (1942).

Despite the fact that source areas in the Owensboro quadrangle were so widespread that distance of any deposit from them is only a few miles at most, variation in thickness of the loess mantle is marked. Thickness ranges from 20 feet or more in places on bluffs adjacent to the Ohio valley to 5 feet or less on the hills in the northeastern and northwestern parts of the quadrangle. Where the loess mantle is less than about 12 feet thick, it has been wholly leached and it is not possible to obtain unweathered samples whose grain-size distribution can be compared with the relatively unaltered calcareous loess of zone 4 from the thicker deposits. For this reason the reported systematic diminution in grain size with distance from the source area cannot be verified locally. Furthermore, where deposits are thin, contamination of the basal 12–18 inches through mixing with underlying material may provide unreliable data.

Postdepositional development of the profile of weathering in thick well-drained sections of Peorian Loess near the source areas has modified the original grain-size distribution. Data tabulated in table 6 [16] indicate the difference in the proportions of silt and clay. These differences are readily apparent. Although zone 3 has not been enriched by illuviation of clay, nor has it been weathered sufficiently to produce significant clay-sized particles in place, its clay content is almost twice that of the unleached but oxidized loess of zone 4, which is believed to approximate the unaltered parent material. The report by Wascher, Humbert, and Cady (1948) that "unweathered calcareous Peorian Loess contains less than 10 percent clay," is confirmed by the analyses (table 6). This apparent enrichment of clay-sized particles in zone 3 over zone 4 is attributed to removal of calcareous silt-sized particles during leaching of zone 3, for commonly as much as 30 percent of the silt-sized particles of zone 4 consists of calcite and dolomite.

How much of the clay in the deeply weathered loess is the product of postdepositional alteration is not known, although analyses (table 6) indicate that it may be appreciable. The clay content of the deeply weathered and illuviated material that has produced the clay-enriched zone 2 of the profile of weathering is assumed to have been originally about the same as the clay content of the relatively unaltered zone 4 of the Peorian Loess. Because the average clay content of zone 2 is almost four times that of the relatively unaltered zone 4, it is concluded that this increase is the result of the production of clay through postdepositional weathering of the original silicate minerals, illuviation of clay from the overlying zone 1, and the loss of silt-sized particles of carbonate minerals through leaching. Similarly, the greater amount of gravel-sized particles in the calcareous Peorian Loess of zone 4 than in the leached loess of zone 3 can be attributed to weathering, for by leaching of the carbonates from zone 3 and their redeposition in zone 4, minute pellets as well as larger nodules are produced. The calcareous pellets are indicated by the grittiness they impart to the loess.

Table 6 also indicates the remarkable uniformity of grain-size distribution of particles in the Farmdale Loess. Believed to have been leached and compacted during its slow deposition, the Farmdale Loess apparently has suffered relatively little postdepositional alteration, for it is highly impervious to ground water and was exposed relatively briefly before its burial by the overlying Peorian Loess. It may represent in effect the character of the deposit at the time its deposition was completed.

Grain-size analyses of the thin deposits of the Loveland Loess in the Owensboro quadrangle are of little critical value for correlation with those deposits elsewhere because of the deeply weathered nature of the deposits. Analyses from locality 3, table 6 (see also section 3), provide data for comparison of zones 2 and 3. Sample 3b was obtained from zone 3 above the basal few inches contaminated by the underlying weathered sandstone bedrock, and below the highly altered gumbolike zone 2 of sample 3a. Analyses indicate that zone 2 has an unusually high clay content, almost equal to that of the silt, but that in the underlying less altered zone 3 the clay content is less than a third that of the silt. The unusually high clay content of the Loveland Loess indicates the intensity of its weathering.

Little definite information on the original texture can be obtained from the single analysis of a deeply weathered silt referred to as Kansan loess (table 7). The sample is contaminated by sand- and gravel-sized particles of slope wash and mixed with material from the deeply weathered shale on which the deposit rests; therefore its recognition as a loess rests primarily on its general character and relationships to the stratigraphic succession observable at the outcrop. Its grain-size distribution, however, when interpreted in the light of its field relationships and the stratigraphic sequence of the outcrop, leaves little doubt as to its original character and origin.

Grain-size analyses of the Peorian Loess in the Owensboro quadrangle indicate that variations caused by weathering are greater and more systematic than differences resulting from the location of deposits relative to source areas. Variations in character of the older deposits of Loveland and Kansan loesses have resulted largely from postdepositional weathering and erosion and from contamination by the underlying weathered bedrock and slope wash. Grain-size distribution of such deposits can be interpreted only in the light of their local field relationships.

[16] Mechanical analyses were prepared by P. D. Blackmon, U.S. Geological Survey, as follows: Air-dried samples were quartered to an approximate weight (40–80 g), weighed, and dispersed in water with sodium metaphosphate as dispersing agent. Sand-sized material was removed by wet sieving, dried, and fractionated according to the Wentworth scale. Percentages of silt and clay were determined by standard pipette analysis.

