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# Final Report

## A Systems Approach to Identifying Exploration and Development Opportunities in the Illinois Basin: Digital Portfolio of Plays in Underexplored Lower Paleozoic Rocks


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# A Systems Approach to Identifying Exploration and Development Opportunities in the Illinois Basin: Digital Portfolio of Plays in Underexplored Lower Paleozoic Rocks

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## ABSTRACT

This study examined petroleum occurrence in Ordovician, Silurian and Devonian reservoirs in the Illinois Basin. Results from this project show that there is excellent potential for additional discovery of petroleum reservoirs in these formations. Numerous exploration targets and exploration strategies were identified that can be used to increase production from these underexplored strata. Some of the challenges to exploration of deeper strata include the lack of subsurface data, lack of understanding of regional facies changes, lack of understanding the role of diagenetic alteration in developing reservoir porosity and permeability, the shifting of structural closures with depth, overlooking potential producing horizons, and under utilization of 3D seismic techniques. This study has shown many areas are prospective for additional discoveries in lower Paleozoic strata in the Illinois Basin.

This project implemented a systematic basin analysis approach that is expected to encourage exploration for petroleum in lower Paleozoic rocks of the Illinois Basin. The study has compiled and presented a broad base of information and knowledge needed by independent oil companies to pursue the development of exploration prospects in overlooked, deeper play horizons in the Illinois Basin. Available geologic data relevant for the exploration and development of petroleum reservoirs in the Illinois Basin was analyzed and assimilated into a coherent, easily accessible digital play portfolio.

The primary focus of this project was on case studies of existing reservoirs in Devonian, Silurian, and Ordovician strata and the application of knowledge gained to future exploration and development in these underexplored strata of the Illinois Basin. In addition, a review of published reports and exploration in the New Albany Shale Group, a Devonian black shale source rock, in Illinois was completed due to the recent increased interest in Devonian black shales across the United States. The New Albany Shale is regarded as the source rock for petroleum in Silurian and younger strata in the Illinois Basin and has potential as a petroleum reservoir.

Field studies of reservoirs in Devonian strata such as the Geneva Dolomite, Dutch Creek Sandstone and Grassy knob Chert suggest that there is much additional potential for expanding these plays beyond their current limits. These studies also suggest the potential for the discovery of additional plays using stratigraphic concepts to develop a subcrop play on the subkaskaskia unconformity boundary that separates lower Devonian strata from middle Devonian strata in portions of the basin. The lateral transition from Geneva Dolomite to Dutch Creek Sandstone also offers an avenue for developing exploration strategies in middle Devonian strata. Study of lower Devonian strata in the Sesser Oil Field and the region surrounding the field shows opportunities for development of a subcrop play where lower Devonian strata unconformably overlie Silurian strata. Field studies of Silurian reservoirs along the Sangamon Arch show that opportunities exist for overlooked pays in areas where wells do not penetrate deep enough to test all reservoir intervals in Niagaran rocks. Mapping of Silurian reservoirs in the Mt. Auburn trend along the Sangamon Arch shows that porous reservoir rock grades laterally to non-reservoir facies and several reservoir intervals may be encountered in the Silurian with numerous exploration wells testing only the uppermost reservoir intervals. Mapping of the Ordovician Trenton and shallower strata at Centralia Field show that the crest of the anticline shifted through geologic time. This study illustrates that the axes of anticlines may shift with depth and shallow structure maps may not accurately predict structurally favorable reservoir locations at depth.

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**Executive Summary**

Devonian, Silurian and Ordovician reservoirs account for approximately 8% of the petroleum produced in Illinois. These reservoirs are illustrative of the potential for Lower Paleozoic production and the opportunity for new exploration targets in the Illinois Basin. Devonian reservoirs, both siliciclastic and several types of carbonate, have been established but lightly explored. Silurian reservoirs, commonly associated with various reef settings, exhibit compartmental characteristics that extend both development and new play production. Non-reef Silurian production has also been established. Ordovician reservoirs are limited to the Trenton carbonate, closed structure fields leaving the prolific Albion-Scipio type hydrothermal play as a potential target. The Lower Paleozoic units have not been extensively explored, in part because of the greater drilling depths and the common practice of testing deeper horizons in fields where shallower production has been established. This strategy has brought sporadic results because structural closure may shift with depth and numerous traps in Lower Paleozoic units are stratigraphic in nature.

This project has been undertaken in conjunction with the Indiana Geological Survey, the Kentucky Geological Survey and the Illinois State Geological Survey. The project has focused on study of existing petroleum reservoirs and the potential for new discoveries in lower Paleozoic units. Major tasks for this project include creating a digital catalogue of existing reservoirs and developing models of the stratigraphic and structural framework of Lower Paleozoic units using available subsurface data. Many of these products are available in digital format on the websites of the Illinois, Indiana and Kentucky Geological Surveys. Results from these studies suggest that applying new exploration strategies to the Illinois Basin can result in significant new discoveries in Lower Paleozoic units.

Several major lower Paleozoic field discoveries were made during the course of this project and these strata have received more exploration interest from small independent petroleum companies. A Petroleum Technology Transfer Counsel (PTTC) sponsored workshop highlighting findings from field studies undertaken for this project was presented by Illinois Geological Survey Staff on March 5, 2008 at the annual Illinois Oil and Gas Association Meeting in Evansville, Indiana. There was standing room only with over 100 attendees at the workshop, most representing small producers active or interested in becoming active in exploration in the Illinois Basin. The workshop was well received and generated additional exploration interest lower Paleozoic units.

Findings include additional exploration and development potential in many lower Paleozoic strata. There is reservoir potential in the New Albany Shale Group in addition to the established scientific consensus that the New Albany Shale is the source rock for nearly all of the petroleum found in Illinois Basin reservoirs Silurian in age or younger. There are secondary sources in Ordovician age strata that appear to be confined to Ordovician age reservoirs. Field case studies show that several different exploration strategies can be implemented to increase discoveries. Additionally, improved development strategies may be used to increase petroleum recovery in existing fields. Middle Devonian Geneva Dolomite and Dutch Creek Sandstone reservoirs can be highly prolific and are commonly associated with structurally high features or are draped over underlying Silurian reefs. These formations are frequently highly porous.   A stratigraphic entrapment component is an exploration strategy that does not appear to be in use. Exploration for subcrop or unconformity traps in lower Devonian strata also has potential

in some portions of the basin. Case studies of Silurian reservoirs in the Mt. Auburn trend along the Sangamon Arch show that there is a likelihood of overlooked reservoirs particularly in wells that only penetrate the uppermost portion of Niagaran strata which is usually the case. Development of reservoir quality porosity and permeability is facies related and occurs in dolomitized intervals of fossiliferous grainstone. The distribution of these reservoirs is complex and several intervals were identified and mapped in the Mt. Auburn trend. Study of lower Paleozoic reservoirs in the Centralia field shows that the crest of the anticline in the field shifts with depth. This illustrates that the practice of drilling deeper on shallow structures may not be an effective exploration strategy for lower Paleozoic reservoirs. Study of Trenton outcrops in northern Illinois shows that there are several types of porosity development in these rocks and faulting and karstification along fault trends has played a major role in porosity development and permeability pathways. These findings may have application and development of Trenton reservoirs in deeper portions of the basin.
A synopsis of major findings follows:

- The Lower Paleozoic strata in the Illinois Basin have a strong potential to contain significant economically viable reserves.
- The New Albany Shale is an excellent source rock with total organic carbon values upwards of 10%, and is in the oil generation window throughout the Basin.
- The New Albany Shale is under-explored for natural gas that is co-generated with the oil. Several tests have been conducted with varied results.
- The Middle Devonian strata have significant potential, especially when new exploration techniques, such as 3-D seismic, are applied.
- Lower Devonian cherts are largely un-explored outside of a very limited region. Additional fields could contain significant untapped reservoirs.
- Some Devonian reservoirs are related to erosion of and deposition on actively growing positive areas and structures (e.g. Sesser and Assumption Consolidated oil fields).
- Much Silurian production is connected with reef structures, either directly as in the pinnacle reef plays and the patch reefs of the Mt. Auburn Trend, or as associated strata as in the Springfield East play.
- There is still potential for additional pinnacle reef discoveries.
- 3-D seismic is an under-utilized tool in the Illinois Basin.
- Existing Trenton production is mostly limited to areas with high degrees of closure, beneath shallower production on large structures.
- Porosity development in the Trenton production is tied to diagenetic alteration.
- The primary reason the Trenton is underexplored because it is the lowest of the proven oil strata in the Illinois Basin.
- Fractures resulting from deeper basement faults can create significant off-structure potential.
- Axial shifts and erosional events can mask Trenton highs, exploration needs to evaluate structural variation at depth.
- There is potential for a sag or down drop fault block pay in the Trenton, similar to Albion-Scipio in the Michigan Basin and recent discoveries in the Northern Appalachian Basin

## Methodology

The Illinois State Geological Survey, Indiana Geological Survey and the Kentucky Geological Survey have interpreted thousands of well records to construct basinwide cross sections, contoured structure maps and isopach maps. Deep well data has been analyzed. Detailed cross sections, structure maps and thousands of well records were analyzed and interpreted to develop a catalogue of existing Lower Paleozoic fields. Data from previous studies as well as new data were analyzed to develop products for exploration and development of reservoirs in lower Paleozoic strata in the Illinois Basin. Samples were selected and analyzed from existing oil collections and new oil samples have been collected and analyzed for gas chromatography analyses. Available cores from Lower Paleozoic strata were examined, described and sampled for thin sections. New field studies were completed. Regional cross sections were constructed and interpreted. Regional contoured structure maps and select regional seismic lines were analyzed to examine the structural evolution of the Illinois Basin.

New field studies have been completed for Middle Devonian, Lower Devonian, Middle Silurian, Lower Silurian and Ordovician Trenton reservoirs. Hundreds of well files have been interpreted and pertinent data entered into the ISGS well data file. Detailed maps have been constructed that provide new understanding of play trends in Lower Paleozoic units in the Illinois Basin.

Construction of 10 digital regional cross sections across the Illinois Basin was completed. Contoured structure maps on the Beech Creek “Barlow” Limestone and Ste. Genevieve Limestones at 100 and 20 foot contour intervals were completed and are available on the ILoil website. Formation depths were interpreted from geophysical logs and assembled into a database for construction of contoured structure maps for the top and base of the New Albany Shale, base of Silurian and top of the Trenton/Galena Formations. Over 100,000 formation depths have been mapped, edited and added to the digital data for construction of contoured structure maps.

Data for waterflood units in Lower Paleozoic units has been added to the ILoil website and is available online including graphs of annual petroleum and water production. Over 140,000 geophysical logs have been scanned in areas best suited for exploration in Lower Paleozoic units. These logs are accessible for viewing and downloading from the ILoil website.

Publications and contract reports pertinent to exploration and development of Lower Paleozoic reservoirs have been added to the ISGS website. Examples of the types of information included in these publications are statewide structure maps on the Ordovician Trenton and Devonian New Albany Shale as well as Field Studies of the Devonian Hoing Sandstone reservoir in the Colmar-Plymouth Field, and Silurian Kankakee dolomite reservoir at the Buckhorn Field in Adams, Brown and Schuyler Counties, Illinois.

## Project Results and Discussion

### Overview Discussion of Devonian, Silurian, and Ordovician Reservoirs

An overview discussion will take place in descending order starting with Middle Devonian reservoir, then Lower Devonian, followed by Niagaran age Silurian reservoirs, then Lower Silurian reservoirs followed by Ordovician Trenton/Galena reservoirs. Correlation charts developed by the Illinois Basin Consortium and shown in figures 1 and 2 were used in this study to construct cross sections and to develop structure and isopach maps. Units that produce from existing Devonian, Silurian and Ordovician age lower Paleozoic units are identified by green dots in the correlation charts (figures 1 and 2). A generalized stratigraphic column of strata in the Illinois Basin highlighting the major unconformities and erosional surfaces is shown in fig. 3. There is a wide distribution of Lower Paleozoic reservoirs (fig. 4). These reservoirs account for approximately 8 percent of production in the Illinois Basin.

### New Albany Shale review

There has been increased interest in the New Albany Shale in recent years as production from other Devonian age black shales has been realized in numerous US basins.The Upper Devonian New Albany Shale is a thick, organically-rich source rock that is present virtually everywhere that oil and gas are produced in the Illinois Basin. It is thickest in southern Illinois and western Kentucky, where it is more than 400 feet thick.

- The source rock is predominantly Type II Oil Prone material and is the major source of oil in Silurian through Pennsylvanian reservoirs in the Illinois Basin.
- Numerous studies of the New Albany Shale in Illinois (by Cluff et. al. 1981, Cluff and Barrows ) describe an organic rich source rock that is generally in the oil window with some areas of intense generation that likely produced gas in the deep basin and in the Fluorspar District in southeastern Illinois.
- There has been recent gas exploration in the New Albany in Illinois, sparse reports of gas discoveries to date have been on anticlinal structure domes, along the LaSalle Anticline trend, at Russellville and Westfield, and on the Clay City Anticline.
- Although the original gas wells drilled are vertical wellbores, it is thought that production can be improved using horizontal drilling programs, such as one recently undertaken at Russellville.
- In Indiana, exploration of the New Albany in predominantly reef-drape structures along the Terre Haute Reef Bank has resulted in several gas discoveries.
- The gas is likely from a mix of thermogenic and biogenic processes. Whether this reef drape play is a model for a gas play in the New Albany in Illinois has yet to be determined.
- A recent horizontal wildcat effort by Bravo is located in southern Saline County, south of the Cottage Grove Fault, and flanking the Hicks Dome feature. The gas play in this area would be a thermogenic play if it proves to be commercially viable. Bravo Natural Gas, LLC (Bravo) Tulsa, Oklahoma, drilled two exploratory New Albany Shale wells in 2006 on a 150,000 acre block controlled by the company in Saline County, Illinois. Bravo chose this geologic area due to its proximity to the thermally mature Hicks Dome area, in the thick untested New Albany Shale penetrations on the acreage block, and

depths/pressures sufficient to yield significant gas in place.
The Gray #1-34, Section 34-T9S-R6E, was originally drilled vertically to a depth of 4580’ to gather extensive electric log data. After plugging back, a 3500’ horizontal leg was drilled in the New Albany Shale and tested in the Gray #1-34H well. Gas shows, sample evaluations, gas analysis, and electric log data confirm that the Gray #1-34H well penetrated highly fractured thermogenic New Albany Shale. Subsequently, the Herrmann #1-7, Section 7-T10S-R7E, was drilled three miles to the southeast of the Gray #1-34 at an updip location. Gas shows were also encountered throughout the New Albany Shale in the 4324’ Herrmann #1-7 well. Both wells penetrated over 300’ of very organic, black carbonaceous New Albany Shale.

**Reservoirs in Devonian Strata**

The sub-Kaskaskia unconformity separates oil productive Middle Devonian dolomite and dolomite cemented sandstones from Lower Devonian through Silurian strata. In the central and deepest portion of the basin the sub-Kaskaskia unconformity separates Middle Devonian carbonates from Lower Devonian carbonates and siliciclastic cherts. In the western portion of the Illinois Basin, the sub-Kaskaskia unconformity represents a much longer period of erosion than in the central portion of the basin. In some areas lower Devonian through upper Ordovician strata have been eroded and Middle Devonian units may directly overlie Ordovician strata. Interpretation of stratigraphic relationships and analysis of facies changes and diagenetic alteration of sub-Kaskaskia rocks shows good potential for additional discoveries in subcrop plays in Middle Devonian through Lower Silurian rocks.

Details of the stratigraphic relationship of Middle Devonian and Lower Devonian reservoir units are shown in figure 5. Middle Devonian oil productive units include the Hoing Sandstone member of the Cedar Valley Formation, the Lingle Formation, and the Dutch Creek Sandstone and Geneva Dolomite members of the Grand Tower Formation. Middle Devonian strata are separated from Lower Devonian rocks by the sub-Kaskaskia unconformity. Lower Devonian producing horizons include the Clear Creek Chert, Backbone Limestone, and Grassy Knob Chert.

The youngest lower Paleozoic reservoirs in the Illinois Basin are found in the Middle Devonian Hoing Sandstone member of the Cedar Valley Formation in westernmost Illinois in the Colmar- Plymouth field. The field was discovered in 1914 and produces from a shallow depth of 450 feet below the surface. It has produced 5 million barrels of oil from 500 wells in an area of 2,500 acres. There is approximately 50 feet of structural closure in the field. The reservoir rock is composed of well sorted, well rounded, medium-grained sandstone cemented with dolomite. Porosity of the reservoir interval averages 19% in core samples and the average permeability exceeds 1 darcy in core samples.

The lowermost members of the Middle Devonian Grand Tower Formation contain some of the most prolific lower Paleozoic reservoirs in the Illinois Basin. The Dutch Creek sandstone grades laterally into the Geneva Dolomite, both are the lowermost members of the Grandtower Formation and unconformably overlie Lower Devonian units. The stratigraphic and facies relationships of these units are shown in the regional cross section in figure 6. The distribution of these two facies as mapped by ISGS geologists in 1965 is shown in figure 7. The 1965 map shows a distinct tongue of Dutch Creek Sandstone with limited areal distribution. Recent work shows a much broader distribution for the Dutch Creek Sandstone, increasing the potential area of this play.

**Middle Devonian Dutch Creek Sandstone Reservoirs**

The Dutch Creek Sandstone is found just above the pre-Middle Devonian unconformity. The sand source is thought to be reworked St Peter Sandstone and other older Ordovician sands that were exposed on the ancient Ozark highlands and swept into the Illinois Basin (Collinson, 1969.) Meents (1965) mapped a regional tongue of Dutch Creek sand primarily located in Wayne County, but North (1969) suggested the Dutch Creek was more widely distributed in the basin.

The Dutch Creek Sandstone is dolomite cemented, fine to medium grained with well sorted and well rounded quartz grains. The histogram of core measured porosity shown in figure 8 illustrates distribution of samples in the 7 – 12% porosity range as well as a distribution of values in the 14 – 20% range. Permeability shown in figure 9 ranges from 10 – 50 millidarcies in samples of marginal reservoir quality and from 70 md to greater than 1 darcy in samples from good to excellent reservoir quality.

Existing Dutch Creek production is primarily located in Wayne County. Production is associated with localized highs contoured on overlying younger Middle Mississippian marker horizons such as the Beech Creek "Barlow" Limestone. These localized highs are not evident on regional Barlow contoured structure maps (figure 10). The regional Barlow map shows that the Dutch Creek pays are found on the northern margin of the deep structural drop-off into the Fairfield Basin.

A closer look at the Dutch Creek pays, imaged on the ISGS vintage 20 foot Barlow contour maps, tells a different story (fig. 11). At Mayberry field, 16 Dutch Creek producers have a strong association with a sharply defined anticlinal nose that trends East-West, dying out into the deep Fairfield Basin to the east.

At Aden field, located on a sharply defined, narrow, elongate anticline that trends directly south off the broad toe of the massive Clay City anticlinal structure, there are 3 Dutch Creek producers and one pay described in the Grand Tower "fracture zone." The pays are associated with more than 20 feet of closure on the crest of the structure. One of these Dutch Creek producers, the Texaco Silverman #16, flowed on choke for 5 years and had a cumulative production of about a half a million barrels. It is one of the deepest producers in the basin at below 5400 feet.

At Mill Shoals field, the Dutch Creek pay is also associated with another sharply defined, narrow, elongate anticline that trends directly south off the toe of the Clay City Anticline. The Dutch Creek pays are on the highest part of the structure with at least ten feet of closure.

The structures defining these fields may be associated with deep basement linear features and it seems possible that episodic movement along zones of weakness may have resulted in fractured reservoirs. Other Dutch Creek pays are associated with sharply defined anticlinal structures, such as at Goldengate Consolidated field, which also flanks the northern margin of the deep Fairfield Basin. There, 18 Dutch Creek producers are found on the crest of the structure with over 20 feet of closure.

**Middle Devonian Geneva Dolomite Reservoirs**

Fields in the Geneva Dolomite in Illinois have been documented in the recent ISGS publication, Illinois Petroleum Series158 titled: The Origin of Prolific Reservoirs on the Geneva Dolomite (Middle Devonian), West-Central Illinois Basin. The Geneva Dolomite is a widespread, brown sucrosic porous dolomite with localized areas of highly developed porosity and permeability. The distribution of the Geneva Dolomite is shown in figure 12. The most productive Geneva Dolomite reservoirs are associated with pronounced structural closure caused by differential compaction over older Silurian age pinnacle reefs. Hydrocarbon becomes entrapped in the younger, porous strata that is draped over the reefs. The Devonian New Albany Shale is the ultimate seal for Geneva Dolomite reservoirs studied to date, including Sandoval, Raccoon Lake, Tonti, Miletus and the oil field at Stephan A. Forbes State Park. Geneva Dolomite reservoirs are also associated with pronounced structural closures at Patoka, Centralia, Salem, and St. James fields.

Maps constructed using modern log suites in the Miletus Field illustrate some of the subtleties of the underlying pinnacle reefs that are not evident in maps constructed for earlier publications that show nearly circular bulls-eye type structural closure at older fields such as Sandoval and Raccoon Lake. A recently constructed structure map, contoured on the top of the Geneva, shows that pinnacle reefs are not flat topped, they undulate or form as clusters (fig. 13). The underlying Silurian Pinnacle reef at Miletus Field is composed of 3 or more separate pinnacles. Each individual pinnacle is separated from the other pinnacles by paleotopographical lows or saddles that tend to be non-productive from the overlying Geneva Dolomite. An isopach map of the Middle Devonian carbonates overlying the Geneva Dolomite at Miletus Field (fig. 14) shows that pronounced thinning of these carbonates coincides with the crest of the structure shown in figure 13 and further thins over the structural relief of the pinnacle clusters. This thinning may be partially caused by differential compaction over the rigid reef core through time relative to greater compaction of the reef flank sediments and subsequent compensating deposition of the Devonian sediments. Thinning of the Middle Devonian carbonate section overlying productive Geneva Dolomite is common to all fields studied in Marion County, Illinois. The ultimate seal in these fields appears to be the Devonian New Albany Shale. The trap in these fields show an inverse relationship between the amount of structural closure and the amount of thinning of the carbonate interval separating the Geneva reservoir rock and the New Albany Shale seal (fig. 15). Petroleum is trapped when closure on the impermeable New Albany Shale encompasses the Geneva Dolomite. As a result, greater structural closure requires less carbonate thinning over the Geneva and more subtle structures exhibit greater thinning of carbonates.

A histogram of porosity values measured from core samples in figure 16 illustrates very high porosities with an interval ranging between 12 – 16% and an additional interval ranging from 17 – 26%. Permeability measured from core samples in figure 17 also show a range of values from 30 md to 500 md representing good to excellent reservoir qualities.

An example of core from a Geneva Dolomite reservoir is shown in figure 18. This example is from the Plains Illinois #25 Smail well in St. James Field. It shows a relatively abrupt contact between the overlying light gray limestone of the Grand Tower Formation and the oil stained highly porous and permeable brown sucrosic dolomite of the Geneva Dolomite. An example of a thin section of a highly porous and permeable reservoir sample is shown in figure 19. The thin section shows a large amount of intergranular porosity stained in blue surrounding well developed fine-grained zoned dolomite rhombs. The porous reservoir intervals are evident on the neutron density curves of the geophysical logs as shown in figure 20.

**Lower Devonian Reservoirs in South Fairfield Basin Area**

The Lower Devonian pays in Illinois are in the Clear Creek, Backbone, and Grassy Knob Formations (fig. 21). It is uncertain if the Bailey, the oldest Lower Devonian formation, produces in Illinois. Lower Devonian rocks are characterized in large part as cherty, sometimes dolomitic limestones with the exception of the Backbone which is described as a clean, white limestone. Production is primarily associated with the pre-Middle Devonian unconformity surface where it is coincident with positions on positive structural features with demonstrated structural closure. All Lower Devonian production is found at or near the crests of domes/anticline noses. Like the Dutch Creek play, it is probable that fracturing and diagenesis at the unconformity exposure surface play important roles in reservoir formation. At the unconformity surface, diagenetic alteration, solution, fracturing and an irregular surface topography are likely. The Lower Devonian subcrop map generally defines trends for the unconformity play. In the center of the Basin, the Clear Creek is present at the unconformity surface.

The Clear Creek is the productive horizon along the margins of the south end of the deep Fairfield Basin, at Sesser, Benton North, and Whittington fields (fig. 21). Most wells only penetrate the top few feet of the Clear Creek, leaving the strata beneath the Clear Creek sparsely tested in the deep basin, and making it difficult to evaluate whether the underlying Backbone, Grassy Knob, or Bailey are potential reservoir zones. The south Fairfield Basin Lower Devonian pays are all located on well defined anticlinal structures. The role of fracturing is unknown but seems likely to be important to reservoir quality and permeability. The fault systems are shown on the regional structure maps; the presence of the Lower Devonian pays near faulted zones or deep structural lineations is probably not a coincidence.

**Lower Devonian Grassy Knob Chert**

The only Grassy Knob production is at Walpole Field in Hamilton County, Section 27, T6S, R6E. It is documented in at least one well, the Henry Energy Satterfield #1. It is the deepest producing zone in Illinois with the Grassy Knob at 5822 feet. The deeper pay was discovered in the Grassy Knob at Walpole Field in 1984. The well was also completed in the Clear Creek at a depth of 5324-34 feet. The well site geologist report indicates that there are numerous porous zones within the Grassy Knob that may be possible pay zones, but log calculations may overestimate the water saturation. The Satterfield #1 has a total cumulative production of over 45,000 barrels from the two Lower Devonian zones. A nearby well, the McPeak #1, was reportedly completed in the Clear Creek pay at 5314-5320 feet, and from a cherty, sandy, dolomitic zone interpreted as the Dutch Creek Sand from 5293-5297 feet, although this zone is suspected to be Clear Creek dolomite, not sand. The McPeak #1 has a cumulative production of over 51,000 barrels. If the Dutch Creek produces at Walpole, which is uncertain because it may be part of the Clear Creek rather than the Dutch Creek, this would make Walpole the southern-most production from the Dutch Creek in Illinois. Structure at Walpole is part of the Dale Anticline, a major anticlinal structure that defines the southern margin of the deepest part of the Fairfield Basin.

The Barlow regional structure map shows Walpole field as an anticline extending south, off of the larger Dale Field structure. At least 20 feet of Barlow closure is mapped on the crest of Walpole. The field has 3 wells completed in the Grassy Knob and the Clear Creek from a cherty dolomite. It also produces from about 150 wells that are completed in Mississippian sandstones and limestones. It has produced nearly 2 million barrels of oil since its discovery in 1941.

**Lower Devonian Clear Creek Chert**

In the south Fairfield Basin area, the Clear Creek pay is established at Sesser, Benton North, Taylor Hill, and Whittington fields. Whittington produces from the upper Clear Creek, a cherty, dolomitic limestone. Whittington has produced over 5 million barrels of oil from 156 wells. There are 31 Devonian producers and about 125 wells producing from Mississippian sandstones and limestones in the field.

**Lower Devonian Pays on the Sparta Shelf**

Lower Devonian carbonates form important reservoirs on the Sparta Shelf, an area west of the Fairfield Basin and considered part of the west flank of the basin. It is separated from the Fairfield Basin by the DuQuoin Monocline. There appear to be several types of pays within the Lower Devonian on the Sparta Shelf, but all the reservoirs have one thing in common; production is generally in the top part of the strata, near and beneath the pre-Middle Devonian unconformity. The Lower Devonian formations are progressively truncated to the west along the unconformity. This results in a series of subcrop belts of older Devonian beds in a westward direction. It is difficult to correlate the Lower Devonian units and map the subcrop using old electric logs. Our work in the next year will examine this subcrop play and study the cores and cuttings. Additional work will examine the role of tectonics on the Sparta Shelf.

The lowermost Lower Devonian Bailey sediments are thought to be transitional from Silurian to Devonian age. Pinnacle reefs developed in the Silurian Moccasin Springs are thought to have continued to grow into the time of Bailey deposition. Along the western margin of Clinton and Washington Counties and continuing west, Silurian reefs were truncated and altered by subaerial exposure, probably during the development of the pre-Middle Devonian sub-Kaskaskia unconformity. Oil production west of the Grassy Knob truncation appears to be limited to the erosionally thinned Bailey and the Silurian reef and reef flank carbonates. In eastern Washington and Clinton counties, it appears that a thicker sequence of Lower Devonian sediments is preserved and some fields, such as Nashville North, produce from Lower Devonian reef drape dolomite. Further to the east, Lower Devonian production at Cordes, Beaucoup, and Irvington fields appears to be from dolomite along larger anticlinal structures. In these fields, there is also established Trenton production. Additionally, these anticlinal features commonly produce abundant oil from Mississippian siliciclastics.

**Silurian Reef Production**

Stratigraphic relationships of Silurian reservoir units are shown in figure 22. Silurian Reef production is well documented in numerous papers, many of which are now available on the ISGS website. Silurian pinnacle reef reservoirs are most commonly found on the Sparta Shelf in western Illinois. New data compiled for this includes an analysis of porosity and permeability data measured from core samples of Silurian reef rock. A histogram of porosity measured from core samples shows a distinct bimodal distribution of values. There is a distribution of samples with poor reservoir quality, averaging between 2 and 4% porosity and a second group of samples with excellent reservoir quality averaging between 18 and 20% porosity (fig. 23). Cumulative production differences from separate Silurian reef wells reflect this bimodal distribution of poor and excellent reservoir quality. Some Silurian reef wells are excellent producers while other nearby wells are marginal producers or non-commercial.

**Silurian Production Associated with the Sangamon Arch**

The Sangamon Arch is a masked paleo-structural feature that today has no distinct structural expression. Present day structure shows a regional, basinward dip to the south-southeast, modified by gentle anticlines. Silurian rocks of the Niagaran series are unconformably overlain by Upper Devonian, New Albany Shale sediments on the crest of the broad positive paleo-structure. Niagaran muddy carbonate and carbonate bank deposits were exposed to prolonged erosion, probably during the Lower Devonian and Middle Devonian. No Lower Devonian rocks are present on the crest of the paleo-arch. Middle Devonian sediments lap onto the flanks but apparently never were deposited on the Arch. Diagenetically-altered Silurian carbonate mud and bank deposits form reservoirs along the flanks of the Sangamon Arch (fig. 24). Occasionally larger framework fossils are observed but the Silurian rocks differ from the "pinnacle reef" buildups observed to the south in the Sparta Shelf area. One large trend of carbonate reservoirs is known as the Mt. Auburn Trend within the Sangamon Arch region. Continuous core from Mt. Auburn has flat to slightly inclined laminated dolomitic limestone with pinpoint porosity and tiny vugs. Springfield East Field forms a small reservoir in Sangamon County, T15N, R3E. Core from a Springfield East producer (Ramsey Edna-Noll) shows the mottled, altered limestone and dolomite reservoir. Clay filled clasts and burrows can be seen, and thin, hairline sub-vertical fractures have been observed. Porous reservoirs commonly appear as dolomite with pinpoint to small vugular pores. Contrasting the producing well with a nearby dry hole, the producer appears to be more pervasively dolomitized. The dolomite in the dry hole tends to have been selectively altered to dolomite along laminae or thin beds or in smaller patches. The Silurian producers in the Sangamon Arch area (blue crosses in figure 24) have an overall linear NE to SW trend, and the coincidence of porous carbonates on the crests of present-day anticlinal features is thought to lead to the best reservoirs. The overall trend may be disrupted by a subset series of nearly perpendicular lineations trending NW to SE.

Silurian production is from Niagaran rocks, similar in age to those found in Silurian pinnacle reefs. Reservoir porosity in this play develops in biohermal build-ups that appear to be shallow water reef-bank or patch reef in nature. A histogram of porosity measured from core samples shows an interval in the 13% - 20% range with good to excellent reservoir quality (fig. 25). The histogram of permeability shows a wide range of values from 50 millifdarcies to over 1 darcy, representing good to excellent reservoir quality (fig. 26.).

On the southern flank of the Sangamon Arch, Middle Devonian rocks lap onto the Arch but never breached the arch. Chert pebble conglomerates have been observed in dry holes flanking the Sangamon Arch. Middle Devonian Lingle Limestone may be productive at their pinchouts. Unconformity sandstones of the Upper Devonian form important, although discontinuous traps such as the large structural nose at Kincaid field. Farther southeast, on the crest of larger anticlines with pronounced structural closure, Middle Devonian Lingle or Grand Tower carbonate reservoirs are observed.

**Lower Silurian Reservoir at Buckhorn Field**

The Buckhorn Field in Adams and Brown counties in Illinois is one of the most productive Lower Silurian fields in the Illinois Basin. The field was discovered in 1961 with a substantial field extension discovery in 1981. This field has produced over 2 million barrels of oil from a depth of 650 feet below the surface. The producing horizon is from a sucrosic dolomite located at the base of the Silurian carbonate section in the Kankakee Formation and directly overlies the sup-Kaskaskia unconformable surface on the Ordovician Maquoketa Shale. The log in figure 27 shows a typical stratigraphic sequence for the area. The Devonian New Albany Shale is the ultimate seal for the field. There is a thin Middle Devonian section of Cedar Valley Limestone that is in unconformable contact with the Lower Silurian Kankakee Formation. The upper portion of the Kankakee Formation is composed of dense light gray carbonate mudstone. The lower portion of the Kankakee Formation contains the reservoir interval which is composed of porous dolomite. The neutron porosity curve on the right side of the log shows approximately 20 percent porosity.

Structure played a minor role in petroleum accumulation at the Buckhorn Consolidated Field. The distribution of producing wells in this field correspond closely with areas where thickening is present in the interval from the highly radioactive “hot spot” marker bed in the New Albany Shale to the top of the Ordovician Maquoketa Shale. This thickening reflects a drainage system of subtle paleovalleys (fig. 28 ) which eroded into the surface of the Maquoketa Shale prior to accumulation of Kankakee carbonates. These channels are delineated by the 110-ft contour of the “hot spot” to Maquoketa interval. This area is shaded in fig. 28 and the outline of the basal porous zone in the Silurian Kankakee is also shown.

The stratigraphic cross section A-A’ (fig. 29) is across the paleochannel (datum is the radioactive “hot spot”). Development of the paleochannel involved erosion of a regional drainage system into the underlying Maquoketa Shale. Silurian age Kankakee carbonates accumulated in the paleochannel in response to the initial Silurian marine transgression. These carbonates accumulated in an equatorial, intertidal to shallow subtidal environment. Later diagenetic events, likely related to concentrated flow of subsurface brines along the floors of the paleovalleys, led to preferential dolomitization and dissolution of fossils to form moldic and vuggy porosity in the basal Silurian carbonates.

**Ordovician-Trenton**

Production from Ordovician age sediments in the Illinois Basin is limited to the Trenton Group equivalent, the Galena Group (fig. 30). Approximately 13.5 million barrels of produced oil is attributed to Trenton fields in Illinois. Bounding the basin to the east, although not considered Illinois Basin production, is the Lima-Indiana hydrocarbon province. An estimated 100 million barrels of Trenton oil has been produced from this region along the Findlay-Cincinnati Arch in east-central Indiana. Another 150 million barrels of oil has been recovered from the Trenton section of the Albion-Scipio and adjacent fields along the Kankakee arch that separates the Illinois and Michigan basins.

Ordovician oil pools in the Illinois Basin are generally small, with recoveries ranging up to 5 million barrels. The pools are associated with well-defined, closed structures and were commonly discovered by drilling deeper into structures with established shallower production. Thirty five separate pools, mostly discovered between 1940 and 1960, have been established in Illinois (fig. 31). The reservoirs are small, ranging in size from 10 to 2, 000 acres and are at depths ranging from 700 to over 4000 feet. The oil typically has a high paraffin content and a gravity of $40^{o}$ or greater unless it has been degraded in shallower pools.

Stratigraphy of the Trenton plays an important role in the establishment of petroleum reservoirs in the Basin. Kolata et al (2001) has postulated that the Sebree Trough, an arm of the open ocean to the south of the Illinois Basin, brought nutrients in up-welling currents that feed an assemblage of fauna that remain as widespread grainstone beds seen in the Trenton section across the basin (fig. 32). Crews (1985) correlated these permeable grainstone beds from the central Basin, DuQuoin Monocline area west across the Sparta Shelf into the Missouri outcrops (fig. 33 ). These beds are important conduits for the migration of dolomitizing fluid and ultimately, oil migration into the present reservoir settings.

Dolomitization is a common and essential characteristic to the Trenton reservoirs that bound the Illinois Basin and is also a component of the Trenton reservoirs in Illinois. Crews thin section analysis of grainstone beds on the west flank of the Illinois Basin showed at least 10% dolomitization. Along the crest of the La Salle Anticline on the east flank of the Basin, the reservoir beds in Westfield oil field are reported by the operator to be very dolomitic and bounded sharply by unaltered, impermeable limestone. These reservoir beds are commonly less than 5 feet thick (fig. 34).

Porosity and permeability of the Illinois Basin reservoirs is consistently low. Porosity rarely exceeds 10% (fig. 35) and permeabilities exceeding 100 millidarcies are likely fracture related (fig. 36). This is in contrast to the Albion-Scipio and Appalachian Basin fault related play where porosity and permeability can be exceptionally high as a result of extensive dolomitization and solutioning along extensional fault zones.

The model describing the reservoir enhancing component of the fault related play in Michigan and regions to the east is likely similar to the mechanism that produced reservoir potential rock in the Illinois Basin. Hydrothermal fluids moved up through fractures and faults in the Trenton carbonates and were sealed within the Trenton by the overlying, impermeable Maquoketa Shale. The fluids were therefore forced to migrate through relatively porous and permeable grainstone beds, selectively dolomitizing and solution enhancing these beds. Production from the Trenton in the Basin is restricted mostly to the upper 100 feet of the carbonates which indicates that fluid migration through the grainstones may have been concentrated closer to the sealing beds of the Maquoketa Shale.

Evidence for hydrothermal influence can be observed in several areas within and immediately flanking the Illinois Basin (fig. 37). These areas include the Fluospar District in southeastern Illinois where fluorite has been mined and the Mississippi Valley mineralization areas in the northwestern region of Illinois and the southeastern part of Missouri where lead and zinc have been mined. Flurospar has also been observed in a core of the Devonian Geneva Dolomite from Patoka Field, a central Basin location. There is no Trenton production and few exploration wells in the Basin based on the Albion

Scipio and Appalachian Basin fault related plays. The fact that widespread evidence of hydrothermal influence exits within the Illinois Basin indicates that these fault related, sag type plays are a potential source of production in the Basin.

Southwestern Indiana has a well developed dolomite trend with numerous hydrocarbon shows. Based on the only core available within the trend, the dolomite is finely crystalline, calcareous (10-40% calcite), and quite permeable. The dolomite forms lenses at different levels within the Trenton that are laterally discontinuous.

The potential for discovery of more Trenton, closed structure reservoirs also exists. Fields with both vertical and tilted axial planes are documented. Tamaroa Field is an example of a field where the structural closure of the Mississippian reservoir is offset by approximately 0.5 mile to the closure on the underlying Ordovician Trenton reservoir. There is potential for locating Trenton reservoirs in established fields even where Trenton dry holes have been located along the structural high of shallower horizons if these fields display a tilted axial plane.

**Secondary Porosity Development in the Trenton (Galena) Dolomite of Northern Illinois**

The objectives of this study were description of the geology of north central Illinois, identification of secondary porosity features in the Trenton at its outcrop area in north central Illinois, characterization of the fracture and karst conduit network, development of a karstification model, development of a triple porosity fluid flow model, and identification of potential hydrocarbon source beds & traps.

Porosity types recognized include single Porosity: Containing one porosity type such as intergranular matrix porosity (i.e. sandstone.), double porosity: Containing two porosity types, such as matrix and fracture porosity, and triple porosity: Containing three porosity types, such as matrix, fracture and karst conduit porosity (i.e. fractured and karst dolomite).

Secondary porosity types identified in the Trenton Dolomite are: Matrix; increased porosity due to reduction in volume resulting from dolomitization, Fracture; northwest and northeast vertical fractures and horizontal bedding plane fractures, and Conduit; vertical and horizontal karst pipes forming at the junction of the vertical fractures and the junction of the vertical and horizontal fractures.

Karstification history of the Trenton occurred in the following sequence: Galena deposition (mid-Ord), uplift and meteoric karstification (mid-Ord), Maquoketa through Devonian deposition (mid-Ord thru Dev), hydrothermal karstification (late Paleozoic), uplift, erosion, and further meteoric karstification (late Paleozoic thru present).

Findings from this study are as follows: Secondary porosity in the Trenton occurs as conduits, fractures, and matrix vugs; Fractures and conduits are arranged in an orthogonal pattern with conduits forming at the fracture junctions. The karstification processes occurred in the following order: 1. Meteoric karstification in post-Trenton, 2. Hydrothermal karstification in late Paleozoic, 3. Post-Paleozoic meteoric karstification.

Additional findings are primary fluid flow occurs through conduits, followed by flow from fractures, with fluid storage occurring in the matrix. Triple porosity and permeability are present; Source beds for the Trenton are the overlying Maquoketa shale and the underlying Guttenberg (Decorah) shale; Hydrocarbon can be trapped in faulted karst domes.

**Source Rocks**

Gas chromatography analyses of oil from 4 Trenton reservoirs, 4 Silurian reservoirs and 3 Devonian reservoirs have been completed for the source rock-oil correlations studies. Preliminary interpretation of gas chromatographs show strong similarities among Trenton samples and similarities among Silurian age oil but Silurian age oils are very different from Trenton age oils. Trenton age oils are largely devoid of n-$C_{17}$ and higher components while the heavy end of the Silurian age oils taper off gradually. Selected gas chromatographs are shown in figures 38, 39, and 40.

**Present Day Structure Maps**

Existing reservoirs in lower Paleozoic units in the Illinois Basin produce from pronounced closed structures. Recent research on the structural evolution of major features in the Illinois Basin suggests that the Illinois Basin was influenced by nearby late Paleozoic events related to the nearby Appalachian – Ouachita Orogenies ( Kolata and Nelson 1991) as well as Ancestral Rockies events associated with compressive block style deformation (Marshak et al. 2003). These findings suggest the potential for fracture and fault related reservoir discoveries within lower Paleozoic units. Examples of digital structure cross sections constructed for this project are shown in figures 41 and 42.

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## Figures

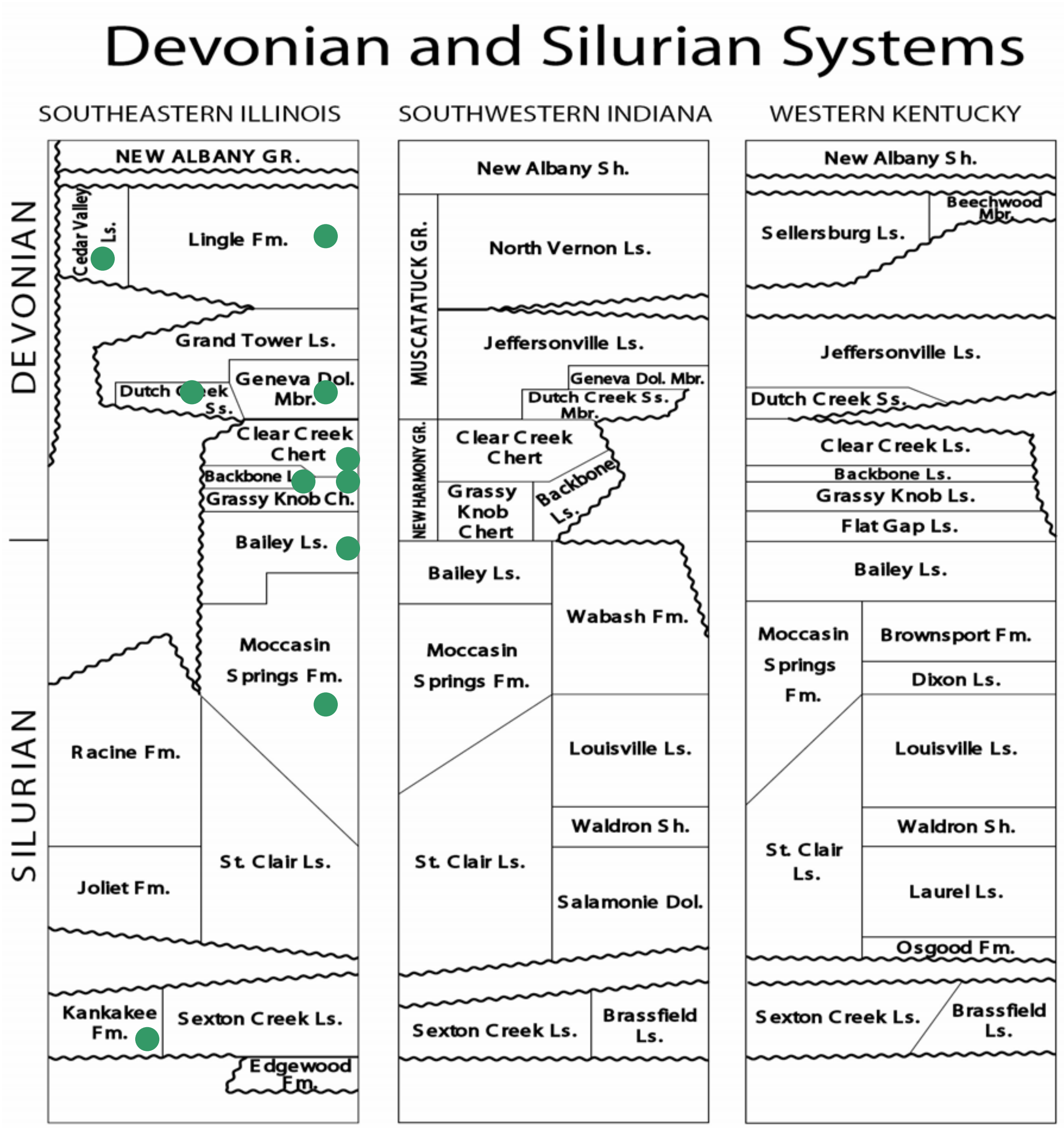



Figure 1. Correlation Chart used for Devonian and Silurian strata in the Illinois Basin. Green dots indicate oil producing horizons. From Shaver et. al., 1986

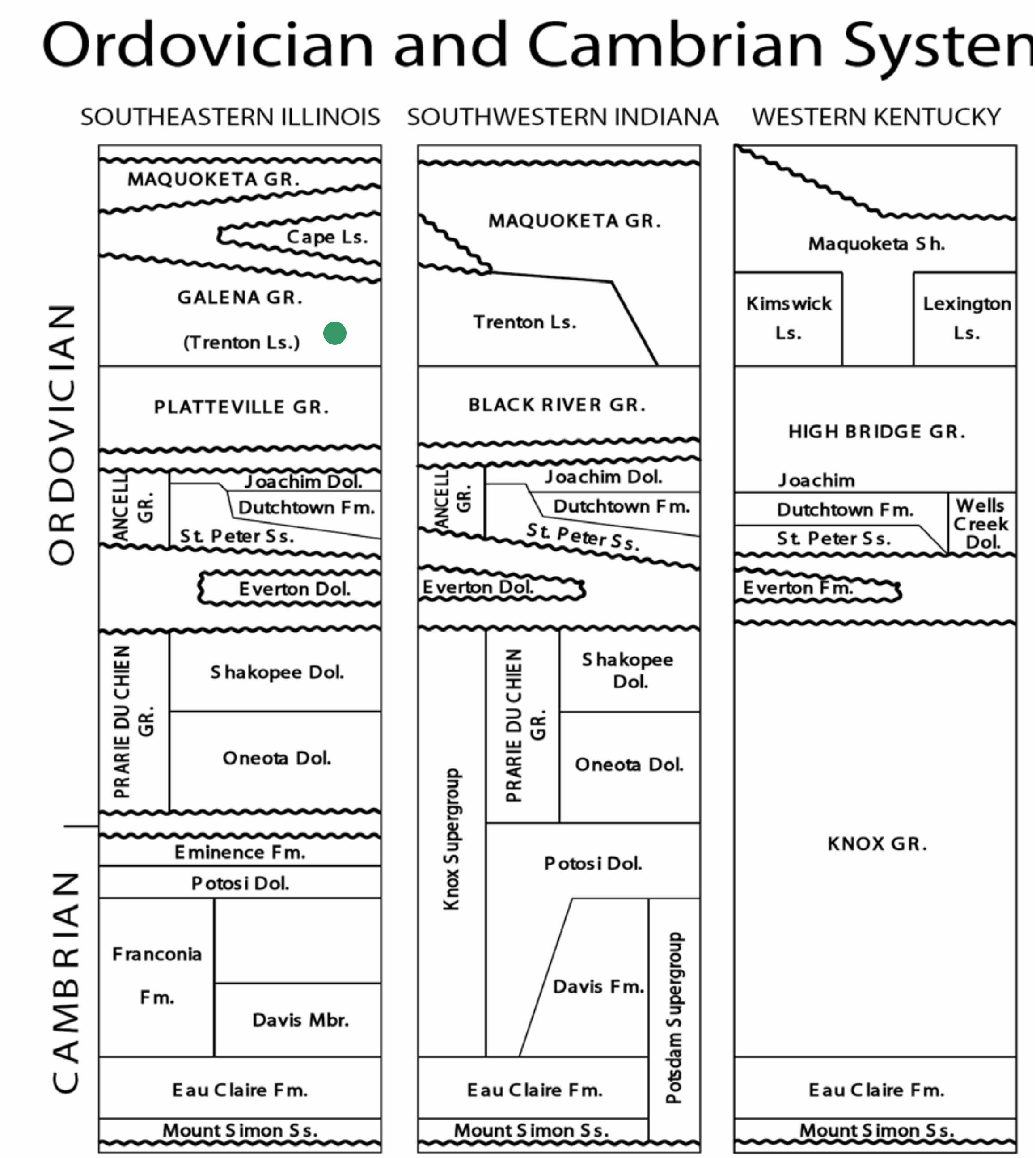



Figure 2. Correlation chart used for Ordovician and Cambrian strata in the Illinois Basin. Green dot indicate oil producing horizon. From Shaver et. al., 1988

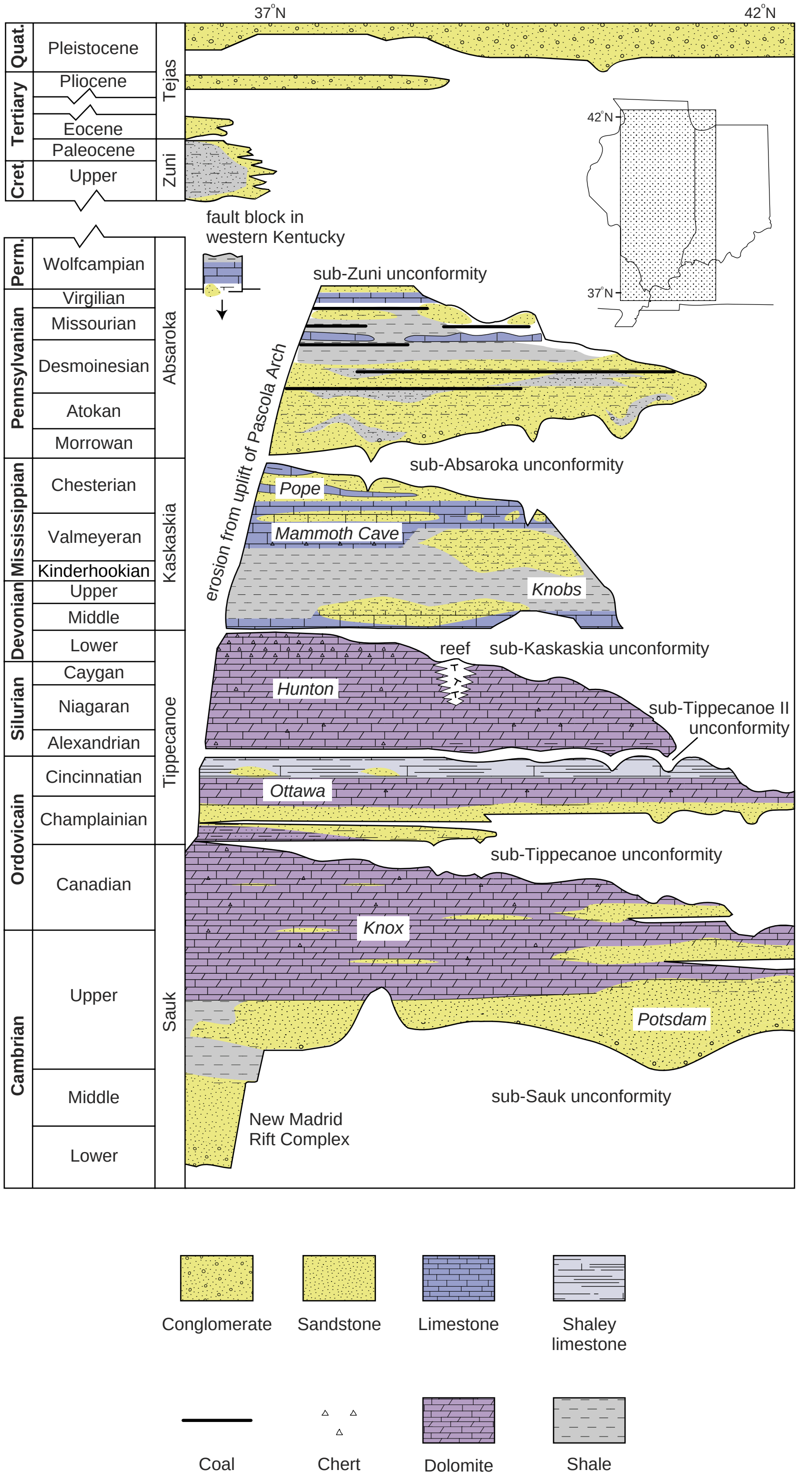



Figure 3. Stratigraphic column of entire rock sequence in the Illinois Basin. From Kolata and Noger, 1991

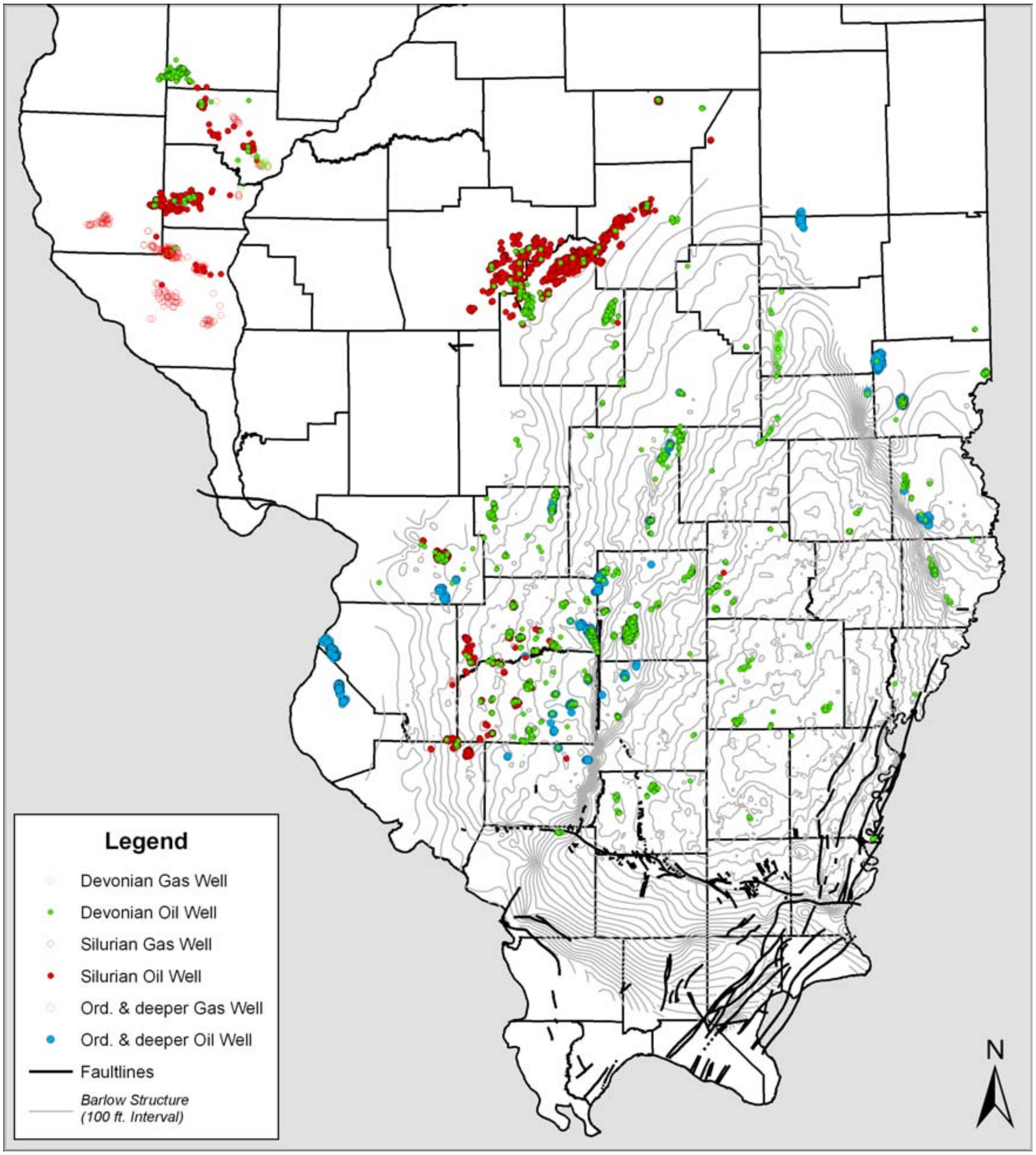



Figure 4. Map showing location of wells with production from Lower Paleozoic horizons in Devonian, Silurian and Ordovician strata.

