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GRAND TOWER LIMESTONE (DEVONIAN) OF SOUTHERN ILLINOIS

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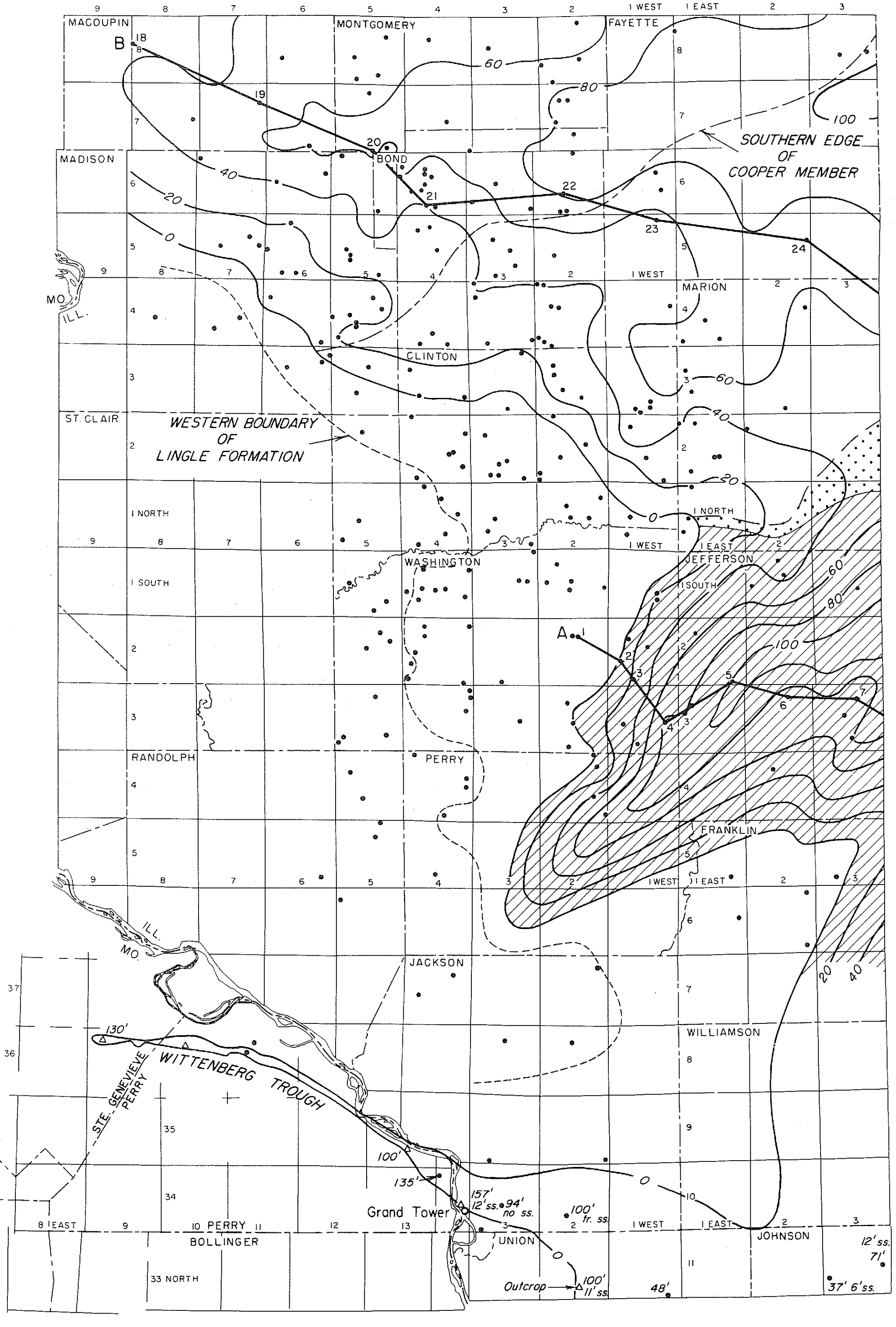

Figure 3 - Thickness and facies of the Grand Tower Limestone in southern Illinois

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ABSTRACT

The Grand Tower Limestone has been the source of over a hundred million barrels of oil in Illinois, the bulk of the Devonian production of the state. The formation underlies most of southern and central Illinois and extends into Missouri, Iowa, Indiana, and Kentucky, where its equivalents are the Cooper, Wapsipinicon, and Jeffersonville Limestones. The Grand Tower has a maximum thickness of a little more than 200 feet. It is a sandy, but otherwise pure, carbonate unit that forms approximately the lower half of the Middle Devonian carbonate sequence of the region. The Grand Tower is dominantly fossiliferous limestone in southern Illinois, dolomite in most of central Illinois, and lithographic limestone where it pinches out in north-central Illinois against the Sangamon Arch. The Sangamon Arch was an east-west structure that probably separated the Grand Tower from the Wapsipinicon Limestone of northern Illinois and Iowa during their deposition. It has been so modified by post-Devonian movements that it is no longer an important structural element.

The Grand Tower is thin or lacking over much of the Sparta Shelf, the western shelf of the Illinois Basin. The type sections of the Grand Tower and of several other Devonian formations lie in the Wittenberg Trough, a partially fault-bounded trench between the Sparta Shelf and the main body of the Ozarks. The Wittenberg Trough was active during Devonian and perhaps the early part of Mississippian time but largely has been destroyed as a structure by subsequent movements.

The three members and one bed formally recognized in the Grand Tower occupy limited areas, so that the bulk of the formation is not differentiated. The Dutch Creek Sandstone Member is a discontinuous but widely distributed basal unit. The Geneva Dolomite Member is a dark brown unit near the base of the formation. It extends into central Illinois from Indiana but does not cross the state. The Cooper Limestone Member is a lithographic limestone that lies at the top of the formation immediately south of the Sangamon Arch. It extends from Missouri into north-central Illinois. The Tioga Bentonite Bed is an altered volcanic ash that extends from the Appalachian Basin into parts of the Illinois Basin where it is only a few inches thick. It lies 6 to 15 feet below the top of the Grand Tower.

The Grand Tower is nearly everywhere overlain by the Lingle Limestone and correlative units of Hamilton (late Middle Devonian) age with, at most, a slight disconformity. The Grand Tower unconformably overlies many formations of Lower Devonian, Silurian, and Ordovician age.

The oil of the Grand Tower largely has been produced from the Geneva and other dolomite units. In recent years the Dutch Creek Sandstone Member has been found to contain oil in the deepest part of the Illinois Basin at depths greater than 5000 feet. The Dutch Creek is potentially productive over a large area in extreme southern and southeastern Illinois.

The cross sections in the report illustrate zonation and changes in the New Albany Shale Group of Upper Devonian and Kinderhookian (lower Mississippian) age, which overlies the Lingle Limestone. The lowest unit in the New Albany in eastern Illinois, the Blocher Shale, grades laterally into the Alto Limestone of western Illinois.

INTRODUCTION

The Grand Tower Limestone forms approximately the lower half of the Middle Devonian carbonate sequence of southern and central Illinois (fig. 1). It is a relatively pure carbonate unit that is commonly 50 to 150 feet thick. It is dominantly fossiliferous limestone in southern Illinois and dolomite in much of the central part of the state. It is lithographic limestone in the northern part of central Illinois where it pinches out against the Sangamon Arch.

In southern Illinois it generally lies on a very cherty carbonate unit, the Clear Creek Limestone, the top formation of the Lower Devonian. The Grand Tower overlaps the Clear Creek and older Devonian formations to lie upon the Silurian in much of central Illinois. The Grand Tower is generally overlain by the Lingle Limestone, a darker more argillaceous limestone that forms the upper half of the Middle Devonian sequence.

The Grand Tower is nearly free of silt and clay but is somewhat sandy. Sand is concentrated near the base; it occurs as floating grains in limestone or dolomite in some areas but as beds of sandstone in others. The basal sandstone is the Dutch Creek Sandstone Member. It is generally only a few inches or a few feet thick and is discontinuous. In many localities the lower beds of the Grand Tower carry little or no sand, but regions without sandstone are not large, and the Dutch Creek is recognized in all parts of the Illinois Basin where Grand Tower sediments are represented.

In central Illinois the Grand Tower is largely dolomite, and the lower part of the formation is a dark brown unit, the Geneva Dolomite Member. The Geneva extends in a broad arcuate band, convex to the north, from the outcrop in south-

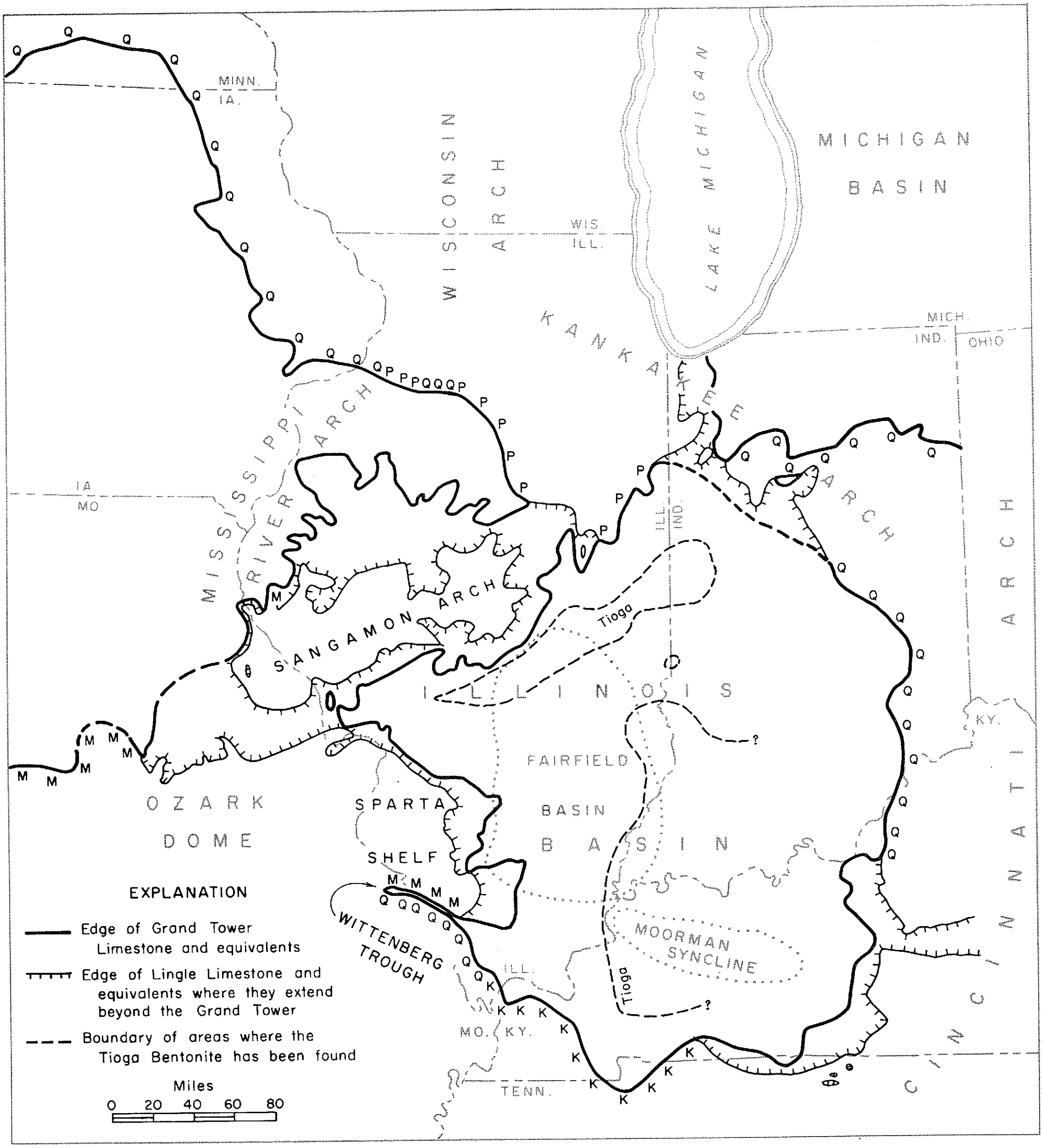


Figure 1 - Distribution of the Grand Tower Limestone and correlative limestone formations in the Illinois Basin region shown in relation to major structures. The age of the deposits truncating the Grand Tower at its margins is shown by the letters Q = Quaternary, K = Cretaceous, P = Pennsylvanian, M = Mississippian and Upper Devonian. Compiled from new data with the aid of William G. North, from literature cited in the report, from published state geologic maps, and from Branson (1923 and 1944), Freeman (1951), Grohskopf, Hinchey, and Greene (1939), Pinsak and Shaver (1964), Ross (1963), and Wilson (1949).

central Indiana into eastern and central Illinois but does not reach across the state. It is overlain by a somewhat thicker sequence of lighter colored dolomites that are also placed in the Grand Tower Formation. In many localities the Dutch Creek occurs at the base of the Geneva, but elsewhere there is little sand, and the Geneva rests directly upon pre-Grand Tower units.