TABLE 6.—*Mechanical analyses of loess, Owensboro quadrangle*

[Analyses by P. D. Blackmon. Distribution, in percent by weight, for indicated grain size, in phi units]

USGS sample	Locality	Zone	Gravel −2 to −1	Sand −1 to 0	Sand 0–1	Sand 1–2	Sand 2–3	Sand 3–4	Silt 4–4.5	Silt 4.5–5	Silt 5–6	Silt 6–7	Silt 7–8	Clay 8–9	Clay 9–10	Clay 10+
Peorian Loess																
150283	1	2	0.1	0.1	0.1	0.2	0.2	0.5	5.2	8.2	33.7	13.7	4.8	2.0	3.7	27.5
150271	2	2	<.1	<.1	<.1	.2	.2	.7	6.4	18.2	32.2	9.8	3.4	1.8	2.6	24.6
150252	3	3	<.1	.1	.2	.3	.6	1.1	4.2	10.1	43.6	19.3	6.0	1.7	2.8	10.0
150251	4	4	.2	.2	.2	.2	1.0	.5	8.0	20.4	46.1	14.5	2.2	.6	1.3	5.5
150248	5	4	1.1	.3	.3	.2	.4	1.9	10.9	20.4	39.7	14.9	2.9	1.3	.8	4.9
150290	6	4	.8	.1	.1	.1	.3	1.2	6.8	18.7	47.8	12.8	2.8	3.1	5.4	
Farmdale Loess																
150289	6	------	1.7	.8	.6	1.0	1.6	1.6	1.6	3.8	34.1	22.6	7.8	6.5	16.3	
150287	7	------	2.6	.3	.3	.5	1.2	1.2	1.3	10.3	33.7	19.7	7.8	3.7	1.1	16.3
150253	3	------	.0	.1	.4	.6	1.4	2.2	1.1	5.3	34.6	19.6	7.6	9.4	17.7	
Loveland Loess																
150286	7	------	.2	.4	.8	.9	4.0	6.4	1.8	8.0	17.3	15.9	10.4	5.4	4.3	24.3
150254	3a	2	.0	.1	.1	.2	.6	.9	1.7	2.8	25.5	16.8	4.5	7.7	39.1	
150255	3b	3	.6	.4	.4	.5	.7	1.1	.3	4.9	40.9	17.4	7.9	7.4	3.4	14.0

Localities:
1. SE. cor. sec. 34, T. 7 S., R. 7 W.
2. Loess mantling dune sand, NE¼NE¼ sec. 12, T. 7 S., R. 7 W.
3. Deep cut, now obliterated, on secondary road in Bon Harbor Hills, 1 mile northwest of road junction with Kentucky State Highway 331 and 400 ft northwest of bridge over unnamed creek. (See section 3.) (3a) Upper deeply weathered part; (3b) lower part of Loveland Loess above zone of contamination from underlying sandstone bedrock.
4. Roadcut along west side NW¼SE¼ sec. 32, T. 7 S., R. 7 W.
5. Roadcut along west side SE¼SE¼ sec. 31, T. 6 S., R. 6 W. (See section 10.)
6. Deep roadcut at valley wall along west side NW¼SW¼ sec. 9, T. 8 S., R. 6 W. (See section 2.)
7. Northwest margin of Bon Harbor Hills, 350 ft west of abandoned open-pit coal mine and about 200 ft south of Louisville & Nashville Railroad tracks. (See section 5.)

TABLE 7.—*Mechanical analyses of bedrock and loess deposits at section 1*

[Analyses by P. D. Blackmon]

Sample		Gravel −2 to −1	Sand −1 to 0	Sand 0–1	Sand 1–2	Sand 2–3	Sand 3–4	Silt 4–4.5	Silt 4.5–5	Silt 5–6	Silt 6–7	Silt 7–8	Clay 8–9	Clay 9–10	Clay 10+
152558	Peorian Loess, noncalcareous.	0.0	Tr.	Tr.	Tr.	0.1	0.1	1.7	7.1	34.8	20.8	7.2	3.2	2.2	22.8
152559	Farmdale Loess	.1	.8	1.1	.8	.6	1.3	3.1	3.1	29.0	25.1	11.5	4.4	2.9	16.2
152560	Loveland Loess, deeply weathered.	.9	1.7	1.3	1.2	1.7	3.3	3.8	3.4	15.8	17.3	11.5	7.5	5.3	25.3
152561	Loveland Loess, weathered.	<0.1	.2	.4	.8	1.8	2.7	2.6	4.1	20.6	19.4	9.5	6.3	4.3	27.3
152562	Compacted slope wash.	18.9	3.3	1.9	1.4	2.0	4.6	4.5	3.9	9.5	9.8	9.7	6.3	4.8	19.4
152563a	Kansan loess	5.5	3.0	1.4	1.0	2.0	5.7	2.5	2.7	8.2	9.6	11.4	9.5	4.8	32.7
152563b	Bedrock (shale), deeply weathered.	.1	.2	.5	.7	.8	1.2	1.7	1.0	1.6	5.3	9.0	13.2	11.5	53.2
152563c	Bedrock (shale), weathered.	17.0	3.5	1.5	.9	.7	1.4	2.0	4.1	14.7	13.3	9.3	6.7	4.2	20.7

MINERALOGICAL COMPOSITION OF LOESS DEPOSITS

Mineralogical composition of the very fine sand, silt, and clay fractions of loess samples from the deposits of the Owensboro quadrangle have been determined and tabulated in table 8 for representative samples.