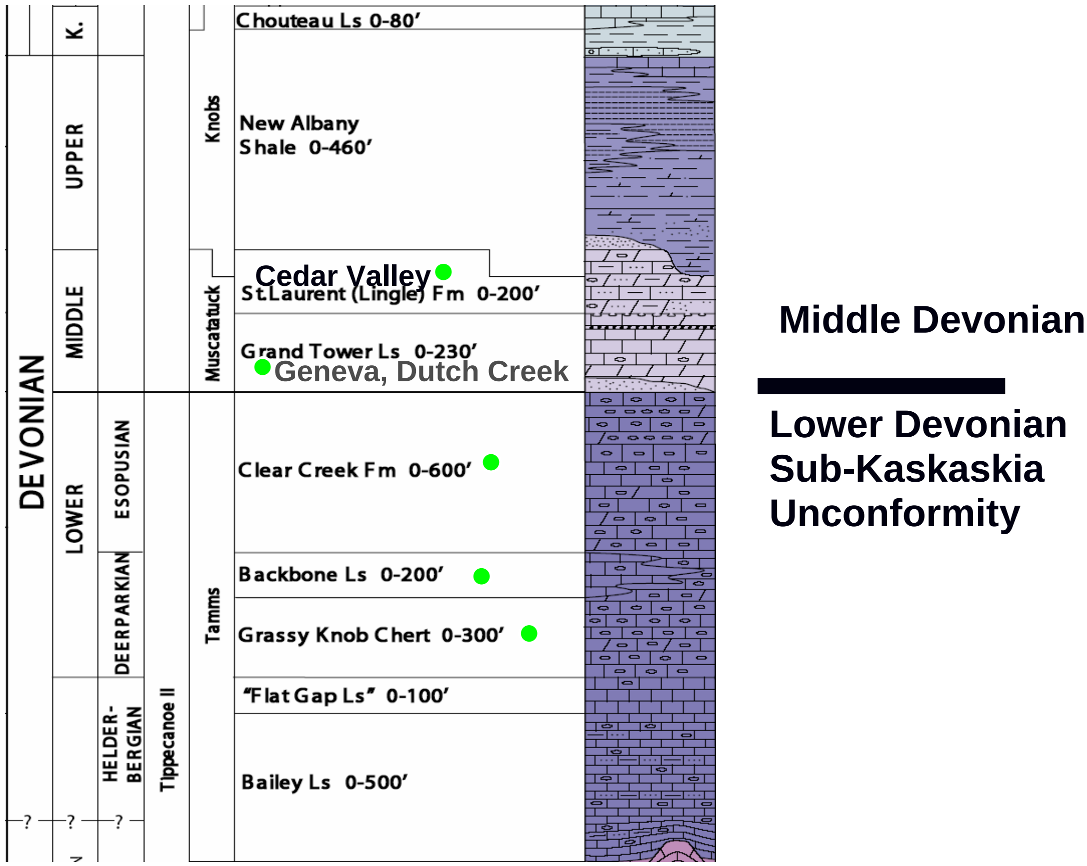



Figure 5. Stratigraphic column of Middle and Lower Devonian units in the Illinois Basin. Units that are oil productive are indicated with a green dot. Modified from Kolata 2005.

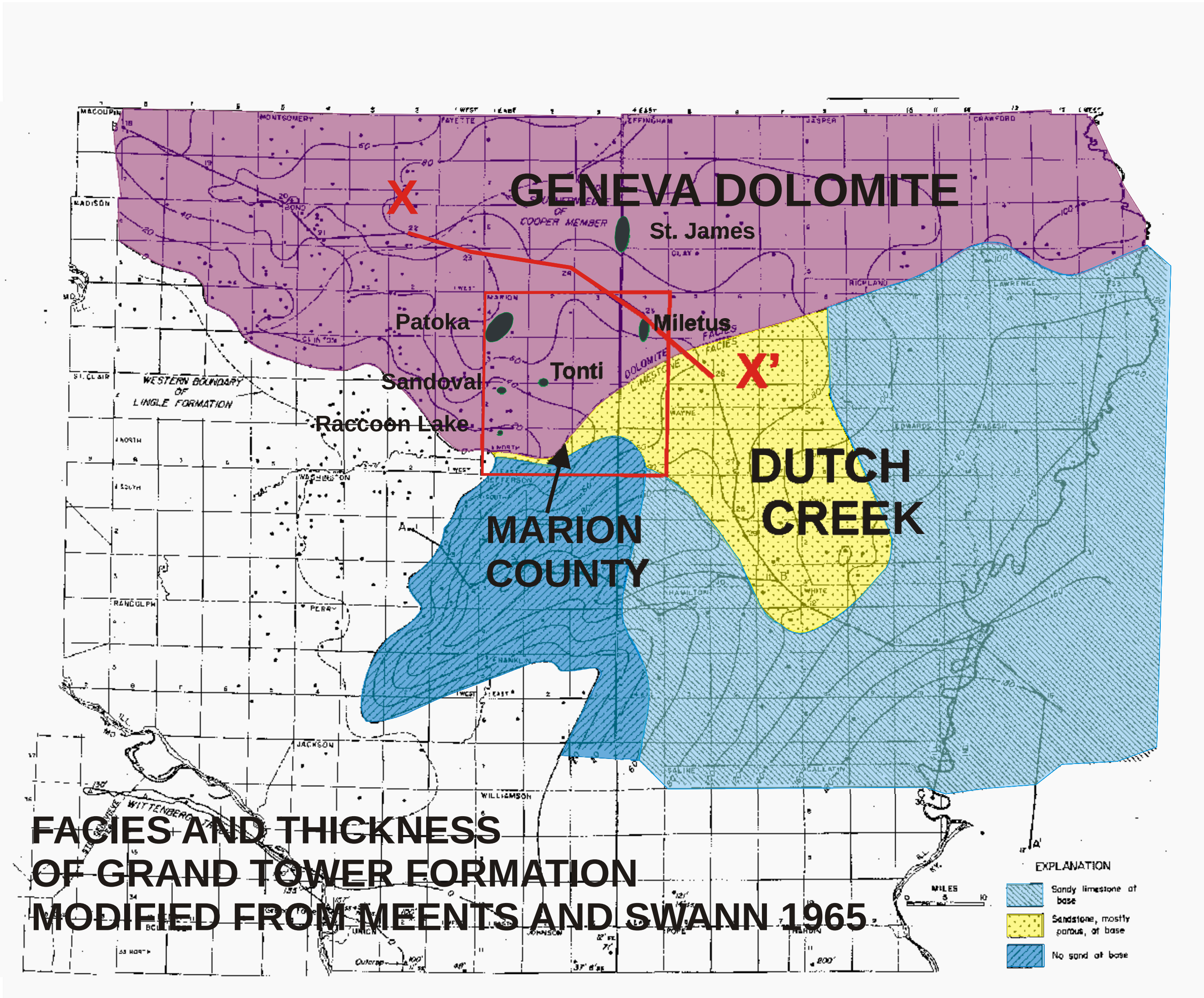



Figure 7. Map showing distribution of Middle Devonian Dutch Creek Sandstone and Geneva Dolomite facies (Modified from Meents and Swann. 1965)

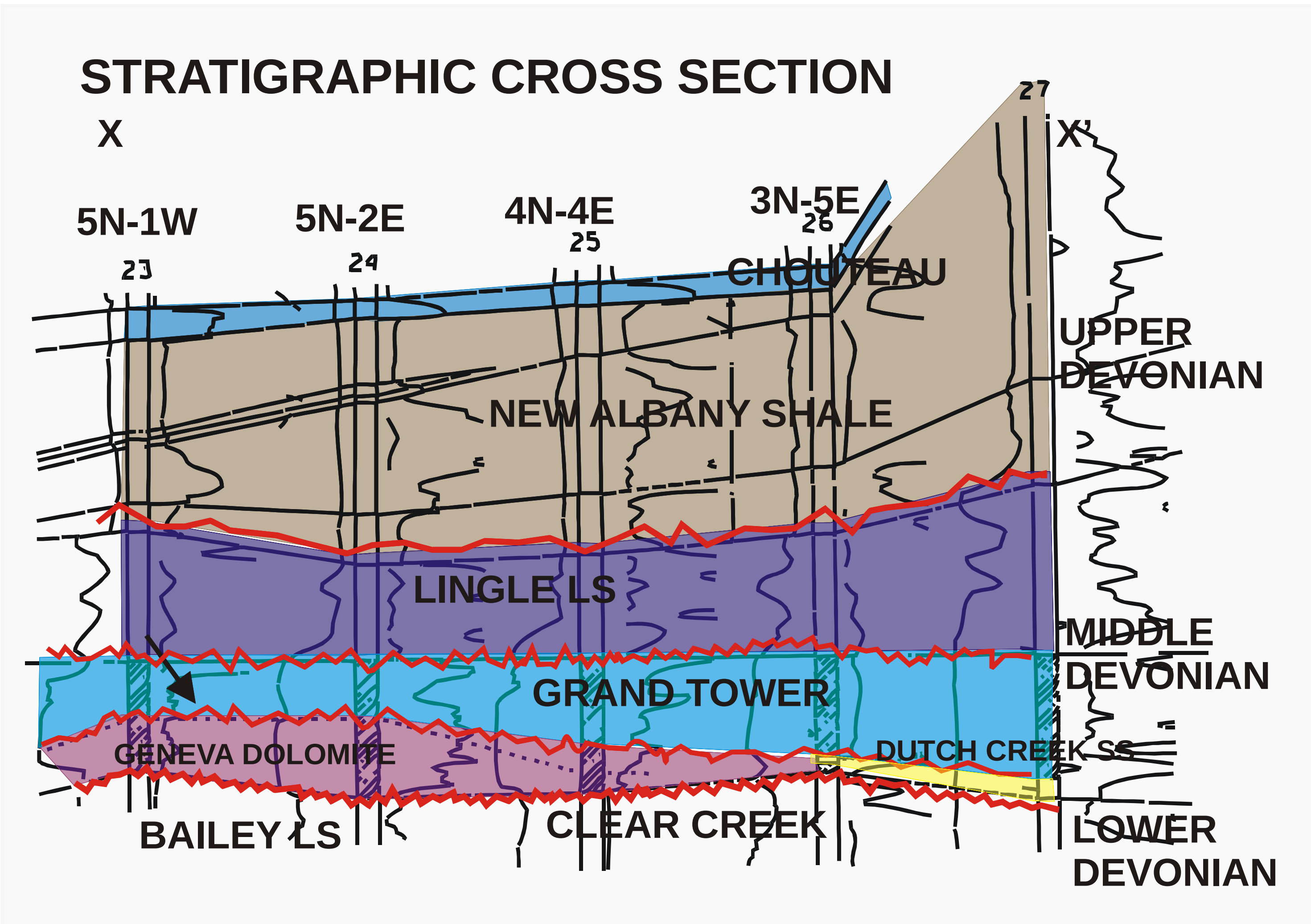



Figure 6. Cross Section illustrating facies relationships of the Geneva Dolomite and Dutch Creek Sandstone members of the Grandtower Formation. Modified from Meents and Swann, 1965.

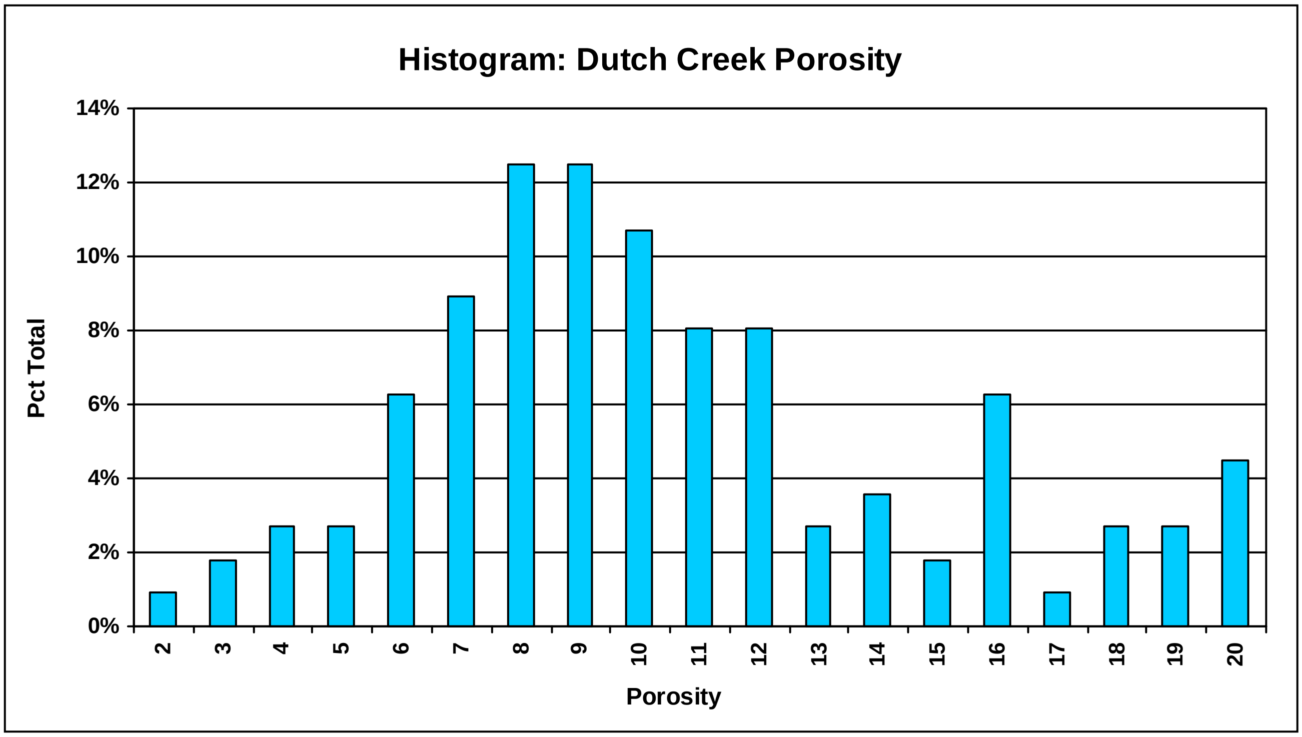



Figure 8. Histogram of porosity measured from core samples of Dutch Creek Sandstone.

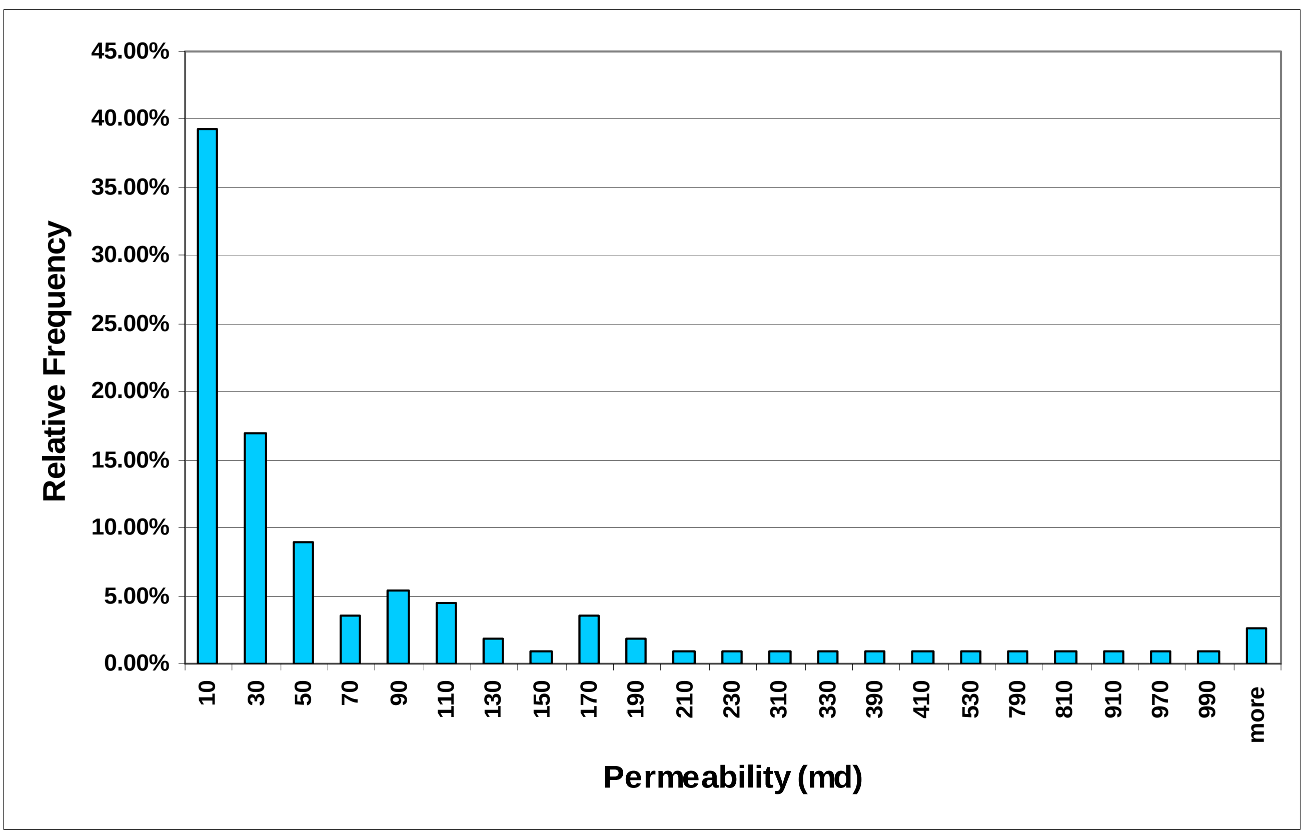



Figure 9. Histogram of permeability measured from core samples of Dutch Creek Sandstone.

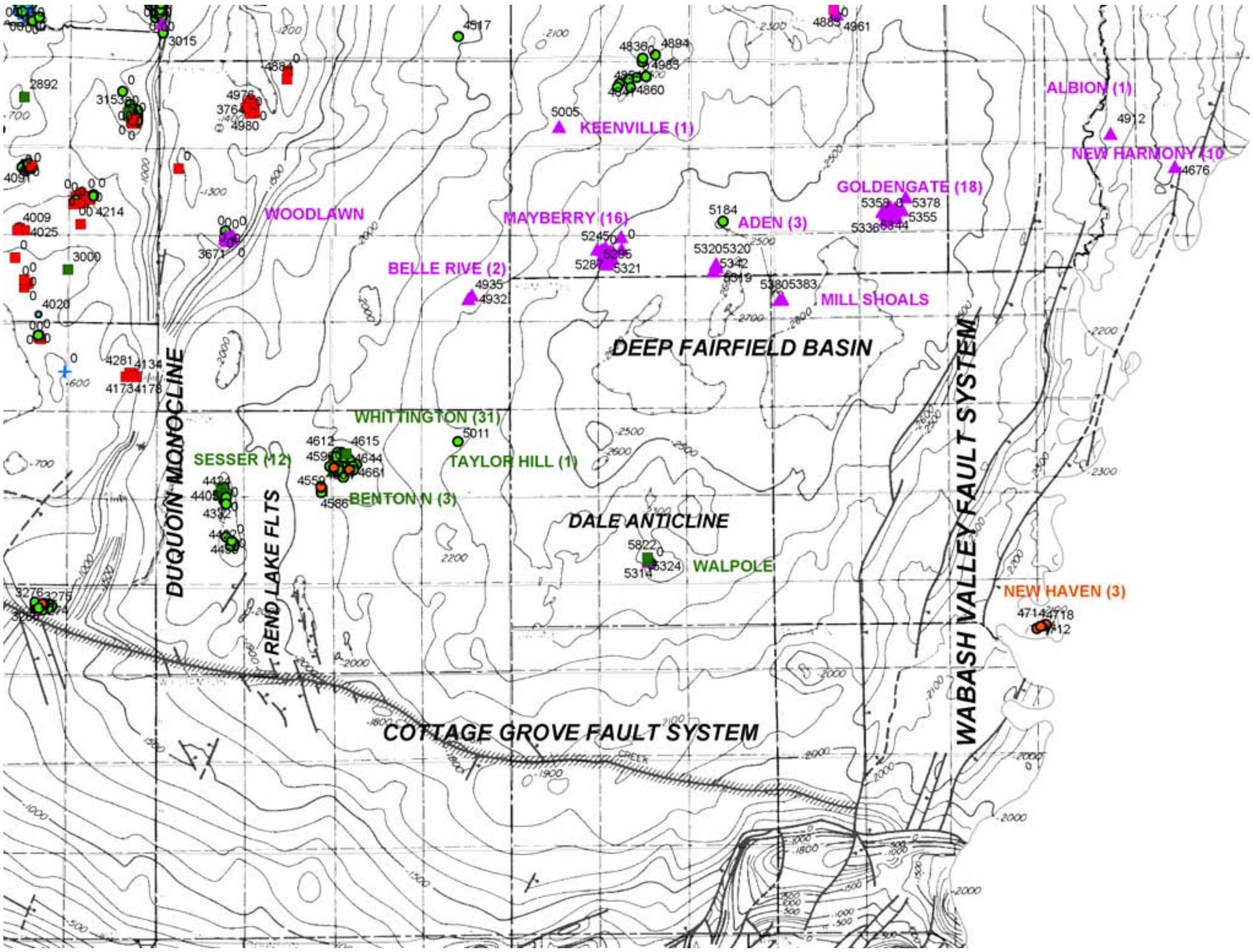



Figure 10. Middle and Lower Devonian producing wells located on regional structure map contoured on the Middle Mississippian Barlow Limestone.

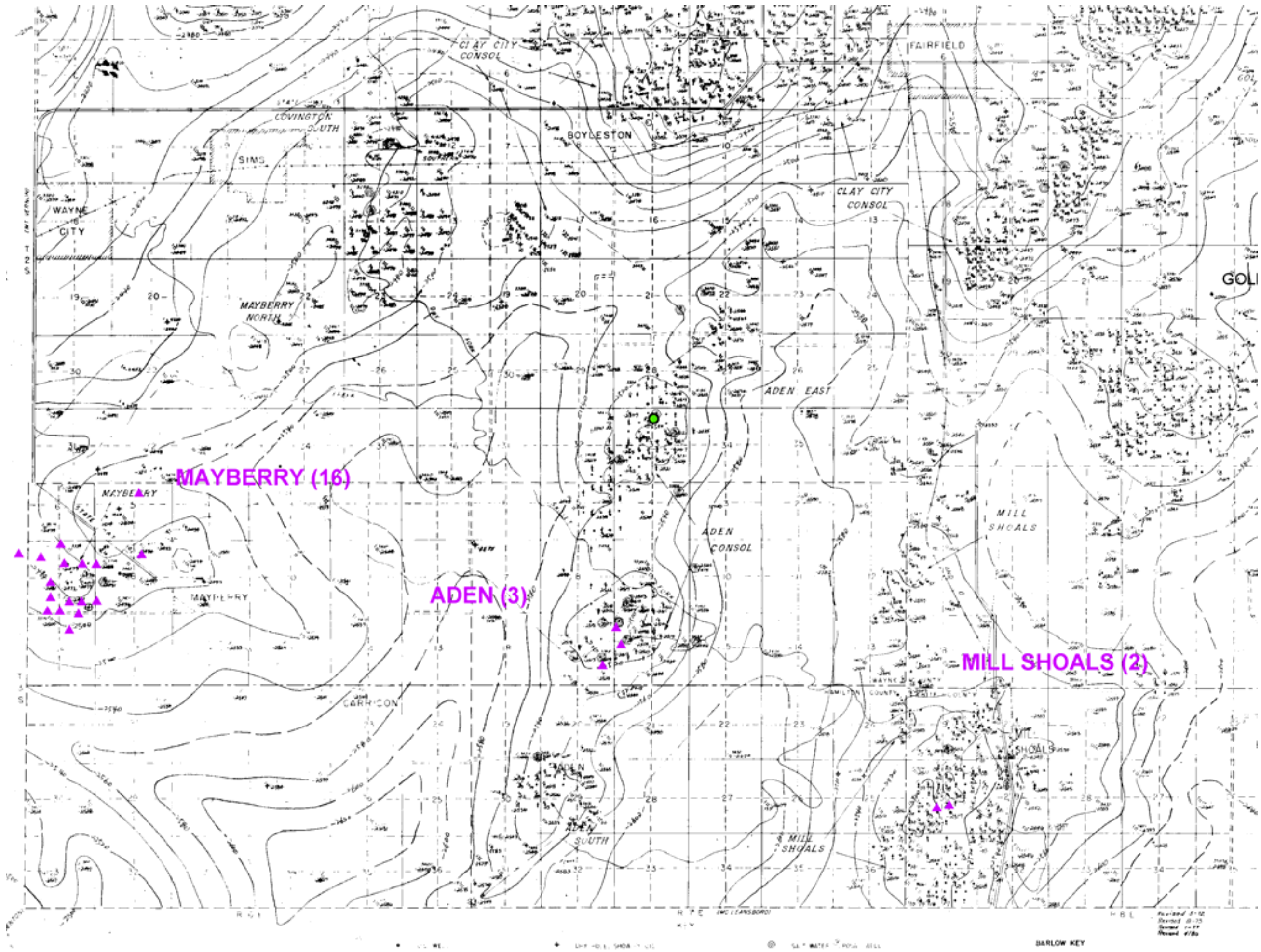



Figure 11. Dutch Creek producing wells shown on Barlow Limestone structure map contoured on a 20 foot interval.

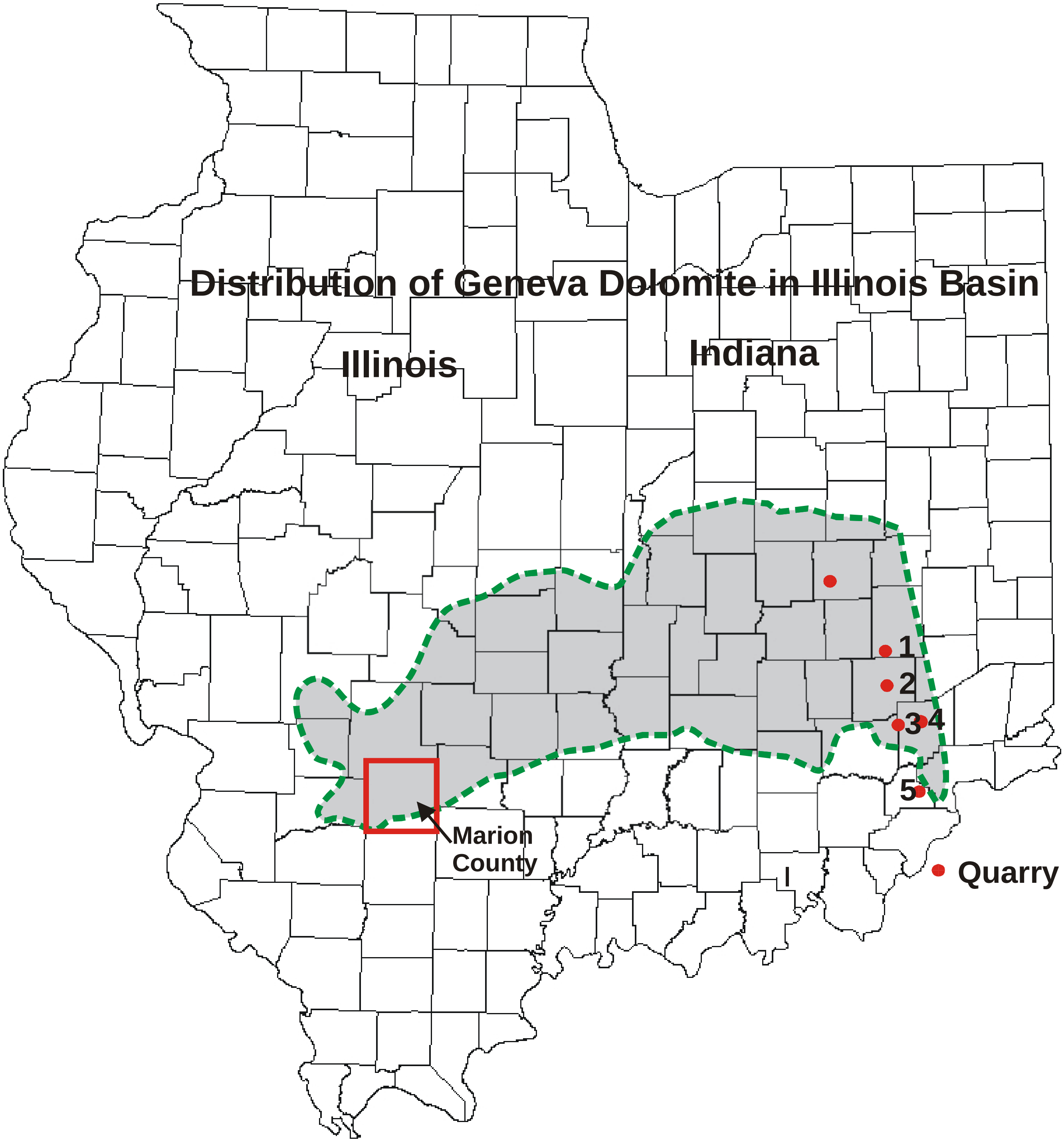



Figure 12. Distribution of the Middle Devonian Geneva Dolomite in the Illinois Basin. Modified from Seyler et. al., 2003

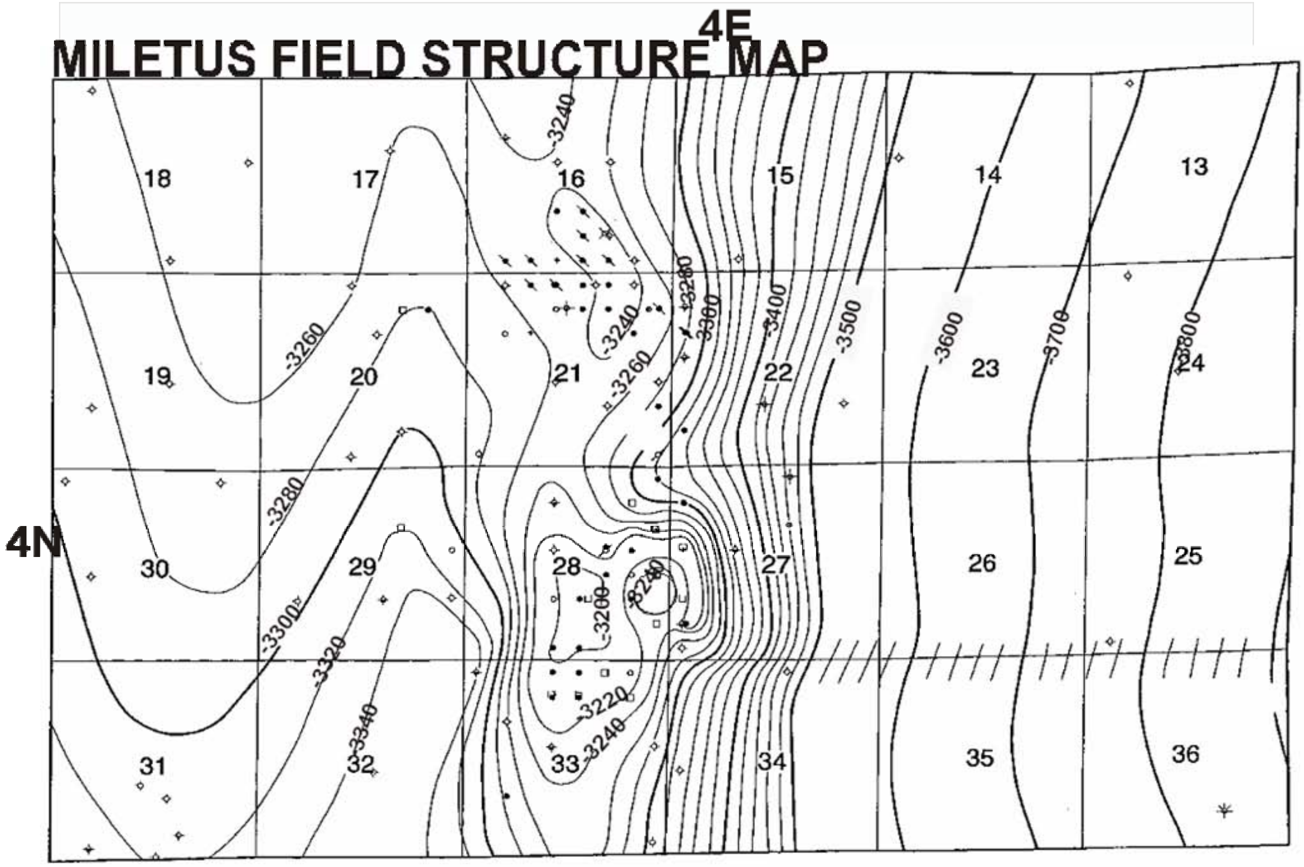



Figure 13. Detailed structure map contoured on the top of the Geneva Dolomite in Miletus Field. From Seyler et. al., 2003.

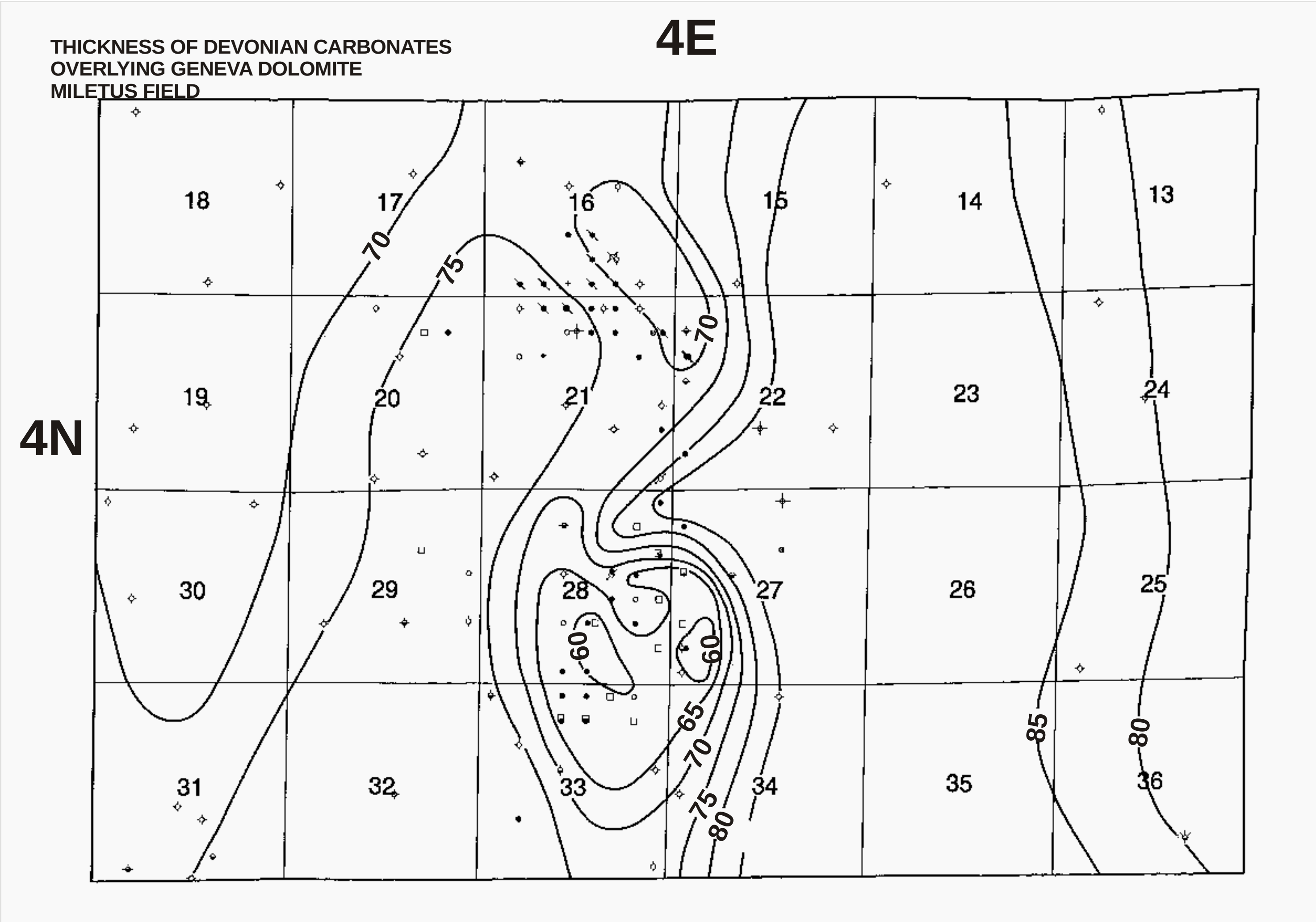



Figure 14. Isopach map of the thickness of Middle Devonian carbonates overlying the Geneva Dolomite at Miletus Field. Thinning of the carbonate unit is illustrated. From Seyler et. al., 2003.

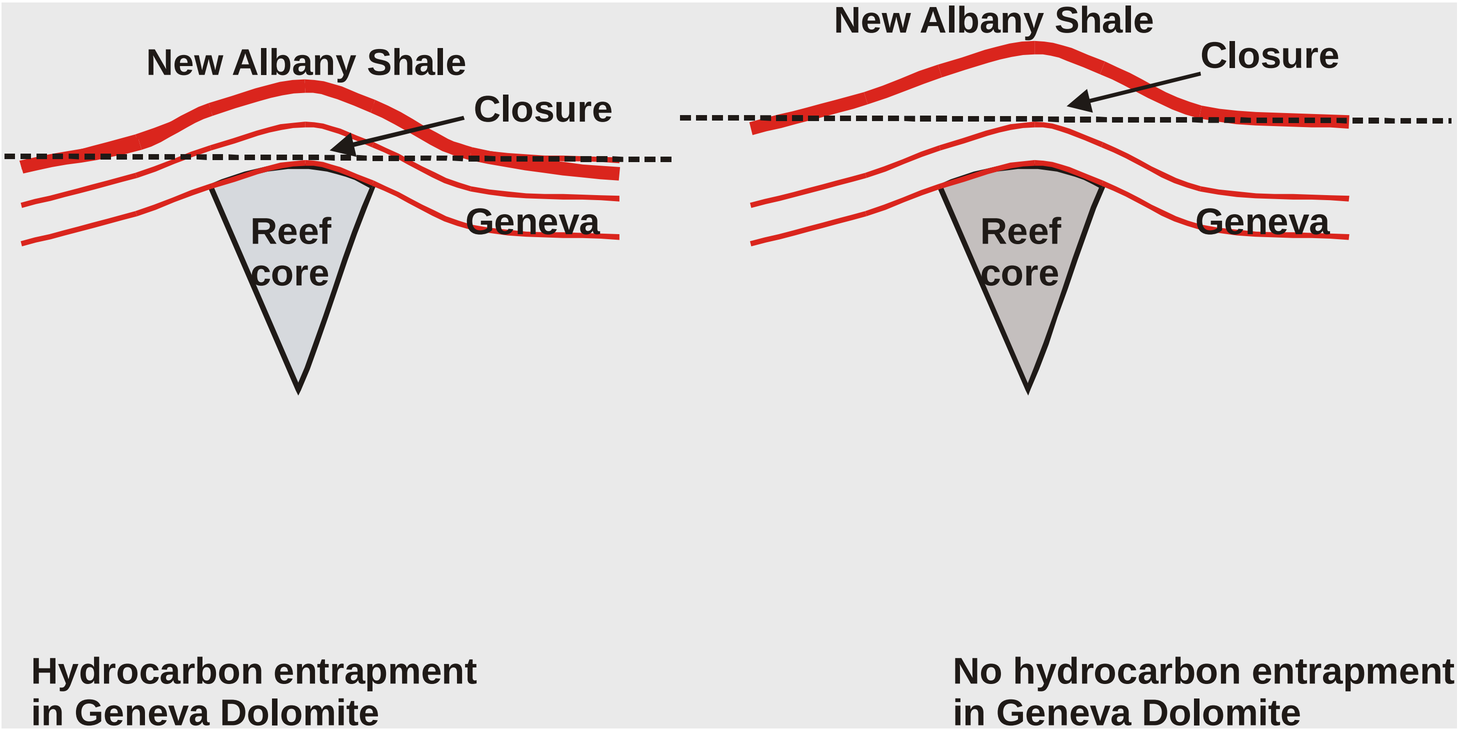



Figure 15. Cross Sections of vertical seals, thickness of Middle Devonian carbonates, and their relationship to hydrocarbon entrapment. From Seyler et. al., 2003.

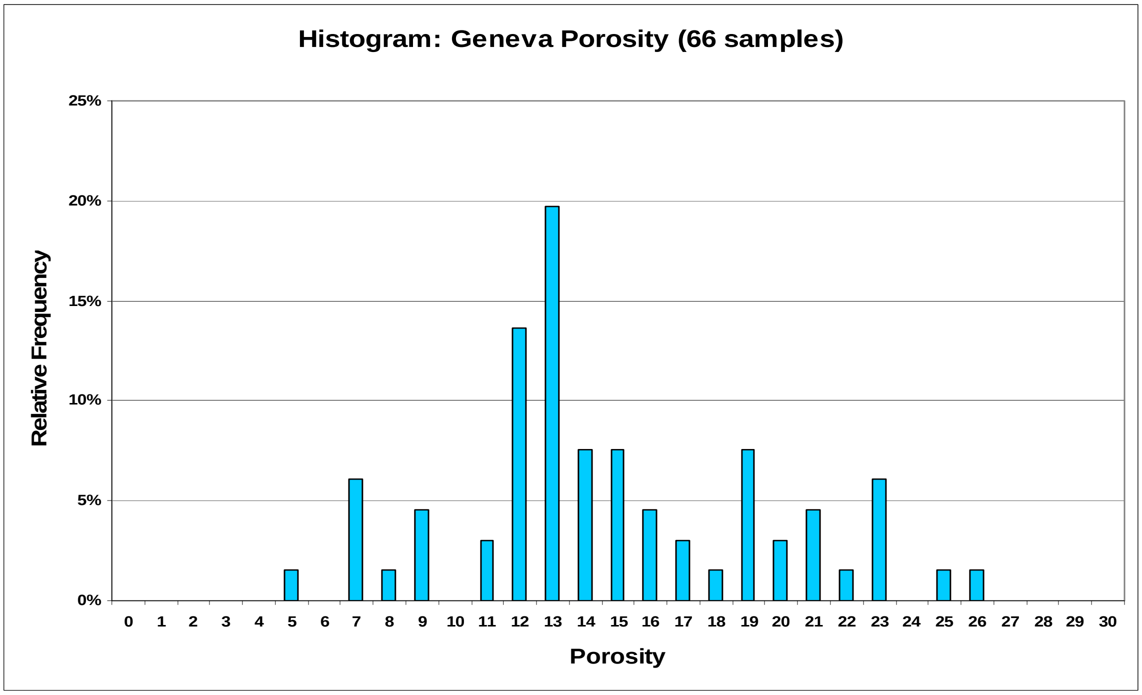



Figure 16. Histogram of porosity values measured from core samples of the Middle Devonian Geneva Dolomite.

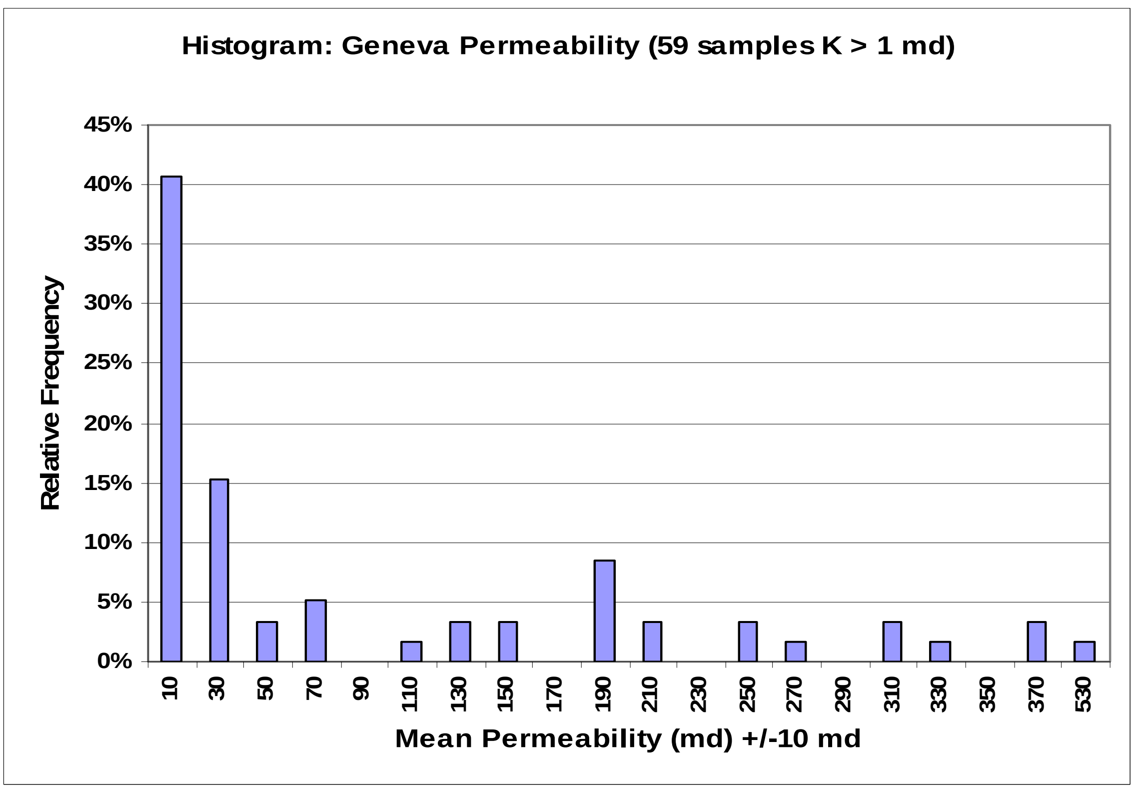



Figure 17. Histogram of permeability values measured from core samples of the Middle Devonian Geneva Dolomite.


Figure 18. Core of the Middle Devonian Grandtower Formation. The lower portion of the core is Geneva Dolomite.

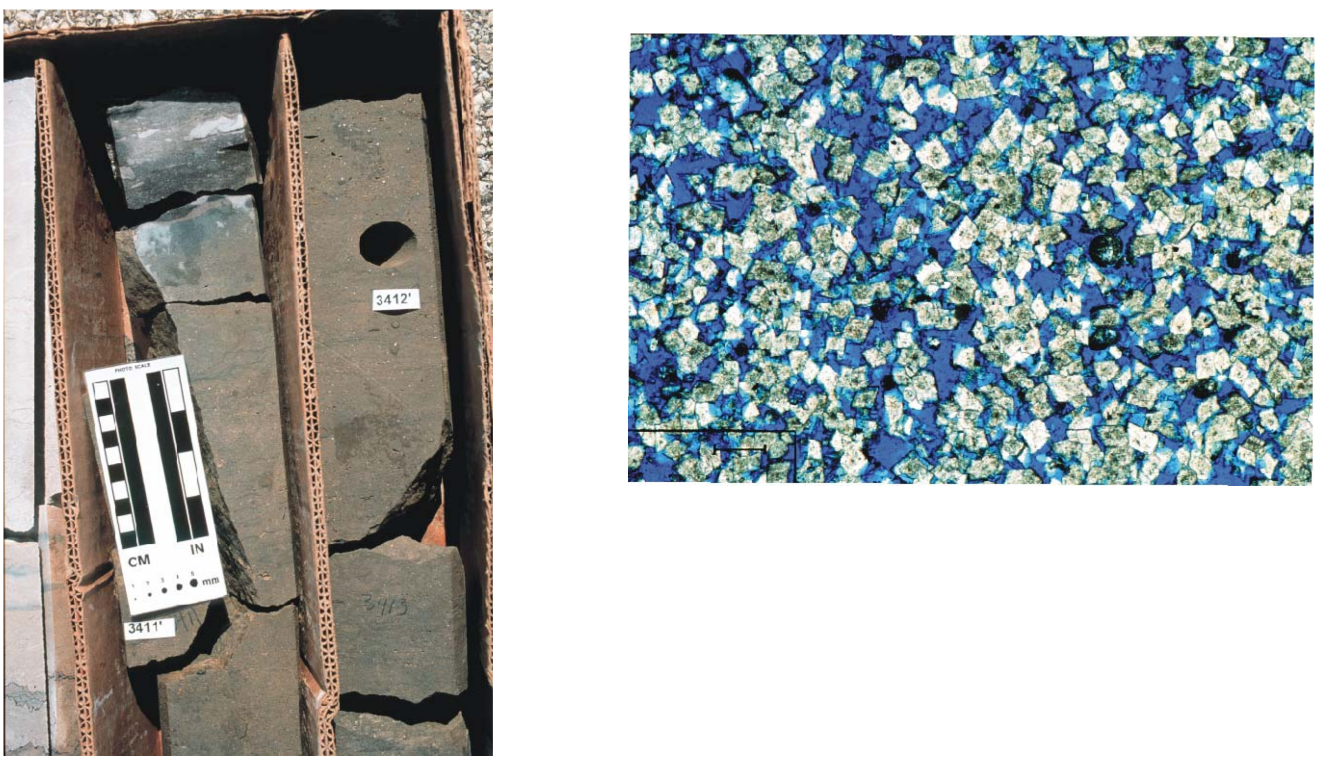



Figure 19. Close-up of Geneva Dolomite reservoir rock composed of brown sucrosic dolomite with moldic and vuggy porosity. Thin section of reservoir rock with porosity stained blue. Large amounts of intergranular and moldic porosity are evident in in this fine-grained dolomite. Zoned rohmbs can also be observed in thin section. Scale bar is .25mm.

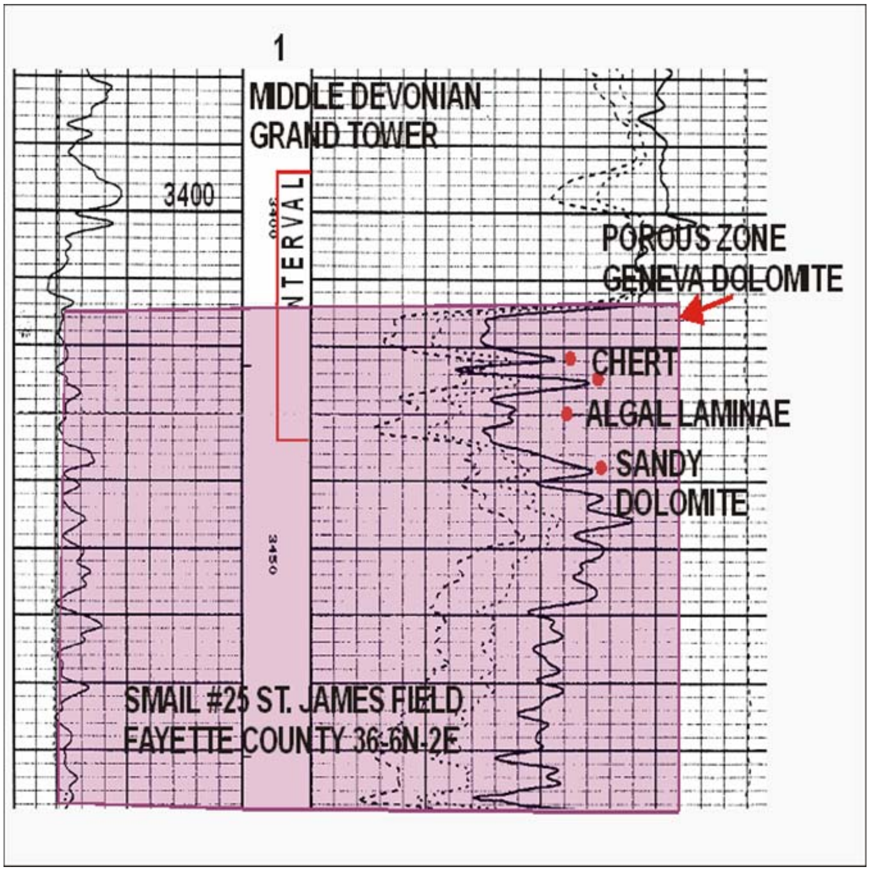



Figure 20. Geophysical logs of the Geneva Dolomite reservoir interval from the #25 Smail well. Log calculated porosity is 20 percent.

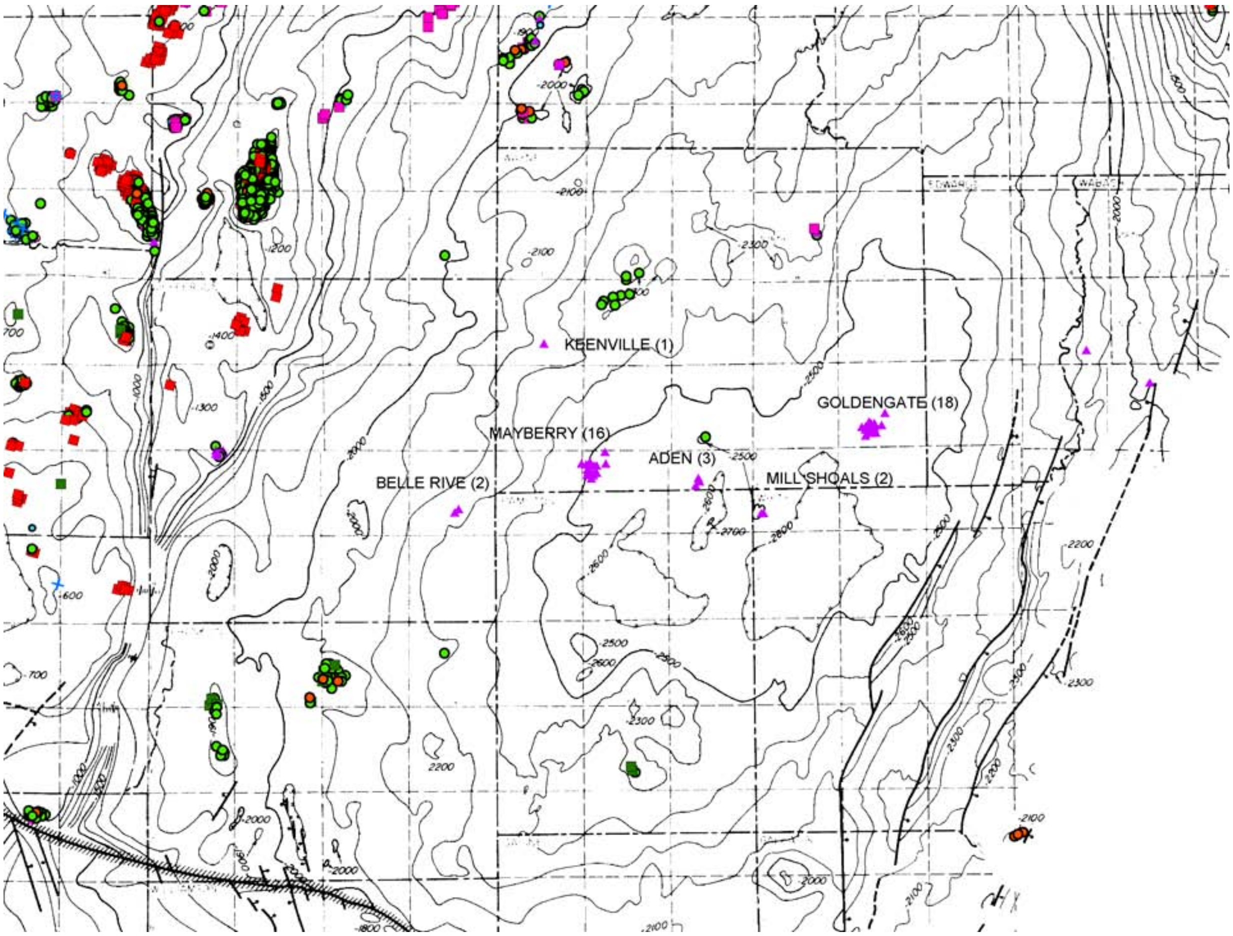



Figure 21. Distribution of Lower Devonian producing wells in Illinois.
color scheme for the pays is:
Trenton: red box
Silurian: blue cross
Hunton/Dev-Sil: aqua cross
Lower Devonian: dark green box
Devonian generic, undifferentiated: bright green dot
Lingle/Middle Devonian undifferentiated: orange dot
Geneva or Grand Tower: pink dot
Dutch Creek or Hoing: purple triangle
Upper Devonian undifferentiated or unconformity sands at base of New Albany: yellow dot
New Albany pay: black triangle.

