The Origin of Prolific Reservoirs in the Geneva Dolomite (Middle Devonian), West-Central Illinois Basin

Beverly Seyler, John P. Grube, and Zakaria Lasemi

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Cover photo: Tank battery and flare for the Deep Rock Energy Corporation Warren No.1-SDU well in Marion County, Illinois (photo by David G. Morse).

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Abstract

The Geneva Dolomite, commonly the basal member of the Middle Devonian Grand Tower Limestone in much of the Illinois Basin, is an exploration target that has recently generated much interest. A new discovery in the Geneva was completed for up to 3,000 barrels of oil per day at a depth of 4,000 feet in the west-central part of the Illinois Basin. A study of reservoirs in the Geneva Dolomite at the Raccoon Lake, Sandoval, Patoka, Miletus, and St. James oil fields shows that pronounced structural closure, fracturing, and formation of secondary porosity through dolomitization and dissolution are associated with reservoir development and entrapment of petroleum.

The draping of younger Middle Devonian strata over Silurian reefs has resulted in approximately 100 feet of closure at Sandoval and Raccoon Lake Fields. Patoka Field, which overlies a larger, deeper seated structure, also produces from the Ordovician Trenton Limestone. The St. James Field is an anticline that initially produced from shallower Mississippian strata prior to the discovery of Devonian reservoirs. Examination of core from Geneva Dolomite reservoirs shows the rock to be a brown, vuggy, and sucrosic dolomite. We suggest that post-depositional dolomitization combined with dissolution of fossil material of Geneva carbonates is a viable mechanism to explain the enhanced porosity, permeability, and brecciation found in Geneva Dolomite reservoirs. Mapping suggests that Devonian age structures, commonly associated with underlying Silurian reefs, are an element that enhances reservoir porosity, and more recent structural movement has created the pronounced closure needed for petroleum entrapment.

Three-dimensional (3-D) seismic technology was used at Tonti Field to accurately delineate the subtleties of reef structures in the field, establishing the presence of multiple Geneva high areas that likely mimic an undulatory surface of the underlying Silurian pinnacle reef. Details of the topography of a pinnacle reef show clustered high areas that are key to exploration and development of Geneva Dolomite reservoirs. Implementation of existing 3-D seismic technology should significantly improve the drilling success rate of these reservoirs. This study shows the successful application of newer, yet readily available, technologies to re-examine old fields and trends to discover and develop economically significant quantities of oil in the mature Illinois Basin.

Introduction and Purpose

Prolific reservoirs are associated with the Geneva Dolomite in the Illinois Basin. In March 2002, a new field discovery was completed immediately south of the Miletus Field in Marion County, Illinois, flowing oil at a rate of up to 3,000 barrels a day from a horizontal well bore. This prolific discovery in the Geneva Dolomite follows several earlier discoveries in the late 1990s that sparked the drilling of an assortment of exploratory wells in the region. The earlier wells were vertical tests and produced in excess of 300 barrels of oil per day. Production from these wells shows a low rate of decline. The recent horizontal discovery and offset horizontal development wells extend under the Stephen A. Forbes State Park (fig. 1). Three-dimensional (3-D) seismic technology was employed to establish the prospect. Further, the combined application of 3-D seismic and horizontal drilling technologies in the Illinois Basin should enhance the exploration and development opportunities in the Middle Devonian Geneva Dolomite as well as structural and stratigraphic prospects in other formations. These technologies have been implemented in other mature producing provinces but had not been proved and refined for application in the Illinois Basin until recently.

This study was undertaken to provide information on the geologic factors controlling the origin of highly prolific petroleum reservoirs in the Geneva Dolomite. Geologic factors include structural, stratigraphic, diagenetic, and sedimentologic relationships. The Geneva Dolomite is widely exposed in quarries located near the Geneva outcrop belt in Indiana (Perkins 1963, Leonard 1996). The description of the Geneva Dolomite in these quarries and examination of continuous core from two recently drilled Geneva wells and core biscuits from wells in several neighboring Geneva reservoirs aided in (1) the interpretation of facies, (2) the determination of stratigraphic relationships within the Grand Tower and Jeffersonville Limestones (fig. 4), and (3) the interpretation of diagenetic alterations that occurred to create the highly porous and permeable sucrosic dolomite of the Geneva. Included is a discussion of Geneva Dolomite reservoirs from several neighboring fields that have similarities to the newly discovered reservoir underlying Stephen A. Forbes State Park (fig. 2). These older fields were also highly productive, and a review of the data from these fields may assist in the future exploration and development of Geneva Dolomite reservoirs. Currently accepted theories that explain the dolomitization process on a regional scale are also discussed.

Geologic Setting

Stratigraphy and Facies Relationships

The stratigraphic column in figure 3 shows the major unconformities found in the predominantly Paleozoic bedrock strata of the Illinois Basin. The sub-Kaskaskia unconformity separates Upper Silurian through Lower Devonian strata from Middle Devonian strata in Illinois (Buschbach and Kolata 1991). The Geneva Dolomite and Dutch Creek Sandstone are the basal members of the Grand Tower Limestone (fig. 4); (Meents and Swann 1965, North 1969) and were deposited on the eroded, exposed surface of the Upper Silurian (Devera and Fraun-

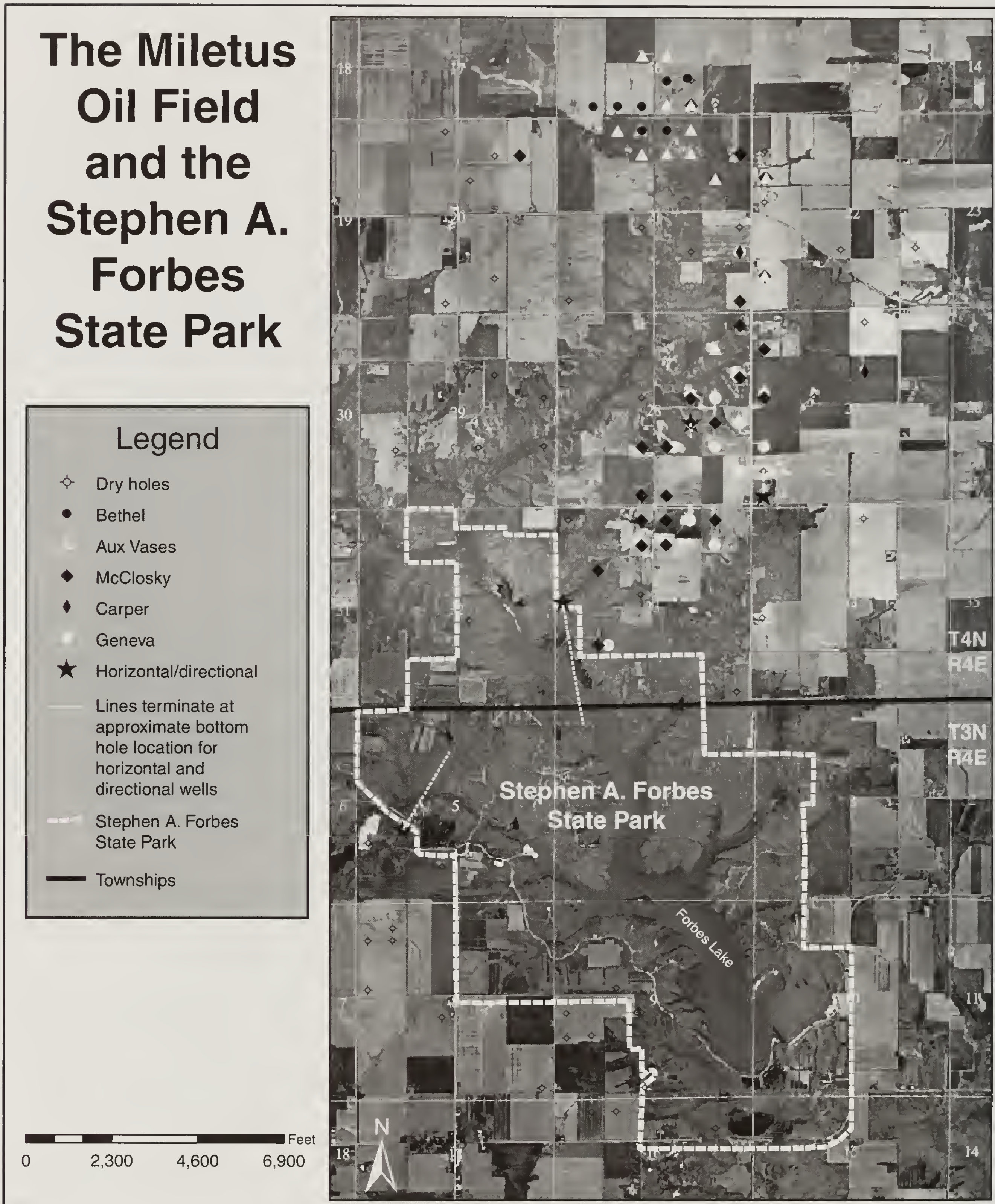


Figure 1 The Miletus Oil Field and the Stephen A. Forbes State Park.

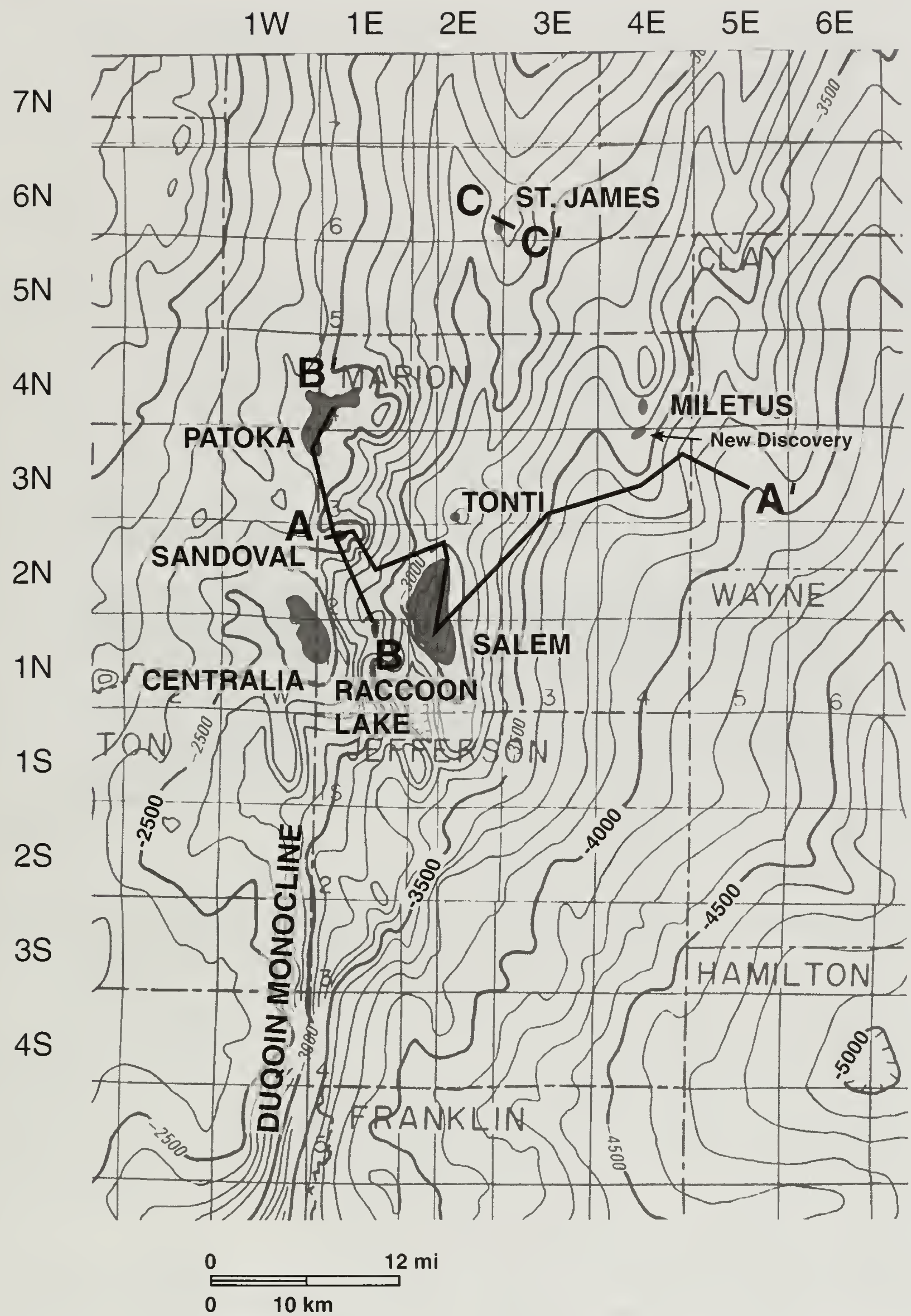


Figure 2 Structure map contoured on the base of the New Albany Shale. Contour interval is 100 feet. Cross section locations and Geneva Dolomite reservoirs are shaded in gray. (Modified from Cluff et al. 1981.)

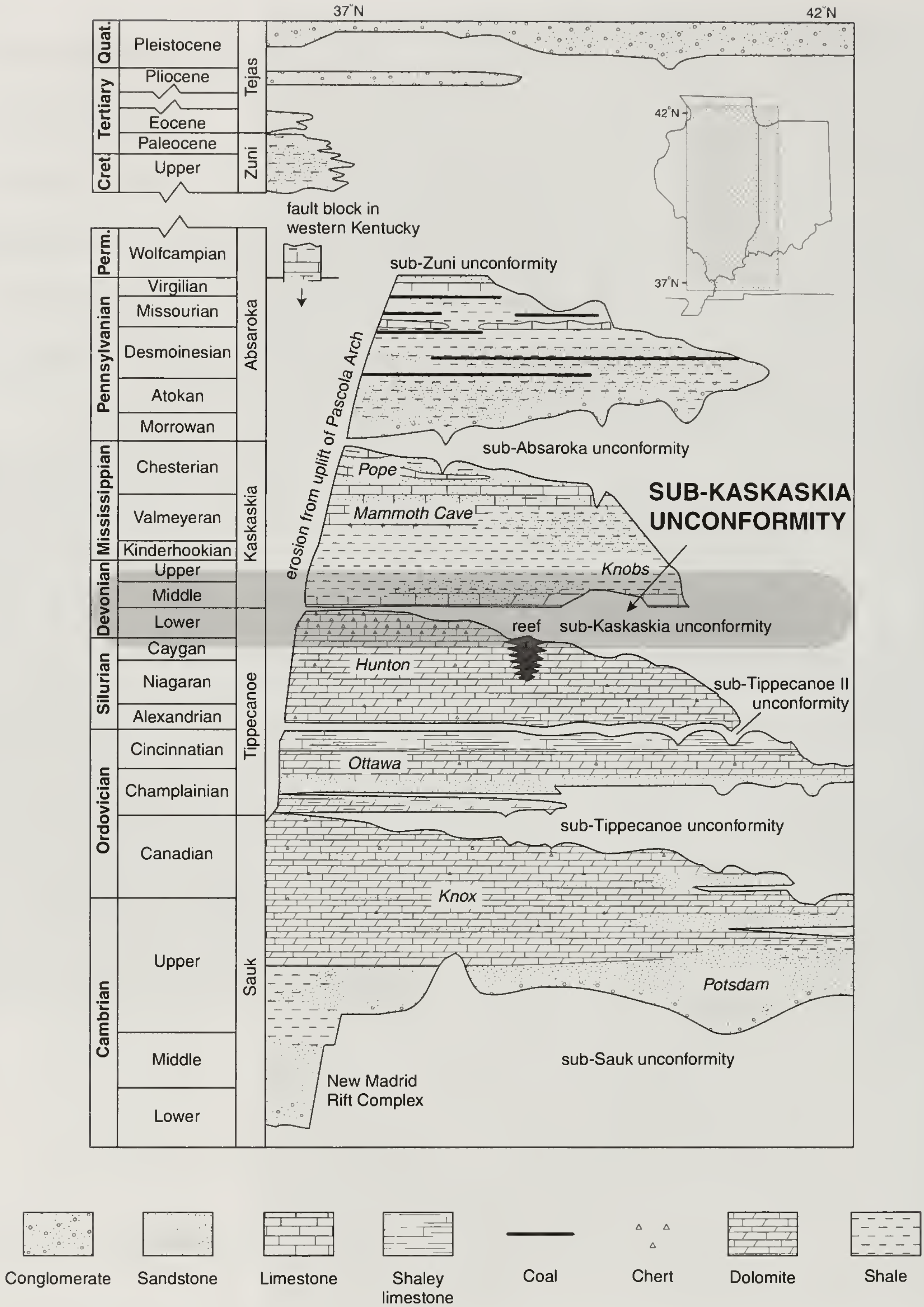


Figure 3 Stratigraphic column showing major unconformities in Paleozoic rocks. The sub-Kaskaskia unconformity separates Upper Silurian through Lower Devonian strata from Middle Devonian strata in Illinois. Quat., Quaternary; Cret., Cretaceous; Perm., Permian. (From Buschbach and Kolata 1991.)

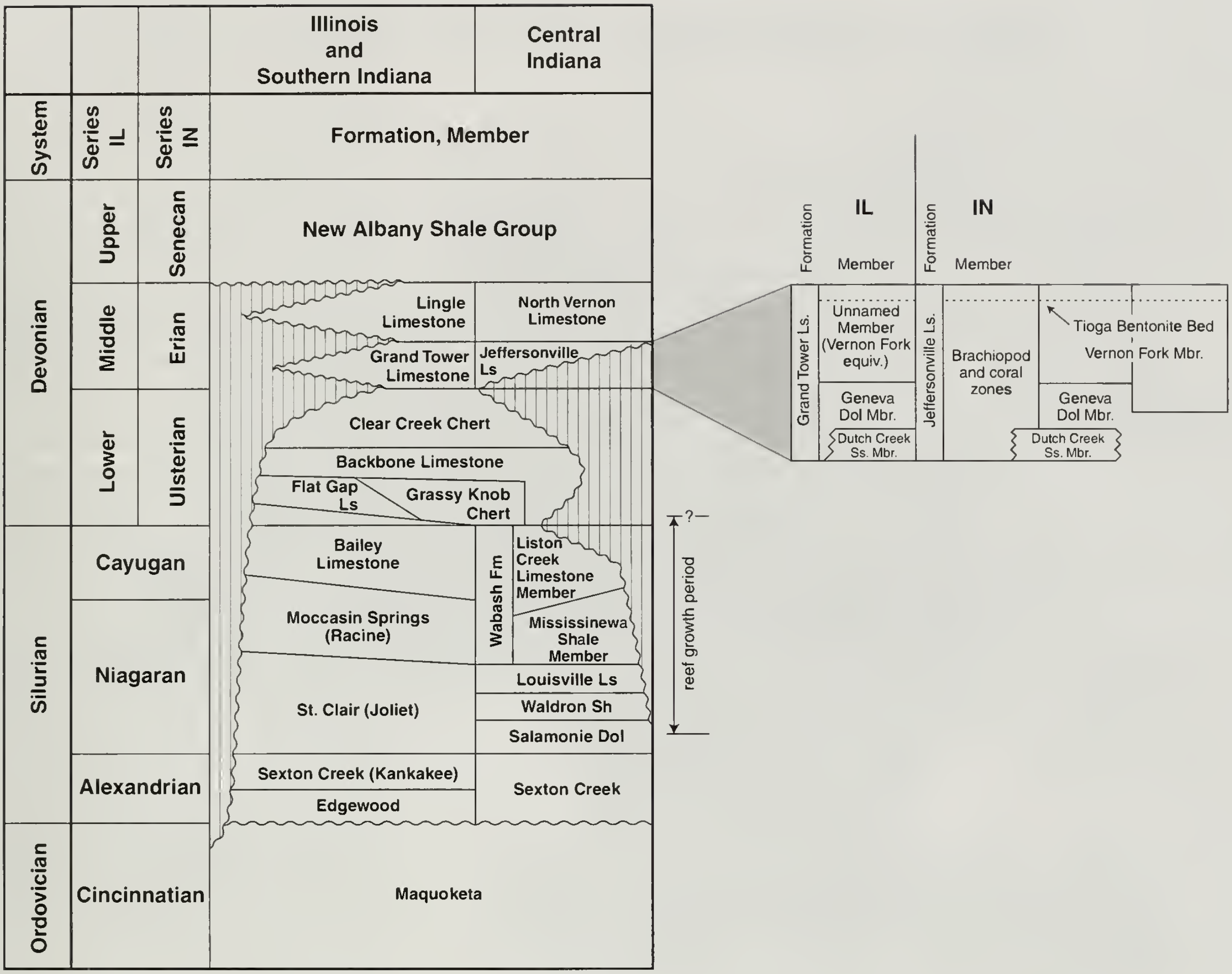


Figure 4. Correlation and nomenclature of the Devonian and Silurian sections of the stratigraphic column in Illinois and Indiana. (Modified from Droste and Shaver 1987, Droste et al. 1975.)

felter 1988, Devera and Hasenmueller 1991) through Lower Devonian strata in Illinois (fig. 5). Figure 6 shows the relationship of the Middle Devonian Geneva Dolomite Member of the Grand Tower Limestone with underlying strata in Marion County, Illinois, the site of the new Geneva discovery.

The Geneva Dolomite has been considered to be a facies of the Grand Tower Limestone in Illinois and the Jeffersonville Limestone in Indiana (Meents and Swann 1965, Droste and Shaver 1975). Thin Dutch Creek Sandstone locally underlies the Geneva Dolomite in the study area, and sandy dolomite intervals are common in the Geneva Dolomite. A facies map showing distribution of the Geneva Dolomite and Dutch Creek Sandstone Members of the Grand Tower Limestone is shown in figure 7 (Meents and Swann 1965). Prolific wells also have been completed in the Dutch Creek Sandstone, a highly porous and permeable dolomitic sandstone (Meents and Swann 1965).