Heavy residues, prepared by bromoform separation, were obtained from the very fine sand fraction (0.125–0.0625 mm) of samples and their percentage weight determined. Mineral identifications were made petrographically. In general, the heavy residues occur in such small amounts that percentage of the various minerals present was not determined. For example, zones 2 and 3 of the profile of weathering developed in the Peorian Loess and the Farmdale Loess normally contain less than 0.1 percent heavy

TABLE 8.—*Mineralogical analyses, in percent, of loess, Owensboro quadrangle*

[Analyses of very fine sand by Dorothy Carroll; analyses of silt and clay by P. D. Blackmon. See table 6 for location of samples]

	Peorian			Farmdale	Loveland	
	Locality					
	2	3	5	3	3a	3b
	USGS sample					
	150271	150252	150248	150253	150254	150255
Zone of profile of weathering	2	3	4	-------	2	3
Percent by weight of heavy minerals	<0.1	<0.1	1.2	<0.1	<0.1	<0.1
Very fine sand						
Ilmenite-magnetite	[1] X	X	X	X	A	X
Amphibole, blue-green	X	X	A	X	-------	-------
Amphibole, brown	-------	-------	X	X	-------	-------
Pyroxene	-------	X	X	X	-------	X
Hypersthene	-------	-------	X	-------	-------	-------
Garnet	X	X	X	X	-------	-------
Tourmaline	X	X	X	A	X	A
Epidote	X	X	X	-------	X	-------
Zoisite	-------	X	X	X	-------	-------
Rutile	X	-------	-------	X	-------	-------
Zircon	X	X	X	X	X	-------
Staurolite	X	-------	-------	-------	-------	-------
Mica	X	-------	-------	-------	-------	-------
Kyanite	X	-------	-------	-------	-------	-------
Silt						
Quartz	8+	9	5	[2] 9	10	9
Feldspar	1+	1	1	1	-------	1
Dolomite	-------	-------	3	-------	-------	-------
Calcite	-------	-------	<0.1	-------	-------	-------
Clay						
Kaolinite	1	2−	1	2	2	2
Mica	1+	2	2	<0.1	1	1
Vermiculite	2+	1+	1	2	1	-------
Mica-vermiculite mixed layering	-------	-------	1	-------	-------	-------
Montmorillonite	1	1−	-------	1	1	-------
Quartz	1+	2	3	2	1	2
Vermiculite-chlorite mixed layering	-------	1	-------	-------	-------	-------
Dolomite	-------	-------	2	-------	-------	-------
Mica-vermiculite-montmorillonite mixed layering	2	1	-------	2+	3	-------
Feldspar	-------	-------	<0.1	-------	-------	-------
Chlorite-mica-vermiculite mixed layering	-------	-------	-------	-------	-------	3
Halloysite	-------	-------	-------	-------	1	-------

[1] A, most abundant mineral; X, mineral present.
[2] Amount of mineral present estimated as parts in 10.

residues (table 8). The less weathered zone 4 of the Peorian Loess contains a slightly higher percentage by weight, for it has not lost some of the weatherable heavy minerals. A somewhat higher percentage of heavy residues has been obtained for some samples of the deeply altered Loveland Loess. This seeming anomaly is presumably the result of concentration of iron oxides developed during the deep weathering of the loess in Sangamon time.

Opaque minerals (ilmenite and magnetite) occur in the heavy residues of all samples, but they are most abundant in the pre-Peorian loesses. Tourmaline, zircon, garnet, and rutile are commonly present, but only in small amounts. Tourmaline particles, where most intensely weathered, have generally become well rounded; where least weathered, they are angular. Only in the Farmdale and Loveland Loesses of zone 3 is tourmaline the most abundant heavy mineral. A blue-green amphibole, most abundant in the less weathered zone 4 of the Peorian Loess, occurs also in zones 2 and 3 and in the Farmdale Loess, but it is absent in the more deeply weathered Loveland Loess. Brown amphibole, probably common hornblende, a pyroxene that is near diopside in optical properties, and hypersthene appear only in the less weathered zone 4 of the Peorian Loess and in the Farmdale Loess. In general, as pointed out by Wascher and others (1948), loss of the weatherable minerals is reflected in a decrease in the percentage weight of heavy minerals as well as an increase in those minerals resistant to weathering.

Silt (0.0625–0.0039 mm) and clay (0.0039–0.00098 mm) fractions were separated by centrifuging and air dried for X-ray analysis. X-ray diffraction patterns were obtained from randomly oriented powder of the silt-sized fraction.

Analyses of the X-ray diffraction patterns indicate that the silt is composed largely of quartz but includes minor amounts of feldspar and the carbonate minerals—calcite and dolomite. Relative proportions of these minerals depend on the intensity of the alteration of the loess by weathering. Where carbonates are present in the less weathered loess, quartz comprises about 50–70 percent of the silt particles; where weathering has been most intense, the silt particles may be 100 percent quartz. Feldspar generally accompanies quartz and in most samples comprises about 10 percent of the silt particles. It is lacking, however, in the sample of deeply weathered Loveland Loess, from which it has been removed presumably by weathering. Wascher, Humbert, and Cady (1948) have pointed out that weathering of hornblende parallels that of feldspar or is even more complete. Analyses (table 8) tend to verify their findings.

