LOST RIVER AT WESLEY CHAPEL GULF, ORANGE COUNTY, INDIANA[1]

CLYDE A. MALOTT, Indiana University

Introduction. It is the purpose of this paper to describe the Wesley Chapel Gulf of Lost River and those parts of underground Lost River which are accessible in and near this gulf. The locality is in western Orange County, Indiana, about five miles southwest of Orleans and about two miles east of the village of Orangeville. The locality is near the western margin of the karst belt developed in the Mississippian limestones in southern Indiana. Undoubtedly the Wesley Chapel gulf and the rise and sink of underground Lost River within it, constitute one of the most interesting individual features in the Lost River karst area. The underground system of Lost River, accessible through an opening in the western wall of the gulf, is a system of unusual interest because its characteristics are largely unknown. A greater section of the underground system has been mapped in detail here than at any other place. The Wesley Chapel gulf and the accessible parts of underground Lost River have never before received an adequate description, nor have their characteristics as features of karst been fully set forth. It is advisable, however, to give the general setting of these features before entering into their detailed description.

Definition of Karst. The term *karst* is a comprehensive topographic term applied to limestone areas which possess a topography peculiar to and dependent upon underground solution and the diversion of surface waters to underground routes. The term is taken from the name of a narrow strip of a limestone plateau in Jugo-Slavia bordering the Adriatic Sea, where occurs a remarkable assembly of features dependent upon subsurface solution. The Karst or Carso plateau itself is composed of a number of geological formations both of Mesozoic and Cenozoic ages, but it is dominated by massive limestone beds. The formations have been gently folded and severely faulted. The structures and the relatively great relief of the Karst plateau and adjacent regions have greatly influenced the development of the features dependent upon underground solution and underground drainage, and the region possesses some rather unusual and unique features. The region, therefore, is somewhat special, and it does not serve as well for a type region for the features dependent upon subterranean solution and underground stream diversion as would a more simple limestone region of moderate relief. Perhaps the low limestone plateaus of the middle Mississippi valley region, in which are exposed the well bedded and nearly horizontal limestones of Mississippian age, present a more normal assembly of

[1] Waterman Foundation, Indiana University. Contribution No. 59. 1931.

"Proc. Ind. Acad. Sci., vol. 41, 1931 (1932)."

features dependent upon underground solution and diversion of surface waters into cavernous routes.

Karst Areas of the Middle Mississippi Valley Region. The areas occupied by the nearly horizontal Mississippian limestones in small parts of Tennessee, western Kentucky, southern Illinois, eastern Missouri, and southern Indiana, comprising an aggregate area of some seven or eight thousand square miles, constitute one of the most notable karst regions of the United States. The strata in which underground drainage is highly characteristic belong to the St. Louis and the St. Genevieve limestone formations. The Warsaw and Salem limestone formations below the St. Louis are much less subject to the development of underground drainage. The still lower Keokuk and Burlington limestones along the upper Mississippi River are subject to underground drainage, but the glacial drift has, except locally, masked or interfered with the karst features developed there. Certain of the Chester beds, above the St. Genevieve, have considerable development of underground drainage. The Chester, however, is typically constituted of alternating clastic and limestone formations, none of which reach any considerable thickness. The sandstone and shale beds in the Chester do not permit complete regional underground drainage development. The aggregate thickness of the limestone formations of the karst region is only a few hundred feet, ranging from about 300 to possibly 600 feet. Typically the strata composing the limestone formations of the general karst areas are relatively thin and the bedding planes are usually well developed. Shale beds are thin or wanting. The limestone beds are rather hard and dense. Some of the beds are conspicuously cherty. Usually two sets of intersecting joints are well developed.

In only a few places does the general karst region reach or exceed an altitude of 1,000 feet above sea level. Chiefly the karst areas range from 500 to 900 feet above sea level. The relief of the typically karst terrains is never great. It is nowhere more than a few hundred feet. Usually it is less than 200 feet. The limited relief does not permit the development of spectacularly deep karst features. For the most part the surface features are gentle rather than abrupt. Nearly everywhere the limestone formations in which the karst features are developed are covered with a relatively fertile reddish soil clothed with vegetation. Thus, the *terra rossa*, so prominently in sight in the Adriatic Karst, is little in evidence. It is, however, by no means lacking. Surface exposures and bedded limestone in relief are relatively rare, except along certain well intrenched major streams. The small relief of the limestone region, however, has not interfered with the development of complete underground drainage over fairly large areas. Areas as large as 100 square miles or more wholly without a surface stream are not uncommon. In such areas underground drainage is developed to the fullest extent possible. These areas of maximum underground drainage development characteristically possess a relief surprisingly small. Frequently it is less than 100 feet. They are veritable sinkhole plains.

Karst Features of the Lost River Region. The Lost River drainage basin in Orange County, Indiana, exhibits in a typical manner nearly all of the features of a karst region. *Sinkholes* are very abundant. A conservative estimate of the number present in the Lost River basin is 25,000. *Sinkhole* ponds are plentifully present. *Sinking creeks* or *lost streams* disappear in *swallow-holes* in stream beds or at the termini of *blind valleys. Sinks* of streams are common. The sink of Lost River and the sink of Stampers Creek are notable examples. *Underground streams* follow cavernous conduits beneath the surface and come to the surface in valleys along the western margin of the karst area as great artesian springs known as *rises.* Rises, *cavern springs* and other springs associated with solution conduits in limestone areas may be called *karst springs. Dry-bed channels* are present. The most notable is the storm-water surface course of Lost River between the sink and the rise of that stream. It is 21 miles in length. *Karst valleys* are numerous along the western margin of the karst area between the rugged ridges capped with the Chester sandstones. Numerous blind valleys descend out of the rugged hills to end in the karst valley areas. *Caverns* occur beneath the karst area. Some of them are dry, while others are either permanently wet or are periodically wet when coursed by inflooding storm waters from the surface. A few *gulfs* are present where underground streams are revealed in a floor-like area hemmed in by steep-sided walls of limestone. *Subterranean cut-offs, karst tunnels,* and *karst bridges* are rare or wanting. *Lapiez* features are practically unknown, chiefly because bare surfaces of limestone are small or are absent.

Characteristics of Lost River. Lost River heads near Smedleys Station in western Washington County at an altitude of about 900 feet above sea level. In the first 10 or 12 miles of its course it is a normal dendritic system which appears to be consequent upon a regional westerly slope. While this slope is developed on the St. Louis limestone, there is little evidence of underground drainage. The absence of karst features here is difficult to explain, except on the basis that the region is remote from entrenched main streams. This part of the Lost River system occupies rather broad shallow valleys the slopes of which ascend to broad flat divides between the valleys. Near the Washington-Orange county line, about five miles from head of the stream, Lost River is broadly intrenched about 75 feet below the westerly sloping upland plain. A few small sinkholes are present in the upland and springs of clear water enter Lost River in and near its channel. About five miles west of the Washington-Orange county line Lost River enters the sinkhole plain proper. Here the westerly sloping plain has descended to an altitude of about 700 feet above sea level. After traversing the sinkhole plain for about two miles Lost River sinks in a number of inconspicuous swallow-holes in its channel. The sink of Lost River is about 12 miles due west of the head of the main stream and about two and one-half miles south-southeast of Orleans. Lost River reappears on the Allen farm a short distance south of Orangeville and about seven miles due west of the sink of the stream. Its reappearance is in the form of a large artesian spring in the bottom of Lost River valley. It is known as the "Rise of Lost River."

The valley of Lost River in the vicinity of the disappearance of the stream is but little below the general level of the sinkhole plain. The sink of Lost River is about 620 feet above sea level and its rise seven miles away is about 490 feet above sea level. Above the sink of the stream the course is rather direct. The dry-bed channel between the sink and the rise of the stream is a very tortuous meandering route fully 21 miles in length. Flood waters only occasionally follow the entire dry-bed route. Rains are sufficiently severe perhaps four or five times a year to flood the entire route. The upper and lower parts of the dry-bed, however, are flooded frequently.

In addition to the small swallow-holes which convey the low water flow of the spring-fed Lost River to the underground conduit, there are three large swallow-holes in or near the dry-bed in the upper seven miles of the dry-bed course. In order, these are the Stein, the Turner, and the Tolliver swallow-holes (see inset map, Fig. 3). The capacity

Fig. 1 View showing vortex in Lost River 100 yards below the Johnson bridge southeast of Orleans. This view was taken December 1, 1931. The arrow shows the direction of the stream flow. The vortex is over a swallow-hole in the dry-bed channel about one-half of a mile below the sink of Lost River. Rains caused the stream waters to pass beyond the sink and occupy the upper section of the dry-bed. Vortices like the one shown in the view are very exceptional.

Fig. 2. View showing the dry-bed channel of Lost River at the bridge on State Highway No. 37, three and one-half miles south of Orleans. The dry-bed here is between the Stein and Turner swallow-holes, about two and one-half miles below the sink of Lost River. The arrow points downstream.

of each of these swallow-holes is about one-half of the capacity of the dry-bed channel. The first two swallow-holes are able to take in nearly a full channel of storm water. Heavy rains send water to the Tolliver swallow-hole. When the dry-bed waters reach this swallow-hole, it soon becomes taxed to capacity. This is because it has a large amount of water entering it from an underground channel and filling it to near capacity before the dry-bed waters reach it. The flood waters course through the entire dry-bed channel for only a few hours following heavy rainfall. It is then left dry except for stagnant pools here and there along the course. In addition to the large swallow-holes there are numerous small ones along the dry-bed course. Fig. 1 is a view of some of the storm waters disappearing in a small swallow-hole in a stream bed a short distance below the Johnson bridge across the dry-bed about one-half of a mile below the sink of Lost River. Vortices like the one shown in the view are unusual.