Both the Grand Tower and Jeffersonville consist of a pure, fossiliferous southern limestone facies (commonly biostromal and/or biohermal) and a northern dolomite facies (Schwalb 1955, Meents and Swann 1965, Droste and Shaver 1975, Devera and Fraunfelter 1988). The limestone facies primarily occurs in the southern portion of the Basin, including its extension into west-central Indiana, and the dolomite facies primarily occurs in the central to northern portion of the Basin (Meents and Swann 1965, North 1969). The dark brown, sandy dolomite of the Geneva occurs at the base of the dolomite facies of the Grand Tower and Jeffersonville Limestones.

The Geneva Dolomite is buff to dark brown but oxidizes into pale tan, cream, and even white in near-surface exposures (Droste and Shaver 1975). The distinctive brown

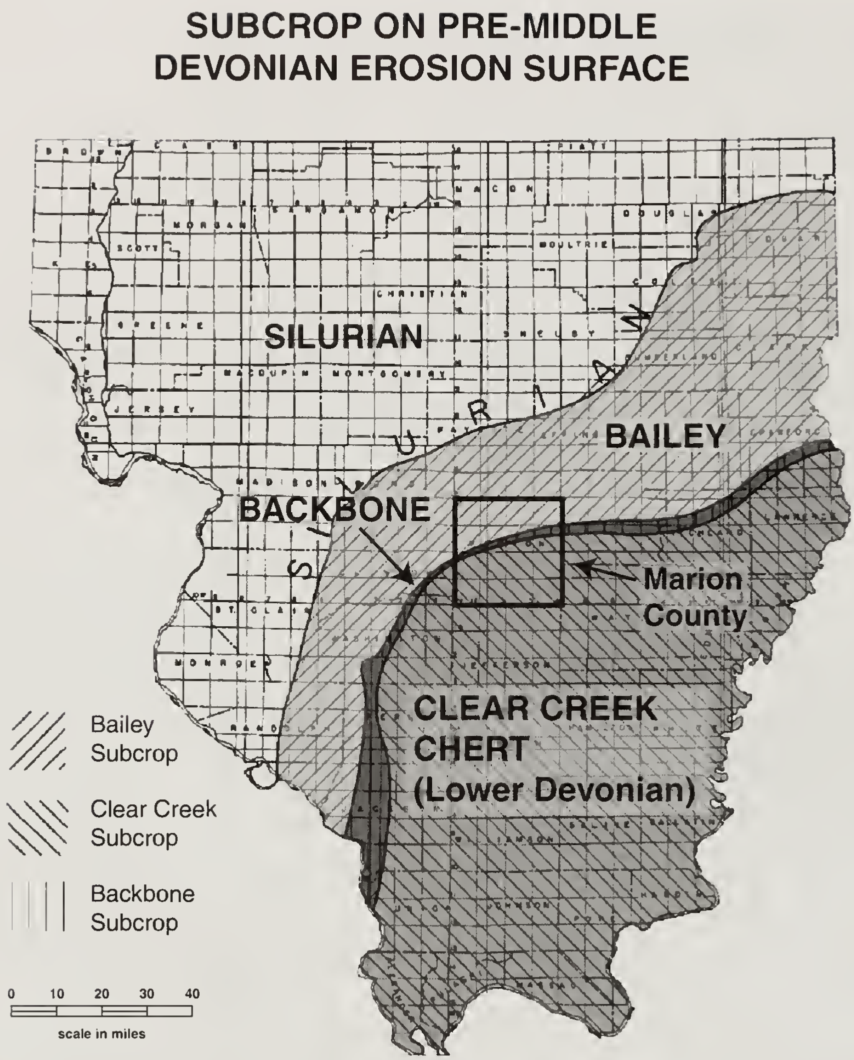
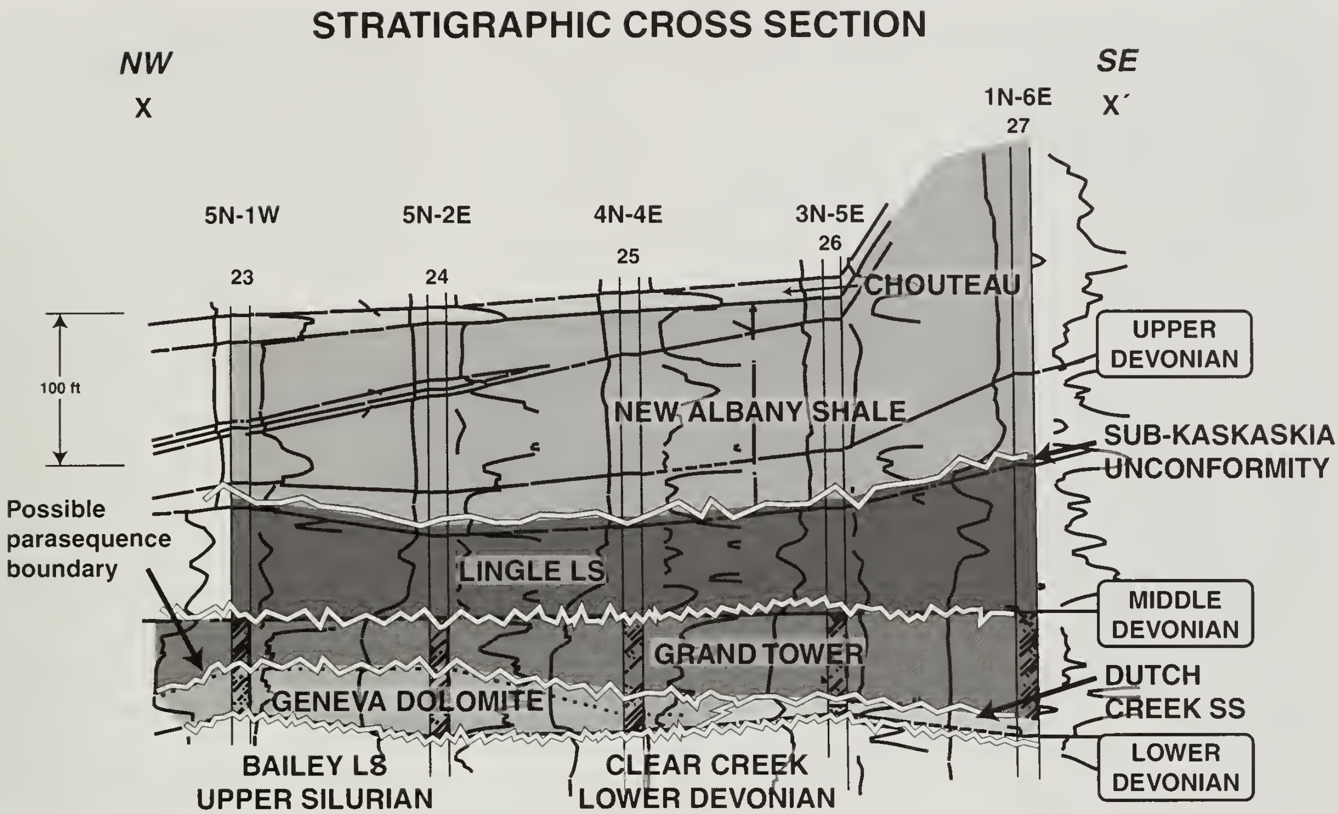


Figure 5 The Middle Devonian Geneva Dolomite Member of the Grand Tower Limestone unconformably overlies Lower Devonian to Middle Silurian strata increasing in age from south to north in Illinois. The underlying strata in much of the study area is the Lower Devonian Clear Creek Chert. (Modified from North 1965.)

color has been attributed to organic material disseminated within the rock (Schwalb 1955). When samples are dissolved in hydrochloric acid, this organic material floats to the surface. In most places, the color darkens toward the base, although in some areas the reverse is true (Schwalb 1955). Quartz sand grains "floating" in the carbonate are present throughout the Geneva but are especially common near the base. The dolomite is massive to thin bedded and granular and vuggy for the most part. In contrast to an earlier interpretation that the Geneva is essentially nonfossiliferous (Collinson 1967), the Geneva has a bioclastic and pelletoidal texture (packstone to grainstone) with common molds and casts of branching and solitary corals, stromatoporoids, and some brachiopods, bivalves, gastropods, and ostracodes (Droste and Shaver 1975). The Geneva appears to have been deposited as skeletal shoals or banks, particularly on preexisting topographic highs created by the underlying Silurian reefs (Droste and Shaver 1975).

Subsurface distribution of the Geneva Dolomite forms an arcuate belt that curves northwest from the outcrop to west-central Indiana and bends to the southwest from Clark and Edgar Counties in Illinois and extends as far as Montgomery, Bond, and Clinton Counties (fig. 8). The Geneva ranges from 0 to 50 feet thick in central Illinois but locally is thicker in some areas (Schwalb 1955). Studies of well cuttings from recently drilled wells show that the Geneva locally may be up to 90 feet thick. In central and west-central Indiana, the Geneva forms a semicircular body ranging in thickness from 0 to 60 feet. The distribution of the Geneva was attributed by Perkins (1963) to pre-Jeffersonville erosion (Geneva erosion). However, no sedimentologic or petrographic evidence was given. Droste and Shaver (1975) suggested that the Geneva distribution pattern was most likely related to the underlying Silurian reefs rather than to post-Geneva erosion. In Indiana, the thickest Geneva Dolomite apparently correlates with the thickened part of the underlying Silurian reef system and the narrow area of Jeffersonville thinning.

The relationship between the Geneva and the Grand Tower or Jeffersonville has been controversial because of the poor preservation of fossil constituents and correlation problems. A few earlier studies have suggested that the Geneva Dolomite is older than the Jeffersonville in Indiana and its lateral equivalent Grand Tower in Illinois (Patton and Dawson 1955, Perkins 1963). Conversely, floating quartz sand grains, invertebrate fossils, and diagnostic chitinozoans of the Geneva are also common in the southern bioclastic facies of the Grand Tower (Warthin and Cooper 1944, Devera and Fraunfelter 1988). The Geneva Dolomite is now generally considered to be a member of the Grand Tower Limestone in Illinois (Meents and Swann 1965, p. 7; Devera and Frauntfelter 1988) and the Jeffersonville Limestone in Indiana (Becker 1974, Droste and Shaver 1975, Leonard 1996). According to Meents and Swann (1965), the Geneva Dolomite



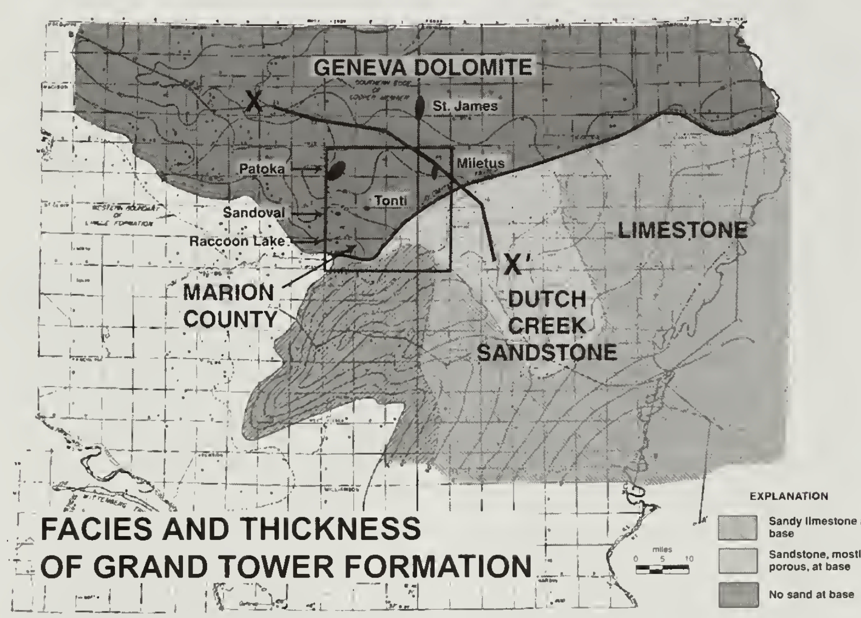


Figure 6 (above) Cross section X–X′ in Marion County, Illinois. Silurian through Devonian strata show the sub-Kaskaskia unconformity separating Upper Silurian and Lower Devonian strata from Middle Devonian strata. Truncation of Upper Silurian through Lower Devonian strata formed an eroded surface on which the Middle Devonian Geneva Dolomite and Dutch Creek Sandstone were deposited. The contact between the Geneva Dolomite and overlying carbonates in the Grand Tower Limestone may define a parasequence (at arrow) boundary. (Modified from Meents and Swann 1965.)

Figure 7 (right) Facies map showing the distribution of the Geneva Dolomite and Dutch Creek Sandstone Members of the Grand Tower Limestone. Both members are at the base of the Grand Tower. Thicknesses shown are of the Grand Tower Limestone. (Modified from Meents and Swann 1965.)

in the Illinois subsurface is a facies that grades laterally into the lower part of the Grand Tower Limestone in southern Illinois. Droste and Shaver (1975) reached the same conclusion regarding the relationship between the Geneva and the Jeffersonville in Indiana.

The Geneva conformably overlies the Dutch Creek Sandstone where it is present at the base of the Grand Tower. However, in many places, the Geneva unconformably overlies Lower Devonian to Middle Silurian strata that increase in age from south to north in Illinois (Meents and Swann 1965) (figs. 4 to 6). The stratum underlying the Middle Devonian Grand Tower Limestone in the southern part of Marion County is the Lower Devonian Clear Creek Chert (figs. 5 and 6). In the northern part of Marion County, the Upper Silurian-Lower Devonian Bailey Limestone (fig. 5) directly underlies the Grand Tower Limestone.

The Geneva Member is overlain by a somewhat thicker section of lighter-colored dolomite. The dolomite above the Geneva has been referred to as the "laminated beds," "laminated zone," "chalk beds," or "fine-grained dolomite of the Jeffersonville" in Indiana (see Droste and Shaver 1975) and the "unnamed," "light-colored dolomite above the Geneva," or "the northward facies of the Grand Tower" in Illinois (Schwalb 1955, Meents and Swann 1965, Collinson 1967, North 1969). Droste and Shaver (1975) named the unit above the Geneva Dolomite the Vernon Fork Member for the central and west-central Indiana Jeffersonville facies. Subsurface data suggest that the Geneva interfingers with the Vernon Fork dolomite in Indiana (Droste and Shaver 1975) and its equivalent unit in Illinois (Schwalb 1955, Meents and Swann 1965). The Geneva is correlated with the lower part of the Middle Devonian Vernon Fork and, therefore, with the lower part of the Grand Tower Limestone of southern Illinois (Schwalb 1955, Meents and Swann 1965, North 1969, Devera and Fraunfelter 1988).

Petrographic details for the Vernon Fork Member (Droste and Shaver 1975) have been presented by Perkins (1963) and for the Vernon Fork equivalent in Illinois by Lasemi (2001). The Vernon Fork ranges from 0 to 80 feet thick in Indiana, but its equivalent in central Illinois can reach up to 105 feet thick. The Vernon Fork extends farther north and south than does the Geneva Dolomite. In west-central Indiana, the Vernon Fork Member is primarily a microcrystalline dolomite, but it contains laminated lithographic to sublithographic limestone and dolomitic limestone in the eastern outcrop belt. The Vernon Fork is slightly fossiliferous and contains sporadic sand grains, birds-eye structures, brecciated laminae, and mud cracks. No gypsum or anhydrite has been found, but possible calcite pseudomorphs after gypsum are present (Perkins 1963).

The petrography of the Vernon Fork Member equivalent in east-central Illinois has only recently been documented in cores and from a quarry exposure in Douglas County, Illinois (Lasemi 2001). Here, the unit is up to 105 feet thick and consists of a light yellowish gray to yellowish tan microcrystalline dolomite. It is slightly to moderately sandy throughout, and several dolomitic sandstone lenses are present in the lower part. Fenestral fabric is common, and mud cracks have been observed in both quarry exposures and cores. The upper part of the unit contains well-developed stromatolitic laminations formed by the trapping of sediments by blue-green algae. Some of the stromatolites form mound-shaped structures approximately 10 feet high. The Tioga Bentonite Bed generally occurs about 20 to 30 feet below the top (Lasemi 2001).

The environment changed gradually from normal marine conditions during the Geneva deposition to shallow, restricted marine conditions during Vernon Fork deposition (Perkins 1963, Lasemi 2001). Abundant and diverse fossil allochems in the Geneva suggest deposition within a normal marine environment. The overlying Vernon Fork Member and its equivalent in Illinois, however, appear to have been deposited in shelf lagoon and tidal flat environments that were periodically subjected to subaerial exposure, as indicated by the presence of mud cracks (Perkins 1963, Lasemi 2001). In such restricted shallow-water settings, evaporation of seawater could have formed the Mg-rich solutions that may have been responsible for formation of the dolomites in the Grand Tower and Jeffersonville Limestones (Droste and Shaver 1975, Lasemi 2001). The boundary between the normal marine Geneva Dolomite and the overlying restricted marine Vernon Fork Member marks a transgressive-regressive sequence. However, biostratigraphically, there is no significant time break along this boundary (Norby 1991; Norby, personal communication 2002), and there has been no unequivocal evidence thus far indicating major subaerial erosion.

The sub-Kaskaskia unconformity separating the Upper Silurian and Lower Devonian strata from the Middle Devonian strata is shown in the cross section in figure 6. Truncation of the Upper Silurian through Lower Devonian strata formed an eroded surface on which the Middle Devonian Geneva Dolomite and Dutch Creek Sandstone Members of the Grand Tower Formation were deposited (fig. 5) (Devera and Fraunfelter 1988, Devera and Hasenmueller 1991).

Structure

The Upper Devonian New Albany Shale (fig. 4) is a widespread and consistent formation that is useful for structural mapping in the Illinois Basin. A structure map contoured on the base of the New Albany Shale reflects structural relationships of the Geneva Dolomite (fig. 2). Pronounced structural closure, as great as 100 feet, is associated with Geneva Dolomite production. Much of this structure is tectonic, but in some cases the closure is caused or enhanced by the drape of younger Middle Devonian strata over Silurian reefs (Bristol 1974). Some of the most prolific

Geneva wells are associated with the postulated underlying Silurian reefs. This postulate is related to enhanced structural closure in the strata overlying the reef, a function of differential compaction. Fractures within the Geneva beds may have resulted from differential compaction. Reef-induced paleostructure (Droste and Shaver 1975) may have influenced Geneva deposition by offering sites suitable for growth of bioherms and the ensuing diagenetic alteration of these carbonates, resulting in improved reservoir porosity and permeability. Structure caused by differential compaction of the fine-grained sediments flanking the rigid core of a Silurian reef has been documented throughout the entire overlying stratigraphic section and can even be detected in structural highs in the overlying Pennsylvanian coals (e. g., Whitaker 1988). Many of these reefs also have topographic expression at the surface that may be located by present-day drainage patterns (Whitaker 1988).

Geneva Dolomite production is also associated with structures induced by tectonism. Production from anticlinal closure at the St. James, Salem, and Centralia Fields indicates that pronounced structural closure from tectonic deformation is sufficient to trap petroleum in the Geneva Dolomite. However, the most prolific production is from highly porous and permeable Geneva Dolomite draped over pinnacle reefs. A number of uplifted fault blocks in the Basin have coincidental reef structures, indicating that Silurian reefs may have preferentially developed atop pre-existing structural highs (Davis 1991).

The close vertical proximity of the New Albany Shale to the Geneva Dolomite is significant because the black shales in the New Albany are considered to be the primary source rock for petroleum in the Illinois Basin (Barrows and Cluff 1984). Black shales in the New Albany reach their greatest maturity in the deepest portion of the basin (Barrows and Cluff 1984). The hydrocarbon charge for the Geneva reservoirs is therefore likely to have migrated from the black shales in the New Albany, located in deeper portions of the Illinois Basin, into the updip, although stratigraphically lower, Geneva Dolomite. Some of the petroleum migration now associated with Geneva Dolomite reservoirs in Marion County likely occurred along the DuQuoin Monocline (fig. 2).

Figure 8 Distribution of the Geneva Dolomite in Illinois and Indiana. The Geneva reaches a maximum thickness of about 90 feet in east-central Illinois; thins to zero in southern Marion County, Illinois; and outcrops in a series of quarries (numbered 1 through 5) in southeastern Indiana, where it is 20 to 30 feet thick. (Modified from Perkins 1963, Schwalb 1955.)

Geneva Dolomite Quarries and Outcrops

A series of quarries was examined in the Geneva outcrop belt in east-central Indiana that extends for 70 miles in a north-south direction (fig. 8). The Geneva is 20 to 30 feet thick here and is quarried for construction aggregate. The fossil content, crystal size, zonation of dolomite crystals, color, staining, porosity, and permeability of the Geneva observed in quarries in Indiana are all similar to the prolific reservoirs in Illinois. The Geneva Dolomite shows widespread porosity in both cores and quarries. Geophysical logs from Indiana and Illinois show that porous zones in the Geneva are widespread throughout the subsurface. The distribution of similar facies and porous zones from central Indiana to south-central Illinois suggests possible connectivity across the entire region. The outcrop region of Indiana may serve as a recharge area for the active water drive that is characteristic of the Geneva Dolomite reservoirs throughout the Geneva fairway.