Analyses indicate that dolomite is the dominant carbonate mineral in all samples of zone 4 of the Peorian Loess. Calcite, which commonly accompanies the dolomite, occurs only in small amounts, from a maximum near 10 percent to less than 0.1 percent. Whether the more soluble calcite has been removed from the loess by partial or incomplete leaching which has left the less soluble dolomite, or whether the calcite was never present, has not been determined. It is suspected that the more soluble calcite has been removed by solution and redeposited as the calcareous nodules that are common in the lower part of zone 4, especially where the Peorian Loess overlies the compact, relatively impervious Farmdale Loess. If this be true, it explains the dominance of calcite in the nodules and of dolomite in the silt fraction. It also suggests that, despite the fact that zone 4 is apparently high in carbonate minerals, partial leaching has reached a greater depth in the Owensboro area than generally suspected.

X-ray diffraction patterns were made for each of the air-dried clay samples from (1) oriented aggregate; (2) oriented aggregate, treated with ethylene glycol; (3) oriented aggregate, heated at 400°C in diffractometer furnace; (4) oriented aggregate, heated at 500°C in diffractometer furnace; and (5) randomly oriented powder. Estimates of relative amounts of minerals present (table 8) are based on relative intensities of diffraction lines, and as many factors affect the intensity of the lines, they indicate only in a very general way the relative amounts of the minerals present.

Clay-fraction samples appear to be consistent with silt samples in that carbonates, in the form of dolomite, are expectable only in samples from zone 4 of the Peorian Loess. Unlike the silt fraction, however, the percentage of quartz is higher in the less weathered clay fraction. Kaolinite and micas occur in all samples, together with various alteration minerals resulting from weathering. Kaolinite is more abundant in the older loesses than in the younger Peorian Loess, a trend noted by Wascher, Humbert, and Cady (1948). Montmorillonite, reported by Beavers and others (1955) to be the predominant clay mineral in the B and C horizons of loessial soils of Illinois, has not been reported in zone 4 of the Peorian Loess nor in zone 3 of the Loveland Loess of the Owensboro quadrangle. This in general appears to be consistent with the evidence of Wascher, Humbert, and Cady (1948) that montmorillonite does not occur in the Loveland Loess and occurs only in moderate amounts in Peorian and Farmdale Loesses along the valleys of the lower Ohio and Mississippi Rivers.

REFERENCES CITED

Ashley, G. H., 1903, The geology of the Lower Carboniferous area of southern Indiana: Indiana Dept. Geology and Nat. Resources Ann. Rept. 27 (1902), p. 49–122.

Audubon, M. R., 1897, Audubon and his journals, with zoological and other notes by Elliott Coues: New York, Charles Scribner's Sons, 2 v. (v. 1, 532 p.; v. 2, 554 p.).

Barton, T. F., 1957, Twenty-five years' use of the 9-foot Ohio River channel: Econ. Geography, v. 33, p. 41–49.

Beavers, A. H., Johns, W. D., Grim, R. E., and Odell, R. T., 1955, Clay minerals in some Illinois soils developed from loess and till under grass vegetation, *in* Milligan, W. O., ed., Clays and clay minerals—proceedings of the 3d National Conference on Clays and Clay Minerals, Houston, Texas, Oct. 26–29, 1954: Natl. Research Council Pub. 395, p. 356–372.

Braun, E. L., 1950, Deciduous forests of eastern North America: Philadelphia, Pa., Blakiston, 596 p.

Braun, E. L., 1955, The phytogeography of unglaciated eastern United States and its interpretation: Bot. Rev., v. 21, p. 297–375.

Brown, C. A., 1938, The flora of Pleistocene deposits in the western Florida parishes, west Feliciana Parish, and east Baton Rouge Parish, La.: Louisiana Dept. Conserv., Geol. Survey Bull. 12, p. 59–96.

Bryan, Kirk, 1928, Glacial climate in non-glaciated regions: Am. Jour. Sci., 5th ser., v. 16, p. 162–164.

Burns, G. W., 1958, Vegetation and burial conditions, pt. 2 *of* Wisconsin age forests in western Ohio: Ohio Jour. Sci., v. 58, p. 220–230.

Campbell, M. R., 1898, Description of the Richmond quadrangle [Ky.]: U.S. Geol. Survey Geol. Atlas, Folio 46, 4 p.

Chamberlin, T. C., 1897, A supplementary hypothesis respecting the origin of the loess of the Mississippi Valley: Jour. Geology, v. 5, p. 795–802.

Cooper, W. S., 1958, Terminology of post-Valders time: Geol. Soc. America Bull., v. 69, p. 941–945.