The area of the drainage basin above the sink of Lost River is approximately 53 square miles. The middle section of the Lost River basin, or the area between the sink and the rise, consists of about 103 square miles. The section below the rise with relatively little Karst embraces about 160 square miles. Thus about one-half of the system is associated with underground drainage. The middle section is a completely disintegrated or dismembered former surface system. No tributaries reach to the dry-bed which was once the surface trunk stream of the system. The distal ends of the former surface tributaries lose their waters in swallow-holes long before they reach the dry-bed of Lost River. Some of the storm waters during exceptional rains, however, pass over dry beds to the dry-bed trunk stream, or more frequently some of the storm waters rise from their underground conduits and enter the lower part of the dry-bed some distance above the rise of Lost River. On the Mathers place in the southwest corner of Sec. 34, T. 3 N., R. 1 W., about half way between Orleans and Orangeville, a large amount of muddy water rises from a pit and flows into the dry-bed of Lost River. It soon ceases to flow after the storm waters have been drawn off. It is an example of the wet weather rises of underground streams.

It is the middle section of the Lost River basin which is typically karst. At least 60 square miles of this section is an ideal sinkhole plain practically without surface streams. Sinkholes are very abundant. At least 20,000 sinkholes are present in this section of the system. State Road No. 37, "The Dixie Highway," passes through this section between Mitchell and Paoli. The highway bridge across the dry-bed (Fig. 2) is between the Stein and the Turner swallow-holes about three and one-half miles south of Orleans. In one square mile southwest of Orleans an actual count revealed the presence of 1,022 individual sinkholes. The region is literally perforated with holes and is a veritable regional sieve. It represents the perfection of subterranean drainage and of karst topography. Sinkholes more than any other feature characterize karst topography. They exist by the hundreds to one of any other feature of karst.

The western margin of the karst area is the more varied part of the karst terrain. Accessible caverns are relatively scarce in the sinkhole plain. They are more abundant and more readily accessible along the western margin where the rugged ridges composed of the clastic Chester beds rise above the sinkhole plain. Farther south, it is in this marginal area that Marengo, Wyandotte, Mammoth, and other noted caverns occur. Here also are found the karst valley areas, the blind valleys, the rises of subterranean streams, and the gulfs. It is in the western margin of the karst region with its sandstone capped hills and ridges that the older and more accessible parts of underground Lost River occur. Here also occurs the Wesley Chapel Gulf where Lost River rises to the surface in a deep pit in the alluviated floor of the gulf. Underground Lost River is readily accessible from the gulf, and it is here that the characteristics of the underground system are best revealed.

Definition of Gulf as a Karst Feature. The term *gulf* as applied to a feature of karst is the name of a steep-walled or abrupt circumscribed

19—47716

depression which characteristically possesses a flat alluviated floor in which an underground stream rises and sinks. The underground stream may be perennially present and greatly swelled following heavy rains, or it may be exhibited on the floor of the gulf following heavy rains only. The feature is always associated with an underground stream, and its development has been dependent upon collapse of the superincumbent rock over the underground stream and the solution and removal of the fallen rock. Apparently gulfs have their beginnings in collapse sinkholes over an underground stream, and in their earlier stages they are not to be distinguished from such a collapse sinkhole. When such a collapse feature has its steep-walled perimeter enlarged to such an extent that it possesses a distinct alluviated floor in which an underground stream rises and sinks, it then may be called a gulf. The alluviated floor is usually marked by stream-formed channels which pass from the rise to the swallow-hole or series of swallow-holes where the water is returned to the underground channel system. Gulfs characteristically contain a rise and sink of the stream revealed in them. The term does not appear to have been applied to the unroofed section of an underground stream which flows out of an open cavern and across an open space and thence into an open cavern on the other side. No name appears to have been given to this latter feature, though it is a relatively common karst feature. I would suggest *karst fenster*, or *karst window*.

Gulfs of the Lost River Region. Gulf as the name of a karst feature has been used in the Lost River region for more than 100 years. Its employment in the literature has been incidental. Richard Owen (1862, 143-144) refers to the Tolliver swallow-hole and the Wesley Chapel gulf as the "gulfs" of Lost River. He presents a woodcut engraving of the steep face of the Tolliver swallow-hole or gulf. Elrod (1876, 225), states that Lost River "comes to the surface at Wesley Chapel gulf, in section 9, township 2 north, range 1 west, where the superincumbent rocks have fallen in and forced the stream to the surface." He mentions the Wesley Chapel gulf in a subsequent paper bearing on the features of the Lost River region (1899, 263). Beede (1911, 87, 105) refers to the Orangeville rise as a "gulf," but he also briefly describes a well developed gulf about one-fourth of a mile north of the Orangeville rise, referring to it as a "gulf" of Lost River. His description is in the caption to a rather good photographic view taken of a part of the floor and the north wall of this gulf. Malott (1922, 208), in a general description of the features of Lost River, and again in a paper describing cavern stages (1929, 202), describes briefly the Wesley Chapel gulf of Lost River and states that it is the most spectacular feature of the Lost River drainage basin. Davis (1930, 538-539), in his excellent treatise on the origin of limestone caverns, gives a brief description of the gulf.

Four gulfs are present in the Lost River region. The largest is the Wesley Chapel gulf. A map and a description of it constitute a part of this paper. A well developed gulf, which may be called the Orangeville gulf, is located on the Ragsdale farm, about one-fourth of a mile north of the village of Orangeville. The flood waters of an underground stream rise from a pit under the steep north wall of this gulf and sink in swallow-holes at the south end of the gulf. The crest of the north wall is fully 65 feet above the pit in which the storm waters rise. Occasionally storm waters overflow the south end of the gulf. At such times the maximum depth of the water in the gulf is about 35 feet. The underground stream whose storm waters rise in this gulf is the same one that rises at Orangeville. This subterranean stream rise is believed by many to be the rise of Lost River. It is very likely the rise of a subterranean stream which comes from the north and which gets its waters from the sinking streams and karst valleys north and northeast of Orangeville. Certain evidence indicates that the waters of Beaver Creek which enter the cavernous swallow-hole about one-half of a mile west of Georgia come to the surface at the Orangeville rise, fully six miles south-southeast of where they sink. A third gulf in the Lost River region is on the farm of Martin Tolliver, near the southwest corner of Sec. 11, T. 2 N., R. 1 W., about three and one-half miles east-southeast of Orangeville. Lost River uses this gulf as a swallow-hole in times of rather heavy rainfall. It is not a fully developed gulf. Following heavy rains an underground stream enters the gulf from the south side and immediately enters a debris-covered opening. Underground Lost River is accessible from this gulf or swallow-hole. The fourth gulf known in the region is on the farm of Roy Daugherty, a short distance south of U. S. Highway No. 150 and about three miles southeast of Paoli. A large spring, known to be the rise of Stampers Creek, enters Lick Creek nearby. The gulf is known as Crow Hollow. Only storm waters of the underground stream rise in this gulf. Its eastern wall rises nearly 100 feet above the floor across which the storm waters pass. Underground Stampers Creek may be reached in a small cavern a short distance south of the gulf. Stampers Creek sinks four miles northeast of its rise. Crow Hollow gulf is in the Lick Creek drainage basin, though the underground stream responsible for it comes from the Lost River basin from which it has been diverted.

The Wesley Chapel Gulf. The Wesley Chapel gulf of Lost River is located on the farm of James Elrod, a short distance east of the center of Sec. 9, T2N, R1W, about four and one-half miles southwest of Orleans (see Fig. 3). It receives its name from the Wesley Chapel Church at the crossroads a little over one-fourth of a mile north of the gulf. The gulf is on a direct line between the sink and the rise of Lost River, five miles due west of the former and two miles due east of the latter. It is also but little off a direct line between the large swallow-holes along the dry-bed and the rise of the river. The dry-bed channel passes about three-fourths of a mile northwest of the gulf. The gulf is in the western margin of the karst belt where numerous karst valleys occur between the rugged ridges capped with the Chester sandstones. It is, therefore, a little west of the sinkhole plain proper. As a surface feature it is entirely in the St. Genevieve limestone. The Lost River chert, near the base of the St. Genevieve, is exposed in places at or just above the level of the alluviated floor of the gulf.

The Wesley Chapel gulf is an abrupt steep-sided depression in a gently undulating soil-covered area of cultivated farm and pasture land.

It is rimmed by trees which partly obscure it during the foliage season. The topographic details are depicted in Fig. 3. The gulf is about three times as long as it is wide, measuring 1,075 feet in length and averaging about 350 feet in width. Its long axis extends north 35 degrees west, or nearly northwest by southeast. Its perimeter measures about 2,700 feet, and encloses an area of 8.3 acres. The floor area is about 6.1 acres. The gulf depression has rounded ends and is slightly constricted in the middle. A broad shallow valley on the north end of the gulf has been interrupted by the development of the gulf. The upper part of this valley, entering from the east, has a hanging relationship to the gulf. Storm waters descending into the gulf from the hanging valley have cut a V-shaped notch in the perimeter of the gulf. The counterpart of this notch is present on the west side of the gulf near the south end, where a mass of broken-down blocks of limestone protrude about 100 feet directly into the gulf. Other than these two features the outline of the gulf depression is quite regular.

Both the north and south ends and the western side of the gulf are nearly or quite perpendicular through a part or all of their ascent above the gulf floor. They are wall-like or form a nearly continuous cliff. The eastern side, except at the south end, is an abrupt acclivity, but is not in the form of a cliff. A roadway descends obliquely along the east side to a cornfield of about two or three acres planted annually on the alluviated floor of the gulf. The height of the walls varies from about 25 feet on the northwest to about 95 feet on the southeast.

The altitudes about the perimeter of the gulf varies from 595 feet above sea level along the north part of the west side, to 640 feet on the southeast where the gulf is developed out of higher land. The lower part on the north is associated with a former surface valley leading west. The development of the gulf disrupted the surface valley and now the storm waters which descended through the upper part of the disrupted valley plunge into the gulf and become subterranean. Attention has already been directed to this hanging valley on the east. The altitude of the alluviated gulf floor is between 570 and 575 feet above sea level.

The floor of the gulf is marked by the deep mud-lined pit of the rise of Lost River at the south end of the gulf and by the overflow channels which lead away from the deep pit. Numerous rather inconspicuous swallow-holes are present in the overflow channels. Two views of the pit taken from opposite sides are shown in Figs. 4 and 5. During low-water periods the waters in the pit are 25 or 30 feet below the level of the gulf floor, and carefully made soundings indicate a maximum depth of 20 feet. The pit is, therefore, 45 or 50 feet deep. The local tradition is that it is bottomless. It lies in the shadow of the abrupt south wall of the gulf which ascends fully 95 feet above the low-water surface in the pit. During the low-water periods the water is clear and frequently of a deep blue color. The water surface is nearly circular and is about 75 feet in diameter. The surface is perfectly calm. The water quietly leaves the pit at the south side and immediately disappears without demonstration in the mud-covered talus rock accumulated at the foot of the towering south wall of the gulf.