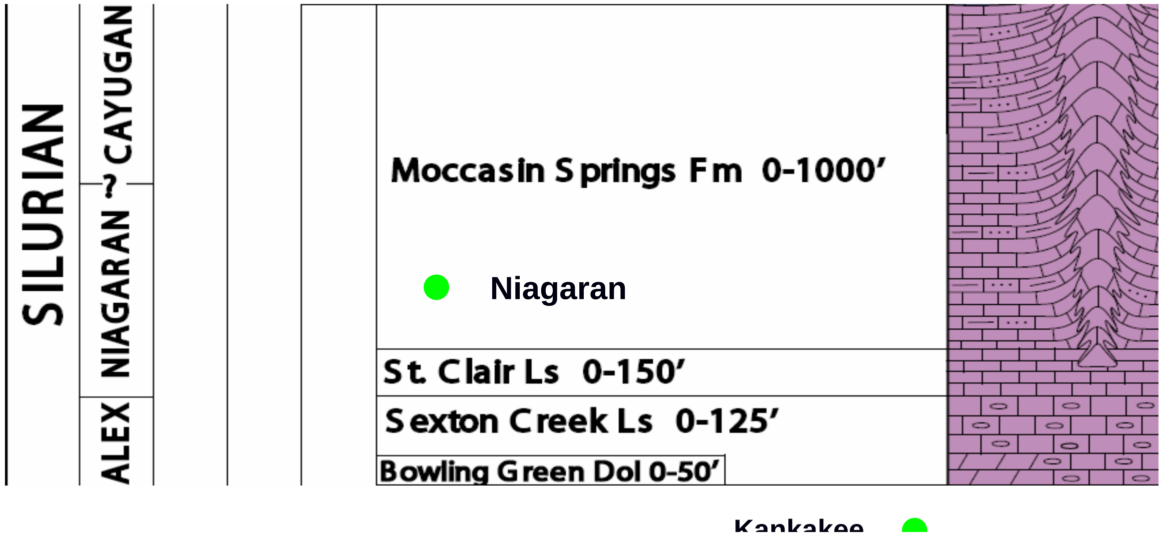



Figure 22. Stratigraphic Column of Silurian strata in the Illinois Basin. Units with production are indicated by green dots. From Kolata, 2005.

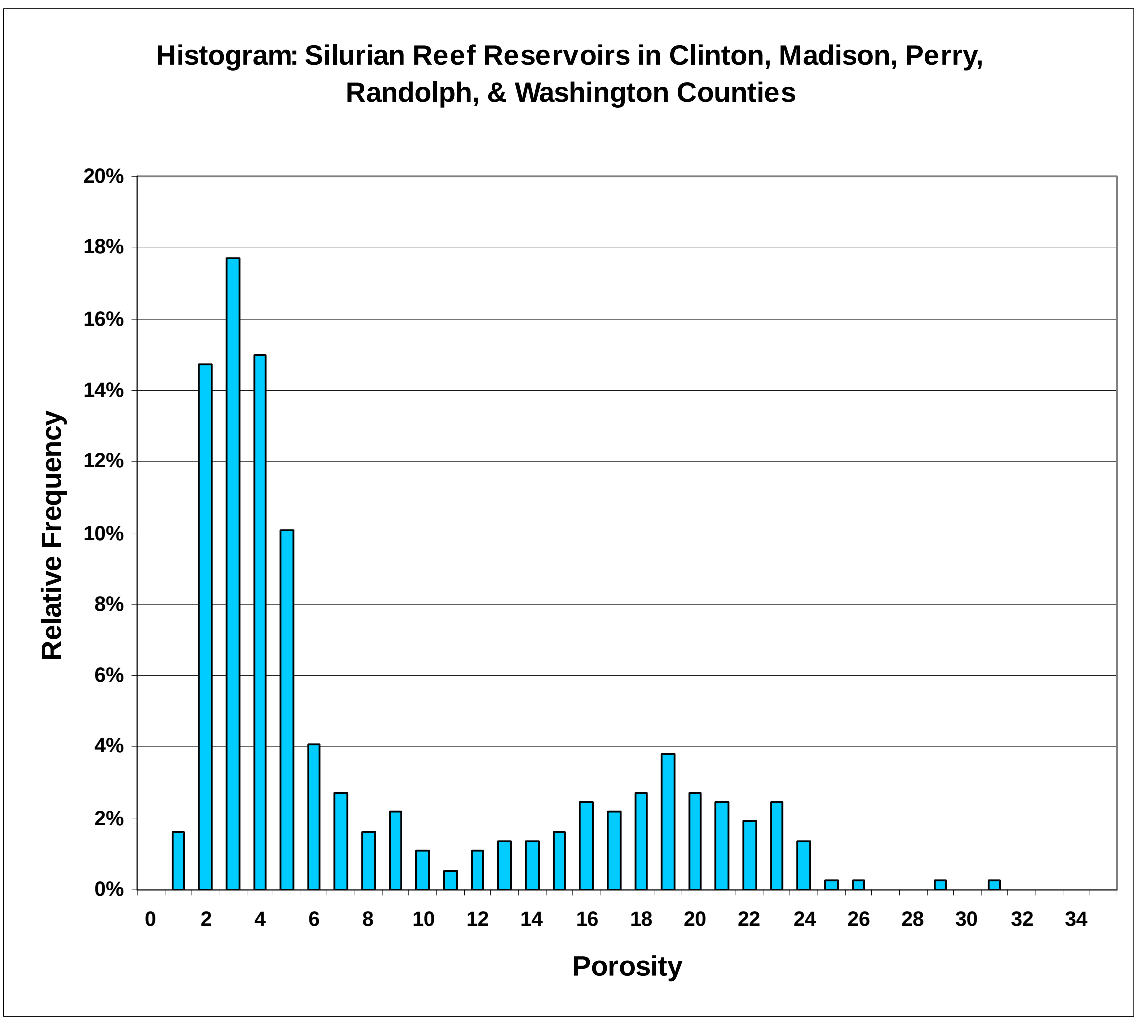



Figure 23. Histogram of porosity values measured from core samples from Silurian Reef Reservoirs in Madison, Clinton, Perry, Randolph and Washington Counties.

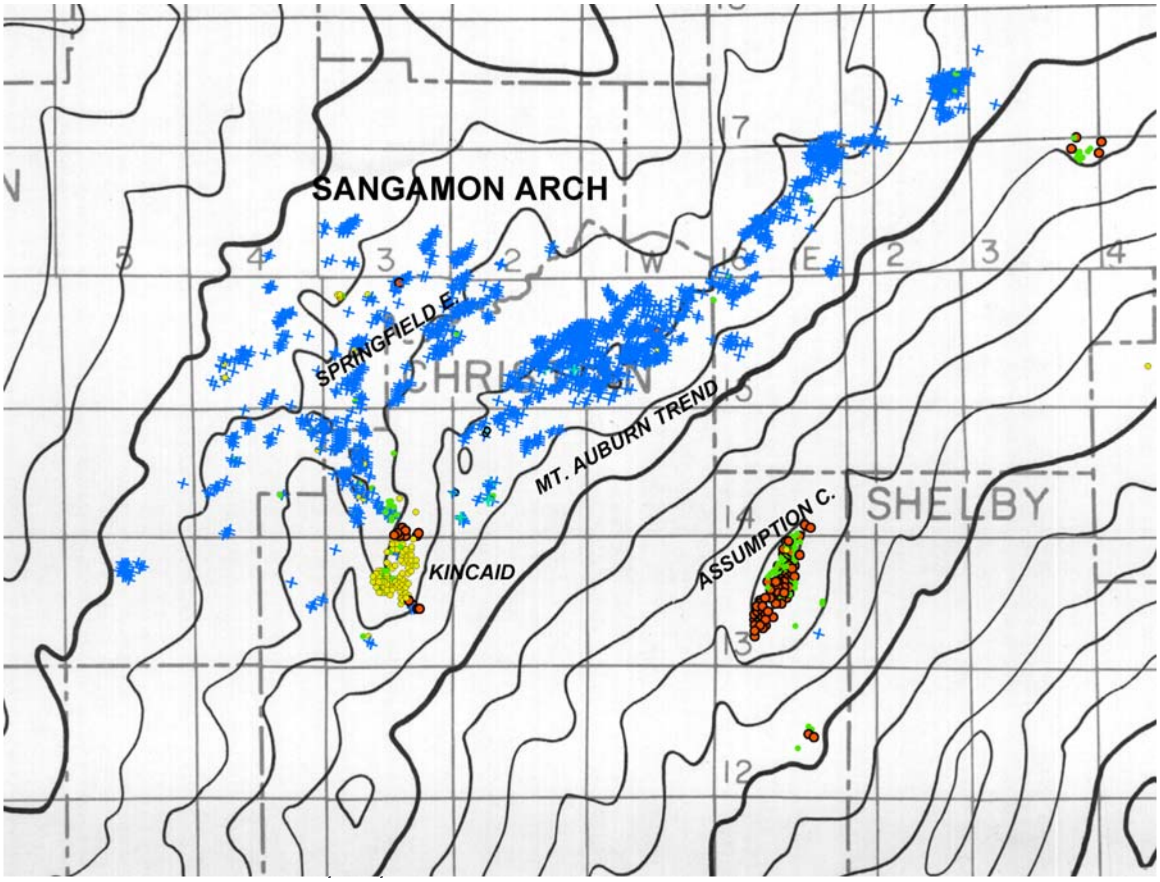



Figure 24. Production along the Sangamon Arch in Illinois. Silurian: blue cross; Hunton/Dev-Sil: aqua cross; Lower Devonian: dark green box,Devonian generic, undifferentiated: bright green dot, Lingle/Middle Devonian undifferentiated: orange dot
Upper Devonian undifferentiated or unconformity sands at base of New Albany: yellow dot

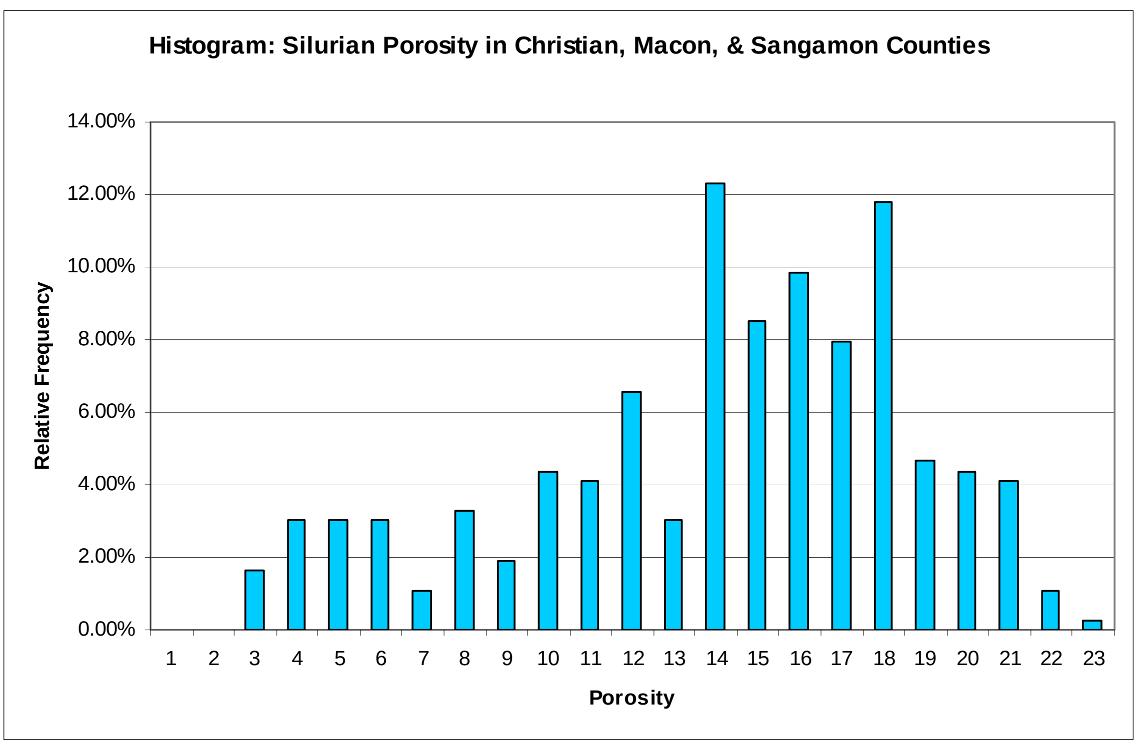



Figure 25. Histogram of porosity measured from core samples of Silurian rock from the Sangamon Arch.

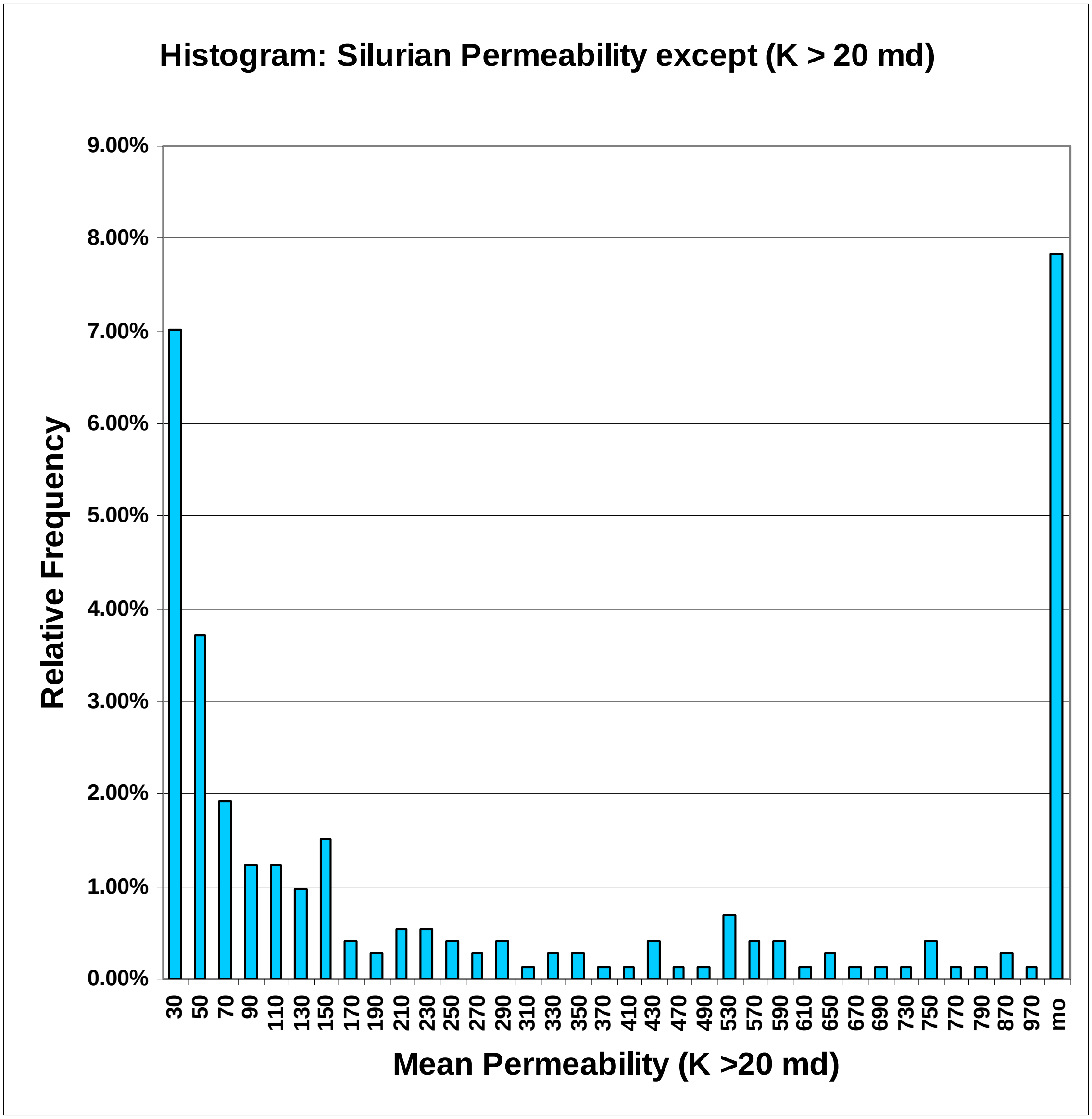



Figure 26. Histogram of permeability measured from core samples of Silurian rock from the Sangamon Arch.

## BUCKHORN CONSOLIDATED FIELD

### KANKAKEE LIMESTONE POOL

T1,2S - R3,4W
Brown County, Illinois
Joan Crockett, Beverly Seyler, Stephen T. Whitaker

### POOL DATA:

| | |
|---|---|
| Discovery year, Buckhorn portion: | 1961 |
| Discovery year, Buckhorn East portion: | 1980 |
| Field consolidation: | 1985 |
| Number of productive wells: | 205 (est.) |
| Cumulative production (7-87): | 1,500,000 BO (est.) |

R & R Enterprises
No. 5 Hecox
Sec. 35, 1S-4W
SW NW SE

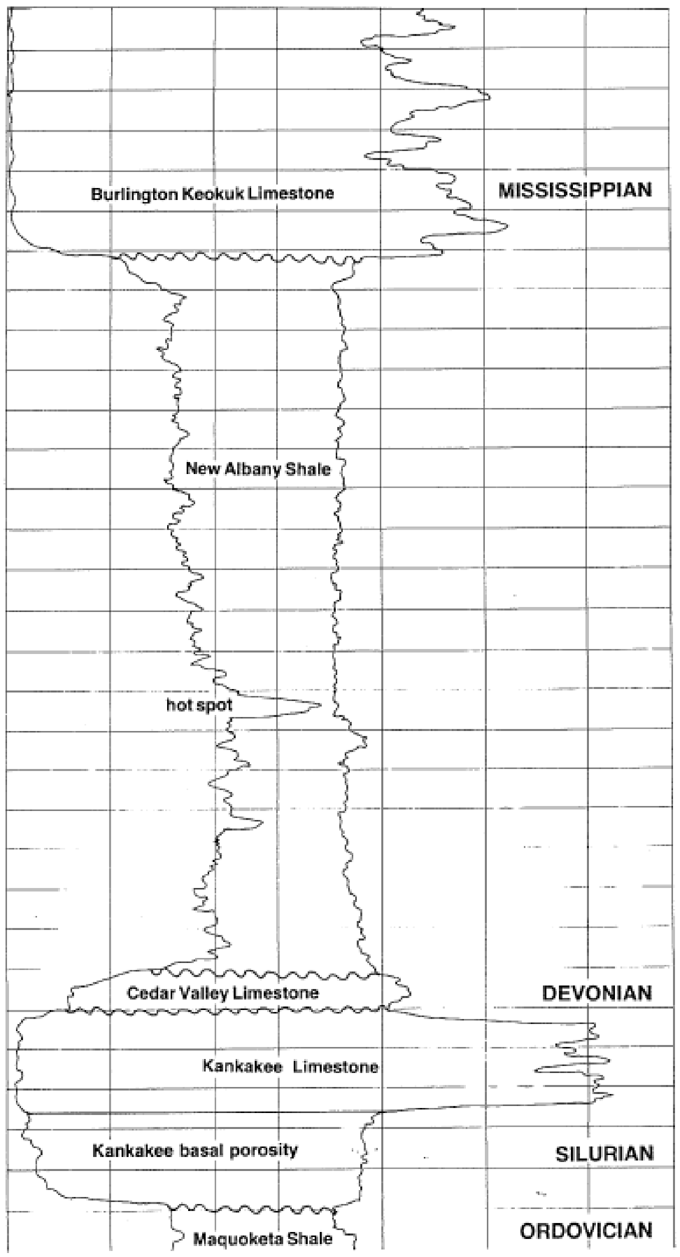



Figure 27. Typical log for Silurian reservoir at Buckhorn Consolidated Field. From Crockett et. al, 1988

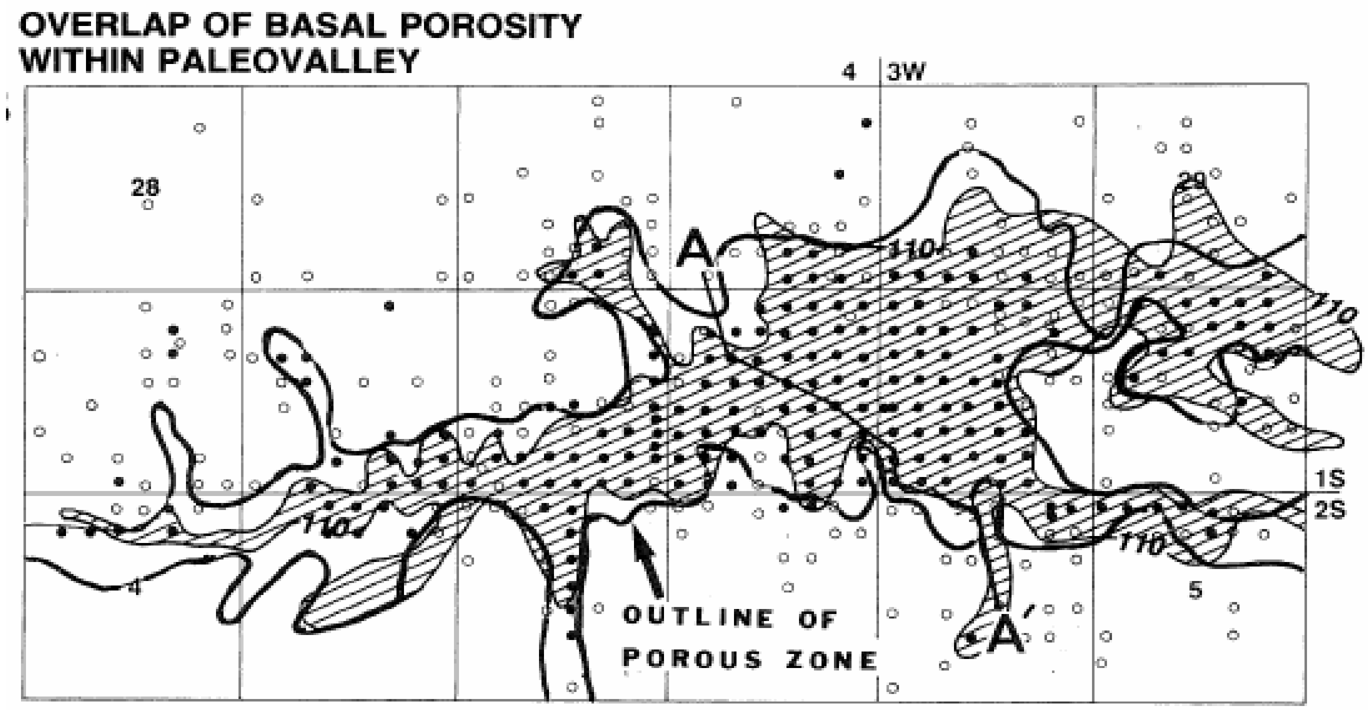



Figure 28. Map outlining drainage in the Maquoketa Shale coinciding with wells producing from basal Silurian dolomite directly overlying valleys eroded into the Ordovician Maquoketa Shale. From Crockett et. al.,1988.

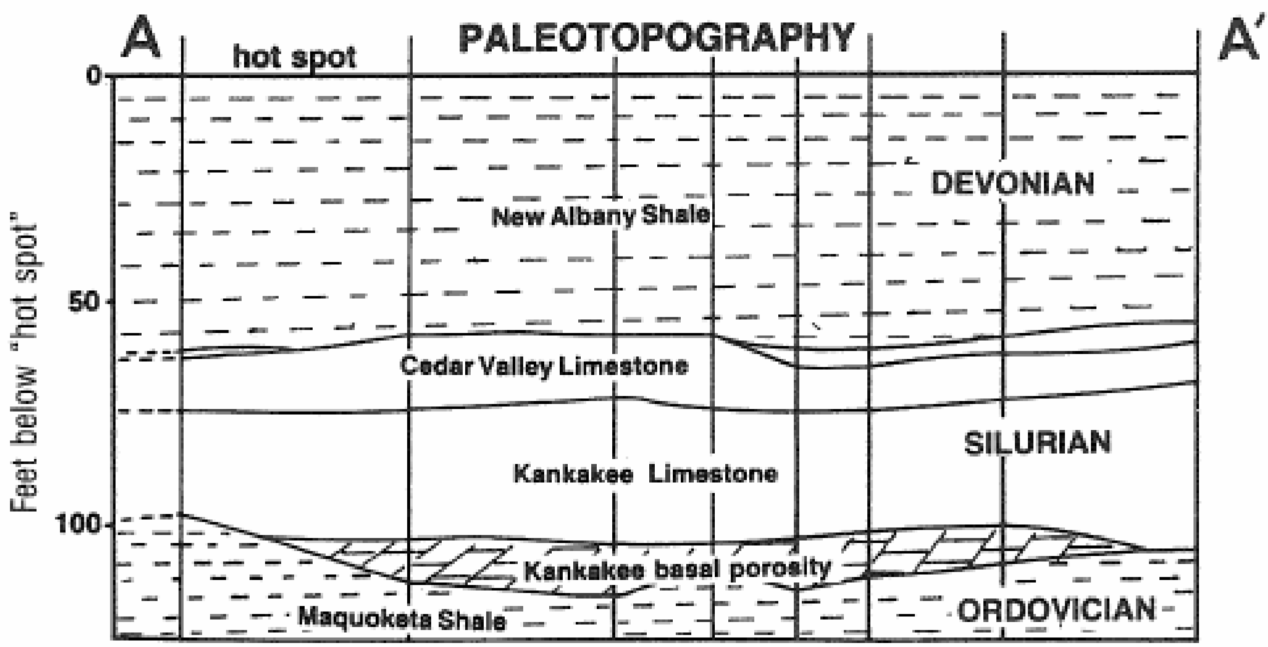



Figure 29. Schematic cross section shown on map in figure 28. Illustrates coincidence of dolomitization of lowermost Silurian rock in valleys eroded into the Ordovician Shale. From Crockett et. al., 1988

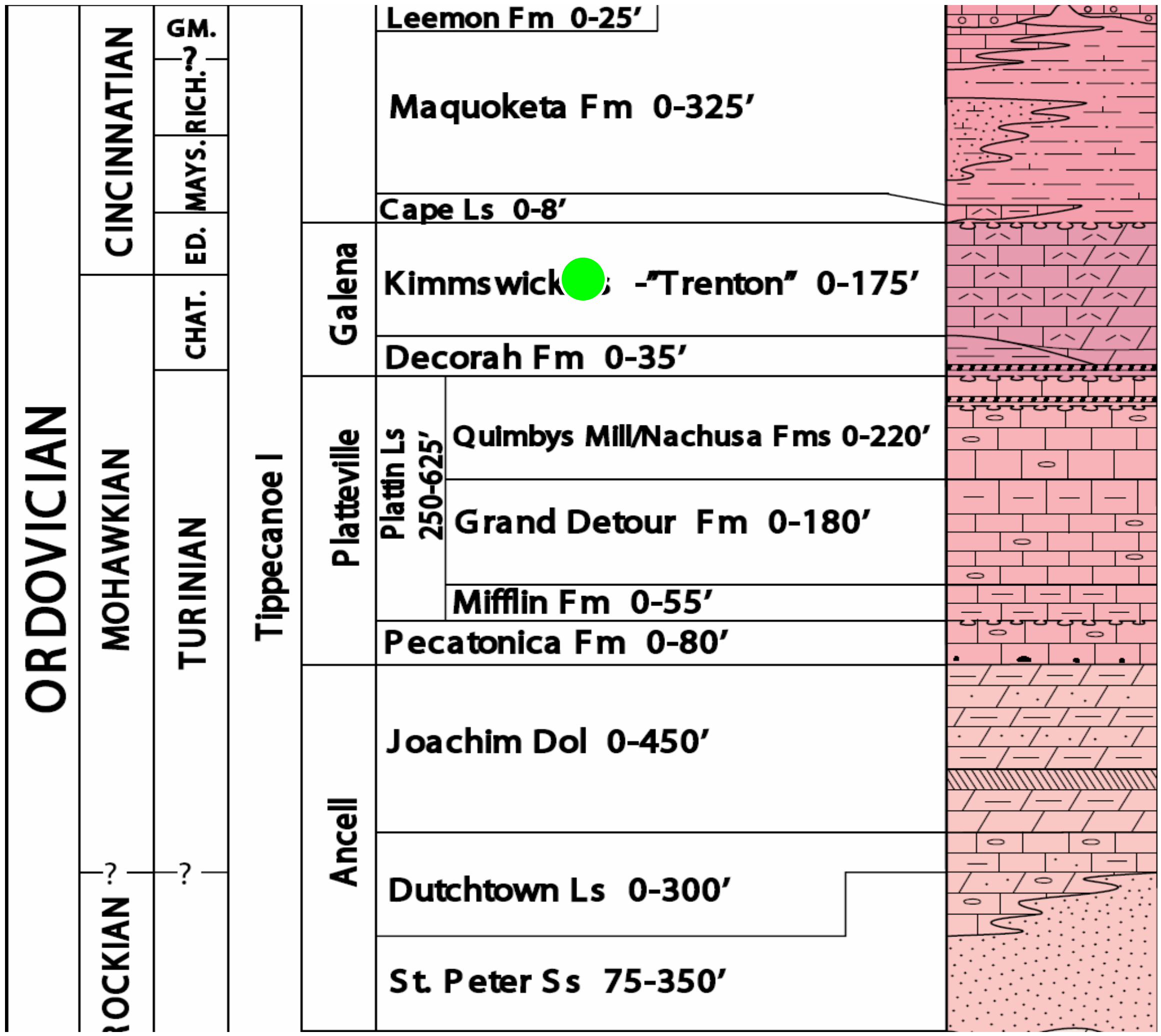



Figure 30. Stratigraphic column of Ordovician strata in the Illinois Basin. Producing unit indicated by green dot. From Kolata, 2005.

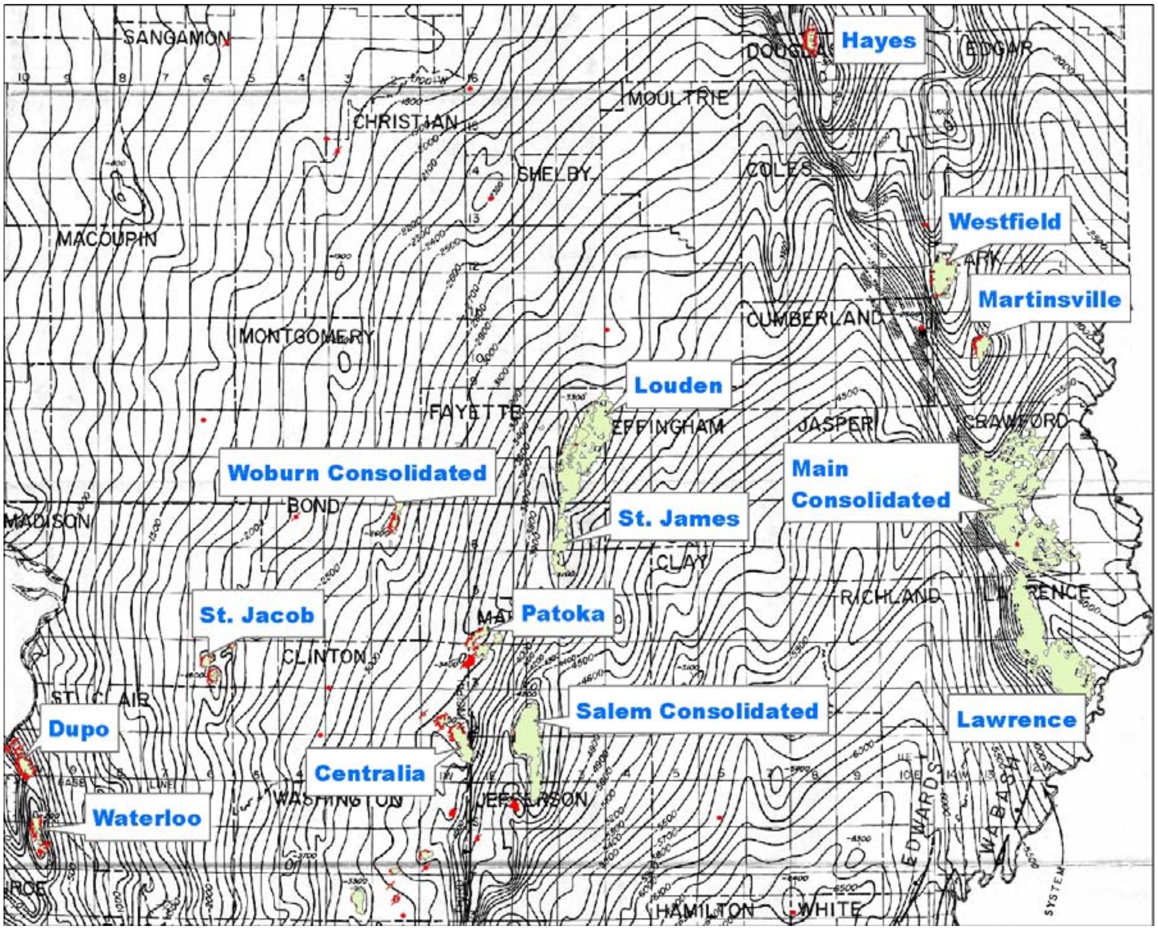



Figure 31. Distribution of wells producing from the Ordovician Trenton Formation in Illinois.

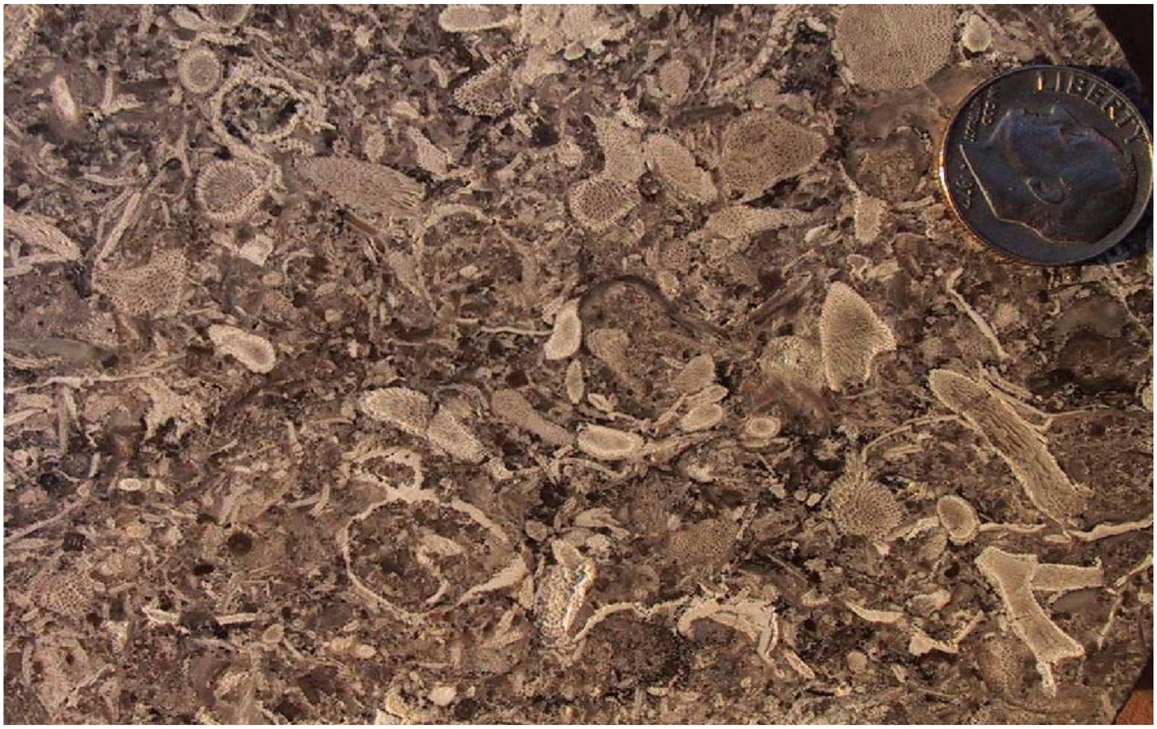


Figure 32. Fossiliferous grainstone in Ordovician Trenton Formation.

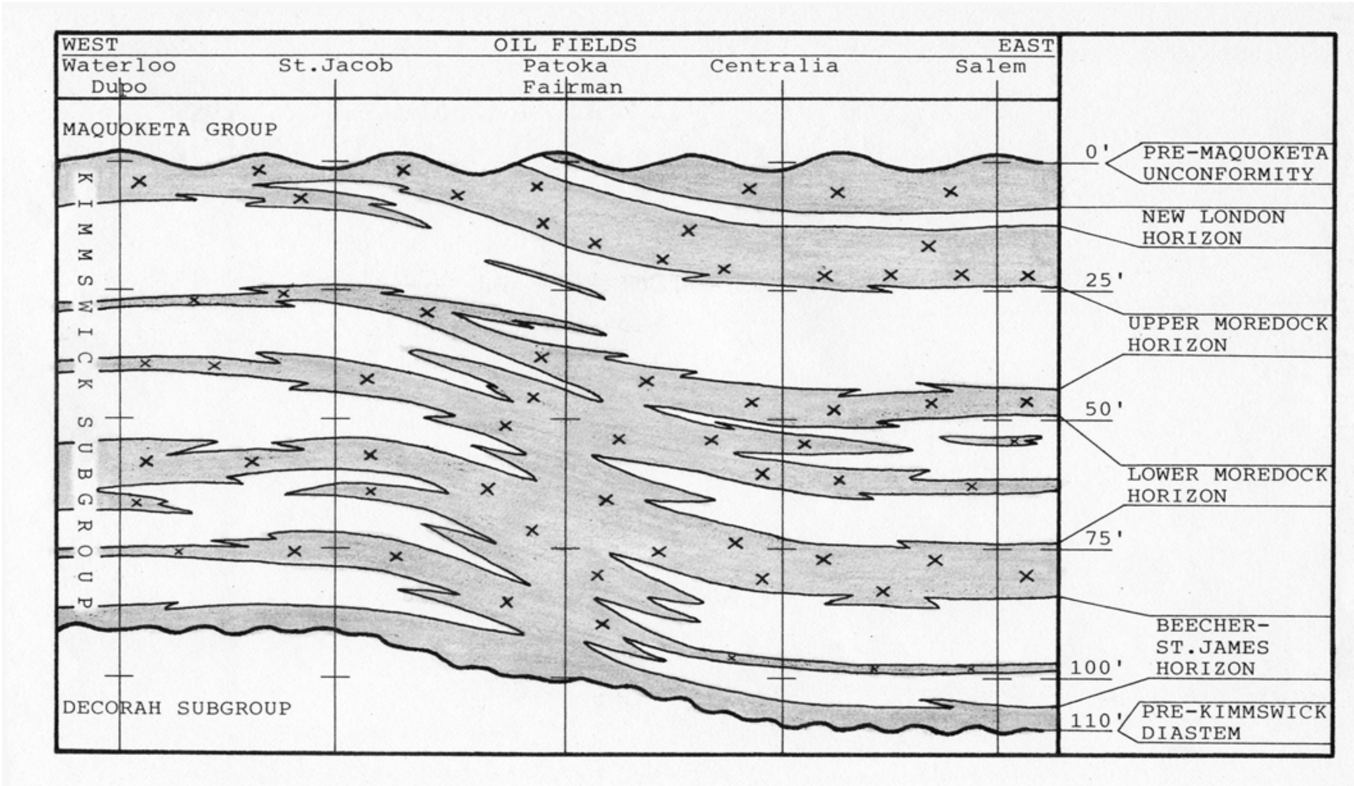



Figure 33. Correlation of porous grainstones in the Trenton Formation from western to central Illinois. From Crews 1985.

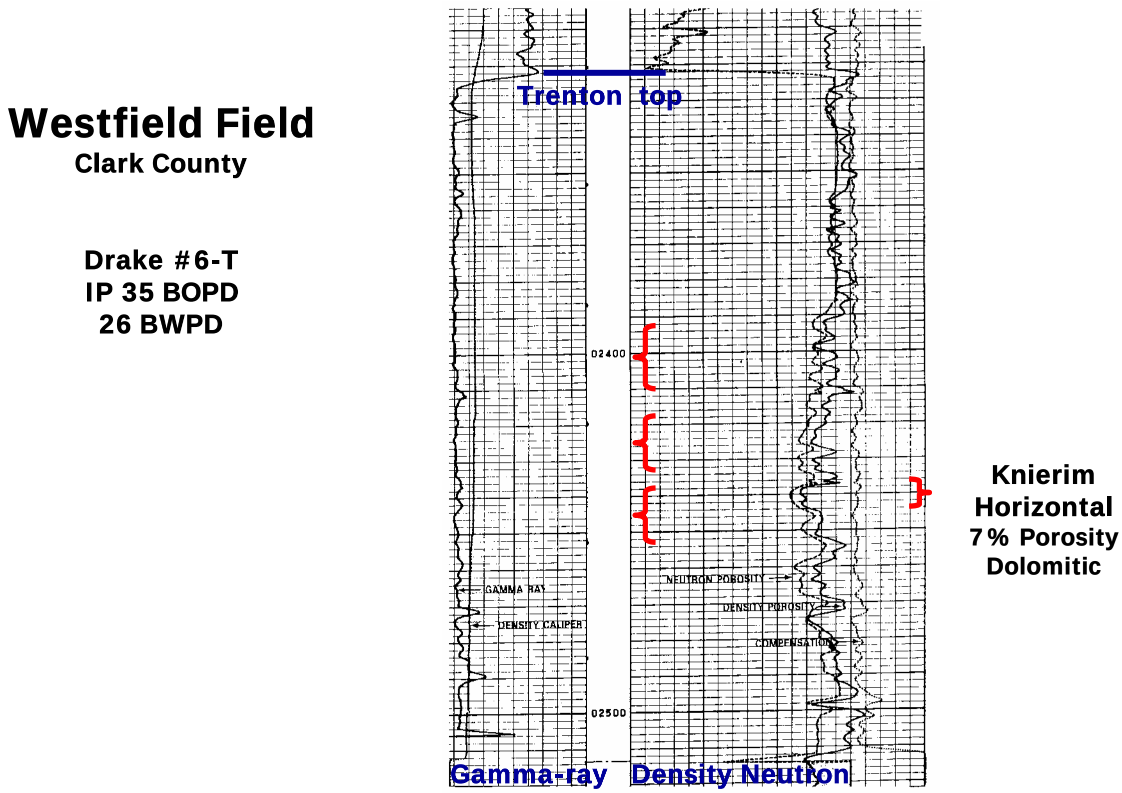



Figure 34. Geophysical log from Trenton reservoir at Westfield.

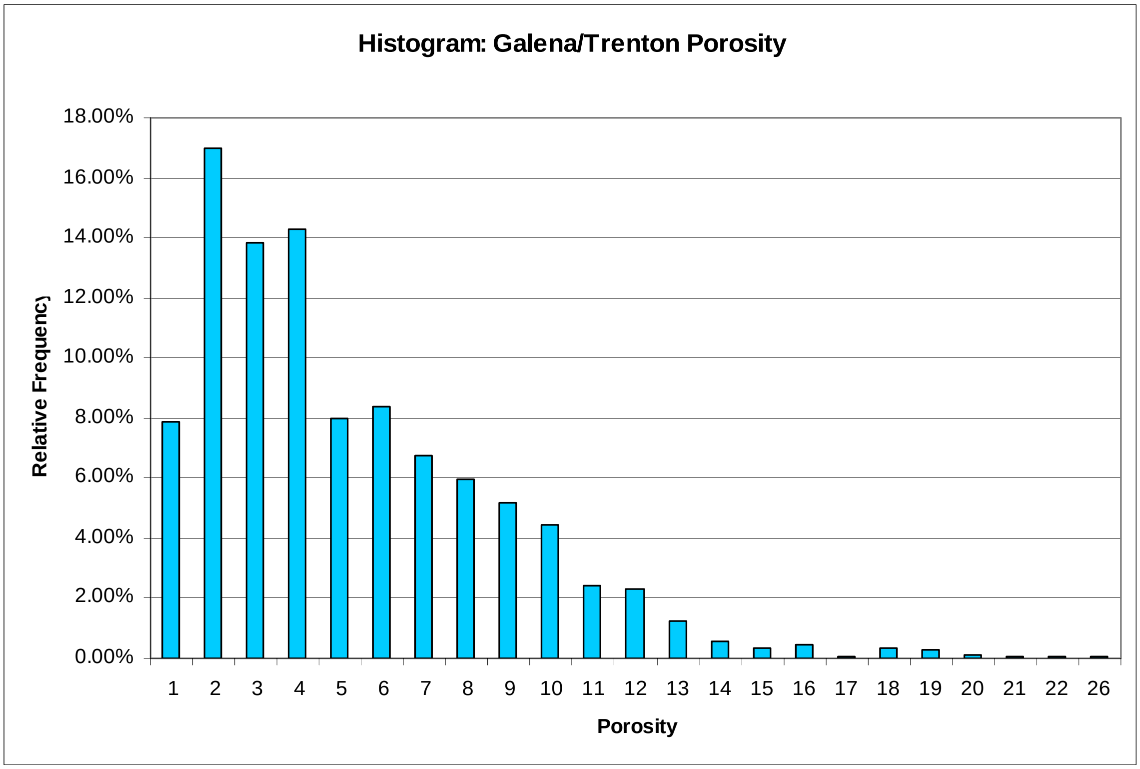



Figure 35. Histogram of porosity measure from Trenton core samples.

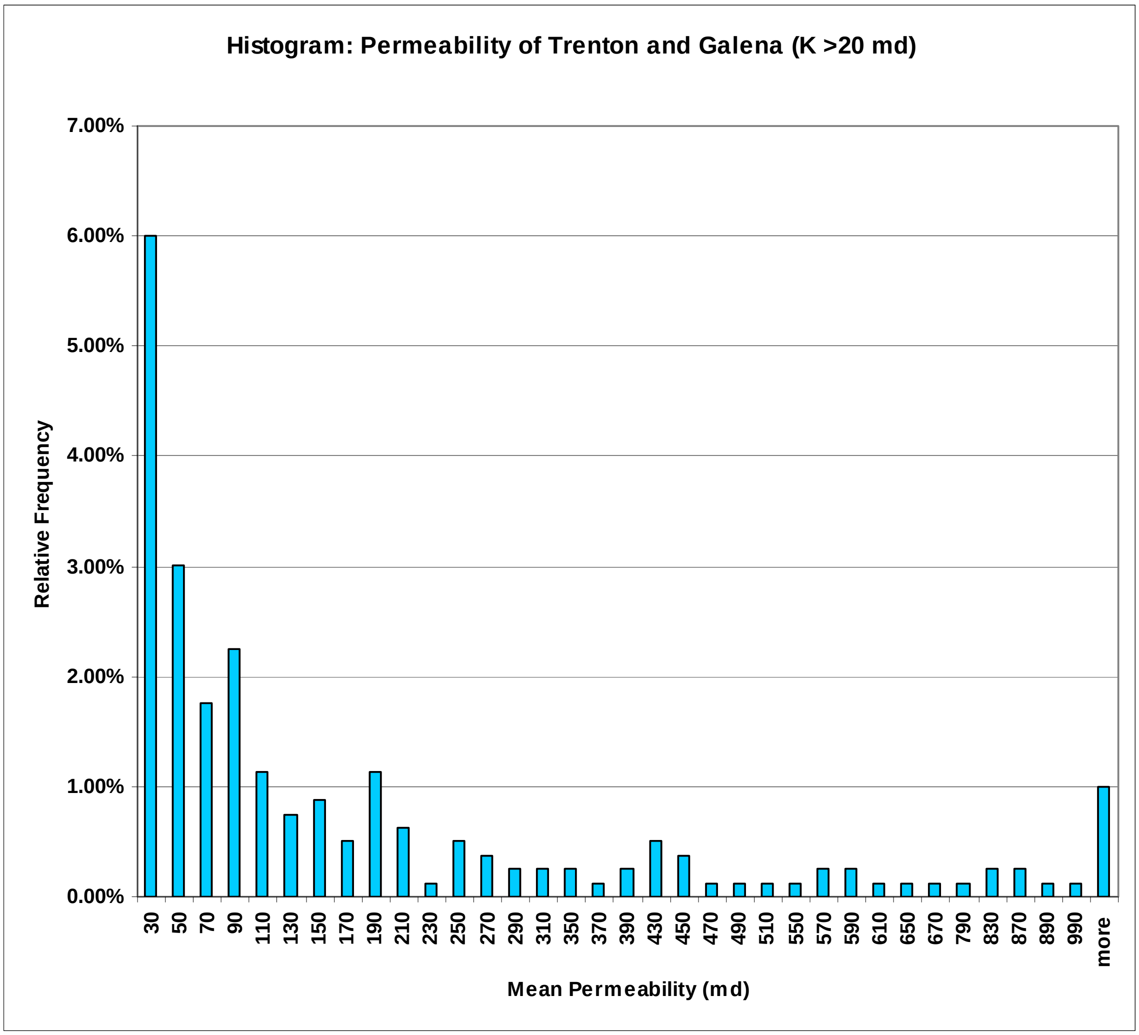



Figure 36. Histogram of permeability measured from Trenton core samples.

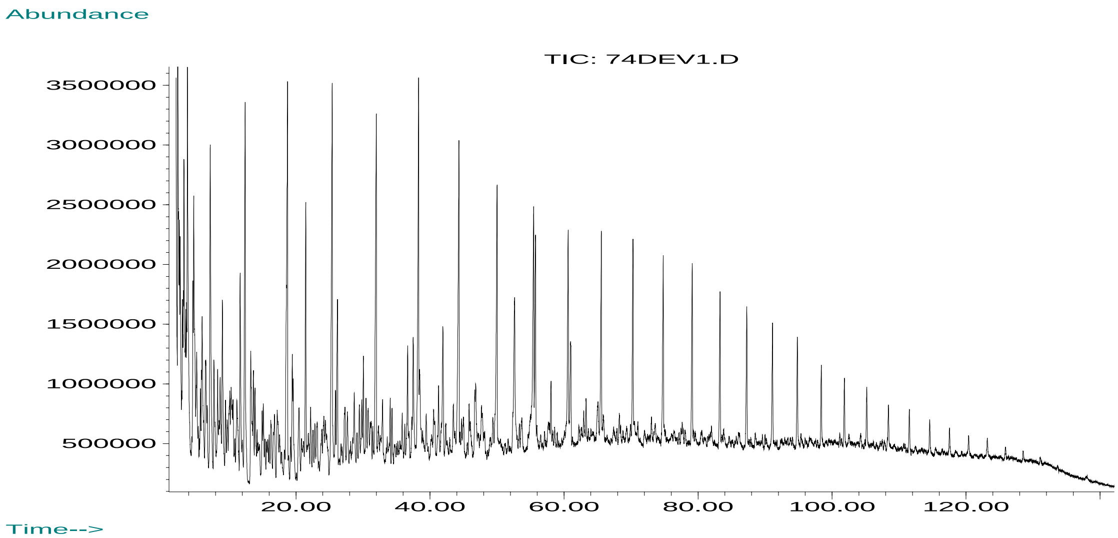



Figure 37. Gas Chromatograph of Devonian oil sample from Weaver Field in Clark County in eastern Illinois.

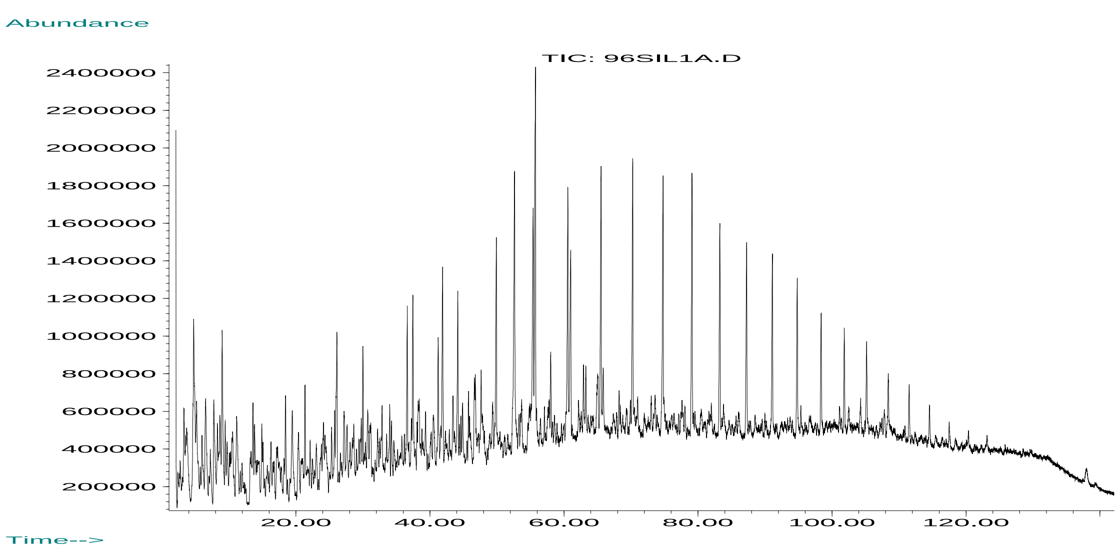



Figure 38. Gas Chromatograph of Silurian oil sample from Wapella Field in Dewitt County Illinois.

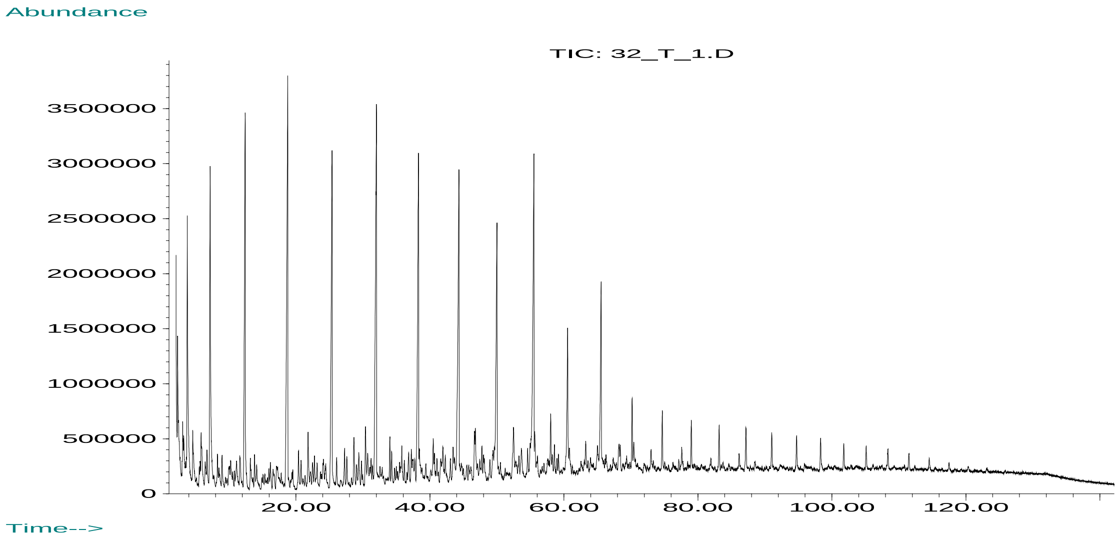



Figure 39. Gas Chromatograph of Ordovician Trenton oil from Posen Field in Washington County Illinois.