Cramer, Zadok, 1818, The navigator, containing directions for navigating the Monongahela, Allegheny, Ohio, and Mississippi Rivers: with an ample account of these much admired waters, from the head of the former to the mouth of the latter; and a concise description of their towns, villages, harbors, settlements, &c. with maps of the Ohio and Mississippi to which is added an Appendix containing an account of Louisiana, and of the Missouri and Columbia Rivers, as discovered by the voyage under Capts. Lewis and Clark: 10th ed., Pittsburgh, Pa., Cramer & Spear, 304 p.

Crider, A. F., 1913, Economic geology of Tell City and Owensboro quadrangles: Kentucky Geol. Survey, ser. 4, v. 1, p. 263–316.

Curry, H. J., 1954, Archaeological notes on Warrick County, Indiana: Indianapolis, Indiana Hist. Bur., 40 p.

Deam, C. C., 1940, Flora of Indiana: Indianapolis, Indiana Dept. Conserv., 1236 p.

Demorest, M. H., 1942, Glacier regimens and ice movement within glaciers, pt. 1 *of* Glacier thinning during deglaciation: Am. Jour. Sci., v. 240, no. 1, p. 31–66.

Douglas, E. M., 1930, Boundaries, areas, geographic centers, and altitudes of the United States and the several States with a brief record of important changes in their territory and government: 2d ed., U.S. Geol. Survey Bull. 817, 265 p.

Fenneman, N. M., 1916, Geology of Cincinnati and vicinity: Ohio Geol. Survey, 4th ser., Bull. 19, 207 p.

——— 1938, Physiography of eastern United States: New York, McGraw-Hill, 714 p.

Fidlar, M. M., 1933, Some hills of circumalluviation in the lower Wabash Valley: Indiana Acad. Sci. Proc., v. 42, p. 135–140.

——— 1948, Physiography of the lower Wabash Valley [Ind.]: Indiana Dept. Conserv., Div. Geology Bull. 2, 112 p.

Fisk, H. N., 1944, Geological investigation of the alluvial valley of the lower Mississippi River: Vicksburg, Miss., Mississippi River Comm., 78 p.

——— 1947, Fine-grained alluvial deposits and their effects on Mississippi River activity: U.S. Mississippi River Comm., v. 1, 82 p.

Flint, R. F., 1928, Natural boundaries in the Interior Low Plateau physiographic province: Jour. Geology, v. 36, p. 451–457.

Flint, R. F., 1941, Ozark segment of Mississippi River: Jour. Geology, v. 49, p. 626–640.

Flint, R. F., and others, 1945, Glacial map of North America: New York, Geol. Soc. America, 2 sheets, scale 1 in. to approx. 72 miles.

——— 1959, Glacial map of eastern United States: New York, Geol. Soc. America, 2 sheets, scale 1 in. to approx. 28 miles.

Fowke, Gerard, 1925, The genesis of the Ohio River: Indiana Acad. Sci. Proc., v. 34, p. 81–102.

——— 1933, The evolution of the Ohio River: Indianapolis, Ind., Hollenbeck Press, 273 p.

Frye, J. C., and Willman, H. B., 1958, Permafrost features near the Wisconsin glacial margin in Illinois: Am. Jour. Sci., v. 256, p. 518–524.

Fuller, M. L., and Ashley, G. H., 1902, Description of the Ditney quadrangle [Ind.]: U.S. Geol. Survey Geol. Atlas, Folio 84, 8 p.

Fuller, M. L., and Clapp, F. G., 1903, Marl-loess of the lower Wabash Valley: Geol. Soc. America Bull., v. 14, p. 153–176.

——— 1904, Description of the Patoka quadrangle [Ind.-Ill.]: U.S. Geol. Survey Geol. Atlas, Folio 105, 12 p.

Gilbert, G. K., 1877, Report on the geology of the Henry Mountains [Utah]: U.S. Geog. and Geol. Survey Rocky Mtn. region (Powell), 160 p.

Goldthwait, R. P., 1958, Age and glacial events, pt. 1, *of* Wisconsin age forests in western Ohio: Ohio Jour. Sci., v. 58, p. 209–219.

Goldthwait, R. P., White, G. W., and Forsythe, Jane, 1961, Glacial map of Ohio: U.S. Geol. Survey Misc. Geol. Inv. Map I–316, scale 1 in. to approx. 8 miles.

Goodspeed Bros. & Co., 1885: History of Warrick, Spencer, and Perry Counties, Indiana: Chicago, Ill., Goodspeed Bros. & Co., 837 p.

Gould, E. W., 1889, Fifty years on the Mississippi, or Gould's history of river navigation: St. Louis, Mo., Nixon-Jones Printing Co., 750 p.

Gregory, J. W., 1930, Stone polygons beside Loch Lomond: Geog. Jour. [London]. v. 76, p. 415–418.

Grover, N. C., 1938, Floods of Ohio and Mississippi Rivers, January-February, 1937: U.S. Geol. Survey Water Supply Paper 838, 746 p.

Guyton, W. F., Stuart, W. T., and Maxey, G. B., 1944, Progress report on the ground-water resources of the Louisville area, Kentucky: U.S. Geol. Survey, 20 p.

Hack, J. T., 1957, Studies of longitudinal stream profiles in Virginia and Maryland: U.S. Geol. Survey Prof. Paper 294–B, p. 45–97.