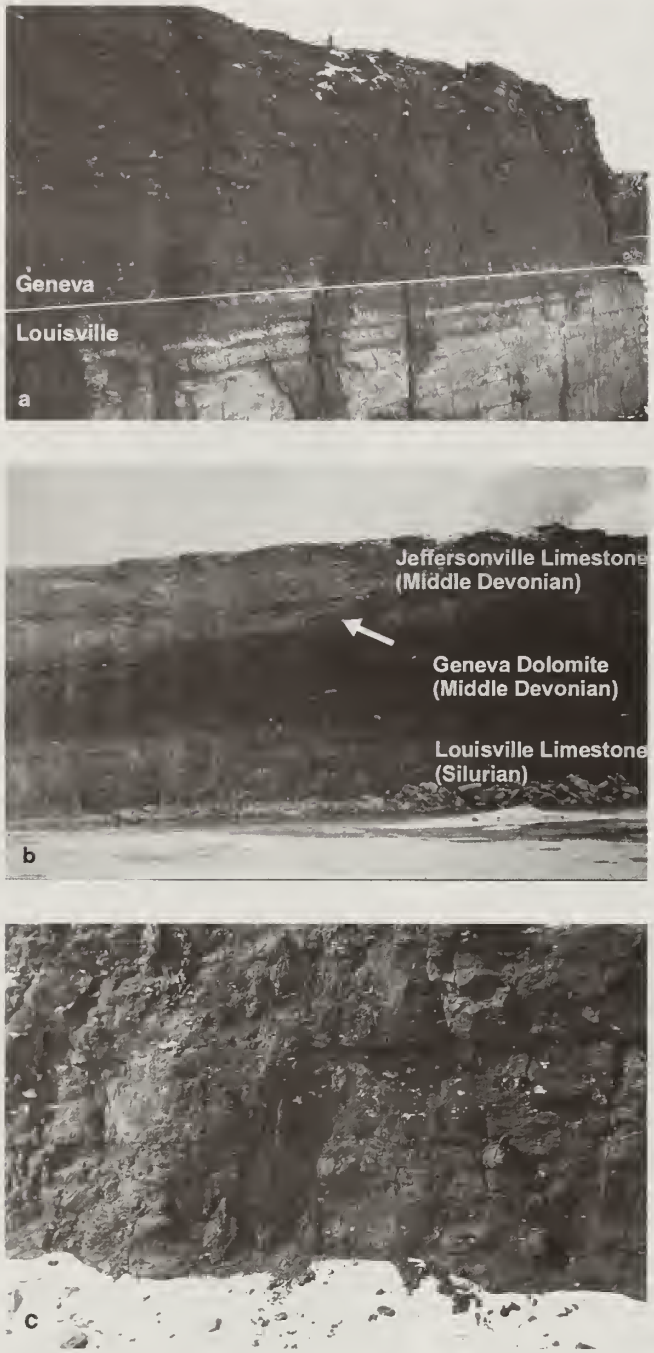


Figure 9 (a) Meshberger Quarry near Elizabethtown, Indiana (number 2, fig. 8), showing the Geneva Dolomite and the unconformable lower contact with the Silurian Louisville Formation limestone. (b) Brown Geneva Dolomite unconformably overlies the gray Louisville Formation limestone. The undulating upper contact (arrow) with the Jeffersonville Limestone (Middle Devonian) may be a parasequence boundary. (c) Vugs filled with late-stage dogtooth spar calcite (white mineral) in the Geneva Dolomite from the Meshberger Quarry. Vugs were likely created by dissolution of large coral heads or stromatoporoids.

Figure 10 (a) North Vernon Quarry near North Vernon, Indiana (number 4, fig. 8). Highly porous, sucrosic Geneva Dolomite is over 20 feet thick and is overlain by the Jeffersonville Limestone. (b) Row (at arrow) of large, empty vugs in the Geneva Dolomite. The highly porous dolomite contains many vugs created by dissolution of marine fossils, including colonial corals and stromatoporoids. (c) Close-up of vug showing detail of smaller branching corals and other marine fossils.

Figure 11 The biostromal facies of the Jeffersonville Limestone are shown on these slabbed rock samples, which were collected from the Scott Quarry near Jeffersonville, Indiana. The Jeffersonville Limestone, considered to be equivalent to the Geneva Dolomite, has not been altered by dolomitization and dissolution.

Meshberger Quarry

Meshberger Quarry (number 2, fig. 8) is located near Elizabethtown, Indiana. The Geneva Dolomite unconformably overlies the Silurian Louisville Formation limestone (fig. 9). The Louisville is a gray, tightly cemented grainstone, and the overlying Middle Devonian Geneva Dolomite is a brown, sucrosic, porous dolomite (fig. 9). Although there is an abrupt and distinctive change between the rock units above and below the sub-Kaskaskia unconformity exposed here, there is no evidence of scouring or other erosion at the contact.

Figure 9b shows the undulating upper contact of the Geneva with the overlying Middle Devonian age Vernon Fork Member of the Jeffersonville Limestone at the Meshberger Quarry. The upper contact of the Geneva is likely a parasequence boundary (Leonard 1996). In the Meshberger Quarry, many vugs in the Geneva Dolomite were filled with white, late-stage dogtooth spar calcite cement, and the matrix surrounding the vugs consists of porous brown, sucrosic dolomite (fig. 9c). The shape and size of some large vugs suggest that they were probably created by dissolution of large coral heads or stromatoporoids.

North Vernon Quarry

The North Vernon Quarry is located near North Vernon, Indiana (number 4 in fig. 8). The highly porous, sucrosic Geneva Dolomite Member is over 20 feet thick and is overlain by the Vernon Fork Member of the Jeffersonville Limestone (fig. 10). The late-stage mineralization by white, sparry, calcite, filling vugs that is prevalent in the Meshberger and other quarries is not common in this quarry. Most Geneva vugs in the North Vernon Quarry are not affected by the late-stage calcite mineralization and remain open. Although dolomitization has obscured the direct fossil evidence, remnants of large coral heads and stromatoporoids are common in this quarry, suggesting potential biohermal or biostromal buildups. An example of one such buildup is shown in figure 10b where a row of empty vugs created by the dissolution of large (40 cm × 25 cm) coral heads and stromatoporoids can be seen. Partially dissolved smaller colonial corals and other marine fossils also were observed in the quarry walls. The matrix surrounding the vugs is composed of highly porous, brown sucrosic dolomite (fig. 10c). Dissolution of the larger coral heads is more complete than that of the smaller branching corals and other marine fossils found in the matrix. The Geneva Dolomite in the North Vernon Quarry very closely resembles the Geneva Dolomite in cores from reservoirs in Marion County, Illinois.

Scott Quarry, Southern Indiana

The Scott Quarry is the southernmost exposure studied (number 5 in fig. 8). The Geneva Dolomite equivalent strata in this quarry are richer in fossils than those in the other quarries (fig. 11), and large unaltered coral heads, stromatoporoids, and other fossils are very abundant. The matrix surrounding the intact fossils is a brown, slightly dolomitic limestone (fig. 11). The Geneva Dolomite equivalent in this quarry is 15 feet thick and lacks the visible porosity that is present in the quarries to the north. This strata most closely resembles the Geneva Dolomite observed in core samples

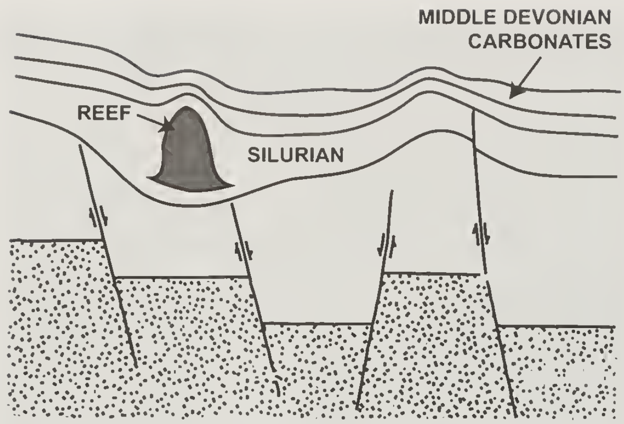


Figure 12 Trapping mechanisms for the Geneva Dolomite reservoirs including drape over Silurian reefs and closure over deep-seated structures. Reefs preferentially grew on structural highs. Reactivation along regional faults likely created structural highs prior to accumulation of Middle Devonian carbonates. Thinning of Middle Devonian units occurs over Silurian reefs and major structures. (Modified from Davis 1991.)

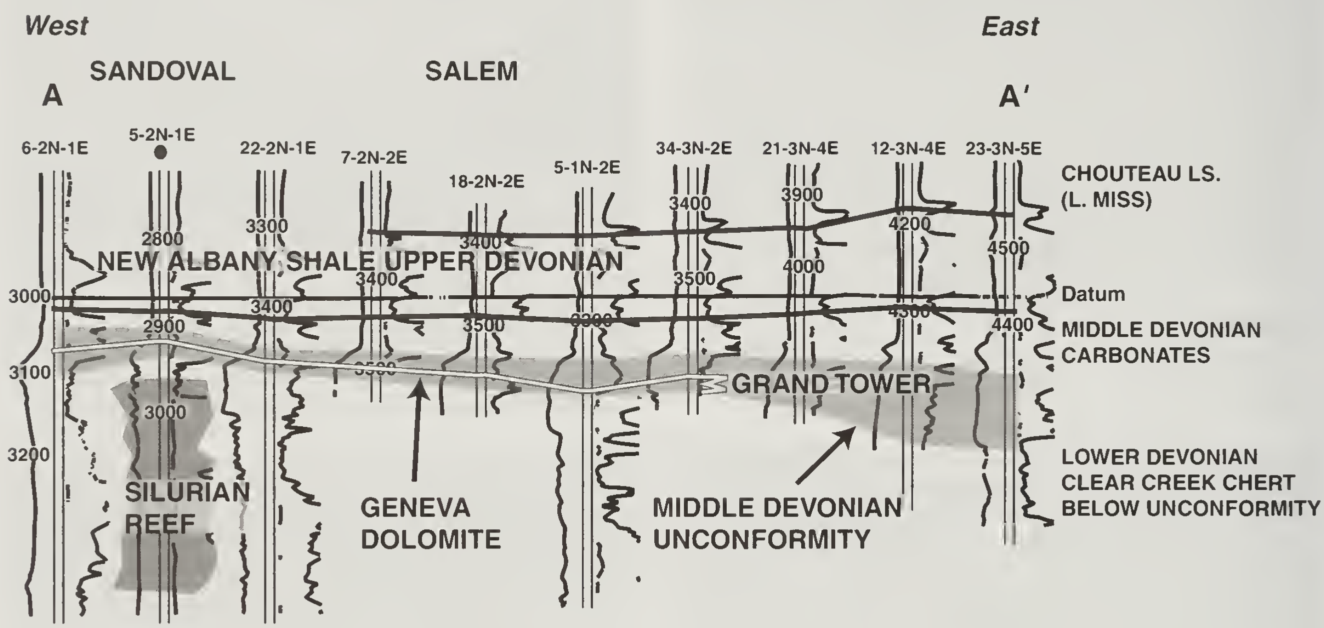


Figure 13 West-east stratigraphic cross section (A–A′, fig. 2) of the study area in Marion County. Lower Mississippian Chouteau Limestone thickens eastward of the DuQuoin Monocline (fig. 2). The Upper Devonian New Albany Shale and Middle Devonian carbonates also thicken eastward. Sandoval field produces from porous Geneva Dolomite draped over a Silurian reef.

from the Sandoval Field in Marion County, Illinois. The change from the visibly porous and permeable dolomite observed in the North Vernon Quarry to the highly fossiliferous limestone in the Scott Quarry is due to less dissolution of calcite fossils and less dolomitization in the more southern extent of the Geneva Dolomite equivalent strata.

Regional Setting of Geneva Dolomite Reservoirs in Illinois

A substantial amount of the petroleum production from the Geneva Dolomite comes from the northern half of Marion County, Illinois. The locations of many of these fields, including the most recent discovery near Miletus Field, is shown in figure 2. Anticlinal closure combined with drape over underlying pinnacle reefs in many instances is the hydrocarbon-trapping mechanism in the Geneva Dolomite reservoirs (fig. 12). In many instances, deep-seated structures likely formed the foundation for the growth of pinnacle reefs during the Silurian (Davis 1991) because the corals and other reef-building organisms thrived in the shallower water found at structurally high locations (fig. 12). Structural noses along major anticlines are potential sites for structural closure and hydrocarbon entrapment in the Geneva Dolomite. The St. James Field, located along the southern nose of the Louden Anticline, is an example of recently discovered production from closure along a structural nose (fig. 2). Portions of these structural noses may also have been potential sites for growth

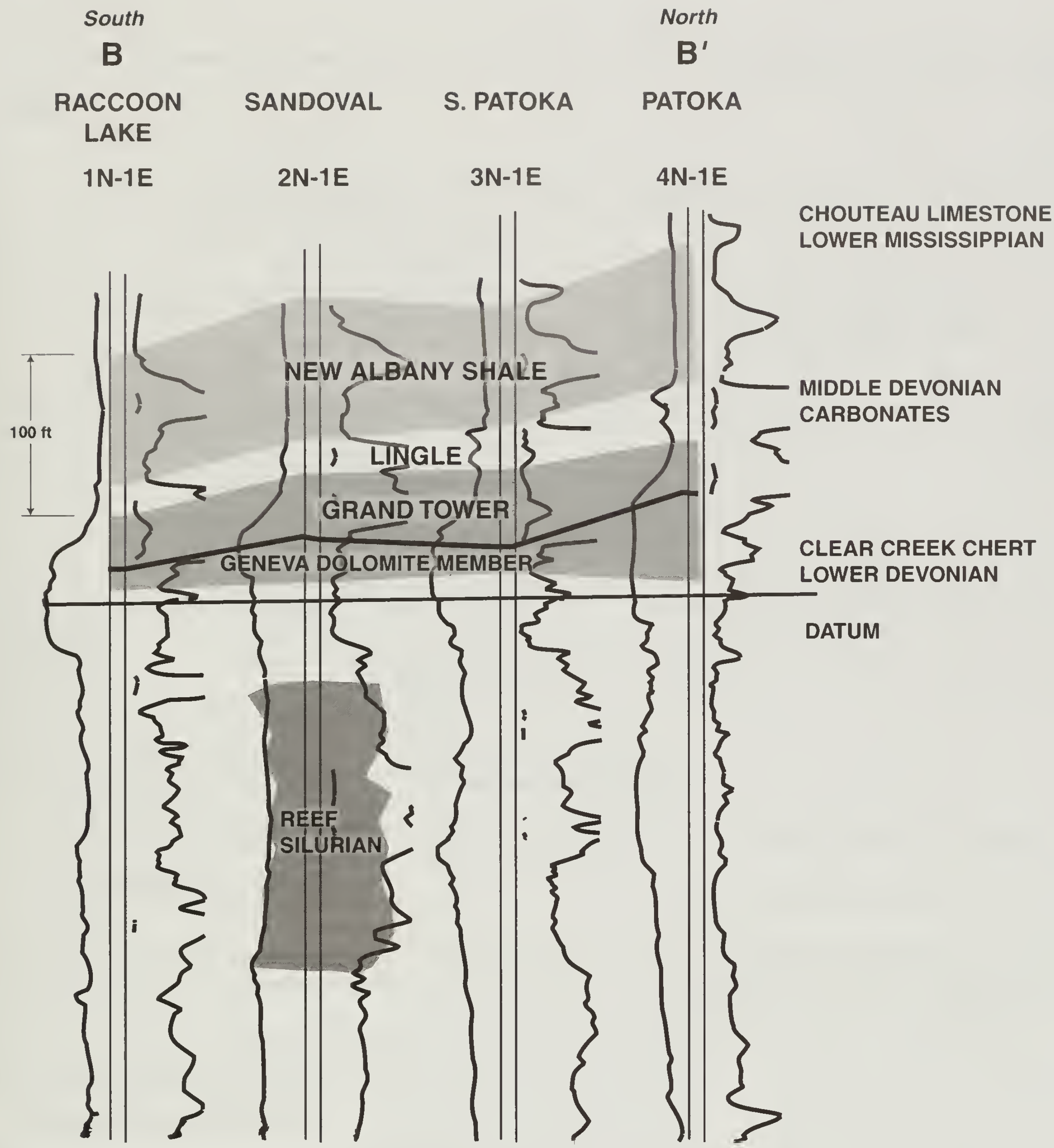


Figure 14 Stratigraphic cross section B–B′ from the Raccoon Lake Field to the Patoka Field in Marion County. Pinnacle reefs underlie the Raccoon Lake and Sandoval Fields. The Grand Tower Limestone thickens from the south to north.

of Silurian pinnacle reefs if the same feature was structurally high during the Silurian. Increasing evidence suggests that many major structural features in the Illinois Basin have a history of episodic movement through Paleozoic time (Davis 1991, McBride and Kolata 2000).

A west-east stratigraphic cross section (A–A′ in fig. 2) crosses Marion County, Illinois, where several prolific Geneva Dolomite oil reservoirs have been found (fig. 13). This section crosses Sandoval Field, which produces from the highly porous Geneva Dolomite that is draped over a Silurian reef. Eastward along the section, the Salem Field produces from two different horizons in the Middle Devonian. The cross section also shows that the lower Mississippian Chouteau Limestone, a marker horizon in some areas of the Illinois Basin, thickens to the east

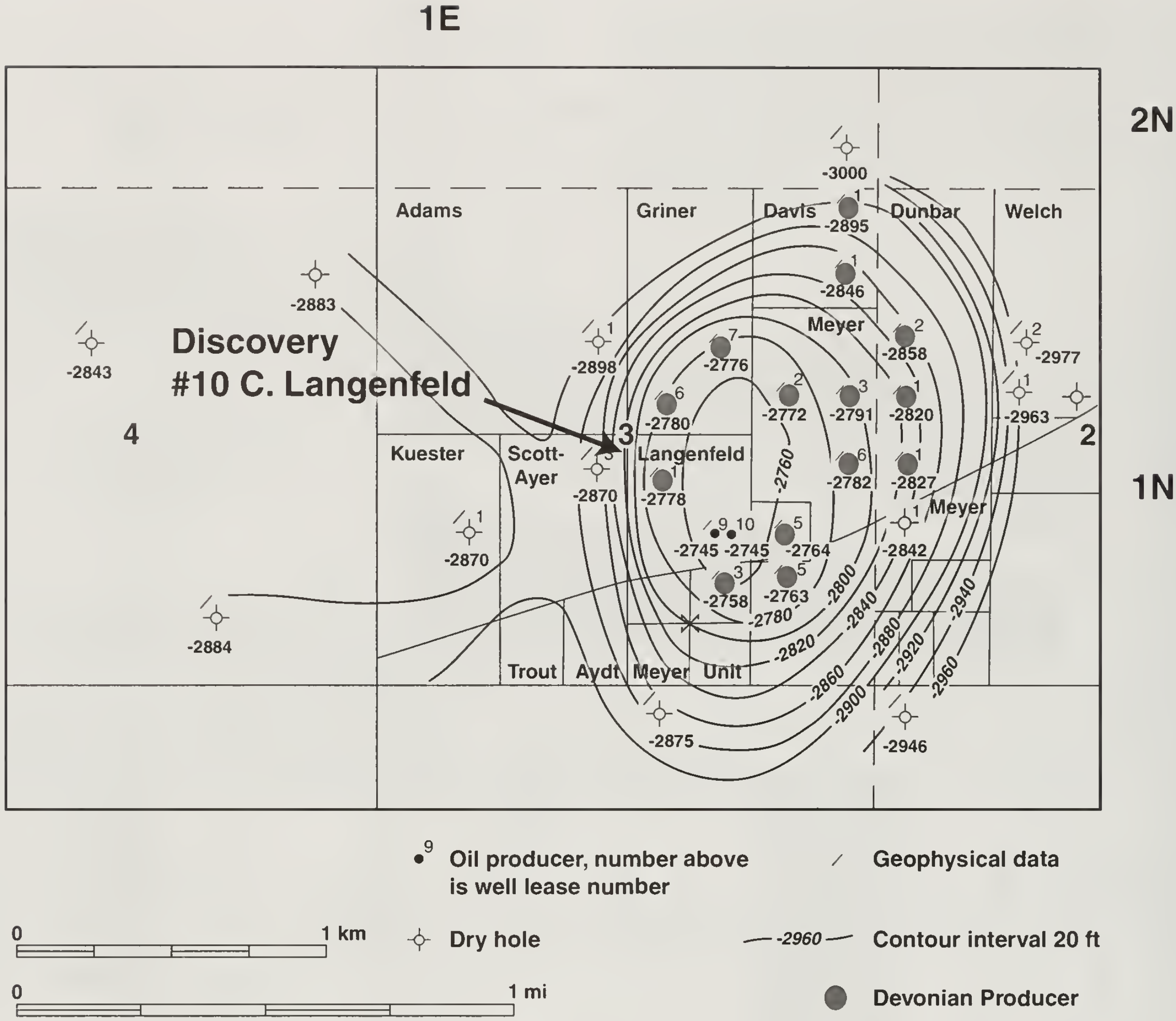


Figure 15 Structure map of the Raccoon Lake Field contoured on the base of the New Albany Shale showing pronounced closure in circular patterns indicating drape over an underlying Silurian reef complex. Logs penetrating Silurian strata also show reef buildups. (Modified from Bristol 1974.)

of the DuQuoin Monocline (fig. 2). The Upper Devonian New Albany Shale and Middle Devonian carbonates also thicken to the east of the Duquoin Monocline, which suggests that the DuQuoin Monocline was a structurally high feature during deposition of these strata and a likely site for accumulation of biohermal carbonates.