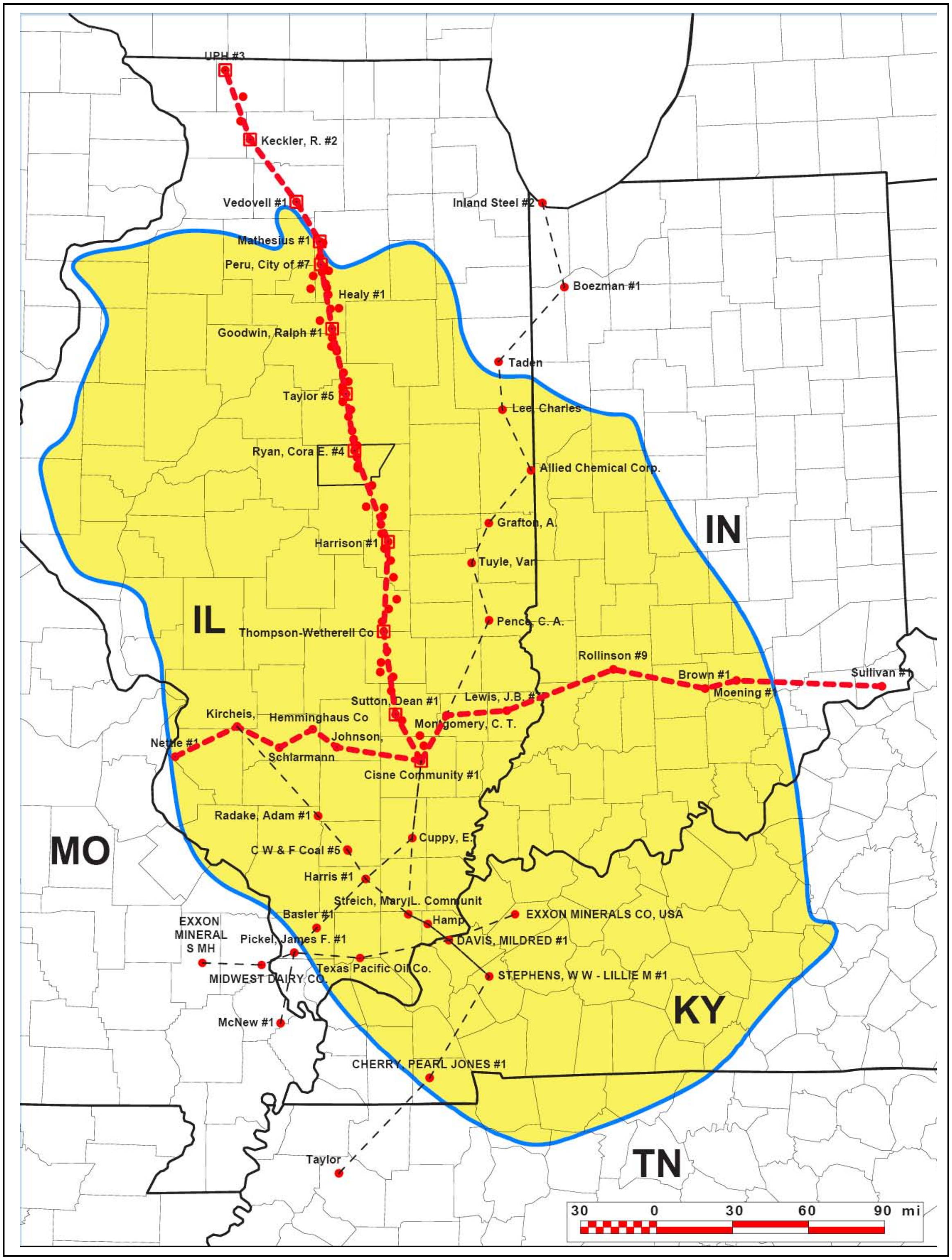



Figure 40. Location of Digital Structure Cross Sections in Figures 41 and 42

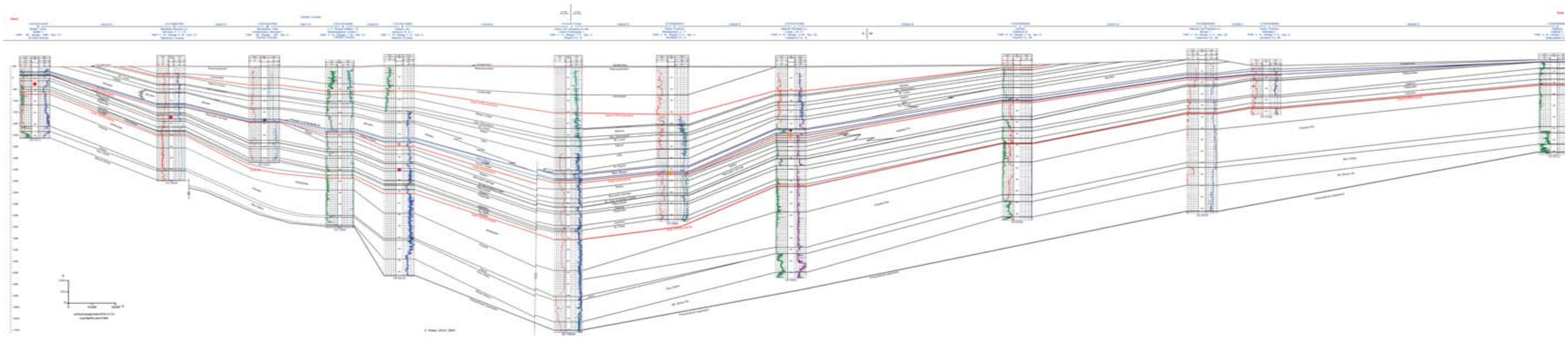


Figure 41. Digital structure cross section the 11:30 cross section runs mainly N-S.

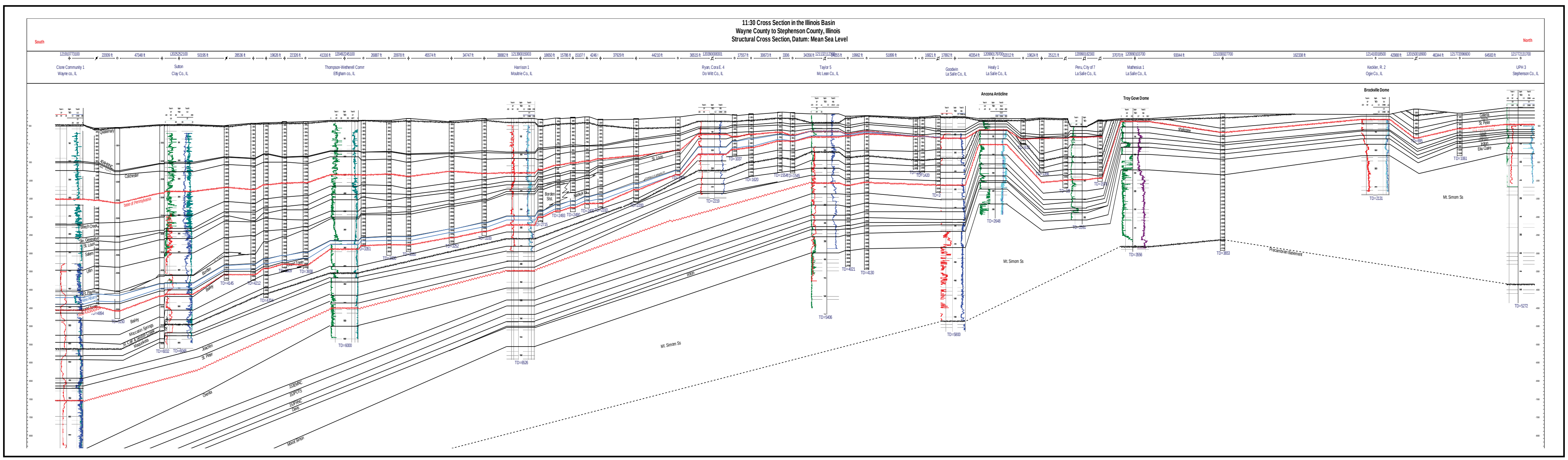



Figure 42. Digital structure west-east cross section of the entire basin from western Illinois to eastern Indiana.  Pay zones are color coded

# FIELD STUDIES

## The Lower Devonian Clear Creek Chert Pool in the Sesser Oil Field, Franklin County, Illinois: **Joan E. Crockett**

### Introduction

Sesser Oil Field is located in southern Illinois, in northwest Franklin County, Townships 5 and 6 South, Range 1 East about 8 miles north of the Cottage Grove Fault and immediately east of the DuQuoin Monocline (Figure 1). It was discovered in 1942 and has produced 4.9 million barrels (bbls) of oil as of January, 2007 from Devonian and Mississippian strata. It currently produces about 25,000 bbls annually. The Rend Lake Fault forms the down-dropped margin of the Sesser Anticline to the east of the field, while the low or sag to the west of Sesser Anticline is associated with the DuQuoin Monocline. West of the DuQuoin Monocline, strata are uplifted about 1200 feet on the Sparta Shelf, a relatively higher, broad shelf proximal to the Ozark Uplift in Missouri.

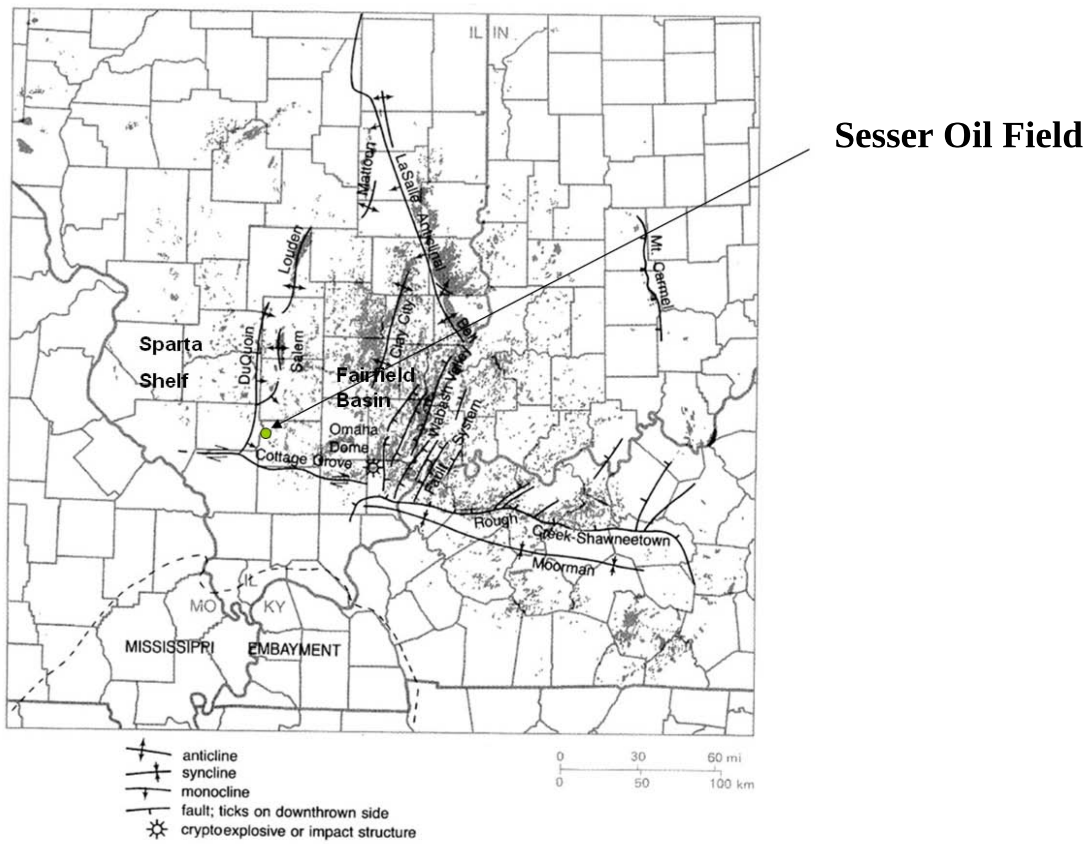



Figure 1. Location map showing Sesser Oil Field location and generalized structural features and distribution of oil fields in the Illinois Basin (modified from Seyler and Cluff, 1991).

The discovery well of Sesser Oil Field is the Old Ben Coal #1, in Section 25, T5S, R1E NW NE NW, drilled by Sun Oil Company and completed as an Aux Vases Sandstone (Mississippian) producer at a depth of 2690' to 2707' in April, 1942. Initial production (IP) of the well was reported at 50 barrels of oil per day (BOPD); no water production was reported. The well was plugged in 1946.

The next pay discovery in Sesser field was the Lower Devonian Clear Creek Chert In 1949 . The discovery was made by Paul Moseback's Bays #1 well in section 35-5S-1E (Figure 2.) The well was completed from 4402 to 4434 feet. The initial production reported on the Bays #1 was 35 BOPD. Clear Creek Chert production continued to be developed in the 1950s, 1970s and 1980s.

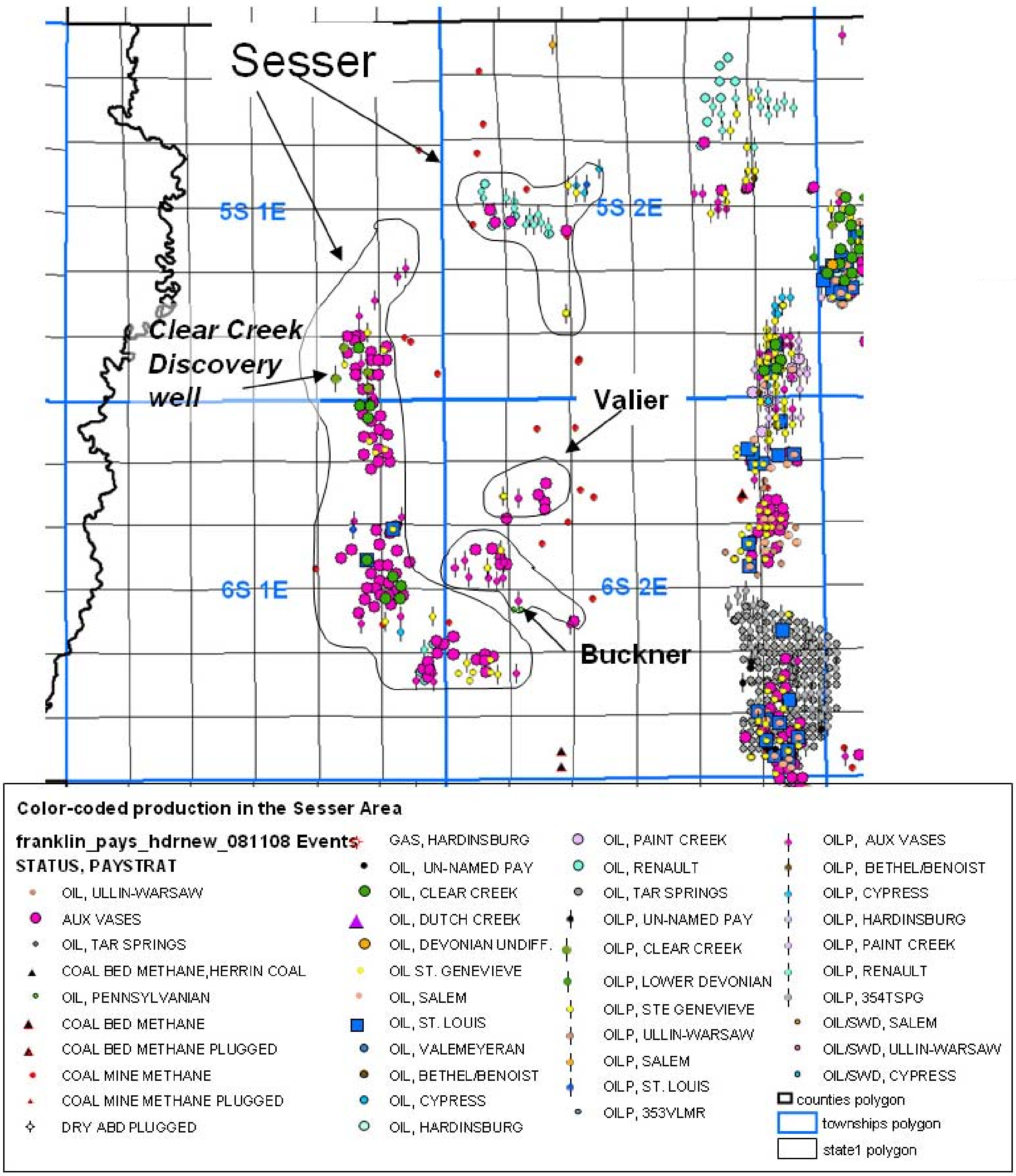



Figure 2. Color-coded pay map and Clear Creek Chert pay discovery well, Sesser area. Production form the Clear Creek Chert is found in 3 separate pods associated with separate structural highs along the anticline's hinge trend. Mississippian production also follows the north-south elongate anticlinal trend.

Additional pay zones were later established in Mississippian carbonates and sands in the 1950s. Three waterflood units which produce from and inject into the Aux Vases Sandstone (Mississippian) have been established in the field.

**Stratigraphy**

Surficial deposits in the area consist of approximately 25 feet of Quaternary glacial deposits (Piskin and Bergstrom, 1975) that unconformably overlie Pennsylvanian sediments. Bristol and Howard (1971) mapped Pennsylvanian sediments of Desmoinesian age beneath the Quaternary at Sesser. A chart depicting the general stratigraphic relationships in southern Illinois strata is shown in Figure 3.

Approximately 1600 feet of Pennsylvanian rocks rest unconformably on Mississippian rocks of the Chesterian Series (Kinkaid Limestone or Degonia Sandstone Formations (Bristol and Howard, 1971)). Pennsylvanian coal was once actively mined in underground mines at Sesser. Many wells are drilled through mine pillars to Mississippian oil-productive strata at Sesser field.

Nearly 2800 feet of Mississippian rocks are present in the Sesser area. A large portion of the oil that is produced from Sesser Oil Field is from Mississippian reservoirs, the Aux Vases Sandstone being the predominant target in the field with 90 producing wells (Figure 2). There is a minor amount of Cypress Sandstone production (4 wells). Production from the Renault Limestone is from 26 wells. Ste. Genevieve Limestone carbonates and sandy carbonates, the O'Hara Limestone Member, Spar Mountain Sandstone Member, and the McClosky Limestone Member, produce in 26 wells. The St. Louis Limestone produces from 4 wells. To date, no production in the lower Mississippian formations has been established at Sesser. Many wells only drill to the Aux Vases or Ste. Genevieve formations leaving deeper strata sparsely tested.

Underlying the Mississippian rocks, Upper Devonian New Albany Shale Group sediments are the source rock and a seal for the oil produced at Sesser. The New Albany Shale Group is approximately 40 feet thick over Sesser, and formations from the top to base include (in descending order) the Hannibal-Saverton Shale, Grassy Creek Shale, and the Sweetland Creek Shale (Cluff and Lineback, 1981).

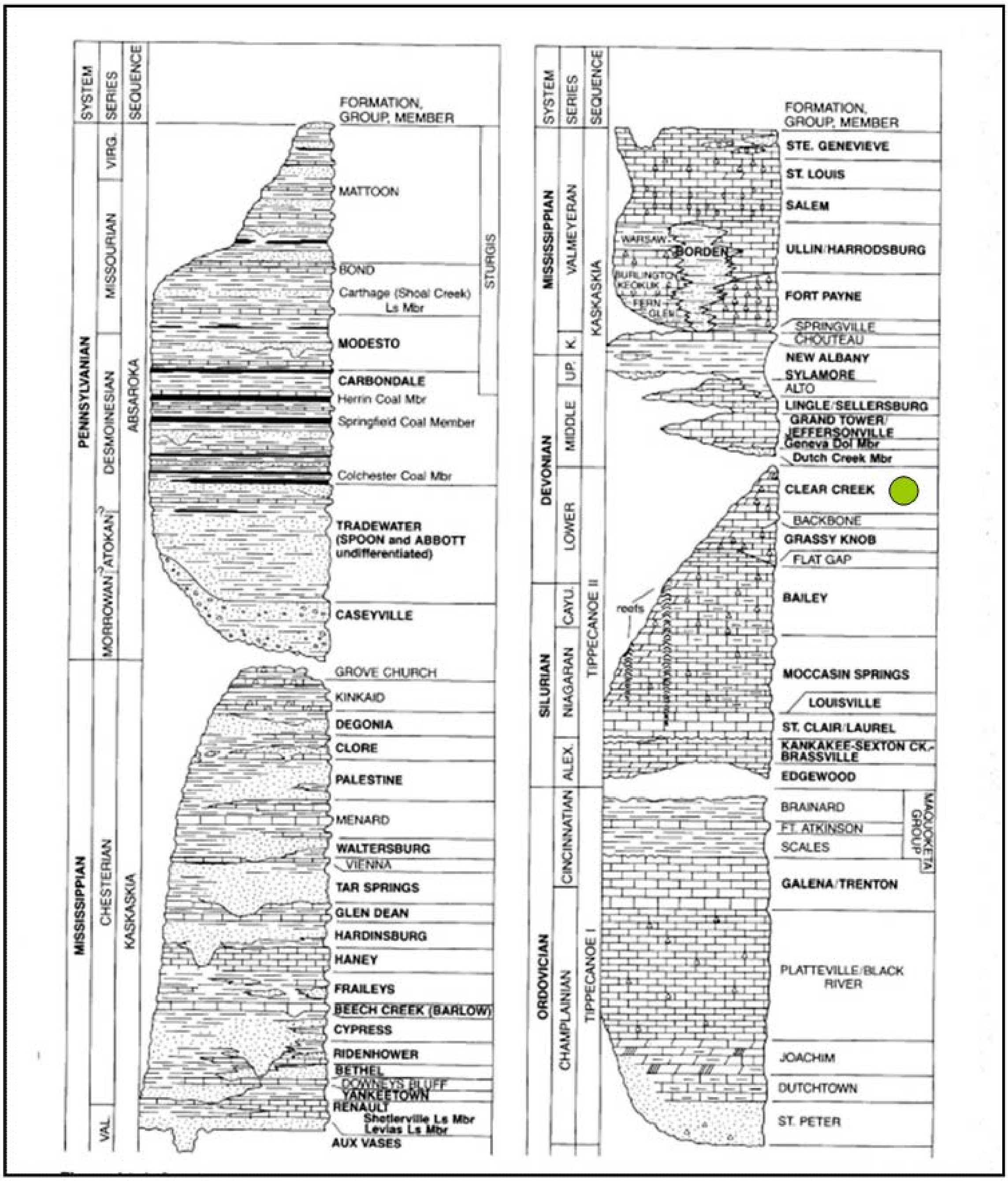



Figure 3. Stratigraphic section of Ordovician through recent rocks in Southern Illinois. Green dot shows stratigraphic position of Clear Creek Chert. Note the Sub-Kaskaskia unconformity that separates rocks of the Kaskaskia Sequence from the Tippecanoe II Sequence. From Howard (1991).

Below the New Albany Group, in disconformable contact, is the Middle Devonian Lingle Limestone. The Lingle Limestone is a brown to gray, silty, argillaceous limestone to dolomitic limestone that may be cherty or fossiliferous. Mapping in this study finds the Lingle Limestone is 40 to 50 feet thick at Sesser

In Franklin County the Middle Devonian Grand Tower Limestone is absent west of Range 2 East which includes the Sesser field area. Reasons for the absence of Grand Tower strata in the west portion of Franklin County and to the west on the Sparta Shelf are not clear. It may be due to non-deposition or erosion (Meents and Swann, 1965, North, 1969). Devera and Hassenmuller (1991) suggested that the Sesser area was part of the Middle Devonian Sparta Shelf uplift, and deposition did not occur on the paleo-high structure. Kolata and Nelson (1991) describe the timing of the tectonic uplift of the Sparta Shelf (hinged along the DuQuoin Monocline) as occurring in Silurian and Devonian times. Because of the absence of the the Grand Tower Limestone at Sesser the Lingle Limestone is in unconformable contact with the Lower Devonian Clear Creek Chert.

The Clear Creek Chert is the youngest Lower Devonian strata in the area and was originally described (Worthen, 1866) at a location along Clear Creek in Union County, southwestern Illinois. The Clear Creek is dominantly a dolomitic, somewhat fossiliferous limestone containing beds or lenses of gray to grayish white siliceous spiculitic chert. The uppermost Clear Creek at Sesser includes stray sand grains that may represent Dutch Creek sands; no bedded sand is observed at Sesser. Limestone-dolomitic limestone facies may be separated from bedded or nodular chert by stylolitc partings. Alterationof the original siliceous limestone has occurred, possibly by dissolution of limestone, replacement of limestone by chert, and fracturing.

The Clear Creek Chert is about 144 feet thick in Sesser. The formation thickens basinward (to the east and south) to at least 400 feet thick in the deep Lower Devonian embayment in the Webber well in Saline County in 6-T8S-R6E, approximately 25 miles southeast. East of Sesser, the Clear Creek section is more completely preserved and a thicker section remains. West of Sesser, across the hinge of the DuQuoin Monocline, and on to the Sparta Shelf, the Clear Creek has been entirely removed by erosion.

The electric log from the Hair #1 well, drilled in 1952 by C. Edwin Hair, in section 35, T5S-R1E, is shown, with formation boundaries and productive zone marked (Figure 4). The Devonian Lingle Limestone commonly has a low spontaneous potential and high resistivity.

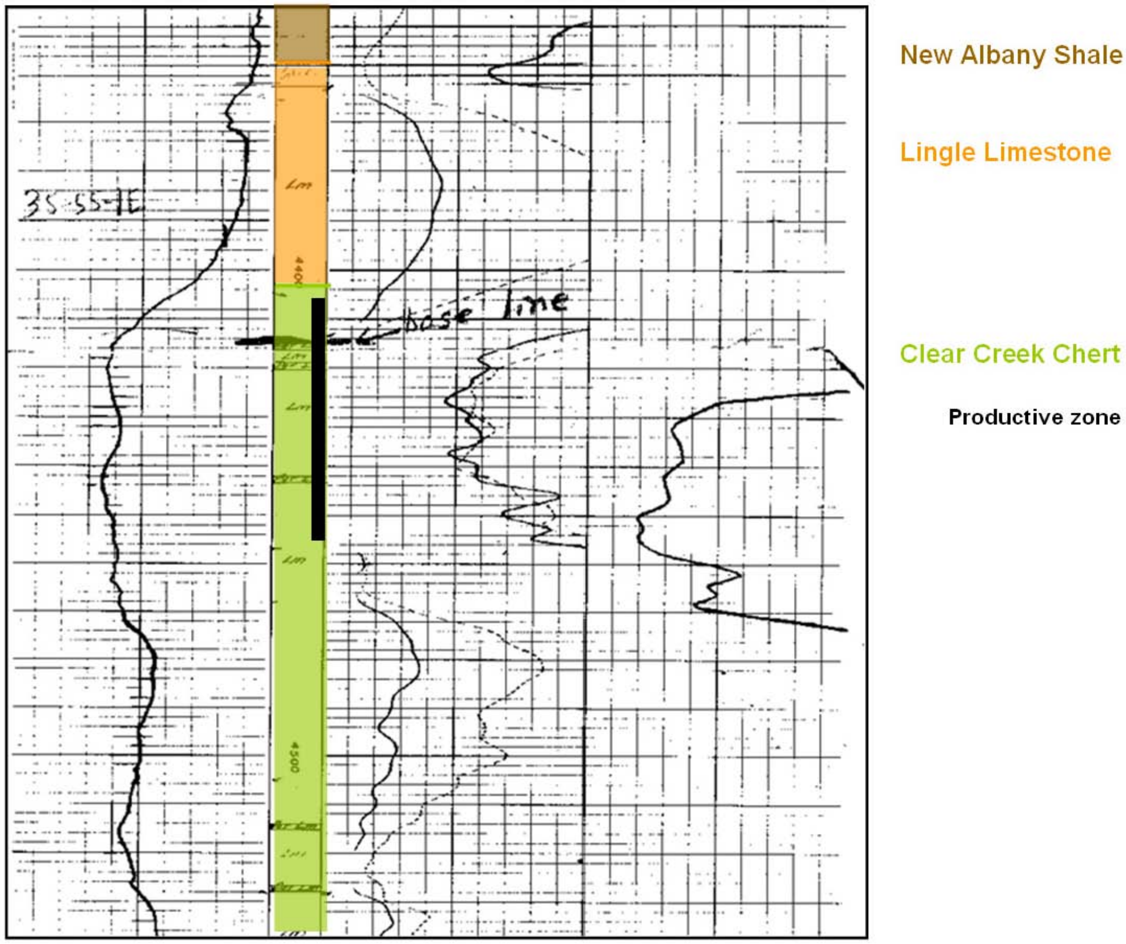



Figure 4 . Electric log from C. Edwin Hair's Hair #1 well 35-5S-1E Franklin County showing Clear Creek Chert characteristics in Sesser Field. Words "base line" and associated arrow and line are not part of this study.

The Clear Creek contact is marked by a rapid increase in the Spontaneous Potential (SP) log, and where the SP achieves its greatest positive deflection, a marked reduction in the Resistivity log is seen. This log signature commonly marks the top of the cherty, dolomitic limestone zone that, if located on a structurally-high position, is a favorable oil-productive zone. The porous low resistivity zone in the Hair well is about 30 feet thick, with increasing resistivity at the base of the zone. Below this zone, the SP diminishes and resistivity increases, finally going off-scale.

Beneath the Clear Creek Chert, in conformable contact (Collinson et al., 1967) is the Backbone Limestone. The Backbone Limestone is described as a facies that rims the deeper part of the Illinois Basin, but thins or becomes absent due to facies changes in the deepest part of the basin (Willman et al.1975). The Backbone is a light gray to white, massive crystalline, pure limestone with a few scattered chert nodules. The limestone contains abundant fossils. At Sesser, regional correlations suggest the Backbone is about 66 feet thick. Collinson et al. (1967) reports that the Backbone represents fossil debris swept into the basin from the basin margins.

Beneath the Backbone is the Grassy Knob Chert. The Grassy Knob Chert is a light gray to buff, cherty limestone with at least two thick chert zones that may be traced regionally across the basin in the subsurface. Fossils are rare in the Grassy Knob Chert, according to Collinson (1967). Willman et al. (1975) describe the Grassy Knob contact with the Bailey (below) as gradational. Regional correlations in this study suggest the Grassy Knob is 430 feet thick.

Underlying the Grassy Knob is the Bailey Limestone. The Bailey is “a gray to grayish-green, silty, cherty thin-bedded, very hard limestone,” with black to dark gray chert occurring in nodules and thin beds (Willman et al., 1975). The Bailey is thought to be transitional from Silurian in age at its base, grading to Lower Devonian in age at the top. The Bailey Limestone at Sesser is 430 feet thick.

The overall thickness of the Lower Devonian at Sesser is about 665 feet thick. In contrast, the Lower Devonian at the Webber well in Saline County 25 miles to the southeast is 1105 feet thick. Stratigraphic correlations show that the thinning observed at Sesser is due to erosion at the sub-Kaskaskia unconformity, which resulted in the removal of the upper part of the Clear Creek Chert.

The Silurian succession at Sesser Oil Field is composed of red, green, and gray limestone. Silurian rocks are 311 feet thick at Sesser and are separated from the Ordovician Maquoketa Shale below by an erosional unconformity.

At Sesser Oil Field, the Maquoketa Shale is markedly thinner than in the area surrounding it. The Maquoketa is 130 feet thick at Sesser, whereas the formation is about 175 to 200 feet thick in surrounding areas to the north, west and east. The Maquoketa is predominantly gray to gray-green shale.

Below the Maquoketa is the Galena Group (Trenton Limestone). Rocks of the Ordovician Galena Group are the oldest pay zone known to produce oil and gas in Illinois. The Galena is a gray to buff colored, fossiliferous limestone that may contain fractured dolomite. In the Sesser area, the Galena is 116 feet thick and tested slight shows of oil and gas in the lower Galena.

Below the Galena is the Decorah Shale, a thin shale that overlies the Platteville Group. The Elcoex/Triple T #1, the deepest well drilled in the field, reached a total depth of 6060 feet in the Platteville Group which consists of gray, fine-grained, lithographic gray limestone.

**Regional Structural Setting**

Sesser Anticline lies near the southern limit of oil production in Illinois. The map of regional structural features in Illinois (figure 1) shows that the Sesser structure lies adjacent to four major regional structural features, the Cottage Grove Fault to the south, the DuQuoin Monocline to the west, the Rend Lake Fault System immediately east of Sesser, and the Fairfield Basin to the northeast. Sesser Oil Field is located on the elongate north-south trending Sesser Anticline with approximately 50 feet of closure mapped on the Beech Creek (Barlow) Limestone (figure 5).

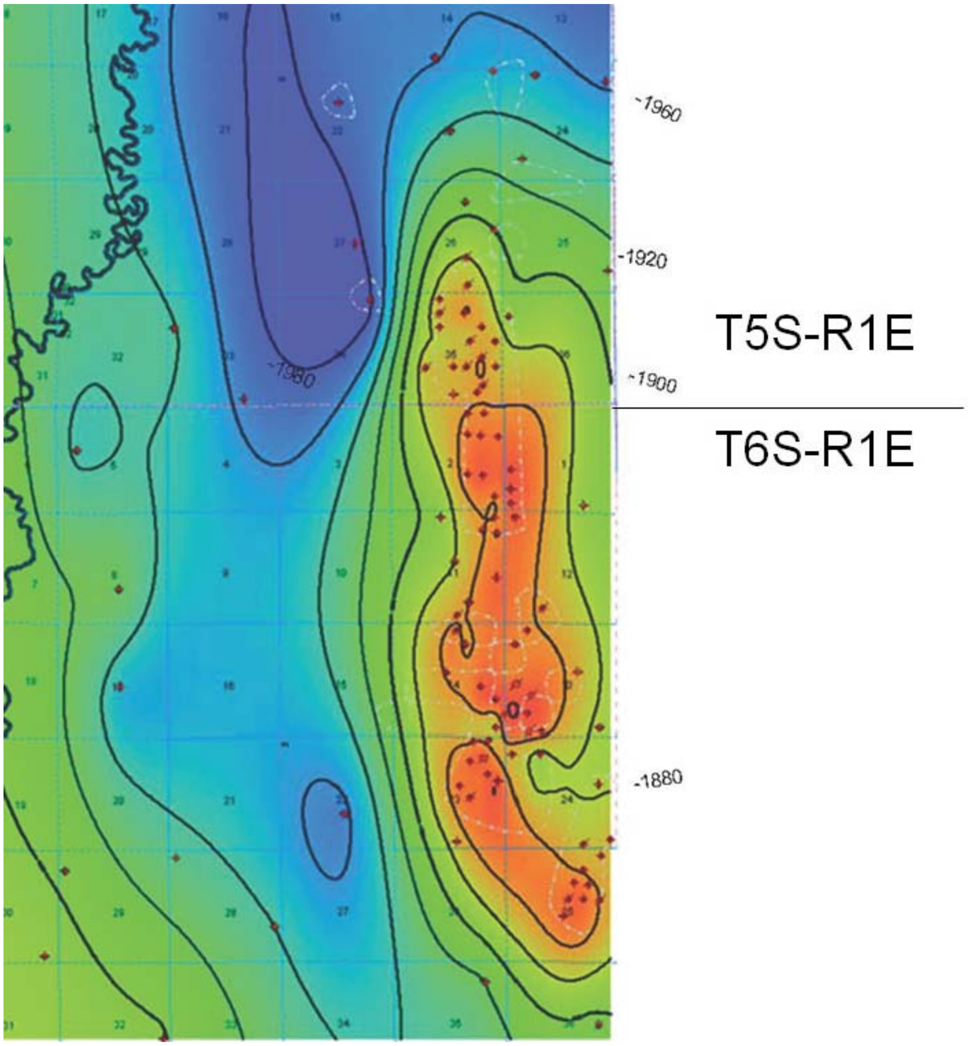


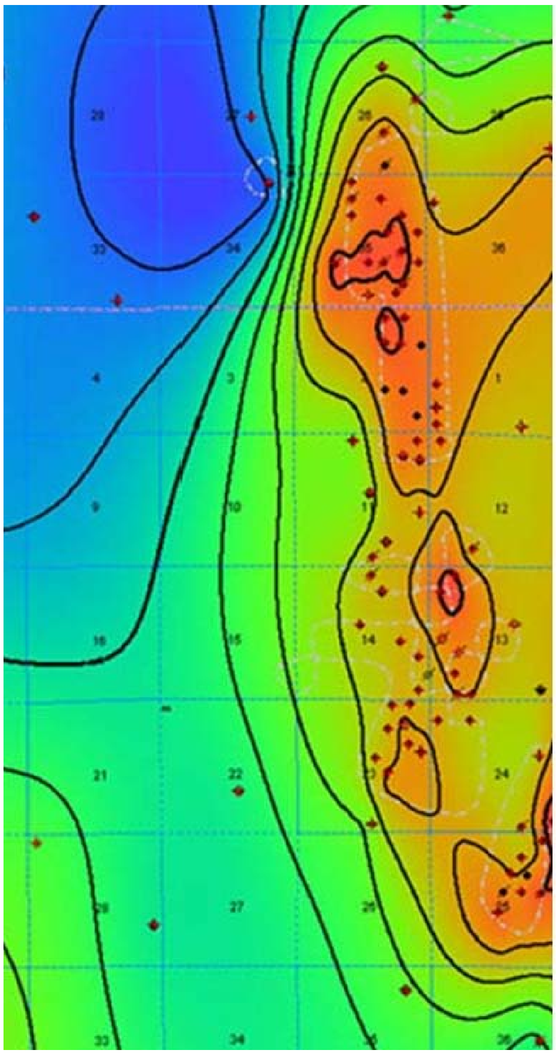

Figure 5 . Structure contour map on the base of the Beech Creek Limestone in the Sesser Oil Field area. Color ramp from blue (lowest) to orange (highest) Contour interval 20 feet.

Nelson (1995) reports that the Sesser Anticline probably developed in latest Mississippian to early Pennsylvanian time, but this study suggests that the region also may have been an active structural high during the erosional event marked by the Sub-Kaskaskia (post-Clear Creek) unconformity. Evidence suggesting that the Sesser and Benton Anticlines may have been structurally high in early Middle Devonian time is based on the absence of Middle Devonian Grand Tower strata in western Franklin County and erosional truncation and thinning of the underlying Clear Creek Chert at Sesser Oil Field.

**Sesser Oil Field Maps**

The base Barlow Limestone subsurface structure map (Figure 5 ) shows the north-south trending Sesser Anticline. . The anticline has two small structural dome-like closures; one in the SE quarter of section 2-T6S-R1E, and another along the section line dividing sections 14 and 13, T6S-R1E. Mississippian and Lower Devonian production is closely associated with the highest structural closure. The west margin of the field is steeplydipping. The eastern flank of the anticline dips more gently.  Mississippian oil production is found under the eastern flank, but no Clear Creek production has been established there. Few wells test the Clear Creek on the eastern side of the field.

The Ste. Genevieve Limestone, another prominent regional mapping horizon, occurs about 300 feet below the Beech Creek (Barlow) Limestone. A structure map on top of the Ste. Genevieive Limestone (figure 6 )  shows an elongate anticline that generally parallels the structure mapped on the Barlow, but has additional structural closures.. One closure is in the south half of 35-T5S-R1E, as well as in 2-T6S-R1E, and in 13 and 14 -T6S-R1E, and in the southern portion of Sesser Oil Field, in section 23-T6S-R1E.



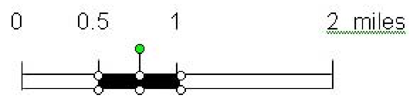



Figure 6 .  Structure contour map on top of the Ste Genevieve Limestone, Sesser Oil Field area. Color ramp from blue (lowest)  to orange (highest)  Contour interval 20 feet.

The paucity of wells drilled to the Devonian off the Sesser structure makes it difficult to interpret the structure over Sesser and on its flanks. In order to interpret the structure on the base of the New Albany, interval thickness projections from the Barlow to the base of the New Albany were made using the nearest neighbor wells that penetrated the Devonian. The structure on the base of the New Albany mapped using this technique is shown on Figure 7. On this map, structure on the base of the New Albany over the DuQuoin Monocline, the Rend Lake Fault zone, and the Sesser Anticline is interpreted to generally parallel those structures mapped on the base of the Barlow and the Ste. Genevieve.

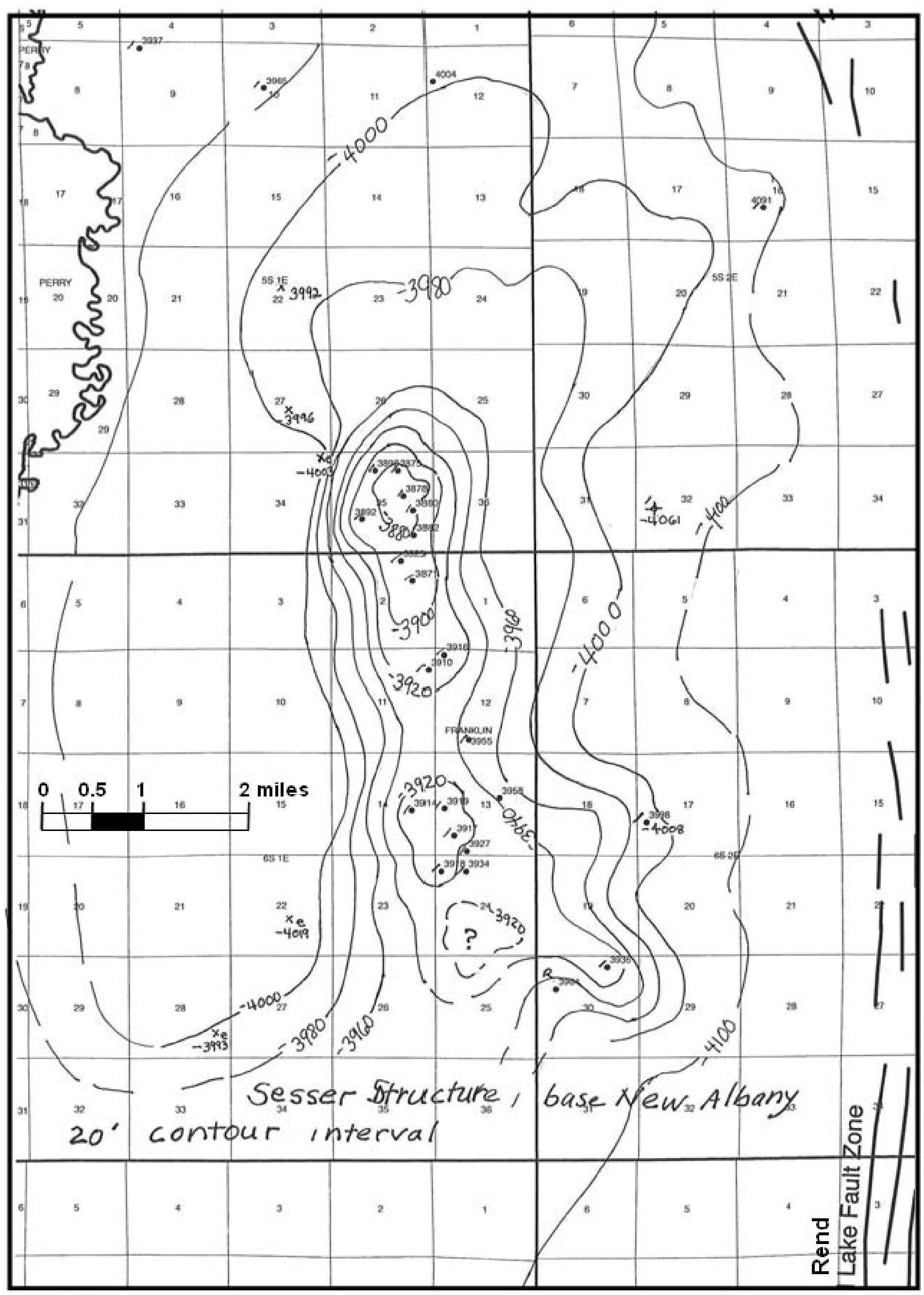



Figure 7 , Base of the Albany Shale, Sesser Oil Field are using nearest neighbor projected interval thickness technique. Contour interval 20 feet

An elongate dome is present on the north part of the anticline, with up to 40 feet of closure in Sections 35 T5S-R1E and continuing south into 2-T6S-R1E. South of section 2, a subtle saddle is present in section 12-T6S-R1E. A small closed dome is present south of the saddle in sections 13 and 14, T-6S-R1E. Another undrilled closure may be present south of there, in sections 23 and 24-T6S-R1E, based on comparison of closure in the Barlow and Ste. Genevieve Formations.

The west margin of Sesser drops at least 60 feet from the crest mapped on the base of the New Albany over about a half mile (1.3°) on the west flank, while on the east margin of the anticline, structure drops about 60 feet over the distance of a mile or more (0.65°).
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**Clear Creek Chert Oil Production at Sesser**

Initial production figures from Clear Creek Chert wells in Sesser Oil Field north pool range from 20 to as high as 100 BOPD. Wells in the south pool had higher initial production rates, ranging from 52 to 241 barrels of oil per day. In both Sesser pools, the wells with high IP's (over 100 BOPD) were wells that were co-mingled with shallower Mississippian production making any accurate assessment of the initial production rates and cumulative totals from the Clear Creek impossible.

Three Clear Creek Chert wells (out of thirteen total Clear Creek Chert producers) report production from only the Clear Creek Chert. An average cumulative production for these Clear Creek wells is about 32,100 bbl. All other wells are reported in co-mingled leases or co-mingled dual-productive wells with Aux Vases production.

Farrar Oil Company's Burlington Northern Greenwood #1, in section 2 T6S-R1E was completed in the Clear Creek Chert in1977. The Burlington Northern Greenwood #1 remains an active oil well and a cumulative production of 33,554 barrels of oil, as of July, 2008 (PI Dwights Plus Pipeline Production Report). The well produced 987 barrels in 2007 and has been producing approximately 1000 bbls/year for the last 5 years.

The Bartoletti #3, in 35-T5S-R1E was completed in 1985, also by Farrar Oil. A Cumulative production of 32,155 barrels of oil is attributed solely to the Clear Creek as primary production for the Bartoletti #3. The Bartoletti #3 was apparently shut in from 1993 to 2000, and then resumed production from 2001 until being plugged in 2006.

The National Associated Petroleum/Lindsay-Bartuelle #1-H in the south pool, in section 13-T6S-R1E reported production from only the Clear Creek. The well was drilled in 1956 by National Associated Petroleum. All the National Associated Petroleum wells in the Clear Creek Chert are classified as temporarily abandoned with permits recording the intent to restore operations in the Clear Creek Chert. There has been no record of activity nor has any production has been reported from these Clear Creek Chert wells since 1963.The Lindsay Bartuelle #1-H produced 22,396 barrels of oil from the Clear Creek. The remaining Clear Creek producers on the National Associated Petroleum/Becker leases in the southern pool were all co-mingled with Mississippian production.

**Log Evaluation of Reservoir Quality in the Clear Creek**

A few wells in the Farrar/Continental Resources lease holdings had Density and Neutron logs run. The highest Density or Neutron porosity obtained from the Clear Creek from the logs was 13% porosity. The porosity from the logs is in thin beds, nearly at the resolution of the log scale . A log analyst from the Illinois Basin (C.D. “Mac” McGregor, personal communication, 2008) evaluated several wells and the most promising calculation showed that in the Reeves-Bartoletti #A1 well in 35-T5S-R1E, there is 12% porosity at 4436’. Using a true resistivity of 15 ohms and a water resistivity value of 0.4 ohms, he calculated 43% water saturation. The well had initial production of 36 barrels of oil, 36 barrels of water, after perforations, treatment with 3,000 gallons of 15%, acid and a Fracture treatment with 20,000 gallons gel frac fluid and 42,000 # sand. The co-mingled lease’s cumulative production was 49,163 barrels, with probable co-mingled production from Aux Vases included in the total. The well is plugged.

**Lithology and Petrography at Clear Creek Chert at Sesser**

One core with chips was studied at Sesser, the Hair #1 in the north part of the field (in 35-T5S-R1E.) The Hair #1 well had a cored interval in the Clear Creek from 4400’ to 4555’, 4555’ being the well’s total depth.

Core chips from the well are half-fist-size or smaller. They are generally fine-grained, dense, gray limestone with asymmetrical white to grayish-white chert nodules, lenses or layers and dark, clay-rich stylolitic partings. The chert may be porous or it may be dense with no apparent porosity or permeability. Hairline fractures are visible in some hand samples. Many fractures and dolomite layers appear to be associated with horizontal bedding planes.

In thin section, the uppermost Clear Creek at Sesser Oil Field is a fossiliferous dolomitic, cherty limestone (figure 8 and 9). Blue epoxy reveals zones with abundant porosity. Some sand grains are scattered irregularly in the matrix. Irregularly distributed crystalline dolomite and microcrystalline to crystalline chert and drusy quartz overgrowths are common in the upper 70 feet of the Clear Creek (figure 9).

Stylolites, with black organic material are common, and are in close association with layers of crystalline dolomite (figures 10 and11). This suggests that stylolites were sites of pressure-solution leaching, and compaction of the original carbonate and concentration of diagenetic dolomite. Fracturing may be related to solution-collapse or tectonic deformation. In places, both healed fractures and porous hairline fractures are observed.

Fossils in the Clear Creek in thin section appear to be disarticulated, abraded marine fossils. Some porosity appears to have developed where fossils have been leached or removed by solution, with partial replacement by dolomite and later by silica.

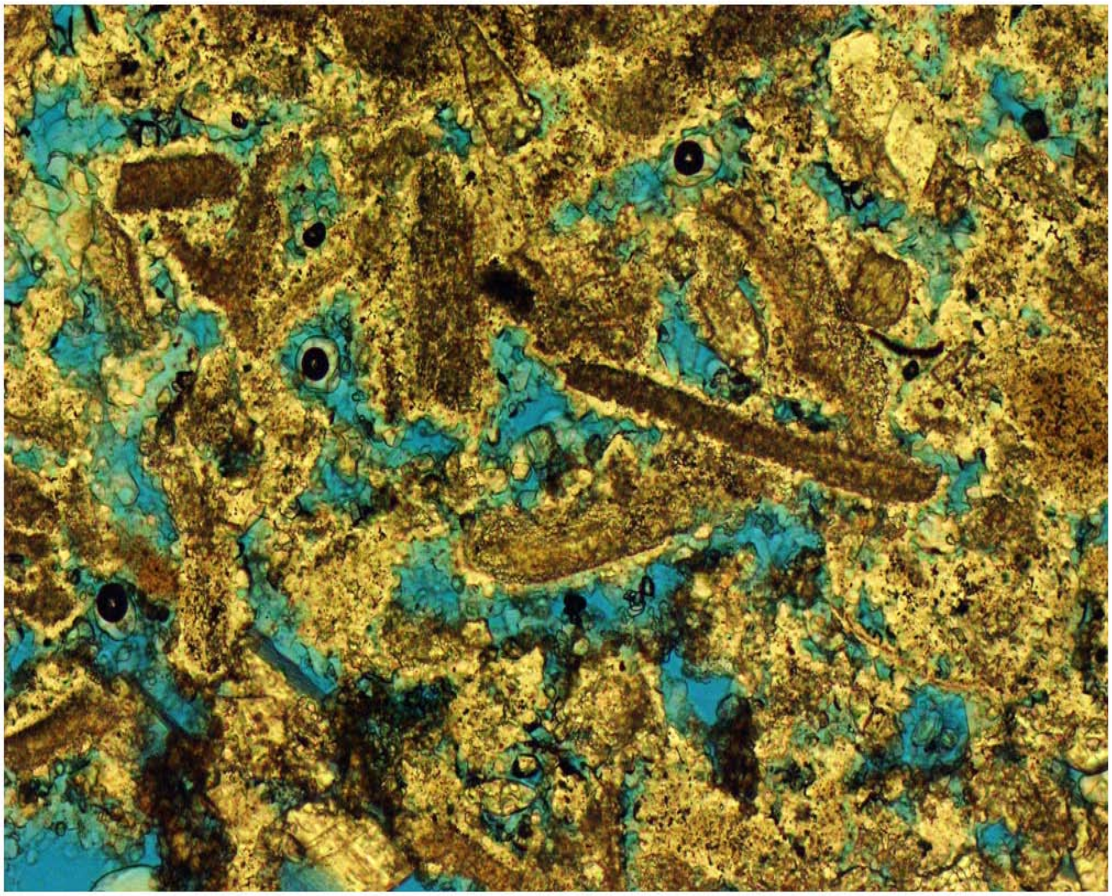


Figure 8. Thin section of Clear Creek Chert porous reservoir zone. Porosity in blue. C. Edwin Hair's Hair # 1 well, 35-5S-1E Franklin County. Depth 4413'. Magnification 50x. Polars not crossed.

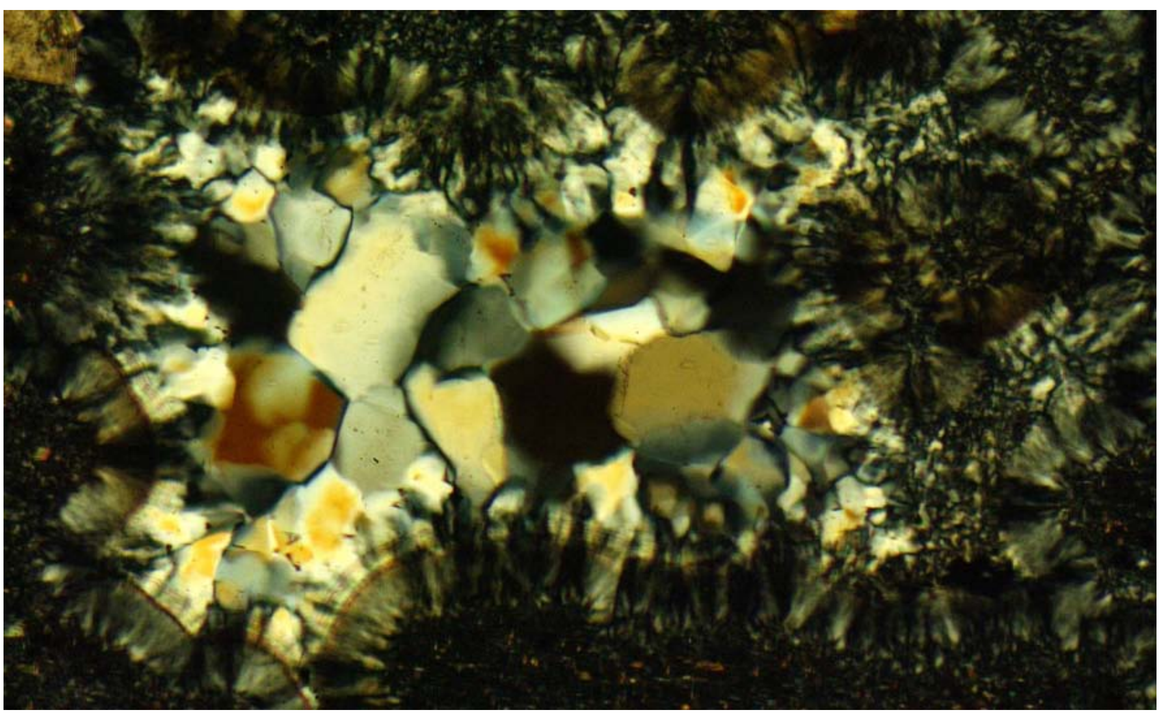
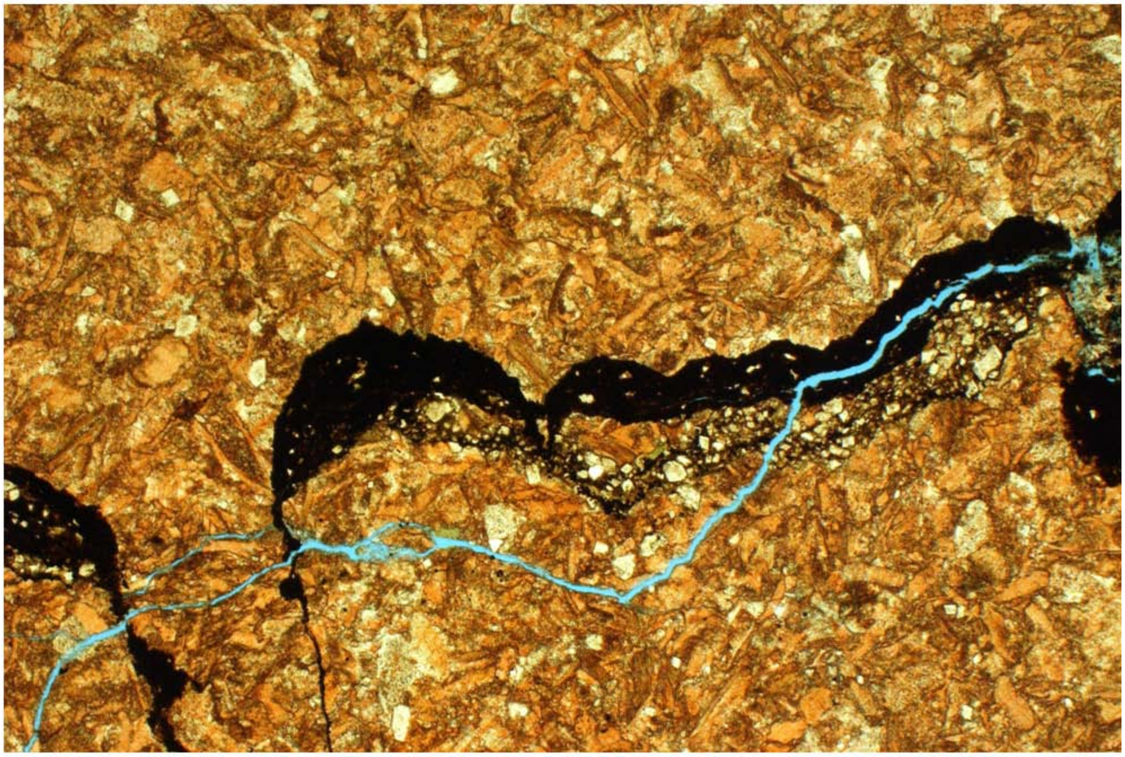


Figure 9. Thin section of Clear Creek Chert showing vuf filled with fibrous chert on edges and mosaic chert in center. C. Edwin Hair's Hair # 1 well, 35-5S-1E Franklin County. Depth 4405'. Magnification 50x. Polars crossed.



.Figure  10. Thin section of Clear Creek Chert showing styolite, microfracture and sand grains concentrated on styolite..  C. Edwin Hair's Hair # 1 well, 35-5S-1E Franklin County.  Depth 4503'. Magnification 25x.  Polars not crossed.