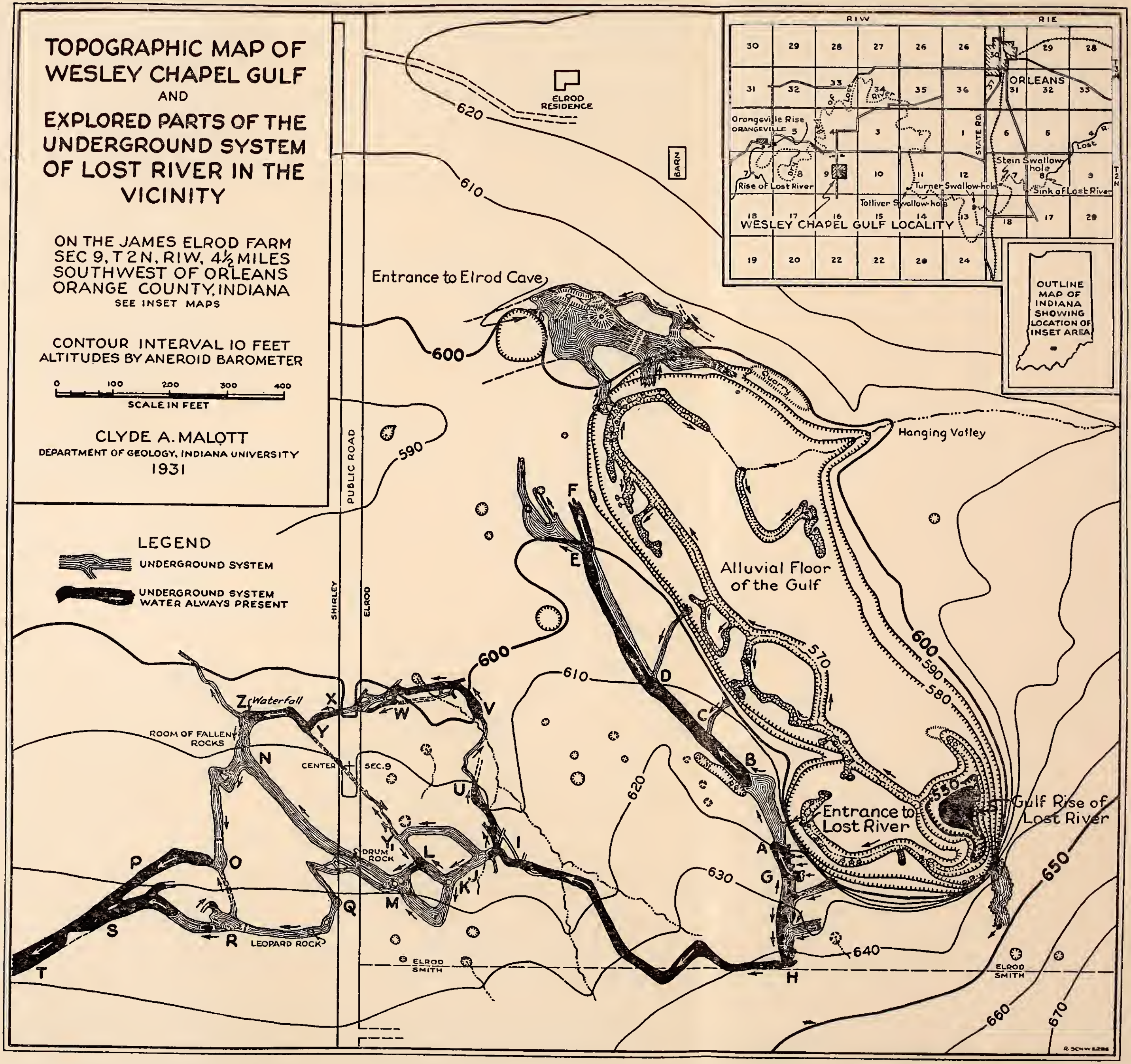

Fig. 3. Topographic map of the Wesley Chapel gulf and vicinity, with the map of the explored parts of underground Lost River near the gulf.

Fig. 4. View of the gulf rise of Lost River at the south end of the Wesley Chapel gulf, looking north. The waters of Lost River rise from the bottom of the pit and flow southeast out of the pit (arrow shows direction of flow). The water in the pit during low-water periods is 20 feet deep. The full depth of the pit is 45 or 50 feet. The eastern wall of the gulf shows indistinctly in the background.

Fig. 5. View across the gulf rise of Lost River in the Wesley Chapel gulf, looking south. The waters flow out of the pit and disappear in mud-covered talus rock just beyond the arrow. The south wall here towers 95 feet above the water in the pit. The cavern opening in the wall receives waters during high flood periods. It is 25 or 30 feet above the low-water level in the pit. All of the rock exposed in the view belongs to the St. Genevieve limestone.

During high-water periods the rising waters are very turbid and yellow with clay and silt. The pit fills to overflowing and discharges into the two flood-water channels (shown in Fig. 3) without any great show of turbulence. The storm waters on leaving the pit through the high-water channels fill to capacity each swallow-hole in succession until all are in use that are reached by the high waters. The channel about the southern end is the first one used, and, upon the subsidence of the high waters, it continues in use for a short time after the waters have ceased to enter the longer northern channel. (See Fig. 6.)

The northern overflow channel, leading west from the deep mud-lined pit, is relatively free of swallow-holes except at the north end. It has, however, overflow connections with numerous swallow-holes along the west side of the gulf floor next to the western wall. This channel extends to the extreme northern end of the gulf and then curves back

Fig. 6. View of flood waters flowing from the gulf rise of Lost River in the south end of Wesley Chapel gulf. Arrow shows direction of flow from the pit. The waters leaving the pit through the overflow channel disappear in a number of swallow-holes on the west side of the gulf. View taken November 19, 1931.

into the alluviated floor of the gulf, and, after being joined by the channel from the hanging valley coming in on the east, it turns toward the east wall of the gulf where it ends in a group of shallow swallow-holes. On the day that the floor of the gulf was mapped in preparation of Fig. 3, September 18, 1931, a careful count of the swallow-holes in the floor of the gulf revealed a total of 100. This number includes the small ones of little importance and probably of temporary position, as well as the more important larger ones.

During high-water periods most of the waters disappear immediately south of the pit. These waters find their way through the chinks between talus blocks of limestone which underlie the overhanging south wall here. Apparently an underground channel passes westward below the level of the floor of the gulf and a short distance back from the foot of the south wall. During exceptionally high waters, entrance is gained directly through a cavernous opening in the south wall 25 or 30 feet above the low-water level in the pit. This cavern (the opening of which may be seen in the view, Fig. 5) can be followed back and downward for about 100 feet over and through broken limestone. The waters which pass through the limestone blocks very likely reach the underground channels west of the gulf (see Fig. 3). Most of the waters which course through the southern overflow channel disappear near the end of this channel under the shadows of the western wall of the gulf. The waters pass to the underground channel system through limestone talus obscured on the outside by the accumulated alluvial material on the gulf floor. The presence of the accumulated limestone talus at the foot of the western wall prevents a direct entrance of the waters to the underground system at this place. It is at this place, between the backslanting wall of the gulf and the accumulated talus underfoot, that a manhole-like opening leads steeply downward to the underground channel of Lost River (see Fig. 7).

A third place where large amounts of flood water disappear is near the north end of the gulf. Waters pour in very noisily at two or three holes along the western wall. Very likely these waters reach the underground channel beyond the broken-down terminus reached in the exploration of the channel leading northwest parallel with the western gulf wall (see Fig. 3). Part of the waters which disappear near the north end of the gulf through the numerous swallow-holes lead into the Elrod cavern which is free of stream waters except during floodings of the gulf.

Very heavy rains bring about a complete inundation of the gulf floor. The flood waters may rise as much as three to five feet over the alluvial floor. Such floodings may occur as often as five or six times a year. Usually they take place in the late winter or in the spring. Occasionally, however, the gulf floor may be inundated during the growing season. Mr. James Elrod relates an interesting occurrence in the flooding of the gulf floor about 15 years ago. He had plowed and prepared the ground for planting, but on account of approaching darkness he did not get the planting done. It was just as well that he did not, for on his return the next morning he found the floor of the gulf under several feet of water. It had not rained in the locality of the gulf, but a heavy rain had taken place in the headwater portion of Lost River the day before. During the night the waters rose in the gulf and completely flooded it. The flooding of the gulf floor takes place because the waters rise into it from the pit faster than it gets away through the numerous swallow-holes. It is believed that the floodings take place more on account of the limited capacity of the underground channel system west of the gulf than on account of the limited capacity of the numerous swallow-holes through which the waters escape from the gulf.

Underground Lost River. Underground Lost River begins at the sink of the surface stream in its channel a short distance west of the center of section 8, T2N, R1E, on the Donald McCart farm, about five miles due east of the Wesley Chapel gulf. Little is known about the underground system in the upper few miles of its underground course, as the openings leading into it are too small to permit entrance and exploration. At the sink the waters descend quietly by entering small openings along the right bank of the stream and in the floor of the channel. None of these holes is conspicuous. The surface channel here is about 620 feet above sea level. It is not likely that the underground channel is very deep below the surface. It does not appear that it could be more than 20 or 30 feet, and it is very likely less. No holes are known at the Stein and Turner swallow-holes which are large enough to enter. It is possible that entrance could be gained at one or the other of these localities were it not for the timber rafts which have accumulated about the more important swallow-holes.

A small collapse sinkhole on the Chas. T. Brown farm, in the NE ¼ Sec. 14, T2N, R1W, leads directly into a cavern system believed to be a part of the underground Lost River system. The writer and Robert Shrock explored and carefully mapped about 3,200 feet of this system in 1929. Three different levels are represented. Only storm waters pass through the explored system. The lowest level has an altitude of about 555 feet above sea level. It is about 40 feet below the dry-bed channel. High-water level in the cavern system is 45 feet above the lowest floor, and is about at the same level as the storm waters in the dry-bed following heavy rains. The system explored on the Brown farm lies between the Turner and the Tolliver swallow-holes, and a little south of the dry-bed channel. The storm waters which course through the system are believed to enter at the Turner swallow-hole complex a little less than one mile east of the entrance into the system on the Brown farm.

A short stretch of about 300 feet of underground Lost River at the Tolliver swallow-hole was explored and mapped by the writer and Robert Bates during the summer of 1931. The passage from the swallow-hole leads north 565 feet and connects with the river. This passage itself is a part of the underground system. It carries storm waters only. The river has an altitude of about 545 feet, and is but little above the low-water level in the pit at Wesley Chapel gulf, a mile and one-half to the northwest.

A short distance south of the center of section 8, a little more than one mile west of the Wesley Chapel gulf, a short channel leads from the dry-bed to a cavernous opening in which water stands at a level about 10 feet below the dry-bed and at an altitude of about 515 feet. This opening receives considerable quantities of storm water from the dry-bed when waters first course down the dry-bed following rains. If the rains are heavy, the water flow is reversed and waters pour out of the opening vigorously. Thus the opening is a swallow-hole for brief periods and a rise at other periods. It is thought that the opening leads directly into the underground Lost River system, as it is located directly between the Wesley Chapel gulf and the rise of Lost River on the Allen farm about three-fourths of a mile south of Orangeville.

It appears that underground Lost River lies 40 to 80 feet beneath the general sinkhole plain. Where it passes beneath sandstone capped ridges in the western part of its underground course, it is as much as 150 or 200 feet beneath the surface. It is not a direct single conduit, but is a rather complex compound system both laterally and vertically.

The system is partly developed in a northwest-southeast joint system and partly in a southwest-northeast system. Some of it is above the water table and some of it is below. The system is developed in the top of the St. Louis limestone near the contact with the St. Genevieve limestone above. The parts of the system accessible at the Wesley Chapel gulf locality, described below, are illustrative of the complexity of the system.

Underground Lost River at Wesley Chapel Gulf. Underground Lost River is readily accessible at the Wesley Chapel gulf through a small

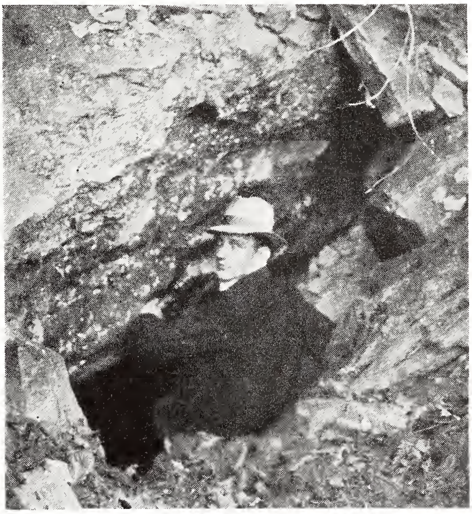

Fig. 7. View of the manhole-like opening into underground Lost River in the western wall of the Wesley Chapel gulf. The opening is 35 feet above the underground stream. The rock ledge at the level of the opening is the Lost River chert near the base of the St. Genevieve limestone. The underground channel below is in the St. Louis limestone.

opening which leads steeply downward between the western wall of the gulf and the talus rock underneath (see Fig. 7). The location of the opening here is dependent upon the proximity of the underground channel to the western wall of the gulf (see Fig. 3). The underground channel has long been known here, though very little is known about it. Elrod (1876, 225), refers to an exploration of the underground system made some years previous to 1875, and Rhodes (1905, 7-11), gives an account of an exploration which took place about 1875. Apparently no map of the underground system has been attempted previous to the work of the present writer. A brief characterization of the underground system at Wesley Chapel gulf was published by the writer a few years ago (Malott, 1929, 202-203). Since then a careful map has been prepared. It constitutes a part of Fig. 3 of this paper. Davis (1930, 541) presented a part of the mapped system from the unpublished maps furnished him by the writer before the mapping of the system there was fully completed.[1]

In presenting the following description of the underground system of Lost River in the Wesley Chapel gulf locality, free use is made of the map of the system shown in Fig. 3. The letters, A, B, C, etc., refer to special features and positions along and in the mapped system. They serve as location points in the description. The positions to which they refer may be readily ascertained by consulting Fig. 3. Only one differentiation is attempted in the map of the underground system. Places in the system where water is continuously present are indicated in solid black. Other parts of the traversed system are shown by water-line shading. It should be borne in mind that practically the entire system is completely filled with water during periods of surface floods.

The small manhole-like opening, Fig. 7, leads directly into a north-south stretch of underground Lost River, the floor of which is about 30 feet below the alluviated floor of the gulf. From A to B, a distance of 115 feet, the eastern side of the underground channel is composed of a talus accumulation which separates the gulf outside from the underground route on the inside. The western (left) side and the ceiling are really the undercut western side of the gulf wall below the level of the alluviated floor of the gulf. At A, 35 feet down and 35 feet forward from the opening into the underground system, the swiftly moving waters of underground Lost River come from a southerly direction and disappear in the talus rock along the western wall of the channel. To the right (slightly west of north), a rocky passage about 10 feet above low-water level extends towards B. This passage is occupied by muddy waters during periods when the gulf is flooded. At B, the waters of the underground river flow out of the talus rock and pass in a northwesterly direction through a cavernous passage in solid limestone. Back from where the waters issue, the talus rock rises for a distance of about 40 feet before coming in contact with the roof-rock above. During high-water periods much water enters through the talus rock and along the northern end of the passage A-B. The freely flowing water which disappears at A passes along the western or left wall and beneath the talus rock. Apparently the waters are dissolving away the foot of the western wall as well as the talus rock through which they pass. The talus crowds the waters to the western wall, and the dissolution of the rock there continues to undermine this wall of the gulf. Further collapse of the overhanging gulf wall will add to the size of the gulf outside.

Beginning at B, the underground channel leads in a northwest direction with but little deviation to F, a distance of 600 feet. This passage is 5 to 15 feet in height and 15 to 35 feet in width. The floor is covered with water over much of the route from a few inches to about three feet in depth, except at two places, C and D, where it is five feet or more in depth. The passage is almost parallel with the west wall of

[1] The map of the underground system, as shown in Fig. 3 of this paper, is a result of string and compass traverses made by the writer and Robert Shrock in 1929, and several additional traverses made during 1931 by the writer and John Huddle, Robert Bates, and Richard Schweers. Also the writer is indebted to his two sons Roland and Floyd Malott, who have accompanied and greatly aided him on many visits into the underground system.

the gulf and is 50 to 100 feet from it. The water-covered floor has an altitude of about 540 feet above sea level. The passage is, therefore, 60 to 70 feet beneath the surface. At C, 110 feet from the beginning of the water course at B, a storm-water tributary channel enters from the right. This passage is about two feet above the water in the river channel, and the storm waters which enter here have formed a plunge basin about five feet deep. The channel is rather uniformly five feet high and six feet wide. In the clean-washed rock bottom are numerous potholes and solution ripples or facets. This passage leads back 75 feet in a northeasterly direction. It ends in a mass of fallen rock beneath the western edge of the gulf. It is evident that the passage conveys storm waters from the gulf during periods of high water. Another passage of similar character enters the main passage at D, about 250 feet from the beginning of the water channel at B. This passage is about five feet in diameter and leads back 140 feet in a northeasterly direction, where it also terminates in a mass of fallen rock under the western edge of the gulf. Waters appear to enter the passage near the bottom of the fallen rock. This passage without doubt is a route of swiftly moving waters during high-water periods in the gulf. The passage is three or four feet higher than the river channel into which it enters. The floor of this tube-like passage is marked by numerous potholes from a few inches across to large ones three feet in diameter. Many of them are perfectly developed, while others form a coalescing series. Their depths are from a mere trace to about two feet. The most perfect ones are four to eight inches in diameter and four to ten inches in depth.

Beyond D the water is shallow and flows in noisy ripples over the rock floor of the channel. It follows the left side of the channel and has undercut the left wall. A ledge of rock two feet thick has fallen from the roof and lies in blocks without much derangement. The channel here is fully 35 feet wide. Its height is only a few inches above the water on the left side, but it is six feet or more on the right. About 175 feet beyond D, a rock fall from the roof is covered with mud from one to three feet in depth, and on the mud are many peculiar mud stalagmites. Sticky mud also coats the walls and the roof of the cavern. Stalactites hanging from the ceiling are composed partly of mud and are rather insecurely attached. Most of them are quite firm with mineral matter, though partly composed of mud. Apparently the mud has come from the storm waters which at times completely fill the cavern system. During low-water periods the mud coatings are succeeded by the precipitation of normal dripstone calcite. The mud stalagmites have a unique origin, and they form the subject of a special paper.[2]

The water is shallow over the broad floor near E and beyond to F, at the end of the water passage. The amount of the water is considerably diminished, indicating that some of the stream water escapes on the left side before reaching E. At the end of the passage the water enters dissolved-out crevices in the beds of limestone. A large crevice on the left was followed for a distance of about 25 feet. It appears that the limestone rock has settled down in the passage without much breaking,

[2] Malott, C. A., and Shrock, R. R., Mud Stalagmites.

thus terminating the passage. At E, an opening leads to the left of the main passage to a level about 10 feet above the floor of the main passage. In this higher level about 65 feet from E, a broken-down rocky passage leads off to the right for a distance of about 85 feet. Near the end, water may be distinctly heard running under the fallen rock below. To the left, about 65 feet from the beginning of this passage at E, the cavern leads up some 10 or 15 feet into a high-level expansive cavern with a width of 30 or 40 feet. It then leads off northward for about 130 feet where it ends in blocks of fallen rock. Water also may be heard quite distinctly trickling through the fallen blocks below. The floor of the expanded cavern room is composed of mud. The highest part of the ceiling here is not coated over with mud. Apparently the muddy storm waters do not reach much higher than about 35 feet above low-water level in the underground river.

The main passage from A to F is 715 feet in length. The two flood-water passages leading from under the gulf are 75 and 140 feet respectively. The cavern complex at a higher level on the left at E shows a total traverse of 300 feet. The entire system on the left of the opening at A has a traversed length of 1,230 feet.

A much larger section of the underground system is available to the left of the opening at A. The water encountered at A, just below the entrance to the system, is one to three feet deep during low-water periods. The waters seen here enter the channel from the left wall in a stretch of about 65 feet in length. Most of it comes out at G, where an opening reaches back about 20 feet. The water comes out through fallen blocks of rock and from low channels dissolved out of the cherty limestone. The main channel from A to G is five to eight feet high and 15 to 20 feet wide. From G to H, the main passage continues nearly south for a distance of 150 feet. Little water is present in this stretch during low-water periods. The passage here is 20 to 30 feet in width and eight to 15 feet in height. The first 50 feet of the floor is covered with mud from a few inches to one foot or more in depth. A small rivulet of water flows north through a mud groove, entering the main flow of water at G. The remaining part of this stretch of the channel is covered with blocks of clean-washed rock. About midway is a pool of water about 30 inches deep. Along the right wall, water flows slowly southward, opposite in direction to that at the north end of this channel stretch. At H, considerable water enters from the left through low cavernous openings in the cherty limestone. Here begins a stretch of river water which continues forward without interruption for 655 feet. Between G and H, however, two cavernous openings, four to seven feet high and 10 to 20 feet wide, enter from the left. The first of these is 35 feet beyond G. It leads back in an easterly direction for 95 feet, where it terminates in a mass of fallen rock beneath the western edge of the gulf. The second passage is about 100 feet beyond G. It is very similar to the first, except that it leads back only about 50 feet. It is apparent that the storm waters entering the main channel from these two tributary channels during high-water periods turn southward rather than northward. The divide of the high waters appears to be represented in the muddy stretch of the passage just beyond G. The waters which fill the passage here are between stretches which flow in opposite directions, and the clay silts which settle out are not carried away.

At H, 250 feet south of the entrance into the underground system, a stretch of water begins which extends mainly west and northwest for 655 feet. In this water course the channel is relatively simple. It is seven to 15 feet in height and 12 to 30 feet in width. It is characteristically eight or nine feet high and 15 feet wide. It is clean-washed and few or no rock masses litter the floor. The water ranges from a few inches in depth over noisy shallow places to about 30 inches in depth in the broad quiet pools, except at the sharp-angled turn 165 feet beyond the beginning of the water stretch, where a depth of seven or eight feet occurs. The deep water may be avoided here by staying close to the

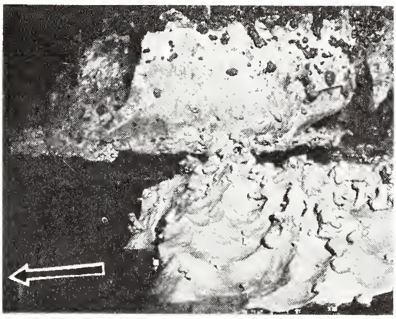

Fig. 8. View of the cherty St. Louis limestone in underground Lost River about 250 feet south of the opening in the western wall of the Wesley Chapel gulf. Spherical and elongated nodules and cellular masses of flint or chert are etched out in relief on the walls of the underground channel.

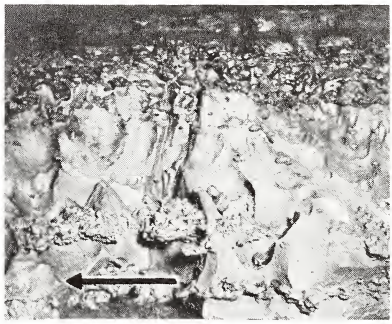

Fig. 9. View of the north wall of the underground channel of Lost River just above low-water level about 40 feet downstream from the view shown in Fig. 8. Scalloped or hollowed out places in the limestone body in which ragged masses of cellular chert occur are rather common in the underground channel. The condition is a result of corrosive erosion by the swiftly flowing waters of the underground stream.

left wall on the inside of the turn. Figs. 8 and 9 are views of the cherty St. Louis limestone walls just above the water level at or near the beginning of the water stretch at H. Solution of the limestone leaves the chert masses and nodules in relief over the surfaces. Corrosive erosion by the flowing waters has scalloped out hollows with sharp ridges and horns separating them. These scalloped out places are conspicuous in the limestone walls immediately above low-water level (see Fig. 9). Fig. 10 is a view showing the water during a low-level period flowing over a narrow shallow stretch about 350 feet beyond H.

At I, the water leaves the main channel and enters a broken-down complex which extends in a northwest direction in harmony with one of the well developed joint systems. The main channel turns abruptly to the southwest in harmony with a second main joint system. The floor of the main channel is three or four feet higher than the low-water level at I. The floor of the main channel beyond I is very rough with solution pits and potholes. We have called the main channel from I to N "Pothole Avenue." The course of the main channel is indicated in Fig. 3 by the letters I, J, K, L, M, N, O, P, and T. It is seven to 12 feet in height and 15 to 20 feet in width over much of the way.

Beginning at I, "Pothole Avenue" extends southwest to K, a distance of 115 feet. At K it makes an abrupt turn to the northwest, a direction it holds only for about 50 feet. Here, at L, it extends southwest again for 65 feet to M, where it turns abruptly again to the northwest. It continues northwest to N, a distance of 350 feet. The changes in direction are dependent upon the development of the channel along the two sets of prominent joint systems which intersect nearly at right angles. Just beyond I, a small tube-like channel two or three feet in

Fig. 10. View showing the swift waters of underground Lost River over a narrow and shallow stretch about 600 feet south and west of the opening in the western wall of the Wesley Chapel gulf.

diameter leads off on the left. It is some five feet above the floor of the main channel. At J, about 40 feet beyond I, a wide passage leads off to the right. After making three angular turns to the left and traversing a distance of 210 feet, it returns to the main channel at L. At Y_1, in this side circuit, a small channel leads off to the northwest. It was traversed with considerable difficulty for distance of about 100 feet. It is slightly uneven in size and has connections with tube-like channels at one or two places which parallel it at slightly higher levels. It is of special interest because it connects directly along a northwest extending joint with the water channel X-Y-Z, and the noise made by the falling water at Z is conveyed through it.

A ragged rock pillar stands in the broad opening of the beginning of a rock-littered circuit and the abrupt turn of the main channel at K.

The broad circuit leading off to the left at K makes one abrupt turn and returns to the main channel at M, after traversing a distance of 175 feet. A small pool of water a little over one foot in depth occurs at L in the main channel. The floor of the main channel just beyond L is very rough with solution pits and potholes. Fig. 11 is a view taken of the potholes here. At M two angular rock pillars support the broad space of roof-rock where the side circuit returns on the left and where an important branch from the main channel leads away on the same side. Here, also, the main channel turns to the northwest. The floor is rugged with great blocks of loose rock and with holes broken through to a lower level a few feet below. About 75 feet beyond M the floor of the main channel is completely broken down for a few yards. At the far side of the broken-down space a ledge of limestone extends across the empty space beneath. Its upper surface is exceedingly rough with solution pits and potholes, some of which perforate it. When stamped upon it

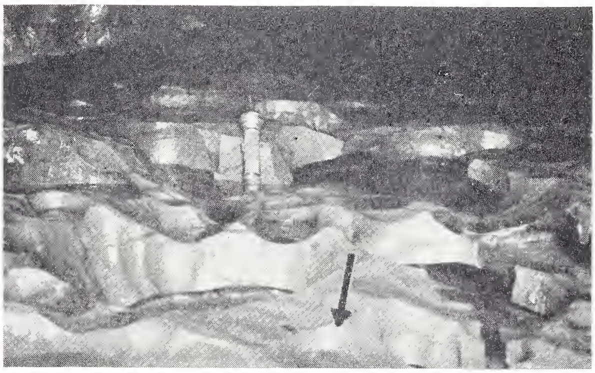

Fig. 11. View of the corrosively eroded floor of underground Lost River in "Pothole Avenue," about 1,110 feet from the opening in the western wall of the Wesley Chapel gulf. The floor is very rough with solution pits and potholes which are difficult to distinguish. "Pothole Avenue" is a few feet above the low-water level of the underground stream.

gives forth a hollow drum-like sound. This ledge may be called "Drum Rock." It is located under the public road between the Elrod and Shirley farms about 150 feet south of the center of section 9. The underground channel here is 75 feet below the surface. Several other holes occur in the floor of "Pothole Avenue" beyond "Drum Rock." Towards the end of the 350-foot northwest stretch, great blocks of rock have fallen from the roof and the floor rises about 10 feet at the end of the passage at N. Back from the fallen rock mud has accumulated along the right side of the channel, forming a steep bank against the rock wall. Numerous mud stalagmites have been formed on the mud bank. Many of them exceed a foot in height.

The long northwesterly stretch, M-N, terminates in a nearly north-south stretch of cavern piled high with fallen blocks of massive limestone. The angular blocks of rock nearly fill the space to the roof in places, while in other places the roof is fully 15 feet overhead. The stretch expands in places to a width of about 40 feet. We have called this rock-filled stretch, extending north 70 feet and south and west for about 100 feet, the "Room of Fallen Rocks." At the north end of the "Room of Fallen Rocks" the turbulent stream X-Y-Z, descends into a lower level, and the noise of the falling waters is exaggerated into a solemn roar in the still cavern air a short distance away. From N the expanded main channel leads southward about 70 feet, and thence west and northwest about 40 feet. A great angular rock pillar stands in support of the roof amidst great blocks of fallen rock near the south end of the room. It is apparent that during times of high water the "Room of Fallen Rocks" has water entering it both from the north and from the east. At the abrupt turn southward out of the room, about 95 feet southwest of N, freshly fractured rock shows conspicuously near the ceiling and on the left wall. Also fragments of the fresly fractured rock were observed on the floor nearby, indicating that some settling of the roof-rock has taken place recently.

The passage southward from the "Room of Fallen Rocks" is practically free of floor fragments. The passage is 10 to 15 feet wide and about 10 feet high. The floor is clean-washed and bears evidence of swiftly flowing flood waters. It bears a little east of south for 120 feet to O, where it reaches a great collapse pit in which the waters pass to a lower level about 15 feet below. The upper level appears to terminate in this pit. The underground channel simply descends to a lower level. At the south end of the pit a small rough-hewn channel comes in from the south nearly at the level of the floor of the pit. It bears marks of water currents entering the pit. To the right, at the south end of the pit, a low opening leads west into a water channel 25 or 30 feet wide and about five feet high. This broad low-roofed passage is half filled with dead or standing water. It extends in a westerly direction for about 80 feet and then turns southwesterly. It was followed to P, about 50 feet beyond the turn to the southwest, where the water becomes deeper and the ceiling descends to within one foot of the water level. An oozy mud covers the rock floor. The altitude of the dead water here is about 525 feet, and the underground channel is about 95 feet beneath the surface. The traverse, ending at P and beginning at the opening in the west wall of the gulf, is 1,870 feet in length along the course of the main channel.

Returning to M of the main channel, it was noted above that an important channel leads off on the left. M is 1,135 feet from the opening in the gulf wall which leads into the underground system, and is marked by two angular rock pillars near the entrance of the channel which leads away from the main channel. This channel joins the main channel at S, a short distance below the end of the traverse of the main channel at P. Its length is about 750 feet. Immediately after leaving the main channel it turns to the right and parallels the main channel for 70 feet. Here it connects with the main channel through a low opening near "Drum Rock." The channel, however, turns to the left in a southwest direction, and thence a little north of west for 75 feet to a very abrupt elbow turn to the southeast. In the stretch between the low connection with the main channel and the elbow turn, three small tube-like channels lead away on the right. These all connect some 20 or 25 feet from where they leave the channel. A small opening from them leads into the main channel just beyond "Drum Rock." The channel, M-Q-R, is 10 to 12 feet wide and five to eight feet high. The floor is very rough with solution pits and potholes. Knife-edge partitions and horn-like projections rise between the separated and coalescing potholes and solution pits. Walking over the rough floor is difficult. At the elbow turn is a small pool of water and some angular blocks of loose rock on the floor. The channel leads southeast 80 feet from the elbow turn to the next turn at Q. Here a small hole is present in the floor leading to a lower level. On the right or the inside of the turn at Q, a short fat drip-stone column has been built by waters seeping from the roof. It fits illy both against the ragged wall and the rough floor. The floor appears to have been partially dissolved from under it. From Q the channel bears to the right finally extending a little north of west at R. About 45 feet beyond Q, a small pillar of rock divides the channel, and about 90 feet beyond Q, a large block of rock nearly obstructs the channel. The flood waters which pass over its upward sloping surface have carved numerous solution ripples or facets which give it a spotted appearance. We called it "Leopard Rock." About 100 feet beyond "Leopard Rock," the channel appears to end in a mud-covered stretch 65 feet long in which are two conical pits 15 feet deep. At the end of the channel, a flowstone mass is built over the rock below an opening one foot high and six feet wide. The opening leads into a small channel practically at the level of the roof of the channel above the mud-lined pits. Water trickles over the flow stone, and a level rim has been built up at the upper edge. This rimstone ponds back a pool of remarkably clear water. The upper level was entered, but not explored. The pits at R are 500 feet from M at the beginning of this channel branch.

Rough cherty limestone shows in the bottom of the pits. Both of the pits have openings along the left wall to a lower level. This lower level was not discovered in the first exploration and mapping of the underground system. It was first entered by the writer and John Huddle in October, 1931. A ledge of limestone a little over one foot thick appears to have been completely dissolved away underneath the pits. A broad low passage leads northward in the direction of the main channel at O, which is less than 100 feet distant. There is little doubt about a connection existing between the pits of the two channels and it is clear that waters pass from R to O through the passage. Most of the waters leaving the pits at R, however, pass through a low broad channel which leads westerly and connects with the main channel at S. This channel is only about three feet high and 10 to 15 feet wide for some 50 feet or more. Farther on it gets wider and higher. The ceiling and side are fantastically rough with protruding masses of cellular and ball-like nodules of chert etched out in relief by the solution of the limestone about them. About 100 feet from R, water is encountered on the floor of the channel. A small low tributary enters on the right about 140 feet beyond R. The dead water deepens to about three feet at the junction of the channel with the main channel at S. Here the water expanse across the channel is fully 40 feet wide. The cherty limestone partition between the two channels is broken through about 25 feet back from the junction at S, and the water expands through the low opening between the two channels. The ceiling here is flat and is two or three feet above the quiet water. From S to T the water deepens to about five feet. A constriction appears in the channel above the water about 75 feet beyond S. The channel, however, maintains its breadth of 30 or 40 feet beneath the surface of the water. At T the ceiling comes within less than one foot of the water, and it is impossible to follow the underground channel farther. The end of the traverse at T is 2,170 feet from the entrance along the main channel and 2,040 feet distant through the branch which leaves the main channel at M. This is the most distant point reached in the explored parts of the underground system in the Wesley Chapel gulf locality.

One of the most interesting places in the mapped system is where the underground stream, H-I, leaves the main channel for a smaller poorly developed route, I-U-V. The influence of the joint systems in the development of the solution channels is quite evident in the network present here. It is apparent that two levels are present in this locality. The upper level consists of tube-like channels two to three feet in diameter. The higher channels are followed only during high-water periods. The lower level system is five to eight feet below the upper. It is a few feet lower than the main channel system beyond I. It appears quite probable that the main channel system has been developed out of the upper system by enlarging it and cutting the floor considerably below the primitive tube-like system that the invading surface waters inherited from the more or less static groundwater development of the system before the water table was lowered to the present levels beneath the surface. At I, the low-water flow of the underground stream has been diverted from the main system through a low system which yet retains some of its primitive characteristics. The water which now courses through it will eventually enlarge it and give to it the same general characteristics of the well developed main system.

At I, the main system is deepened nearly to the level of the youthful system into which it is diverted. In the ceiling above, an opening extends upward perhaps 10 feet into the roof-rock. Beautiful clusters of stalactites have been formed by water seeping through the rock here. The water leaves the main channel through blocks of rock where the upper and lower systems have merged through collapse of the rock separating them. The water passes through the fallen rock from I to U, a distance of 90 feet. At U, a few yards of the lower system are free of rock and the channel is dissolved out sufficiently large to be entered. Immediately, however, the water passes into a low channel which cannot well be traversed. It passes underneath the higher tube-like channel above and leads off in a northerly direction. The water is not seen again until the two levels are merged through collapse at V, about 150 feet nearly due north of U. The two places are connected by the upper channel which follows a somewhat winding course of rather small diameter. It was traversed from U forward for a distance of about 70 feet to a pool of water. Later it was entered at V and traversed towards U to the same pool of water. The entire length of the passage is about 175 feet. The floor is scoured by the high waters which pass through the channel.

The system extending from V to Z was explored by entering the system at Z through the "Room of Fallen Rocks." The water issues from the lower level at V into a room developed by the collapse of the rock between the two levels which here are only a few feet apart. A block of rock 12 feet across and 20 feet in length occupies the floor of the room. The water passes about it on both sides. About 10 feet back in the tube-like upper level is a window-like opening in the floor through which the flowing water in the lower level may be seen.

The underground system from V to X is a complex system of low channels with rough floors and walls. The distance along the main channel is about 300 feet. The height varies from three to five feet and the width is from ten to 20 feet. Many small channels lead away or connect with the main channel. They are all occupied by water when the underground stream is slightly swollen by storm waters. Ragged pillars of rock between the passages are common. At W, the low-water stream leaves the main channel and follows a small low side route. At X, the waters return to the main channel by issuing noisily up through crevices and pothole-like openings in the rough floor. The channel, X-Y-Z, has a zig-zag course developed along intersecting joints. The passage is five to eight feet in height, eight to 12 feet in width, and 175 feet in length. The water flows noisily over the rough floor. At Y, a small tube-like channel comes in from the southeast. While it was not traversed, there is little doubt about its connection with the main system at Y_1, as indicated in the map, Fig. 3. At Z, the waters descend over the rough floor and into an enlarged joint crevice to a lower level. The fall through the crevice is about three feet. The total fall here is only about five feet. The joint crevice through which the water falls is not large enough to enter. The water falls on a roughened floor and flows westerly through a broad passage but little more than one foot high. Forward from the waterfall and about eight feet above, a small channel two or three feet in diameter leads off in a northwest direction. It was traversed about 150 feet, beyond which it was impossible to go.

The underground system extending from I to Z through the low-level channels has the appearance of being unfinished as compared to the main system. The waters passing through it play hide-and-seek through the rough low channels, some of which still retain the tube-like characteristics of underground channels developed below the water table. It is quite apparent that the underground stream has been diverted from the main system at I into the smaller and slightly lower system. The invasion of the river waters through the illy prepared lower route is so recent that the new route is not fully integrated. It still follows the network rather than any one continuous route through the network system. This network system is modified but little from its primitive condition as formed below the water table by groundwaters independent of the influx of surface waters diverted into it after the withdrawal of the groundwater to lower levels.

In summary the system described above and shown in plan in Fig. 3 consists of two diverging main channels which lead in somewhat different directions. The waters coursing through these channels enter them principally near the south end of the gulf close to the manhole-like opening in the western wall through which entrance into the system is gained. The shorter system leads northwest parallel with the western edge of the gulf. It is relatively simple. It is quite direct and has few connecting channels. Its traversed length is 715 feet, and the aggregate traverse of the main channel and the connecting channels totals 1,230 feet. The second main channel leads generally west away from the south end of the gulf, though its course is far from direct. It follows a zig-zag course, alternating chiefly northwest and southwest in conformity to two major intersecting joint systems. It is a complex channel system consisting of many minor leads which leave and return to or branch off from the main channel. Also it is developed at two distinct major levels with minor connections at still other levels. Water does not follow the main channel through the entire system, except during times when the underground stream is swollen by the storm waters of the surface system far to the east. The low-water stream is diverted from the main channel and follows a poorly developed system at a slightly lower level. In turn the diverted stream descends to a still lower level which it was impossible to follow. The main channel has a traversed length of 2,170 feet, and the entire system, left of the entrance opening, has an aggregate traverse totalling 4,945 feet. The aggregate traversed length of the entire system reached through the small opening in the western wall of the gulf is 5,175 feet.

Elrod Cavern and Underground Lost River. A round, steep-sided, collapse sinkhole, 90 feet in diameter, lies about 125 feet northwest of the north end of the Wesley Chapel gulf and about 400 feet south of the Elrod residence (see Fig. 3). On the north side of this flat-bottomed, abrupt sinkhole, a steep slope leads under the overhanging rock wall into a cavern known as the Elrod cave. It extends a little south of east for 350 feet and varies in width from 40 to 125 feet, except at the extreme eastern end where it ends in a narrow passage in broken-down rock. An outline of the cavern is shown in Fig. 3. Its width of 125 feet just east of the collapse sinkhole is rather remarkable. The cavern undoubtedly extends westward from the sinkhole, as the circular sinkhole is clearly a feature formed by the falling in of the rock which once formed the roof of the cavern. No openings can now be found through which entrance may be gained to the cavern system west of the collapse sinkhole, and nothing is known about it there.

The cavern is entered through a small opening about 15 feet below the flat bottom of the sinkhole. A steep inside talus slope composes a further descent of 15 feet to a clay-silt platform which forms a considerable part of the cavern floor. A deep trench with steep slippery sides extends along the north side of the cavern. The bottom of this trench is 16 feet below the level of the expansive mud floor. Apparently the mud floor is a platform built up by the clay silts which have accumulated in the cavern through repeated floodings at least to the height of the mud platform. A number of shallow trenches lead across the mud platform from the south side of the cavern to the trench and to a deep, funnel-shaped pit on the north side. It is quite evident that streams of muddy water at times pass across the mud floor in a northerly direction. The trench on the north side of the cavern begins in several small leads coming from talus rock about 110 feet nearly due east of the entrance into the cavern. It is evident that at times waters issue here and follow the trench for about 75 feet to its western end, where they disappear in holes in the loose rock. These waters appear to escape in a westerly direction through the rock litter which obstructs the western end of the cavern. On the sides of the slimy mud trench are many well developed mud stalagmites formed through the dropping of water from the roof on the mud surfaces (see Fig. 12). The sides of the funnel-shaped pit have recently caved in, and a tumbled mass of mud and mud clots form its steep sides. The upper edge of the pit is nearly vertical, and the perimeter of the pit is only roughly circular. The pit is 30 or 35 feet across. Its western edge is low and merges with the trench just west of it.

The mud platform south of the trench reaches nearly to the massive rock forming the ceiling of the cavern. South of the pit the ceiling is

Fig. 12. View showing mud stalagmites on the side of the flood-water trench on the north side of the Elrod cavern, about 60 feet from the cavern entrance. Flood waters from Wesley Chapel gulf enter the Elrod cavern and flood a considerable portion of the floor. The mud stalagmites have a peculiar origin.

higher, reaching five to seven feet above the mud floor. The mud floor extends 175 feet eastward from the entrance of the cavern. It is terminated by an abrupt scarp of fallen rock which rises seven or eight feet above the mud floor. The mud platform in the cavern has an altitude of about 555 feet, and is about 50 feet beneath the surface of the field above. It is significant that this flood-formed platform is at least 15 feet below the level of the alluviated floor of the gulf just southeast of it. There can be no doubt that the shallow trenches leading across it are runways made by waters which have entered through leads directly connected with the gulf.

Water seeping through the ceiling has formed numerous stalactites which hang as slender pendants or in massive clusters from the cavern roof. The drip on the mud floor has formed many scattered small stalagmites and occasional thin plaques of calcite which scarcely rise above the mud floor. Several nests of cave pearls were found where the drip from the ceiling has been responsible for the formation of angular to rounded discreet structures in shallow pools on the mud surface. Most of these structures resemble slightly rounded angular pebbles, but they have been built up of calcite in concentric layers, much like the structure of oolites. Many of them are hollow or porous inside, and some have calcite crystals partly filling the interior. Some of them in the middle of the nests, where the drops of water fall directly on them, have been beautifully polished by the motion against one another caused by the falling drops of water. Those at the outer margins of the nests are much larger, more irregular in shape, and have a rough, burr-like surface. Recently Hess (1929) and Davidson and McKinstry (1931) have discussed in some detail the nature and origin of these little known structures.

South of the deep pit a low-roofed channel partly blocked by masses of fallen rock leads southward and directly under the gulf at the northwest corner (see Fig. 3). It has a mud floor, and current marks indicate quiet clearly a northward flow of the flood waters which at times come from the gulf. Another broad channel with a rock-covered floor and a low ceiling leads south for a distance of 65 feet from the main cave about 30 feet east of the scarp made by mass of fallen rock near the middle of the cavern. This low channel is about 30 feet in width. It terminates in a mass of broken rock under the northern edge of the gulf. Rill marks are present on the floor where waters enter this channel from the gulf during high-water periods. These rills become lost under the masses of fallen rock composing the rocky platform and lying upon the mud underneath.

The rocky platform upon which occur many well-formed conical stalagmites is seven or eight feet above the mud floor of the western part of the cavern. The floor is very rugged and irregular. Small pools of clear water in rimstone basins are perched here and there on the rock masses, the water having accumulated from the drip from the roof. The ceiling is seven to 15 feet above the irregular floor and is beautifully decorated with stalactite pendants. The cavern extends a little south of east for about 175 feet beyond the scarp marking the western edge of the fallen rock mass. The width varies from 40 to 60 feet to near the end. The eastern extremity rises up over fallen rock and ends in a narrow passage of broken-down rock. The terminus is along the northern edge of the gulf near the level of the alluviated floor, and just west of the old quarry. Tree roots penetrate the rocky mass at the very eastern end of the cavern.

About 75 feet beyond the western end of the rocky platform, near the middle of the cavern, the north wall of the cavern is well separated from the platform floor of the cavern. The opening here leads down some 20 feet under the overhanging north wall to a muddy cavern channel which comes from the east. This channel leads north about 15 feet and then turns to the left in a westerly direction. The passage coming from the east is directly connected with an underground stream at a slightly lower level which may be seen through a muddy opening under the overhanging rock. This underground stream remained undiscovered by the writer until December 1, 1931, after much of this paper had been written. Only about 20 feet of the underground stream is visible through the low opening. On the two ocasions that this stream has been seen by the writer, it was about 10 feet wide and one foot or more in depth. It was flowing rather swiftly in a northwest direction nearly parallel with the northern wall of the cavern. It was not entered, as its roof is rather forbiddingly low. Its exploration must await more favorable conditions than the rather high-water period and the winter weather of December impose. The altitude of the underground stream is about 535 feet. It is, therefore, about five feet lower than the low-water level of the water of Lost River in the pit at the south end of the gulf.

There is little question about this stream being part of the underground system of Lost River. It very probably branches off the underground stream east of the rise in the gulf and follows a course about the gulf along the east side and around the north end. It is quite likely that the swallow-holes in the cluster at the end of the overflow channel on the eastern side of the gulf floor connect with this underground stream. During high-water periods the waters of this stream rise between the gulf wall and the mud platform and flow through the muddy passage leading west, some seven or eight feet higher than the underground stream. This passage is about eight feet wide and three feet high. It follows a winding westerly course for about 130 feet, where it connects with the trench and pit along the north wall in the western part of the cavern. Its connection here clearly indicates the source of the waters which flood the trench during periods of high water both in the gulf and in the cavern which are so intimately connected.

CONCLUSION

In this paper an attempt is made to give the general setting of the Lost River karst region and to present the details of a section of the underground stream system in a locality where it is available for study. The presentation of the details is prefaced by defining karst and identifying the individual features which compose the karst assembly in the Mississippi valley areas which exhibit in a marked degree the features peculiar to underground drainage in limestone regions. The underground system described in considerable detail is largely available for exploration and study because of its connection with a gulf which in itself is one of the most outstanding individual features of the Lost River karst region. The Wesley Chapel gulf and underground Lost River in its vicinity are in themselves of sufficient interest to merit description independent of the principles which they teach in the developmental history of karst features. The carefully prepared map which accompanies this paper presents many of the details and relations which are discussed in the text. The work necessary for its preparation has been great, but it is believed that this map is as essential as the text itself. It is the writers' intention to present at some future time the full details of the Lost River karst area, as many other localities have features of instructive interest in the behavior and in the product of a river that runs many miles underground. No other locality, however, has been more interesting and instructive than the Wesley Chapel gulf and the underground river system in its vicinity. Certain developmental phases of the gulf and the underground course of the river may be presented as the conclusion of this paper.

Wesley Chapel gulf as a surface feature represents the destruction and removal of 720,000 cubic yards of native limestone, an amount equivalent to a block of limestone 1,000 feet long, 300 feet wide, and 65 feet thick. The void created by the removal of such a prodigious amount of rock has been filled to a depth of 30 feet over the bottom by the deposition of 275,000 cubic yards of alluvial silt. The void remaining is a depression averaging 1,000 feet long, 325 feet wide, and 38 feet deep. It was once occupied by 445,000 cubic yards of limestone rock. This abrupt, level-floored depression is remarkably symmetrical in outline. Both ends are equally round. They are semicircles of equal radii. Both ends are of slightly greater breadth than the middle section between them. The length is approximately three times the width. The long axis conforms in direction almost exactly with a major joint system in the rocks from which the feature has been cut. This is not without certain significance.

The width of the gulf is far greater than any known section of the underground channel of the river with which it is related. It is not merely a fallen-in cavern channel whose collapse rock has been dissolved away. The shape of the gulf and its present relations to the underground water courses suggest something of the nature of its development. It very probably was initiated as a small feature of collapse over a broad and weakened portion of the underground stream system. Overbroadening and consequent collapse very likely may have resulted from the dissolving out of rock walls between parallel underground channels. After such initial collapse the underground stream would find passages about the sides of the collapsed rock, and solution and removal of the walls about the collapsed material would undermine the walls. In time further collapse would increase the perimeter of the collapse depression. It is readily conceivable that two or three collapse areas may have formed in a row. Through increase in their perimeters they would eventually merge to form an enlarged depression in common with semicircular ends, such as Wesley Chapel gulf possesses. Horns of rock would for a time extend out into the gulf floor area, but in time they would melt away. One such horn of rock, tumbled and broken, still protrudes into the general floor area of Wesley Chapel gulf.

Wesley Chapel gulf is unusually symmetrical in outline. It may not always remain so. An underground stream swings around under the south end. Further growth through collapse is undoubtably taking place there, but it is at such a place that the symmetry is maintained. The underground system just west of the south end, however, is promoting a marked growth in this direction, and growth here will interrupt the present symmetry. At the north end of the gulf, a cavern carrying the flood waters of the subterranean stream has developed an enormous width and is in the process of collapse. Eventually the gulf will be united with the circular collapse feature through which entrance to Elrod cavern is gained. Even in this cavern an underground stream is carrying on a sapping action under the northern wall. This same underground stream no doubt is enlarging its route along a part of the eastern margin of the gulf. The entire present gulf is surrounded by active underground streams. Water cannot get through the compact and insoluble alluvial silt of the gulf floor. It must find its way about this built-up barrier through the fallen rock along the base of the walls and between the walls and the fallen rock, exactly as it does in the excellent example exhibited from A to B just inside the manhole-like opening in the west wall of the gulf. Or it follows small passages along joints which in time are greatly enlarged. When a mass tumbles in from the gulf perimeter, the dissolution of the broken rock goes on apace. Wesley Chapel gulf is thus a product of progressive perimeter collapse and dissolution of the fallen rock. The enveloping underground streams are thin but vigorous dissolving machines which insidiously sap the foundations of the gulf walls. These walls are hollowed out and weak at their bases. They do not stand on solid rock. 720,000 cubic yards of rock have been undermined, tumbled in, dissolved away, and a new level created. The process of rim enlargement of the gulf will eventually extend the gulf to such proportions that the underground stream will cut a channel through the alluvial floor which then will mark a change from that of a gulf feature to that of a valley. It will become elongated and pass into a valley expanse. The floor level will merge with other surfaces to form an integrated valley system open to the light of day. A gulf is a temporary feature in the karst cycle of land destruction which marks a beginning of the uncovering of an underground stream and the development of a valley.

It is conceivable that underground Lost River follows a simple underground conduit from the sink to the rise. The fact that the series of major swallow-holes along the dry-bed, the momentary appearance of the stream in the Wesley Chapel gulf, and the single rise south of Orangeville are nearly in a direct line gives weight to this conception. No such simplicity, however, is revealed in the map of the system in the Wesley Chapel gulf locality. Instead, it is a very complex system, consisting of a series of anastomosing channels which conform in the main to two intersecting joint systems directing the waters chiefly in alternate northwest and southwest directions. The complexity is even greater than the network pattern itself suggests. A great difference in volume exists between low-water and high-water periods. This gives opportunity for routes to be occupied during high-water periods that are not reached during low-water periods. Thus, there is an anastomosing of channels in a vertical direction as well as a horizontal. During low-water periods small and poorly developed passages at slightly lower levels may be followed instead of the broad, open passages at slightly higher levels. Such a condition is excellently illustrated in the system west of the gulf, and it has been described in detail.

No doubt the presence of the gulf has considerable influence on the development and maintenance of more than a single passage. All collapse features tend to pond or impede the stream waters and force them to rise to higher passages. There is little doubt about the waters of Lost River passing both to the north and to the south of the gulf. But the waters, after escaping about the gulf around the south end, go in two directions in a passage, even in low-water periods. This divergence is not to be charged to the influence of the gulf, as it takes place below it. The diversion of the waters to the low, poorly developed system at I, 500 feet west of the gulf, is in no way connected with an impediment. It must be acknowledged, however, that diversions very probably exist because of rock falls and consequent ponding in the undergrounding system.

The network system of underground Lost River has been cited by Davis (1930, 540-542) as evidence of development of caverns below the water table. The writer agrees with this view most heartily, but he would have the chief excavational development take place after the system became the route of discharge of the river waters from the surface, rather than that it took place chiefly during a long period of solutional development below the water table. The network system may be attributed to the following five factors: *First*, the dense and well-bedded limestone of the karst terrain is traversed by two intersecting joint systems. The bedding planes and the joint fractures are permissive planes or thin passageways along which percolating groundwaters may go. Groundwater percolation is practically nil through the dense beds themselves. Movement is therefore confined to the joint systems and the bedding planes. This is a fundamental and all important factor. The character of the network system is determined by these predetermined permissive planes. *Second*, groundwater percolation and movement below the water table have dissolved out connecting three-dimensional systems sufficiently large to permit free flow of waters through them. It is not believed that these water-filled systems are fully integrated into flow or stream systems. They are embryonic passages only. They are larger and more systematically developed in certain beds which are more readily soluble than others. When the water table is lowered to them, then they may serve as a network system into which vadose waters may enter and follow in accordance with the fortuitous development of the primitive network system. *Third*, the network is maintained above the water table by flood waters which rise in the system and follow all channels open to them. Were it not for floods certain runways would become integrated into a relatively simple system, as certain passages would be developed which would carry all the stream waters and others would not be developed beyond their small and poorly integrated condition attained while below the water table. Flood waters, however, fill all of them up to the limiting heights of the floods and develop the network as a whole. *Fourth*, as the surface drainage is lowered the water table also is lowered, and slightly lower primitive routes are taken over by the invading streams. The earlier well developed passages are left at slightly higher levels and are used only during high-water periods. Eventually the earlier well developed routes are left as dry caverns. *Fifth*, ponding of the underground system behind barriers, such as collapsed superincumbent rock, or gulfs, cause waters to develop or follow other passages. This factor is local in the system and is far less important than floodings by storm waters which reach high levels throughout the system.

Thus the network system is a natural consequence of a number of factors imposed on an underground system which flows long distances beneath the surface. A simple conduit would be more difficult to explain under the conditions imposed in the Lost River system than the complex network which it possesses. All of the factors enumerated in the above paragraph are well illustrated in the underground system in the Wesley Chapel gulf locality.

Another feature of the underground system of Lost River which deserves discussion is the relatively great width as compared to the height of the channels. The main channels are usually from two to three times wider than they are high, and certain stretches have a nearly continuous width of five to eight times the height. Sections B-F, V-X, O-T, and R-S of the mapped system, Fig. 3, are examples of relatively low ceilings and great width. Three factors appear to be influential in the attainment of relatively great width and little height. First, certain beds are undeniably more soluble than others. These beds are the chosen zones in which a better integrated system is developed beneath the water table long before their invasion by surface stream waters. A zone 10 to 20 feet below the Lost River chert and near the contact of the St. Genevieve and St. Louis limestones is conspicuously ramified by underground channels in the karst region of southern Indiana. Other zones below in the St. Louis limestone are also conspicuously channeled out. Lost River is developed at several levels which are connected with abrupt descents and ascents. The highest of these levels is in the very top of the St. Louis limestone, about 15 or 20 feet below the Lost River chert of the St. Genevieve limestone. At least two other levels lower in the formation are occupied by the river system for considerable stretches. Two of these major levels are present in the mapped system at the Wesley Chapel gulf.

A second factor which favors width development is the development of the underground system near the water table the westerly slope of which is very gentle. Bottom erosion is not conspicuous. The nearly water-filled section, O-T, at the end of the explored main channel system west of Wesley Chapel gulf, is an excellent example of the course at the very level of the water table. The water here is practically without flow except during high-water periods. The height of the channel is about five feet, while the width is 30 to 40 feet. During high-water periods great quantities of water are forced through the system here. The low roof is washed with as much force as is the floor. The great width of the channel is probably because of more ready solubility of the limestone. Depth attainment by bottom erosion is certainly very little.

A third factor which is of some influence in the lack of height development is the tendency of the underground stream to vacate a channel level whenever a slight lowering of the water table takes place. The underground stream enlarges and develops the routes open to its flow at or near the water table. Primitive undeveloped systems are ready to take some of the rivers waters when the water table approaches their levels. Waters enter at some favorable vertical connection or opening and gradually vacate the higher level while the lower level is being developed larger. Floor erosion of the upper level thus is not permitted to take place for long periods of time. The river literally changes floors too frequently for any considerable depth attainment by floor sculpture. During floods floor sculpture will take place on all the levels occupied. A good example of three levels with communicating holes connecting them is found in the Chas. T. Brown cavern between the Turner and Tolliver swallow-holes.

Three rather broad levels are present within a vertical space of 45 feet. High waters flow through all three of them. Perhaps floor erosion is of somewhat less consquence because of the distribution of the erosion to the network of floors instead of it being confined to a single floor.

Underground Lost River is a stream system beneath the surface which occupies a network at three or more levels. The waters in the system are chiefly waters which have invaded the system from the surface. They have deserted a long stretch of a surface system almost completely. The master surface stream leaves its well developed surface channel and passes underground many miles before coming to the surface. This stream has developed beneath the surface a subterranean system sufficiently large to justify its appellation of underground river. Only a little of its underground system is known. Much of the little that is known about it has been presented in this paper.

REFERENCES

J. W. Beede: The Cycle of Subterranean Drainage as Illustrated in the Bloomington, Indiana, Quadrangle. Proc. Ind. Acad. Sci. for 1910, Vol. 20, 1911, pp. 81-111.

S. C. Davidson and H. E. McKinstry: Cave Pearls, Oolites, and Isolated Inclusions in Veins. Econ. Geol., Vol. 26, 1931, pp. 289-294.

W. M. Davis: Origin of Limestone Caverns. Bull. Geol. Soc. Amer., Vol. 41, 1930 pp. 475-628.

M. N. Elrod: Orange County. Ind. Geol. Surv., Seventh Ann. Rept., 1876, pp. 203-239.

The Geologic Relations of Some St. Louis Group Caves and Sinkholes. Proc. Ind. Acad. Sci. for 1898, Vol. 8, 1899, pp. 258-267.

F. L. Hess: Oolites or Cave Pearls in the Carlsbad Caverns. Proc. U. S. Nat. Mus., Vol. 76, Art. 16, 1929, pp. 1-8, pl. 1-8.

C. A. Malott: The Physiography of Indiana. Handbook of Indiana Geology, Pt. 2, Indiana Dept. of Conservation, Publ. 21, 1922, pp. 59-256.

Three Cavern Pictures. Proc. Ind. Acad. Sci. for 1928, Vol. 38, 1929, pp. 201-206.

R. Owen: Geological Reconnoissance of Indiana. (Ind. Geol. Surv.) 1862.

A. J. Rhodes: The Wonders of Lost River. Private publication, 1905, 21 pages.