A north-south cross section, B–B′ (located on fig. 2), from Raccoon Lake through Sandoval, South Patoka, and Patoka Fields shows the Geneva Dolomite thickening from south to north (fig. 14). The Raccoon Lake Field is located near the southern limit of the Geneva Dolomite. The cross section (fig. 14) also shows an increase in thickness of Middle Devonian carbonates above the Geneva Dolomite from south to north. This increase may be due to the Lower Devonian Clear Creek Chert unconformity, which underlies the Middle Devonian Geneva Dolomite in the southern half of Marion County, Illinois.

Historical Production in the Geneva Dolomite

Indiana Geneva Production

The Geneva Dolomite together with other Middle Devonian dolomites are productive from a number of fields that lie within the Indiana portion of the dolomitic fairway. Hydrocarbons in these fields are commonly trapped in structures formed by drape over Silurian reefs, particularly along the southeast-northwest–trending Terre Haute Reef Bank (Droste and Shaver 1975) in the western Indiana counties of

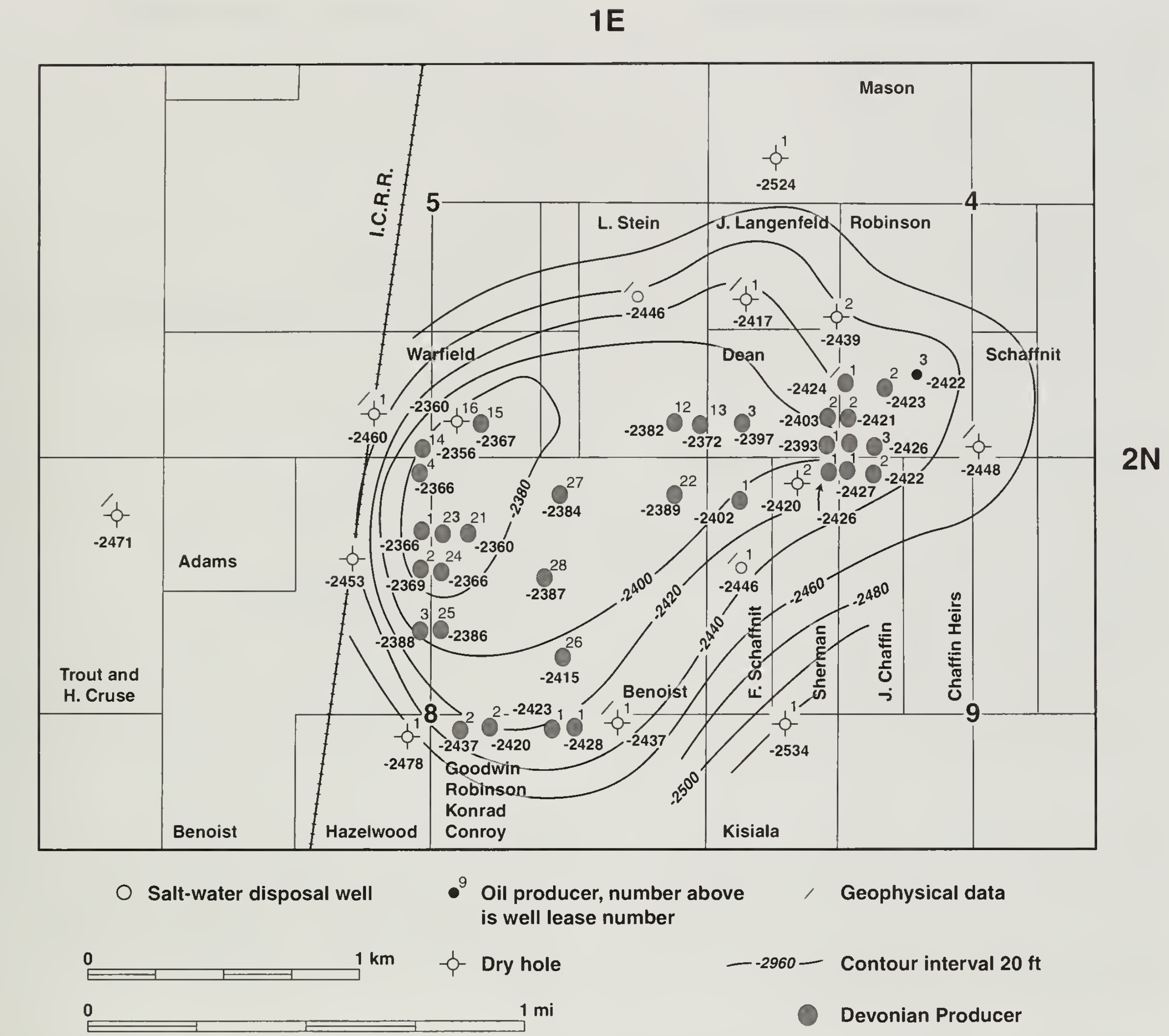


Figure 16 Structure map of the Sandoval Field contoured on the base of the New Albany Shale showing pronounced closure in circular patterns indicating drape over an underlying Silurian reef complex. Logs penetrating Silurian strata also show reef buildups. (Modified from Bristol 1974.)

Sullivan, Vigo, Clay, and Greene. Two fields with significant Middle Devonian production are Siosi and Fairbanks, both of which are in Sullivan County. The Siosi was discovered in 1926 and has produced 5.2 million barrels of oil through 1999. The Fairbanks was discovered in 1950 and has produced 3.2 million barrels of oil through 1999 (Cazee 2000). There have been no significant new Geneva field discoveries since the late 1960s in Indiana.

Illinois Geneva Production

Structure maps contoured on the base of the New Albany Shale show pronounced circular closure, suggesting drape over underlying Silurian reefs at Raccoon Lake and Sandoval Fields (figs. 2, 15, and 16) (Bristol 1974). Logs penetrating Silurian strata also show reef buildups with a thickened section of Silurian carbonates during the reef growth period (fig. 14). Closure in the overlying strata at these two fields is caused by differential compaction over the rigid reef core relative to the finer-grained compactable sediments flanking the reef core. There are over 150 feet of closure at Raccoon Lake and 140 feet of closure at Sandoval Field, and each field is less than one mile wide. Thirteen wells in Raccoon Lake and 32 wells in the Sandoval Field were completed in the Geneva Dolomite, which is the most prolific reservoir

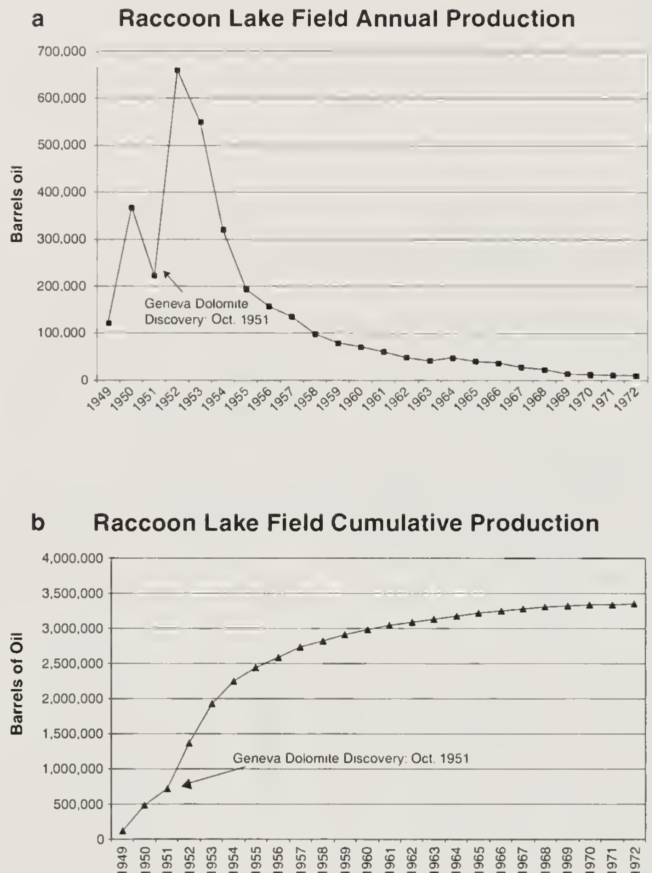


Figure 17 (a) Graph of annual production from the Raccoon Lake Field showing the rapid increase from 220,000 barrels of oil to 660,000 barrels of oil with discovery of the Geneva Dolomite reservoir. (b) Cumulative production curve shows that much of the production in the Raccoon Lake Field occurred in the five years following the discovery of the Geneva Dolomite reservoir.

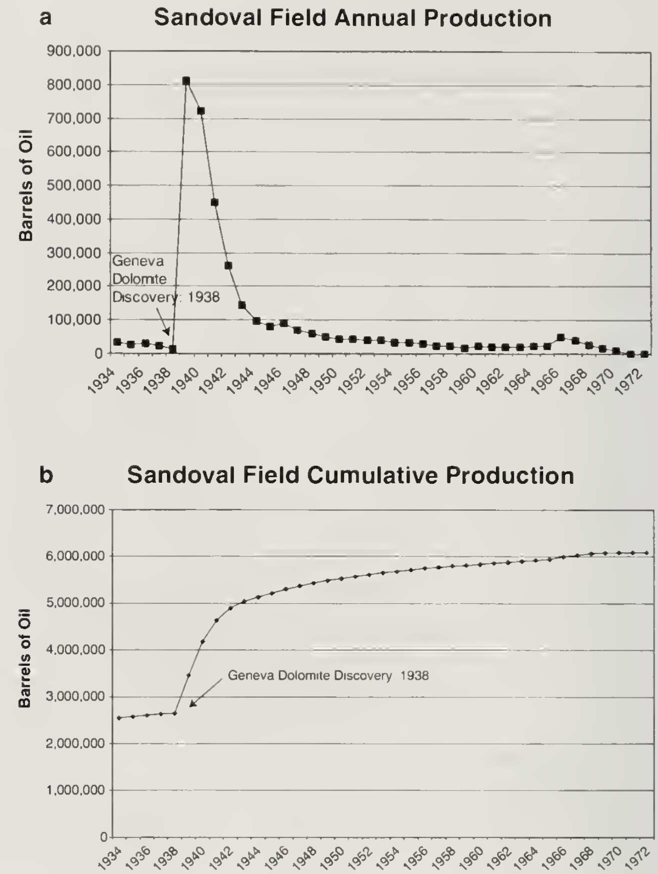


Figure 18 (a) Graph of annual production from the Sandoval Field showing the large increase following discovery and development of the Geneva Dolomite reservoir. (b) Cumulative production curve in Sandoval Field also shows a significant increase in production following the discovery and development of the Geneva Dolomite reservoir.

in each of these fields. Many of these reefs are less than one mile in size and have approximately 100 feet or more of closure. It is likely that 3-D seismic techniques can be used successfully to explore for additional reef and reef-drape production. A recent 3-D seismic survey was successfully used to locate and drill a Geneva well on a local high point on the Tonti Field reef (Helpingstine et al. 2001).

Raccoon Lake Field

Raccoon Lake Field was discovered in 1949 using seismic technnology. Shallow reservoirs at Raccoon Lake are found in middle Mississippian sandstones and carbonates including the Cypress, Benoist, and Rosiclare Sandstones and the Ohara and McClosky Limestones. The Geneva Dolomite reservoir was discovered with the drilling of the Texas No. 10 C. Langenfeld in Sec. 3, T1N, R1E, in 1951 at a depth of 3,385 feet. Initial daily production from the well was 109 barrels of oil and 101 barrels of water. The discovery and development of the Geneva Dolomite reservoir rapidly increased annual production from 220,000 to 660,000 barrels of oil (fig. 17). The cumulative production curve (fig. 17b) shows that much of the production in the Raccoon Lake Field occurred in the 5 years following the discovery of the Geneva Dolomite reservoir. The Geneva Dolomite has produced over 2.5 million barrels of oil from an area of only 230 acres.

Sandoval Field

The Geneva Dolomite reservoir at the Sandoval Field was first exploited in 1938 with the drilling of the Southwest Oil and Gas No. 21 Benoist in Sec. 8, T2N, R1E, at a depth of 2,926 feet. The initial production of this well was 319 barrels of oil flowing in 19 hours with a natural completion. The Sandoval Field was initially discovered in 1908 and has produced over 6 million barrels of oil from the middle Mississippian Cypress and Benoist Sandstones and the Middle Devonian Geneva Dolomite. Over 2.5 million barrels

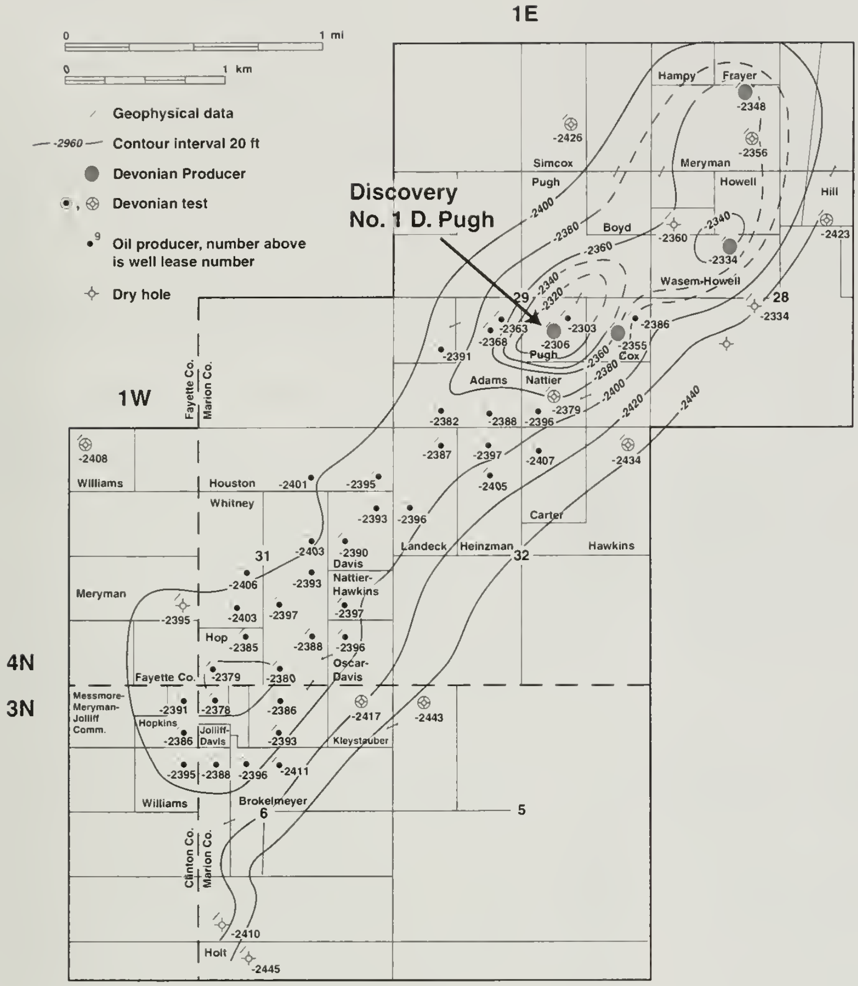


Figure 19 Structure map of the Patoka Field contoured on the base of the New Albany Shale. The structural feature at Patoka is larger than the structures induced by pinnacle reefs at Raccoon Lake and Sandoval Fields. There is evidence of deep-seated tectonic control of structure. (Modified from Bristol 1974.)

were produced from a relatively small area of 280 acres in the 5 years immediately following the initial Geneva Dolomite discovery. The rapid increase in annual production followed development of the Geneva Dolomite reservoir in the field (fig. 18a). The cumulative production curve (fig. 18b) in the Sandoval Field also shows the significant increase in production following the discovery and development of the Geneva Dolomite reservoir.

Patoka Field

The Patoka Field was discovered in 1937 using structure mapping on the Herrin (No. 6) Coal Member and was confirmed by a seismic survey. The structure map of the Patoka Field illustrates a pronounced closure of 80 feet (fig. 19), most of which is likely from tectonic deformation. The four-mile-long and one-mile-wide anticline at Patoka is a larger feature than the reef drape structures found at Sandoval and Raccoon Lake. A Silurian reef has been reported at the northeast end of the field (Bristol 1974) over which four wells are producing from the Geneva Dolomite. Most of the wells in the area of the Geneva reservoir were drilled to the Ordovician Trenton carbonates, but records indicate that most production is from the Geneva. Initial production in the field was from the middle Mississippian Benoist sandstone. Discovery of the Geneva Dolomite reservoir occurred in 1943 at a depth of 2,908 feet in the Adams Oil and Gas No. 1 D. Pugh well, Sec. 29, T4N, R1E, Marion County. The Patoka Field has produced in excess of 14.9 million barrels of oil. The field's largest increase in annual production came after the 1943 discovery of the Geneva Dolomite reservoir when annual production increased from 298,000 barrels of oil in 1943 to 630,000 in 1944 and 1,644,000 barrels of oil in 1946 (fig. 20a). Cumulative production in the field (fig. 20b) increased from 2,841,000 barrels of oil in 1943 to over 10 million barrels of oil by 1950. Approximately 10 million barrels of the total production from the Patoka Field can be attributed to the four Geneva Dolomite wells.

Tonti Field

Another highly productive Geneva Dolomite reservoir in Marion County, Illinois, is the Tonti Field. The Geneva Dolomite produces from 15 feet of brown, porous sucrosic dolomite draped over a Silurian reef (Bristol 1974). Approximately 80 feet of closure is apparent at the base of the New Albany Shale. The Tonti Field was discovered in 1939 and initially produced from middle Mississippian sandstone and carbonate reservoirs in the Benoist, Aux Vases, Spar Mountain, and McClosky. The Geneva Dolomite reservoir was discovered in 1940 at a depth of 3,414 to 3,430 feet in the Harvey No. 6 "B", J. K. Kagy well, Sec. 33, T3N, R2E. This well flowed 4,200 barrels of oil per day from the Geneva Dolomite. Although Tonti is a small field, with just 80 acres of proved reserves, it has produced more than 13.5 million barrels of oil from eight wells. Annual produc-

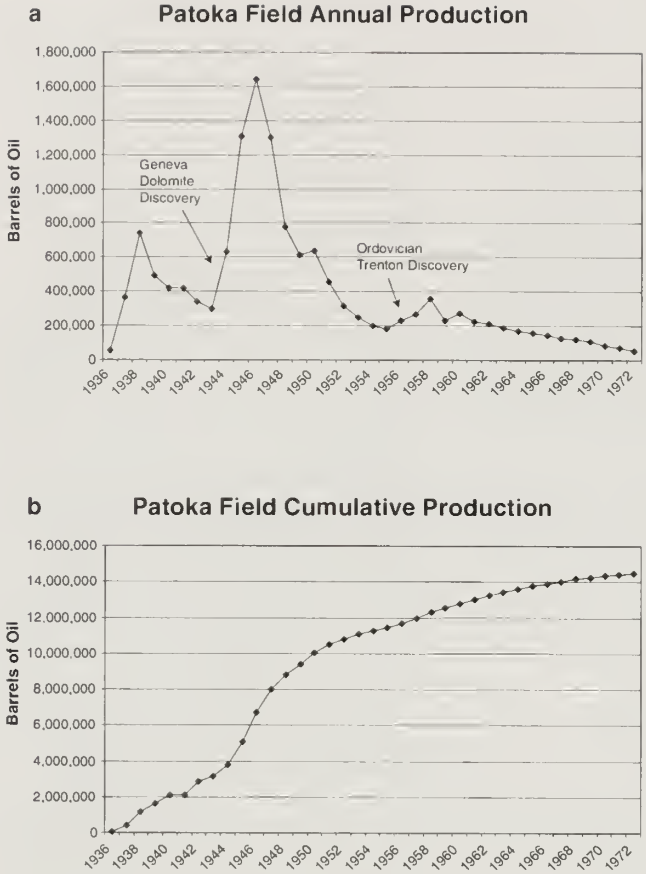


Figure 20 (a) Graph of annual production from the Patoka Field showing a large increase between 1943 and 1944 that coincides with discovery of the Geneva Dolomite reservoir in the field. (b) Cumulative production graph in Patoka Field shows a large increase in production starting in 1943. The increase in cumulative production can be attributed to production from the Geneva Dolomite reservoir.

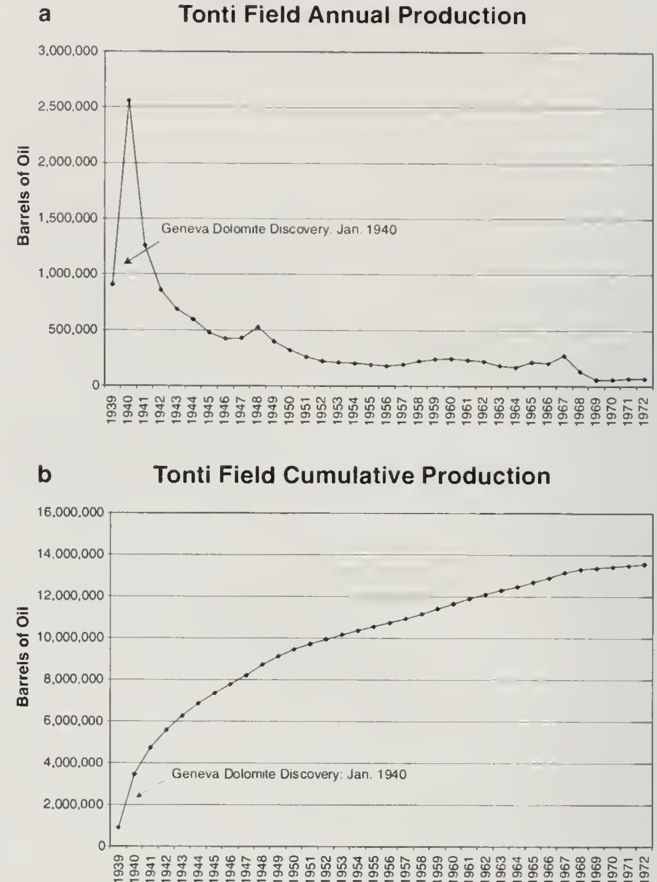


Figure 21 (a) Graph of annual production from the Tonti Field showing outstanding production after the discovery and development of the Geneva Dolomite reservoir. Annual production increased from 900,000 barrels of oil in 1939 to 2,560,000 barrels of oil in 1940. (b) Cumulative production graph shows an increase in production from 900,000 barrels of oil in 1939 to over 8 million barrels by 1947.

tion (fig. 21a) was outstanding after the discovery and development of the Geneva Dolomite reservoir in the Tonti Field. Annual production increased from 900,000 barrels of oil in 1939 to 2,560,000 barrels of oil in 1940. Cumulative production increased from 900,000 barrels of oil in 1939 to over 8 million barrels by 1947 (fig. 21b).