Harvey, E. J., 1956, Geology and ground-water resources of the Henderson area, Kentucky: U.S. Geol. Survey Water-Supply Paper 1356, 227 p.

Henry, A. J., 1919, River and floods, February, 1918: U.S. Weather Bur., Monthly Weather Rev., v. 46, p. 83–95.

Hjulström, Filip, 1953, På expedition till Isländska sandurfält 1951 och 1952. An expedition to Icelandic sandur fields in 1951 and 1952: Ymer, v. 73, no. 3, p. 161–191. [English summary.]

——— [1956], The geomorphology of the alluvial outwash plains (sandurs) of Iceland and the mechanics of braided rivers: Internat. Geog. Cong., 17th, Washington 1952, Proc., p. 337–342.

Horberg, C. L., 1945, A major buried valley in east-central Illinois and its regional relationships: Jour. Geology, v. 53, p. 349–359.

Horberg, C. L., 1950, Bedrock topography of Illinois: Illinois State Geol. Survey Bull. 73, 111 p.

——— 1956, Pleistocene deposits along the Mississippi Valley in central-western Illinois: Illinois State Geol. Survey Rept. Inv. 192, 39 p.

Inter-State Publishing Co., 1883, History of Daviess County, Kentucky: Chicago, Ill., Inter-State Pub. Co., 870 p.

James, Edwin, 1823, Account of an expedition from Pittsburgh to the Rocky Mountains performed in the years 1819 and '20 * * * Major Stephen H. Long: Philadelphia, Pa., Cary & Lea, 2 v.

Jillson, W. R., 1950, American fluvial Pliocene deposits bordering the western margin of the Cumberland Plateau: Internat. Geol. Cong., 18th, London 1948, Rept., pt. 9, p. 54–58.

Johnson, W. A., 1936, Ohio River * * * Letter from The Secretary of War: U.S. 74th Cong., 1st sess., H. Doc. 306, p. 41–194.

Krumbein, W. C., 1937, Sediments and exponential curves: Jour. Geology, v. 45, p. 577–601.

Lee, Wallace, 1916, Geology of the Kentucky part of the Shawneetown quadrangle: Frankfort, Kentucky Geol. Survey, 73 p.

Leighton, M. M., 1926, A notable type Pleistocene section; the Farm Creek exposure near Peoria, Illinois: Jour. Geology, v. 34, p. 167–174.

——— 1931, The Peorian loess and the classification of the glacial drift sheets of the Mississippi Valley: Jour. Geology, v. 39, p. 45–43.

——— 1946, Geological implications of the loesses of the upper Mississippi River Valley region [abs.]: Geol. Soc. America Bull., v. 57, p. 1213.

——— 1958a, Important elements in the classification of the Wisconsin Glacial Stage: Jour. Geology, v. 66, p. 288–309.

——— 1958b, Principles and viewpoints in formulating the stratigraphic classifications of the Pleistocene: Jour. Geology, v. 66, p. 700–709.

Leighton, M. M., Ekblaw, G. E., and Horberg, C. L., 1948, Physiographic divisions of Illinois: Jour. Geology, v. 56, p. 16–33; *reprinted as* Illinois State Geol. Survey Rept. Inv. 129.

Leighton, M. M., and MacClintock, Paul, 1930, Weathered zones of the drift sheets of Illinois: Jour. Geology, v. 38, p. 28–53.

Leighton, M. M., and Willman, H. B., 1949, Itinerary of [2d Pleistocene] field conference; late Cenozoic geology of Mississippi Valley, southeastern Iowa to central Louisiana, June 12–25, 1949; Urbana, Ill., auspices of the State Geologists, 86 p.

——— 1950, Loess formations of the Mississippi Valley: Jour. Geology, v. 58, p. 599–623; *reprinted as* Illinois State Geol. Survey Rept. Inv. 149.

Leopold, L. B., and Wolman, M. G., 1957, River channel patterns —braided, meandering, and straight: U.S. Geol. Survey Prof. Paper 282–B, p. 39–85.

Leverett, Frank, 1899, The Illinois glacial lobe: U.S. Geol. Survey Mon. 38, 817 p.

——— 1921, Outline of the Pleistocene history of Mississippi Valley: Jour. Geology, v. 29, p. 615–626.

——— 1923, Glacial deposits of Missouri and adjacent districts [abs.]: Geol. Soc. America Bull., v. 34, p. 91–92.

——— 1929, Pleistocene of northern Kentucky: Kentucky Geol. Survey, ser. 6, v. 31, p. 1–80.

Leverett, Frank, and Taylor, F. B., 1915, The Pleistocene of Indiana and Michigan and the history of the Great Lakes: U.S. Geol. Survey Mon. 53, 529 p.

Lobeck, A. K., 1930, The Midland Trail in Kentucky; a physiographic and geologic guide book to U.S. Highway No. 60: Kentucky Geol. Survey, ser. 6, v. 33, p. 165–252.

——— 1939, Geomorphology, and introduction to the study of landscapes: New York, McGraw-Hill, 731 p.

MacCary, L. M., compiler, 1955, Map of the Louisville area, Kentucky, showing contours on the bedrock surface: U.S. Geol. Survey Hydrol. Inv. Atlas HA–5, scale 1 in. to approx. 4,700 ft.