A zone dominated by lithographic limestone occurs at the top of the Grand Tower in the northern and western parts of central Illinois. The lithographic unit grades southeastward into the light-colored dolomite of the upper part of the Grand Tower, but northward and westward it overlaps these dolomites and is the only part of the Grand Tower to reach the outcrops in Calhoun County, Illinois, and adjacent Missouri. It has generally been correlated with the Wapsipinicon Limestone in the subsurface of western Illinois, but it is identical in lithology with the unit commonly called Cooper in outcrops in northern Missouri and is here recognized as the Cooper Limestone Member of the Grand Tower. The name Wapsipinicon is restricted to the limestone north of the Sangamon Arch. The Cooper Member underlies the Lingle Limestone or equivalent strata in the Cedar Valley or Callaway Limestones. At the east it overlies other units in the Grand Tower, but westward it overlaps these to lie on various Silurian or Ordovician formations.

A thin bed of altered volcanic ash, the Tioga Bentonite Bed, occurs in several counties in the eastern part of Illinois near the top of the Grand Tower (fig. 1). It is the thin western edge of a volcanic ash fall that blanketed the eastern states. It has not been traced to western Illinois, and its position with respect to the Cooper Member is not known.

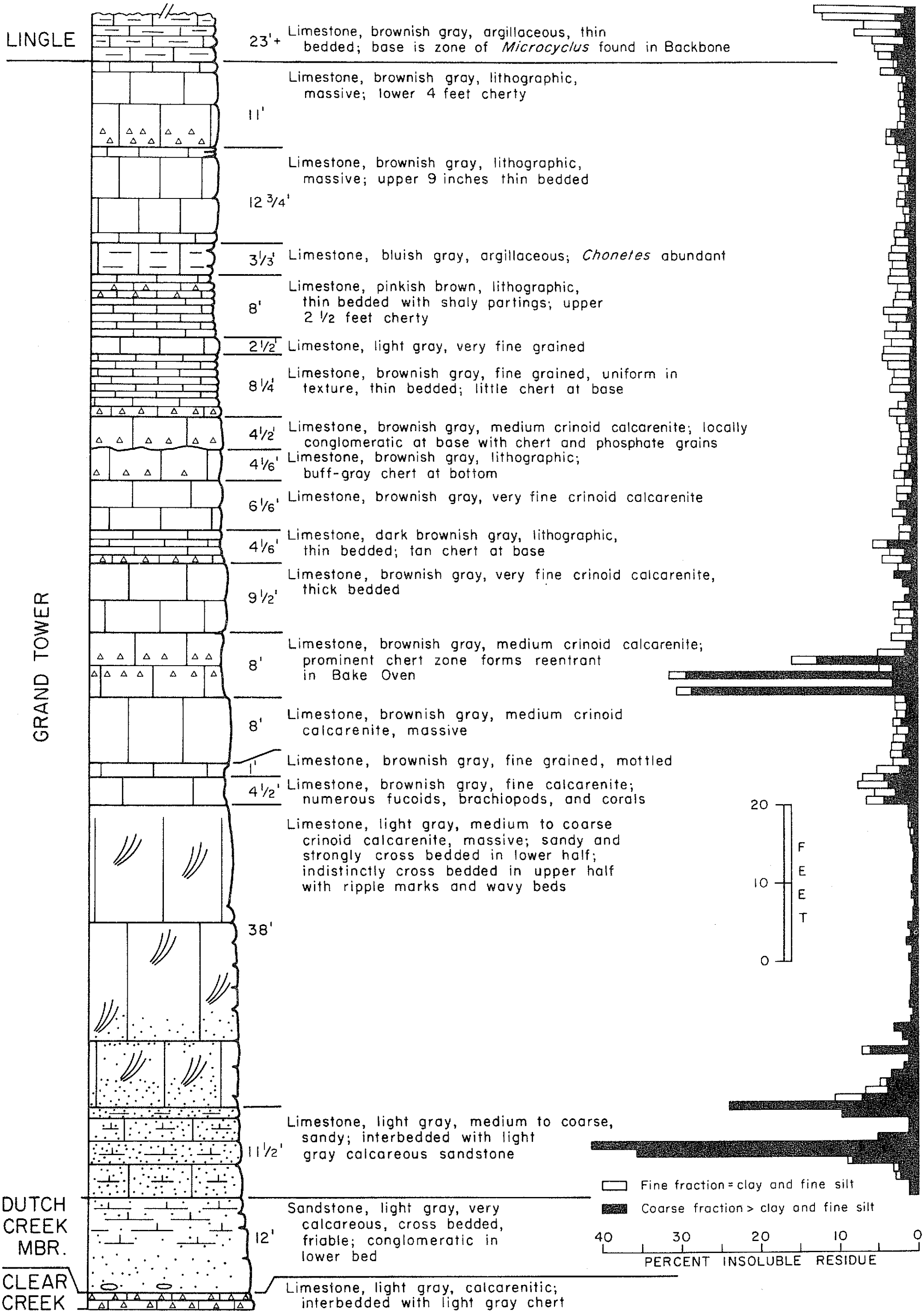
The Geneva Member and overlying dolomite beds in the Grand Tower have been the most prolific oil pay zones in the Devonian of Illinois and Indiana. The Dutch Creek Sandstone Member carries oil in the deep part of the Illinois Basin in southern Illinois. The production is from depths below 5000 feet, the deepest yet found in the Illinois Basin.

STRATIGRAPHY

Grand Tower Limestone

The Grand Tower Limestone was named by Keyes (1894) for Grand Tower, Illinois, where the formation is well exposed along the Mississippi River north of the town in two hills known as the Bake Oven and the Backbone (fig. 2).

At the Bake Oven, the formation is 157 feet thick and has been completely exposed during some extremely low river stages. The lower 15 to 25 feet is commonly beneath water and is covered by river silt during some low stages. Keyes' original usage is identical to that of the present report. His Grand Tower Limestone consisted of the section above the Clear Creek Limestone and beneath the dark, shaly limestone (with Hamilton fossils) that he included in his Callaway Limestone but which is now assigned to the Lingle Limestone in southwestern Illinois and to the Beauvais Sandstone and the St. Laurent Limestone in southeastern Missouri. Ulrich, in Buckley and Buehler (1904, p. 109-111), revised the Grand Tower to include the younger beds now assigned to the Lingle Limestone and its equivalents. Savage (1910, p. 116) restored the original limits to the Grand Tower, although he believed that by excluding the Clear Creek Formation he was emending rather than following Keyes. He was apparently unaware of the original reference and misread



23'+ Limestone, brownish gray, argillaceous, thin bedded; base is zone of *Microcyclus* found in Backbone

11' Limestone, brownish gray, lithographic, massive; lower 4 feet cherty

12 3/4' Limestone, brownish gray, lithographic, massive; upper 9 inches thin bedded

3 1/3' Limestone, bluish gray, argillaceous; *Chonetes* abundant

8' Limestone, pinkish brown, lithographic, thin bedded with shaly partings; upper 2 1/2 feet cherty

2 1/2' Limestone, light gray, very fine grained

8 1/4' Limestone, brownish gray, fine grained, uniform in texture, thin bedded; little chert at base

4 1/2' Limestone, brownish gray, medium crinoid calcarenite; locally conglomeratic at base with chert and phosphate grains

4 1/6' Limestone, brownish gray, lithographic; buff-gray chert at bottom

6 1/6' Limestone, brownish gray, very fine crinoid calcarenite

4 1/6' Limestone, dark brownish gray, lithographic, thin bedded; tan chert at base

9 1/2' Limestone, brownish gray, very fine crinoid calcarenite, thick bedded

8' Limestone, brownish gray, medium crinoid calcarenite; prominent chert zone forms reentrant in Bake Oven

8' Limestone, brownish gray, medium crinoid calcarenite, massive

1' Limestone, brownish gray, fine grained, mottled

4 1/2' Limestone, brownish gray, fine calcarenite; numerous fucoids, brachiopods, and corals

38' Limestone, light gray, medium to coarse crinoid calcarenite, massive; sandy and strongly cross bedded in lower half; indistinctly cross bedded in upper half with ripple marks and wavy beds

11 1/2' Limestone, light gray, medium to coarse, sandy; interbedded with light gray calcareous sandstone

12' Sandstone, light gray, very calcareous, cross bedded, friable; conglomeratic in lower bed

Limestone, light gray, calcarenitic; interbedded with light gray chert

Figure 2 - Type section of the Grand Tower Limestone in the Bake Oven and Backbone hills, north of Grand Tower, near the center of the $E\frac{1}{2}$ sec. 23, T. 10 S., R. 4 W., Jackson County. Compiled and described by Charles W. Collinson, incorporating insoluble residue analyses from a study by Hallstein (1952).

a later vague statement by Keyes (1895, p. 339) which, unlike the original, did not specifically exclude the Clear Creek from the Grand Tower.

The Grand Tower is recognized throughout southern Illinois. It extends eastward into Indiana where it is called the Jeffersonville Limestone. The lower part of the Grand Tower is overlapped eastward, so that the base of the Jeffersonville at its type outcrop on the Ohio River in south-central Indiana is younger than it is in the subsurface at the Indiana-Illinois border, and probably younger than the base of the Grand Tower outcrops in southwestern Illinois.

The Grand Tower extends northward in Illinois to a pinch-out on the south flank of the Sangamon Arch (fig. 1). The Sangamon Arch was a structural uplift trending slightly north of east that crossed central Illinois during Devonian deposition. It has been downwarped since then until it is not a present-day arch (Whiting and Stevenson, 1965). It is recognized by stratigraphic relations.

Strata north of the Sangamon Arch essentially equivalent to the Grand Tower are assigned to the Wapsipinicon Limestone. Although the name Wapsipinicon was formerly used south of the Sangamon Arch (Lowenstam, 1948, p. 162-164; Workman, 1944, p. 195, 197), there is no natural boundary to separate the Grand Tower from the Wapsipinicon south of the 50 to 80 mile gap at the Sangamon Arch. The beds in Illinois north of the arch extend continuously to the outcrops along the Wapsipinicon and Cedar Rivers in Iowa (fig. 1).

Other aspects of the regional correlations have been discussed by Cooper et al. (1942), Cooper (1944), Croneis (1944), Savage (1920a, 1920b), and Weller (1944).

Dutch Creek Sandstone Member

A basal sandstone or sandy limestone unit was mentioned by all of the early writers, both before and after the formal naming of the Grand Tower Limestone. Except for early reference to the Oriskany Sandstone of New York (Worthen, 1866, p. 124), this arenaceous unit was described as the basal member but not named by the early writers. Savage (1920, p. 175) named it the Dutch Creek Sandstone and gave it formational rank, thus separating it from the Grand Tower. Savage's classification has been followed since 1920, although the gradational nature of the Dutch Creek-Grand Tower contact and the occurrence of the sandstone in isolated bodies has been commonly noted. In the present paper the Dutch Creek is recognized as a discontinuous basal member of the Grand Tower Limestone rather than as a distinct formation. Because sandy limestone occurs throughout the Grand Tower, the name Dutch Creek is used only where beds of sandstone are present.

The Dutch Creek Sandstone was named for unspecified exposures along Dutch Creek, a tributary of Clear Creek, which flows northwest in central Union County 3 or 4 miles west of Jonesboro. Few, if any, sandstone outcrops occur along and near the bed of the main stream, but loose float is present on the valley walls and in the stream bed. Poor outcrops can be found along some hill slopes and in the beds of several tributaries. The contacts of the Dutch Creek are obscure in most exposures because of solution of the carbonates immediately above and below the sandstone. A sharp contact with the underlying Clear Creek and a gradational one with the main body of the Grand Tower are well shown north of Clear Creek along a secondary road about 1.1 miles northwest of its junction with Illinois highway 127, in the center of the W$\frac{1}{2}$ NW$\frac{1}{4}$ sec. 27, T. 11 S., R. 2 W., Union County, Cobden Quadrangle. Other important Dutch Creek outcrops are listed by Weller and Ekblaw (1940).