A 3-D seismic survey limited to 0.37 square miles was completed at the Tonti Field to redefine the structural interpretation of the Geneva Dolomite reservoir in order to replace a damaged production well and to identify potential new well locations for incremental production (Helpingstine et al. 2001). A Vibroseis source was used in a design that included six north-south receiver lines and seven east-west shot lines spaced 110 feet apart. A sequence of four maps interpreted from the 3-D seismic data was used to alter the original interpretation of a single closure over a single Silurian pinnacle reef. The data revealed two separate areas of closure over multiple Geneva high areas that mimic the undulating surface of the underlying Silurian pinnacle reef. Maps used in the interpretation included (1) a two-way time map to the top of the Devonian, (2) a map of the range and distribution of the average velocity to the Devonian, (3) a time map to depth, (4) a top-of-Devonian structure map, and (5) a time-slice map taken at 569 milliseconds (Helpingstine et al. 2001). Based on these company maps, the original interpretation of structural closure in the field was revised and used to define a new well location that encountered the Geneva pay zone 12 feet higher than the existing well scheduled for replacement. Such detailed 3-D seismic has the potential for redefining reef structures in older fields and delineating new reef structures in the Geneva Dolomite.

The previously mentioned Marion County oil fields all experienced rapid increases in production when Geneva Dolomite reservoirs were discovered and developed. Graphs of annual production (figs. 17, 18, 20, and 21) from each of these fields show approximately six years of significantly increased annual production from relatively few wells. The increased production attributed to the development of the Geneva Dolomite reservoir substantially contributed to the total cumulative production in each field. In most of these fields, the Geneva Dolomite is the most prolific reservoir.

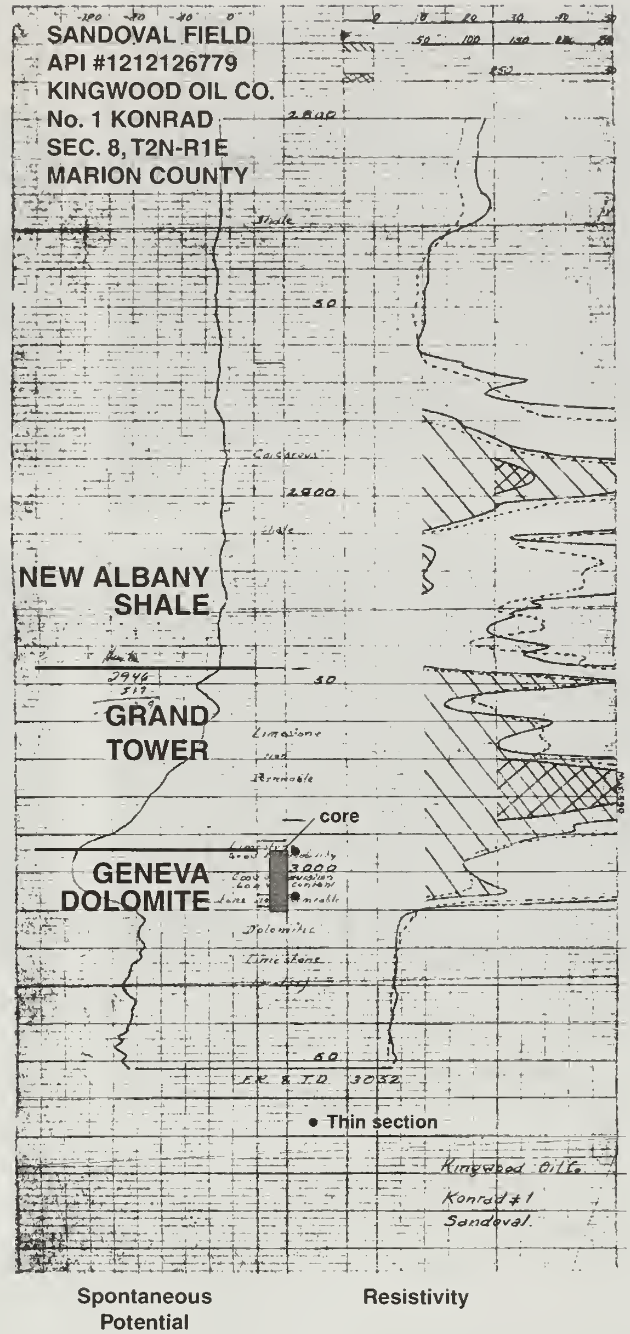


Figure 22 Old-style geophysical log from the Sandoval Field for the Kingwood Oil Company No. 1 Konrad in Sec. 8, T2N, R1E, Marion County, Illinois. Formation depths, cored interval, and thin section depths are shown on log. This well was drilled in 1939 with an initial production of 600 barrels of oil per day.

Log, Core, and Rock Descriptions of Geneva Dolomite in Historical Fields

Examination of core biscuits from the Geneva Dolomite in Sandoval, Raccoon Lake, and Patoka Fields indicate that, prior to dolomitization, the rock was originally composed of shallow marine, bioclastic packstones to grainstones. Correlations and similarities to quarries and outcrops in Indiana support this interpretation (Leonard 1996). Dissolution of fossils and dolomitization of the surrounding matrix carbonate have enhanced porosity and permeability. The amount of moldic porosity appears to be dependent on the initial quantity of fossil material in the sediment and the extent of the dissolution of those fossils. Porosity and permeability are least where the quantity of coarse fossil material was initially small and dissolution of the fossils was incomplete. Although dolomitization has obscured the original fossil content of the Geneva sediments, the porous and moldic characteristics of the highly dolomitized Geneva sediments strongly indicate that the visible and measured porosity and permeability are now greatest in sediments where large amounts of fossil material have been completely dissolved and the original carbonate matrix is completely dolomitized.

The geophysical log in figure 22 is from the Kingwood Oil Company No. 1 Konrad, in the Sandoval Field in Sec. 8, T2N, R1E. Core samples of the Geneva Dolomite from this well at a depth of 2,993 feet show numerous branching corals surrounded by a matrix of brown sucrosic dolomite (fig. 23a). The branching corals are composed of calcite, remain intact, and show little evidence of dissolution. The photomicrograph in figure 23b, under white light and stained with alizarine red, is from the core sample in figure 23a and illustrates intact branching corals composed of red-stained primary calcite. The tan, unstained mineral in the thin section is dolomite, and the white, silt-sized grains are quartz. Porosity is shown as blue in the thin section.

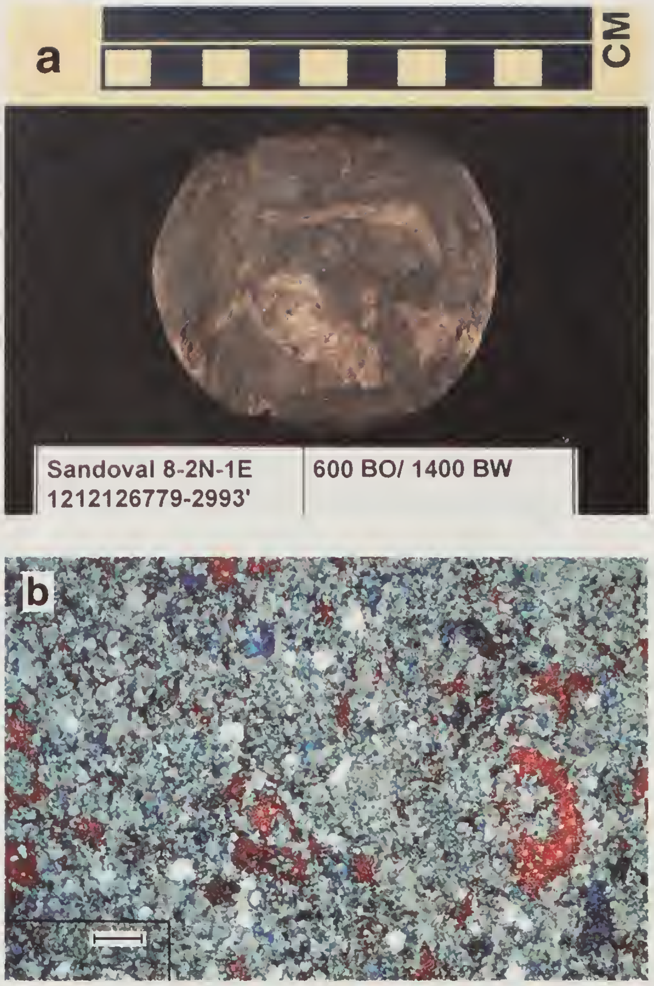


Figure 23 (a) Core of Geneva Dolomite from the Sandoval Field at 2,993 feet. Branching corals are common. (b) Thin section shows porous dolomite with shallow marine fossil fragments composed of primary calcite stained red. Scale bar is 0.5 mm.

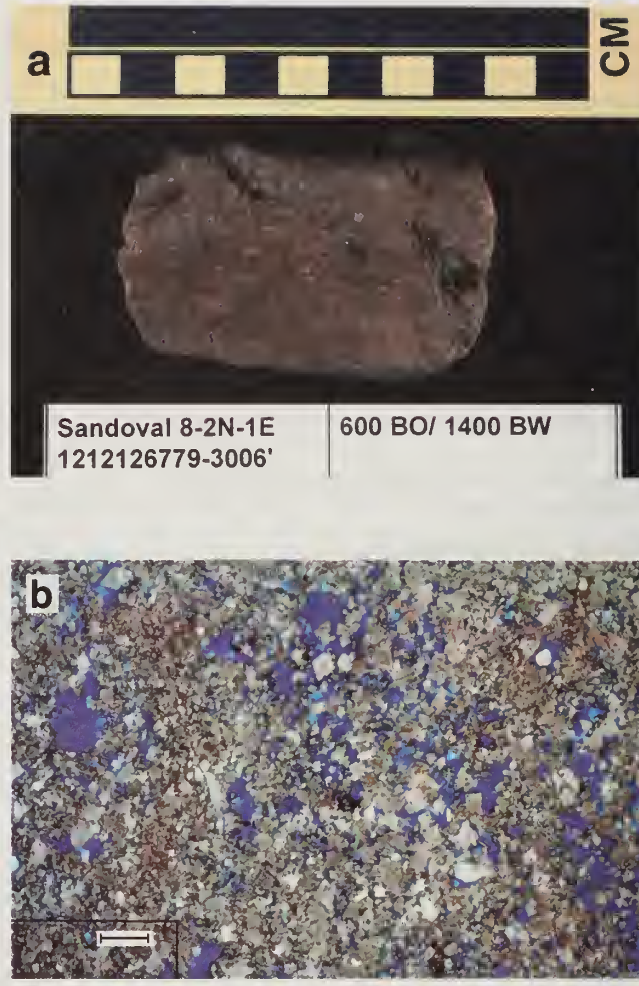


Figure 24 (a) Core of Geneva Dolomite from 3,003 feet. Few fossils remain. Numerous moldic pores have been created by the dissolution of fossils. (b) Thin section shows fine- to medium-crystalline, porous, sucrosic, dolomite. Moldic pores are common; no primary calcite is seen. Scale bar is 0.5 mm.

The dolomitized matrix surrounding the red-stained branching coral is porous.

In contrast, the core sample of the Geneva Dolomite from 10 feet below the previous sample, at a depth of 3,003 feet, contains little to no intact fossil material (fig. 24a) and shows numerous moldic pores created by dissolution of the original marine fossils (fig. 24b). These two samples from the Sandoval Field show the influence that the dissolution of marine fossils has on the development of porosity and permeability in the Geneva Dolomite. A thin section of this core sample (fig. 24b), photographed under white light, shows a porous, fine- to medium-grained sucrosic dolomite. Porosity is highlighted by blue-stained epoxy. Moldic pores created by dissolution of fossils are common in this sample, and calcite is missing, as indicated by the absence of alizarine red staining. The porosity and permeability in this sample are greater than those found in the sample from 2,993 feet.

A geophysical log (fig. 25) from the Eddie Self Dunbar No. 1 well in the Raccoon Lake Field, Sec. 2, T1N, R1E, shows the character of the Geneva Dolomite reservoir. This well initially flowed at the rate of 960 barrels of oil per day. The log from this well shows the New Albany Shale, the Geneva Dolomite, and a portion of the Silurian section. The cored interval includes samples from the Geneva Dolomite and the underlying Silurian rocks. Thin sections of the Geneva Dolomite from this core contain small amounts of undissolved coral fragments. Although the original fossil fragments remain in the rock, the moldic porosity created by dissolution of coral and other marine fossil fragments has enhanced the overall porosity of these samples. Fine- to medium-grained, zoned dolomite crystals with scattered sand grains are the most common features observed in

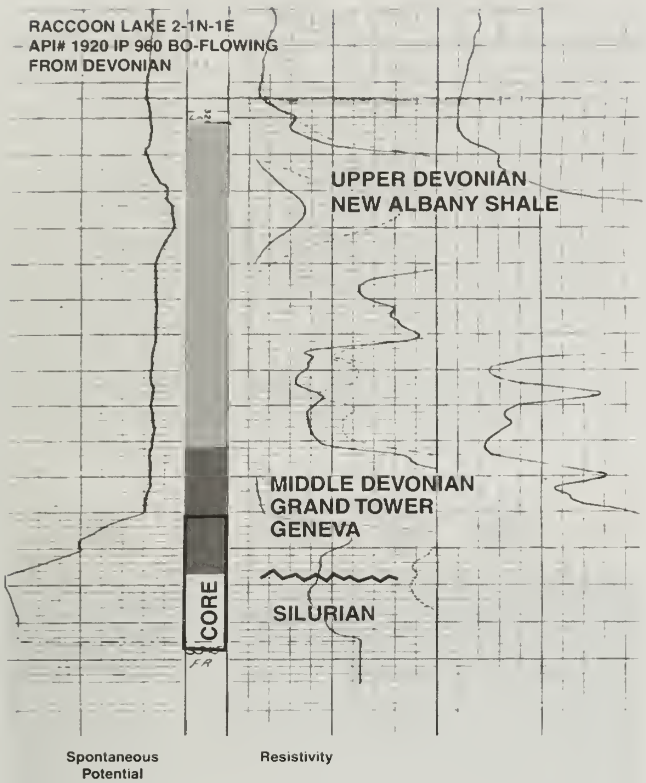


Figure 25 Geophysical log from the Raccoon Lake Field for the Eddie Self Dunbar No. 1 in Sec. 2, T1N, R1E, Marion County, Illinois. Formation depths and cored interval are shown on the log.

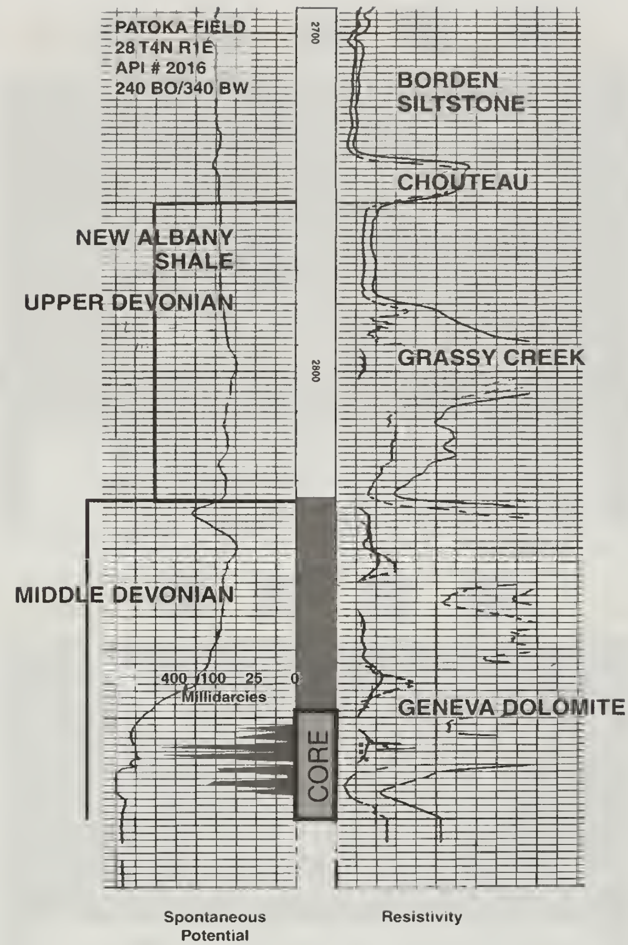


Figure 26 Geophysical log from the Patoka Field for the Sohio Petroleum Company Howell Community–Patoka No. 1-D well, Sec. 28, T4N, R1E, Marion County, Illinois. Formation depths and cored interval are shown. Permeability is graphed on the left side of the log.

thin sections of samples from the Raccoon Lake Field.

Evidence of fracturing following dolomitization is found in cores of the Geneva Dolomite in the region. Some fractures are open, but others are filled with late-stage sparry calcite cement. Late-stage fluorite mineralization has also been observed along some fracture planes. An example of this fracturing was found in the Sohio Petroleum Company Howell Community–Patoka No. 1-D well, Sec. 28, T4N, R1E, Patoka Field (fig. 26). Initial production from this Marion County well was 240 barrels of oil per day and 340 barrels of water per day from the Geneva Dolomite.

Figure 26 shows the Mississippian Chouteau Limestone, Upper Devonian New Albany Shale, and Middle Devonian Grand Tower Limestone and the cored interval between 2,897 to 2,930 feet. The core sample from 2,921 to 2,922 feet in the Howell Community–Patoka No. 1-D well is composed of highly porous and permeable, brown, sucrosic Geneva Dolomite that displays a considerable amount of moldic porosity. Evidence of dissolution along a fracture can be seen in the solution collapse breccia located along the fracture plane shown in figure 27. Fragments of dolomite have collapsed into a fracture enlarged by dissolution and were then cemented within the fracture by late-stage calcite. The late-stage calcite cement appears as a white mineral in both views of the core sample (fig. 27, a and b). The thin-section photomicrograph of the collapse breccia (fig. 27c) shows that late-stage calcite cement, stained red by alizarine red dye, filled the fracture after fragments of the dolomite had collapsed into it, indicating that dissolution occurred prior to the calcite cementation and showing that there were at least two stages of carbonate dissolution that enhanced porosity and permeability. The first stage involved dissolution of fossils composed of calcite; the second stage involved dissolution of some dolomite along fracture planes.

The Geneva Dolomite in the Howell Community–Patoka No. 1-D well is highly permeable. The permeability data graphed on the left side of the geophysical log (fig. 26) show permeabilities exceeding 600 millidarcies (md) at some intervals.

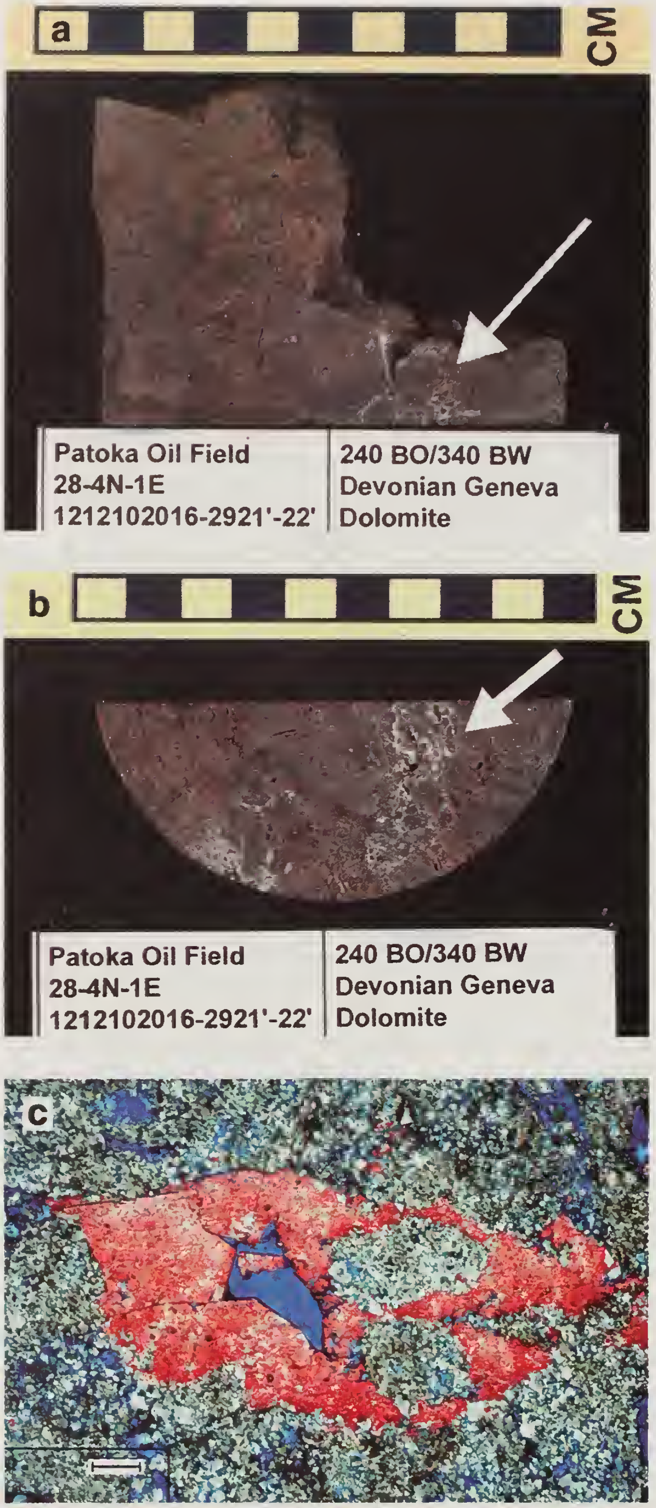


Figure 27 (left) (a) Brown sucrosic Geneva Dolomite with moldic porosity. Solution collapse breccia is located at arrow along fracture plane in sample from the Patoka Field. (b) Bottom view of same core sample. Solution collapse breccia located along the fracture plane in sample from the Patoka Field. Fragments of dolomite have collapsed into a solution-enlarged fracture and were cemented by a late-stage calcium carbonate (white mineral at arrow in core photo). (c) Photomicrograph of collapsed breccia. Late-stage calcite cement is stained red and surrounds fragments of collapsed dolomite. Scale bar is 0.5 mm.

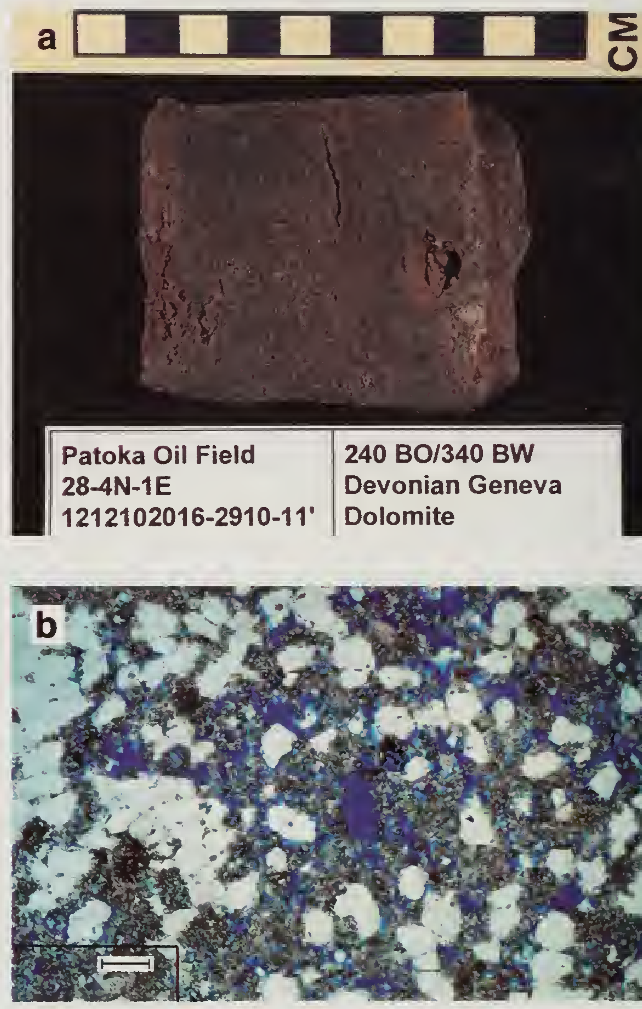


Figure 28 (above) (a) Brown, sucrosic, sandy Geneva Dolomite. Large amounts of moldic porosity created by the dissolution of marine fossils. Vugs were created by the dissolution of larger fossils. Sample is from 2,911 feet. Porosity is 13.7%, and permeability is 624 md. (b) Thin section from core sample. Porosity is highlighted by blue. Rounded quartz sand grains with overgrowths, some floating in finely crystalline dolomite. Scale bar is 0.5 mm.

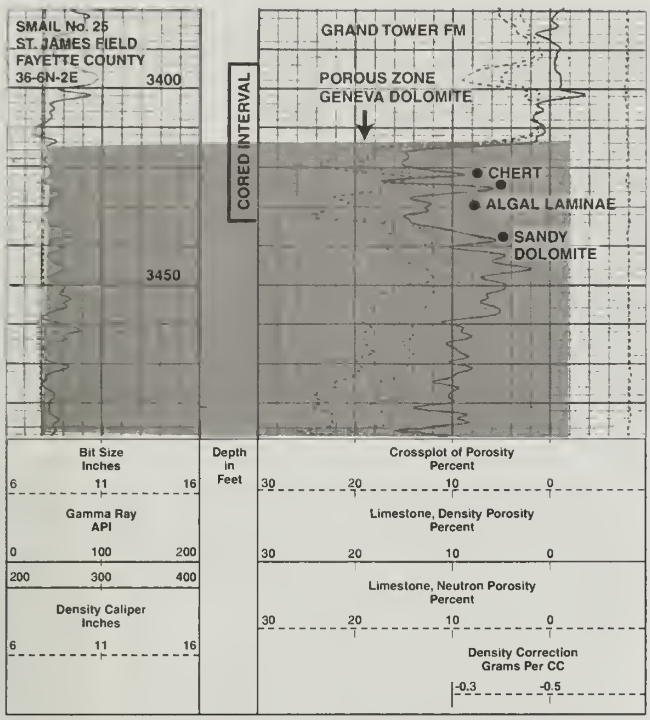


Figure 29 Geophysical log from Plains, Illinois, Smail No. 25 in the St. James Field. This is well No. 1 in cross section C–C′(figs. 2 and 32). Cored interval is shown. Core footage is approximately 3 feet high to log footage.

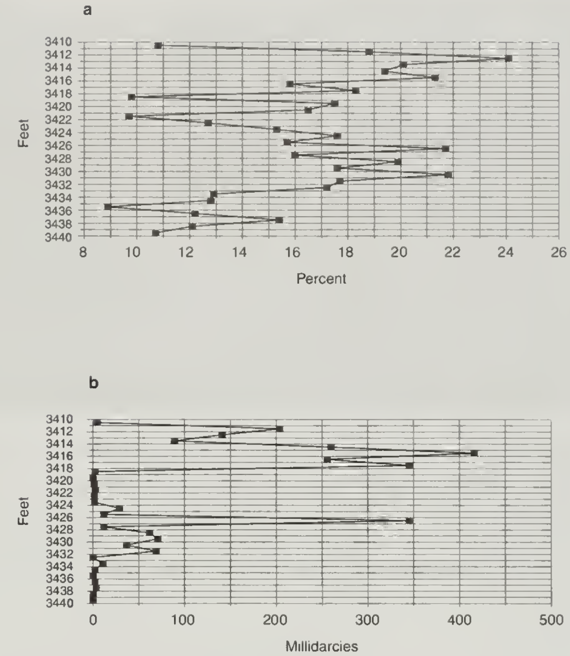


Figure 30 Porosity (a) and permeability (b) data for the cored interval from the Plains, Illinois, Smail No. 25 in the St. James Field. There is a highly porous and permeable reservoir zone in the upper portion of the Geneva Dolomite. The cherty zone starting at 3,418 (core) feet is much less permeable than the brown, sucrosic dolomite above it.

A Geneva Dolomite core sample from a depth of 2,911 feet contains moldic porosity created by the dissolution of marine fossils. Measured porosity in this core sample is 13.7%, and permeability is 624 md. A thin-section photomicrograph from this sample (fig. 28b) shows a large amount of porosity (highlighted by blue-stained epoxy) and numerous rounded quartz sand grains with overgrowths, some floating in finely crystalline dolomite. Sandy dolomite and very thin dolomitic sandstones were observed in some Geneva cores. Sand grains can be scattered or concentrated into thin beds in the Geneva Dolomite. Beds of the Dutch Creek Sandstone commonly underlie and grade sharply into the Geneva, although interfingering of these sands may occur, particularly along the southern boundary of the Geneva fairway.

Recent Geneva Dolomite Discoveries

St. James Field

The Geneva Dolomite reservoir in the St. James Field (fig. 2) was discovered in 1998 with the drilling of the Plains Illinois Smail No. 25 well in Sec. 36, T6N, R2E, Fayette County. A geophysical log of the Smail No. 25 is shown in figure 29. The cored interval in this well from 3,410 to 3,434 feet includes part of the dense bioclastic limestone of the Grand Tower overlying the Geneva Dolomite Member. Graphs of core analysis measurements of porosity and permeability (fig. 30) show porosities as high as 24% and permeability as high as 400 md in the Geneva Dolomite reservoir.

The core from the Smail No. 25 well starts in the dense limestone of the Middle Devonian Grand Tower Limestone at 3,393 feet and extends down into the upper portion of the Geneva Dolomite Member at 3,434 feet (fig. 31). The upper contact of the Geneva Dolomite with the overlying limestone of the Grand Tower at 3,410 feet is undulatory and abrupt (fig. 31). There is no transition zone from the white, tightly cemented bioclastic grainstone above and the brown, highly porous and permeable Geneva Dolomite below. The widespread and abrupt nature of the upper contact suggests a possible parasequence boundary across the St. James Field and across the region. The lower portion of the cored interval contains a cherty, light- to medium-brown, fine-grained dolomite containing algal laminations and tidal rhythmites with low measured porosity and low permeability. The cherty interval correlates well with a similar cherty interval in a Lillyville Field core from the Dart Energy Corporation Breer-Heuerman No. 3-1, Sec. 1, T8N, R6E, Effingham County, Illinois.

Figure 31 Core from the Plains, Illinois, Smail No. 25 in the St. James Field, Sec. 36, T6N, R2E, Fayette County. This is well No. 1 in cross section C–C′. The cored interval is from the Middle Devonian Grand Tower Limestone through a cherty zone in the Geneva Dolomite. The upper contact (at arrow) of the Geneva Dolomite with the overlying Grand Tower Limestone is abrupt. There is no transition zone from the bioclastic grainstone above and the brown Geneva Dolomite below. The contact between the Geneva Dolomite of the typical brown sucrosic dolomite with the underlying cherty interval also is abrupt (arrow).

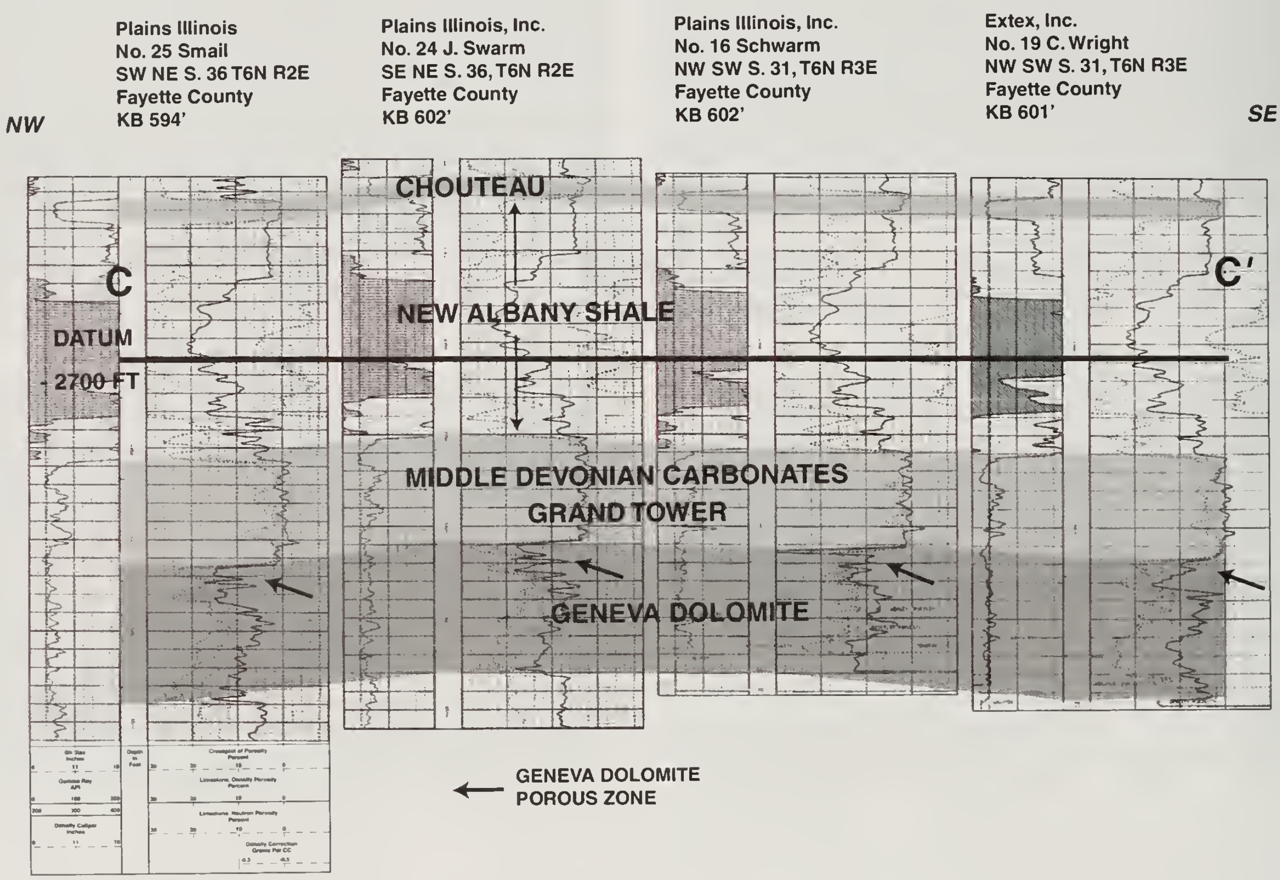


Figure 32 Structural cross section C–C′ (fig. 2) of the Geneva Dolomite reservoir at the St. James Field in southern Fayette County, Illinois. Included in the cross section is the Plains, Illinois, Smail No. 25 (well No. 1). Section shows a well-developed zone of highly porous dolomite (at arrows) immediately underlying dense, bioclastic grainstone in the Grand Tower Limestone. This upper contact of the Geneva Dolomite with the Grand Tower Limestone is abrupt across the field.

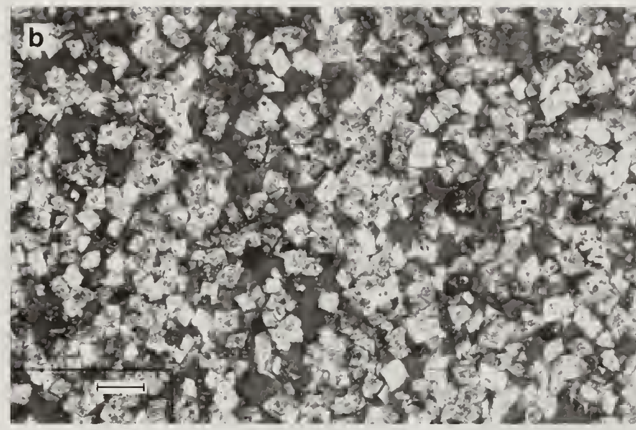


Figure 33 (a) Close-up of core from the Geneva Dolomite in the Plains, Illinois, Smail No. 25 in the St. James Field. The core is a brown, sucrosic, highly porous dolomite with large amounts of moldic porosity caused by dissolution of fossil fragments. (b) Thin section of this core from 3,411 feet with 200 md of permeability and 19% porosity is a fine- to medium-grained crystalline dolomite. The scale bar is 0.5 mm. Dolomite rhombs are zoned, indicating several episodes of recrystallization.

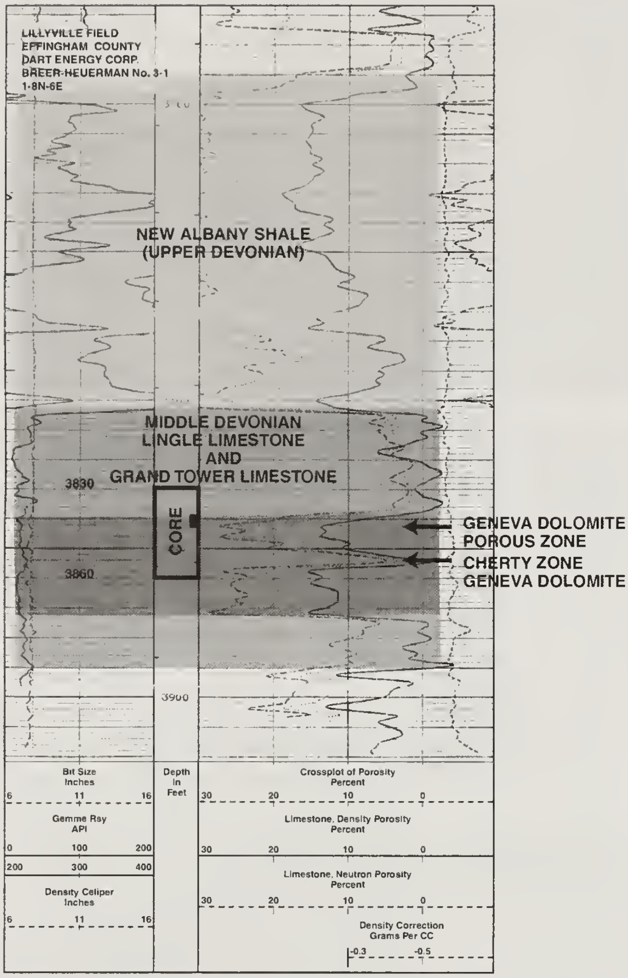
Cross section C–C′ (figs. 2 and 32) through the Geneva Dolomite reservoir at the St. James Field in southern Fayette County, Illinois, shows a well-developed zone of highly porous Geneva Dolomite immediately underlying the dense, bioclastic grainstone in the Grand Tower Limestone.

Figure 33a is a photograph of a typical core sample from the Geneva Dolomite reservoir from the Smail No. 25 from a depth of 3,411 feet. The sample is a brown, sucrosic, highly porous, and permeable dolomite with large amounts of moldic porosity caused by dissolution of fossil fragments. This sample has 200 md of permeability and 19% porosity in a fine- to medium-grained, crystalline dolomite. The thin section from 3,411 feet shows zonation of dolomite crystals, indicating several episodes of precipitation in which crystals were enlarged by the addition of dolomite on crystal edges (fig. 33b). The enlargement of dolomite crystals occurred during several episodes of dolomite recrystallization. Porosity (indicated in the thin section by blue-stained epoxy) and permeability appear to increase with dolomite recrystallization.

Lillyville Field

Another recently discovered Geneva Dolomite reservoir was found in the Lillyville Field by the Dart Energy Corporation, Breer-Heuerman No. 3-1 well, in Sec. 1, T8N, R6E, Effingham County, Illinois (fig. 34). This well was a deeper test drilled in 1989. Combined production from this well and the offset Breer No. 2-1 exceeds 180,000 barrels of oil (fig. 35). The cored interval is shown on the geophysical log (fig. 34) of the well. Characteristics of the Geneva Dolomite in this well are similar to those in the Geneva Dolomite reservoir in the Smail No. 25 in St. James Field. The Geneva in this core (fig. 36) shows an abrupt upper contact with the overlying Middle Devonian carbonates of the Grand Tower Limestone similar to that observed in the St. James Field. This abrupt contact, from the brown sucrosic dolomite typical of the Geneva to the overlying dense, light gray grainstone, suggests the presence of a parasequence boundary. This core also contains a cherty, light brown dolomite interval underlying the typical highly porous, dark brown Geneva dolomite that is similar to the cherty interval that underlies the high-porosity zone in the Geneva in the St. James Field. The low-porosity cherty interval can be correlated on geophysical logs between the St. James and Lillyville fields.

The Lillyville and Lillyville North Fields formed along a northeast-trending fault block that shows steeply dipping beds to the southeast into the Illinois Basin and more subtle dips to the northwest. A seismic line over the Lillyville North Field shows a small reef with a pro-



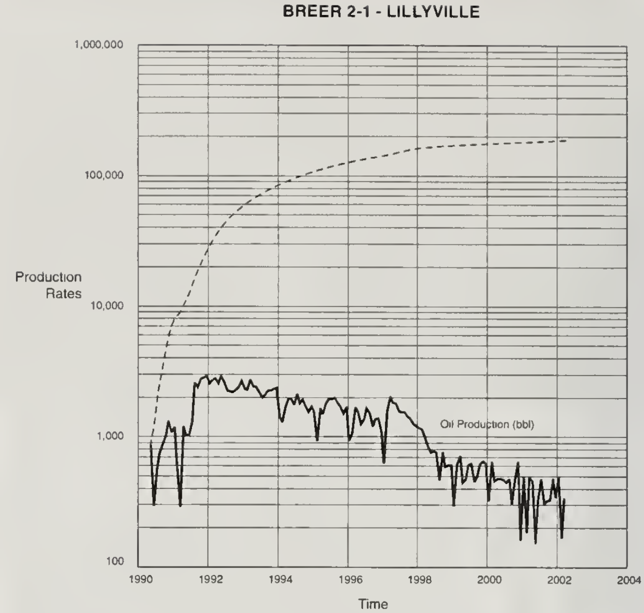


Figure 34 (left) Geophysical log from the Dart Energy Corporation Breer Heuerman No. 3-1 well in the Lillyville Field in Sec. 1, T8N, R6E, Effingham County, Illinois. Formation depths and cored interval are shown.

Figure 35 (above) Combined graphs of the monthly production (solid line) and cumulative production (dashed line) for the Dart Energy Corporation Breer-Heuerman No. 3-1 well and the offset Breer No. 2-1 well in Sec. 1, T8N, R6E, Effingham County, Illinois, showing production from the Geneva Dolomite reservoir exceeded 180,000 barrels of oil. (Unpublished data from the IHS Energy Group.)

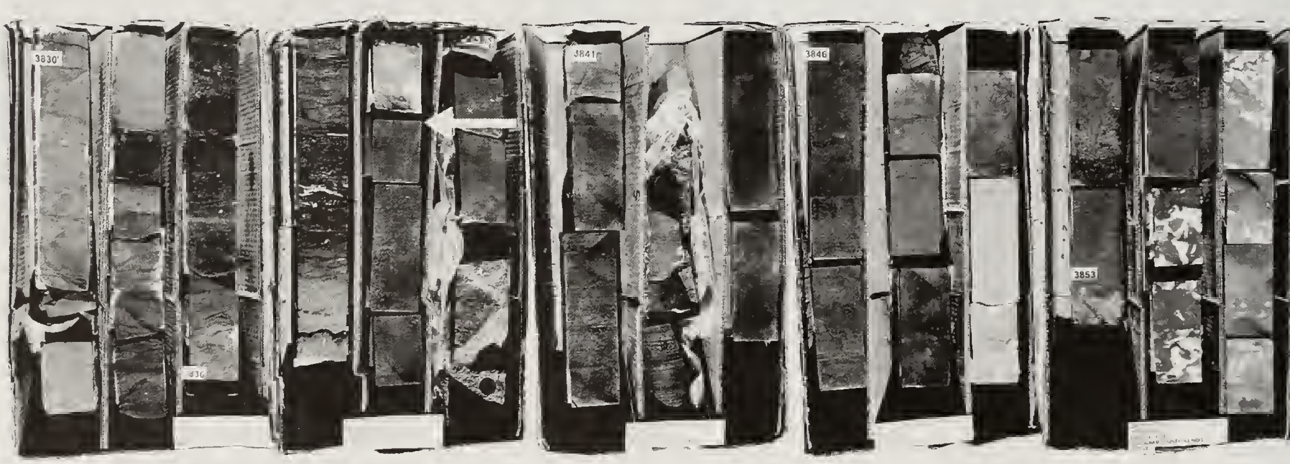


Figure 36 Core from the Dart Energy Corporation Breer-Heuerman No. 3-1 well (log in fig. 34) in the Lillyville Field, Effingham County, in Sec. 1, T8N, R6E. This core shows the abrupt upper contact with Middle Devonian carbonates of the Grand Tower Limestone (at arrow). This core contains a cherty interval in the Geneva Dolomite similar to that observed in the Plains Illinois No. 25 Smail at the St. James Field. The Geneva Dolomite extends north of Marion and southern Fayette Counties. Comparison of this well with the Smail No. 25 in St. James Field shows similar reservoir characteristics.

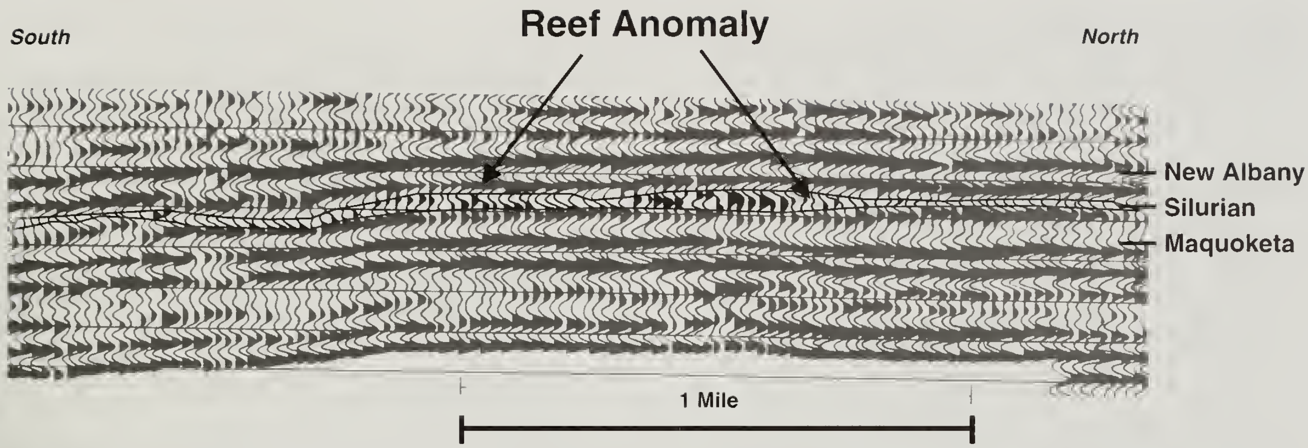


Figure 37 Seismic line over a Silurian reef at the Lillyville North Field in Effingham County, T9N, R7E. The structure over the reef is obvious on this seismic line. (Modified from Whitaker 1988.)

nounced structural rollover in the Silurian through Devonian section (fig. 37) that is easily observed and interpreted even on older seismic data (fig. 37) (Whitaker 1988). Most of the early seismic data acquired in Illinois are best suited for structural interpretation and, to a lesser degree, stratigraphic interpretation. The seismic line in figure 37 shows a positive amplitude waveform anomaly that is shaded in light gray in the Silurian and is unique to the reef facies (Whitaker 1988).

A large amount of vintage 2-D seismic data from the 1970s and 1980s for the Illinois Basin is available for purchase and reprocessing. These data can be useful for interpreting the presence of structural features and possibly defining reef location. However, recent successful uses of 3-D seismic to redefine structures has shown that 2-D seismic data have limitations and that the newer techniques may offer key information for locating overlooked prospects with high potential.

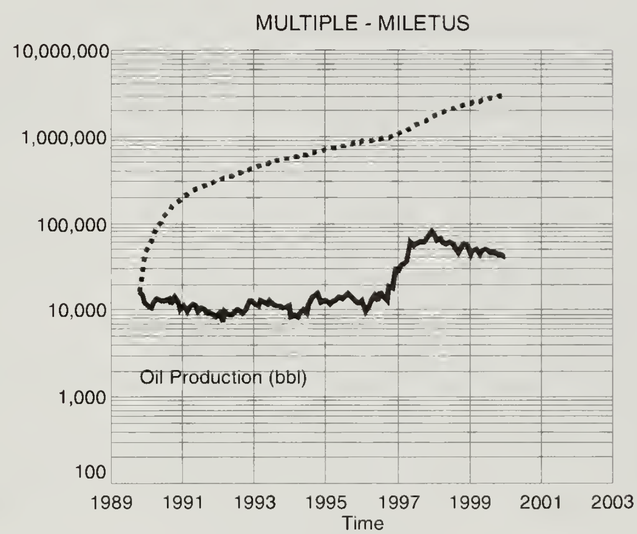


Figure 38 Combined graphs of the monthly production (solid line) and cumulative production (dashed line) from the Geneva Dolomite reservoir in Ceja Corporation wells in the Miletus Field showing a sharp increase in annual and cumulative production of over 2 million barrels of oil over a period of two and one-half years. (Unpublished data from the IHS Energy Group.)

Miletus Field

The Geneva Dolomite reservoir in the Miletus Field (figs. 1 and 2) was first drilled in the early 1980s, but the initial well was determined to be non-commercial and was abandoned. In late 1996, a second attempt was made to drill an exploratory well to the Geneva Dolomite. The second attempt was successful during fall 1996 when the Ceja Corporation Basset No. 3 was deepened into the Middle Devonian Geneva Dolomite and completed an open hole for 158 barrels of oil per day. Ceja Corporation subsequently developed the Geneva reservoir in the Miletus by drilling additional wells. The combined monthly production and cumulative production graphs (fig. 38) show a sharp increase in annual and cumulative production of more than 2 million barrels of oil over a period of 2.5 years. Monthly and cumulative production graphs from the Ceja Corporation Church No. 5, Hogan No. 2, Keller No. 2, and Basset No. 3 wells show very high monthly rates of production, some exceeding 10,000 barrels of oil (fig. 39). Each of these wells produced more than 200,000 barrels of oil between late 1996 and June 2000. These data illustrate the high pro-

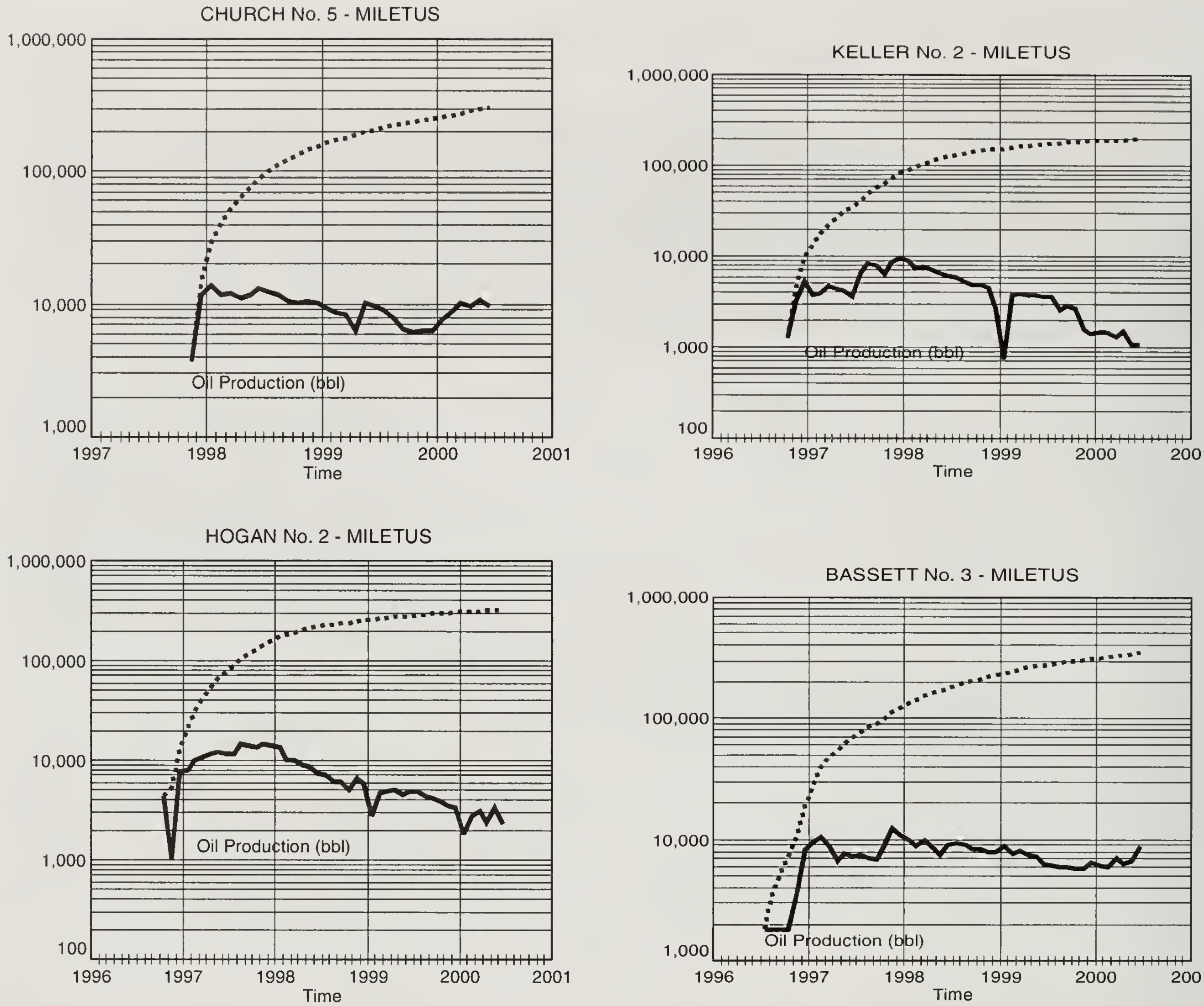


Figure 39 Combined graphs of the monthly production (solid line) and cumulative production (dashed line) from the Ceja Corporation wells in the Miletus Field: (a) Church No. 5, (b) Hogan No. 2, (c) Keller No. 2, and (d) Basset No. 3 wells show very high monthly rates of production, some exceeding 10,000 barrels of oil per month. Each of these wells produced over 200,000 barrels of oil between late 1996 and June 2000. These wells produce from a highly productive Geneva Dolomite reservoir that is adjacent to the new discovery underlying the Stephen A. Forbes State Park. (Unpublished data from IHS Energy Group.)

ductivity potential of good-quality Geneva Dolomite reservoirs.

A structure map on the top of the Geneva Dolomite porosity zone at the Miletus Field is shown in figure 40. The field lies on an anticlinal feature with 60 feet of closure on the top of the Geneva. The structure has a steep east flank and becomes more subtle in the shallower horizons, indicating recurrent movement of the structure through time. Details of the closure on the Geneva horizon show an arcuate geometry that possibly reflects an underlying atoll-like Silurian reef. Geneva production has been established in Sec. 27, 28, and 33, T4N, R4E. The most productive wells correlate with the maximum closures on the top of the Geneva (fig. 40).

An isopach map of the Middle Devonian carbonates overlying the Geneva Dolomite at the Miletus Field (fig. 41) shows that the pronounced thinning of these carbonates coincides with the crest of the structure shown on the structure map of the Geneva Dolomite (fig. 40). The thinning of the section over the structure could be the result of compensating deposition over a paleohigh that was induced tectonically, or by an underlying Silurian reef, or by a combination of the two. The stratigraphic section over Silurian pinnacle reefs commonly is thinner than the section adjacent to the reefs in the Illinois Basin.

The density-neutron log of the Hogan No. 2 well in Sec. 28 is shown in figure 42. The Middle Devonian carbonates start at a depth of 3,712 feet and are 65 feet thick in this well. The top of the Geneva Dolomite starts at 3,777 feet. For many wells, crossplot density-neutron porosity of the Geneva interval averages approximately 15%; porosity spikes exceed 20%.

Discovery at Stephen A. Forbes State Park

A new field discovery was made with the drilling of the Deep Rock Energy Corporation Warren No. 1-SDU, followed by a development well, the Carter No. 1-SDU. Both wells have a horizontal leg that was drilled under the Stephen A. Forbes State Park in Marion County, Illinois (fig. 1). The Warren No. 1-SDU—completed as a flowing well in March 2002—is one of the most prolific producers drilled in Illinois in the last 50 years. Production is reported at up to 3,000 barrels a day while choked down (Shirley 2002). A significant quantity of gas also is being produced from this well. The surface location for this well is 129' FSL 186' FWL SW NW, Sec. 33, T4N, R4E (fig. 1). Recent well locations and status of wells in the vicinity of this discovery are shown in figure 1. This new field discovery was defined using 3-D seismic technology. A third horizontal well location has been staked by Deep Rock Energy Corporation as of July 2002.

Petroleum Entrapment in the Geneva Dolomite

Figure 43 shows the structural grain at the base of the New Albany Shale, the Marion County boundary, and the southern boundary of the Geneva Dolomite. Also shown in shaded gray is the region where the Middle Devonian carbonates overlying the Geneva Dolomite thin to less than 60 feet. The best production from the Geneva Dolomite generally occurs where the overlying Devonian carbonates are thinner than 60 feet. Thinning of these overlying carbonates is apparent in all of the described fields, and in some wells there is less than 30 feet of carbonate.

In these fields, the ultimate seal appears to be the New Albany Shale. Therefore, the trap at these fields shows an inverse relationship between the amount of structural closure and the amount of thinning of the carbonates between the Geneva reservoir rock and the New Albany Shale seal (fig. 44). Petroleum entrapment occurs when structural

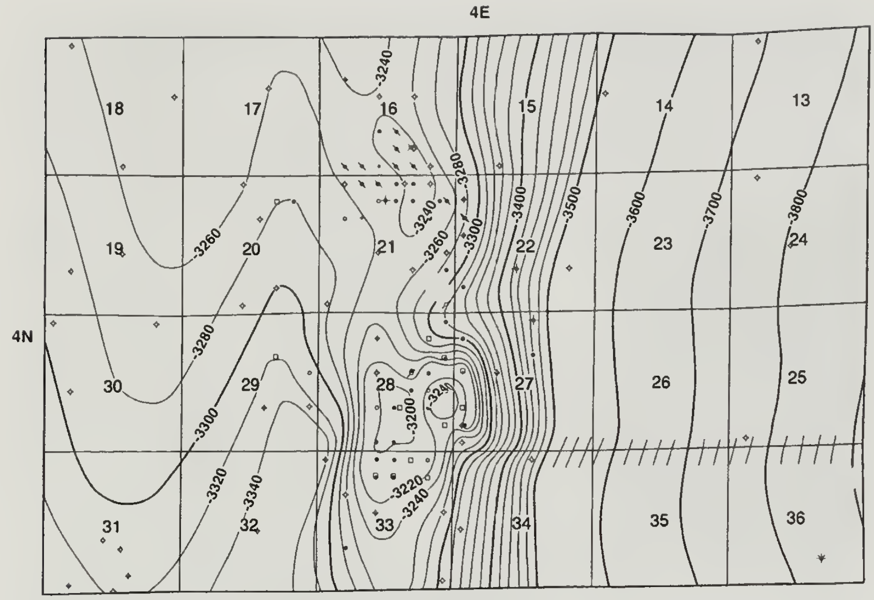


Figure 40 Structure map on the top of the Geneva Dolomite porosity at the Miletus Field. The field lies on a pronounced nose with closure of approximately 60 feet.

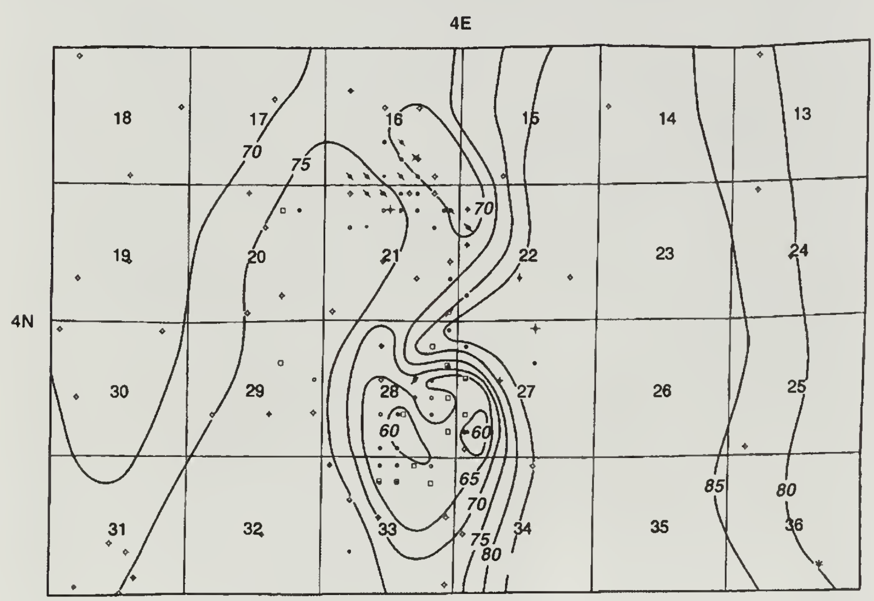
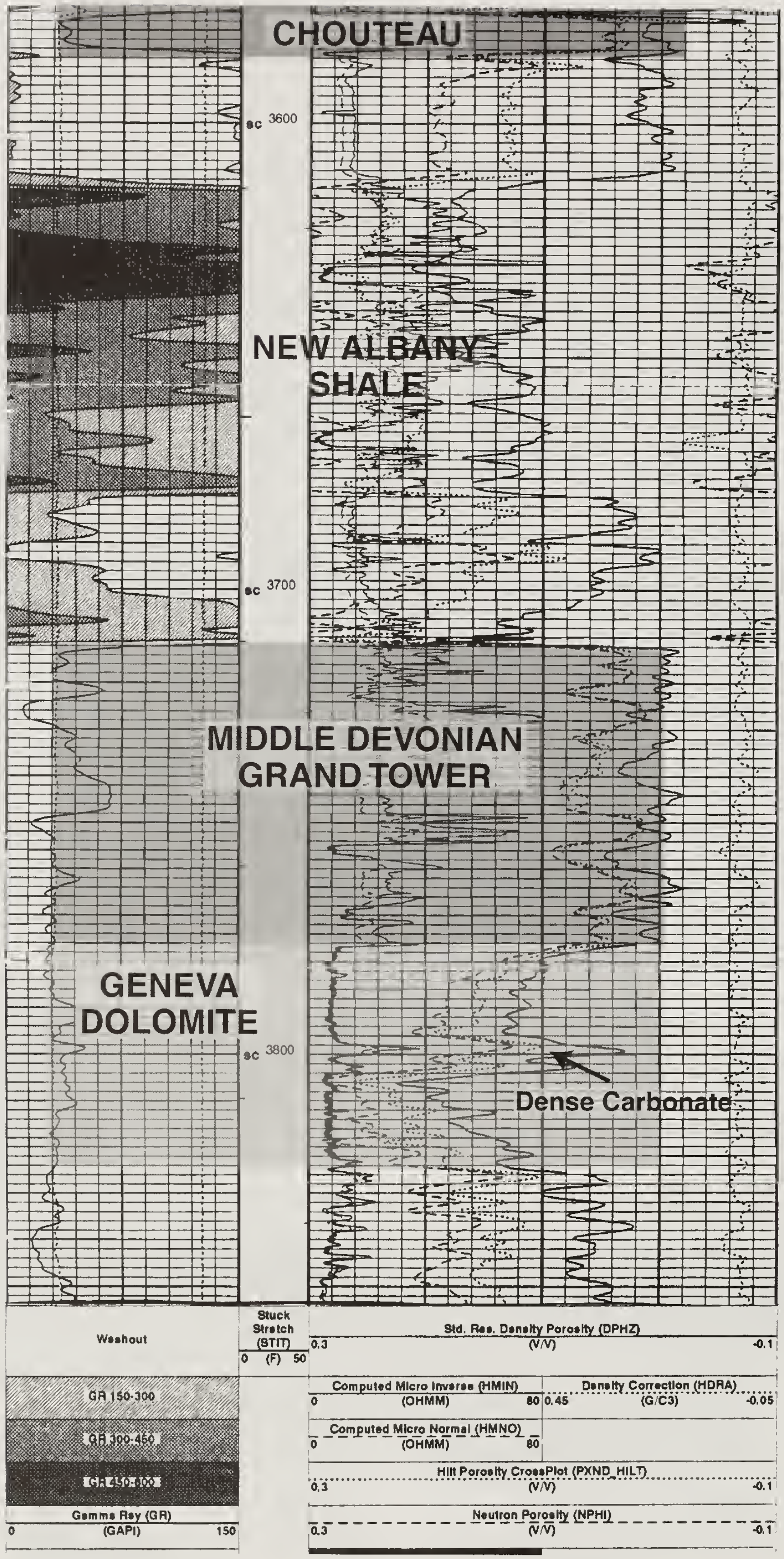


Figure 41 Thickness map of the Middle Devonian carbonates overlying the Geneva Dolomite at the Miletus Field. A pronounced thinning of these carbonates coincides with the crest of the structural nose shown on the structure map in figure 40.



closure on the impermeable New Albany Shale encompasses the Geneva Dolomite (fig. 44); therefore, greater structural closure requires less carbonate thinning, and subtle structures require a greater amount of carbonate thinning. Thinning of these carbonates overlying the Geneva can occur both within the Middle Devonian and by truncation of the carbonate section along the unconformable contact with the overlying Upper Devonian New Albany Shale. Much of the thinning is attributed to recurrent movement on deep-seated structures and the probable differential compaction associated with underlying Silurian reefs. Thinning of sediments overlying structural elements may also result from compensating deposition associated with either recurrent structural movement or differential compaction.

The geographic distribution of the Geneva Dolomite coincides with a regional thinning of the New Albany Shale, a relationship that is shown in figure 45. This coincidence may suggest that accumulation of Geneva carbonates was compensated for during Late Devonian deposition of the New Albany Shale. It is also possible that the region was high during deposition of the New Albany (Workman and Gillette 1956) but low during accumulation of the original Geneva Dolomite carbonates.

Events leading to the accumulation of the carbonates in the Middle Devonian Geneva Dolomite are shown in figure 12. Silurian reefs likely grew in areas that were structurally favorable to reef growth. At least some of these faulted structures were likely reactivated through time creating structural highs prior to accumulation of Middle Devonian carbonates. A long period followed when Silurian

Figure 42 Geophysical log of the Ceja Corporation Hogan No. 2 well in the Miletus Field in Sec. 28, T4N, R4E. This lease has produced over 250,000 barrels of oil since its discovery in 1996.

through Lower Devonian strata were eroded, forming the sub-Kaskaskia unconformity (Devera and Hansen-mueller 1991). Middle Devonian carbonates accumulated on the eroded surface during a major transgression of the sea, but Silurian reefs and major structures remained as high spots where the Middle Devonian carbonates were thinner.

Dolomitization

The dolomite of the Geneva and overlying units formed from replacement of carbonate sediments, as indicated by the common presence of dolomitized bioclastic allochems in the Geneva and of dolomitized algal structures and scattered dolomitized fossil allochems in the overlying units. The Geneva Dolomite occurs at the base of the northern dolomite facies of the Grand Tower and Jeffersonville Limestones in central Illinois and west-central Indiana. The northern dolomite facies of the Grand Tower and Jeffersonville also includes a microcrystalline dolomite facies that overlies the Geneva. This microcrystalline dolomite was named the Vernon Fork Member in Indiana (Droste and Shaver 1975). The close resemblance between the distribution of the Geneva Dolomite and that of the Vernon Fork dolomite of the Jeffersonville Limestone in Indiana and its equivalent in Illinois suggests a genetic relationship (Perkins 1963). Therefore, any mechanism that dolomitized the Geneva sediment must also explain dolomitization of the overlying unit.

Droste and Shaver (1975) suggest that dolomitization occurred in a supratidal sabkha (evaporitic) environment within a highly saline, Mg-rich pore water system. Although tidal flat conditions prevailed during deposition of the Vernon Fork dolomite, the sabkha dolomitization model as envisioned by Droste and Shaver (1975) cannot adequately explain the formation of over 150 feet of combined dolomite of the Geneva and the overlying unit. In sabkha environments, the Mg/Ca ratio of the pore fluid increases through evaporation and precipitation of calcium carbonates and calcium sulfates. The amount of dolomite formed in such environments is, however, very small and is restricted only to the upper 3 to 5 feet of sediments. In addition, any dolomite formed from a highly saline brine generated within the sabkha environments appears to be a direct precipitate (Machel and Mountjoy 1986, Hardie 1987) rather than a replacement of pre-existing sediments, a conclusion supported by scanning electron microscopy (Lasemi et al. 1989).

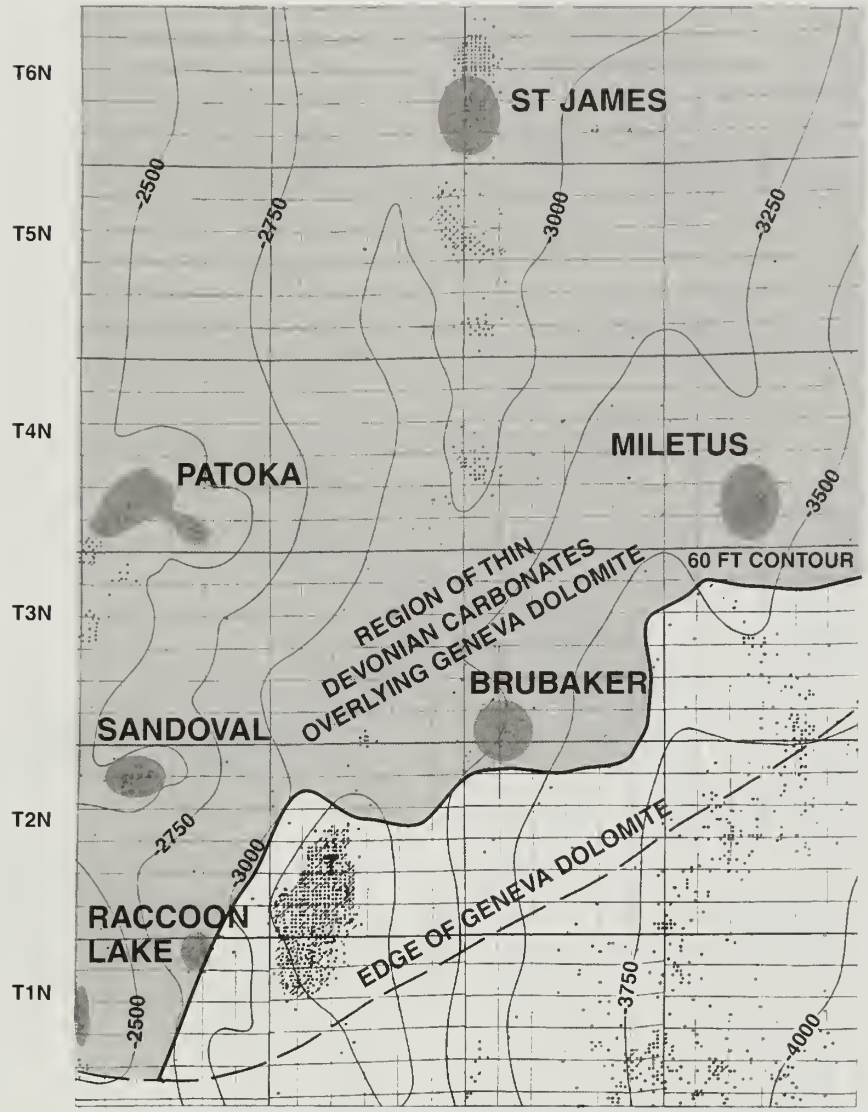


Figure 43 Map showing the structural grain at the base of the New Albany Shale in Marion County. Shaded areas in the region show where the Middle Devonian carbonates overlying the Geneva Dolomite thin to less than 60 feet. Better production from the Geneva Dolomite occurs where the overlying carbonates are thinner than 60 feet. These carbonates thin over all known Geneva Dolomite reservoirs in the region.

Mixing zone dolomitization, although extensively suggested as the mechanism for dolomitization of many carbonates in the 1970s and 1980s, has now been largely discounted (Machel and Mountjoy 1986, Hardie 1987). The very slow rate of dolomite precipitation (because of the ordered nature of

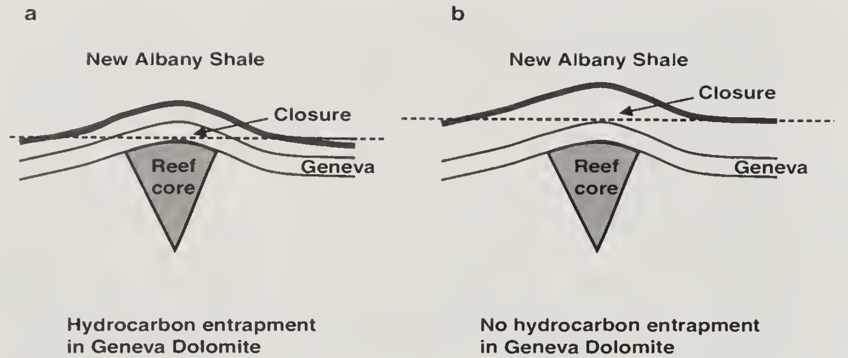


Figure 44 Cross sections of vertical seals, thickness of Middle Devonian carbonates, and their relationship to hydrocarbon entrapment in the Geneva Dolomite. (a) Hydrocarbon entrapment occurs when structural closure on the impermeable New Albany Shale draped over a reef encompasses the Geneva Dolomite. (b) Structural closure on the New Albany Shale does not encompass the Geneva Dolomite. (Modified from Whitaker 1988.)

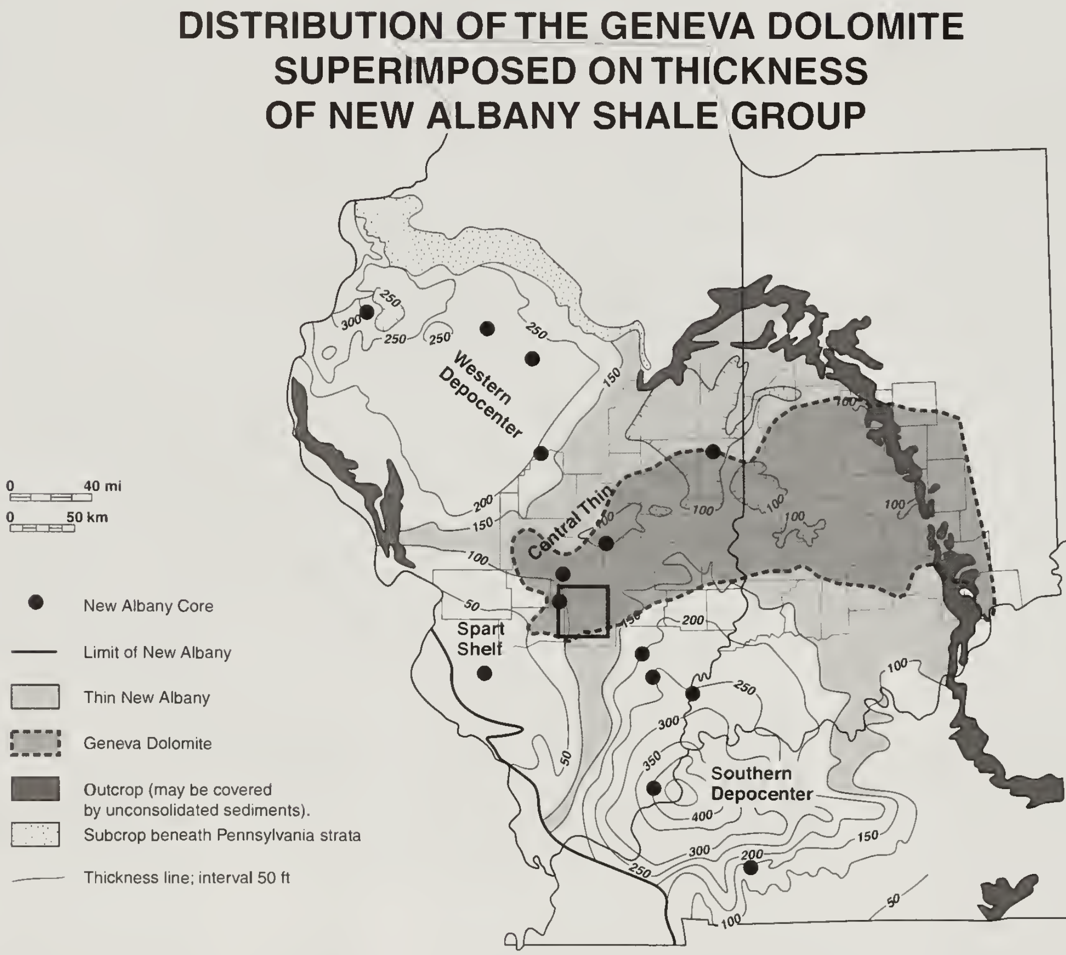


Figure 45 Geographic distribution of Geneva Dolomite coinciding with thin New Albany Shale. This coincidence may suggest that accumulation of Geneva carbonates was compensated for during late Devonian deposition of the New Albany Shale. This also may suggest that the region was high during deposition of the New Albany but low during the accumulation of the original Geneva Dolomite carbonates. (Modified from Cluff et al. 1981, Perkins 1963.)

dolomite crystals) relative to calcite dissolution would mean that dolomite could not precipitate in significant quantities in a mixing zone (e.g., Machel and Mountjoy 1986, Hardie 1987). As in the sabkha environment, the amounts of dolomite formed in mixing zones is small and texturally different from the ancient massive, replacement dolostones. At low temperatures, replacement dolomite requires long reaction times, and, as a result, mixing-zone dolomitization may occur only below major unconformities. However, many shallowing-upward cycles and even major unconformities with exposure surfaces lack dolomite (Machel and Mountjoy 1986).

Another dolomitization model commonly applied to dolomite sequences associated with evaporites is the seepage-reflux model (Adams and Rhodes 1960). Here, extensive evaporation results in a hypersaline brine with a high Mg/Ca ratio through precipitation of gypsum. The dense and hot, highly alkaline and magnesium-rich brine is capable of percolating through porous and permeable underlying carbonate sediments resulting in extensive dolomitization. Unfortunately for this mechanism, there is no evaporite deposit associated with the Geneva Dolomite and the overlying Vernon Fork Member or its equivalent in Illinois. A few thin brecciated laminae and minor calcite pseudomorphs after gypsum in the dolomite above the Geneva (Perkins 1963) suggest the minor deposition of evaporites, but not enough to explain the formation of thick, widespread dolomite. Furthermore, as in the sabkha model, a highly saturated, hypersaline brine created during seepage-reflux would most likely have led to precipitation of dolomite rather than the replacement of preexisting carbonate sediments.

A variation of the reflux model as suggested by Simms (1984) is now favored by many as an effective mechanism for dolomitization in modern and ancient carbonate platforms that experienced hydrographic restriction. In this model, during a long residence time, the seawater trapped on the platform top fluids becomes progressively concentrated by evaporation (even in humid climates) to greater than normal salinities. The slight difference in the density of the water on the shallow platform and that of the pore water generates a long-term, vertical fluid flow system that is capable of causing large-scale dolomitization of platform sediments. Hypersaline conditions are not required, and the lack of evaporites does not preclude dolomitization through reflux. This flow system is potentially large scale, affecting rocks over a region of thousands of square miles to depths of 1,000 feet or more (Simms 1984), assuming no aquicludes (such as evaporites or clay beds) prevent downward flow. If long-lived, such a flow system can produce massive replacement dolomite that cuts across formation boundaries (Hardie 1987).

Hydrographic restriction occurred in shallow lagoonal and tidal flat settings that developed over the Vandalia Arch. According to Workman and Gillette (1956), the Vandalia Arch was a depositional high during deposition of the Grand Tower and Jeffersonville Limestones that trended northeast-southwest from the Clinton County area in southwestern Illinois to the Indiana state line in Edgar and Clark Counties. Distribution of the Geneva and the overlying units of the Grand Tower and Jeffersonville indicates that the arch extended into west-central and central Indiana. The New Albany Shale thins over the position of this arch. Because of a lack of evidence indicating tectonic influence, Cluff et al. (1981) rejected the term "Vandalia Arch" and informally referred to the area of thin New Albany as the "central thin" (Nelson 1995). However, we find that the dolomitization of the Grand Tower Formation argues for the use of the term Vandalia Arch. Evaporation of seawater in restricted lagoonal and tidal flat settings on the arch could have formed denser fluids that percolated through the underlying carbonate sediment. The reflux began toward the end of the Geneva deposition and continued through deposition of the overlying Vernon Fork Member of the Jeffersonville in Indiana and its equivalent unnamed unit of the Grand Tower in Illinois. The lack of evaporites indicates that the environment was not hypersaline. Deposition of over 100 feet of carbonates with features that indicate deposition under restricted marine conditions in the Grand Tower and Jeffersonville over the Geneva Dolomite suggests that such a flow system could have persisted for a relatively long time.

Conclusions

Recent prolific oil discoveries in the Geneva Dolomite Member of the Grand Tower Limestone have again focused attention on this Middle Devonian rock unit in the Illinois Basin. The Miletus Field in Marion County, Illinois, and the March 2002 discovery of a new Geneva pool one mile to the south are at the center of this attention. Considering that initial production from the recently completed horizontal well is approximately 3,000 barrels per day, that the daily production from individual Miletus Field vertical wells exceeds 300 barrels per day, and that there is a concentration of nearby prolific Geneva fields, the Geneva Dolomite has been established as having excellent reservoir qualities in Marion County, Illinois. Although this summary has focused on the Marion County, Illinois, area, the Geneva Dolomite's characteristics and the exploration and development techniques used at Miletus and the other fields are universal within the Geneva fairway in Illinois and Indiana.

The Geneva Dolomite Member is recognized as a highly dolomitized facies of the Grand Tower Limestone in Illinois and the Jeffersonville Limestone in Indiana. A fossiliferous, open marine, partly biostromal to biohermal facies containing abundant corals and stromatoporids in the Grand Tower and the Jeffersonville correlates with and is comparable with the brown, vuggy, porous, and permeable zone that characterizes the best reservoir interval of the Geneva Dolomite. The shape, size, and distribution of fossils in the Grand Tower and Jeffersonville match the shape, size, and distribution of the moldic or vuggy porosity of the Geneva Dolomite Member, although dolomitization and dissolution have partially to totally obscured the original fossil content in the Geneva.

A variation of the reflux model as suggested by Simms (1984) is proposed as the mechanism for dolomitization of the Geneva Dolomite and the overlying units of the Grand Tower and the Jeffersonville in Illinois and Indiana. The model employs an increase in the salinity of seawater over time by evaporation in a shallow restricted sea. An increase in the density of the water in the shallow lagoons with respect to that of pore water generated a long-term, vertical fluid flow system that was capable of causing large-scale regional dolomitization of the underlying sediments, including the Geneva.

The Geneva Dolomite occurs in the subsurface in an arcuate belt or fairway, which curves northwest from the outcrop in southeastern Indiana, through west-central Indiana, bending to the southwest through Clark and Edgar Counties in Illinois extending as far west as Montgomery, Bond, and Clinton Counties, Illinois. The Geneva is generally up to 50 feet thick in central Illinois and is locally thicker. Cuttings from some wells show up to 90 feet of Geneva Dolomite in some areas in Illinois. The Geneva typically has a distinctive brown color caused by disseminated organic material. When the dolomite is dissolved in dilute hydochloric acid, the brown organic residue floats on the surface of the acid, a characteristic that separates it from other Devonian carbonates (Schwalb 1955).

Oil is trapped in the Geneva on pronounced, closed structures. Much of this structure is related to tectonics, but, in many cases, the closure also seems to be caused or enhanced by the draping of younger Middle Devonian strata over Silurian reefs. Some of the most prolific Geneva wells are associated with underlying Silurian reefs. Some uplifted fault blocks in the Illinois Basin have coincidental reef structures, suggesting that the Silurian reefs may have developed preferentially on paleostructures that projected above their surroundings.

The following is a list of the characteristics that make the Geneva Dolomite a particularly attractive target for further exploration and development:

- regionally widespread and correlative, highly porous, and permeable reservoir rock;
- relatively shallow reservoirs with drilling depths of less than 4,200 feet;
- active water drive combined with gas solution drive;
- common high-volume completions and cumulative per well production greater than 100,000 barrels;
- high oil gravity (40 API and higher); H_2S is a minor drawback; and
- seismically definable, closed structures and reef anomalies.

Seismic surveys have been used successfully in the Illinois Basin to locate Geneva Dolomite oil pools. Use of established 3-D seismic technology should significantly improve the ability to locate new pools, and the drilling success rate should increase. The capability of the 3-D tool to accurately pinpoint the location of subtle reef structures has been established at the Tonti Field. The Miletus Field Geneva reservoir and the new field Geneva discovery immediately to the south were precisely delineated using 3-D technology. Forefront horizontal drilling techniques utilizing 3-D data to pinpoint the location of the drill bit while drilling was combined with underbalanced drilling technology to complete the well successfully in the new discovery reservoir. These examples show the successful application of newer, yet readily available, technologies to re-examine old fields and trends to discover and develop economically significant quantities of oil in the mature Illinois Basin.

Acknowledgments

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