McFarlan, A. C., 1943, Geology of Kentucky: Lexington, Univ. Kentucky, 531 p.

McGee, W. J., 1891, The Lafayette formation: U.S. Geol. Survey Ann. Rept. 12, pt. 1, p. 347–521.

McKelvey, V. E., 1941, The flotation of sand in nature: Am. Jour. Sci., v. 239, p. 594–607.

Malott, C. A., 1919, The "American Bottoms" region of eastern Greene County, Indiana—a type unit in southern Indiana physiography: Indiana Univ. Studies, v. 6, no. 40, 61 p.

——— 1922, The physiography of Indiana, *in* Handbook of Indiana geology: Indiana Dept. Conserv. Pub. 21, p. 59–256.

Mangum, A. W., and Neill, N. P., 1905, Soil survey of the Boonville area, Indiana: U.S. Dept. Agriculture, Field Operations of Bur. Soils, 1904, 6th rept., p. 727–749.

Mansfield, G. R., 1938, Flood deposits of the Ohio River, January-February 1937, a study of sedimentation: U.S. Geol. Survey Water-supply Paper 838, p. 693–736.

Marble, J. P., chm., 1950, Report of the Committee on Measurement of Geologic Time, 1949–1950: Natl. Research Council, Div. Geology and Geography, 118 p.

Mather, W. W., 1839, Report on the geological reconnaissance of Kentucky made in 1838: Kentucky, House of Representatives, Jour. 1838–1839, app., p. 239–278.

Matthes, G. H., 1941, Basic aspects of stream meanders: Am. Geophys. Union Trans. 22d Ann. Mtg., pt. 3, p. 632–636.

Maxwell, B. W., 1954, Public and industrial water supplies of the western coal region, Kentucky: U.S. Geol. Survey Circ. 339, 41 p.

Mayfield, S. M., 1934, Geology of Fordsville and Cannelton quadrangles [Ky.]: Chicago, Ill., 181 p. [Univ. Chicago, dissertation, private ed.]

Melton, F. A., 1936, An empirical classification of flood-plain streams: Geog. Rev., v. 26, p. 593–609.

Morrison, R. B., Gilluly, James, Richmond, G. M., and Hunt, C. B., 1957, In behalf of the Recent: Am. Jour. Sci., v. 255, p. 385–393.

Owen, D. D., 1838, Report of a geological reconnaissance of the State of Indiana made in the year 1837 * * *: Indianapolis, Ind., 34 p.

——— 1839, Second report of a geological survey of the State of Indiana made in the year 1838 * * *: Indianapolis, Ind., 46 p.

——— 1856, Report of the geological survey in Kentucky, made during the years 1854 and 1855: Frankfort, Ky., 416 p.

Péwé, T. L., 1951, An observation on wind-blown silt: Jour. Geology, v. 59, p. 399–401.

Potter, P. E., 1955, The petrology and origin of the Lafayette gravel—Pt. 1, Minearlogy and petrology; Pt. 2, Geomorphis history: Jour. Geology, v. 63, no. 1, p. 1–38; no. 2, p. 115–132.

Rafinesque, C. S., 1819, Natural history of the fishes of the Ohio River and its tributary streams: Western Rev. and Misc. Mag., v. 1, p. 305–313; Lexington, Ky.

Ray, L. L., 1957, Two significant new exposures of Pleistocene deposits along the Ohio River valley in Kentucky: Jour. Geology, v. 65, p. 542–545.

Ray, L. L., Butler, A. P., Jr., and Denny, C. S., 1946, Geologic map Fort Knox and vicinity; scale 1:50,000: Washington, prepared by U.S. Geol. Survey for the Chief of Engineers, U.S. Army.

Rozanski, George, 1943, Stone-centered polygons: Jour. Geology, v. 51, p. 330–341.

Rubey, W. W., 1952, Geology and mineral resources of the Hardin and Brussels quadrangles (in Illinois): U.S. Geol. Survey Prof. Paper 218, 179 p.

Rubin, Meyer, and Alexander, Corrine, 1960, U.S. Geological Survey radiocarbon dates V: Am. Jour. Sci., Radiocarbon Supp., v. 2, p. 129–185.

Rubin, Meyer, and Suess, H. E., 1956, U.S. Geological Survey radiocarbon dates III: Science, v. 123, p. 442–448.

Russell, R. J., 1940, Quaternary history of Louisiana: Geol. Soc. America Bull., v. 51, p. 1199–1233.

——— 1944, Lower Mississippi Valley loess: Geol. Soc. America Bull., v. 55, p. 1–40.

Salisbury, R. D., and Atwood, W. W., 1908, The interpretation of topographic maps: U.S. Geol. Survey Prof. Paper 60, 84 p.

Savage, T. E., 1915, The loess in Illinois, its origin and age: Illinois Acad. Sci. Trans., v. 8, p. 100–117 [1916].

Scheidig, Alfred, 1934, Der Löss und seine geotechnischen Eigenschaften: Dresden and Leipzig, Theodor Steinkopff, 233 p.

Schultz, J. R., and Cleaves, A. B., 1955, Geology in engineering: New York, John Wiley & Sons, 592 p.

Sears, P. B., 1948, Forest sequence and climatic change in northeastern North America since early Wisconsin time: Ecology, v. 29, p. 326–333.

Shantz, H. L., and Zon, Raphael, 1924, The physical basis of agriculture, *in* sec. E, Natural vegetation: U.S. Dept. Agriculture Atlas Am. Agriculture, 29 p.

Shaw, E. W., 1910, The geology and coal resources of the Murphysboro quadrangle, Ill.: Illinois Geol. Survey Bull. 16, p. 286–294.

——— 1911, Preliminary statement concerning a new system of Quaternary lakes in the Mississippi basin: Jour. Geology, v. 19, p. 481–491.

——— 1915a, Newly discovered beds of extinct lakes in southern and western Illinois: Illinois Geol. Survey Bull. 20, p. 139–157.

——— 1915b, On the origin of the loess of southwestern Indiana: Science, new ser., v. 41, p. 104–108.

Smith, G. D., 1942, Illinois loess—variations in its properties and distribution, a pedologic interpretation: Illinois Univ. Agr. Expt. Sta. Bull. 490, p. 139–184.

Stout, W. E., Ver Steeg, Karl, and Lamb, G. F., 1943, Geology of water in Ohio: Ohio Geol. Survey, 4th ser., Bull. 44, 694 p.

Sundborg, Åke, 1956, The river Klarälven; a study of fluvial processes: Geografiska Annaler, Stockholm, v. 38, no. 2–3, p. 125–316.

Theis, C. V., 1922, The geology of Henderson County, Kentucky: Univ. Cincinnati, unpub. doctoral dissertation, 215 p.

Thornbury, W. D., 1932, Notes on the glacial boundary in southern Indiana: Indiana Acad. Sci. Proc. (1931), v. 41, p. 351–354.

Thornbury, W. D., 1937, Glacial geology of southern and south-central Indiana: Indiana Dept. Conserv., Div. Geology Pub., 138 p.

——— 1938, Loess and lake silts of southwestern Indiana [abs.]: Geol. Soc. America Proc. 1937, p. 327.

——— 1940, Weathered zones and glacial chronology in southern Indiana: Jour. Geology, v. 48, p. 449–475.

——— 1950, Glacial sluiceways and lacustrine plains of southern Indiana: Indiana Dept. Conserv., Div. Geology Bull. 4, 21 p.

——— 1958, The geomorphic history of the upper Wabash valley: Am. Jour. Sci., v. 256, p. 449–469.

Troll, Carl, 1958, Structure soils, solifluction, and frost climates of the earth. Translation by H. E. Wright, Jr.: U.S. Snow Ice and Permafrost Research Establishment, Translation 43, 121 p.

U.S. Forest Service, 1949, Areas characterized by major forest types in the United States: map, scale 1:5,000,000.

U.S. Geological Survey, 1957, Compilation of records of surface waters of the U.S. through September 1950: U.S. Geol. Survey Water-Supply Paper 1305, 652 p.

U.S. Weather Bureau, 1954, Local climatological data with comparative data, 1953, Evansville, Indiana: Kansas City, Mo., U.S. Weather Bur., [4 p.].

Veatch, A. C., 1898a, An old river channel in Spencer County, Indiana: Indiana Acad. Sci. Proc. 1897, p. 266–271.

——— 1898b, Notes on the Ohio Valley in southern Indiana: Jour. Geology, v. 6, p. 257–272.

Visher, S. S., 1929, The climate of Kentucky: Kentucky Geol. Survey, ser. 6, v. 31, p. 81–167.

——— 1944, Climate of Indiana: Indiana Univ. Pub., Sci. Ser. 13, 511 p.

Walker, E. H., 1954, The deep channel and the alluvial deposits of the Ohio Valley in Kentucky: U.S. Geol. Survey open-file report, 68 p.

——— 1957, The deep channel and alluvial deposits of the Ohio Valley in Kentucky: U.S. Geol. Survey Water-Supply Paper 1411, 25 p.

Wascher, H. L., Humbert, R. P., and Cady, J. G., 1948, Loess in the southern Mississippi Valley; identification and distribution of the loess sheets: Soil Sci. Soc. America Proc. 1947, v. 12, p. 389–399.

Wayne, W. J., 1952, Pleistocene evolution of the Ohio and Wabash valleys [Ind.]: Jour. Geology, v. 60, p. 575–585.

——— 1958, Early Pleistocene sediments in Indiana: Jour. Geology, v. 66, p. 8–15.

Wayne, J. W., and Thornbury, W. D., 1951, Glacial geology of Wabash County, Indiana: Indiana Geol. Survey Bull. 5, 39 p.

White, G. W., 1953, Sangamon soil and early Wisconsin loesses at Cleveland, Ohio: Am. Jour. Sci., v. 251, p. 362–368.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U.S. Geol. Survey Bull. 896, 2396 p.

Wolman, M. G., and Leopold, L. B., 1957, River flood plains—some observations on their formation: U.S. Geol. Survey Prof. Paper 282–C, p. 87–109.