Geneva Dolomite Member

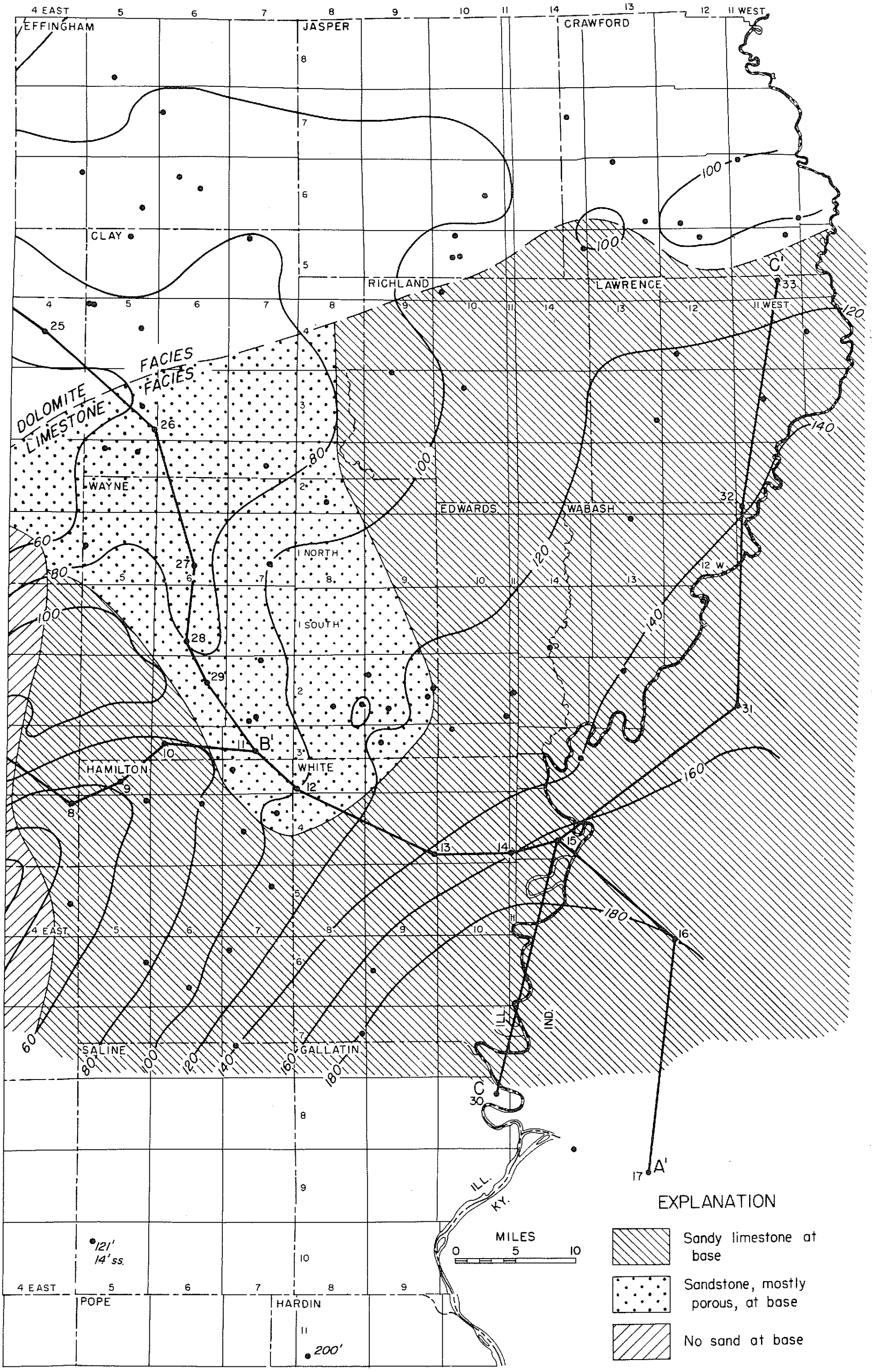
The Geneva Dolomite, named for a town in southeastern Shelby County, Indiana (Collett, 1882, p. 63, 81-82), is a dark brown, crystalline dolomite that reaches the surface only in the northern and central parts of the Devonian outcrop belt in southern Indiana, where it underlies the Middle Devonian Jeffersonville Limestone and unconformably overlies Silurian strata. In the subsurface it extends westward in a belt that arches gently to the north and crosses west-central Indiana (Bieberman, 1949) and central Illinois (Schwalb, 1955) but does not reach the west side of the Illinois Basin. Controversy has arisen concerning the nature of the surface separating the Geneva from the Jeffersonville in the Indiana outcrop area and the presence or absence of lateral gradation between the two. In the subsurface of Illinois the Geneva is a facies that grades laterally into the lower part of the Grand Tower Limestone. It is considered a member of the Grand Tower in Illinois. The Dutch Creek Sandstone Member is present in patches at the base of the Geneva Dolomite Member just as it is at the base of the limestone facies of the Grand Tower farther south. The Geneva is overlain by undifferentiated limestone and dolomite units of the Grand Tower.

Cooper Limestone Member

An unfossiliferous to poorly fossiliferous limestone that crops out in patches in Cooper and other counties in north-central Missouri was named the Cooper Marble (now Limestone) by Swallow (1855, p. 108, 196). In its type section it is the only Devonian unit exposed. In some other outcrops it is overlain by a darker, shalier, much more fossiliferous limestone that is equivalent to the Lingle and was named the Callaway Limestone by Keyes (1894, p. 43). The Cooper has generally been placed beneath the Callaway as a distinct, separate formation, but Unklesbay (1952, p. 30-31) considered it a gradational unit within the Callaway and designated it the Cooper Facies of the Callaway Limestone.

The Cooper occurs in the northern and central part of the Devonian outcrop belt in Calhoun County, Illinois (Rubey, 1952, p. 31), where it is a lens of relatively dense, light colored, pure limestone forming the basal few feet of the Cedar Valley Limestone. A few feet of light gray to light brownish gray, extra finely crystalline to lithographic, unfossiliferous limestone that contains small tubes or "bird's-eyes" of clear calcite is exposed on the west bank of the Illinois River, 1.5 miles south of the bridge at Hardin, at the center of the west line of the SW$\frac{1}{4}$ sec. 35, T. 10 S., R. 2 W., Calhoun County, Hardin Quadrangle. This outcrop is typical of the Cooper. Several hundred feet to the southwest these beds are overlain by 15 to 18 feet of medium to dark brownish gray, shale-streaked, fossiliferous limestone that was formerly classified as Cedar Valley (Cooper and Cloud, 1938; Rubey, 1952) but that is here assigned to the Lingle Formation, although still correlated with the Cedar Valley.

East of the Illinois River the Cooper occurs in the subsurface in a belt 60 to 90 miles wide extending eastward across the state just south of the Sangamon Arch. The Cooper generally rests on Ordovician rocks in Missouri but on Silurian rocks, or other parts of the Grand Tower, in Illinois. On its north margin the Cooper is overlapped by the Lingle. On the south it grades laterally into the light-colored dolomites that form the upper part of the Grand Tower above the Geneva Member. The contact between lithographic limestone to the north or northwest and dolomite to the south or southeast rises stratigraphically so that the highest, youngest bed of the Cooper extends farthest south to the limit shown on figure 3.



showing lines of cross sections A-A' (fig. 4), B-B' (fig. 5), and C-C' (fig. 6).

Because of its gradation with the upper part of the dolomitic facies of the Grand Tower Limestone, the lithographic limestone unit is classified in Illinois as the Cooper Limestone Member of the Grand Tower Limestone. The unit was formerly assigned to the Wapsipinicon Limestone (Workman, 1940; Lowenstam, 1948) in the subsurface of Illinois and to the Cedar Valley Limestone in the Calhoun County outcrops. The name Wapsipinicon will be used only north of the Sangamon Arch.

Although Cooper strata in many ways resemble those of the Wapsipinicon, they tend to be more fossiliferous, they do not include anhydrite or gypsum, and they are probably less brecciated than certain beds in the Wapsipinicon. The maximum thickness of the Cooper in Illinois is about 60 feet.

Tioga Bentonite Bed

Although the presence of a thin bed of bentonite, altered volcanic ash, near the top of the Grand Tower and the Jeffersonville in Illinois and Indiana was known by 1940, it has not been noted in the literature. The bentonite is generally no more than 1 or 2 inches thick. It locally becomes 6 or 8 inches thick in the Illinois Basin but is much thicker in the Appalachian Basin. Its presence there was noted by Fettke (1931) who later (in Ebright, Fettke, and Ingham, 1949) named it the Tioga Bentonite Bed because of its usefulness as a subsurface stratigraphic marker in the Tioga Gas Field, Tioga County, Pennsylvania. The distribution and thickness of the Tioga Bentonite in the Appalachian region as reported by Fettke (1952), Flowers (1952), Oliver (1954, 1956), and Dennison (1961) led Dennison to conclude that the bed consists of ash ejected from a volcano located near Lexington, Virginia.

In the Illinois Basin the bed generally occurs 6 to 15 feet beneath the top of the Grand Tower or the top of the Jeffersonville. It has been found in many wells in southwestern Indiana and eastern Illinois and is probably present throughout the area indicated on figure 1, although its thinness precludes its recognition in all wells. Its distribution is traced most readily on geophysical logs (fig. 6), because its physical attributes contrast sharply with those of the dolomite or limestone in which it occurs. It is probably 1 to 4 inches thick in the majority of wells in which it has been noted on electric logs. However, it is at least 8 inches thick in southern Sullivan County, Indiana, and it has been identified on some sonic logs where it is probably no more than $\frac{1}{4}$-inch thick.

In samples, the bentonite is represented by rounded, somewhat blocky chips of greenish gray to brownish gray shale containing small flakes of brown biotite that distinguish it from normal Devonian shale. Its color differs only slightly from the medium gray to brownish gray of normal detrital shales. However, the abundant mixed-layer clay mineral that characterizes metabentonite or K-bentonite is shown by the X-ray spectrograph and differs sharply from the illite-quartz suite of the normal shales.

The Tioga has not been recognized in wells in the southwestern part of the state, nor in outcrops of the Grand Tower in southwestern Illinois and southeastern Missouri. It occurs about 4 or 5 feet above the base of the Wapsipinicon Limestone, $1\frac{1}{2}$ feet below the top of the basal Coggin Dolomite Member in the Central City quarry, on the north bank of the Wapsipinicon River, northwest of Central City, in the SE$\frac{1}{4}$ sec. 28, T. 86 N., R. 6 W., Linn County, Iowa. The relation of the Tioga Bed to the Cooper Member in western Illinois and adjacent Missouri is not known. Its position in Iowa suggests that it may lie near the base of the Cooper where the Cooper is best developed.

Formations Above the Grand Tower Limestone

Figures 4 through 6 illustrate the character and stratigraphic relations of the Lingle Limestone, the Alto Limestone, and units in the New Albany Shale Group, as well as those of the Grand Tower. Figure 4 shows that the unit called Alto Limestone in western Illinois (west of well No. 8 in eastern Jefferson County) grades laterally into the Blocher Shale of the New Albany Shale Group in eastern Illinois. The top of Devonian Limestone (top of Hunton Limestone Megagroup) is at the top of the Alto in the western region but at the base of the Blocher in the eastern region. In the vicinity of well No. 8, the surface that is used to separate the New Albany Shale Group from the Hunton Limestone Megagroup has an abrupt cutoff or step-down to the east of about 30 feet.

DISTRIBUTION AND THICKNESS

The thickness in southern Illinois of the entire Grand Tower Limestone, including its members, is shown on figure 3. The thickness in the central and west-central parts of the state is shown by Whiting and Stevenson (1965). The regional distribution of the Grand Tower and its correlatives with regard to major structural features is shown on figure 1.

Sparta Shelf

The Grand Tower is absent in a large area in southwestern Illinois, including most of St. Clair, Monroe, Randolph, Washington, Perry, and Jackson Counties. The region in which it is absent or thin corresponds roughly to the western shelf of the Illinois Basin, a feature here named the Sparta Shelf (fig. 1) after the town in Randolph County. The Sparta Shelf lies between the Fairfield Basin, the larger and more northerly deep depression of the Illinois Basin, and the main body of the Ozarks. On the east it is sharply differentiated from the Fairfield Basin by the DuQuoin Monocline. On the southwest it is sharply differentiated from the Ozarks by the Ste. Genevieve Fault System and the feature later described as the Wittenberg Trough. Its limits on the north are indefinite. The Sparta Shelf expands northward into the broad northwestern flank of the Illinois Basin that lies between the Fairfield Basin and the Mississippi River Arch but is sharply differentiated from neither. In earlier discussions of Silurian, Devonian, and lower Mississippian stratigraphy, the Sparta Shelf was referred to as the eastern lobe of the Ozarks, eastern extension of the Ozarks, or the area with little or no sediments (Lowenstam, 1948; Workman, 1944; Workman and Gillette, 1956).

The Grand Tower is overlapped on the Sparta Shelf by the overlying Lingle Limestone (fig. 4). The Lingle in turn is overlapped by younger units that rest on progressively older pre-Grand Tower formations farther west. At the west edge of the shelf, Valmeyeran (Middle Mississippian) rocks lie on the Silurian or Ordovician.