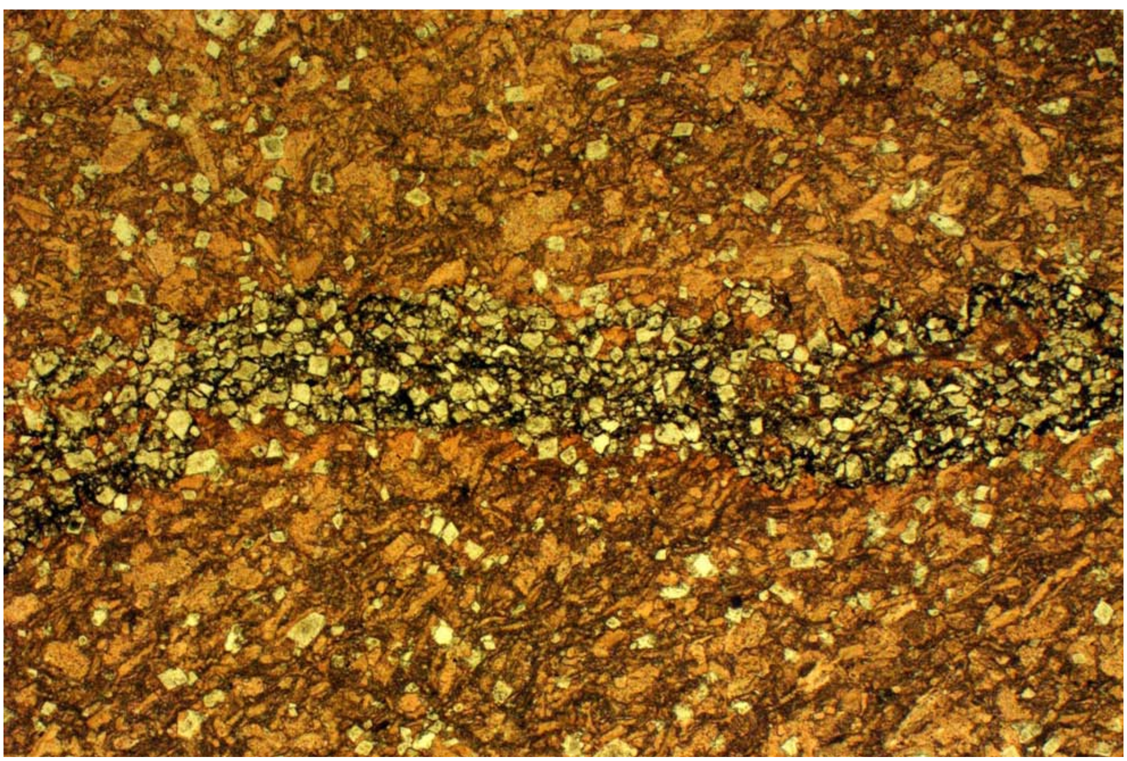


Figure 11. Thin section of Clear Creek Chert showing styolite with dolomite and sand grains concentrated on styolite.  C. Edwin Hair's Hair # 1 well, 35-5S-1E Franklin County.  Depth 4473'. Magnification 25x.  Polars not crossed.

## Discussion of lithology and petrography

Erosional processes and diagenesis in the Clear Creek have resulted in porosity development by leaching carbonate and silica fossil fragments. Stylolitic partings apparently were sites of pressure-compaction, leaching and recrystallization of dolomite. Later episodes of dolomite and silica cementation occurred in patches and along stylolites and fractures.

Similar to Saller et al. (2001) model for the Dollarhide Field in Texas, the Clear Creek model for Sesser includes

- Deposition on a marine carbonate shelf, with sponges, echinoderms, bryozoans and possible ostracods; subsequent reworking of fossils to disaggregate and abrade the fossils, and possibly debris flow down-slope
- Uplift along DuQuoin Monocline removed upper Clear Creek section by erosion at Sesser
- Early marine meteoric diagenesis in the exposed Clear Creek along the sub-Kaskaskia unconformity may have enabled meteoric dolomitization as well as leaching of carbonate
- Dissolution of silica in many sponge spicules, resulting in porosity development in upper Clear Creek
- Alternatively, or in addition, dolomite and silica cement may be associated with hydrothermal groundwater movement along faults
- re-precipitation of silica as microcrystalline chalcedony and quartz in patches, nodules, or lenses
- Later, fracturing; some fractures are healed, some are open

## Clear Creek play potential

Where a relatively thick section of Grand Tower sediments is preserved (east of Sesser, Benton, and Whittington, in southeastern Illinois), there is only one established Lower Devonian field, at Walpole (Hamilton County, section 27-T6S-R6E). The anticlines at Sesser and Benton and the structural nose at Whittington, in the absence of Grand Tower deposits, may have enabled accumulation of hydrocarbons from New Albany source rocks in the low areas adjacent to the Sesser, Benton, and Whittington anticlines, into Clear Creek reservoirs. This study suggests that less than 50 feet of intervening Middle Devonian strata, and diagenesis at the sub-Kaskaskia unconformity are favorable factors for development of Clear Creek reservoirs in this area.

No waterflood operations or enhanced oil recovery operations are known to have been conducted on Clear Creek wells in Illinois. Some Lower Devonian cherty carbonate reservoirs in Texas have been documented to be excellent candidates for waterflooding as well as carbon dioxide injection (Saller et al., 2001.)

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**Springfield East Oil Field: Bryan Huff**

Springfield East Oil Field in Sangamon County (Figure 1) was studied as representative of Silurian oil fields in Sangamon and Christian counties. These oil fields include discontinuous, small, though some quite productive reservoirs. Most of these fields are discovered by drilling on trend of previously discovered fields with ensuing development consisting of several offset wells defining the limits of the reservoir.

Springfield East was discovered by the Aladdin Oil Company #1 Scott in Section 21, Township 15 North, Range 4 West that was drilled to a total depth of 1605 feet. The well was completed in February 1960 for an initial production of 582 barrels of oil per day (BOPD). It was completed open hole in the Silurian dolomite from 1592-1606 feet. Hibbard production was discovered in November by the Morgan & Wilkening # 1 Herndon in Section 29, Township 15N, Range 4W. The well was completed for an initial production of 50 BOPD as a dual completion in the Devonian and Silurian. The deepest well in the area is in section 29 and is 2824 feet deep. It tested strata into the Knox Dolomite with no additional pay zone discoveries.

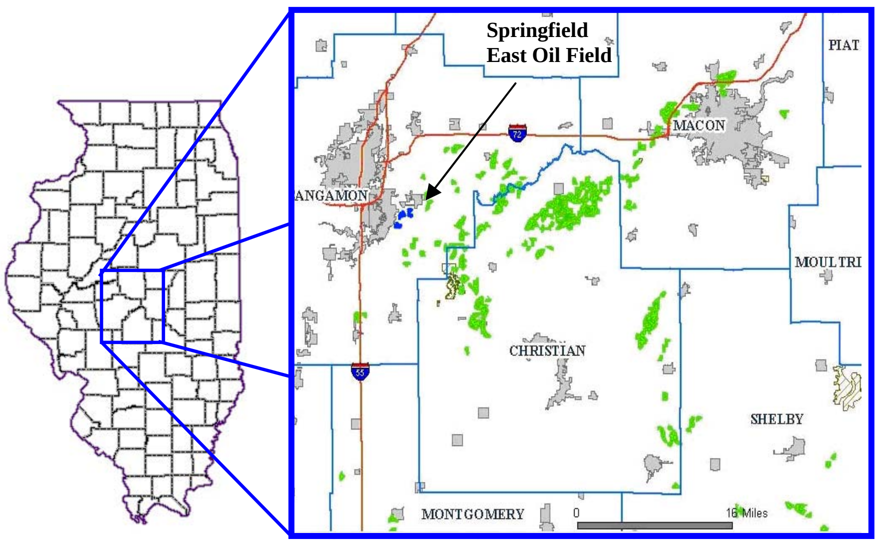


**FIGURE 1**. Location Map of Springfield East Oil Field (in blue) in west-central Illinois. Expanded view shows county names, municipalities in gray, other oil fields in green. Note the northeast-southwest trend of oil fields in the area.

**STRATIGRAPHY**

Surficial sediments in the area consist of approximately 50 feet of Quaternary glacial deposits. These overlay Pennsylvanian sediments of Missourian age. The Pennsylvanian rocks unconformably overlie Mississippian strata. Directly below Springfield East field all Chesterian sediments have been eroded and the first Mississippian strata encountered is the Valmeyeran Ste. Genevieve Limestone (Figure 2). To the east as one enters Christian County Chester sediments younging towards the east are encountered. The lowest Mississippian strata in the area is the Chouteau Limestone which overlies the

Devonian New Albany Shale Group (Figure 3). The lower Devonian limestones were not deposited over this area and this hiatus is represented by a thin, discontinuous sandstone/sandy dolomite/dolomite lag deposit (Hibbard Sandstone) that marks the disconformity between the Devonian and Silurian rocks. Mapping shows this sandstone/sandy dolomite is sporadic and, in areas, is concentrated in channels cut into the underlying Silurian dolomite and that there is a very high correlation between these channel deposits and producing oil well occurrence.

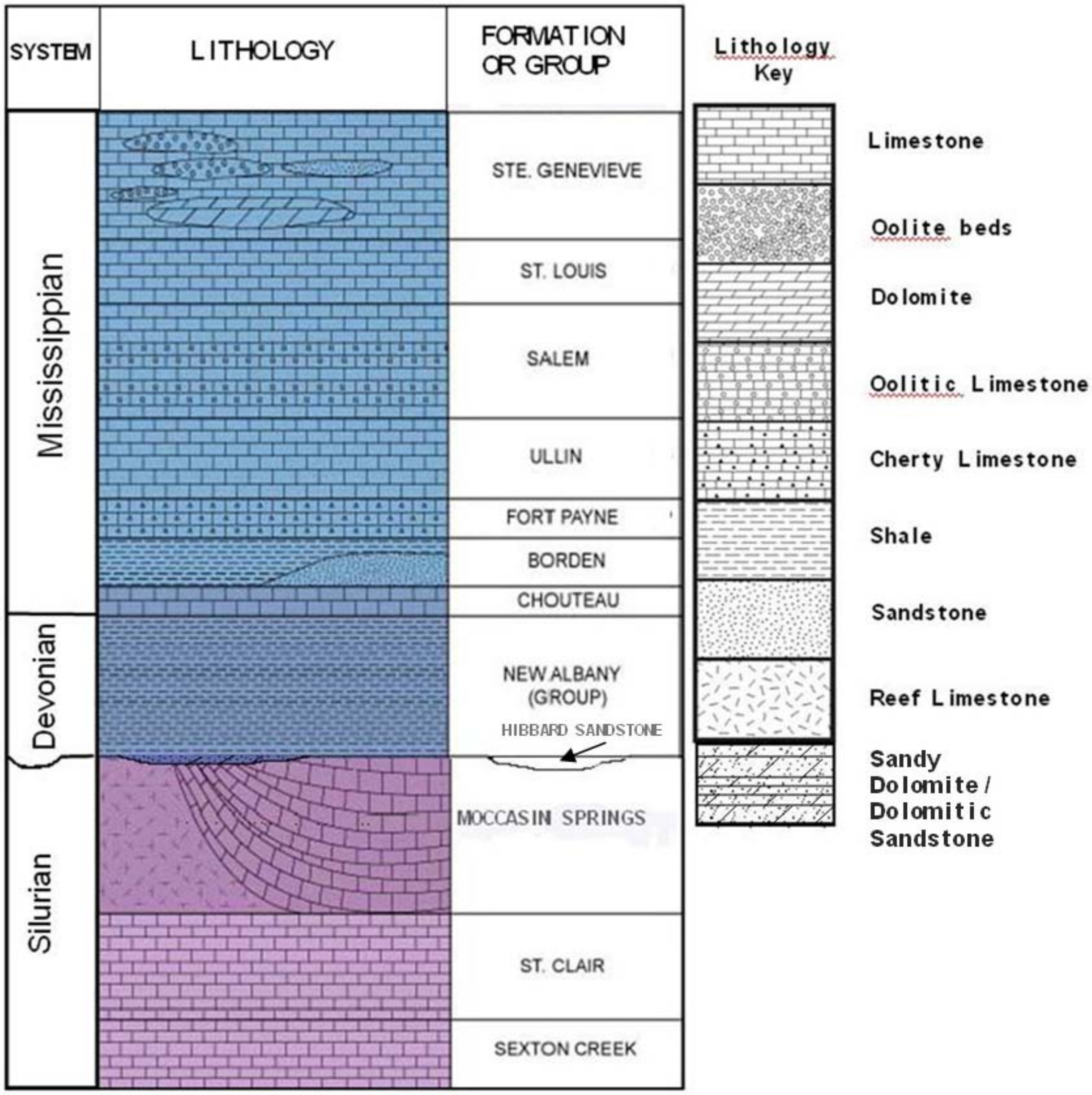


**FIGURE 2.** Schematic stratigraphic section of Mississippian through Silurian strata in the Springfield East field area.

**Eastern American Energy Corporation**
**Thomas Scott # 1**
**330’ NL 485’ EL SW/c**
**Section 21 Township 15 North Range 4 West**
**Sangamon County, Illinois**

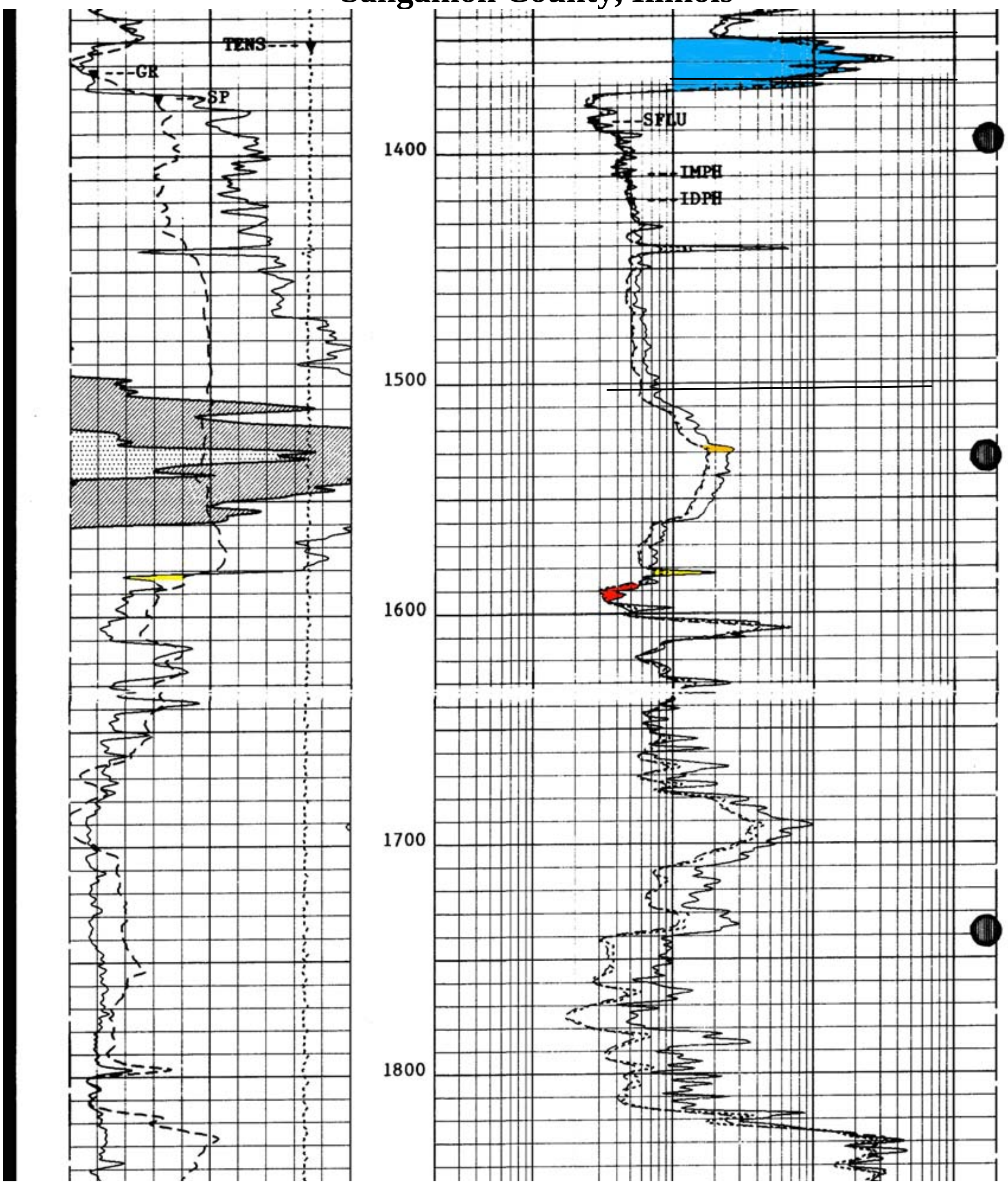


**FIGURE 3**. Induction, gamma ray and spontaneous potential logs from Springfield East Field showing the Mississippian Chouteau Limestone in blue (1350-1375), Devonian New Albany Shale (1375-1580), New Albany hard and hot zone (1528), Devonian Hibbard Sandstone in yellow (1580-1588), Silurian top (1588 ) Pay zone development is shown in red at 1588-1595.

**STRUCTURE**

Regional mapping on the top of the Silurian by Whiting (1956, p. 3 and 5) shows a southwest northeast striking monocline dipping to the southeast. Mapping on top of the Silurian at Springfield East shows that the major feature in the field is a structural nose 4 miles wide dipping southeastward at less than 0.2 degrees (figure 4). Major oil production is out of a mile wide structural high on the nose with approximately 28 feet of closure in section 21. Lesser production comes from 2 small (>1/4 mile) structural highs on the nose trending in a line southwest of the major high. These highs have closures ranging from 10 to 25 feet.

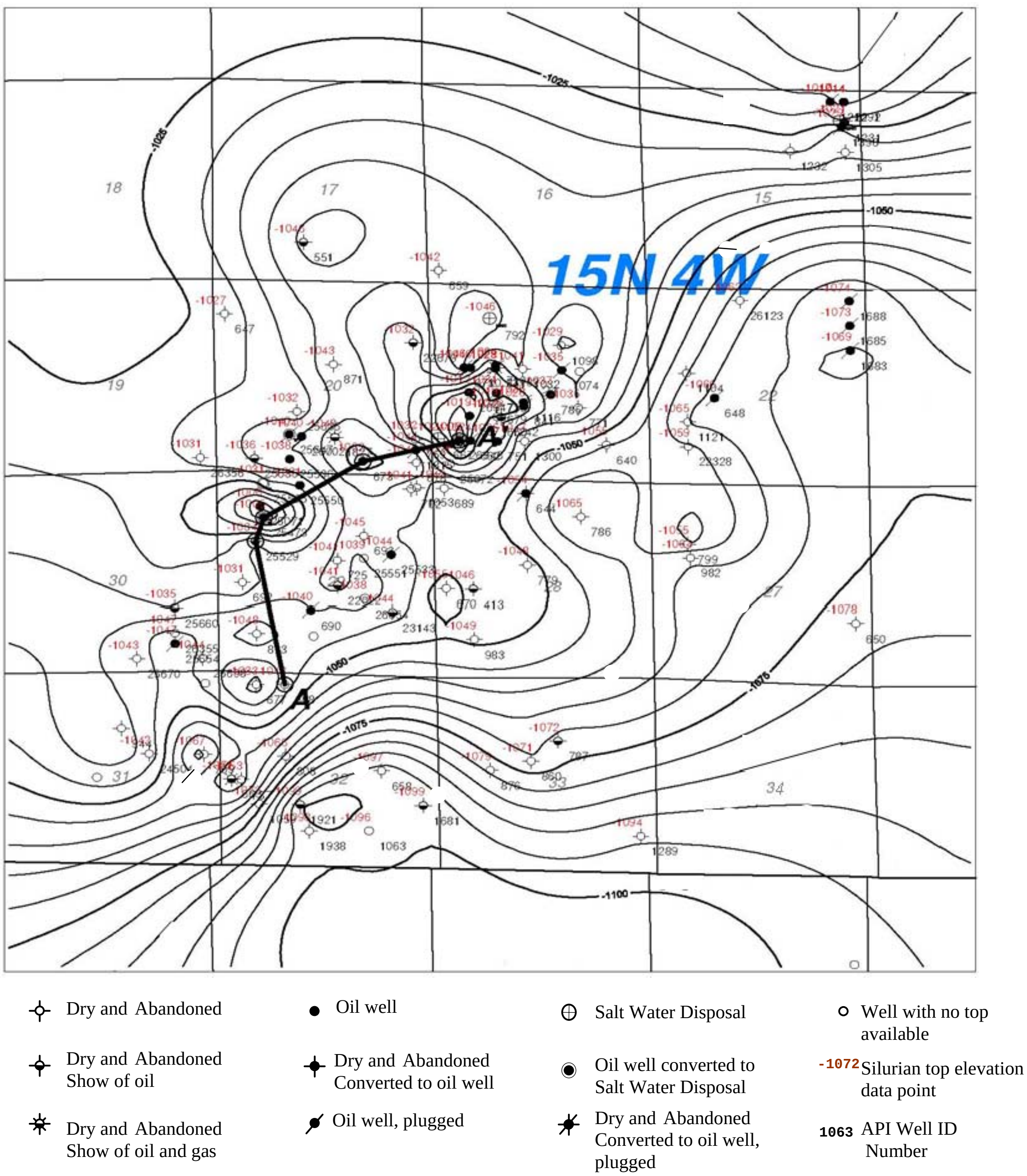

**Figure 4.** Structure on top of the Silurian at Springfield East Oil Field. Line of cross section A-A' (Figure 9) shown. Contour interval 5 feet.

## RESERVOIR CHARACTERISTICS

The primary reservoir in this field is the uppermost Silurian dolomite. The dolomite is finely crystalline, gray to blue and shows extensive fracturing, solution collapse, vugs and fossil molds (figures 5, 6 and 7). Pay zone thickness is estimated at 10-15 feet thick based on log responses. The porosity and permeability were possibly developed during early to middle Devonian exposure and erosion (Whiting, 1956, p.9). Reservoir quality porosity and permeability are discontinuous across the field. The isopach map of the Devonian sandstone shows a strong correlation between the occurrence of Devonian dolomitic sandstone in channels eroded into the Silurian Dolomite and the occurrence of oil wells (figures 8 and 9) supporting a theory that reservoir development is more pronounced in channels were water would have been concentrated and accelerated dissolution of the original rock.

The Hibbard sandstone is listed as a producing formation for 2 wells. Its contribution to production is unknown but probably minimal. It is a gray-green-brown fine grained sandstone with a dolomite matrix. The only rock available for description came from a well that did not produce out of the Hibbard; no reservoir quality rock was available for description.


Figure 5. Slabbed core of Silurian reservoir from Springfield East Field showing vugs, solution features and fractures. Depth 1569-1575. Scale in inches. Eastern American Energy Ramsey /Noll et al. #1 29-15N-4W, Sangamon County.


Figure 6. Exterior view of core showing vugular nature of reservoir rock from Springfield East field. Scale is in inches. Silurian dolomite depth 1571’. Eastern American Energy Ramsey /Noll et al. #1 29-15N-4W, Sangamon County.


Figure 7. view of core showing vugs and solution-collapse in reservoir rock from Springfield East field. Scale is in inches. Silurian dolomite depth 1572’. Eastern American Energy Ramsey /Noll et al. #1 29-15N-4W Sangamon County.

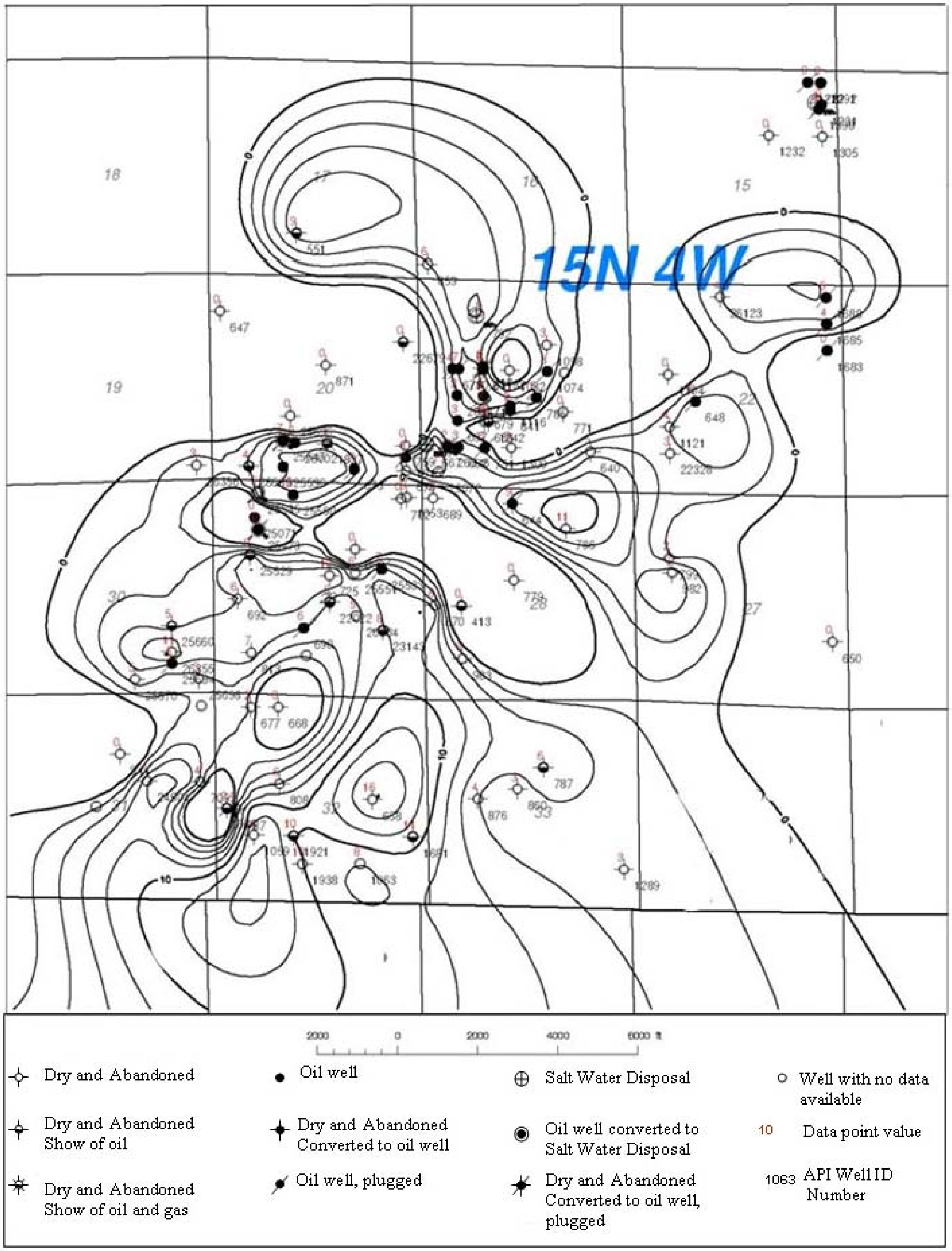


Figure 8. Isopach of Lower Devonian sandstone showing correlation between sandstone occurrence in channels and occurrence of oil wells. Isopach interval 2 feet.

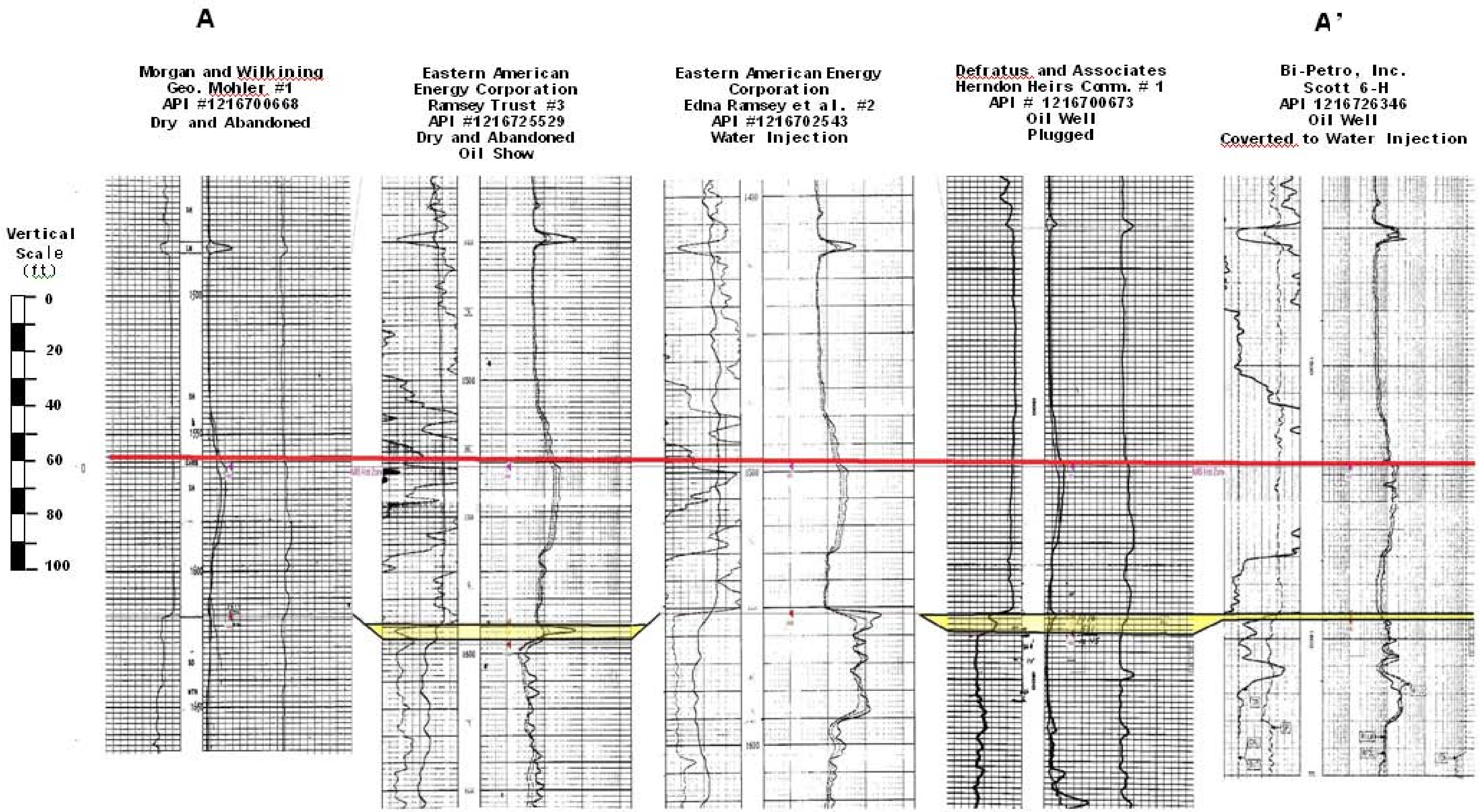


**FIGURE 9.** Cross section from A to A' (for line of section see figure 4) showing a cross section hung on a New Albany Shale hard and high gamma ray zone (red line)that shows stratigraphic relationships during New Albany time. Note how Devonian Dolomitic sandstone (yellow) fills channels in the Silurian rocks. Well spacing is not relative.

**PETROGRAPHY**

Under the microscope the reservoir rock is a relatively pure oil stained brown dolomite (figures 10, 11 and 12). The dolomite is fine to coarse grained; the fine grained dolomite is the result of dolomitization of the micrite matrix. Coarse grained dolomite has replaced fossils and may occur in areas where moldic porosity caused by dissolution of fossil fragments creating voids for the crystals to grow. Ghosts of replaced crinoids, brachiopods and bryozoans are abundant. Porosity is primarily moldic after fossils and, in some areas, can be greater then 30%. Other notable features are occasional silt sized grains of quartz and a few stylolitized fractures.

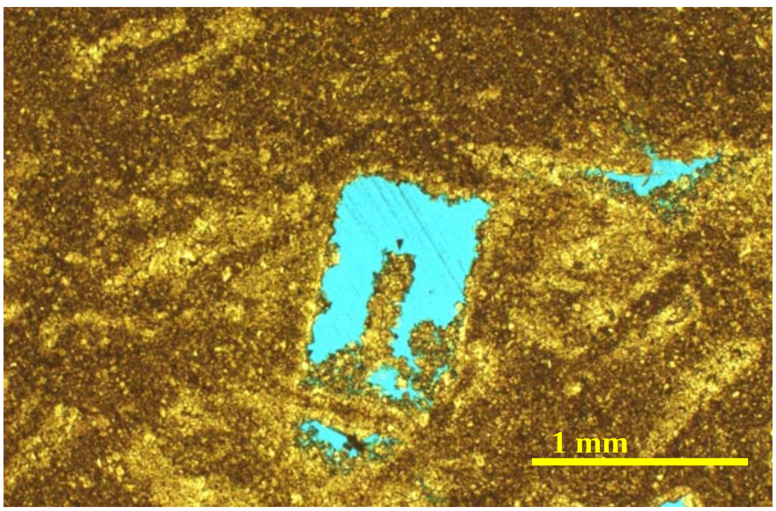


**FIGURE 10.** Photomicrograph of reservoir rock showing petroleum stained dolomite; fine grained dolomite has replaced matrix. Coarse grained dolomite in fossil ghosts and moldic porosity after a crinoid fragment. Porosity shown in blue. Polarizers not crossed. Depth 1587.6'. Eastern American Energy Ramsey /Noll et al. #1 29-15N-4W Sangamon County. Magnification is 25x.

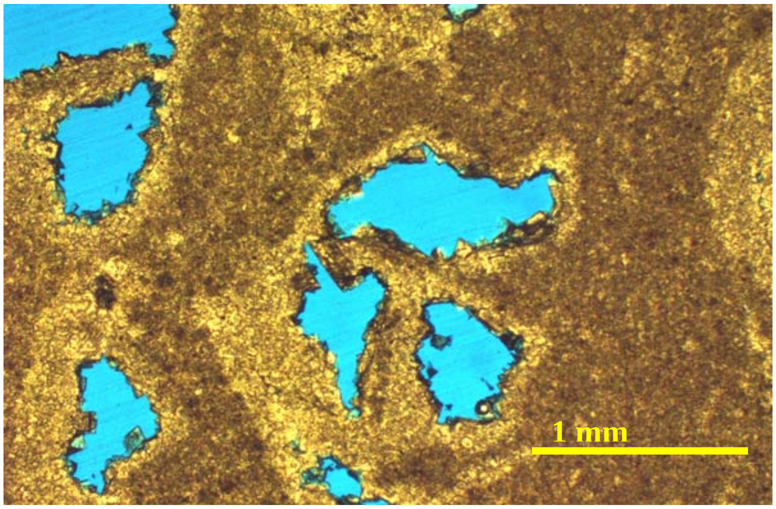


**FIGURE 11.** Photomicrograph of reservoir rock showing well developed moldic porosity in fossil fragments. Porosity shown in blue. Polarizers not crossed. Depth 1570.5'. Eastern American Energy Ramsey /Noll et al. #1 29-15N-4W Sangamon County. Magnification is 25x.

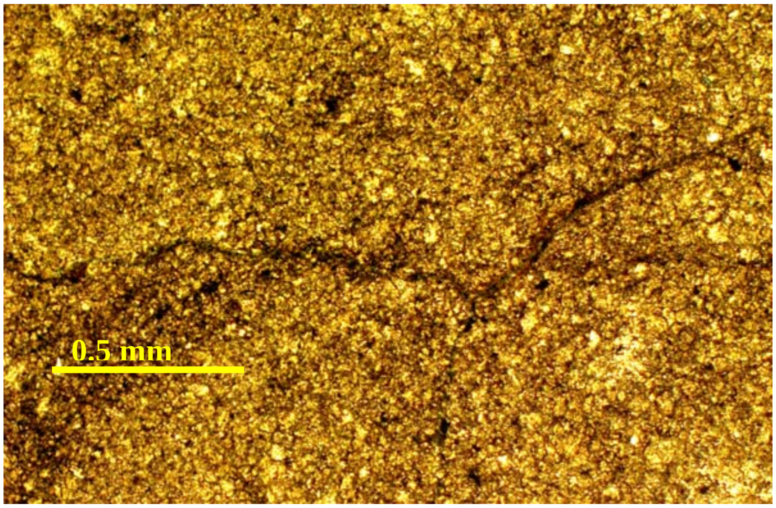


**FIGURE 12.** Photomicrograph of core showing styolitized fracture. Polarizers not crossed.Eastern American Energy Ramsey /Noll et al. #1 Depth 1570.5'. 29-15N-4W Sangamon County. Magnification is 50x.

## COMPLETION TECHNIQUES

Holes in the field were drilled to total depth using rotary tools. Casing was usually set at or slightly below the top of the Silurian. No liner was set and almost all tests were open hole completions. In deeper Silurian zones wells had casing set through the pay zone and were perforated

An average acid treatment of 2500 gallons was given to most wells. Treatments ranged from 500 to 11000 gallons of acid. Wells were then given a water-sand fracture treatment averaging 7000 gallons of water and 8600 pounds of sand.

**PRODUCTION**

Thirty-one oil wells have been completed in the field since its discovery in 1960. All were productive in Silurian rocks, 2 listing additional production from the Hibbard Sandstone. Initial production from the wells range from 7 to 528 barrels of oil per day (figure 13).

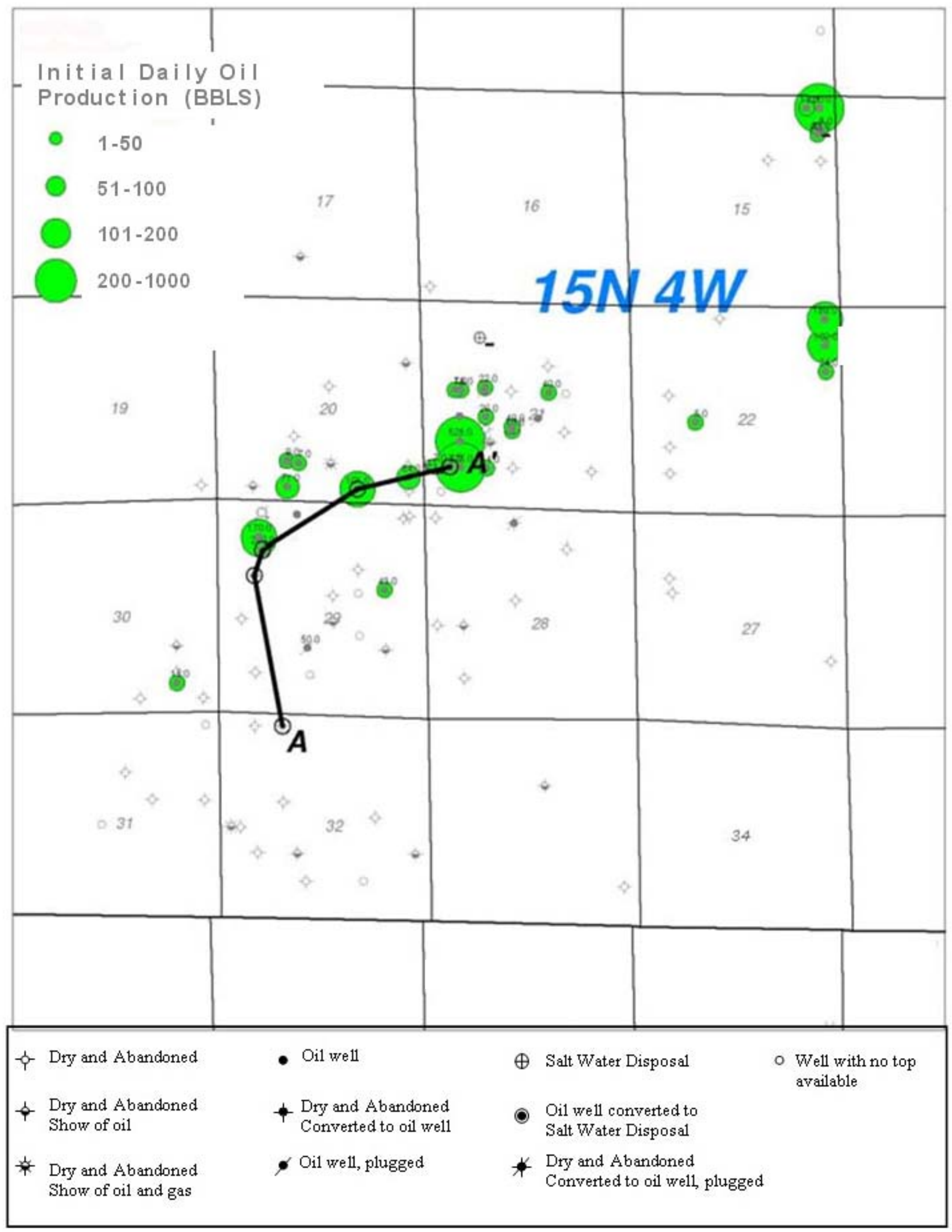


Figure 13. Bubble diagram showing initial production rates for wells in the Springfield East oilfield. Line of section A to A' of figure 9 shown.

Through 2006 the field has produced 679,500 barrels of oil. The discovery well, the #1 Scott, accounts for over 45% of this volume having produced a total of 308,578 barrels of oil when it's last production was recorded in November of 2001. The decline curve (Figure 14) indicates that no new production is found in the field and no waterflood is attempted at current production rate there is an estimated 27,600 barrels of recoverable oil remaining before production for the field falls below 50 barrels/year.

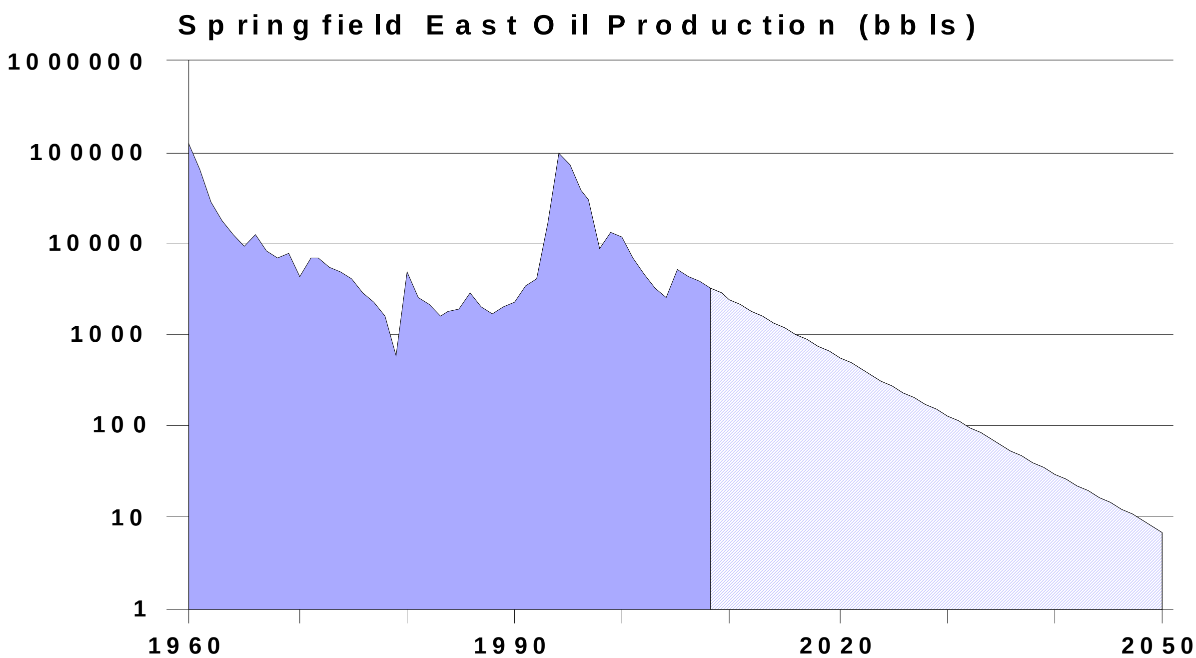


**FIGURE 14**. Springfield East oil production. Values after 2006 are estimated based on historical decline for reserve calculations (hatchered area).

This field, as most reservoirs in the Mount Auburn trend, has not been waterflooded. The discontinuous non-communicative reservoirs of limited area and limited reserves make the field a questionable candidate for waterflooding. Three floods have been attempted in other fields in the Mount Auburn trend in larger reservoirs. While a sharp waterflood peak does not occur, a boost in production is evident and results are good with a long term increase after fill up. Similar results could be expected from Springfield East Oil Field.

**Reference**

Whiting, Lester L., 1956. Geology and history of oil production in the Decatur-Mt. Auburn-Springfield area, Illinois. Illinois State Geological Survey Circular 211. 17p.

## Silurian Carbonate Reservoirs of the Mount Auburn Trend Along the Sangamon Arch, West-Central Illinois **Yaghoob Lasemi**


### Abstract

The Silurian succession of the Sangamon Arch, a broad southwest-trending structure in west-central Illinois, is composed of hydrocarbon-bearing carbonate rocks. Over 12 million barrels of oil have been produced from these rocks in the Mount Auburn trend, along the southern flank of the arch, chiefly from dolomitized carbonate reservoirs in the upper part of the Niagaran series. To date, there has been no detailed study of the Niagaran reservoirs in the Sangamon Arch area; there is a general lack of understanding of the reservoir facies types, distribution, geometry, porosity development, petroleum entrapment and their controls.

Detailed subsurface studies along the Mount Auburn trend have revealed the presence of permeability pinch outs at several horizons. They include dolomitized wackestone-grainstone facies in the upper part (reservoir units A-C) and patch reefs facies in the lower part of the Niagaran succession (reservoir unit D). The reefs are composed mainly of coral skeletons, but their internal structure is poorly preserved as a result of pervasive dolomitization. These reservoirs are characterized by lenticular bodies of limited lateral extent that grade laterally and vertically into an impermeable limestone facies or a very finely crystalline, argillaceous dolomite facies. They were deposited along a southwest trending platform margin that was roughly parallel to the Sangamon Arch trend and graded basin ward into muddy carbonates below wave base.

Hydrocarbon production along the Sangamon Arch thus far has been chiefly from the non-reef carbonate reservoirs in the uppermost part of the Silurian succession. Most wells drilled thus far have only tested the uppermost part of the Niagaran succession; only a few wells have tested the lower reservoirs that include the newly-recognized patch reefs. The results of this study suggest that there is an excellent possibility for finding more productive Niagaran dolomitized patch reefs and non-reef reservoirs along a vast area of the Sangamon Arch.


### 1. Introduction

The Middle Silurian (Niagaran) rocks in the Mt. Auburn Trend of the Sangamon Arch in west Central Illinois (Figs. 1 and 2) contain prolific petroleum reservoirs, which have been producing for over 80 years. The first commercial production from the area was in 1925 from the Decatur Field, but the major activity did not begin until 1954 after Sun Oil Company completed Damery No. 1 in December 1953, which flowed over 700 barrels of oil per day after a fracturing treatment of the Silurian reservoir (Whiting, 1956). The Mt. Auburn trend along the southern flank of the arch includes several oil fields (Fig. 2) that have produced over 12 million barrels of oil chiefly from the dolomitized carbonate reservoirs that occur in the upper few feet of the Silurian succession. However, there have been conflicting views on reservoir development, petroleum entrapment and their controls. To date there has been no documented studies regarding the reservoir facies types, porosity, occurrence, and petroleum entrapment of the Upper Silurian rocks of the Sangamon Arch.

The objectives of this report are to determine reservoir facies types, occurrence, geometry, distribution, porosity development and petroleum entrapment of the Silurian carbonate reservoirs of the Mt. Auburn Trend of the Sangamon Arch for exploration, development and secondary recovery enhancement. This study should generate interest for exploration in the unexplored areas of the Sangamon Arch. It could also result in developing models for depositional environment and reservoir development of the Silurian rocks in other productive areas of the basin.

Reservoir characterization of the Silurian deposits in the Mt. Auburn Trend was established using available subsurface data, including well samples (cuttings/cores) and geophysical logs to determine facies types, facies geometry, entrapment and their control. The area of Blackland North Field and the Southern margin of the Harristown Field was chosen for a more detailed subsurface mapping. The wells in this area were mainly drilled in the early 1980's and as a result more complete subsurface data are available. These maps and stratigraphic cross-sections of different areas of the Mt. Auburn Trend were constructed using GeoGraphix and Adobe Illustrator software. The reservoir facies are classified on the basis of the Dunham (1962) and the Embry and Klovan (1971) textural schemes.

## 2. Geologic setting and stratigraphy

The Sangamon Arch is a broad southwest trending structure in west Central Illinois, which was formed as a result of upward warping during Silurian and Devonian times (whiting and Stevenson, 1965). It is located in the shelf area just northwest of the Illinois Basin where the Lower to Middle Devonian deposits are absent (Fig. 1). The isopach map of the New Albany Shale Group along the Mt. Auburn Trend (Fig. 3) shows the pre-New Albany structure of the arch. The general thinning of the shale towards the center of the arch suggests that the axis of the arch was still active during Late Devonian time. The exposure of the arch during the Early and Middle Devonian times resulted in partial erosion of the Silurian deposits and formation of an uneven topography. The uneven topography is nicely displayed by the structure contour map of the base of the New Albany Shale Group (top of the Silurian succession), showing several noses and minor closures (Fig. 4) and by a series of cross-sections that are prepared on a Silurian datum (see reservoir characterization below). The structure contour map (Fig. 4) also indicates the direction of the regional dip in the study area, which is on the whole towards the southeast.

The Mt. Auburn Trend is located along the southern flank of the Sangamon Arch in west central Illinois. It encompasses several oil fields and covers parts of Macon and Christian Counties in west central Illinois (Figs. 1 and 2). The Silurian deposits in the Mt. Auburn Trend (Fig. 5) are overlain by the Upper Devonian New Albany Shale Group with a pronounced erosional unconformity (sub-Kaskaskia unconformity) and are underlain by the Upper Ordovician Maquoketa Shale Group with a distinct unconformity (sub-Tippecanoe II unconformity) (Fig. 6).

In the Mt. Auburn Trend, the Middle Silurian (Niagaran) Moccasin Springs Formation is the only petroleum producer. The formation comprises several dolomitized producing horizons that grade laterally and vertically to impermeable fossiliferous limestone (argillaceous and cherty in some parts) or to a very finely crystalline argillaceous and calcareous dolomite (Fig. 5). The Silurian succession is a part of the Silurian-Middle Devonian Hunton Megagroup (Swann and Willman, 1961), which constitutes the upper part of the Tippecanoe Sequence of Sloss (1963) (Fig. 6).

## 3. Reservoir characterization

Detailed subsurface studies along the Mt. Auburn trend have revealed the presence of permeability pinch outs (here referred to reservoir units) at several horizons displaying a shallowing-upward cycle. They include dolomitized wackestone to grainstone facies in the upper part and coral patch reefs in the lower part of the Niagaran succession. These coarsely crystalline dolomite reservoirs are interlayered with tight limestone or impermeable very finely crystalline argillaceous dolomite. The laterally extensive impermeable units have formed flow barriers that divide the Niagaran deposits into stratigraphic cycles of porous and impermeable horizons. The reservoirs were deposited along a southwest trending platform margin that was roughly parallel to the Sangamon Arch trend and graded basinward into muddy carbonates below wave base similar to the numerous modern and ancient examples (e. g., Wilson, 1975, Tucker and Wright, 1990; Flugel, 2004).

The reservoir units are defined on the basis of facies and their stratigraphic position and are designated, from top to base, as reservoir units A, B, C and D. The isopch map of units A-C (greater than 8 percent porosity) for the Blackland North and the southern part of the Harristown Field are shown in figures 8, 10 and 12. These maps, together with a series of stratigraphic cross-sections in different parts of the Mt. Auburn Trend, reveal the lateral distribution and vertical compartmentalization of the reservoirs recognized. Examination of the numerous wells in the Mt. Auburn Trend indicates that most of the wells drilled thus far have only tested the uppermost part of the Niagaran succession; only a few wells have tested the lower reservoirs that include the newly-recognized patch reefs.

### 3.1. Non-reef reservoir facies A-C

The non-reef facies A-C are characterized by porous dolomitized wackestone to grainstone facies with packstone and grainstone being the predominant precursor facies (Figs. 7 B-E and 14 B). They consist of coarsely crystalline dolomite that may contain partially dolomitized echinoderm (mainly crinoids) fragments (Fig. 7 C-E) and molds of bioclasts including crinoids, bivalves, brachiopods and other non-recognizable grains. In some areas or in some samples within a reservoir, only dolomite crystals are recognized (Fig. 14 A), showing a very faint relic that could represent the organic residue of the original bioclasts. It appears that the dolomitizing fluid initially affected the groundmass (cement or matrix) and the more susceptible fossil fragments; crinoids were the last grains to be dolomitized (Fig. 7 C-E). A later reservoir porosity enhancement occurred by partial dissolution of the dolomite crystals along the pore walls by fluids undersaturated with respect to dolomite (Fig. 14 A and F). The reservoirs are surrounded by impermeable limestone (Fig. 7 A) or shaley and calcareous, very finely crystalline dolomite (see cross-sections AA’ to FF’ below), suggesting sea level fluctuation and seawater chemistry as primary control for dolomitization of the compartmentalized Silurian reservoirs. This interpretation is further supported by the resistance of dolomite layers to chemical compaction and resulting cementation as opposed to limestone (e. g., Brown, 1997; Lucia, 2004; Ehrenberg, 2006).

#### 3.1.1. Reservoir unit A

Unit A is a lenticular reservoir of limited lateral extent (Fig. 8) that is recognized in the uppermost part of the Silurian deposits. It is up to 14 feet thick separated from the unit B by about 10 feet of impermeable fossiliferous limestone (Figs. 9 and 11 and 16-20). This limestone contains chert nodules and is a laterally persistent horizon in the Mt.

Auburn Trend, except in areas that is removed by pre-Devonian erosion. Unit A is capped by another impermeable limestone of variable thickness (Figs. 9 and 11 and 16-20), but where it is removed by erosion, the New Albany Shale becomes the capping facies for petroleum entrapment (see Philips No. 1 in Fig. 19 and Drysdale No. 1 in Fig. 20). Reservoir A is a permeability pinch out primarily controlled by depositional setting of the Silurian deposits. In some areas of the Mt. Auburn Trend, however, the absence of reservoir A may be the result of post Silurian erosion, which is well illustrated in cross-sections DD' and EE' (Figs. 19-20). Deep erosion in Dipper No.1 (Fig. 19) and in Drysdale No. 1 (Fig. 20) has removed the interval that could otherwise embrace reservoir A.

**3.1.2. Reservoir Unit B**

Reservoir B is another lenticular horizon along the trend of the Sangamon Arch and is best developed in the Blackland North Field (Fig. 10). It is up to 5 feet thick and occurs just below the impermeable and persistent limestone marker (Figs. 11 and 18). A tight limestone of up to 6 feet separates unit B from the underlying unit C. In the southeast of the Blackland North Field and in other fields of the Mt. Auburn Trend, Unit B and the tight underlying limestone may thin out or pinch out to form a single C reservoir (see Fig. 13, and Dipper No. 1 in figure 19). The pinch out of reservoir A could be the result of pre-Devonian erosion (see Hill Estate No. 1 in figure 18).

**3.1.3. Reservoir Unit C**

Reservoir C could attain a thickness of over 20 feet in parts of the Mt. Auburn Trend and is more extensive than the other reservoirs (Fig. 12). It is overlain by up to 6 feet of impermeable limestone in Blackland North Field (Figs. 11 and 18). This tight limestone thins out laterally beyond the resolution of the geophysical logs (see Hill Estate No. 1 in figure 18). Due to lateral thinning of this tight limestone, reservoirs B and C may coalesce forming a composite reservoir underlying the widespread impermeable cherty limestone marker (Figs. 9, 13, 16-17 and 19). Reservoir unit C is also lenticular and pinches out laterally to impermeable limestone (see Elder No. 1 in figure 20), shale/argillaceous limestone (e. g., Nolan No. 3 in figure1) or impermeable, very finely crystalline argillaceous dolomite.

**4. Reef reservoir facies D**

To date, there have been no documented reports of any reef reservoirs in the Sangamon Arch area. The inspection of well sample and cores (Dipper No. 1 in Blackland Field North, Macon County and Elder No. 1 in Mt. Auburn Consolidated Field, Christian County) and well log stratigraphic correlation with other areas of the Sangamon Arch (for example, Parks Comm. No. 2-L in the Mechanicsburg Field, Sangamon County and Garver No.1 in the Harristown Field, Macon County) led to recognition and documentation of a reef facies in the study area of the Sangamon Arch (Figs. 14 C-D and 22).

The reef facies is characterized by porous dolomitized coral reef/reef rudstone facies and is the lowermost productive horizon recognized in the Sangamon Arch area (Fig. 14 C-F, 16-17, 19-20 and 22). It consists of coarsely crystalline dolomite containing remains and molds of reef building organisms (mainly corals). The reef building skeletons are recognizable in cores and hand samples (Fig. 14 C-D), but the detail of their structure is lost due to pervasive dolomitization so that in thin sections only a very faint relic of the organic material of the original skeleton is visible (Fig. 14 E-F). Both intercrystalline and moldic porosities are present and the total porosity could reach over 20%.

The reefs occur as patch reefs of a very limited lateral extent and with a thickness of up to 30 feet, which grade laterally and vertically into impermeable, bioturbated and bioclastic mudstone to wackestone or to a very finely crystalline, argillaceous dolomite inter-reef facies. The reefs and associated facies display a shallowing-upward cycle and may occur in 1 to 3 horizons (Figs. 9, 18, 20 and 22). The patch reefs developed on the monocline platform of the Sangamon Arch with a very gentle slope (ramp platform of Ahr, 1973, 1998), similar to the southern part of the Persian Gulf (Purser, 1973), where the wave energy was not strong enough for the reef builders to construct barrier reefs or large pinnacle reefs described in other parts of the Illinois Basin (e. g., Bristol, 1973). Similar to the non-reef reservoirs (see above), dolomitization of the reef facies occurred very early during diagenesis and seawater chemistry and/or sea level fluctuation appear to have primarily controlled dolomitization.

The majority of wells in the study area have not tested the lower part of the Niagaran deposits that include the newly-recognized patch reefs, so the potential of these prolific lower horizons has been mostly overlooked. Examination of a few highly productive wells indicates that the highest initial production (up to 3000 barrels per day) is normally associated with this type of reservoir. Therefore, there is an excellent possibility for finding more productive Niagaran patch reefs along a vast area of the Sangamon Arch.

## 5. Conclusions

1. Four dolomitized permeability pinch outs are recognized in the Silurian deposits of the Mt. Auburn Trend including non-reef reservoir units A-C in the upper part and patch reef reservoir unit D in the lower part of the Niagaran series.

2. The reservoirs are surrounded by impermeable limestone (Fig. 7 A) or shaley and calcareous very finely crystalline dolomite suggesting seawater fluctuation and seawater chemistry as primary control for dolomitization of the compartmentalized Silurian reservoirs.

3. The laterally extensive impermeable units have formed flow barriers that divide the Niagaran deposits into stratigraphic cycles of porous and impermeable horizons. The reservoirs were deposited along a southwest trending platform margin that was roughly parallel to the Sangamon Arch trend and graded basin ward into muddy carbonates below wave base.

4. Examination of the numerous wells in the Mt. Auburn Trend indicates that most of the wells drilled thus far have only tested the uppermost part of the Niagaran succession; only a few wells have tested the lower reservoirs that include the newly-recognized patch reefs, so the potential of these prolific lower horizons has been mostly overlooked.

## Figures Mt Auburn Trend Sangamon Arch

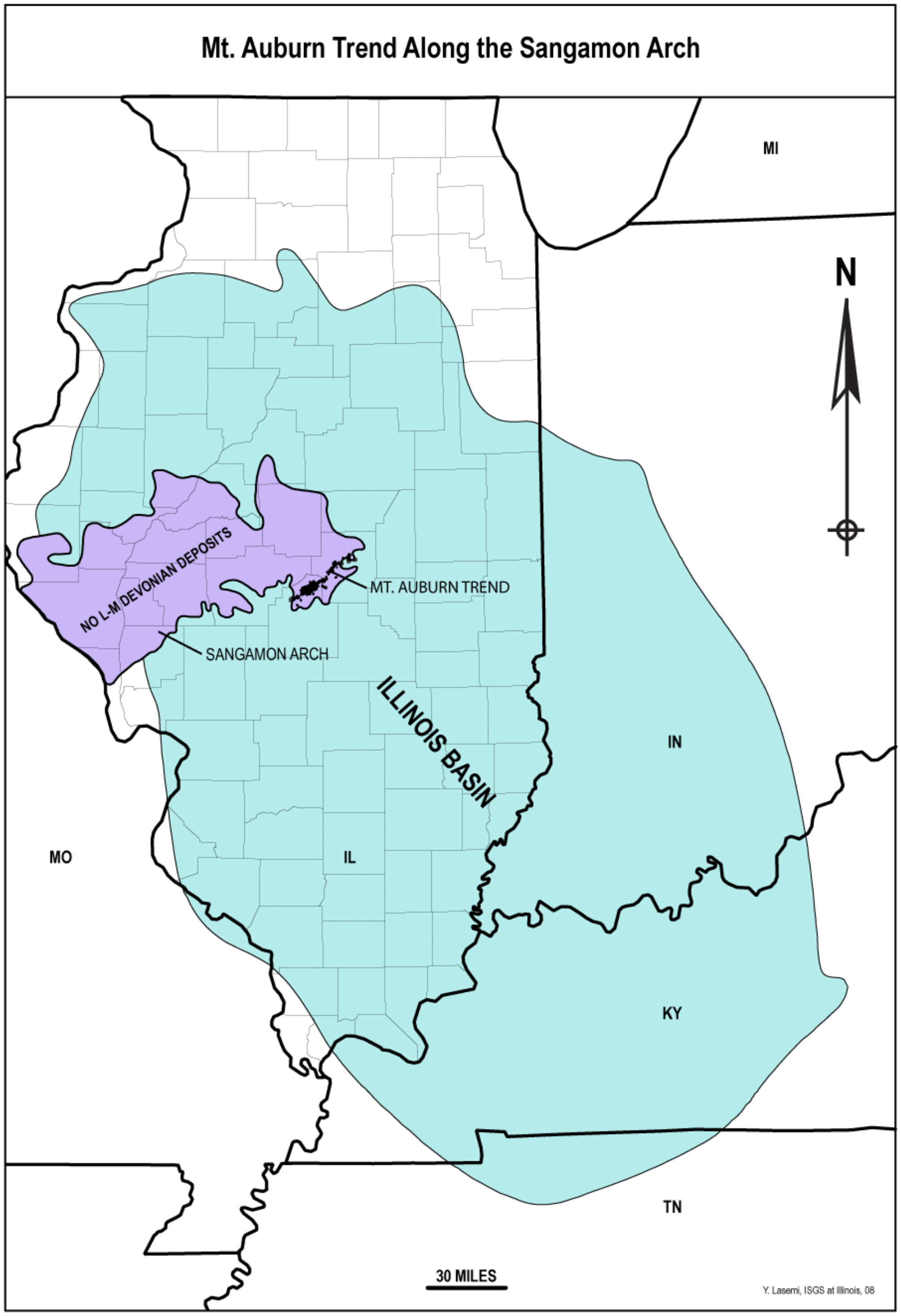


Figure 1. Outline of the Sangamon Arch in west central Illinois, which is defined by the zero isopach contour of the Lower- Middle Devonian deposits in the northwest of the Illinois Basin (Whiting and Stevenson, 1965). The Mt. Auburn Trend (the subject of this study) is located along the south eastern flank of the arch and includes several oil fields (see figure 2).

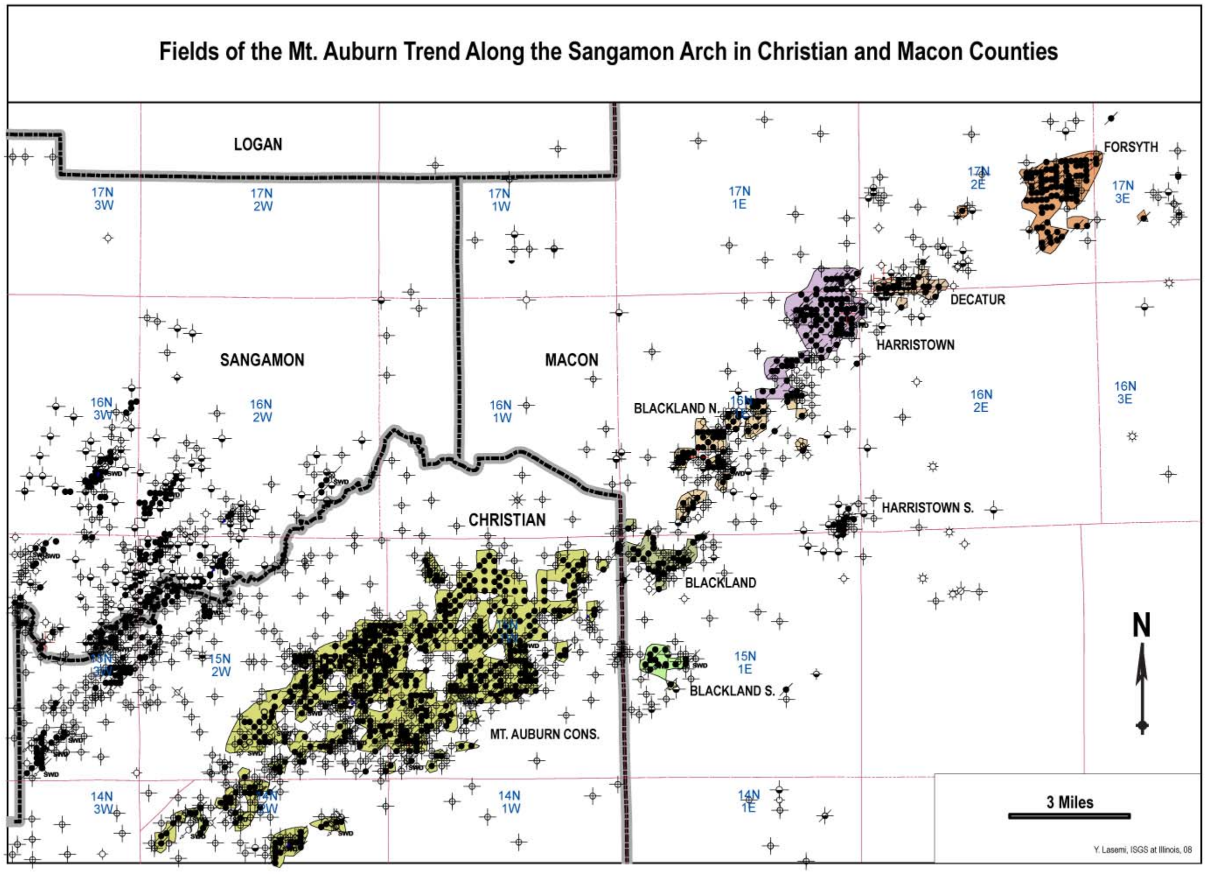


Figure 2. The eastern part of the Sangamon Arch showing the Mt. Auburn Trend at its southeastern flank. The trend is delineated by a number of oil fields that have produced from the Silurian reservoirs.

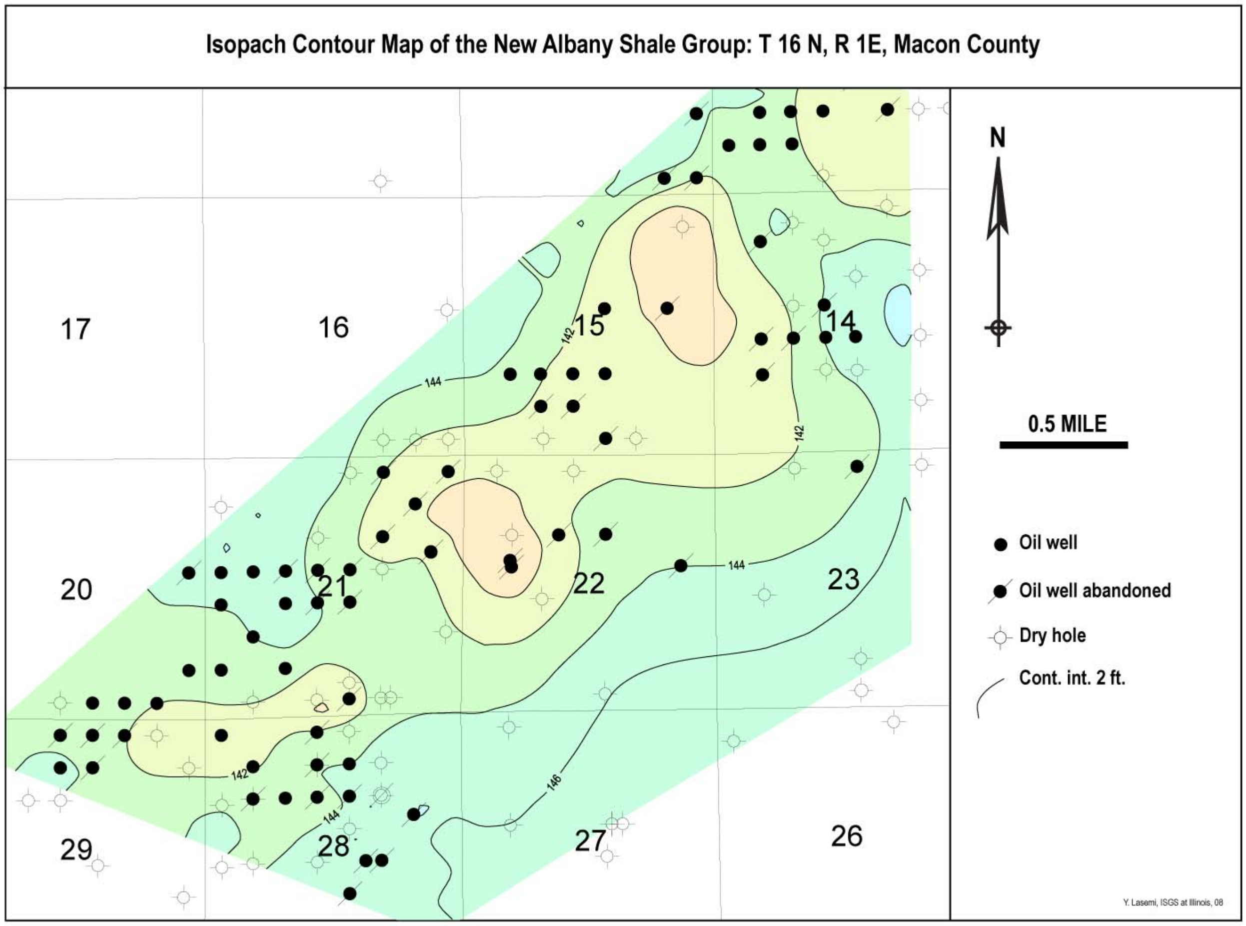


Figure 3. Thickness map of the New Albany Shale Group (from the top of Silurian deposits to the base of Chouteau Limestone); the New Albany thins towards the center of the arch suggesting that the arch was still active at the onset of the Upper Devonian deposition.

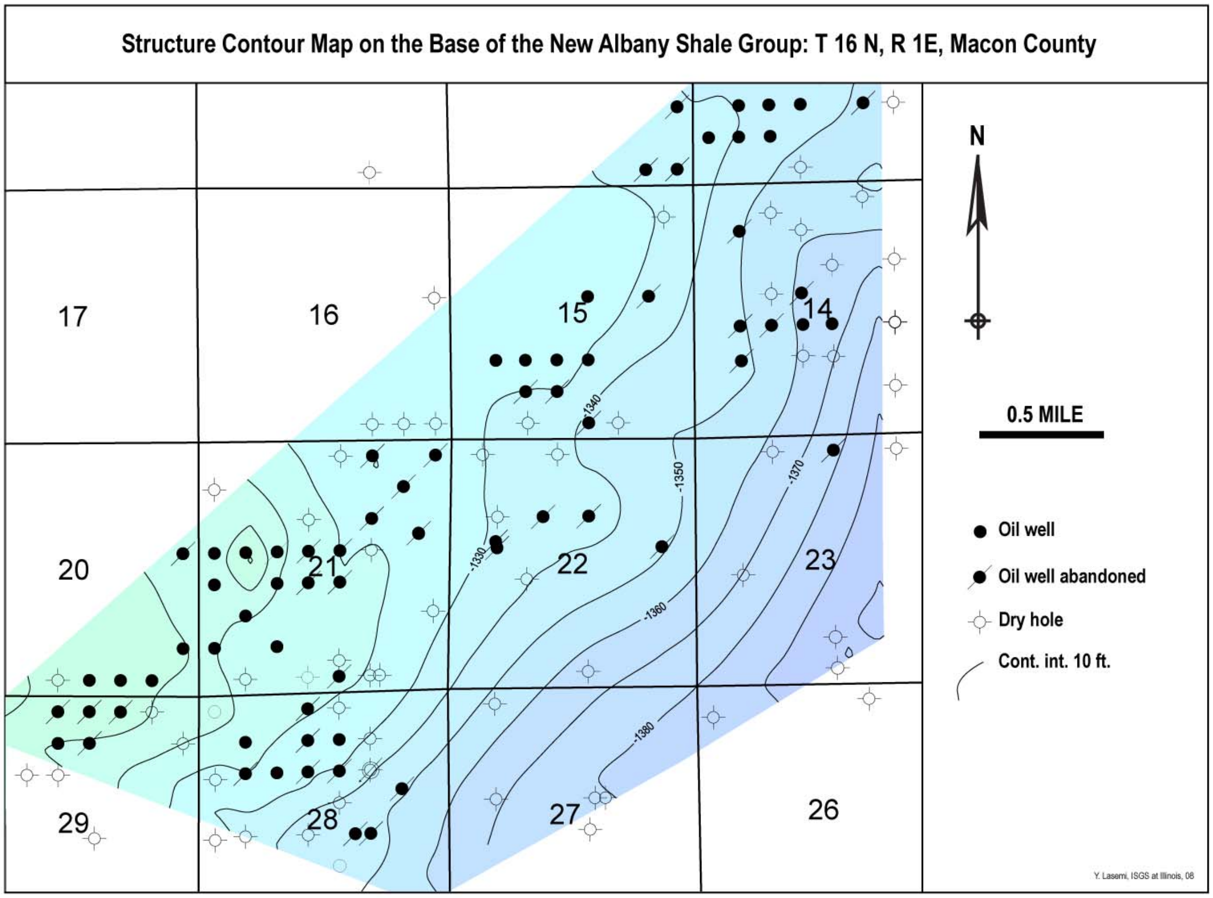


Figure 4. Structure contour map of the base of the New Albany Shale Group showing the direction of the regional dip that is towards the southeast. Note minor closures and noses that are due to uneven Pre-New Albany topography.

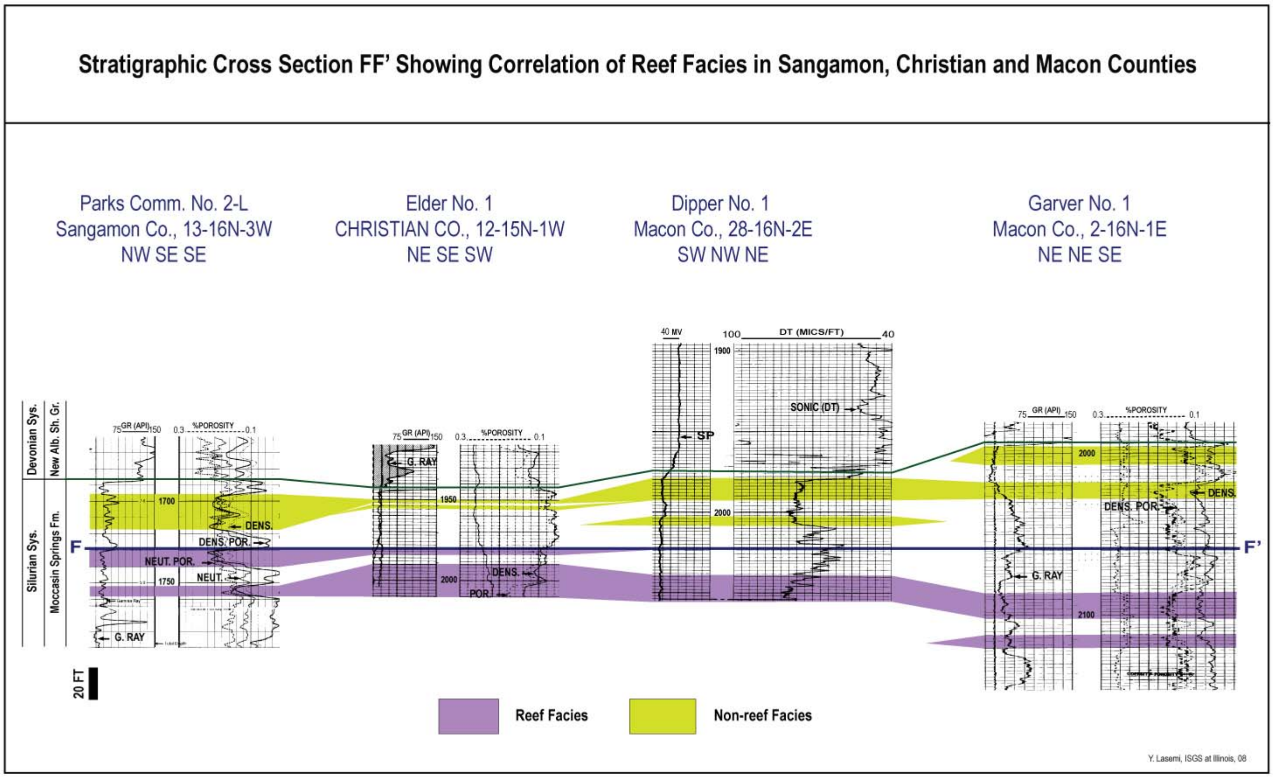


Figure 22. Cross-section FF' showing the correlation of reef and non-reef reservoirs in Macon, Christian and Sangamon Counties; note that the reef facies may occur in more than one interval in the lower part of the Niagaran Series (for the line of cross-section see Fig. 15).

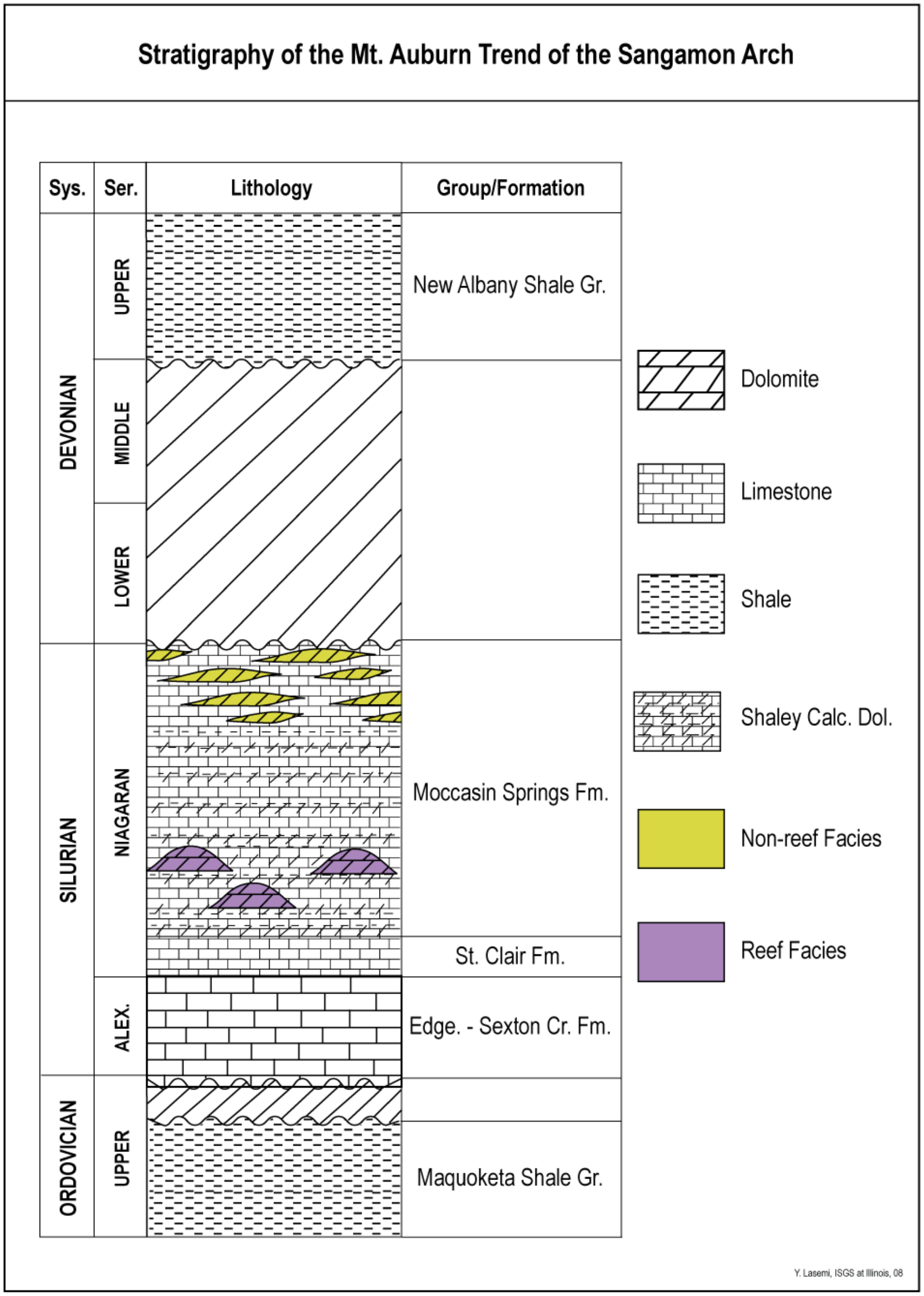


Figure 5. General stratigraphic column of the Upper Ordovician to Upper Devonian strata in the Sangamon Arch area showing the absence of Lower- Middle Devonian deposits.

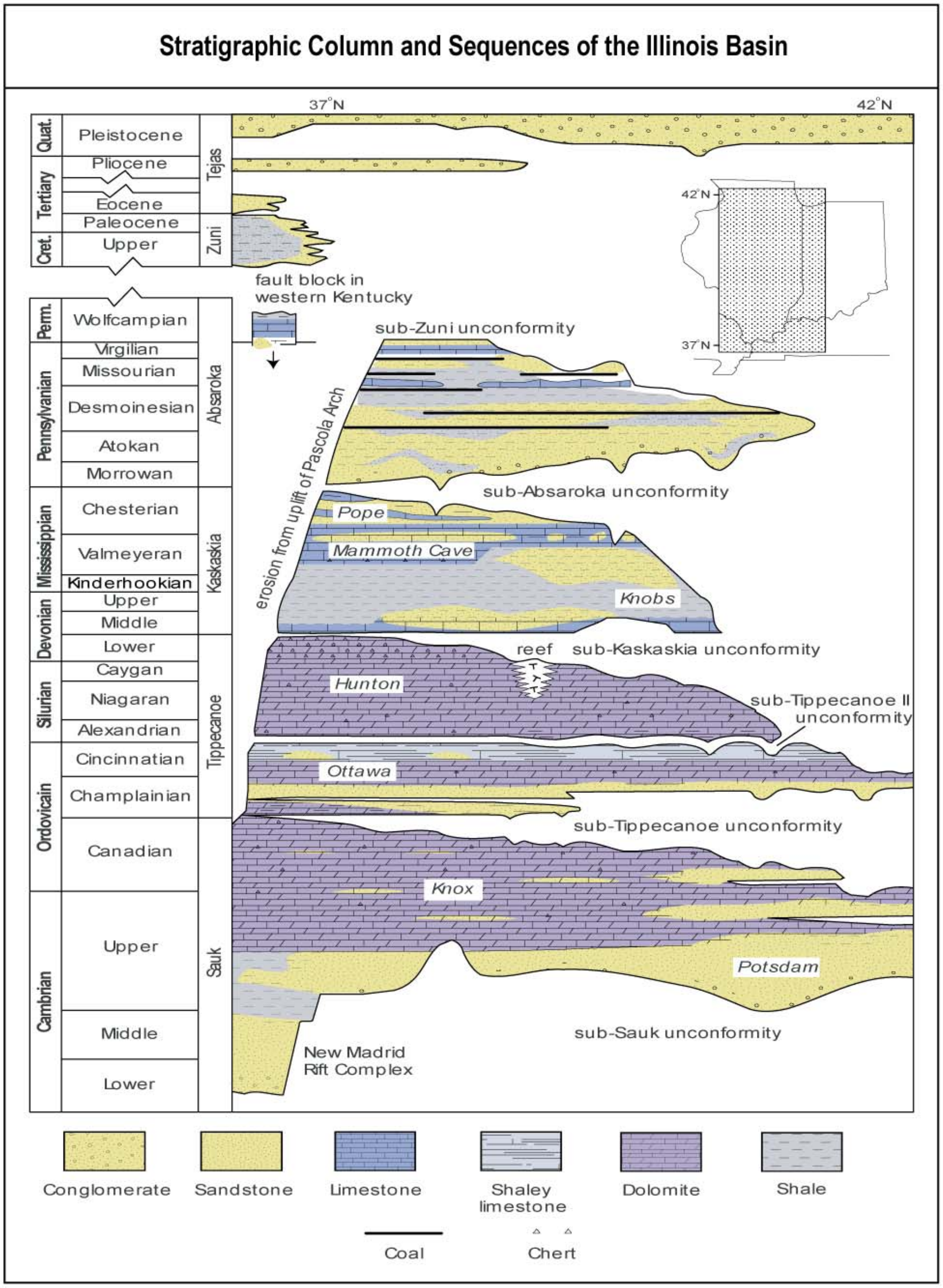


Figure 6: Stratigraphic column and sequences of the Illinois Basin (based on Swann and Wilman, 1961). In the Sangamon Arch area, the Upper Devonian deposits rest on the Silurian strata with the pronounce sub-Kaskaskia unconformity.

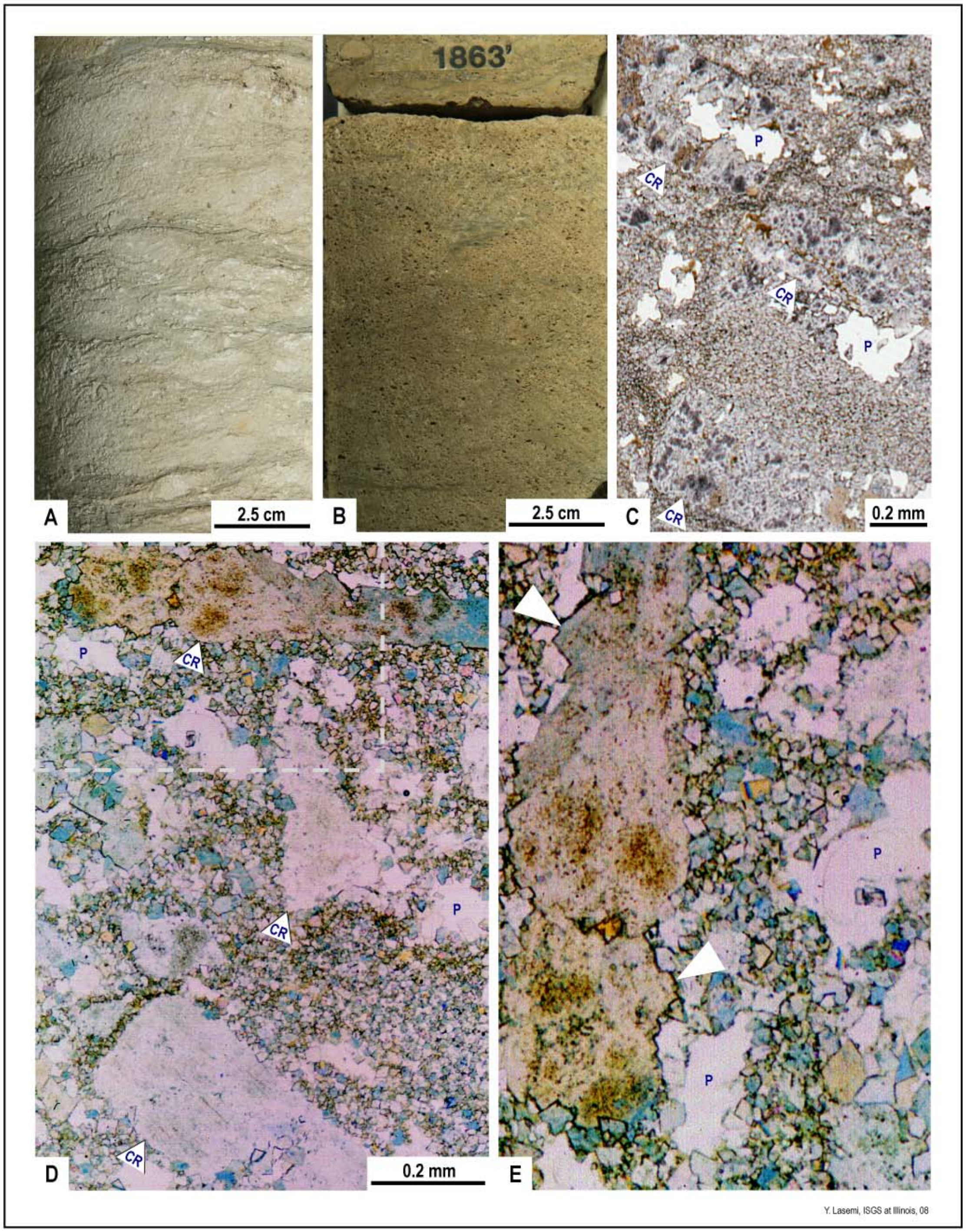


Figure 7. (A) Core of a limestone (bioturbated lime mudstone to wackestone facies) that is normally interlayered with reservoir facies. (B) Core slab of a porous dolomitized grainstone facies. (C) Scanned thin section photograph of B in plane light showing the remains of partially dolomitized crinoids (CR) and the pore spaces (P) formed as a result of dolomitization. (D) Photomicrograph of C under polarized light showing dolomite crystals and remains of crinoids (CR). (E) Enlarged portion of D (upper left rectangle outlined by white dashed lines) showing irregular dolomitization front (Arrow) and formation of dolomite rhombs and void spaces at the expense of crinoids.

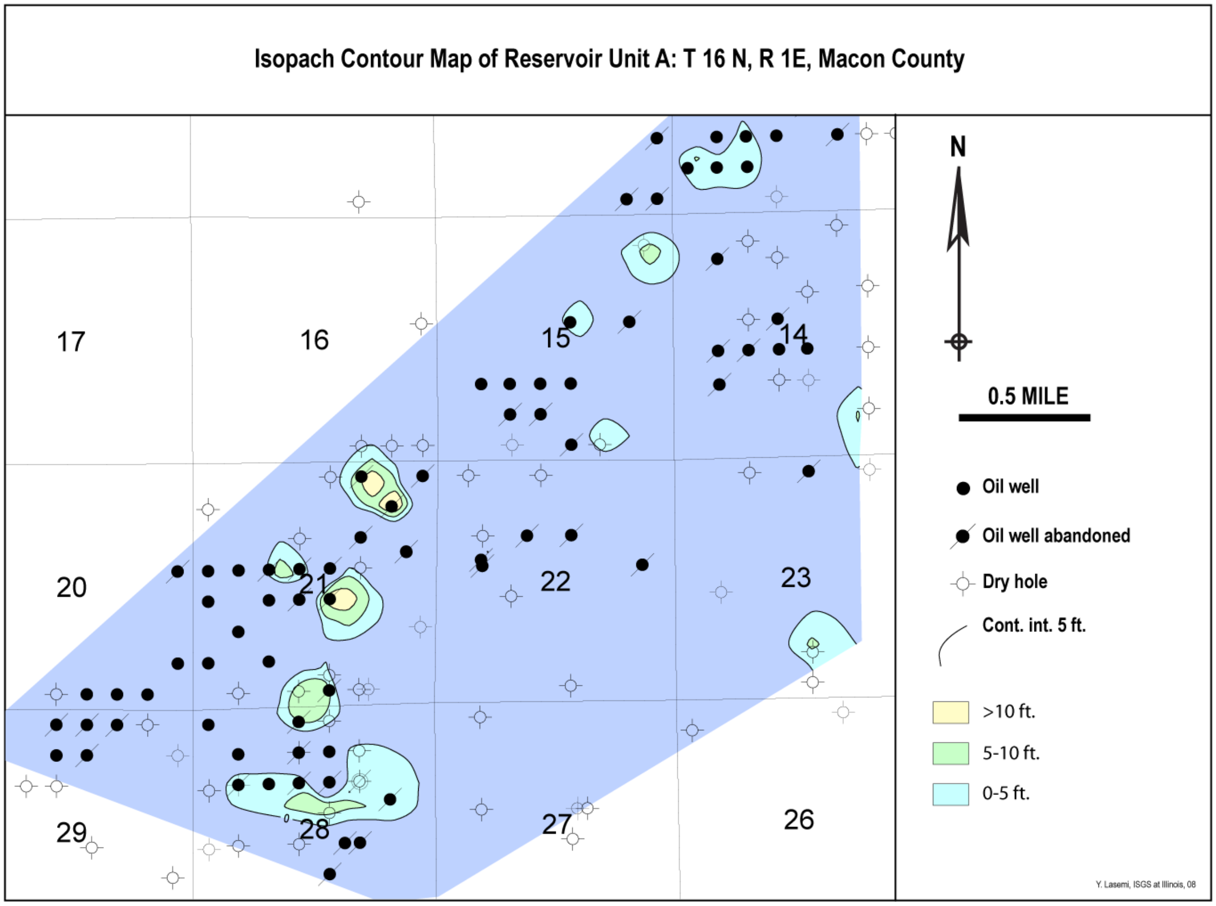

Figure 8. Thickness map of reservoir unit A (greater than 8% porosity) showing lenticular bodies that laterally pinch out to impermeable limestone facies.

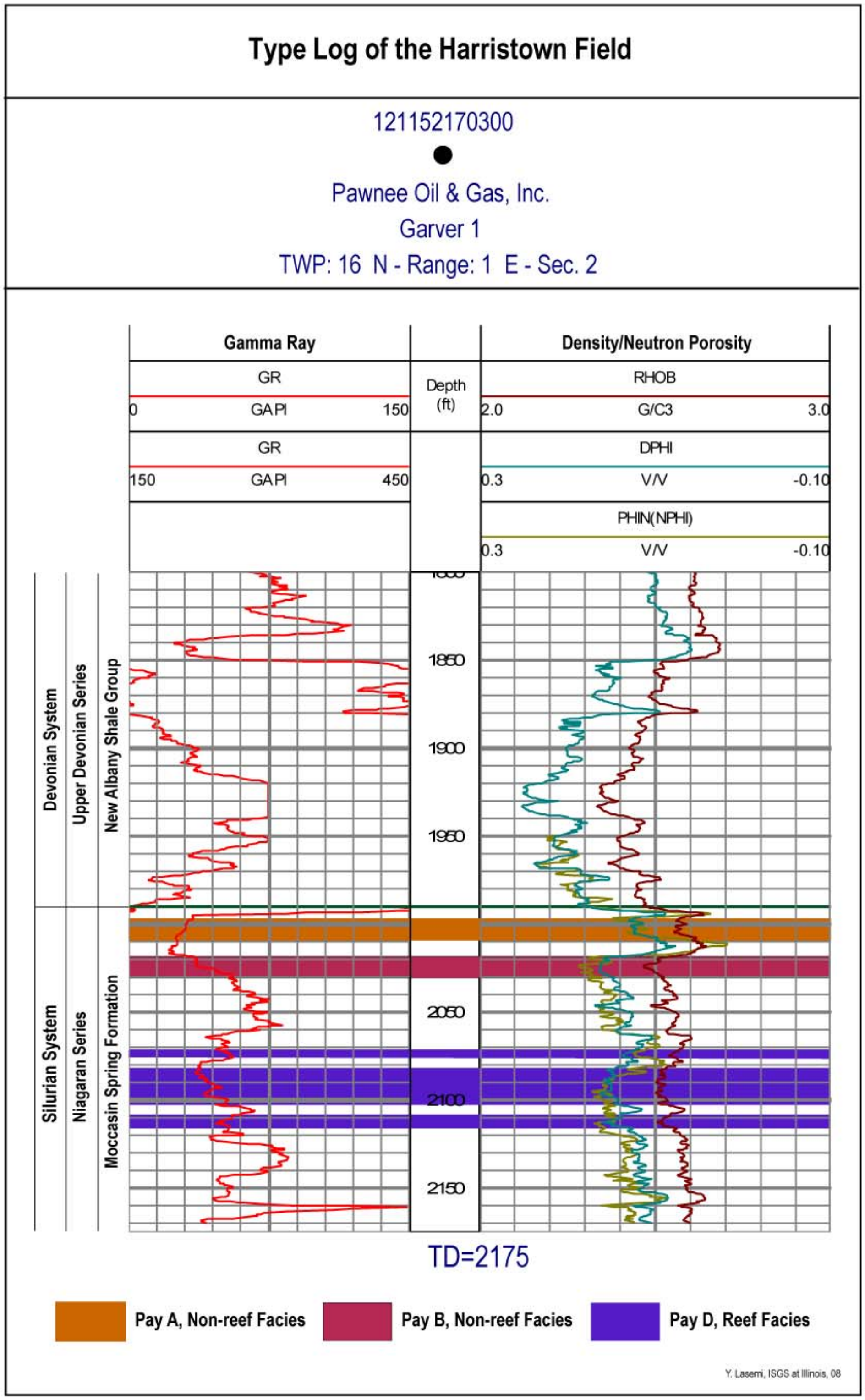


Figure 9. Type log (Gamma Ray, Density, and Density/Neutron porosity curves) of the Harristown Field in Macon County showing the development of non-reef reservoir units (Pays) A and B and a lower reef reservoir D.

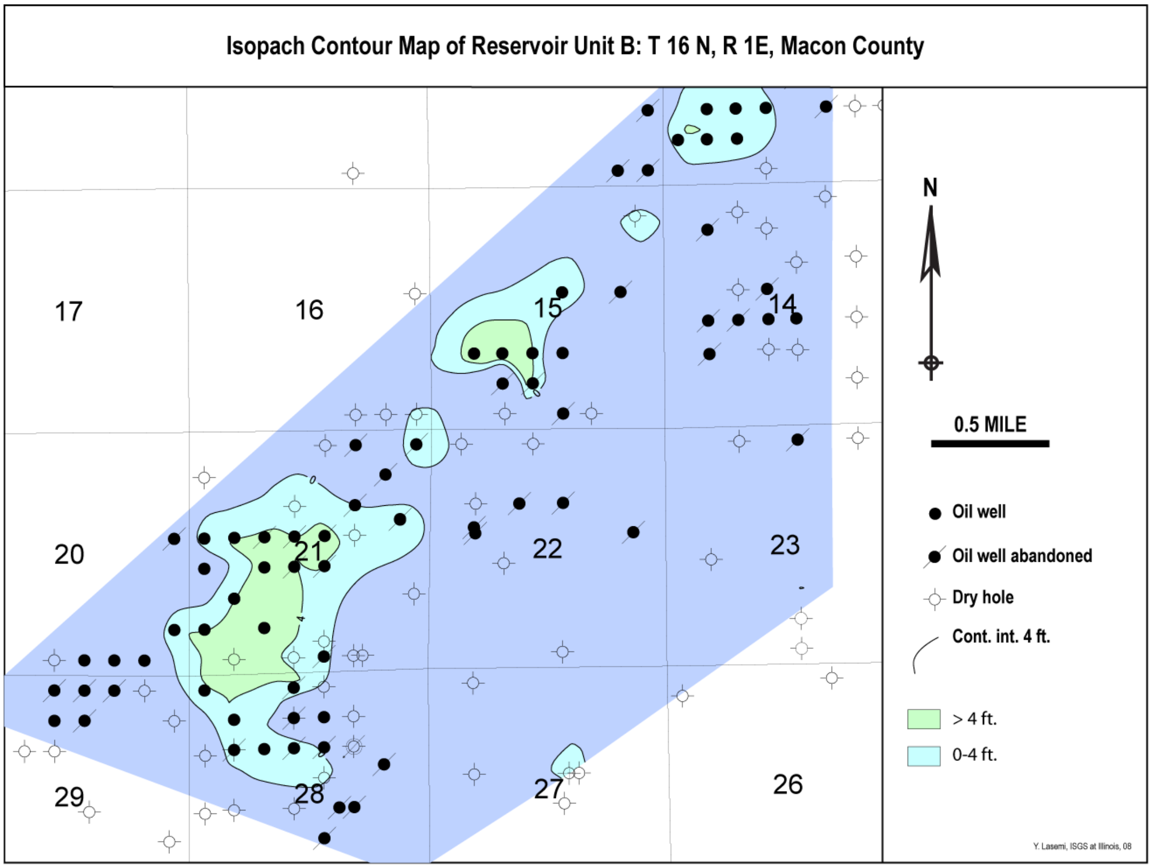


Figure 10. Thickness map of the reservoir unit B; similar to reservoir A, this reservoir is characterized by dolomitized lenticular permeability pinch outs along the Mt. Auburn Trend.

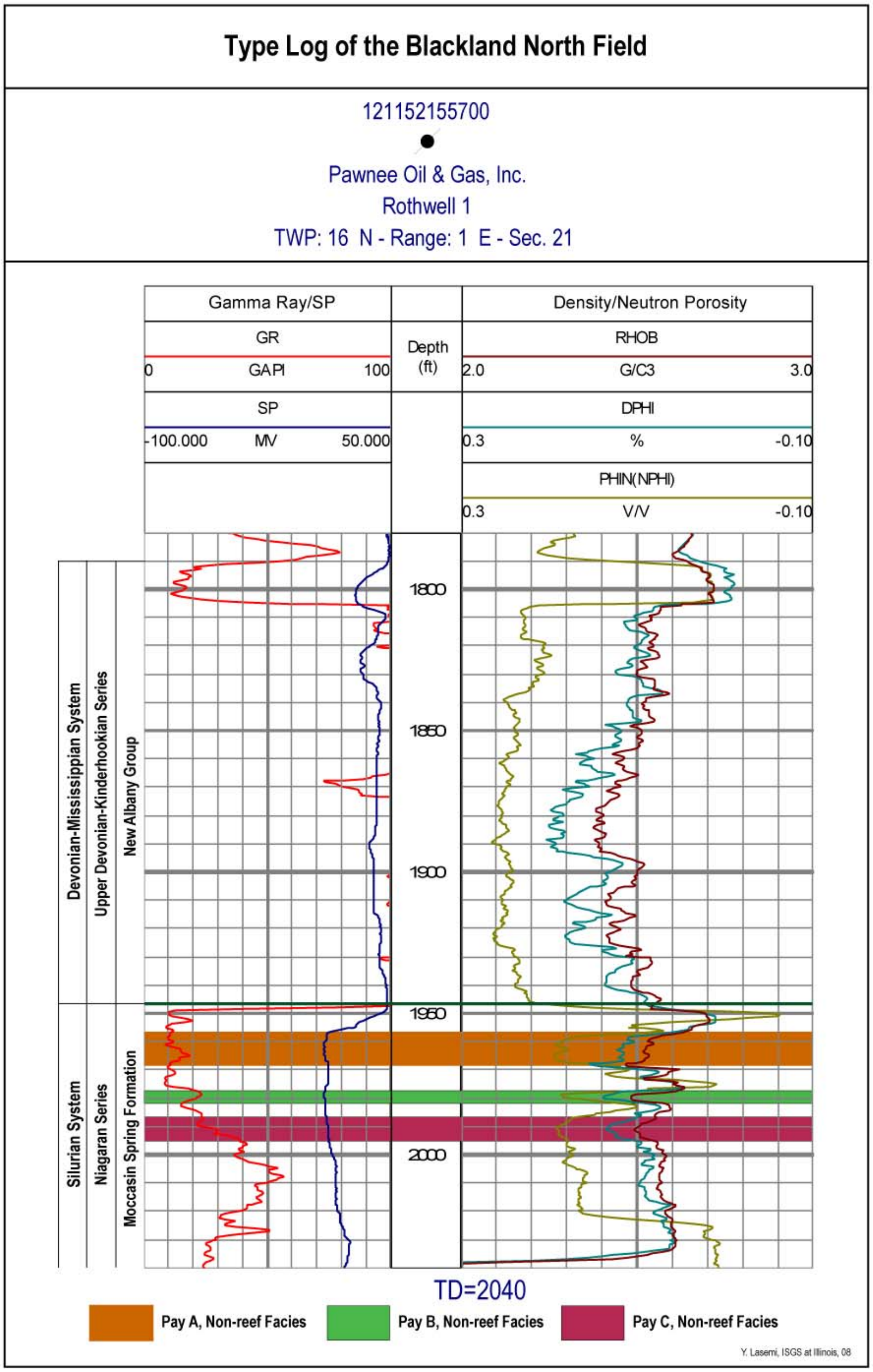


Figure 11. Type log (Gamma Ray, SP, Density, and Density/Neutron porosity curves) of the Blackland North Field in Macon County showing the development of non-reef reservoir units A, B and C.

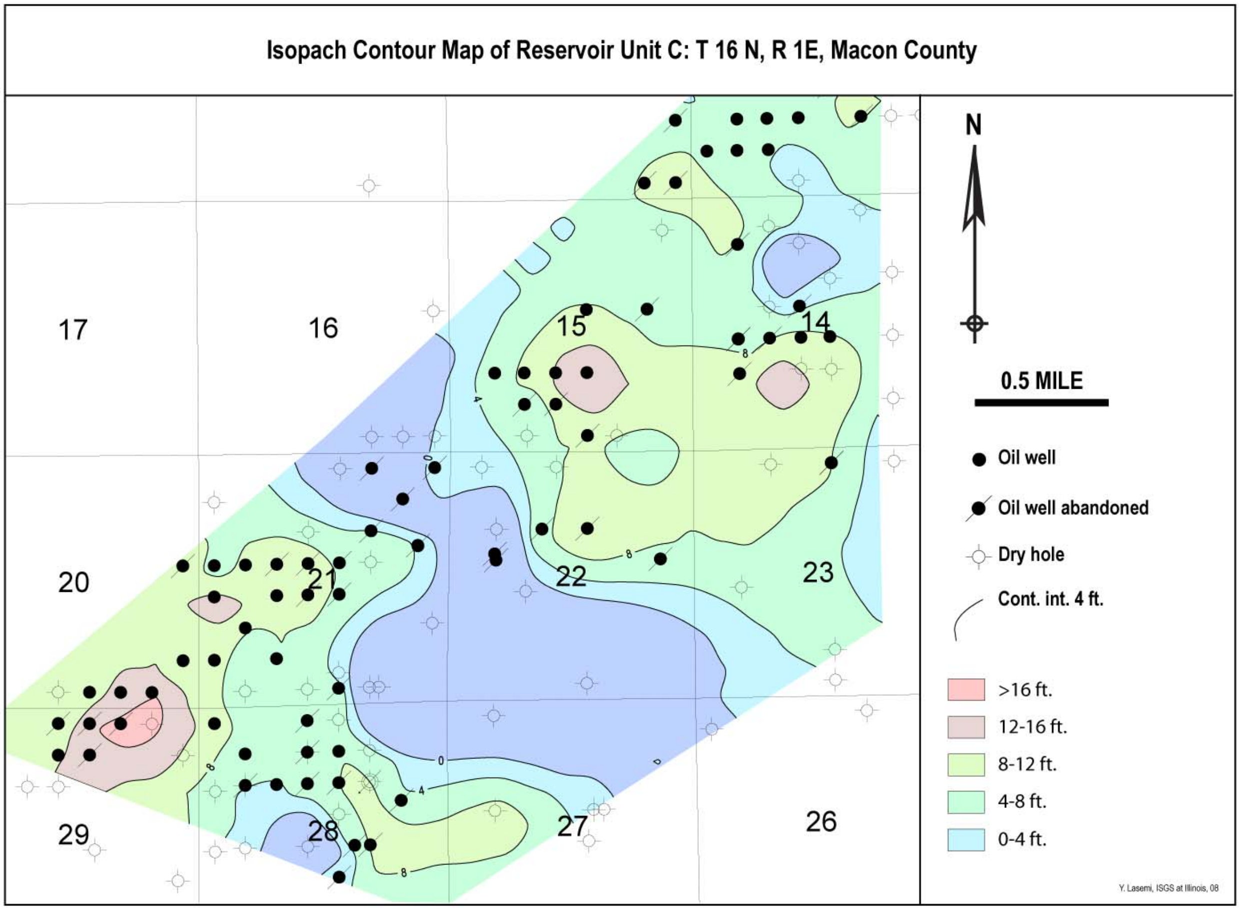


Figure12. Thickness map of the non-reef reservoir unit C; this lenticular reservoir is more persistent than the other reservoir units.

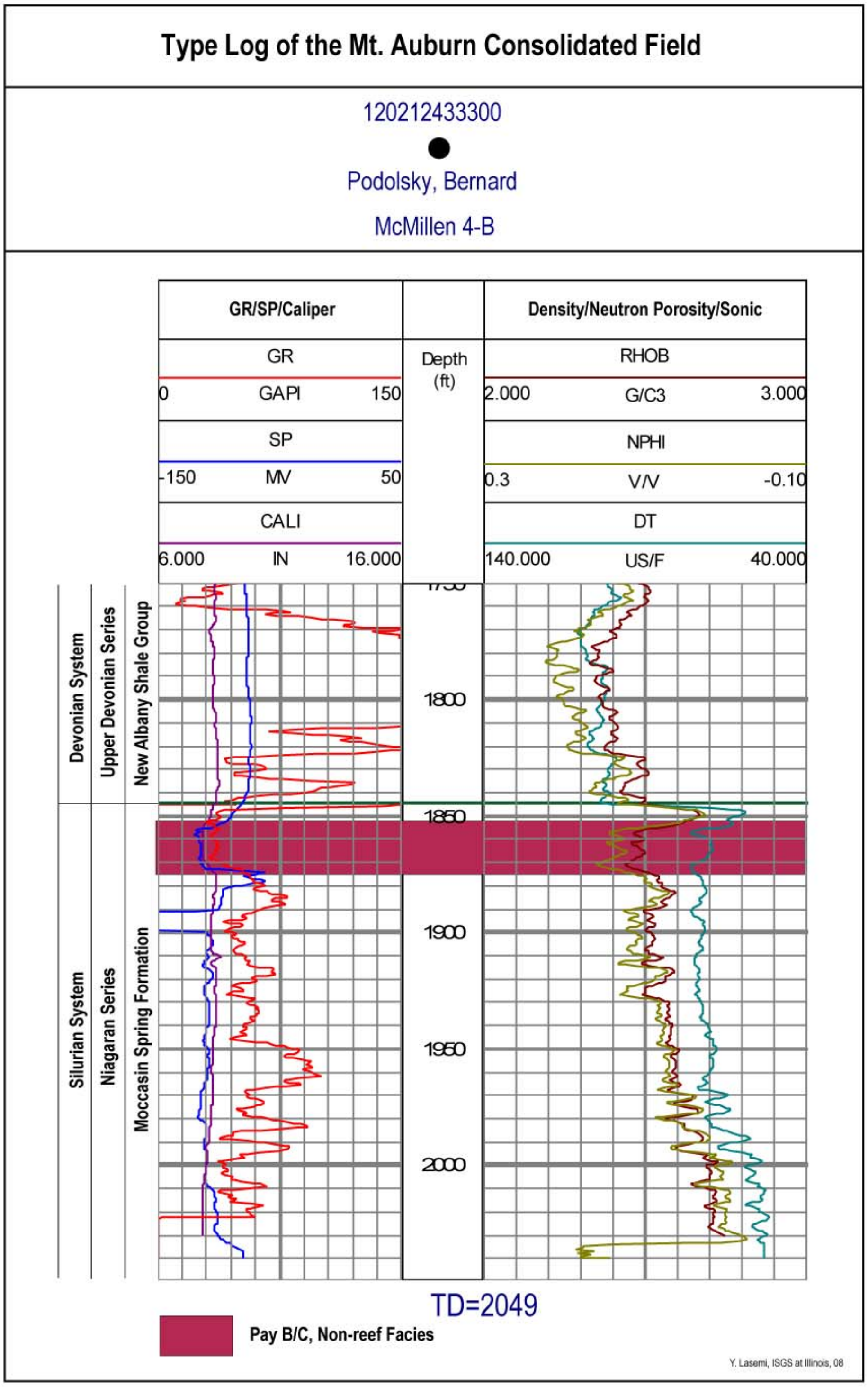


Figure 13. Type log (Gamma Ray, SP, Caliper, Density, Neutron porosity and Sonic curves) of the Mt. Auburn Consolidated Field in Christian County. Similar to other areas of the Mt. Auburn trend, reservoir unit B is absent or it is combined with C to make a single reservoir.

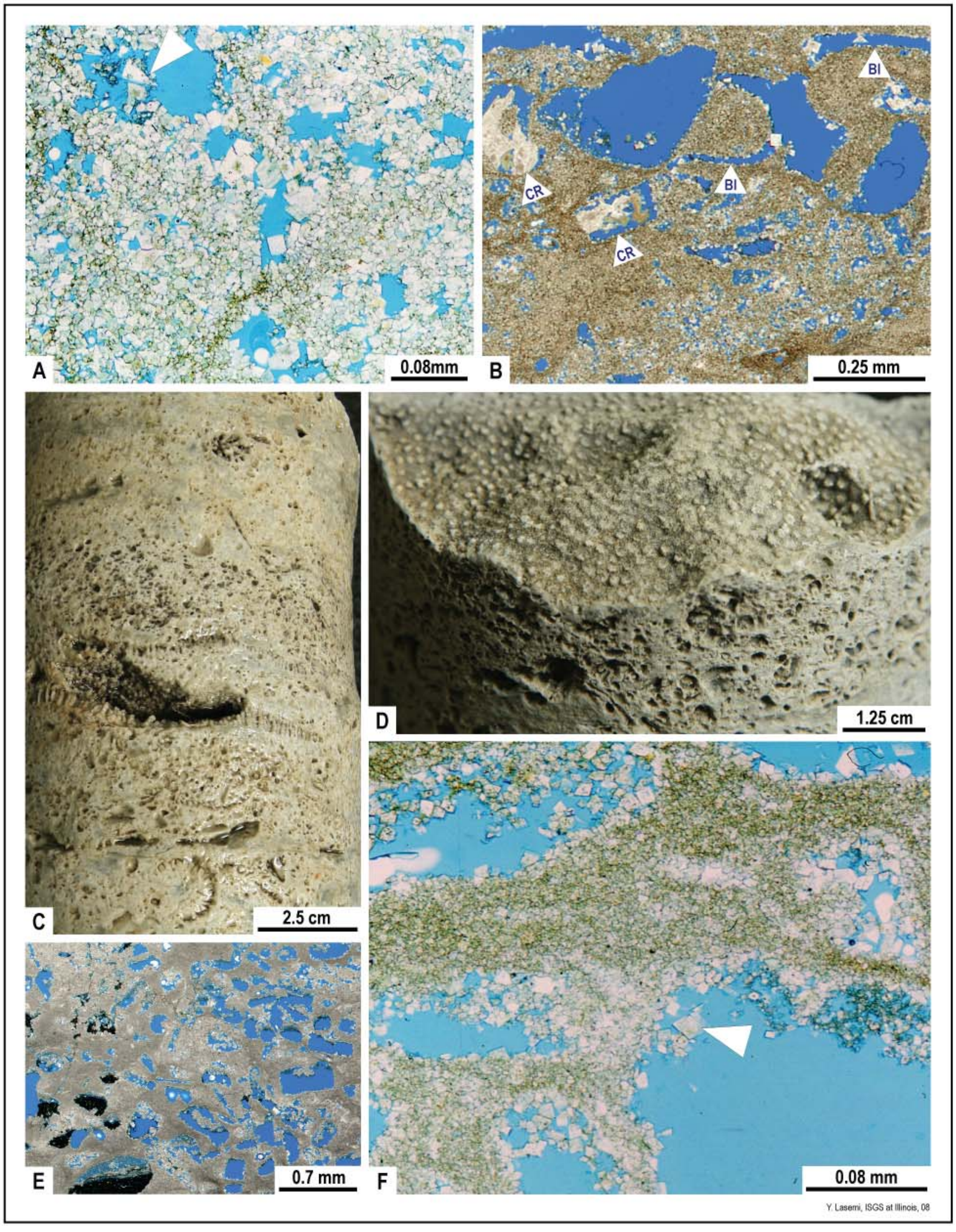


Figure 14. (A) Blue dye impregnated photomicrograph of a porous dolomitized non-reef reservoir in which the original texture has been destroyed by pervasive dolomitization. Note the dissolution of the dolomite rhombs and enlargement of the pore spaces (white arrow). (B) Scanned thin section photograph of a non-reef wackestone-packstone reservoir showing partially preserved crinoids (CR) and molds of bivalves (BI) and other unrecognizable grains in a finely crystalline dolomite groundmass. (C-D) Core photographs of a dolomitized reef facies composed mainly of coral skeletons. (E) Scanned photograph of a thin section of D showing vugular porosity as a result of dissolution of the skeletons that are hardly recognizable in thin diction. (F) Photomicrograph of an enlarged portion of E. Note the organic residue of the original skeletons and the dissolution of dolomite rhombs (white arrow) to form larger pore spaces.

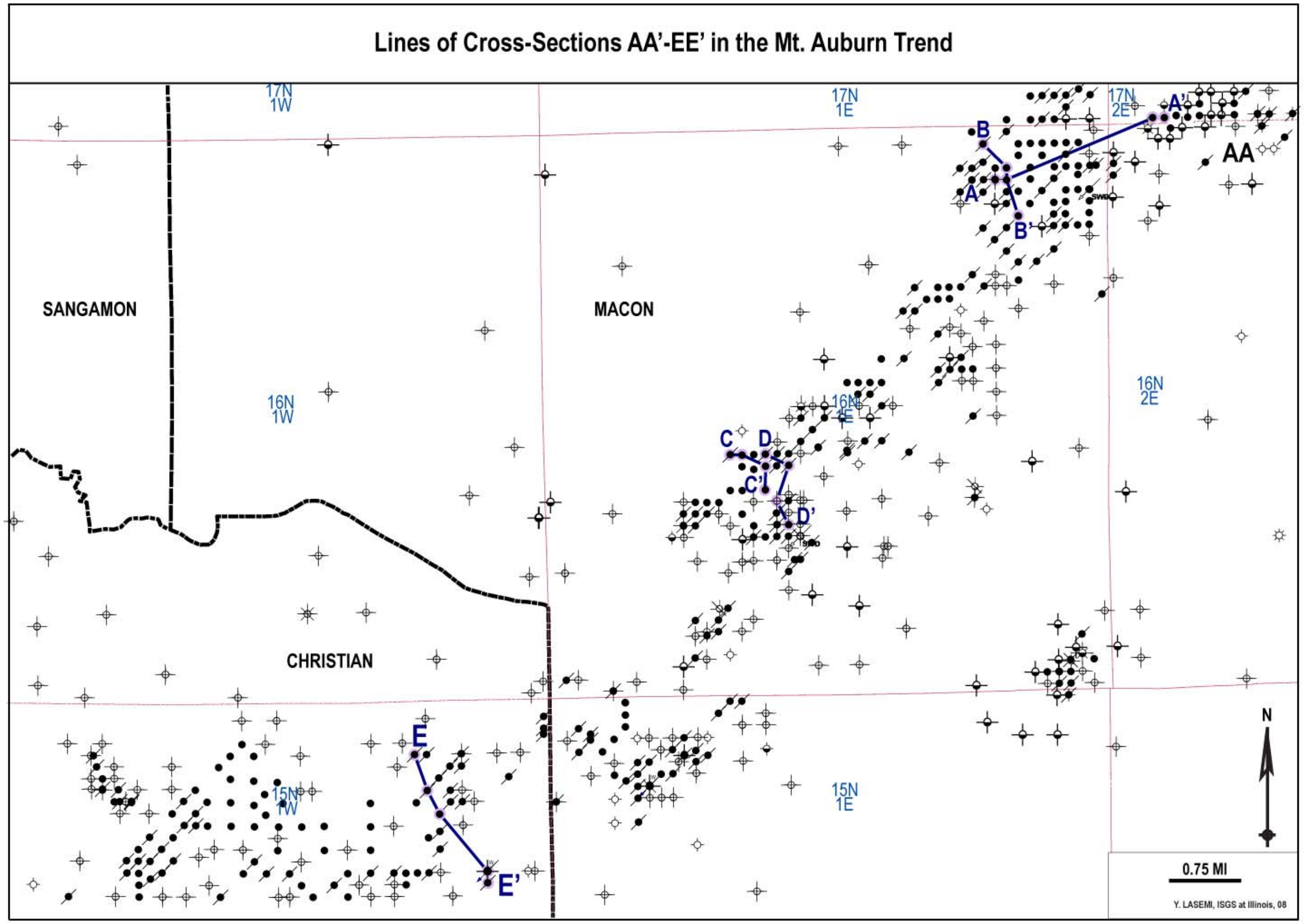


Figure 15. Map of a part of the Mt. Auburn Trend in Christian and Macon Counties showing the lines of cross-sections AA' to EE'.

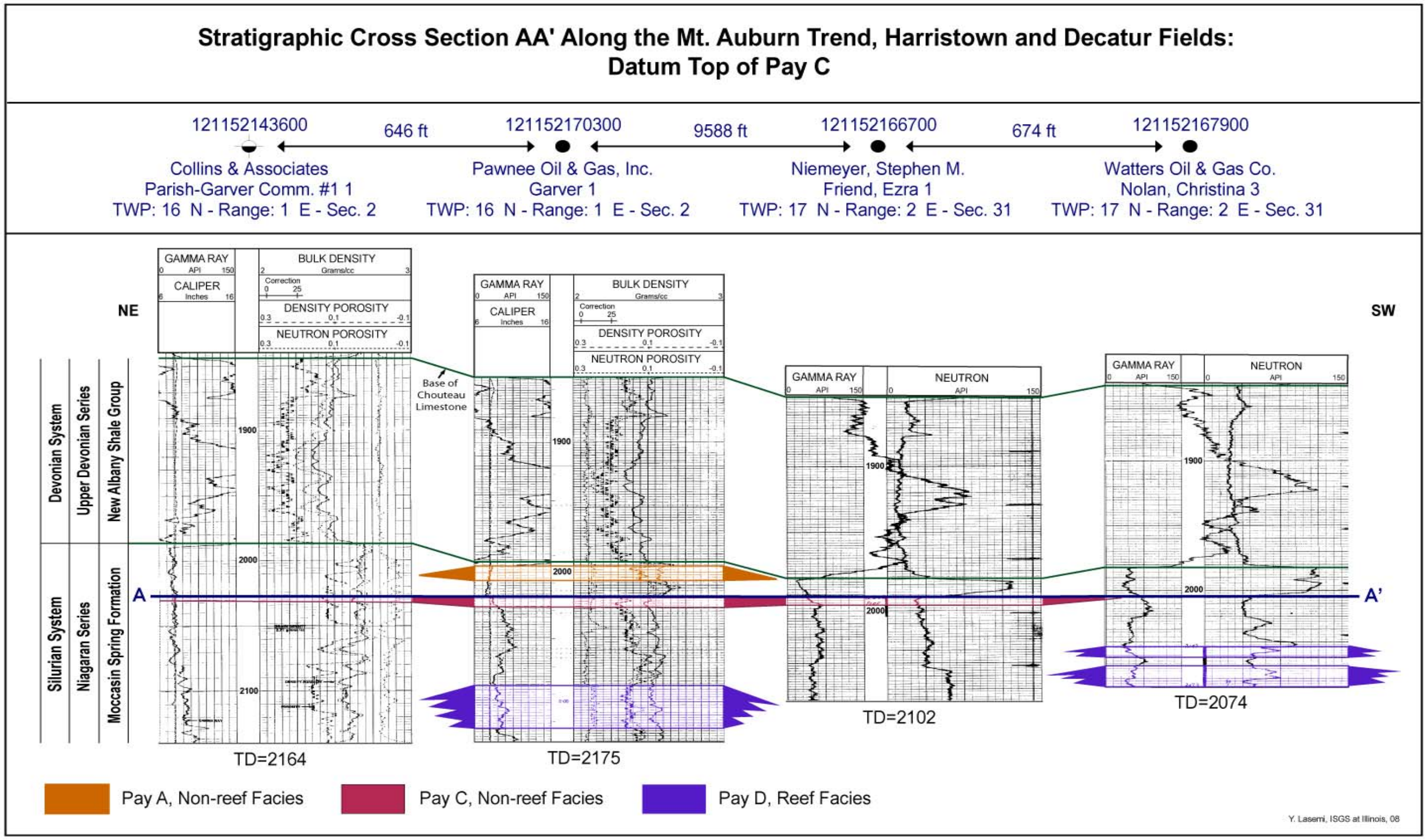


Figure 16. NE-SW cross-section AA' along the Mt. Auburn Trend showing the lenticular nature of the porosity pinch outs within the Silurian impermeable carbonates. Note the uneven topography of the Silurian surface in this cross-section and in figures 18-21 (for the line of cross-section see Fig. 15).

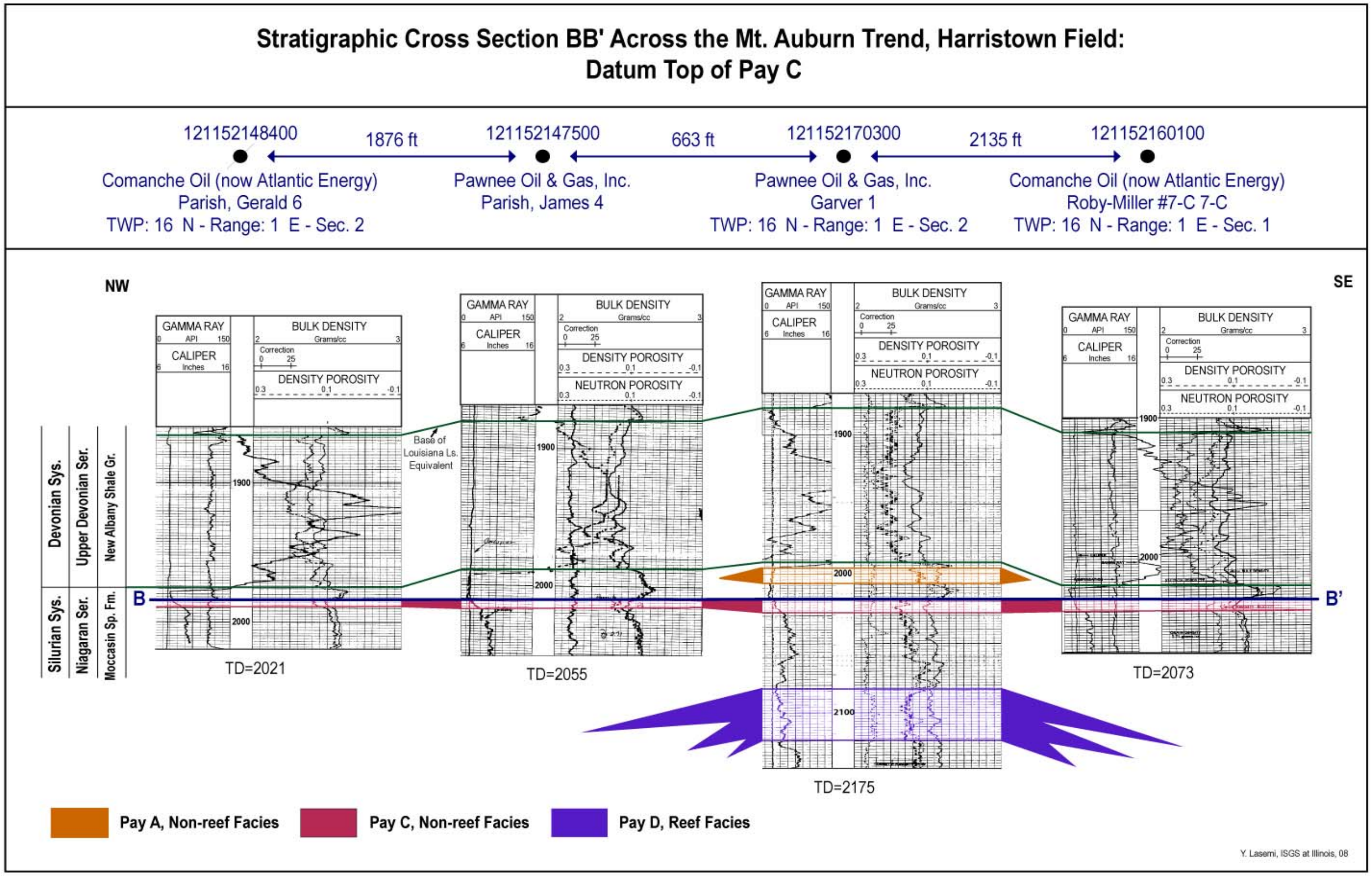


Figure 17. NW-SE cross-section BB' across the Mt. Auburn Trend. Note that reservoir C is more persistent than reservoirs A and D (for the line of cross-section see Fig. 15).

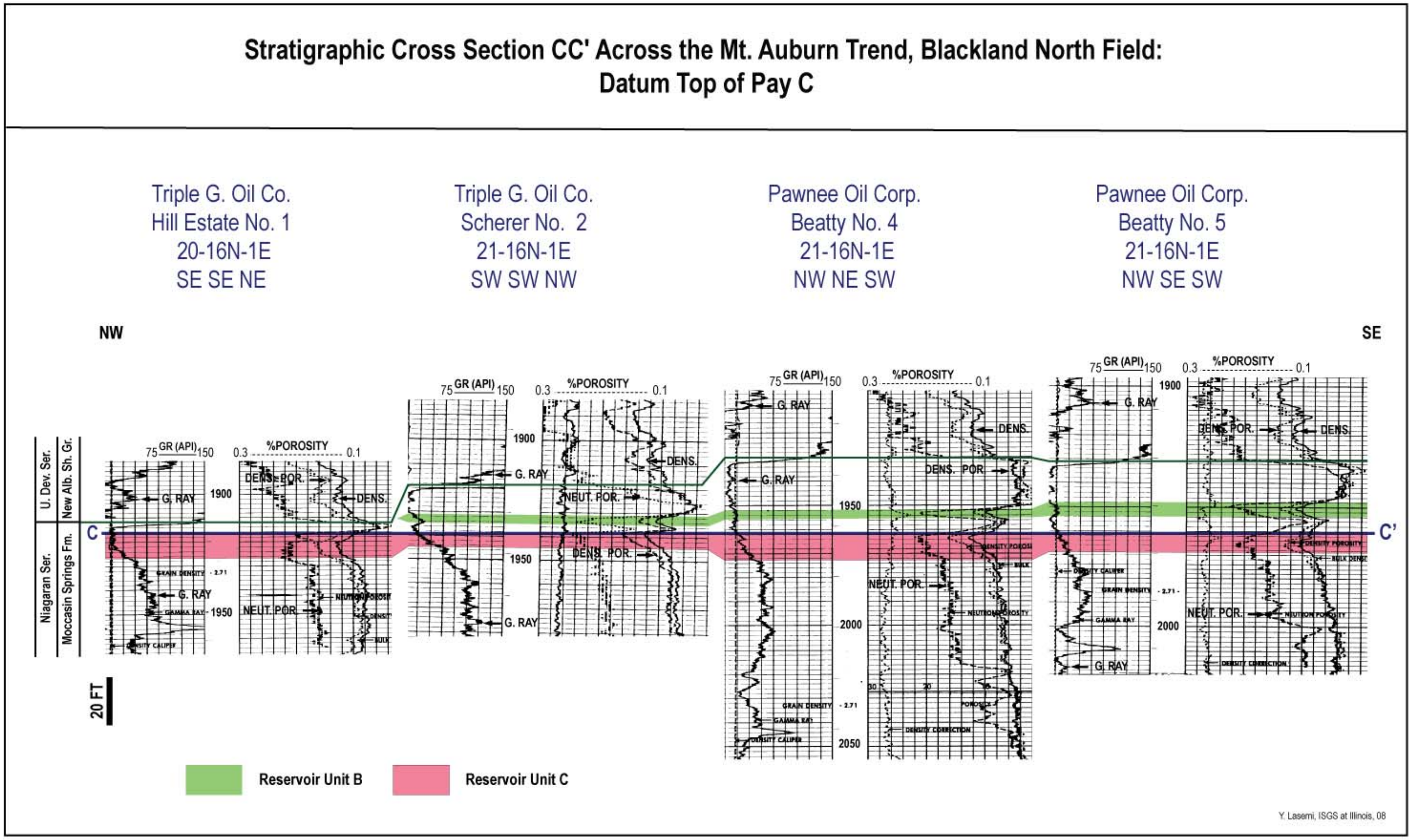


Figure 18. NW-SE cross-section CC' across the Mt. Auburn Trend showing the development of reservoir units B and C. Note that reservoir B pinches out in Hill Estate No. 1 as a result of pre-Devonian erosion (for the line of cross-section see Fig. 15).

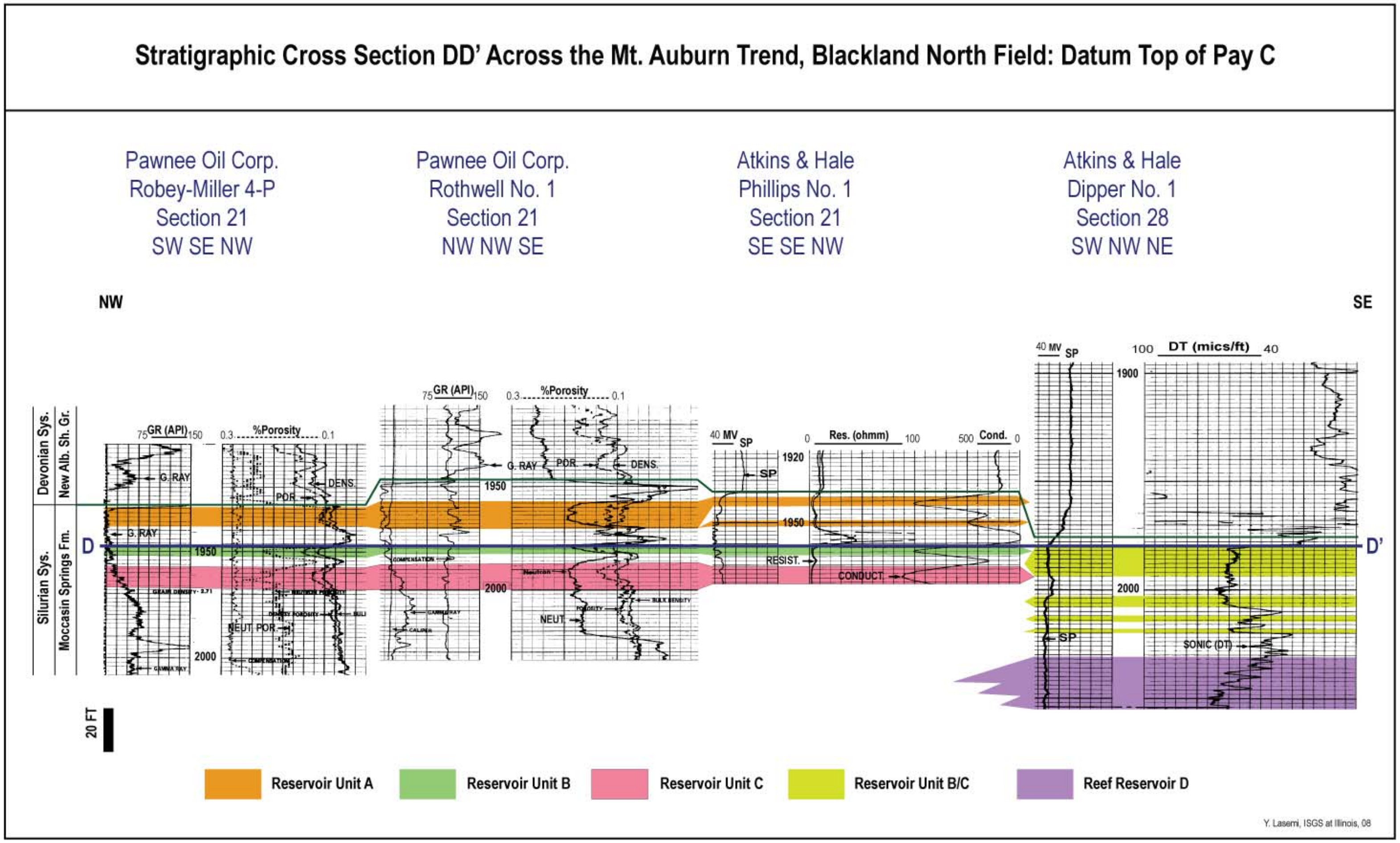


Figure 19. Cross-section DD' across the Mt. Auburn Trend showing the development of reservoir units A-C and reef reservoir D (Dipper No. 1). Note that other wells were not deep enough to test the reef reservoir. Note also that the absence of reservoir A in Dipper No. 1 could be the result of post Silurian erosion. In Dipper No. 1, the absence of the tight limestone between A and B has resulted in the formation of a single reservoir (for the line of cross-section see Fig. 15).

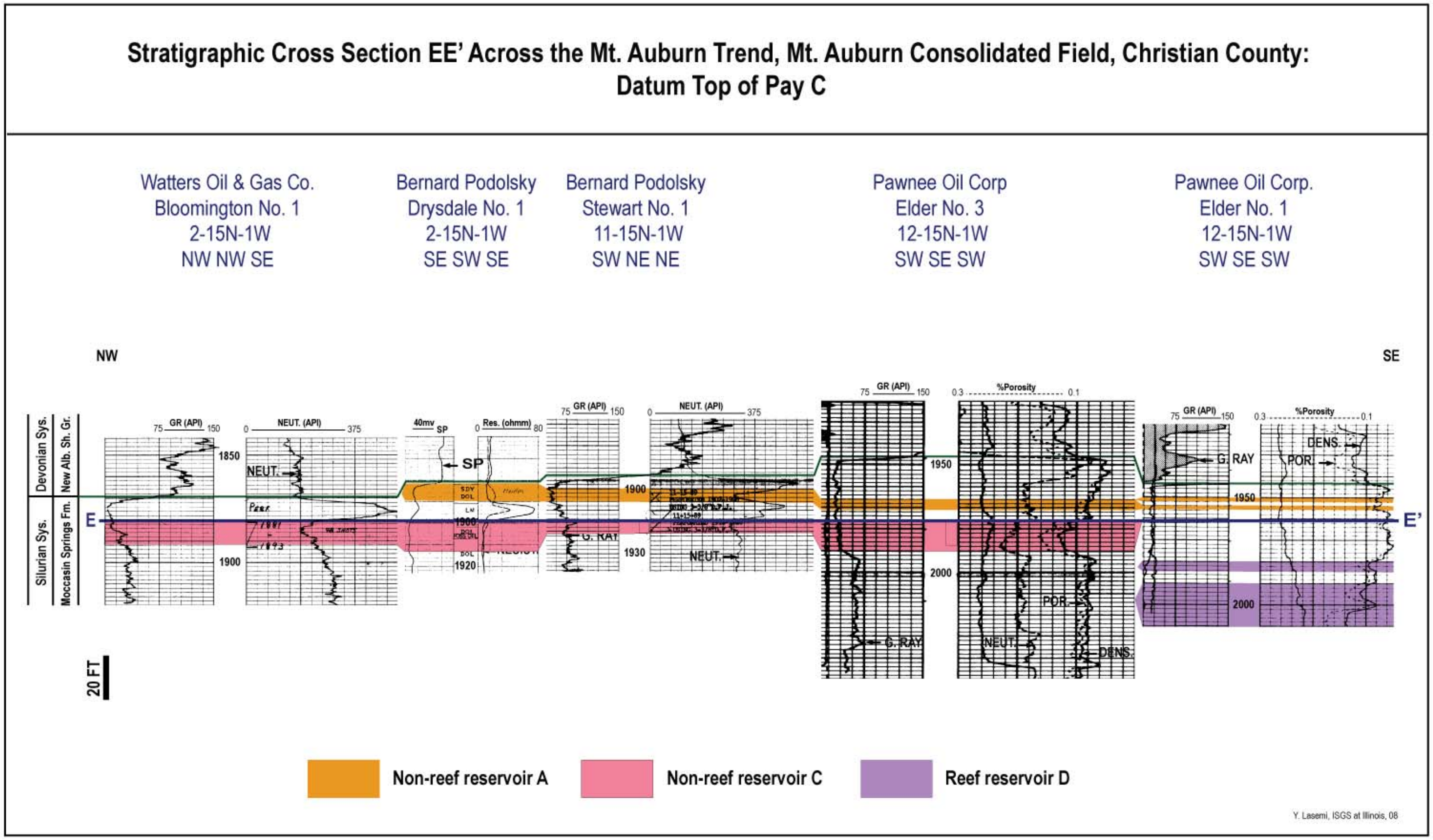


Figure 20. NW-SE cross-section EE' across the Mt. Auburn Trend in Christian county showing the occurrence of non-reef reservoirs A and C and reef reservoir D. Note that reservoir C is more persistent than reservoirs A and D, but it pinches out in Elder No. 1. The upper reservoir is missing in Bloomington East No. 1 towards the northwest, as the result of post Silurian erosion (for the line of cross-section see Fig. 15).

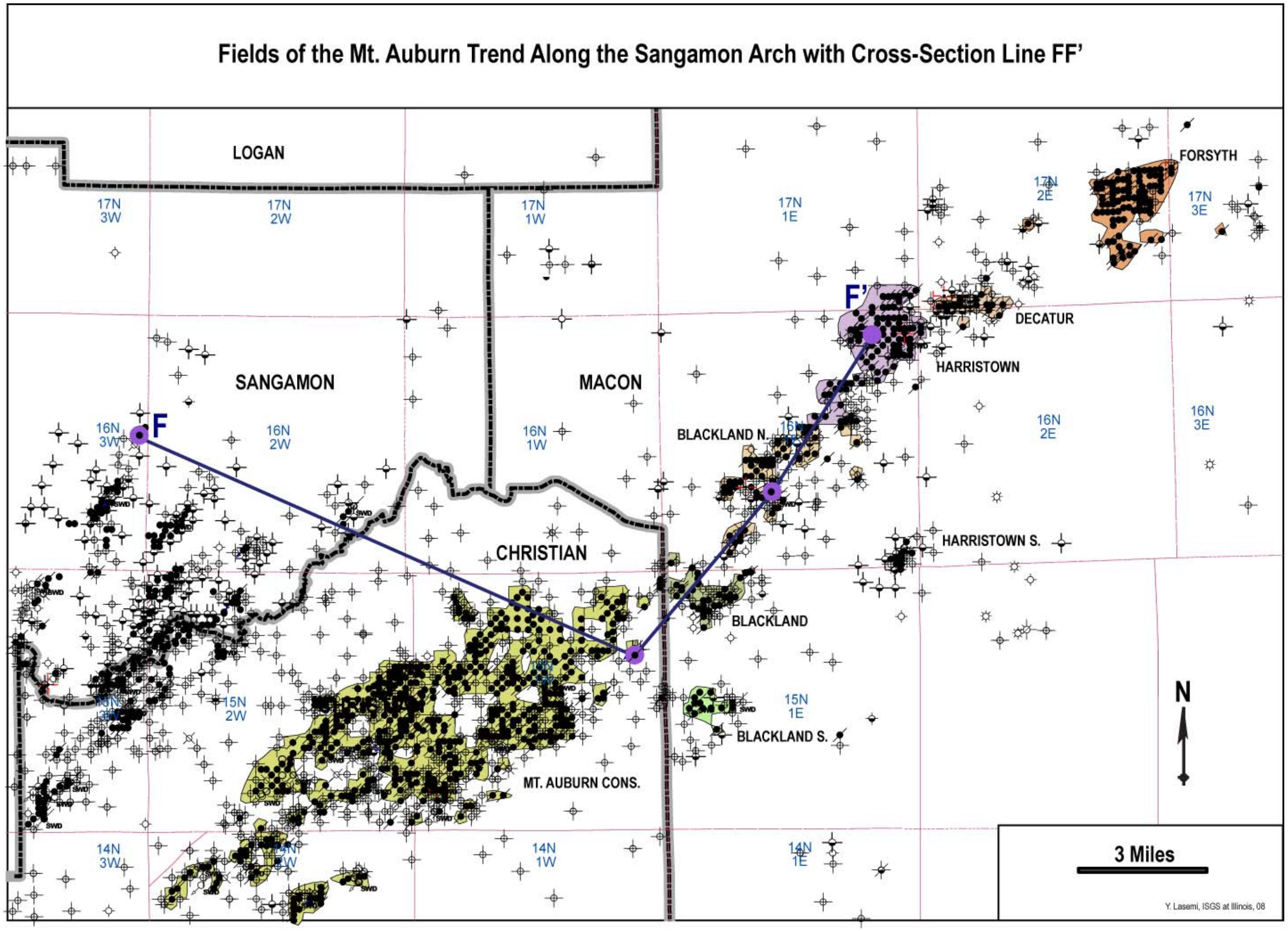


Figure 21. Line of cross-section FF' to correlate the reef reservoir in Sangamon, Macon and Christian Counties.

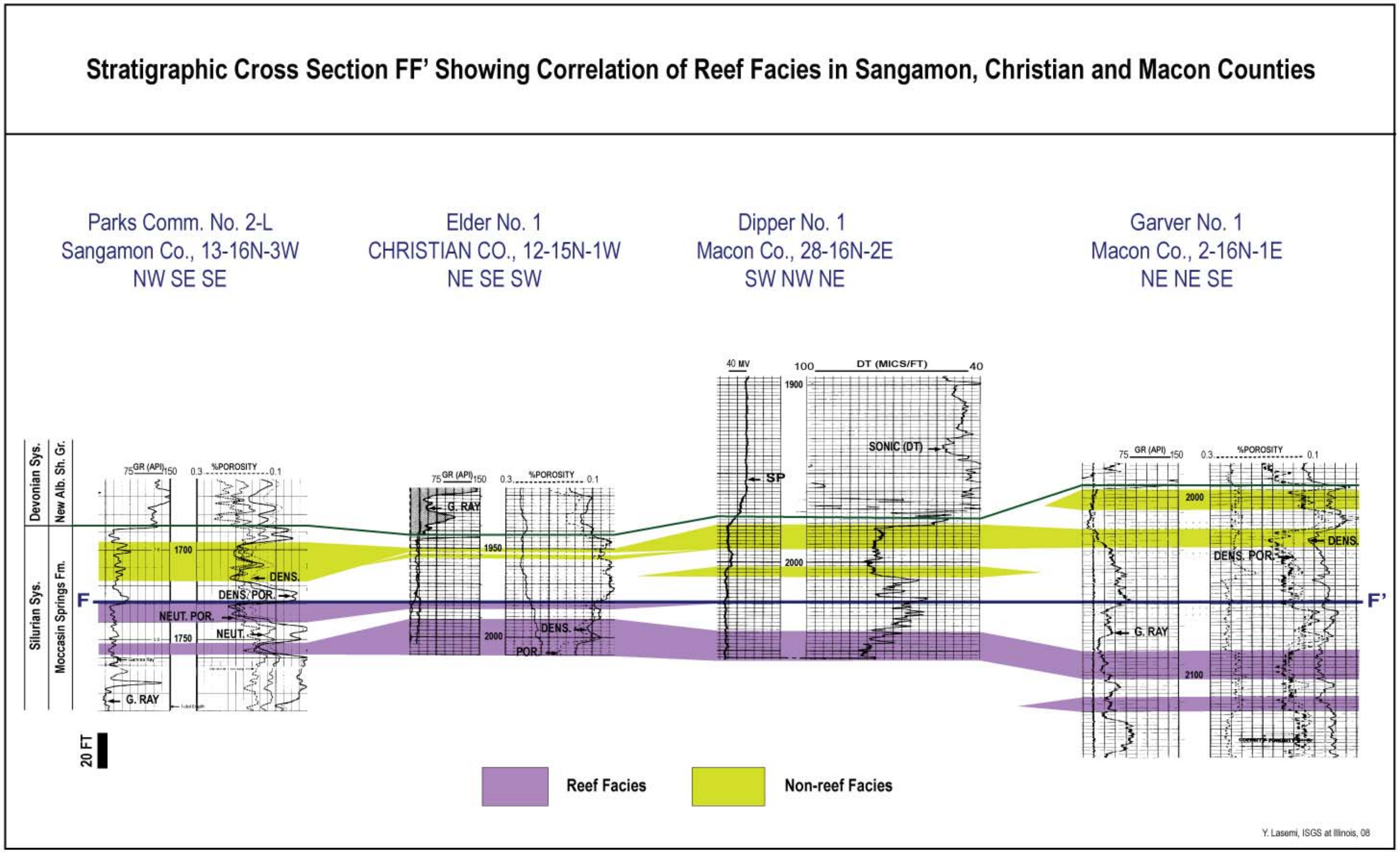


Figure 22. Cross-section FF' showing the correlation of reef and non-reef reservoirs in Macon, Christian and Sangamon Counties; note that the reef facies may occur in more than one interval in the lower part of the Niagaran Series (for the line of cross-section see Fig. 15).

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**Centralia Field Study Devonian And Ordovician Reservoirs**: **Jon Brenizer**

## Geological setting:

Regionally the Centralia field is located directly west of the DuQuoin Monocline, in and around Centralia, IL (see Figure 1). This places the field on the western edge of the deepest part of the basin. The field is located on the Centralia anticline, which has experienced significant growth between the Ordovician and Late Paleozoic time.

## History of development:

The Centralia Field was discovered in 1922, with the first producing well drilled into Pennsylvanian sands. The first well was drilled on the highest point on the anticline, in the southern end of the field. Deeper wells were drilled into a variety of Chesterian aged sandstones and the wells were eventually deepened into the Middle Devonian dolomitic sandstones. The first Devonian wells were deepening of shallower wells, and were first drilled on one of the highest areas of the Mississippian structures. The initial well was located off of the Trenton structure, and the initial production, while significant, was less than 10-20% of the initial production values at the northern end of the field. The field was a gas driven system, as indicated by both significant gas present in drill stem tests and personal accounts of gas flaring. Of the 330 completions of producing wells in the Devonian strata in Centralia, 324 of them were completed between December 1939 and August of 1940 (figure 2). These two factors served to shorten the length of production from the Devonian strata, causing the period of primary production to be less than 6 months in most cases, and less than 2 years in all cases. Production dropped an average of 85-90% from the first month to the second month, and a similar amount in the second month (figure 3). By the end of the first year, production is less than 1-5% of the initial production.

Trenton production was discovered in August 1940, but was largely ignored in the drive to drill Devonian wells. The discovery produced 100 barrels per day, but the decline was much more gradual than the Devonian wells and primary production lasted 7 years, and produced almost 100,000 barrels of oil. In the late 1940's many of the Devonian wells were deepened to the Trenton, and production ranged from 0-300 bpd. The northern end of the field was again the highest producing area, with values around 200-300 barrels per day. These wells were less productive overall, with primary production averaging 40-50,000 barrels over the life of the well. Several wells were notable however, in that they lasted up to 14 years in primary production and produced more than 100,000 barrels. The wells responded well to water flooding, and production was increased from several hundred barrels per year to several thousand per year for periods ranging from 2 years to 6 years (figure 4). Several of the wells that were drilled to the Trenton were perforated in the Devonian and Mississippian strata, which also served to increase the life and productiveness of the wells.

**Stratigraphy:**

A typical electric log is shown in Figure 5. This well was chosen for it's location near the crest of the Trenton anticline and the availability of continuous core in the Trenton, and good samples from the remainder. The Chouteau limestone is the last unit that is completely Mississippian in this area, as the lower most members of the New Albany Shale are thought to be Devonian in age. The New Albany Shale is the source rock for all of the oil in the Devonian and higher strata. The New Albany Shale unconformably overlies the Lingle Limestone, which is the upper most formation in the Hunton Megagroup. The Devonian reservoir unit is found at the base of the Grand Tower formation, which is marked by the sharp drop in SP and the reservoir unit is bounded by two inflections in the short normal resistivity. There is possibly a small section of Cayugan aged strata at the top of the Silurian section, but this analysis is based on logs alone, as there are no reliable samples from this section. The Niagaran aged section thickens up to 30 feet to the south of the Trenton structure, causing the structure to be extended stratigraphically throughout the deposition of the Hunton Megagroup. The Maquoketa shale also shows slight thickening, off of the Trenton structure, but the overall regional basinward thickening is much more significant, indicating that the thickening may be due to differential compaction rather than any depositional cause. The Trenton limestone is made up primarily of fossiliferous grainstone. There several porous zones that have been separated by mostly impermeable strata that were completely cemented. These porous zones also provided conduits for later hydrothermal alteration, which further increased the permeability within the original open zones.

**Structural changes on the Centralia Anticline:**

The structure of the Centralia Anticline is shown in detail in Figures 6 through 12. These seven figures are based on a similar data set, although there are significantly more completions in the Devonian than in the Trenton. Even with the lower data density, the Trenton structure is still well defined, but any structural features in the southern end of the field are poorly defined (Figure 13). Formations above the Middle Devonian have significantly better well control throughout the field and surrounding area (Figure 14).

The structure has evolved from a small dome-like structure during the Middle and late Ordovician time to a more elongated anticline in the Mississippian time. On the structural maps that have been modeled, it is difficult to see the thickening in individual formations due to poor sampling in the data. However, mapping thicker units such as the Hunton Megagroup shows the thickening quite clearly (Figure 15). The thickness of the upper Devonian through the Valmyrean series also has distinct thinning, although the relationship to the Devonian structure is less clear than the thickening in the Hunton Megagroup (figures 16 and 17). Two projected cross sections have been drawn, as shown in Figure 18. Thinning in individual formations is visible in the axial cross-section (Figure 19 and 20). The St. Clair formation is fairly uniform throughout the section, but the Moccasin Springs formation clearly thins across the top of the Trenton structure and extends the structure to the south (Figures 19 and 20). The Lower Devonian strata show a similar pattern, extending the structure further to the south than in the Silurian time (Figure 20). The cross axial cross sections show slight widening of the anticline, but the change is less than 5% (Figures 21 & 22). The differential deposition continues on into the Lower Mississippian sequence, being evident in the section from the base of the New Albany to the top of the St. Genevieve formation (Figure 21 and 22). This has the effect of elongating the structure increasing the size of the closure from 2250 acres, to 3500 acres in the Devonian, to 4000 acres in the Mississippian. The main extension has occurred southward (over 2 miles additional length), with the northern end of the field remaining relatively unchanged from the Ordovician to the Mississippian time. The overall closure on the structure has decreased from 90 feet to 50 feet and the structure has broadened from 2 to 2.25 miles.

There has also been a lateral shift in the fold axis due to the inclined axial plane. The shift is clearly visible in figures 23, 24, and 25, which are separated by comparable amounts of section (roughly 1200 feet between each interval). The high points on the structure also show a distinct linear relationship, although it is difficult to determine if this pattern holds for all layers. It is also possible that this pattern is simply coincidence at this location, and not diagnostic for other Trenton structures, although if it were diagnostic, this would prove a valuable assessment tool.

**Reservoir Characterization:**

The Trenton pay zone is a small anticline that formed over a deeper seated fault. The total thickness of the Trenton is undetermined, but three main oil saturated zones are present in the upper 50 feet (Figure 23). The sections have been described in more detail by Crews (1985), but are generally fossiliferous grainstones (Figure 26), with secondary enhancement in layers that had an initial porosity greater than 5% (Figure 27). Impermeable layers have original porosities of 0-2%, with no solution enhancement of the porosity (Figure 28). The permeable layers are easily distinguishable in on geophysical logs, appearing as areas of slightly lower resistance than the surrounding units.

The Devonian pay was originally deposited as an interbedded sand and limestone ranging between 6-12 feet. The sandstone beds range from several inches thick to several feet thick, although there is often a significant amount of limestone present within the sandstone layers. The dolomite formed later at as a hydrothermal product, replacing 99-100% limestone present. The field is located near the Geneva Dolomite and the Dutch Creek Sandstone lateral contact.

The porosity observed in Devonian samples is up to 20% (Figures 29 and 30), in both the sandstone and the dolomite. The highest areas of the pay are almost water free, with higher water cuts down dip from the crest. The pay is elongated from the pay in the Trenton due to thickening of the Silurian section, but is most productive above the Trenton structure. Figures 31 and 32 both show a map of the Devonian initial production, and it is clear that while overall production mimics the Devonian structure, the highest production does not occur over the peak of the Devonian structure. The Trenton structure corresponds well with the highest values, indicating that there is some relationship between the paleostructure and production from higher units.

**Conclusions:**

The Centralia field is an excellent example of the potential of the Lower Paleozoic strata for oil production. The change in the structure from the Trenton to the Mississippian strata indicates one of the risks of drilling based on shallower structures. However, by mapping unit thicknesses and fold axis positions, it is possible to constrain the position of paleostructures. Further exploration into Devonian aged dolomites and sands along the DuQuoin Monocline could also be worthwhile due to the high porosities within these units.

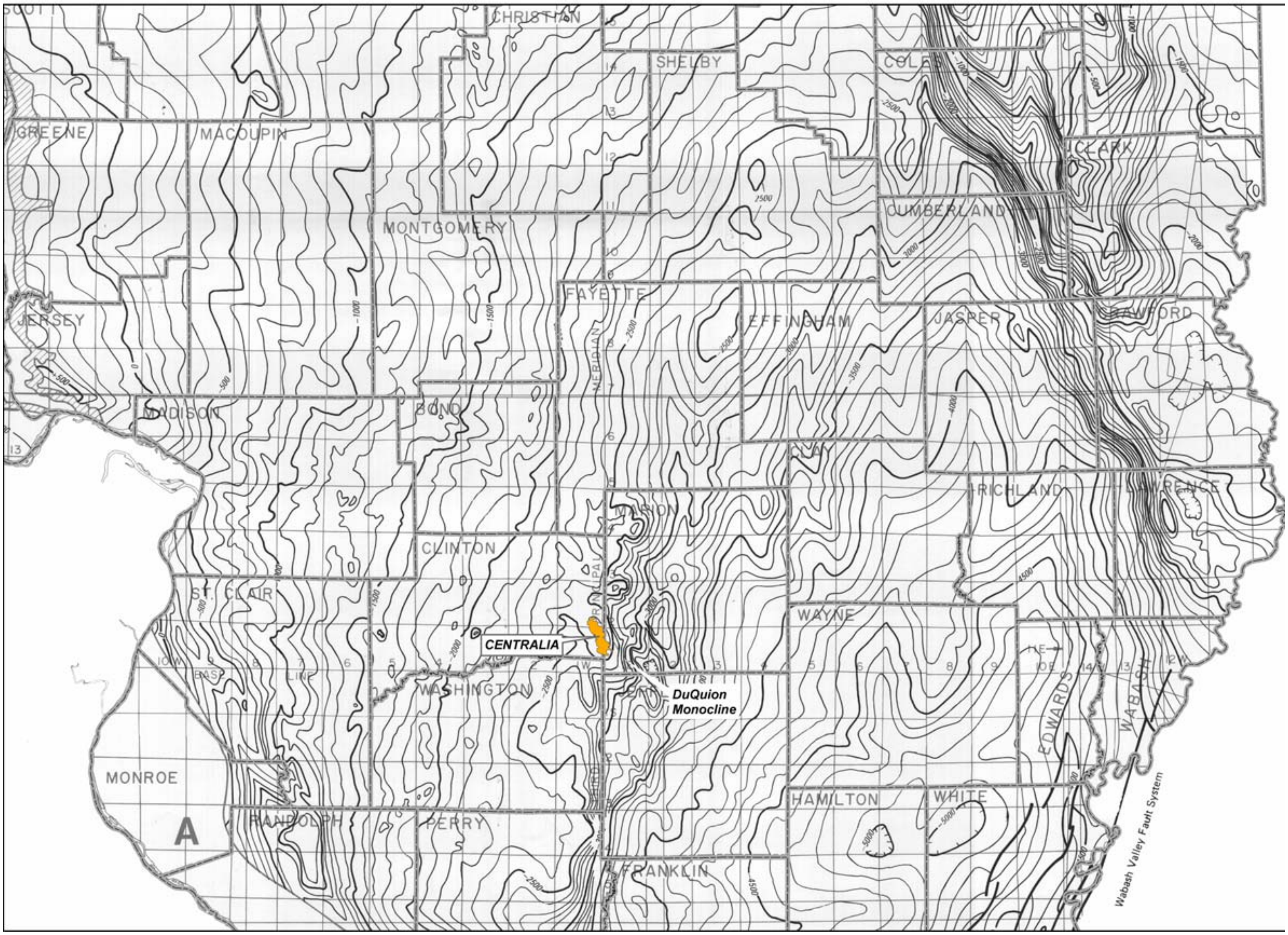


**Figure 1. Structure contour map of the base of the New Albany Shale Group. Contour interval is 100 feet.**

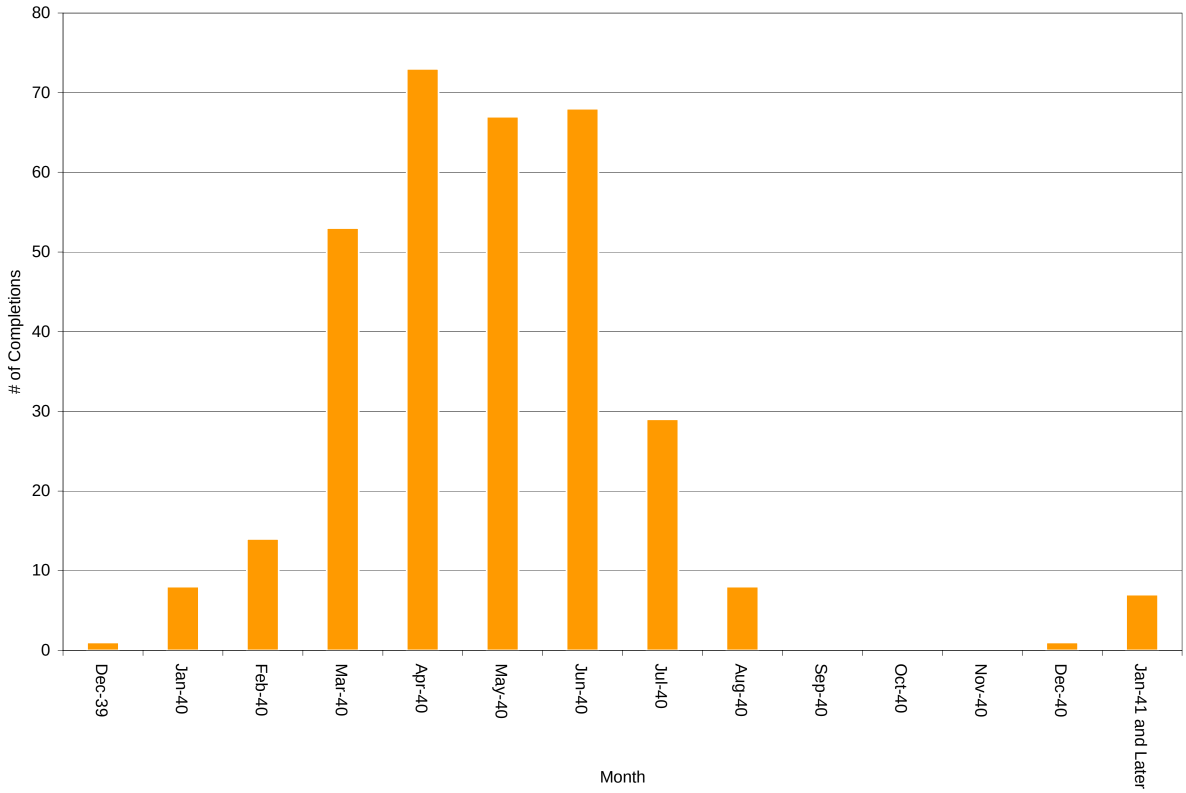


Figure 2. Chart showing the time of well completion within Devonian strata.

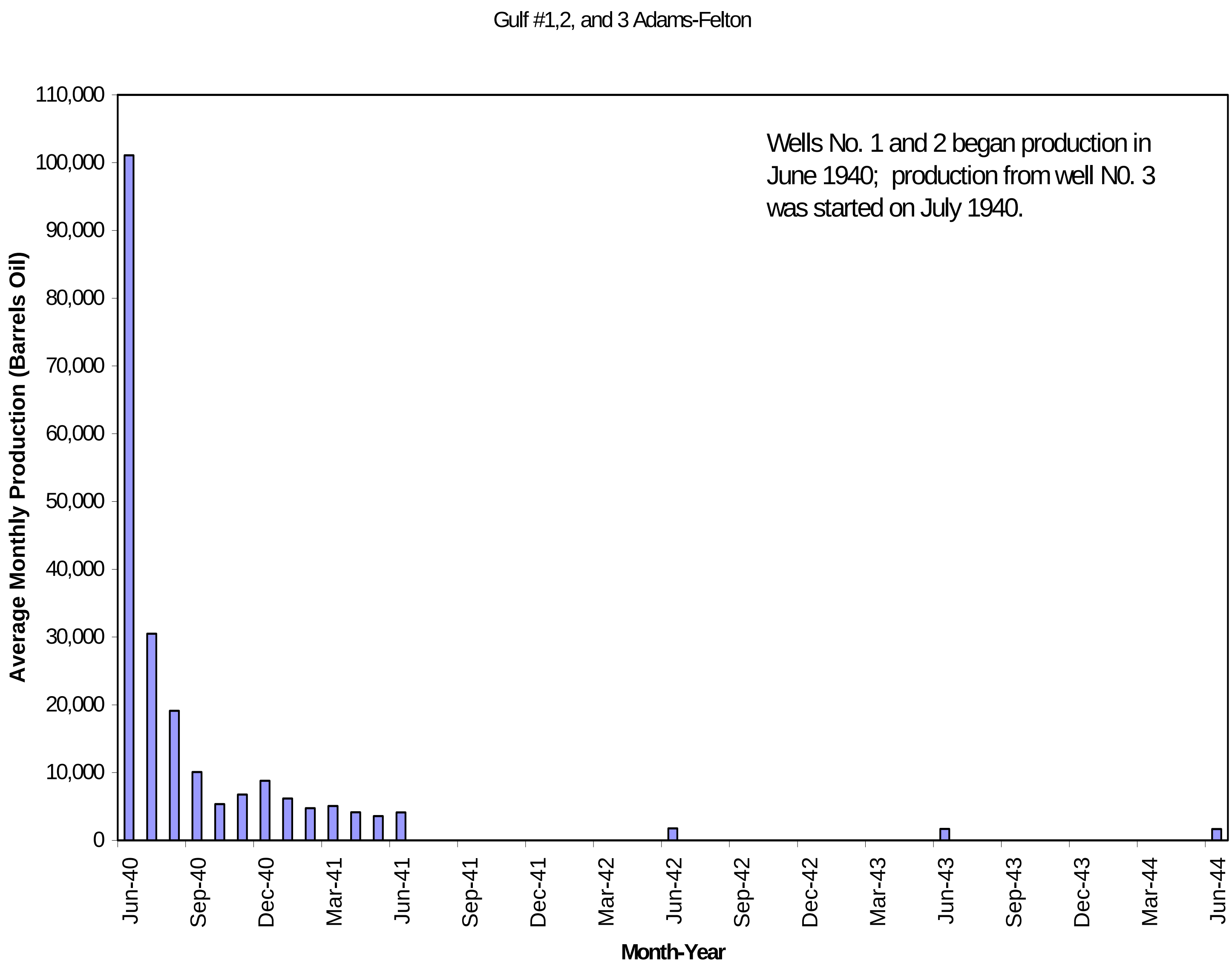


**Figure 3. Chart showing a typical decline curve of Devonian wells. During the second month, even with the addition of a second well, production is less than 30% of the previous month, note that after the first year, monthly production is about 1% of the first month production.**

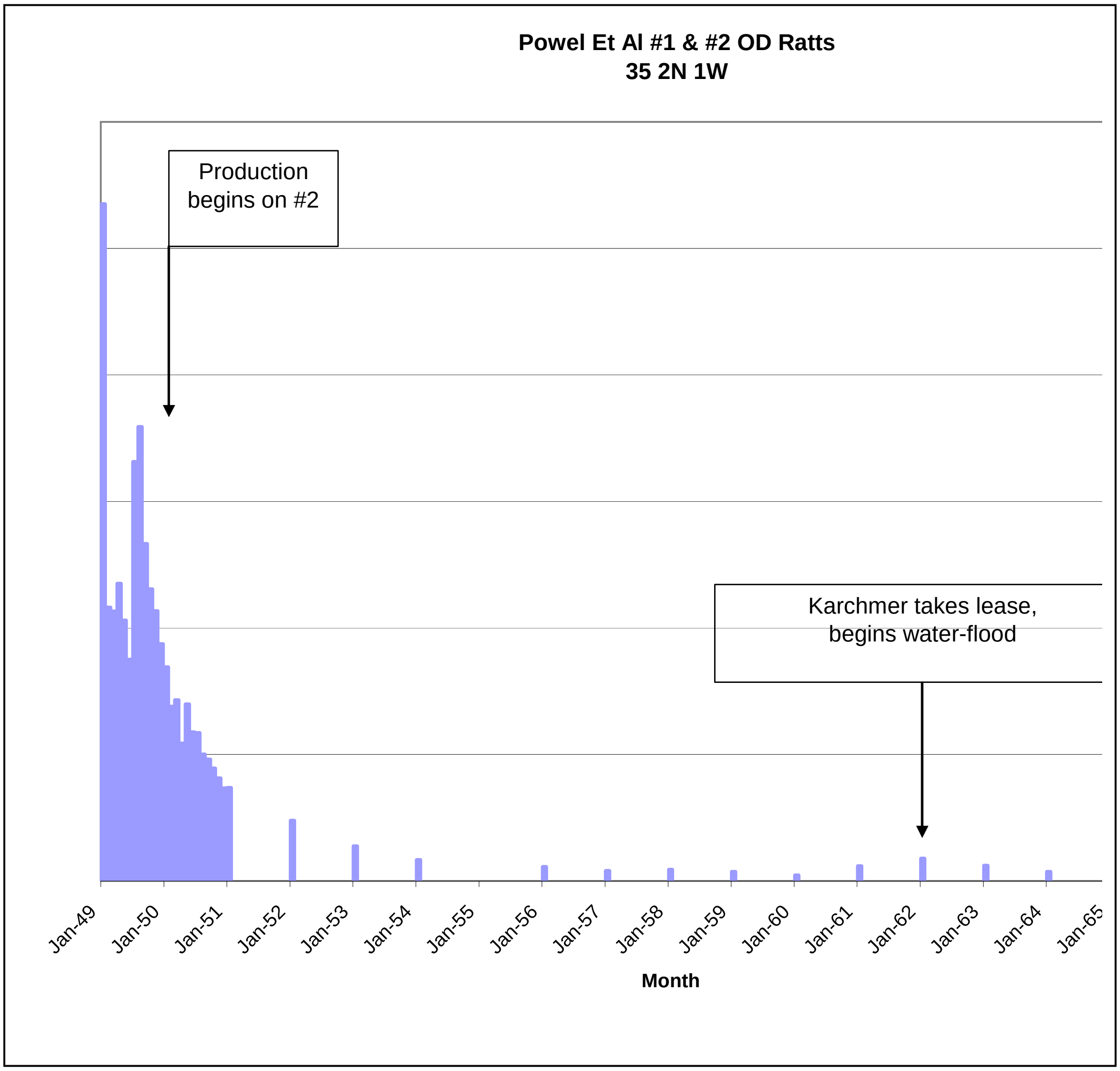


**Figure 4. Chart showing a typical decline curve of a Trenton well in Centralia. Cumulative production for this lease was 74,000 barrels before a shallower zone was opened for production in 1968.**

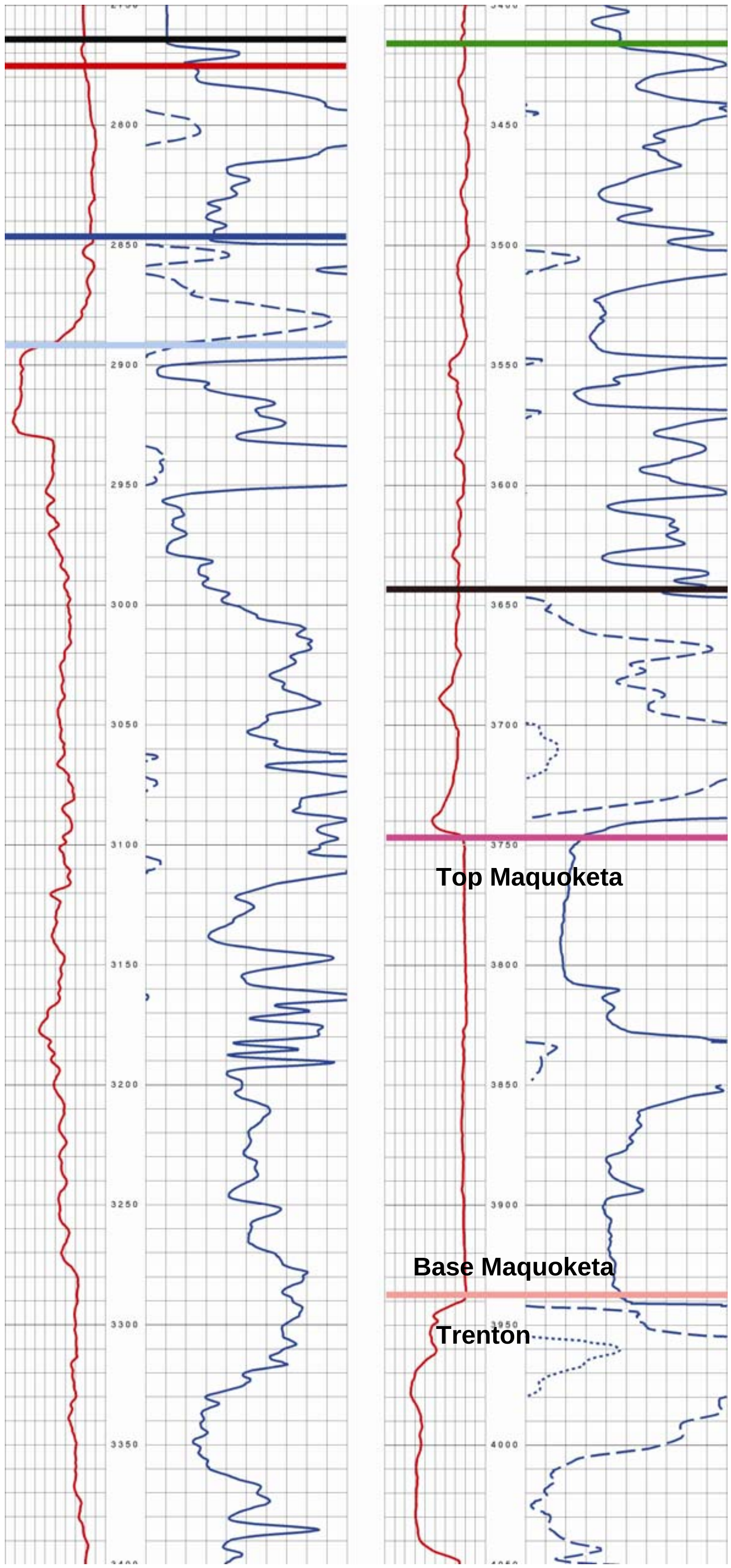


**Figure 5. Electric log from the Shell #37-T Criley well. Log has been cut just below the top of the Silurian Section, and continued in the second column.**

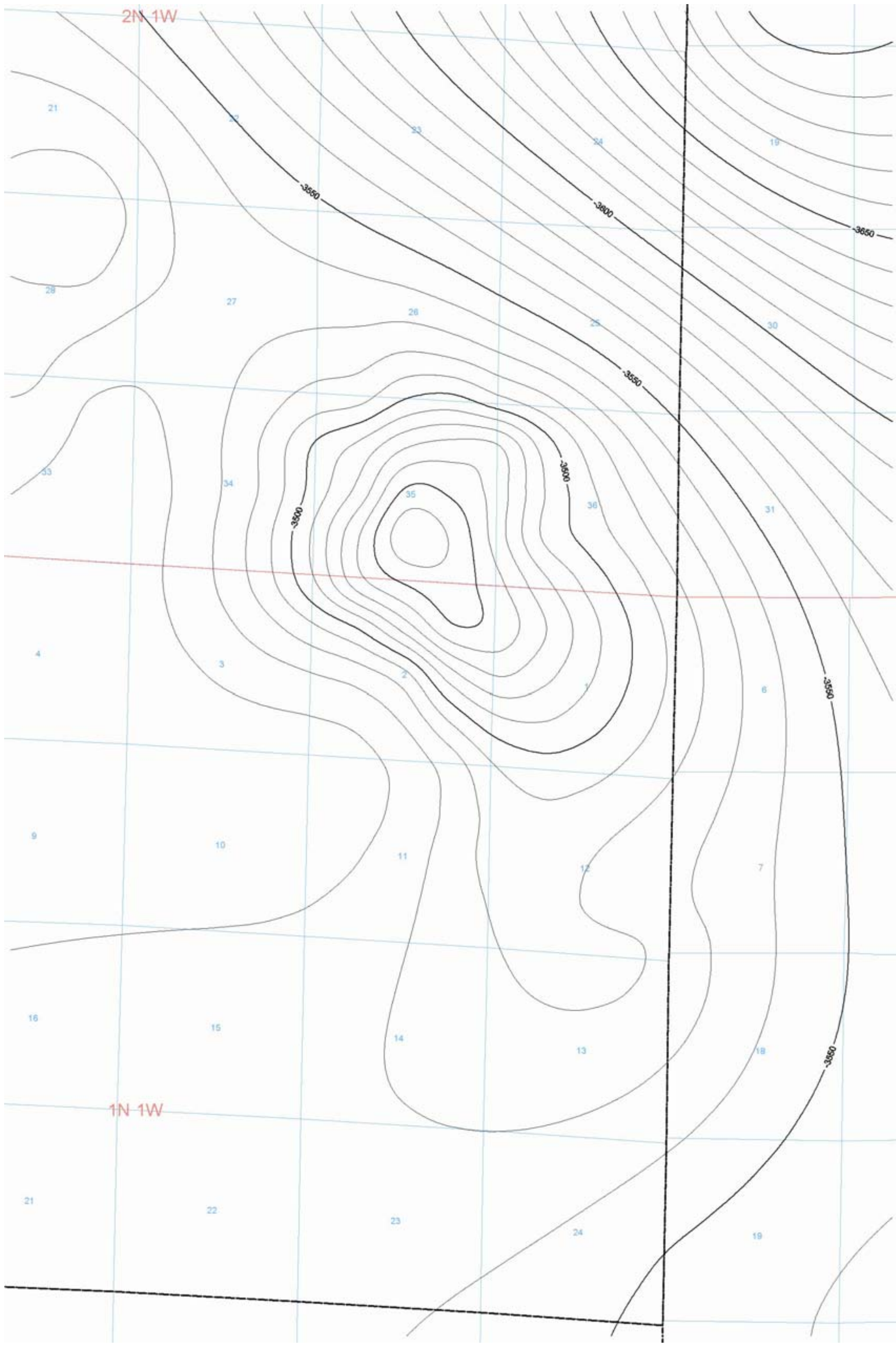


Figure 6. Structure on the top of the Trenton limestone. Contour interval is 20 feet.

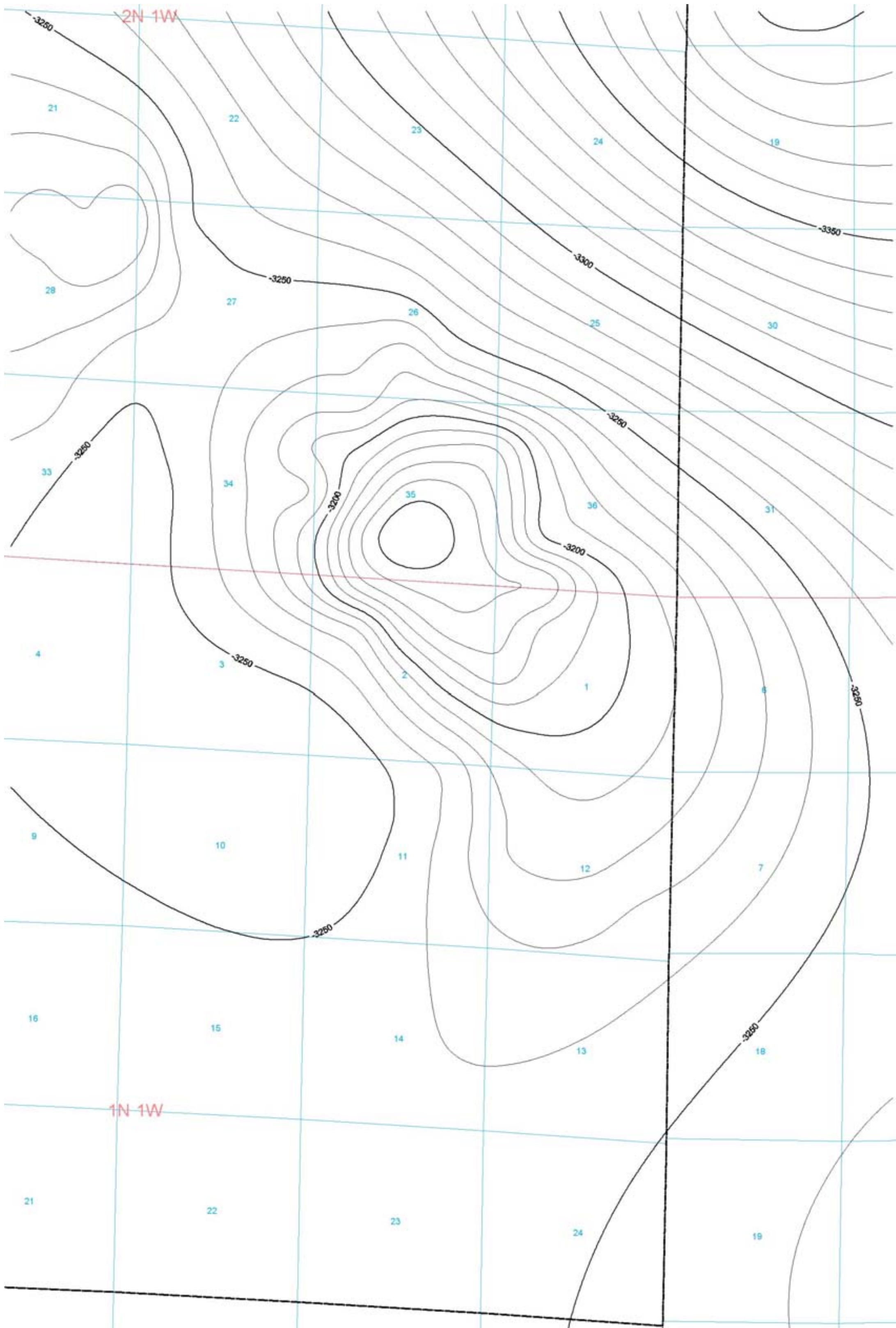


**Figure 7. Structure on the top of the St. Clair formation. Contour interval is 20 feet.**

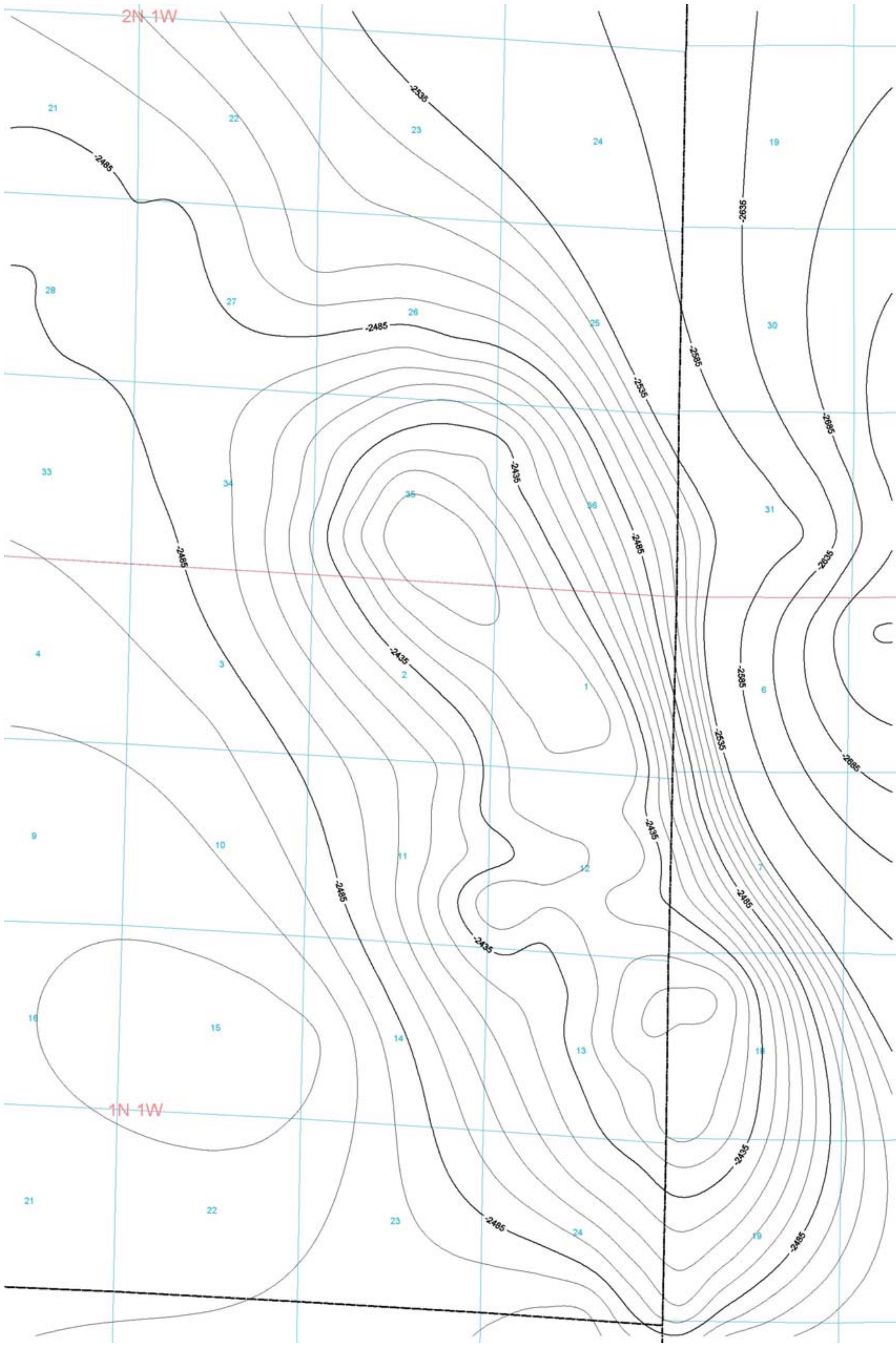

**Figure 8. Structure on the top of the Geneva Dolomite. Contour interval is 10 feet.**

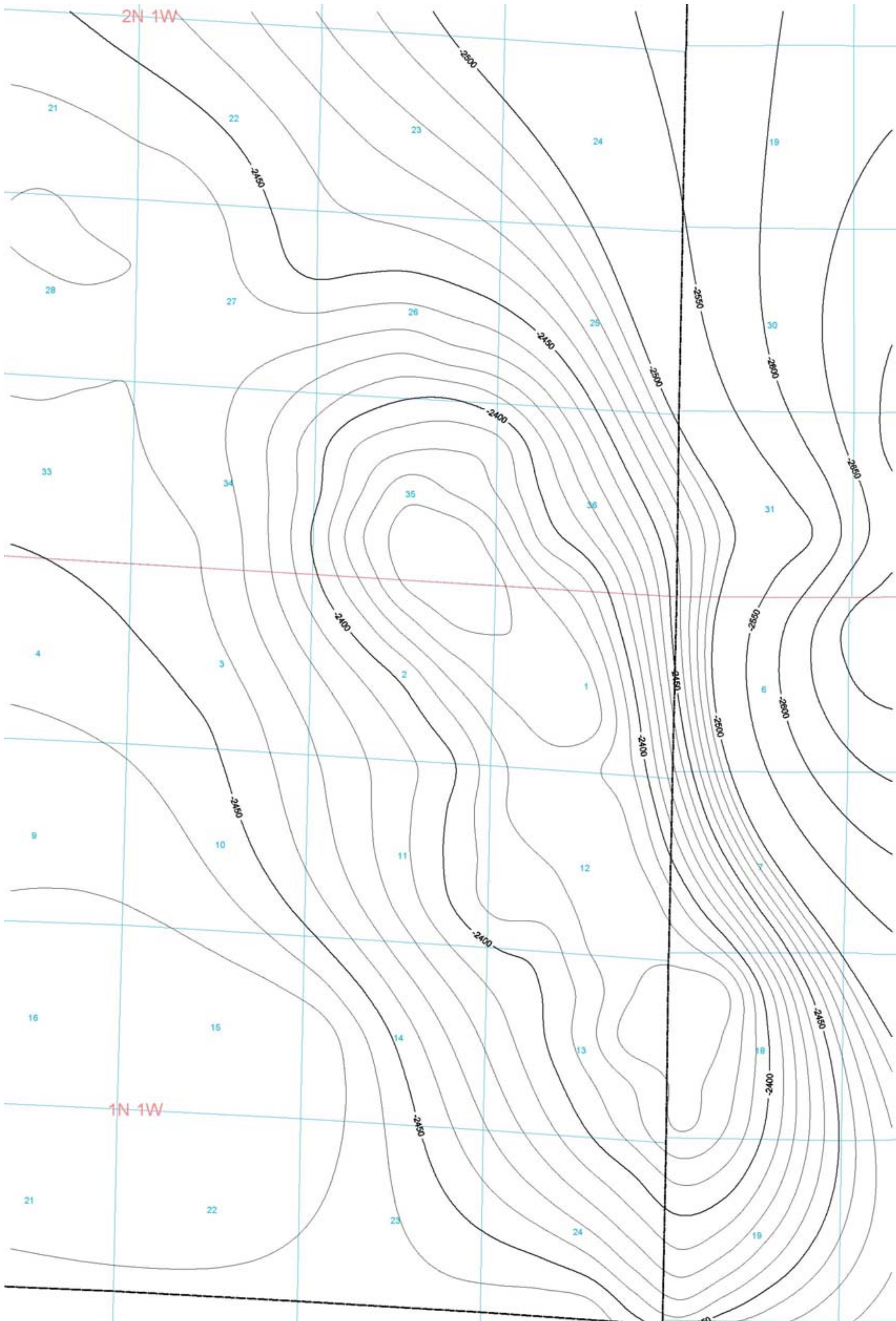


**Figure 9. Structure on the top of the Lingle Limestone. Contour interval is 10 feet**

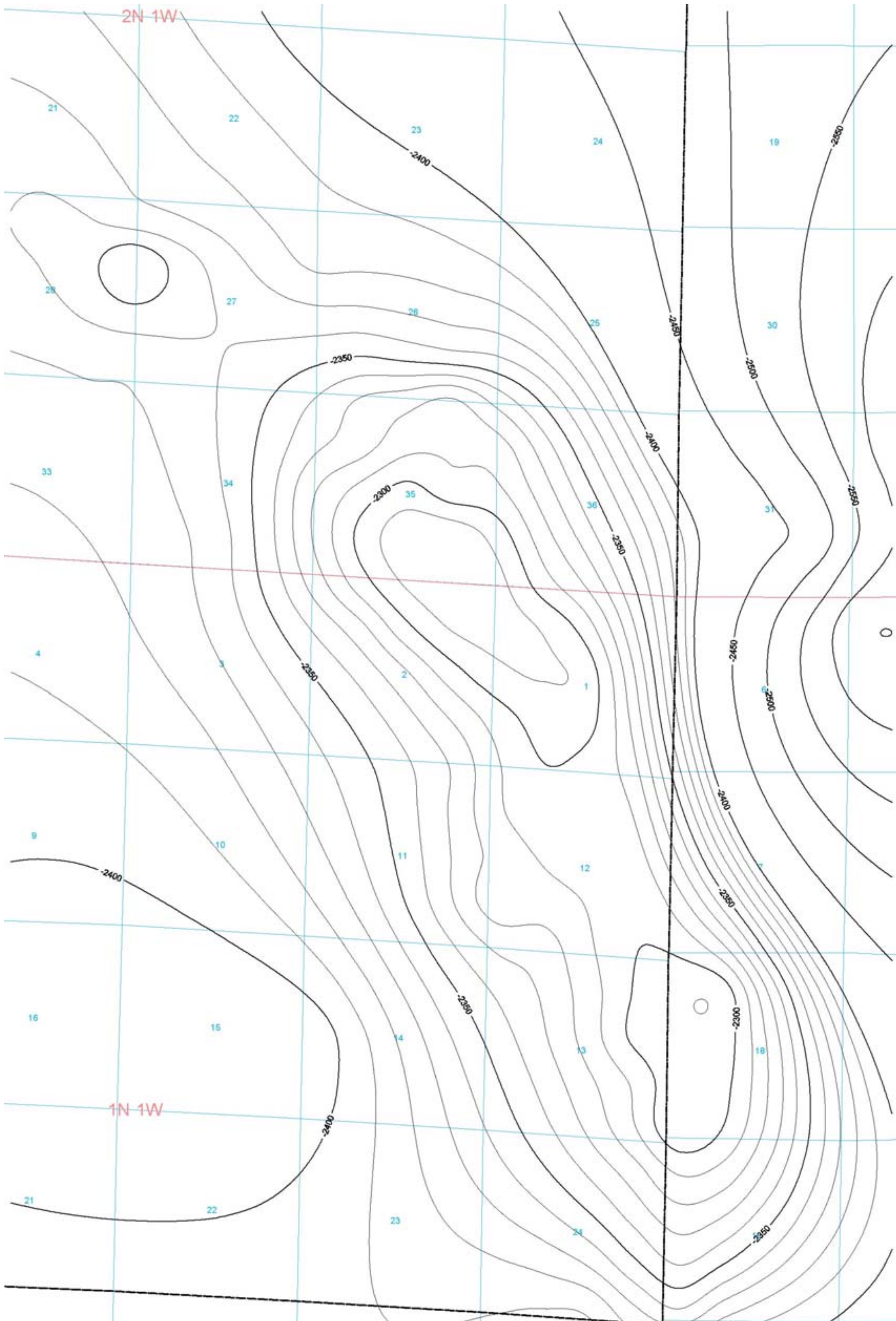


**Figure 10. Structure on the top of the New Albany Shale. Contour interval is 10 feet.**

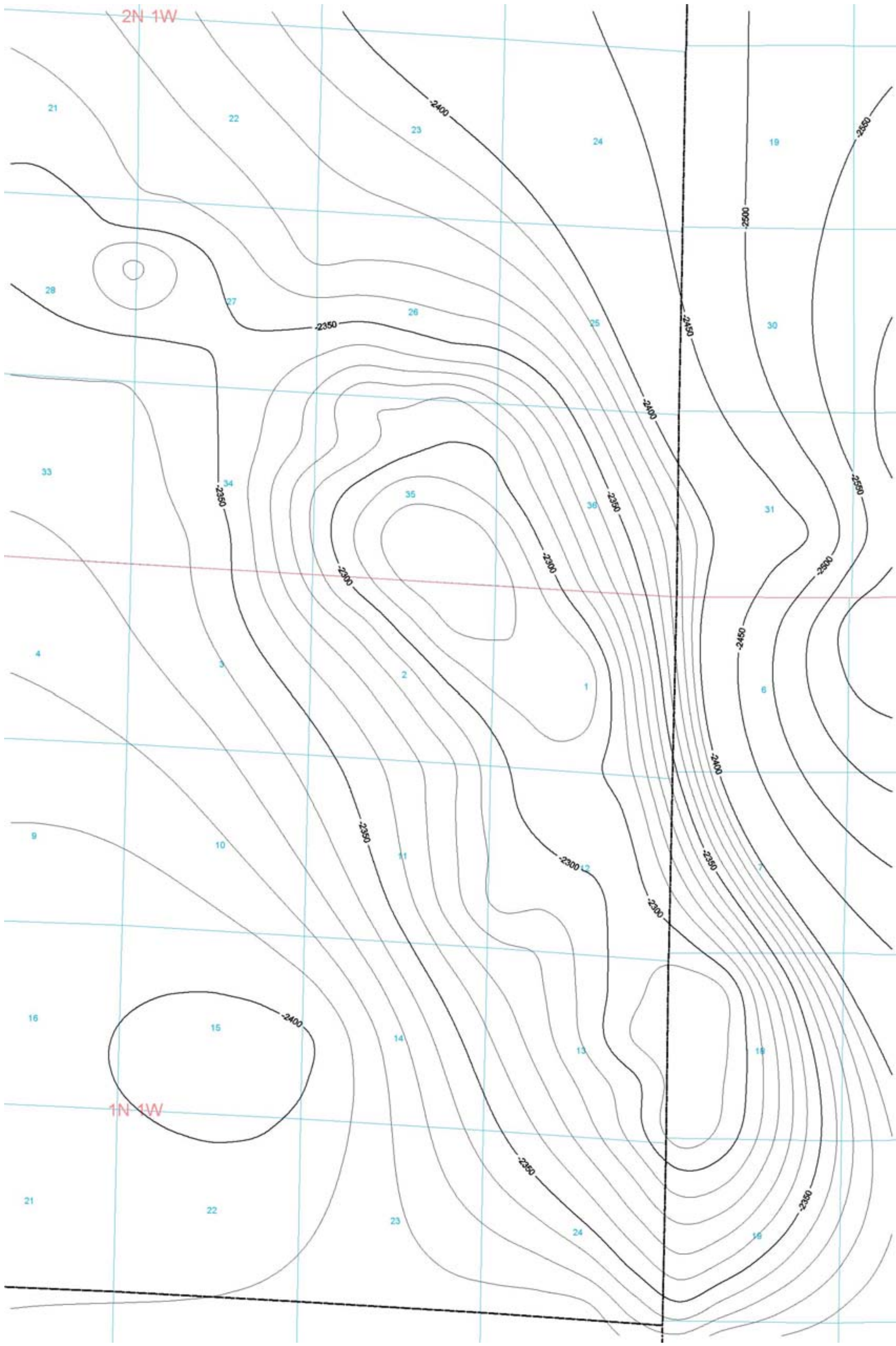

Figure 11. Structure on the top of the Chouteau limestone. Contour interval is 10 feet.

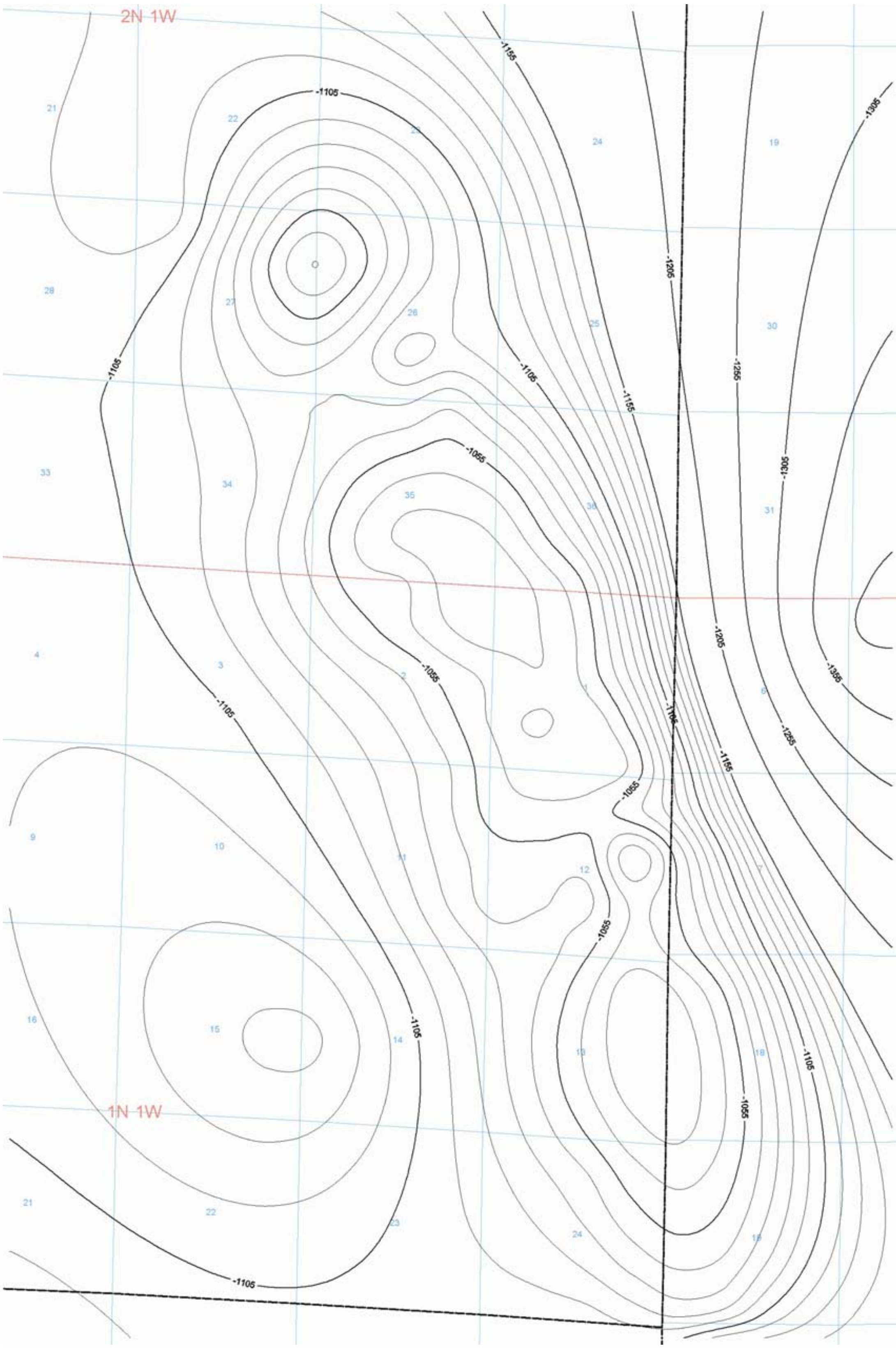


**Figure 12. Structure on the top of the St. Genevieve formation. Contour interval is 10 feet.**

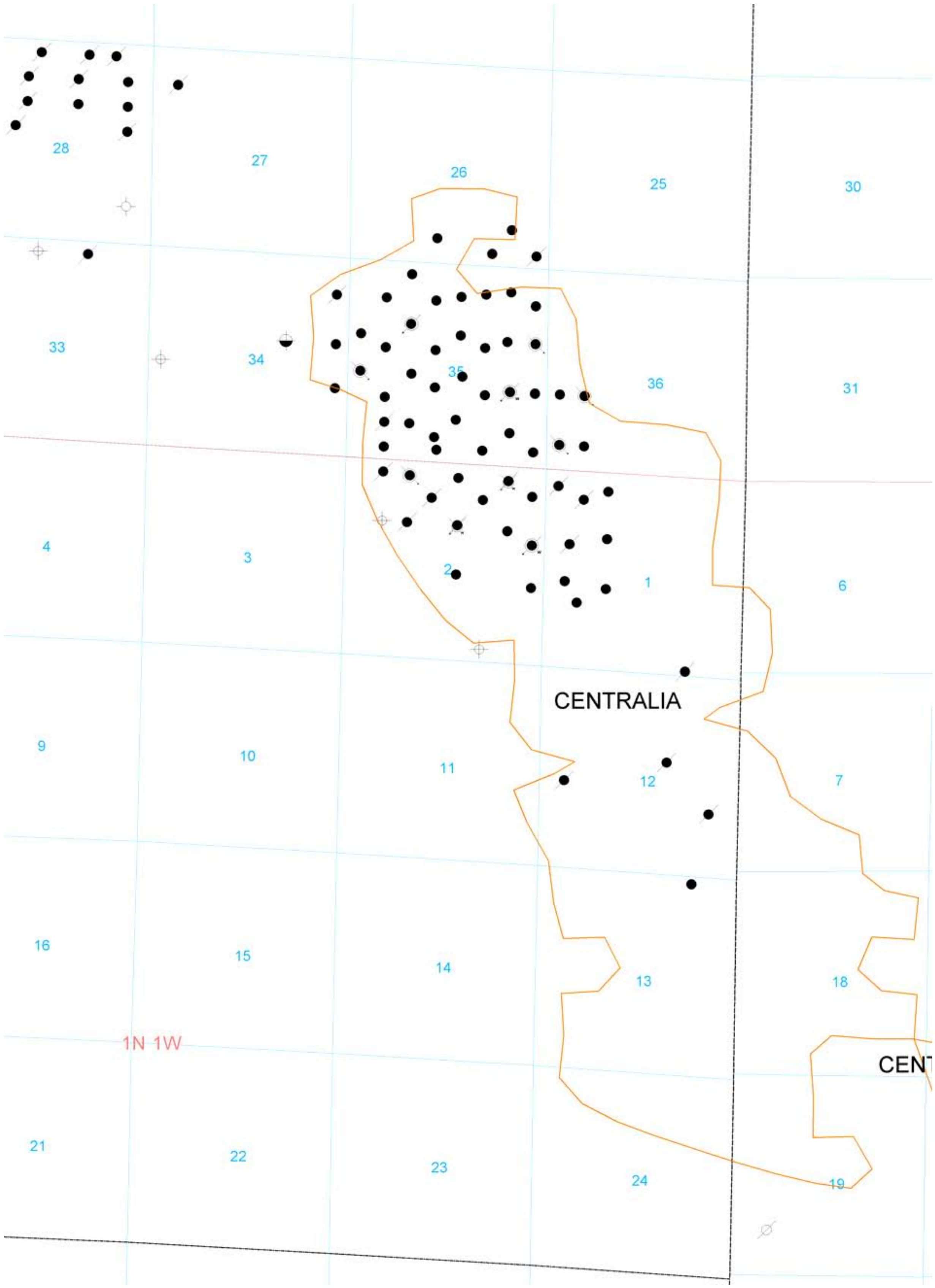


**Figure 13. Map showing wells that have penetrated the Trenton Limestone.**

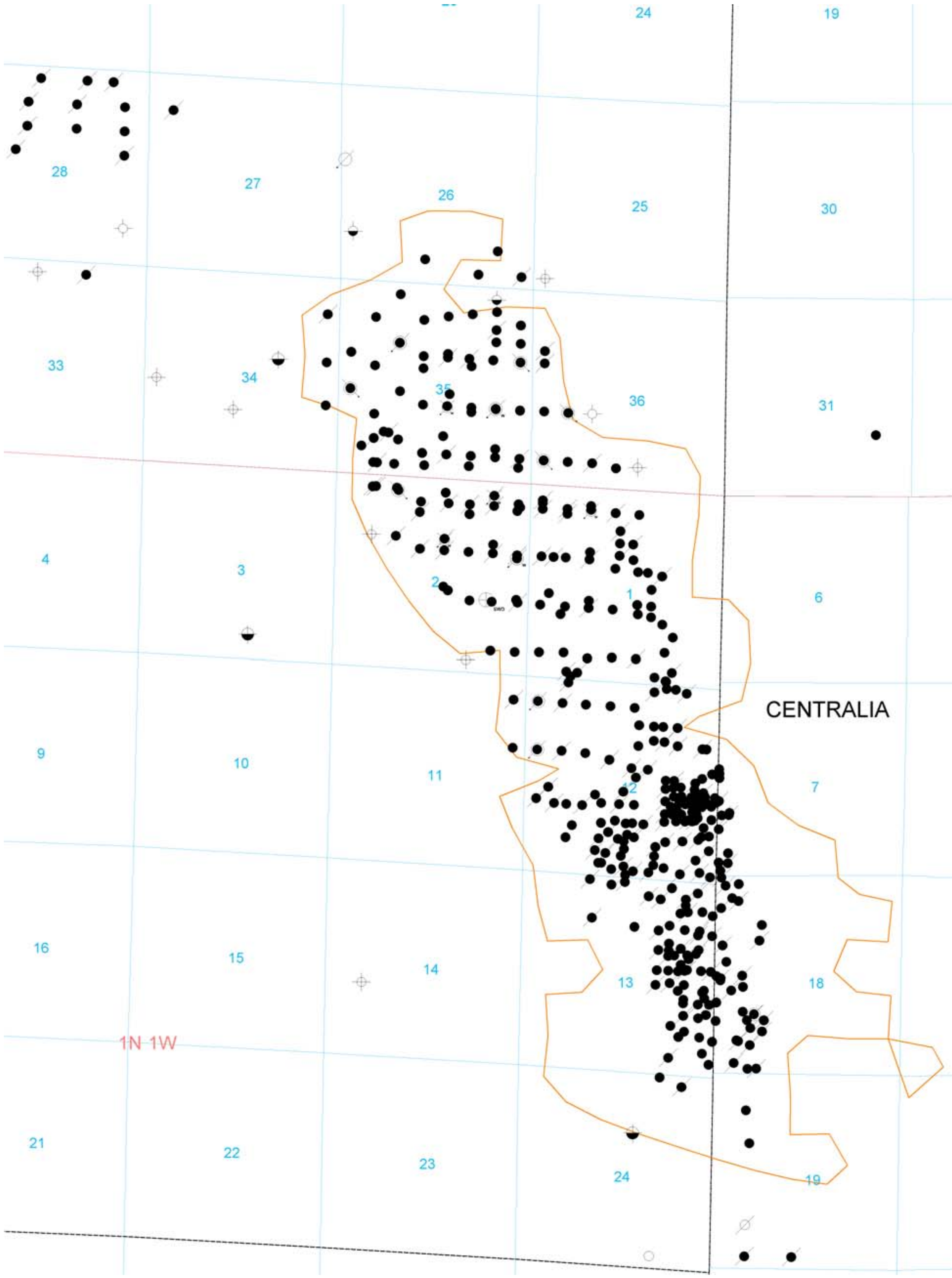


**Figure 14. Map of wells penetrating the top of the Middle Devonian Limestones.**

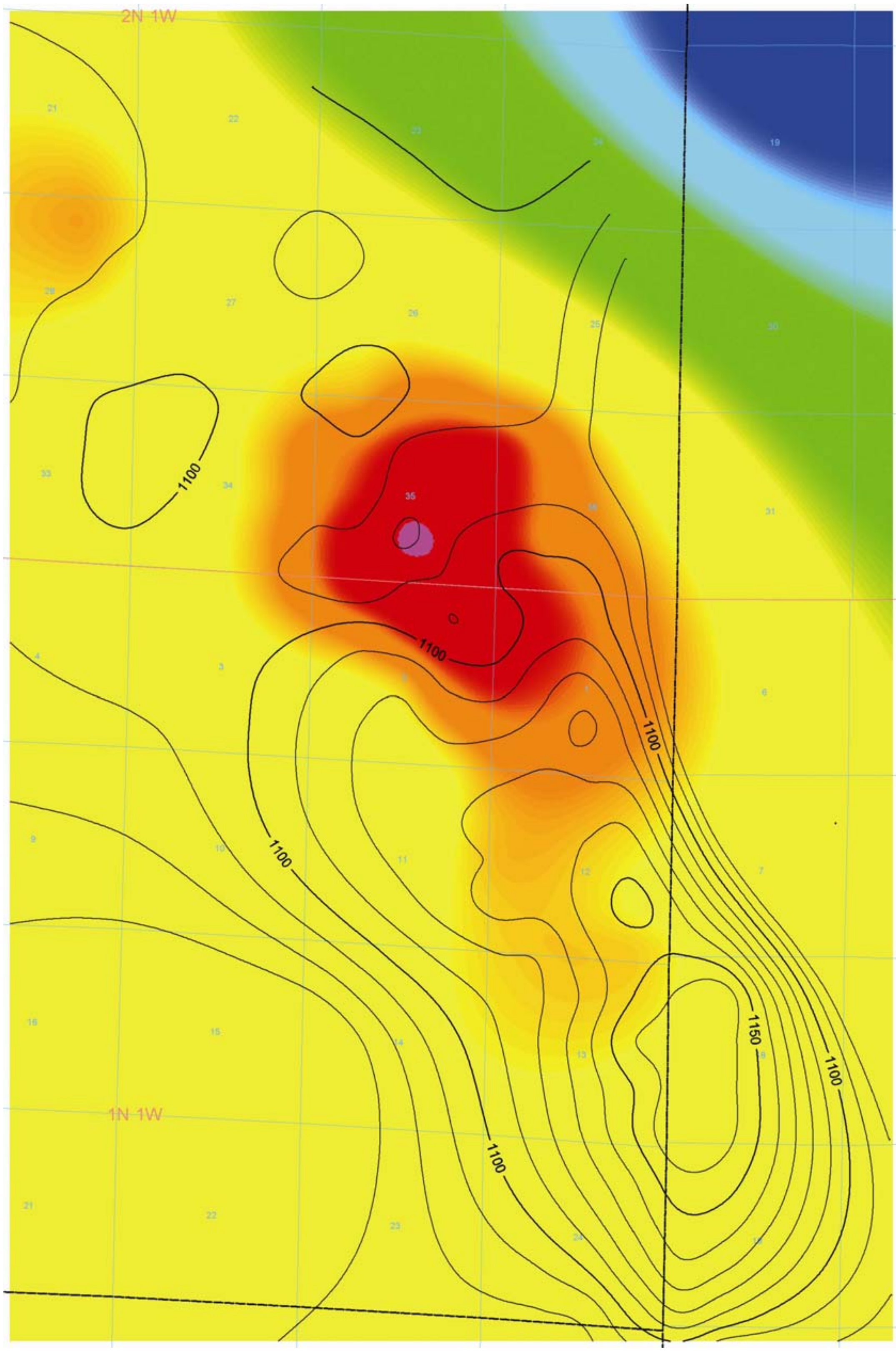


**Figure 15. Isopach map of the Hunton Megagroup. Contour interval is 10 feet. Color background is the structure of the Trenton. The blue hues represent the lowest areas and the pink the highest.**

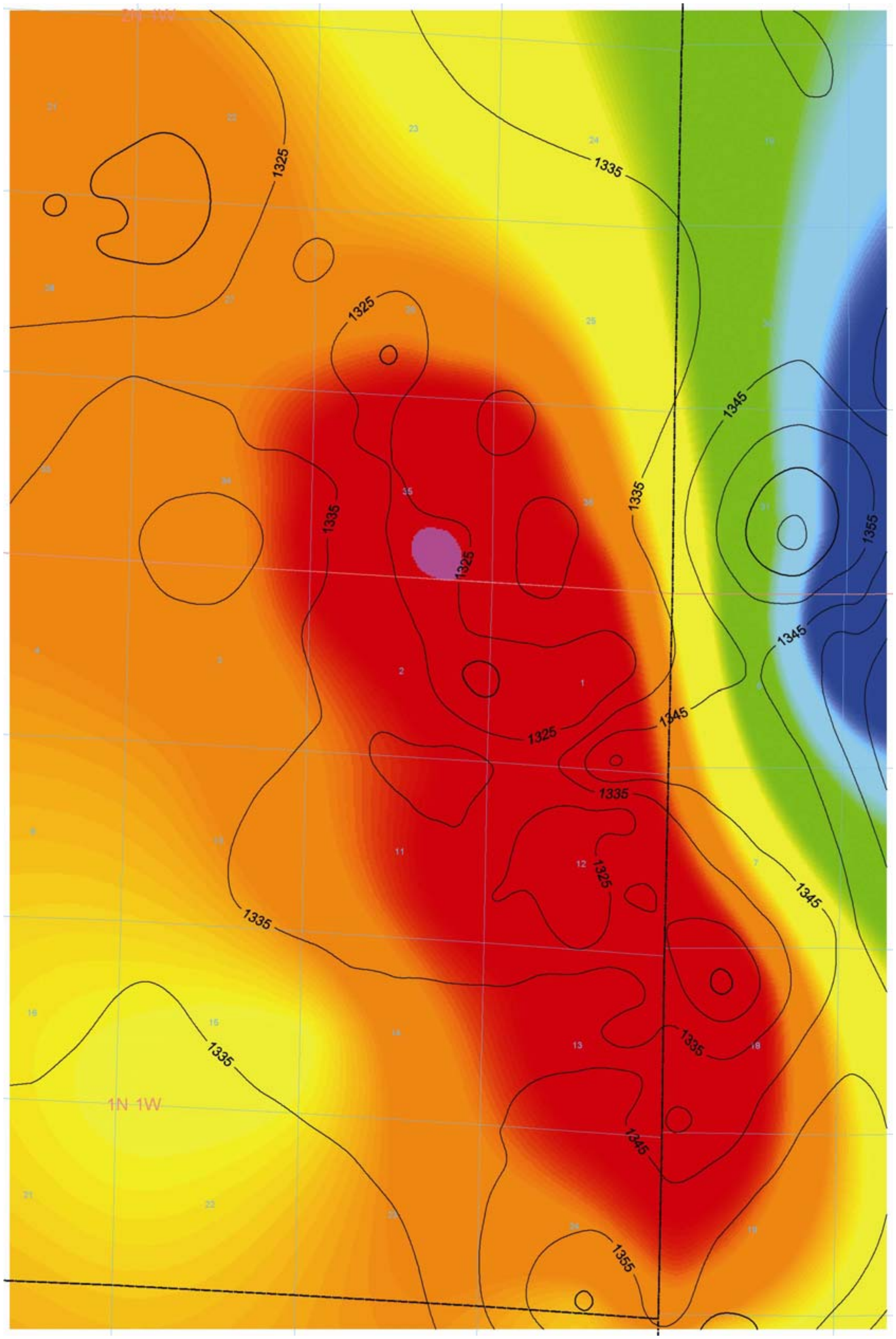


**Figure 16. Map of the Valmeyeran thickness overlain on the color coded map of the base of the New Albany Shale. Color codes are the same as in Figure 4.**

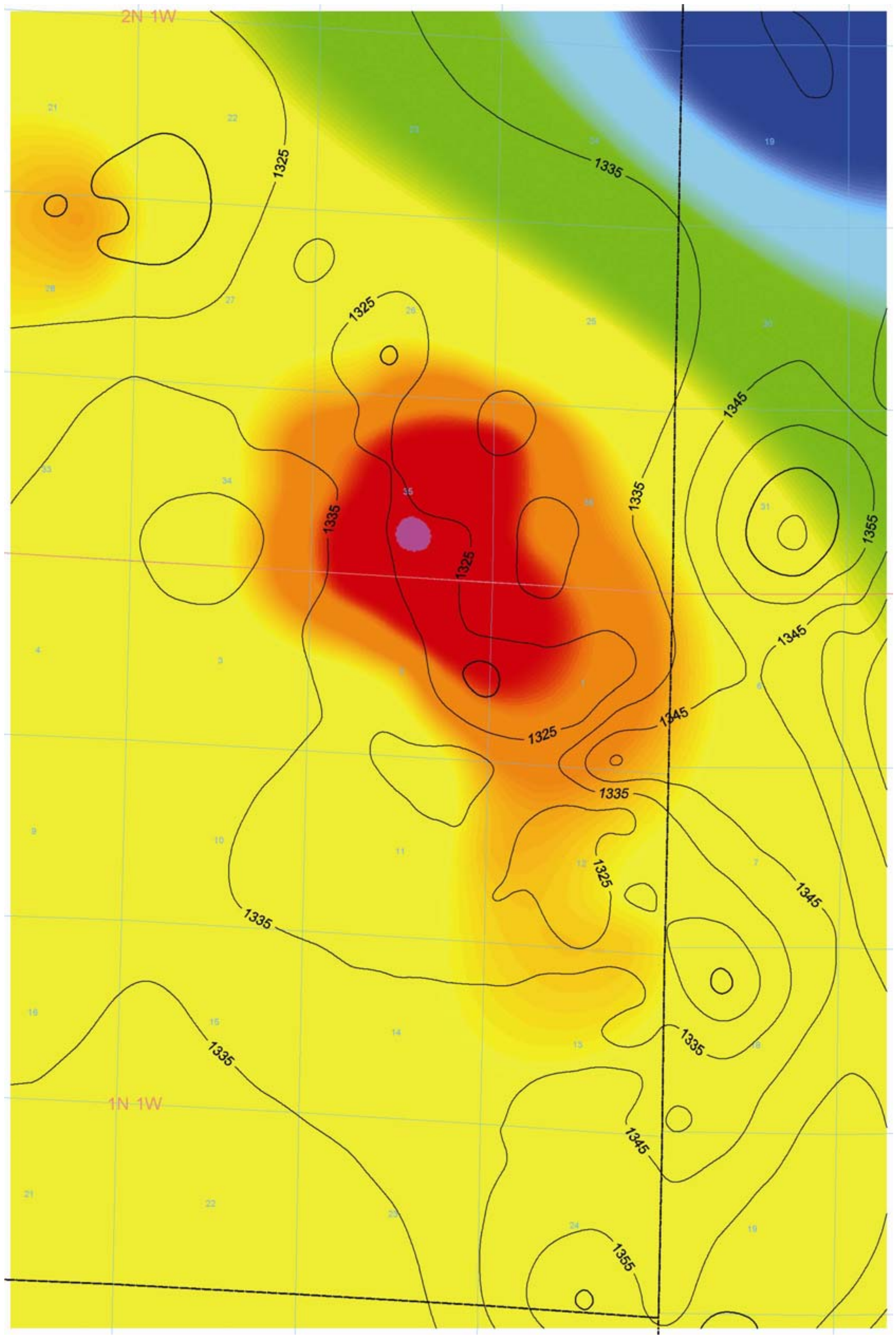

**Figure 17. Map of the Valmeyeran thickness overlain on the color coded map of the top of the Trenton Limestone. Color codes are the same as in Figure 4.**

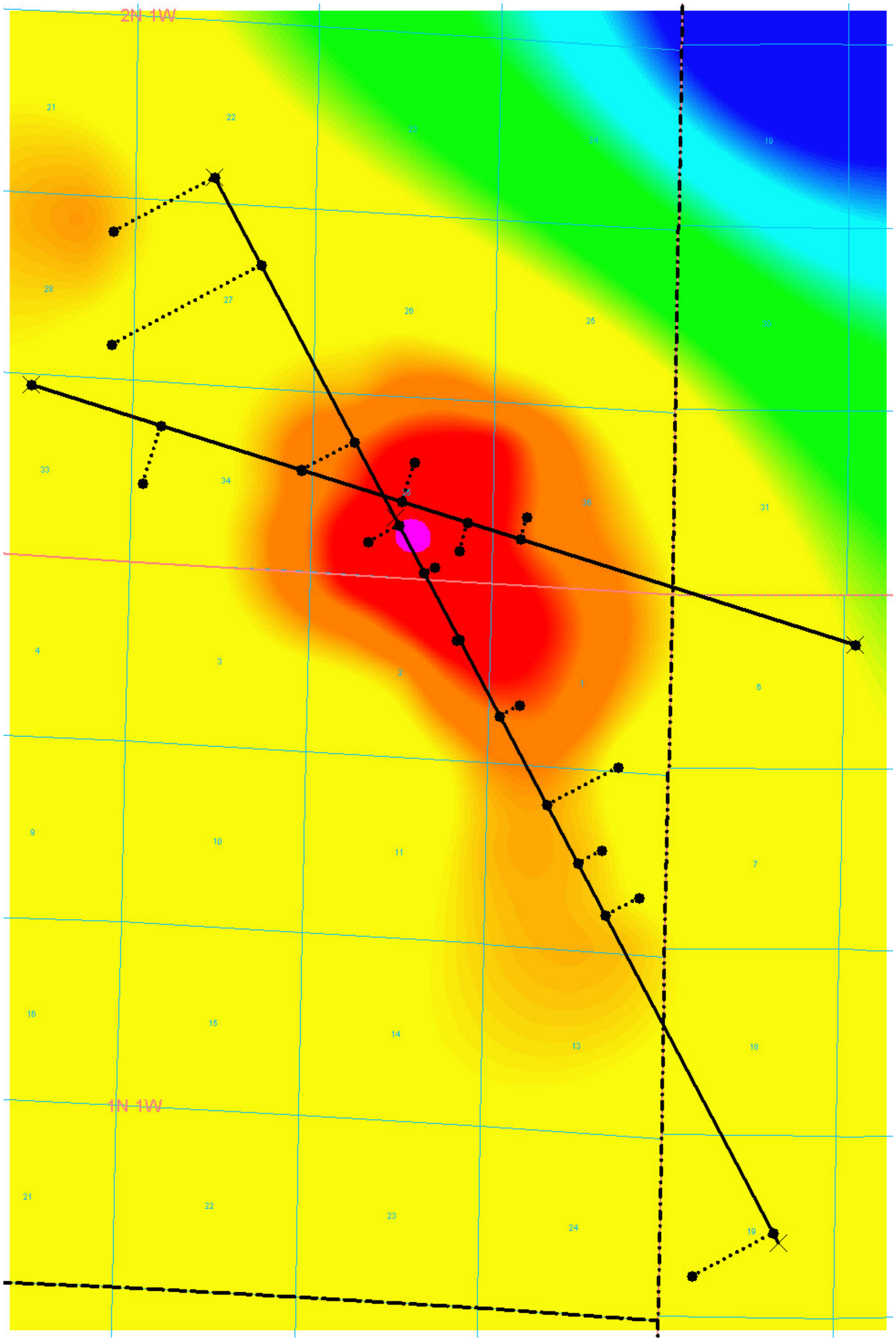


**Figure 18. Map showing the two cross sections. All cross sections are projected onto the solid line and individual wells are show in actual positions, and projected placement on the line.**

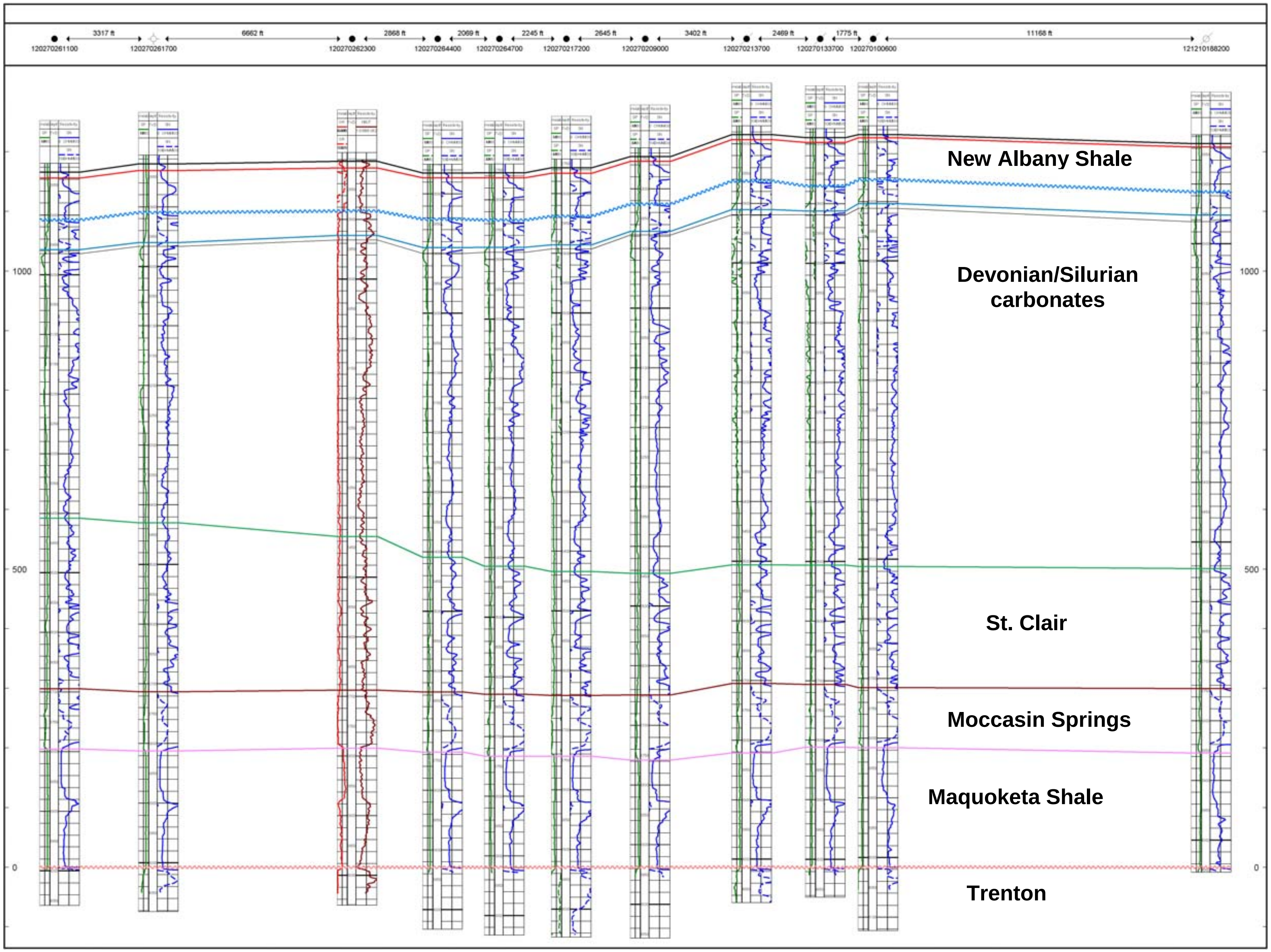


**Figure 19. Stratigraphic cross section based on the top of the Trenton. Note thinning over the top of the Trenton structure, and the slight thickening visible in the St. Clair and Moccasin Springs formation to the south of the structure. