

CHAPTER TWO

GEOLOGY AND PEDOLOGY

2.0 INTRODUCTION

The close relationship between geology, pedology, and engineering should be recognized by all dedicated personnel who are concerned with the design, construction, and maintenance of highways. This association is especially valid in the case of highway engineering where highways are built on, through, above, and of earth materials. Unfortunately, most engineers receive little more than a superficial introduction to pedology and geology.

Geology is the scientific study of the origin, history and structure of the earth. It provides the basis for differentiating the materials comprising the earth's crust and interpreting the earth's history. In highway engineering, the importance of geology is in the interpretation of landforms; their history, the processes that shaped them, and the materials that comprise or underlie their surfaces. While pedology deals primarily with the product of surficial weathering, geology is concerned with the underlying material's character, distribution, and origin. Engineering geology studies help to outline areas of potential slope instability, buried zones of compressible materials, areas of possible surface subsidence, and areas of undesirable bedrock conditions.

Pedology is the scientific study of the origins, characteristics and uses of soils comprising the zone 3 to 6 ft. thick, immediately underlying the earth's surface. An important branch of soil science, pedology is concerned solely with the earth's surficial materials.

Applications of geological and pedological knowledge provide the ground work for delineating types of earth materials and potential problem zones. Then various sampling methods and tests, from the art of soil mechanics, supply the necessary quantitative data for incorporation into design criteria.

Some of the basic objectives of geotechnical investigations are to define the nature, characteristics, properties, thickness, and lateral extent of bedrock and overlying soils as well as ground water conditions within a given project area. An understanding of some of the basic geologic processes and how they combined to create the varied landscapes in our state, give us a base line of information from which to begin more detailed studies of the subsurface.

2.1 A BRIEF OVERVIEW

The geology of Indiana is both complex and diverse. The geologic history includes periods of deposition and subsequent erosion, subsidence and faulting, submersion by epi-continental seas with subsequent deposition of thousands of feet of material to form sedimentary rocks. All of these events took place prior to the start of the Quaternary Period, which began about two million years ago. The bedrock that was created over time is buried in most of the northern $\frac{2}{3}$ of the state by more recent, unconsolidated Quaternary deposits.

Most of the present land surface in Indiana was developed during the Quaternary Period, which includes the Pleistocene (Glacial) and Holocene (Recent) Epochs. In light of this, much of the emphasis of this chapter will be on Quaternary geology, including glacial soils and landforms, recent soil types, and hydrogeology. The bedrock geology will be discussed only in generalities because it is too complex and

diverse to cover within the scope of this manual. All of the topics presented in Chapter 2 fall under the sphere of geology, and questions or problems in characterizing soils or bedrock or ground water conditions should ultimately be directed to the Field Unit of the Geotechnical Section.

2.2 QUATERNARY GEOLOGY

The start of the Quaternary Period was marked by cyclic variations in the climate, which resulted in successive advances and recessions of glacial ice sheets across Indiana. This time period, referred to as the Pleistocene Epoch, or the “Great Ice Age”, has been subdivided into four major glaciations, with interglacial periods. These are from youngest to oldest:

Present interglaciation
Wisconsin glaciation
Sangamon interglaciation
Illinoian glaciation
Yarmouth interglaciation
Kansan glaciation
Aftonian interglaciation
Nebraskan glaciation

A succession of glacial advances and intervening episodes of soil formation during the Wisconsin, Illinoian, and older glaciations are recognized by various glacial sediment sequences, including glacial till and granular materials. Interglacial periods are recognized by evidence of soil development; fossils and pollen, and from sediments which indicate warmer climate, such as lake deposits, beach ridges, and peats.

During the Pleistocene Epoch, the movement of ice and ice-bound debris was a strong abrasive force, and most of Indiana bears the scars of this force. The final glaciation, the Wisconsin, lasted from about 75,000 to 12,000 years before the present time and was responsible for the majority of the landforms seen in Indiana today. Glacial activity during the Wisconsin glaciation eroded or buried earlier glacial deposits from the Nebraskan, Kansan, and most of Illinoian glaciations, largely obscuring evidence of these earlier deposits.

The Wisconsin glaciation is characterized by advances and retreats of ice lobes that protruded from the main ice sheet that covered most of Canada. The movement of the ice lobes across Indiana was controlled by major bedrock topography of the area over which the ice moved. In general, the ice lobes followed lowlands that were developed on the softer sedimentary rocks that flank the rim of the Michigan Basin Regional Structure.

The Wisconsin Age of glaciation brought three main lobes of glacial ice (and “unconsolidated” materials) into Indiana. In Northwestern Indiana, the Lake Michigan Lobe of ice flowed south into the west central part of Indiana as it carved out Lake Michigan and deposited layers of till and other glacial drift. Similarly, in Northeastern Indiana the Huron-Saginaw Lobe flowed southwesterly into Indiana from the Saginaw Bay area of Lake Huron in Northeastern Michigan. Thirdly, the Ontario-Erie Lobe came from the Northeast and East and crossed most of the northern half of Indiana. Each of these 3 lobes brought unique combinations of minerals and rock fragments in the soil material that they deposited as glacial drift.

2.2.1 PLEISTOCENE SURFACE GEOLOGY

Most of the surface features created during the Pleistocene Epoch are the result of either direct contact with glacial ice or from the action of glacial meltwater. Glacial erosional features were created by the gouging and/or scraping of the underlying bedrock or older glacial deposits, or by glacial meltwater. These topographic erosional features include striations, and tunnel valleys.

Glacial depositional features are more common and are the result of material dumped by the ice as it rode over the land surface or left behind as the ice melted or retreated. All material deposited by glacial action, whether it be directly from the ice or indirectly from meltwater, is classified as Drift.

Drift deposited directly by glacial ice with no sorting action, include erratics and till. Materials that are deposited by waters associated with the glacial ice include; glaciofluvial, which are deposited by a stream or river originating from glacial meltwater, and glaciolacustrine, which are sediments deposited in lakes bordering and/or supplied by the glacier. Deposits from meltwater exhibit some degree of sorting and are often stratified. Also associated with glacial and post-glacial activity are wind-blown or Eolian deposits.

Topographic depositional features include moraines, drumlins, kames, eskers, kettle lakes, lake plains, outwash plains and till plains. The terms, “outwash” and “till” have been used in the literature to describe both topographic landforms and soil types. However, they both possess very unique and easily identifiable soil types, and as such, it has been useful to apply them as an adjective to the basic soil type description. To avoid confusion, the term “plain” will be added to the description when a topographic landform is being described in this manual, such as outwash plain or till plain.

Many topographic features (landforms) are associated with narrow ranges of soil types: e.g. peat bogs with organic soil, lake plains with clay to silty clay, eskers with sand and gravel, and moraines with sandy loam to clay loam. Most landforms visible in Indiana today are the result of the Wisconsin glaciation - the final advance of glacial ice to blanket the state. Many of the landforms and associated glacial sediments, discussed in the following sections, and their major areas of occurrence in the state, can be seen in the 1989 map entitled: “**Quaternary Geological Map of Indiana**” by Henry H. Gray produced by the Indiana Geologic Survey.

2.2.1.1 GLACIAL EROSIONAL FEATURES

Bedrock outcrops that have survived the abrasive forces of glaciers display distinctive scars. Striations occur as parallel linear scratches on the bedrock, caused by movement over the bedrock surface of individual rock fragments embedded in the base of the ice. Quarrying, or plucking, is glacial erosion on a much larger scale. Bedrock weakened by fractures is pulled away by the overriding ice and removed by the glacier. This process occurs most frequently on the lee side of the bedrock feature.

Tunnel valleys are trenches cut in drift or bedrock by large quantities of flowing subglacial meltwater. They may be many meters deep, over a kilometer in width, and extend for many miles. Typically they are developed in pre-existing glacial drift. Tunnel valleys could also be discussed under topographic depositional features, because many erosional valleys are subsequently filled by younger drift. Occasionally, when the quantity of meltwater lessens and the subglacial tunnel chokes with sediments, eskers will develop within the course of the tunnel valley.

2.2.1.2 GLACIAL DEPOSITIONAL FEATURES

In considering glacial depositional features, care must be taken to discriminate between glacial deposits (soils) and topographic landforms. The general term that describes glacial deposits is drift. Drift includes all the material ever handled by the ice even if it is subsequently affected by wind or water. Abundant glacial drift deposits, some more than 400 feet thick, cover most of the Northern two-thirds of Indiana. Drift from glacial advances older than the Illinoian and Wisconsin glaciations are largely obscured, either by erosion or by burial beneath younger deposits. Even the earliest deposits of the Wisconsin glaciation are difficult to identify because of subsequent advances and retreats of the ice lobes. A map showing the Southern limits of the Illinoian and Wisconsin glaciation is shown on the “**Physiographic Map of Indiana**” by *Clyde A. Malott*. Also attached is “**Map of Indiana Showing Thickness of Unconsolidated Deposits**” by *Henry H. Gray, 1983*, and a “**Map of Indiana Showing Topography of the Bedrock Surface**” by *Henry H. Gray, 1982*.

2.2.1.2.1 UNSORTED DEPOSITS

Till is unstratified and unsorted debris deposited directly from glacial ice without subsequent movement by wind or water. It consists mainly of mechanically broken fragments of bedrock, as well as any soils or earlier glacial deposits that were overridden by the glacier and commonly displays a mixture of a few large rock fragments within a matrix of fine sand, silt and clay. Gray, slightly moist, hard, clay loam, with a trace of gravel, is the most commonly described till in Indiana.

Individual boulder - sized rock fragments deposited far from their bedrock sources are called erratics.

2.2.1.2.2 SORTED DEPOSITS

Glaciofluvial deposits form when meltwater generated along the margins of melting glaciers picks up sediment and redeposits it as sorted beds of sand and gravel. These granular deposits are referred to as outwash. Outwash deposits are typically good sources of sand and gravel. The high permeability of outwash materials makes them excellent ground water sources.

Sediments derived from glacial ice, deposited in fresh water lakes, are known as glaciolacustrine. As the glacial ice melts, meltwater runoff is dammed behind morainal deposits and other glacial features creating extensive lakes. During the Pleistocene, such glacial lakes were generally short lived, however, they had a lasting effect on the land surface.

Lake sediment deposits are also common in tributary valleys of the Ohio River, Wabash River and White River in Indiana, south of the Wisconsin and Illinoian glacial boundaries. These tributary valley lakes filled with silt and soft clays, because, as the main river valleys filled with outwash sand and gravel, water levels rose in the tributary valleys and formed lakes.

Lake sediments are also quite commonly found under peat deposits in Northern and Central Indiana. These types of deposits are often found in depressional areas called kettle-lakes, formed as large stranded blocks of glacial ice were buried in till and later melted. These kettle lakes often have a predictable sequence of deposits on a base of hard “loaded ice” ground moraine till:

First, a layer of “normally loaded” lake bottom till, usually medium stiff; then often a thin layer of sand; then soft lacustrine clay; then marl, usually very soft; then peat, usually very soft, at the top.

Lake sediments are characteristically well-bedded silts and clays with occasional fine pebble to boulder size erratics (dropstones) interspersed. These sediments are commonly varved, consisting of pairs of light/dark layers corresponding to summer/winter annual cycles.

Wind-driven waves created beach ridges or strand lines at the edges of many of the glacial lakes. These old beaches remain visible in many places in the north portion of the state, and mark former shorelines. Often elevated above the present topography of lake sediments, lake beaches are visible as linear ridges, 3 to 10 meters in height, 100 meters or more in width, and extending up to tens of miles. These beach deposits consist primarily of sand and/or gravel, with characteristic cross bedding. Some of the more prominent lake beaches (shorelines) are shown on the [Quaternary Geologic Map of Indiana](#).

2.2.1.3 TOPOGRAPHIC FEATURES

Distinctive depositional landforms are constructed of sediments deposited by glacial ice and/or its meltwater. Soil and rock debris entrained within the glacial ice can be deposited during an advance or retreat of the glacier. Till dropped during the advance of a glacier or deposited by a retreating glacier as a thin blanket marked by low hills and swales is called ground moraine or a till plain.

The margins of glacial ice are especially active sites for the accumulation of debris, because there, melting is most intense. As a result this melting of the glacier and continued conveyance of the debris toward the margin, considerable volumes of sediments build up to form terminal moraines. These long, relatively high ridges of till mark the farthest advance of the ice sheet. Recessional moraines form at locations where the glacier “pauses” temporarily, during its final retreat, (where it was melting at about the same rate of advance). The term end moraine is more general and includes both terminal and recessional moraines.

Kames are formed when a cavity within or on stagnant ice, fills with soil and rock debris. When the glacier melts, this collection of material is left behind as a mound or irregularly shaped hill of crudely stratified sand and gravel. Kames often occur in groups with kettles resulting in a hummocky topography with variable soil and water conditions.

Eskers originate from stream flow through tunnels within or below the glacial ice. As the melting glacial ice sheets thinned and hydrostatic pressure decreased, water velocity in the tunnel was no longer sufficient to transport all of the sediment supplied to the stream. Coarser sand and gravel were deposited with crude bedding, and finer materials were carried beyond the front of the glacier and deposited in lower energy lakes or streams. Subsequent melting of the ice sheet exposed these irregularly stratified and sorted sand and gravel deposits, which often extend for tens of miles. Due to their coarse-grained nature and length, eskers may provide an excellent source of granular materials.

Meltwater streams carried sediment out from the toe of the glacial front in large alluvial fans called outwash plains. Large systems of braided streams often carried material in thin sinuous ribbons distances of many miles from the ice front. The resulting, sorted, granular deposits are mixed sands and gravel with crude bedding and many scour-and-fill structures. Many large areas of Northern Indiana are outwash plains, such as the Kankakee outwash plain and the areas around the St. Joseph

River and other rivers. Because of their great aerial extent, outwash plains can be sources of abundant water.

2.2.1.4 WIND BLOWN DEPOSITS

Wind – blown deposits, also known as eolian deposits, typically are of two categories, loess, comprised of silt particles and fine sand and *dune sand*, comprised of the larger sand particles.

2.2.1.4.1 LOESS

Loess deposits in the middle regions of the United States are a result of the thousands of years of the winds blowing the soils of the desolate, vegetation poor, wastelands caused by the retreat of the great Illinoian and Wisconsin Ice Ages. Massive sheets of ice scoured the hilly terrain and left extensive flat beach-like areas, with no plant life. Fast moving northwesterly winds had nothing to slow them, and the lighter soils (silts) were picked up by the winds and scattered all over the central United States, covering the landscapes with a mantle of silt in varying depths.

Most of the thicker deposits have been associated with the Illinoian Stage Glaciation and the subsequent erosion and deposition of the fine particles found between till layers. The Wisconsin Stages, deposited second, are a less thick deposit, but is also widely spread.

In Indiana, a thick mantle of loess deposits are evident throughout most of the state, but are far greater in the southwestern geographical quarter where there may be silt deposits as thick as 40 ft. in some locations. The counties of Vigo, Sullivan, Knox, Davis, Gibson, Pike, Posey and Vanderburg are where the deepest deposits of wind-blown silt occur. Indiana Geological Survey has an excellent map, *Quaternary Geologic Map of Indiana*, by Henry Gray, 1989, which illustrates where these deposits are located.

Loess, from an engineering standpoint, is very interesting soil and can be a challenge for road construction. Loess material is able to stand in a vertical, or near vertical position, in cut sections with few stability problems for long periods, but is subject to rapid erosion when exposed to water or wind in the absence of a protective vegetation cover. Loess may also be subject to settlement problems and the bearing capacity may be affected, by the presence of percolating water. The resulting instability could result in a collapse of vertical soil walls if care is not taken.

2.2.1.4.2 DUNE SANDS

Sand dunes, along with dune formations, both ancient and modern, can be found throughout Indiana. Most are easily recognized by the clean, well sorted, frosted, fine grain sized particles and cross-bedding of the layers. These particularly fine, well sorted, sands are easily recognizable from the highly variable, mixture of sands deposited by water.

2.2.1.5 DRIFTLESS AREA

The majority of Indiana experienced periodic overriding by coalescing glacial ice lobes. However, south central Indiana has escaped modification by glacial ice. This region includes most of the Crawford Upland, the Mitchell Plain, and Norman Upland physiographic units, and much of the southern part of the Wabash Lowland physiographic unit.

While not extensively modified by ice, the driftless area has experienced enhanced topographic development as a result of glacial meltwaters and modern rivers and streams. Surface materials in this area consist predominantly of loess-covered residual soils on bedrock, as well as colluvium and bedrock outcrops.

2.2.3 HOLOCENE GEOLOGIC FEATURES

Holocene surface features are the result of reworking/deposition of soil materials which have taken place since the last glaciation, hence - recent. A short discussion of these soil types and their general characteristics and uses follows.

2.2.3.1 ALLUVIAL

An important feature from prehistoric times is the preglacial Teays River which flowed through north central Indiana and was the major source of Indiana's deep deposits of alluvial sediments, which includes extensive boulder and cobble beds, in the now buried Teays Valley. The deep valley extends out of Ohio at a point in southern Adams Counties, where it continues west into Miami and Cass. At that juncture, the ancient valley tracks almost due west along the Warren and Benton County line, and exits Indiana into Illinois. For several miles starting in Wabash County through Tippecanoe County, the valley roughly parallels the present Wabash River.

2.2.3.2 LACUSTRINE

Lacustrine Sediments are fine-grained sediments which are deposited in fresh water lakes. These lakes may or may not still be in existence. Wave action in lakes carries the finer grained silt and clay sized particles in suspension towards deeper water. As the water calms, these particles settle out and accumulate in the lake bed to form what is known as lacustrine soil. (As mentioned earlier, many lacustrine sediments were formed in glacial lakes.) Old lake plains are frequently evidenced by a very flat topography. Remnants of lacustrine terraces are common in southern Indiana valleys that were tributaries to larger rivers that carried outwash sediment.

2.2.3.3 PEAT AND MUCK

Peat is formed when organic material is deposited in a predominantly cool and oxygen-deficient environment. These conditions lead to preservation of the plant matter, with leaf and stem materials often remaining identifiable. Peat bogs are dominated by sphagnum moss with stands of black spruce and tamarack, and contain highly acidic waters. Fens are dominated by grasses, sedges, and reeds, with waters rich in minerals and less acidic than that of bog waters. These organic sediments typically form as vegetation encroaches into and then totally fills shallow lakes.

Peat is found commonly in the Northern Lake Moraine Physiographic Region in the Northern $\frac{1}{3}$ of the state and occasionally in the central $\frac{1}{3}$ of the state. Organic soils contain well-decomposed organic matter with or without some plant fibers of different decomposed states; e.g., "organic soil" has 15 to 30 percent organic matter. Peat is considered to be greater than 30 percent organic matter.

Peat (more than 30 percent organic content) can be further subdivided as follows:

- **Spongy Peat** is a well-decomposed organic soil that has been subjected to certain consolidation conditions that cause it to appear and feel spongy. It varies in its mineral soil content, and there is little or no fiber content visible.
- **Well-Decomposed Peat** is an organic soil whose organic content has been subjected to a thorough decay process in which most fibers are invisible to the naked eye and which varies in its mineral content.
- **Partially Decomposed Peat** is a short-fibered organic soil that may be fairly well decomposed and may contain mineral soil. Most of the fibers are less than approximately 3 mm in length.
- **Semi-fibrous Peat** is an organic soil whose plant fibers range from approximately one-eighth to one inch in length and are partially decomposed. These fibers may be mixed with some fairly well-decomposed organic matter and have varied mineral soil content.
- **Fibrous Peat** is an organic soil in which plant fibers are mostly one inch or more in length and are partially decomposed. These fibers may be mixed with some fairly well-decomposed organic matter and a small amount of mineral soil. The term “woody” is sometimes used for very coarse organic deposits.

2.2.3.4 MARL

Carbonate-rich, light gray to almost white layers of silts and clays formed by the precipitation of calcite in the bottom of lakes or swampy areas are known as marls. The carbonate generally found in marl comes from two sources, high calcium-carbonate groundwater and carbonate – fixing aquatic organisms such as diatoms (one-celled alga) and snails. Identification can be easily made if there are still shells or fragments of shells observed in the samples, otherwise, because of the high carbonate content of the material, the use of dilute hydrochloric acid may be required to test it. This easy field test of a few acid drops will cause marl soils to effervesce when applied, and help differentiate it from the fine gray sands which can also be found in swamp bottoms.

2.2.3.5 RESIDUAL SOILS

Residual soils are the product of weathered and/ or decomposed shale, limestone and sandstone bedrock and are common in the southern 1/5th of Indiana, in the unglaciated physiographic areas. The principal products of bedrock’s in-place weathering are the clay minerals, such as kaolinite and chlorite and often contain remnant minerals of the pre-existing rock structure.

Residual clays are known for their brightly colored hues of green, brown, blue-gray, purple, and red, such as in the well known “Terra-Rosa” (red earth) clays weathered from the limestone bedrock in the Mitchell Plains and the Crawford Uplands Physiographic Regions near Bloomington and Bedford. The “Terra Rosa” clays are among the purest clay found in the State of Indiana.

2.2.3.6 COLLUVIUM

Unsorted, rock fragments and soil materials produced by gravity or mass wasting are called colluvium. Landslides, mud slides, and talus are all colluvial deposits. These heterogeneous deposits are generally identifiable in the field and typically lie in a slump at the base of a hill or rock outcrop. The presence of such material usually indicates an unstable area subject to debris flow, slides, slumps, or down-slope creep. Highly variable soil conditions should be expected. Variable subsurface conditions or possible boulders may give misleading information as to soil type conditions or possible boulders may give misleading information as to soil type and depth to bedrock.

2.3 BEDROCK GEOLOGY

The bedrock in Indiana is sedimentary rock. There is no igneous or metamorphic bedrock known to be encountered in Indiana without first going through at least a half-mile thick sequence of sedimentary bedrock before encountering the Precambrian “basement” igneous rocks. This sedimentary bedrock is all of the Paleozoic Era. There are no Mesozoic or Cenozoic bedrock deposits found in Indiana.

Much of the bedrock in the northern two-thirds of the state is covered by thick “unconsolidated” deposits (up to 400 feet) of glacial drift, but the southern one-third of the state has relatively thinner soil deposits. The southeast part of the state has generally thin, older glacial and residual soils on shale and fossiliferous limestone bedrock of the Ordovician, Silurian, and Devonian systems. The south-central, unglaciated part of the state has generally thin residual clay soil on bedrock of Mississippian siltstone and limestone, and Pennsylvanian shale, sandstone, and limestone. The bedrock in the southwest part of the state is mostly shale, sandstone, limestone and coal of the Pennsylvanian System, which is covered in most areas by older glacial soils and residual soils, with some large lakebed clay deposits, and almost all of the southwest part of the state has a surface layer of silty wind-blown loess.

2.4 STRUCTURAL GEOLOGY

Structural Geology describes the tectonic influence on the rock, such as folding, tilting, cracking, bending and faulting of the strata. The general attitude of strike and dip of bedrock strata in Indiana is governed by three major regional structural elements, the Illinois Basin, the Cincinnati Arch, and the Michigan Basin.

2.4.1 FAULTS

Displacement along these faults occurred millions of years ago. None show any ground surface differential displacement today and most do not show any surface expression for displacement of any sort. A few places show some surface expression where distinctive soil types form due to different weathering characteristics of the individual bedrock types outcropping along a fault, such as along the Mount Carmel Fault in Northern Lawrence County, where, limestone weathers to residual red clay on one side of the fault and shaley siltstone weathers to yellow silty clay on the other side of the fault.

The Mount Carmel Fault is about 50 miles long and has a vertical displacement of around 200 feet. It runs from northern Washington County, northward through Lawrence County and Monroe County and into southern Morgan County. One of the few places in Indiana where an actual fault surface, and displacement in a bedrock exposure, can be seen, is at an accessory or branch fault of the Mount Carmel

Fault on S.R. 446 in Lawrence County at about 2¹/₂ miles south of the Monroe-Lawrence County line. It's near the north end of a long bedrock cut section on the east side of S.R. 446. Shaley siltstone is on the north side of the fault and limestone is on the south side at this exposure.

The Fortville Fault is about 50 miles long and has a vertical displacement up to 60 feet. It runs from southeastern Marion County in a northeasterly direction across corners of Hancock County and Hamilton County and diagonally through Madison County and slightly into Grant County. It is covered by thick glacial drift deposits for most of its length. Some exposures may become apparent in future limestone and dolomite quarries for crushed stone aggregate mining in Madison County.

The Royal Center Fault is about 35 miles long and has about 100 feet of vertical displacement. It runs from northeastern White County in a northeasterly direction and crosses part of Cass County and runs diagonally through Fulton County. It is covered by thick deposits of glacial drift. No exposures are known.

The New Harmony Fault is about 30 miles long and has more than 400 feet of vertical displacement. It runs through parts of western Posey County and Gibson County in Indiana and into parts of Illinois, trending generally about 20 degrees east of north. It is a zone of overlapping parallel faults. There are many other more or less parallel faults in Posey County and Gibson County which are known in much greater detail due to exploratory drill holes for oil, gas and coal. These Posey and Gibson County faults are in an area of seismic activity associated with the New Madrid Seismic Region. Because of this, there is a higher degree of seismic risk in southwestern Indiana.

Other smaller faults are: Deer Creek Fault in southern Perry County and some possible faults in southern Spencer County and western Floyd County.

All of the faults in Indiana are "Normal" type faults, with vertical displacement, rather than "strike-slip" type faults with horizontal displacement. Many of them have anticline structures associated with them usually on the "down-thrown" side. Exposures are scarce or non-existent and most of these faults are known only from drill-hole correlation.

2.4.2 JOINTS AND BEDDING PLANES

Joints and bedding planes are the most obvious bedrock structural elements seen in samples and outcrop exposures.

Bedding planes, sedimentary depositional features are the horizontal planes of separation of the bedrock strata. They are often points of weakness along which the rock is most easily broken, and are especially obvious in core samples of shale.

Joints are usually medium to high-angle fracture planes (cracks) in bedrock that are commonly seen as angular surfaces in rock cut back slopes along roadways, and as high-angle separations in rock core samples. They are the resultant stress fractures from bending of rock strata. Joints can be so closely spaced that they severely lower the strength of the rock mass and limit its capabilities with regards to foundations and cut slopes. They also become the main pathways for ground water flow through bedrock. These pathways often appear as brown weathered zones in otherwise unweathered rock. These zones of accelerated weathering can grow to become large cavities, especially in limestone.

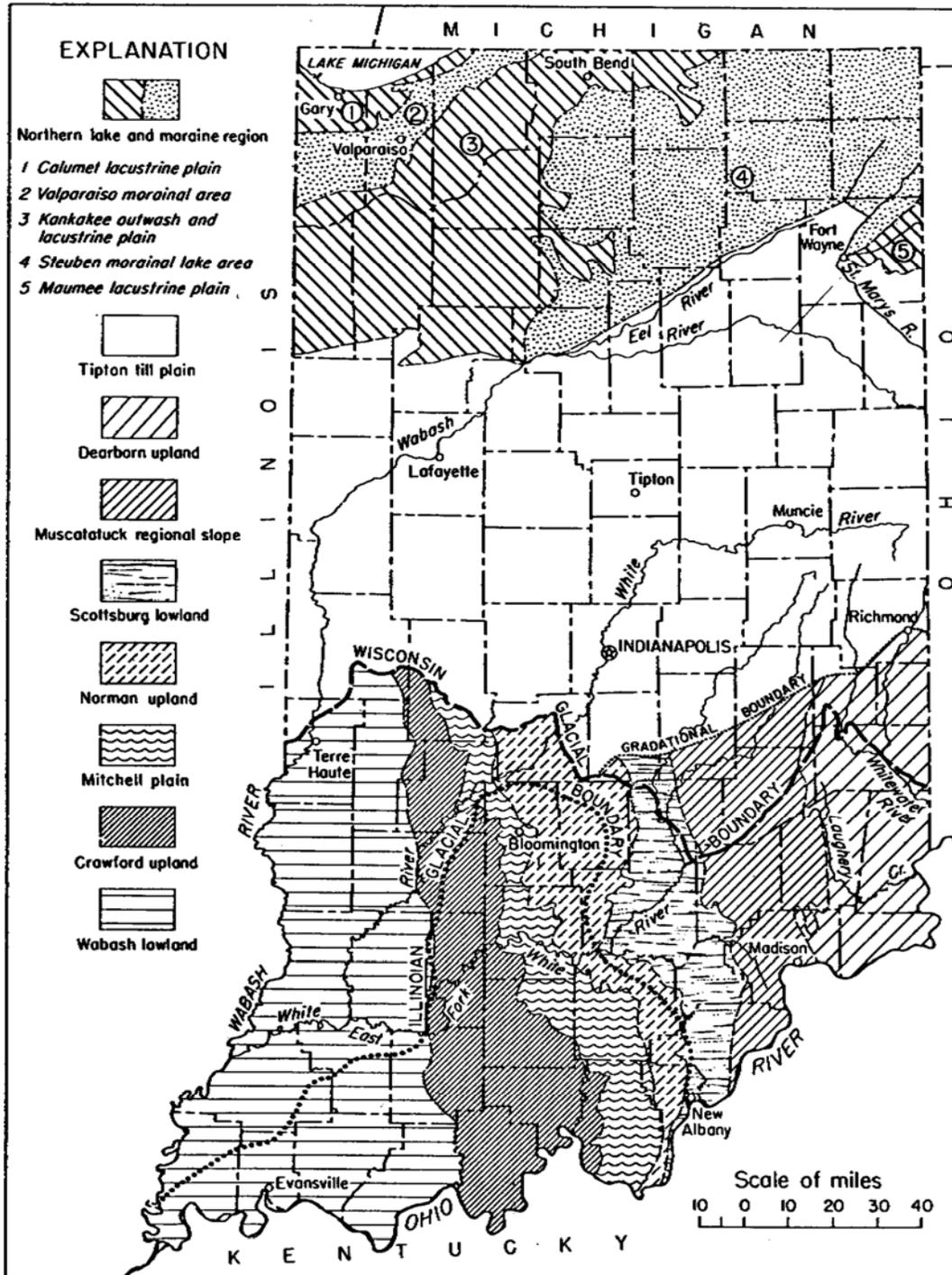
2.4.3 DEPOSITIONAL BASINS

The Illinois Basin and the Michigan Basin are “Structural Low” areas, towards which the sedimentary bedrock strata are dipping. In Indiana, the Cincinnati Arch is the relative “Structural High” area that is left after the subsidence that occurred which formed the Illinois Basin and the Michigan Basins. Bedrock strata are generally level along the Axial plane of the Cincinnati Arch which runs from southeastern to northwestern Indiana. Bedding planes of the rock strata then dips generally at an increasingly steeper rate as the Illinoian Basin is approached in the southwest direction, towards south-central Illinois, and as the Michigan Basin is approached towards the northeast direction, towards central Michigan. Locally there are broad, open syncline, anticline, and monocline structures superimposed on the regional structure that have more effect on the local dip of strata.

2.5 INDIANA KARST

Carbonate rock, which is chiefly limestone, can yield freely to the solvent action of water when the water is charged with carbon dioxide (CO₂), such as from rainfall or organic soils. This weakly acidic (carbonic acid) water reacts with the limestone and slowly dissolves: widening fissures and joints, weakening the rock. As these joints and fissures grow to cavity size the roof can become unstable and collapse, in near surface areas this results in sink holes.

The Mitchell Plain, Crawford Upland, Muscatatuck Plateau and Dearborn Upland Topographic Regions (See Fig. 2.1) are the dominant regions for the surficial expression of karst features in Indiana. Throughout the Mitchell Plain carbonate rocks such as the predominate limestone and dolomite have developed into an extensive system of solution cavities which is expressed topographically as sinkholes, sinking streams and caves. There are areas of buried karst in the Bluffton Till Plain, Newcastle Till Plain and the Tipton Till Plain.



Map of Indiana showing regional physiographic units based on present topography. Modified from Malott, 1922, pl. 2.

Fig. 2.1: Map of Indiana Showing Regional Physiographic Units Based On Present Topography. Modified from Malott, 1922, pl.2.

Table 2.1 General Stratigraphic Column for Paleozoic Rocks in Indiana

| PERIOD | EPOCH | THICKNESS (FT)* | LITHOLOGY | ROCK UNIT | | | PERIOD | EPOCH | THICKNESS (FT)* | LITHOLOGY | ROCK UNIT | | | | | |
|---------------|--------------|-----------------|-----------|--------------------|--------------------|---------------|--------------|--------------------|-----------------|--|--------------------|-------------------|------------------|------------------|---------------|---------------|
| | | | | SIGNIFICANT MEMBER | FORMATION | GROUP | | | | | SIGNIFICANT MEMBER | FORMATION | GROUP | | | |
| PENNSYLVANIAN | MISSOURIAN | 170 to 770 | | Merom Ss. | Mattoon | McLeansboro | DEVIANIAN | SENIOR ERIAN | 20 to 250 | | New Albany Sh. | Ellsworth Sh. | Muscatatuck | | | |
| | | | | Livingston Ls. | Bond | | | | | | North Vernon Ls. | Traverse | | | | |
| | | | | Carthage Ls. | Patoka | | | Jeffersonville Ls. | Detroit River | | | | | | | |
| | | | | Vigo Ls. | Shelburn | | | Geneva Dol. | | | | | | | | |
| | DESMOINESIAN | 290 to 460 | | Darville Coal | Dugger | Carbondale | | ULSTERIAN | 0 to 750 | | SW. IND. ONLY | Clear Creek Chert | New Harmony | | | |
| | | | | Hymera Coal | | | | | | | Petersburg | Grassy Knob Chert | | Backbone Ls. | | |
| | ATOKAN | 160 to 980 | | Alum Cave Ls. | Staunton | Raccoon Creek | | CAYUGAN | 50 to 770 | | Kenneth Ls. | Wabash | Bailey Ls. | | | |
| | | | | Springfield Coal | | | | | | | Linton | | Kokomo Ls. | Mocc. Springs | | |
| | | | | Survant Coal | | | | | | | Brazil | | Mississinewa Sh. | | | |
| | | | | Colchester Coal | | | | | | | Mansfield | | Leban Cr. Ls. | | | |
| MISSISSIPPIAN | CHESTERIAN | 160 to 375 | | Lower Block Coal | Buffalo Wallow | SILURIAN | MAGARAN | 50 to 350 | | Salina Gr. | Pleasant Mills | Louisville Ls. | St. Clair Ls. | | | |
| | | | | Lead Creek Ls. | | | | | | | Waldron Sh. | | | | | |
| | | | | SW. IND. ONLY | | | | | | Grove Ch. Sh. | Limberlost Dol. | Salamonie Dol. | | | | |
| | | | | Negill Creek Ls. | | | | | | Kinkaid Ls. | Laurel Osgood | Cataract Ls. | Brassfield Ls. | Sexton Creek Ls. | | |
| | | | | Deonia Ss. | | | | | | Clore Ls. | | | | | | |
| | VALMEYERAN | 40 to 680 | | Siberia Ls. | Menard Ls. | Blue River | ORDOVICIAN | CANADIAN | 0 to 2000 | | Shakopee Dol. | Potosi Dol. | Muncising | Potsdam Supergr. | | |
| | | | | | Leopold Ls. | | | | | | Waltersburg Ss. | | | | SW. IND. ONLY | Everton Dol. |
| | | | | | Vienna Ls. | | | | | | Vienna Ls. | | | | | Shakopee Dol. |
| | | | | | Tar Springs | | | | | | Glen Dean Ls. | | | | | Onecta Dol. |
| | | | | | Hardinsburg | | | | | | Haney Ls. | | | | | |
| MISSISSIPPIAN | CHESTERIAN | 130 to 240 | | Branchville | Stephensport | ORDOVICIAN | CHAMPLAINIAN | 0 to 500 | | Plattin | Pecatonica | Black River | | | | |
| | | | | Waltersburg Ss. | | | | | | Beech Creek Ls. | | | Cypress | Elwren | | |
| | | | | Reelsville Ls. | | | | | | Sample | | | | | | |
| | | | | Beaver Bend Ls. | | | | | | Bethel | | | | | | |
| | | | | Paoli Ls. | | | | | | Renault | | | | | | |
| | VALMEYERAN | 130 to 910 | | Floyds Knob Ls. | Edwardsville | Sanders | CAMBRIAN | ST. CROIXAN | 20 to 2000 | | Franconia | Ironton Ss. | Galesville Ss. | | | |
| | | | | | Spickart Knob | | | | | | Mt. Simon Ss. | | | | | |
| | | | | | New Providence Sh. | | | | | | | | | | | |
| | | | | | Rockford Ls. | | | | | | Coldwater Sh. | | | | | |
| | | | | | Sunbury Sh. | | | | | | | | | | | |
| PRE-CAMBRIAN | >1900 | | | | Borden | PRE-C | | | | Granite, basalt, arkose, and other rocks | | | | | | |

*Thicknesses are not scaled in proportion to vertical space
 Explanation of abbreviations: Alex., Alexandrian; Sen., Senecan; Chau., Chautauquan; and Mocc., Moccasin.
 (Adapted from Indiana Geological Survey Bulletin 59, 1986, by Robert H. Shaver and others)

2.6 HYDROGEOLOGY

Hydrogeology is the study of groundwater; its occurrence, movement, and relationship with the geologic media in which it resides and passes through.

2.6.1 ENGINEERING HYDROGEOLOGY

Engineering hydrogeology is the study of groundwater and surface water with emphasis given to the application of the laws of occurrence and movement. It studies the fundamentals of groundwater flow using the principles of dispersion and diffusion in porous soils and rocks.

2.6.2 GROUNDWATER OCCURRENCE

2.6.2.1 OCCURRENCE IN NON-INDURATED SEDIMENTS

This refers to the unconsolidated deposits of alluvium, tills, ice-contact deposits, loess, dune sand, marine sands and clays, colluvial deposits, and lacustrine clays and sands. It also includes residual soils, which have hydrogeologic characteristics in common with colluvium and alluvium. In these soils, permeability coefficients tend to be quite high and close approximations of permeability can be made if the origin of the sediment is known.

2.6.2.2 OCCURRENCE IN SEDIMENTARY ROCK

Sedimentary Rock: Sedimentary rocks in Indiana are predominantly shales, siltstones, sandstones, limestones, and coal. These rock types are bedded in a wide range of thicknesses that often vary greatly within a single unit. In addition to variable bed thicknesses these rock types often grade into other facies. Facies changes within a rock body can create stratigraphic controls on porosity and permeability, the rocks hydrologic properties. Also affecting groundwater movement are the joints and fractures contained within and between strata, they can provide conduits for rapid fluid flow and have the potential for large storage capacities.

Because of the number of variables influencing permeability, including but not limited to, cementation, grain size, compaction, fracturing, and joint placement, it is almost impossible to predict the permeability rate based on porosity alone. In more dense rock (i.e., limestone) fractures and void openings are the main determinate in groundwater quantities and movement.

2.6.3 GROUNDWATER SUREY

Generally, elevations of the water table are determined in bore holes or wells. The depths at which water is apparent is measured three times: 1). During drilling, 2). When the boring is complete, and, 3). 24 hours after completion; occasionally additional measurements may be taken. Other subsurface conditions such as artesian flow, perched water table or sand-heave conditions should be noted on the boring logs since these can be considered unfavorable to the stability of engineered structures, slopes or subgrades.

During the initial field survey, any springs in the project area should be noted since this indicates a location where the groundwater table intersects the ground surface, and unusual conditions such as swamps, bogs, gravel pits or lakes which could affect the groundwater should be noted also.

2.7 SOIL PROFILE AND HORIZONS

The soil profile is the result of weathering of the original parent material, which may be unconsolidated materials deposited by glacial, wind, or fluvial processes, or bedrock. The soil profile is divided into **horizons** based on the degree of chemical and physical weathering of the parent material. At any one location, these horizons would always occur, from the surface downward, in the order described below; however, not all of these horizons may be present at any one location.

2.7.1 “O” HORIZON

The “O” Horizon is not really a “soil” at all, but merely undecomposed organic debris and black humus (a relatively stable residuum of decomposed organic matter). Naturally, this unit is present only in well-vegetated areas.

2.7.2 ”A” HORIZON

The “A” Horizon, the uppermost portion of the soil profile, is a mixture of mineral material and partially degraded organic debris. Soils in this horizon crumble easily due to their lack of consolidation. Usually, water percolating through this horizon winnows out the finer silts and clays leaving a sandier lighter textured material. Dark colors are common, due to a high organic content. The mineral assemblage is quite variable.

These materials are generally undesirable for engineering purposes, due to their high degree of compressibility, variability, and high organic content. An increased organic content often makes both the “O” and “A” horizon soils suitable for use as topsoil.

2.7.3 “B” HORIZON

The “B” Horizon is often referred to as the **zone of accumulation**. Here, materials weathered out of the “A” horizon – such as clay, iron and aluminum minerals – are deposited. This results in a fairly uniform, lighter colored, denser soil which may have a blocky structure and may be more brownish or reddish in color than its overlying counterpart.

2.7.4 “C” HORIZON

The “C” Horizon represents the parent material of the soil profile – either glacial drift or weathered parent rock (saprolite). “C” horizon materials are generally lighter in color than both the “A” and “B” horizons and remain in essentially the same form as when originally deposited. This material retains its original structure but is leached of more mobile elements, such as calcium or magnesium. Where “A” and “B” soil horizons are thin, the “C” horizon may be encountered during exploration or construction.

2.7.5 “D” HORIZON

The “D” Horizon may also be referred to as the “R” Horizon. It indicates consolidated unweathered bedrock which is not the parent material for the soil, but which may influence the overlying soils by controlling drainage or surface morphology. For the purpose of a geotechnical survey, the “D” horizon is of interest only when there are outcrops or when borings indicated that bedrock will be encountered within the roadway section.