Eastward from its feather edge, the Grand Tower thickens across the Fairfield Basin to 140 to 200 feet (figs. 3, 4, and 6). It is thickest near the Illinois-Indiana boundary. Farther east the Geneva Dolomite and the Jeffersonville Limestone, which are equivalent to the Grand Tower, thin gradually across the eastern shelf of the Illinois Basin. At the Indiana outcrop they are only half as thick as at the state line. The eastward thinning is more abrupt in Kentucky, where the Jeffer-

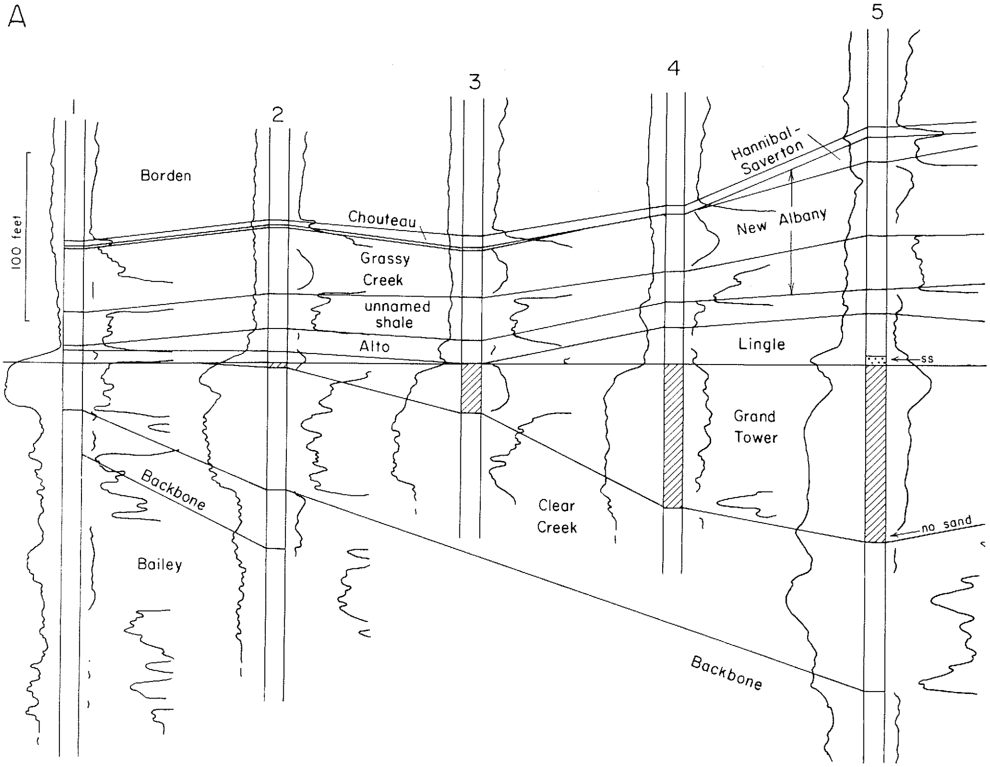


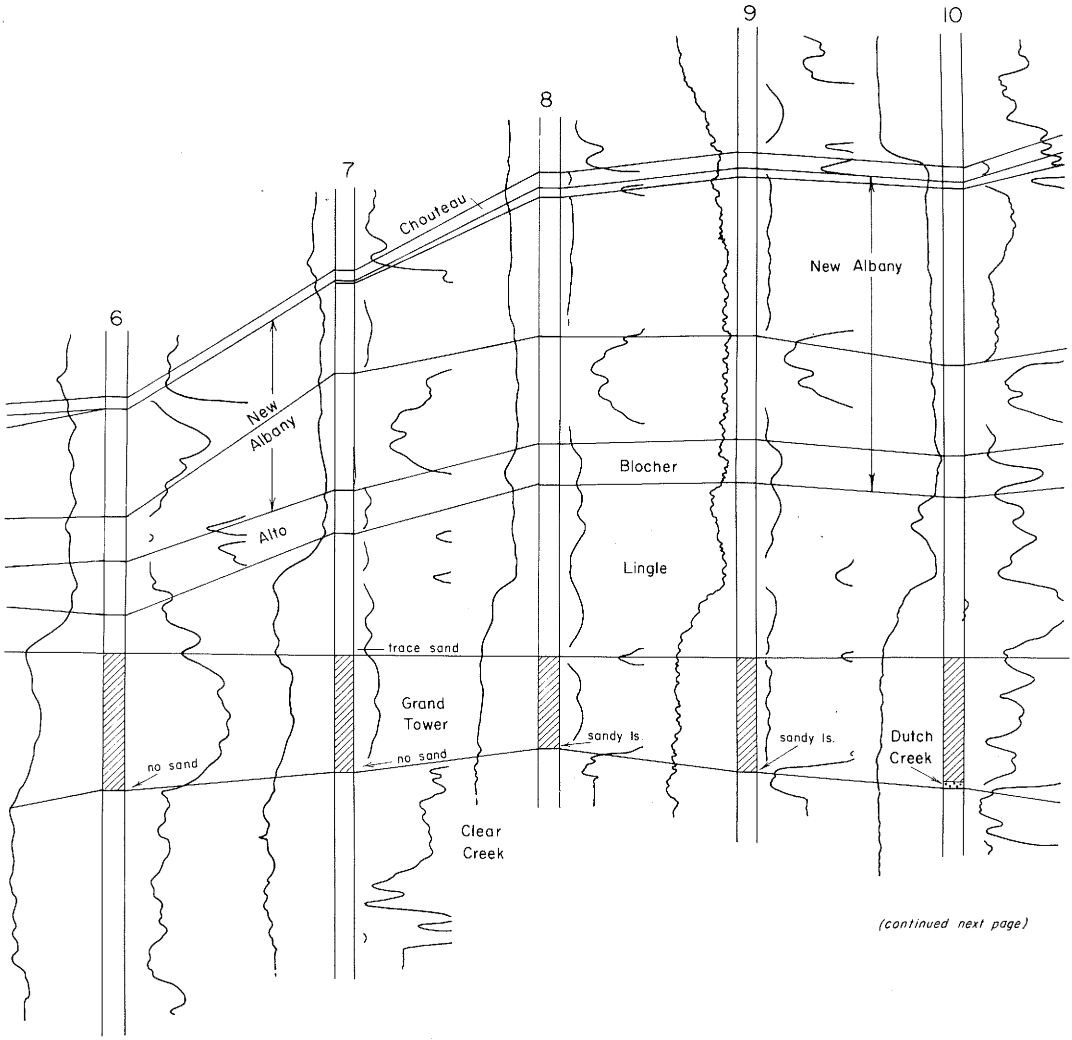
Figure 4 - East-west electric log cross section of the Grand Tower and associated
See Appendix for list of wells.

sonville is generally overlapped in the subsurface west of the outcrop belt. A few thin scattered outliers of equivalent strata in west-central Tennessee have been included in the lower part of the Pegram Limestone (Lingle equivalent).

The Grand Tower occurs in central western Illinois in a broad belt that crosses the north part of the Sparta Shelf south of the Sangamon Arch (figs. 1 and 5). In this region the formation is thinner than it is in the Fairfield Basin. Isolated patches of equivalent strata as much as 30 feet thick continue this belt westward halfway across Missouri.

Wittenberg Trough

A striking feature of the distribution of the Grand Tower Limestone is the narrow tongue or series of isolated blocks that extend northwestward from central



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units from Washington County, Illinois, to Union County, Kentucky (on four pages).

Union County in southwestern Illinois into Ste. Genevieve County, Missouri. The structural trough in which this tongue of the Grand Tower was deposited, and which is largely responsible for its preservation, is here named the Wittenberg Trough (figs. 1 and 3). The Wittenberg Trough developed largely during the Devonian, and by early Mississippian time was a structural trench 70 miles long, 1 to 10 miles wide, and 100 to more than 1000 feet deep that broke the simple structural slope between the Ozarks and the Illinois Basin. Post-Mississippian movement has distorted and partially destroyed the Wittenberg Trough. The northwest end has been tilted up. The structural displacement has been increased along most of the southwest side, the edge toward the Ozarks, whereas it has been decreased or even eliminated on the northeast or basin side.

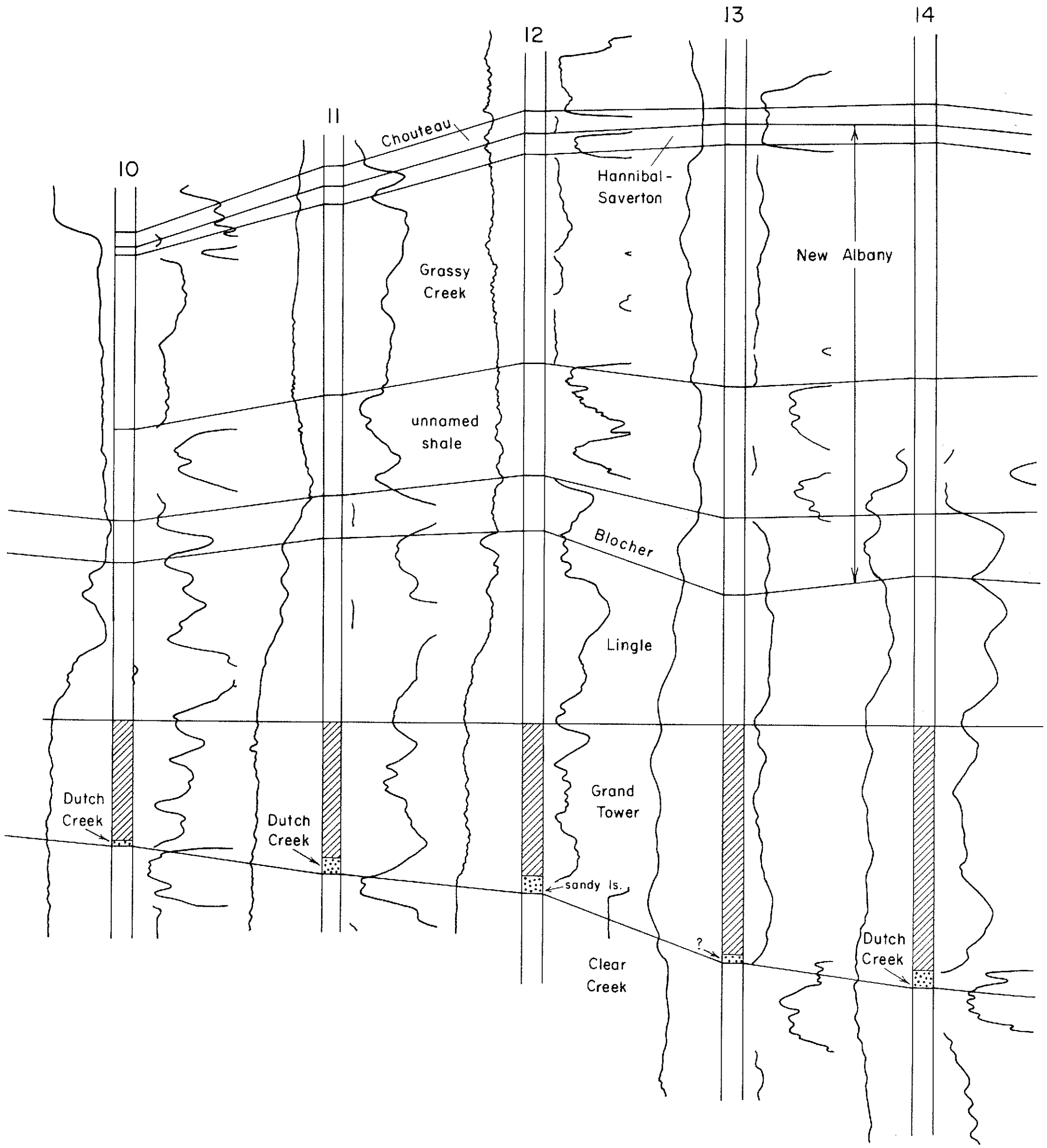
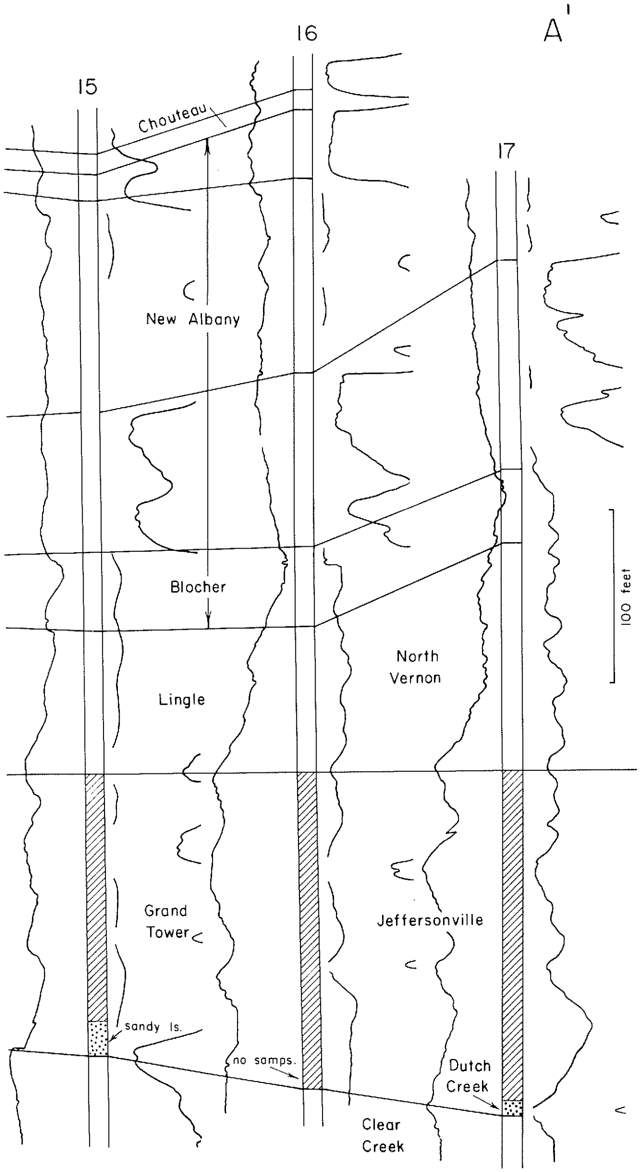


Figure 4 -

The trough is shown on the geologic map by the Ordovician outlier in the Weingarten Graben in western Ste. Genevieve County; by the Devonian and Silurian grabens in southern Ste. Genevieve County; by the upper Mississippian of eastern Perry County, Missouri; by the Pennsylvanian outlier at Fountain Bluff, in southwestern Jackson County, Illinois; and by the structurally controlled course of the Mississippi Valley from Ste. Genevieve to Grand Tower. Although the Wittenberg Trough is now largely outlined by faults, its margin included monoclinal flexures so that the term graben would not be appropriate.



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The western end of the structure was described by Weller and St. Clair (1928) in their discussion of faulting in Ste. Genevieve County. At the eastern end puzzling contradictions in facies and thickness of outcropping Devonian units in different parts of Jackson and Union Counties, Illinois, have long been noted, but subsurface information was needed to complete the picture. Although well control is still very sparse, the Wittenberg Trough appears to merge at its eastern end into the southern part of the Illinois Basin and to be in effect the westernmost extension of the southern deep of the basin, the Moorman Syncline.

The Wittenberg Trough affected not only Grand Tower sedimentation, but that of other Devonian formations. In it were deposited the thickest Lower Devonian sections of the Midwest as well as the thickest Middle Devonian outside the Michigan Basin. During the Devonian, the axis of the Wittenberg Trough may have migrated slightly northward, because the thickest sections of the Clear Creek apparently lie 2 to 6 miles southwest of the thick sections of the Grand Tower, Lingle, Alto, and New Albany.

The outcrops of thick Grand Tower Limestone lie in fault blocks and tilted sections on the downthrown northeastern side of the major faults of the Ste. Genevieve-Rattlesnake Ferry system. These faults are largely post-Mississippian and, at least in part, post-Pennsylvanian. They now outline the southwest edge of the Wittenberg Trough, although they appear to lie somewhat north of the original edge of the trough. The Grand Tower Limestone does not descend into the basin from

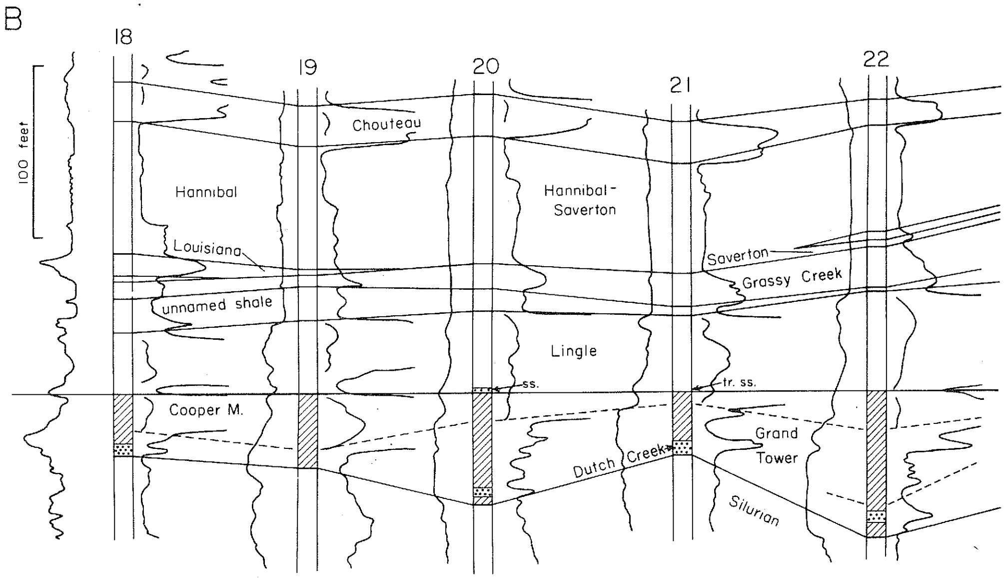
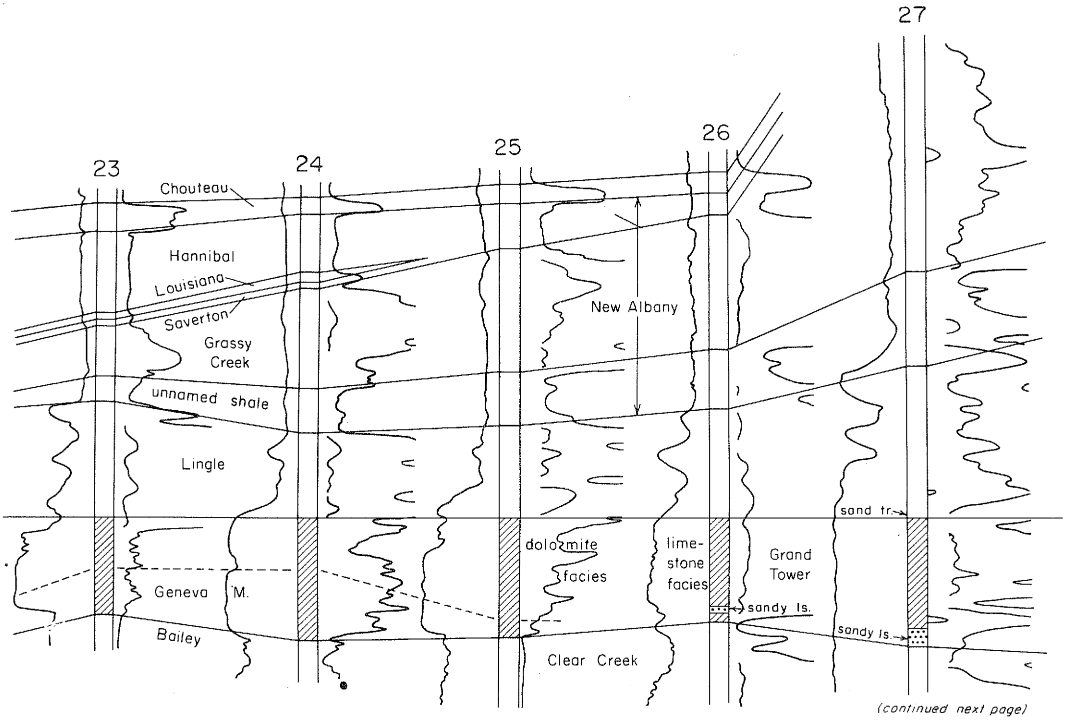


Figure 5 - Northwest-southeast electric log cross section of the Grand Tower Limestone See Appendix for list of wells.

these outcrops but is cut off abruptly within 1 to 6 miles by pre-Mississippian faults and corresponding monoclines that are down to the southwest toward the Ozarks. These mark the edge of the extensive area of the Sparta Shelf over which the Grand Tower is lacking. Although the Lingle, Alto, and New Albany overlap the Grand Tower on the Sparta Shelf, they, too, are gone at the southwest edge next to the Wittenberg Trough. Within the trough the Grand Tower is 100 to 200 feet thick and is overlain by 200 to 300 feet of Lingle and Alto and by 0 to 100 feet of New Albany. The type section of the Grand Tower (fig. 2) is typical of the sections in this region. The Grand Tower is absent south of the western end of the Wittenberg Trough where the Ordovician rocks of the Ozarks are found immediately south of the bounding faults. In Illinois, south of the eastern end of the trough, the formation thins rapidly. Limestone disappears and only a few feet of the Dutch Creek Sandstone Member is left 5 miles beyond the axis of the trough.

Dutch Creek Sandstone

The Dutch Creek Sandstone averages about 15 feet thick at the outcrops in Union and Jackson Counties, Illinois. As much as 35 feet has been reported at poorly exposed outcrops where much of the section, before leaching, may have consisted of sandy limestone. In extreme southern Illinois, south of the area shown on figure 3, several wells have 10 to 15 feet of good sandstone. In the patterned area on figure 3 the maximum thickness approaches 15 feet, but many wells have only 1 or 2 feet of permeable sandstone, and the average for the area is probably no more than 4 or 5 feet. In east-central Illinois, north of the mapped area, both



(continued next page)

and associated units from Macoupin County to Wayne County (on three pages).

the average and maximum thicknesses appear to increase so that as much as 20 feet of sandstone has been recorded in Edgar and Douglas Counties, although some wells in these counties have no sandstone.

STRATIGRAPHIC RELATIONS

Upper Contact

The Grand Tower Limestone is everywhere overlain by the Lingle Limestone in the area mapped in detail on figure 3. In general, there is a slight disconformity above the thinner sections in the western part of the area and an apparent conformity in the east over the thicker sections in the Fairfield Basin. In the west, the basal beds of the Lingle Limestone tend to be quite sandy, and a basal sandstone member equivalent to the Beauvais Sandstone of Missouri is present in many localities. In cores the contact is sharp and in many cases uneven. However, truncation of the upper part of the Grand Tower is limited because the Lingle rests on the same bed over large areas. The westward thinning of the Grand Tower results more from internal thinning and from overstep at the base than from pre-Lingle truncation at the top.

Regionally, too, the Grand Tower and equivalent strata are generally overlain and overlapped by the Lingle or other carbonate formations of late Middle Devonian (Hamilton) age (fig. 1). There are a few exceptions. The feather edges of Grand Tower and Lingle on the south side of the Sangamon Arch approach each other in Christian County where the New Albany Shale in some wells is underlain by a

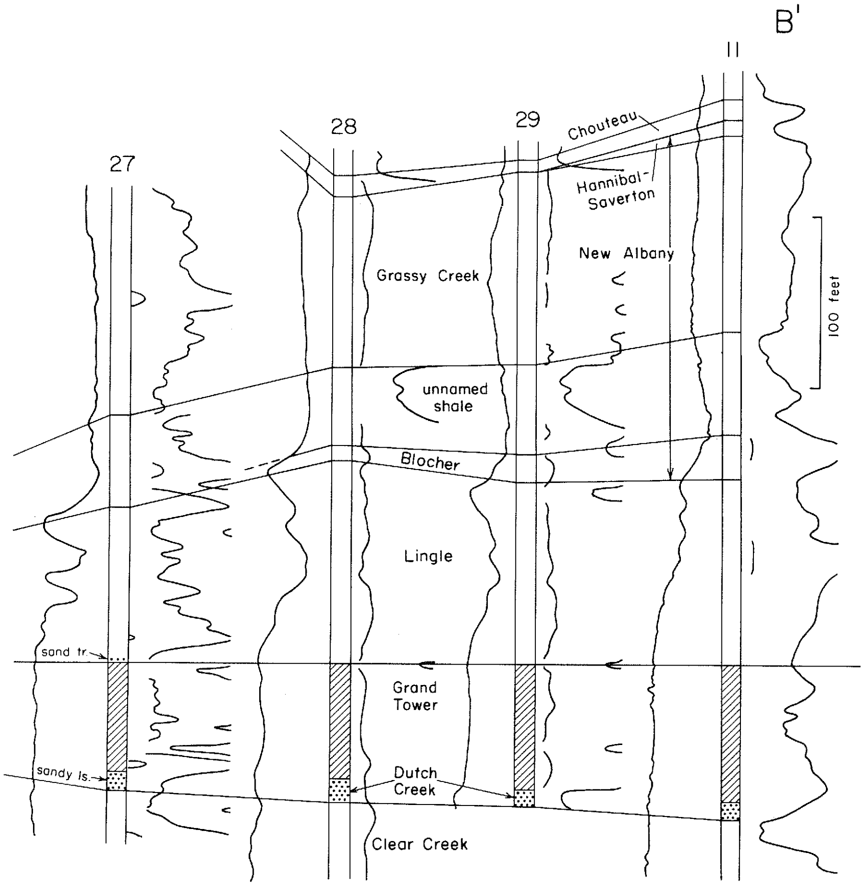


Figure 5 - Continued.

few feet of Middle Devonian limestone that might belong to either formation. North of the arch the Wapsipinicon Limestone, the equivalent of the Grand Tower, is directly overlain by the New Albany over a few square miles in Adams County (Whiting and Stevenson, 1965). In Iowa and northeastern Missouri, limestone equivalent to the Lingle overlies the Grand Tower equivalents, but in three or four counties in north-central Missouri, Lingle equivalents are overlapped by thin sandstones of Kinderhookian (Lower Mississippian) and Upper Devonian age, which lie directly on the Cooper, the representative of the Grand Tower. In west-central Tennessee, some remnants of the Middle Devonian Pegram Limestone beneath the black shale have been variously equated to the Grand Tower and the Lingle. Most, if not all, Pegram outcrops include beds of Hamilton (Lingle age) so that areas where the Grand Tower equivalents are overlain by the Chattanooga (New Albany) must be small. Thus, the Grand Tower is nearly everywhere overlain by Lingle, except where both formations or their equivalents are beveled along the edges of the basin by pre-Pennsylvanian, pre-Cretaceous, or pre-Quaternary erosion (fig. 1).

Lower Contact

In contrast to its conformable or nearly conformable upper surface, the lower surface of the Grand Tower is one of the major unconformities of the Midwest. In

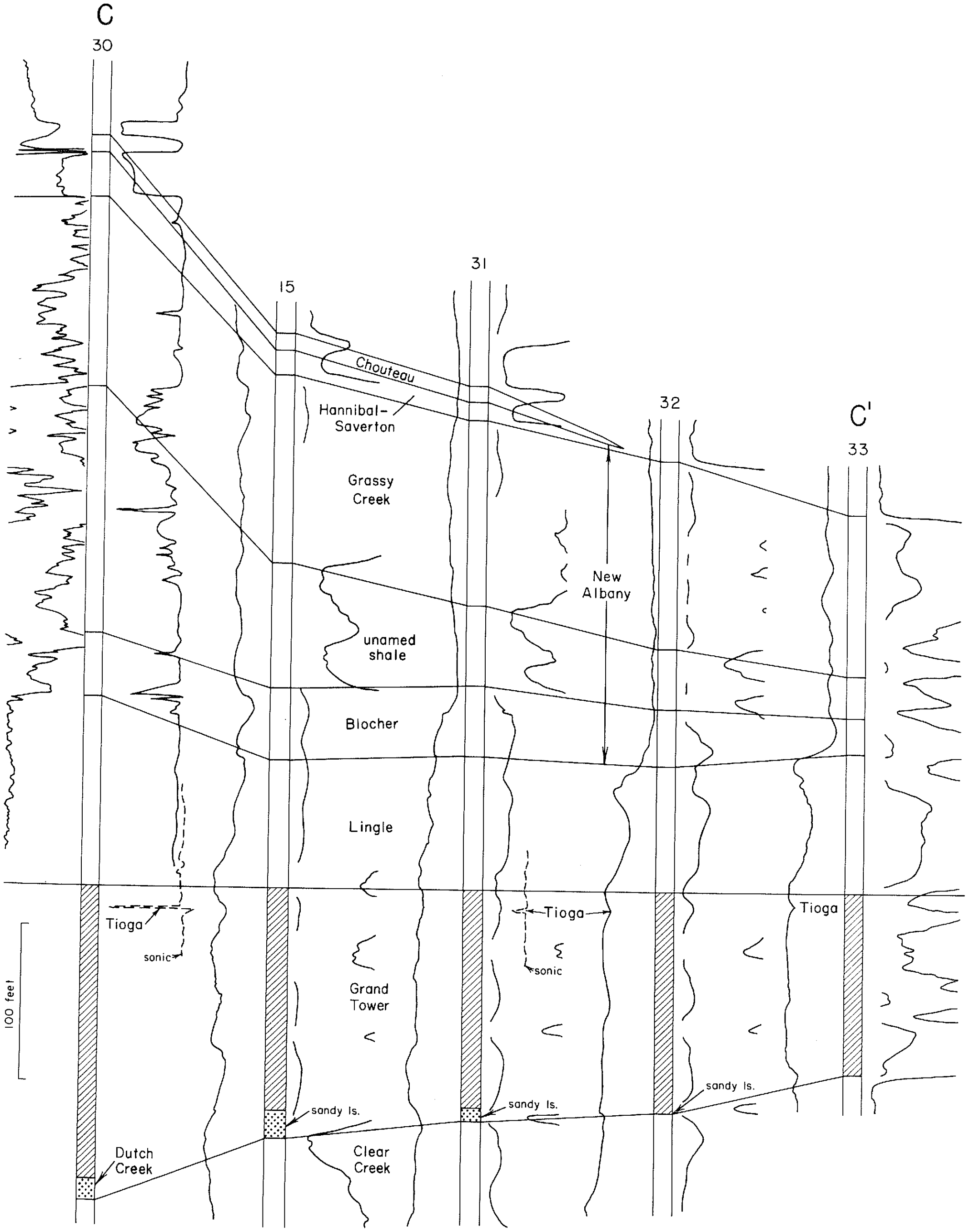


Figure 6 - North-south cross section of the Grand Tower and associated units from Gallatin County to Lawrence County. See Appendix for list of wells.

the eastern and southern parts of the area mapped on figure 3, the Grand Tower lies on the Clear Creek Limestone. The relation is generally unconformable, although the time interval separating the two formations could not have been very great. The contact is abrupt. At a single outcrop in Union County, the typical Clear Creek and Dutch Creek lithologies have been reported to be interbedded, but minor faulting and slumping at this locality obscures the true relation, and the contact is probably simple and abrupt. In the subsurface, too, the contact has been sharp in all cored wells, and reports of intergrading or interbedding seem restricted to studies of relatively inferior sample sets.

The base of the Grand Tower truncates the pre-Clear Creek Devonian formations in a belt that crosses Clinton, Marion, Fayette, Effingham, and Shelby Counties. Farther northwest the Grand Tower lies on Silurian dolomites that are of Niagaran age within the area of figure 3. Beyond the limits of the map, the Grand Tower overlaps the Niagaran to lie on Alexandrian (Lower Silurian) and Ordovician rocks. The situation is similar north and east of the mapped area in central Illinois and in Indiana, where the Grand Tower and its equivalents overlap the Lower Devonian and rest on the Silurian. To the southeast, in central Kentucky, the truncation extends down to the Ordovician.

Considering its regional truncation, the surface upon which the Grand Tower was deposited appears astonishingly smooth. The other major unconformable surfaces, at the base of the Cambrian, the Champlainian (Middle Ordovician), the Pennsylvanian, the Gulfian (Upper Cretaceous), and the Pleistocene are scarred by erosion features with relief measured in tens or hundreds of feet. Valley systems, scarps, sink holes, and buried hills mark these unconformities. Although the sub-Grand Tower surface records the truncation and removal of several hundred feet of rock in some areas, no comparable erosion features have been noted. An exception might be a channel or valley in Morgan and Sangamon Counties that is suggested by scattered, thick, conglomerate sections (Whiting and Stevenson, 1965). Indirect evidence suggests that channels were cut 50 feet or more into Silurian and possibly Lower Devonian rocks during pre-Grand Tower erosion.

The Silurian rocks in several areas covered by the Grand Tower contain a system of solution-enlarged joints, "fissures," and cavities down to a depth of at least 70 feet. Many of these are filled by sand that is like the sand of the Dutch Creek but less well cemented, and by green or greenish gray clay that in places contains Middle Devonian fossils. The enlarged joint system resulted from pre-Grand Tower underground solution. Its wide extent suggests that during its development the water table lay some distance below the present top of the Silurian. This, in turn, requires that some master streams were incised as deeply as 50 to 70 feet beneath the general surface. Such stream valleys may have been overlooked because they occupy a minute fraction of the entire surface and wells have chanced not to hit them. On the other hand, the carbonates above and below the surface are so similar that some wells drilled through pre-Grand Tower valleys may have been misinterpreted.

Beyond the limits of the Grand Tower, similar solution features beneath the unconformities that bevel the Lower Devonian, Silurian, and Ordovician strata have become filled by post-Grand Tower sediment of several ages. At the Marine oil field, in the northern part of T. 4 N., R. 6 W., Madison County, the solution network was formerly considered to be post-Grand Tower, pre-Lingle (pre-Cedar Valley) (Lowenstam, 1948). However, much more extensive regional knowledge suggests that the sediment filling the cavities is of Grand Tower rather than Lingle age.

Although the Dutch Creek Sandstone Member is not present in the thin Grand Tower deposits over the Silurian reef at Marine, the sand in the cavity fillings is of the type found widely in the Dutch Creek. The clay in the cavities is not the eastern or Appalachia-derived mud that formed the shales of the Lingle but is essentially a locally derived insoluble residue of the Silurian and earlier limestones. Only a few pre-Lingle solution cavities have been found in the Grand Tower Limestone of the Marine area, where the cavities are unusually abundant in the Silurian. It is concluded, therefore, that the solution system at Marine, as elsewhere in the area covered by the Grand Tower, extends downward from the surface at the base of the Grand Tower rather than from that at the base of the Lingle.

LITHOLOGY

The Grand Tower Limestone is a carbonate unit within a much thicker carbonate sequence, the Hunton Limestone Megagroup. In a broad sense, the formations composing the megagroup are lithologically similar, with much duplication of specific rock types between the different units. Some rocks in the Grand Tower cannot be distinguished from some rocks in each of the other formations, but in its over-all characteristics, the Grand Tower can be set off as a sandy, nonsilty, nonargillaceous formation. It and the overlying Lingle Limestone include sandstone and sandy limestone, whereas sand in any form is rare in the rest of the Hunton and is unknown in some units. The Lingle is characterized, in addition, by including silty limestone, argillaceous limestone, and calcareous shale, which are essentially lacking in the Grand Tower. The Grand Tower shares its freedom from clay and silt with the Backbone Limestone and some Silurian units, but these are not sandy.

All parts of the Grand Tower are thick bedded. Stylolites are fairly common but are widely spaced. They tend to be conspicuous with interpenetrating columns as much as several inches in length.

The Grand Tower is characteristically fossiliferous limestone in the southern part of the state, dolomite in a belt crossing the south-central part, and unfossiliferous or poorly fossiliferous lithographic limestone near the northern border in the central part (fig. 3).

Limestone

In the southern area, the limestone is generally rather light colored, varying from light brownish gray and light grayish brown, buff, and tan, to almost white. The values are nearly all lighter than medium, and the hues are on the yellow or yellow-red side of neutral gray. Pink, red, or green tints occur rarely, if ever. The over-all color is lighter than that of most formations with which the Grand Tower is in contact. The Backbone Limestone and some Silurian rocks may be as light, but they tend to be partly pinkish or greenish. White chert is common in the Clear Creek, but the carbonate of the Clear Creek is generally darker than that of the Grand Tower in the southern region.

Texturally the limestones of the southern region range from fine-grained micrite, both with and without scattered fossils, to coarse, fossil-hash calcirudite. Entire fossils are probably commoner than fossil fragments, although beds of each occur. Oolites have not been found, and pelitic texture does not appear to be very common. The common fossil forms are crinoids, brachiopods, corals, stromatoporoids, and bryozoans. The gastropod Platyceras is conspicuous in some cores, partly because its dark shell contrasts with the light color of most other constituents in the limestone.

Lithographic limestone is uncommon in the southern limestone facies, but it is the dominant and almost the only rock in the Cooper Limestone Member in central Illinois, immediately south of the Sangamon Arch. The rock is a pure, dense, nonporous micrite. Fossils are rare, but the few that occur are generally entire and include brachiopods, pelecypods, ostracods, and corals. In some localities a small amount of clear calcite (sparite) fills irregular breaks in the lithographic rock or occupies tubular "bird's-eyes" one-half to three millimeters in diameter. Sand grains are scattered through the lithographic rock in some localities, but elsewhere 10 to 40 feet or more of lithographic limestone contains very little sand and almost no other insoluble residue.

Dolomite

Between the two limestone regions is a belt in which the Grand Tower is almost exclusively dolomite. The area of interbedded dolomite and limestone between the southern limestone facies and the central dolomite belt is only a few miles wide and is represented on figure 3 by a single line. At the north, the contact between the dolomite facies and the lithographic limestone of the Cooper Member slants stratigraphically down to the north, so that a southward-thinning wedge of Cooper overlies a northward-thinning wedge of dolomite. The sequence within the dolomite belt and its relation to the southern limestone unit were described by Schwalb (1955).

The most characteristic type of dolomite is confined to the Geneva Member, which is essentially the lower one-third of the dolomite in the central and southern part of the dolomite belt (fig. 5). This is a brown to dark brown, medium-grained, sucrosic, porous dolomite. The crystals are uniform in size. Porosity averages around 17 percent but ranges from about 12 to 25 percent. The very dark brown color is due to a small amount, no more than 1 percent, of organic matter that appears as minute, floating, waxlike flakes when set free from the carbonate by acid. This flaky, floating residue is characteristic of dolomite from the Geneva. The Geneva is very nearly unfossiliferous; some cavities suggest poorly preserved fossil molds and a few chitinous microfossils—scolecodonts, chitinozoans, and charophytes—have been found. Preliminary examination has failed to reveal conodonts, although these are common in the limestone facies to the south. Except for the organic flakes, the insoluble residue of the Geneva consists almost entirely of the sand described later.

The typical dark brown dolomite of the Geneva is overlain and grades laterally northward, and in some places southward, into a greater thickness of light-colored dolomite. These lighter dolomites are not formally named, but in Indiana they have been recognized informally as the "laminated beds" of the Jeffersonville. They constitute the bulk of the rock in the dolomite zone.

The lighter colored, undifferentiated dolomites vary in color through gray, yellow, and tan. Occasional beds are almost as dark as the Geneva, but these lack the characteristic insoluble residue of the Geneva. The undifferentiated rocks are generally finer grained than the Geneva. They are laminated in part. The laminae consist of alternating layers of extremely fine and somewhat coarser crystalline dolomite. In some beds several feet thick the crystal size is fairly uniform, and in other beds larger crystals float in a matrix of extremely fine crystals. The average porosity is less than in the Geneva, but the porosity is more variable. The argillaceous content is extremely low, and the rock resembles the Geneva in its sand content. Although there is a little interbedding of other types of dolomite with typical Geneva, in general the separation is sharp. The Geneva type cannot be distinguished from the other dolomites on most geophysical logs (fig. 5).

Local zonation of the Grand Tower on the basis of relative abundance of fossil components and textural types is possible, as demonstrated by the zonation of the Jeffersonville in part of southern Indiana (Perkins, 1963). This kind of zonation cannot be extended across the entire basin. Concentrations of corals and stromatoporoids, for example, occur at several positions within the formation in different areas, although they are more common near the base.

Chert

Chert occurs sporadically in the Grand Tower, as it does in the overlying Lingle. No outstanding concentrations of chert, like those in the older Clear Creek and Bailey Formations, are present. Except at the extreme southern end of the state, chert is never more than about 1 percent of the Grand Tower, and in many wells no chert is noted. The chert occurs in irregular nodules. Vitreous as well as dull, opaque varieties occur. Color ranges through gray, brownish gray, and brown and from very dark to light. The dense, white, opaque chert frequently seen in the underlying Clear Creek does not occur.

Phosphate Nodules and Glauconite

Glauconite is very rare. It goes unnoticed in most sample studies but is occasionally noted in insoluble residues. The Grand Tower has the least glauconite of any of the Devonian limestone formations. Phosphate is also very rare. Only a few small black phosphatic nodules have been seen, and there are no concentrations of phosphate comparable to those at the base of certain beds in the Lingle and in the Lingle correlatives in Indiana and Ohio.

Sand

By far the most characteristic and abundant noncarbonate constituent of the Grand Tower is quartz sand. Sand occurs in many parts of the formation in all concentrations, from widely scattered individual grains to beds of sandstone several feet thick. The sand has undergone many cycles of erosion and deposition. It is, therefore, mature in the petrologic sense. Only the most stable heavy mineral suite—zircon, tourmaline, ilmenite, and leucoxene—is present. Where it is not affected by secondary enlargement, the sand in the Grand Tower is exceptionally well rounded. Both roundness and sphericity are particularly high in the large and medium size grades but decrease somewhat in the fine and very fine sizes. The larger grains also tend to be heavily frosted, whereas the smaller grains are more apt to be clear. Secondary crystal growth destroys the roundness of some quartz grains, but about 90 percent of the tourmaline grains, less subject to recrystallization, are rounded (Potter and Pryor, 1961).

Where the sand is concentrated in sandstone beds, its sorting is good. Where the sand is only a minor constituent of a limestone or dolomite, its sorting is much less perfect, and bimodal distributions are quite common. Payne (1942) illustrates such bimodal sand in an insoluble residue from the Grand Tower.

Sand is irregularly distributed, both geographically and stratigraphically. It tends to increase downward and westward, but with many exceptions. For example, sand is more abundant near the top of the formation in east-central Illinois and adjacent Indiana than it is farther south or directly west. Near the close of Grand Tower deposition, more sand may have come into the Illinois Basin from the Wisconsin Arch region than from the Ozarks, which provided most of the sand lower in the Grand Tower.

Most concentrations of sand into sandstone beds more than a few inches thick are at the base of the formation in the Dutch Creek Sandstone Member. The Dutch Creek is not present everywhere, and in a few regions the basal beds of the Grand Tower are not even sandy. Moreover, the Dutch Creek is not present as a sandstone in all wells, even in those regions where it is best developed. Sand does not occur near the base of the Grand Tower in the outcrops at the western end of the Wittenberg Trough in Ste. Genevieve County, Missouri, in the subsurface in and near Jefferson County, Illinois (fig. 3), or in the outcrops and shallow subsurface sections of the Jeffersonville in its type region near Louisville, Kentucky.

The distribution of the Dutch Creek Sandstone within the dolomite region is imperfectly known. No basal sand is found in some wells. The sandstone is difficult to distinguish from the surrounding dolomite on geophysical logs, whereas its presence is at least suggested on many logs within the limestone region. Moreover, sandstone is of no economic significance where it is overlain by porous, permeable dolomite. As a result, many wells stop within the dolomite, and very few wells have been cored all the way through the dolomite into the sandstone. For these reasons, the basal sandstone was mapped only in the southern limestone facies (fig. 3).

The sand in the Grand Tower and Lingle Limestones is indistinguishable from the sand of the St. Peter Sandstone and other Ordovician and Cambrian sandstones. During the Middle Devonian these formations were exposed on the Ozark and Wisconsin Arches. Sand that was eroded from the arches was carried eastward and incorporated into the Grand Tower and other Middle Devonian formations.

The Dutch Creek Sandstone Member at any one point tends to be a very well sorted selection of the total population of available sand grains, better sorted than the scattered sand grains incorporated in beds that are mainly carbonate. Because of the general dominance of fine-grained sand, the Dutch Creek in most localities is a well sorted, fine-grained sandstone, so that the overlying carbonates contain some coarser grains, as was noted by Schwalb (1955). However, at localities both in the outcrop and the subsurface, where the energy level was higher during deposition, the coarser sand grains were selectively retained, and the Dutch Creek at these localities is medium grained or medium to coarse grained. Preliminary studies of the Dutch Creek in Illinois and of similar Middle Devonian sandstones in Ohio, Indiana, and Kentucky suggested broad, simple patterns of size distribution. However, additional data have shown that these patterns are extremely complex (Charles H. Summerson, personal communication).

Except where it has been leached on the outcrop, the Dutch Creek everywhere contains some carbonate and commonly is fossiliferous. In a few localities, a basal conglomerate consists of chert fragments from the immediately underlying formation.

The porosity of the Dutch Creek varies widely. It is low where there is much carbonate cement. In some places in the dolomite belt where the Dutch Creek is only a few inches thick, it is a single tightly cemented quartzite bed of very low porosity that fractures across rather than around the individual grains. This type of rock is not known in either of the limestone belts or in the thicker sections of Dutch Creek in the dolomite belt. In these situations, porosity reaches 15 or even 20 percent and permeability is correspondingly high.

GEOPHYSICAL CHARACTERISTICS

The geophysical logs of the Grand Tower vary greatly from region to region (figs. 4, 5, and 6). Porosity is low in the limestone facies and moderate to high in the dolomite facies, so that the geophysical properties that are closely linked to porosity—electrical resistivity, neutron response, density, sonic velocity, and drilling time—are high in the limestone regions and low in the dolomite regions. Logs of these properties, which are normally plotted on the right-hand track, tend to be off-scale in the limestone regions and on-scale in the dolomite belt. Because of its very low clay content, the Grand Tower has extremely low natural gamma radioactivity and relatively high negative electrical self-potential. Logs of these properties, which are plotted on the left-hand track, are far to the left throughout the Grand Tower, except for a notch where the Tioga Bentonite Bed is thick enough to record (fig. 6).

A rough zonation of the formation in the southern limestone phase is possible on the basis of electrical resistivity (fig. 4). Where the fossiliferous limestone phase is more than 60 or 80 feet thick, most logs show three high resistivity zones, near the top, middle, and bottom of the formation, separated by two zones of moderate resistivity. These zones do not have sharp boundaries, but blend into each other, so that the resistivity curve through the Grand Tower resembles a sine curve of 2½ cycles. This resistivity zonation extends into Indiana and Kentucky but becomes obscure as the section thins near the outcrop. However, the lowermost of the three high resistivity zones seems to drop out before the outcrop is reached. The slight increase in porosity responsible for the decreased resistivity of the intermediate zones is not evident on visual examination of either cuttings or cores. In a few wells, traces of chalky texture have been noted in these zones, but in most wells, there is no obvious differentiation.

Within the dolomite region the Geneva can be picked in a few wells because it is slightly more porous and, therefore, has slightly lower resistivity than the overlying dolomites. However, this criterion must be used with caution, and in most wells the Geneva can be picked only by visual or even insoluble residue examination of cuttings or cores.

The Cooper Limestone Member is sharply differentiated from underlying dolomites by its high resistivity (fig. 5).

The Dutch Creek Sandstone Member in the southern limestone area frequently can be differentiated from the overlying limestone by its lower resistivity. However, in most of this region, the underlying Clear Creek Limestone is partially dolomitized, and in places it is impossible on the basis of resistivity alone to tell the Dutch Creek from the Clear Creek. The sonic log in combination with a resistivity, neutron, or density log differentiates the Dutch Creek from rocks in the Clear Creek with similar porosity because the sonic velocity in quartz is appreciably lower than that in dolomite.

LITHOLOGIC DIFFERENTIATION OF THE GRAND TOWER FROM ADJACENT FORMATIONS

Whereas the Grand Tower Limestone is virtually free of clay and fine silt, the overlying Lingle Limestone is markedly argillaceous. Most of the lithologic criteria that distinguish the two units are related to the increased clay and fine silt of the Lingle. Clastic particles in the Grand Tower were inherited from the early Paleozoic terranes of the Ozark and Wisconsin Arches and consist almost exclusively of sand grains. Mud from the rising Appalachia landmass to the east did not reach Illinois until Lingle time. Thus, the Lingle clastics include both western-derived sand and Appalachia-derived mud.

The Lingle includes shale beds inches or feet thick, whereas shale streaks in the Grand Tower are no more than partings. The range of limestone types in the two formations is similar, except for the common occurrence of argillaceous varieties in the Lingle and their virtual absence in the Grand Tower.

Lingle rocks are darker than the Grand Tower, but there is some overlap in this respect. The dark brown color of the Geneva Dolomite Member of the Grand Tower is due to organic rather than clay content and is an obvious exception to the general rule. The Grand Tower is thick bedded with widely spaced stylolites up to several inches in amplitude, whereas the Lingle is thin bedded with more numerous stylolitic partings of modest proportions.

Dolomite is common in the Grand Tower but very rare in the Lingle. The purest phases of the Lingle are occasionally replaced by dolomite or dolomitic limestone, but in a broad area of central Illinois the Lingle-Grand Tower boundary can be placed with assurance at the top occurrence of dolomite.

Chert is a minor constituent in both units but is relatively more abundant in the Lingle in western Illinois and in the Grand Tower in eastern Illinois. No varieties of chert seem characteristic of either unit. Oolites occur in the Lingle at two or three levels but have not been found in the Grand Tower. Phosphatic nodules and glauconite are moderately common in the Lingle but extremely rare in the Grand Tower.

Beds of pure, lithographic limestone in the Lingle are particularly troublesome because of their resemblance to the Cooper Limestone Member at the top of the Grand Tower in central and west-central Illinois. The two lithographic phases appear identical lithologically, so that the Lingle occurrences can be identified only because distinctive Lingle rocks lie beneath or lateral to them. In central Macoupin and Montgomery Counties, near the north border of figure 3, the lithographic zones in the Grand Tower and Lingle are 20 to 40 feet apart, but this interval narrows as the entire section thins northward toward the Sangamon Arch. A similar situation in central Missouri has led some authors to apply the term Cooper to lithographic limestones within the Callaway (Lingle equivalent).

The fossils of the Grand Tower and Lingle differ specifically, but the same general types and even genera occur in both. The pteropod Tentaculites, a tiny ringed cone, is common in the Lingle and extremely rare in the Grand Tower. For practical purposes it may be used as an index to the Lingle.

On geophysical logs the differentiation of Lingle from Grand Tower varies greatly from region to region. Except for the thin Tioga Bentonite Bed, the Grand Tower includes only rocks with high negative self-potential and very low radioactivity. Because of clay content, some beds of the Lingle have lowered self-potential and increased gamma radiation. The electrical resistivity, neutron response density, sonic velocity, and drilling time are influenced primarily by porosity and, therefore, are greatly affected by dolomitization. Where the Grand Tower is largely limestone these porosity-related properties tend to be higher in the Grand Tower than in the Lingle, whereas the situation is reversed in areas in which the Grand Tower is largely dolomite. Within the southern limestone facies of the Grand Tower, recognition of three zones of high resistivity in the Grand Tower is helpful because it permits placing of the Lingle-Grand Tower boundary on the electric logs on the resistivity slope just above the uppermost of these zones (fig. 4).

Where post-Lingle rocks overlie the Grand Tower, they are so unlike the Grand Tower that their differentiation presents no problems.

In general, the sand in the lower part of the Grand Tower serves to differentiate it from the older rocks on which it lies. However, in some localities sand is rare or lacking at the base of the Grand Tower. Moreover, in some types of well records the presence of sand is not indicated and this criterion cannot be applied.

The Clear Creek Formation underlies the Grand Tower in part of central Illinois and in most of southern Illinois and adjacent parts of Indiana and Kentucky. The Clear Creek may generally be distinguished by greater abundance of chert, glauconite, and small black spheroidal fossil chitinozoans. Most beds in the Clear Creek are fairly cherty, and some are essentially solid chert. An opaque white variety characteristic of the Clear Creek has not been seen in the Grand Tower. Some of the less cherty beds in the Clear Creek are quite glauconitic. The most common chitinozoans are relatively large forms, the size of small to medium sand grains, and resemble miniature blueberries. The rare chitinozoans of the Grand Tower are unlike the common ones in the Clear Creek. Both faunas were described and illustrated by Collinson and Schwalb (1955). Doubly terminated quartz crystals of silt size are characteristic of some beds in the Clear Creek. The carbonate in the Clear Creek is generally darker than that in the Grand Tower. It is commonly dolomite or dolomitic limestone in much of the southern part of the state where the Grand Tower is entirely limestone. In that region the Clear Creek has lower electrical resistivity than the Grand Tower. On electric logs alone, the base of the limestone facies of the Grand Tower is sharp, but in places it is impossible to tell whether a few feet of the Dutch Creek Sandstone Member underlie the limestone or whether the limestone rests directly on the Clear Creek. On sonic logs the Dutch Creek is represented by slow travel times that lie beneath the fast travel times of the limestones in the Grand Tower and above the moderate travel times of the underlying Clear Creek.

The Backbone Limestone underlies the Clear Creek and should be present directly beneath the Grand Tower in a narrow belt north and west of the edge of the Clear Creek in central Illinois. However, this relation has been found in few, if any, wells. In several cross sections the Backbone appears to thin abruptly and perhaps disappear as it comes up to the pre-Grand Tower surface. The relatively pure limestone may have been leached during the development of the unconformity. The Backbone is a pure white or pink limestone that is dominantly crinoidal. In a few places a white crinoidal limestone in the Grand Tower is difficult to distinguish from crinoidal beds in the Backbone. However, the Backbone is commonly glauconitic, and pink crinoidal limestone is common in the Backbone but extremely rare in the Grand Tower.

The Bailey Limestone is much more silty, cherty, and darker colored than the Grand Tower, and it presents no difficulty in identification. Where it underlies the dolomitic facies of the Grand Tower, the Bailey generally can be distinguished by a lower self-potential than the high negative self-potential of the Grand Tower.

Many different varieties of Silurian rocks underlie the Grand Tower. Except for oil stains, shades of brown, tan, buff, and yellowish gray are practically nonexistant in Silurian rocks and practically universal in the Grand Tower. When rocks that have been called white or gray are directly compared, a yellowish tint can normally be distinguished in the Grand Tower and a greenish tint in the Silurian. Pink is also fairly common in the Silurian and extremely rare in the Grand Tower. The Silurian rocks that are strikingly glauconitic, cherty, silty, or argillaceous are readily distinguished from the Grand Tower. The chief problems arise in fine- to coarse-grained, white to gray, pure, dolomitic limestone or calcareous dolomite, particularly in the vicinity of the Sangamon Arch, where the Grand Tower is thin and may be absent in some wells, and where the Silurian rocks commonly are cut by crevices filled with Devonian sand. An unconformity representing 20 or 30 million years separates the two units, but it is difficult to place the unconformity precisely in all wells. However, only a few feet of beds of questionable age are present between rocks definitely assigned to the Devonian and to the Silurian.

PETROLEUM IN THE GRAND TOWER

The Grand Tower Limestone is quarried in Ste. Genevieve County, Missouri, and was formerly quarried at Grand Tower, Illinois. However, there has been no active quarrying in Illinois for many years, and the Grand Tower is now of economic interest primarily as an oil reservoir.

About 125 million barrels of oil have been produced from the Devonian rocks of Illinois. About 90 percent of the Devonian oil has come from the Grand Tower. The rest of the Devonian oil has come from sandstones in the Lingle and from cherty dolomitic limestone and dolomite in the upper part of the Clear Creek. Locally some oil has come from dolomite lenses in the Lingle, but Lingle carbonates are generally too argillaceous to serve as reservoirs.

The most prolific of the Grand Tower reservoirs have been in the dolomites of the central dolomite belt and particularly in the Geneva Dolomite Member. The entire Devonian section was opened in many wells in such pools as Salem, Louden, and Centralia, but it is clear that the Geneva yielded much more oil than the rest. The Devonian production in Indiana is from the Geneva and also from overlying dolomite that is assigned to the Jeffersonville but equivalent to the post-Geneva dolomites in the Grand Tower of Illinois. The Geneva has provided the most prolific wells in Illinois, as much as 12,000 barrels in initial production and half a million barrels in cumulative production. The more important pools were discovered between 1936 and 1941. Oil has been produced from the dolomites of the Grand Tower in stratigraphic traps, in normal deformational anticlines, and in domes formed by the draping of the Devonian strata over Silurian reefs.

In more recent years the Dutch Creek Sandstone Member in the southern limestone area has been of great interest. Dutch Creek production is the deepest in the Illinois Basin (below 5000 feet) and has been very prolific, although only two relatively small pools have been discovered. The first of these, in Aden Consolidated field, secs. 16 and 17, T. 3 S., R. 7 E., Wayne County, was discovered in December 1959, when Texaco No. 16 Silverman was completed in the Dutch Creek at 5325 feet for a prorated initial production of 207 barrels. The well has remained a flowing well, and at the end of 1964 had produced about 350,000 barrels of oil with no brine (fig. 7). It is prorated by the operator to a little more than 150 barrels

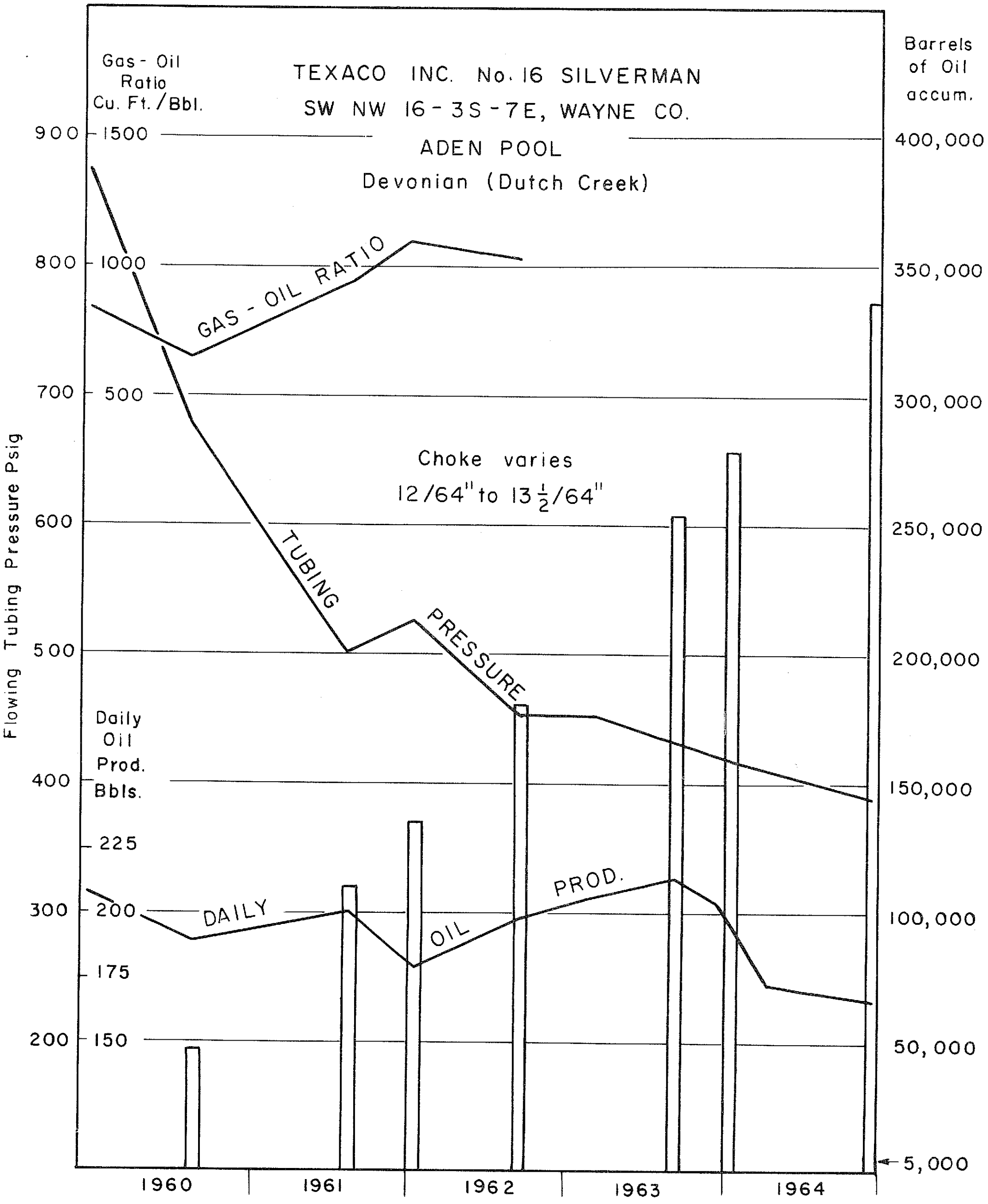


Figure 7 - Production history of Texaco Inc. No. 16 Silverman, Aden pool, the discovery well of Dutch Creek oil in the deep part of the Illinois Basin.

per day. The oil is 41.5 degrees API gravity, and the produced gas-oil ratio has averaged 900 cubic feet per barrel. The well is the most valuable in the state. A well a quarter of a mile to the north, No. 3 Silverman, was deepened to the Dutch Creek and has produced about half as much oil. It is now pumping oil with brine of 122,000 parts per million chlorinity and 209,000 parts per million total dissolved solids. A third well has produced a small amount of Devonian oil in a common completion with Mississippian pay zones.

About 12 miles to the east, Dutch Creek production has been found in secs. 28, 29, 32, and 33, T. 2 S., R. 9 E., Goldengate Consolidated field, Wayne County. The discovery well was Collins Brothers No. 1 Wood "A," in the NE$\frac{1}{4}$ NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 32, completed in August 1961. The well flowed 270 barrels of 39.4 degrees API oil from 5350 feet. Of 16 wells completed in this pool, 6 or 7 have accounted for most of the production, and these were generally completed at higher initial production, up to 840 barrels per day. None now flow. Gas-oil ratios have averaged about 1900 cubic feet per barrel. The produced brine, which ranges in chlorinity from 124,000 to 126,000 parts per million, and in total dissolved solids from 210,000 to 216,000 parts per million, is the most concentrated brine produced in the state.

The search for Dutch Creek production in the surrounding areas of Wayne, Hamilton, White, and Edwards Counties has been unsuccessful. Nearly all significant closures mapped on Mississippian horizons have been penetrated by at least one test. In about half of these the Dutch Creek has been tight, or represented by sandy limestone, but many have found permeable sandstone sections with brine. Some of the wells with brine have been on structures with much greater closures than the two structures that produced oil.

Despite the disappointing record since the discovery of the pools at Aden and Goldengate, the Dutch Creek offers the possibility for production over a considerable area. In the fault-line pools of the Wabash Valley fault complex, shows in the Dutch Creek were in sections too tight to be productive. In addition, Dutch Creek shows have been found in some wells in the extreme southern part of the state, south of the region that now produces in the Mississippian rocks. The Dutch Creek Sandstone must be considered a potential drilling target in part or all of the counties of extreme southern Illinois.

APPENDIX

WELLS USED IN CROSS SECTIONS (FIGS. 4-6)

1. Obering No. 1 Hasemeier, NW SW 10-2S-2W, Washington County
2. National Associated Petroleum No. 1 Norma R. Jack et al. Comm., SE SE 19-2S-1W, Washington County
3. Ohio Oil No. 1 Sawyer et al., SW NW 33-2S-1W, Washington County
4. Ohio Oil No. 1 Lamczyk, NE NE 23-3S-1W, Washington County
5. Magnolia Petroleum No. 9 Eubanks-Winesburgh, SE SE 35-2S-1E, Jefferson County
6. Magnolia Petroleum No. 1 Jones, NE NE 10-3S-2E, Jefferson County
7. Athene Development No. 1 Williford-Bosworth Comm., SE NE 10-3S-3E, Jefferson County
8. Sun Oil No. 1 Aydt, SE SW 1-4S-4E, Jefferson County
9. Athene Development No. 1 Scrivner, N½ S½ 27-3S-5E, Hamilton County
10. Texaco No. 1 Draper, NW SW 8-3S-6E, Wayne County
11. Texaco No. 3 Silverman, NW NW 16-3S-7E, Wayne County
12. Nation Oil No. 2 W. P. McIntosh, NE SW 31-3S-8E, White County
13. Toto Gas No. 1 E. J. Winter, NW NE 36-4S-9E, White County
14. Phillips Petroleum No. 1 Garr, NW NW 31-4S-11E, White County
15. Superior No. C-17 H. C. Ford, SW SE 27-4S-14W, White County
16. Indiana Farm Bureau No. 1 Rowe, SE NE 36-5S-13W, Posey County, Indiana
17. Carter No. 13 Culver heirs, SW SW 24-P-21, Union County, Kentucky
18. Joe Simpkins No. 1 Pointer, NW SW 18-8N-8W, Macoupin County
19. Glen Bryant No. 1 Menke, NE SW 12-7N-7W, Macoupin County
20. Stewart Producer's No. 1 Griffith, SW SW 34-7N-5W, Montgomery County
21. Stewart Producer's No. A-1 Donk Bros. Coal, NE NW 33-6N-4W, Bond County
22. W. L. Belden No. 1 John Anthony, NE NW 28-6N-2W, Bond County
23. Thomas Doran No. 1 Baumann-Weaver, SE NW 2-5N-1W, Fayette County
24. Kewanee Oil No. 1 Gehle, SE NE 13-5N-2E, Fayette County
25. National Associated Petroleum No. 5 Ed Lacey et al., NW NE 21-4N-4E, Marion County
26. Texaco No. 7 Allen "A," NE NE 36-3N-5E, Clay County
27. Texaco No. 1 Greathouse, SE NW 27-1N-6E, Wayne County
28. Texaco No. 5 H. O. Fuhrer NCT-1, SW SE 28-1S-6E, Wayne County
29. Peake Petroleum No. 1 Feathers, SE NW 14-2S-6E, Wayne County
30. Humble No. 33 Busiek-Crawford, SE NE 11-8S-10E, Gallatin County
31. Superior No. 1 P. Braselton Comm., SW SE 24-2S-12W, Gibson County, Indiana
32. E. Paul DuPont, Jr. No. 1 Schafer, NW NE 31-2N-11W, Wabash County
33. Bell Brothers No. 1 Wampler, SE NE 27-5N-11W, Lawrence County

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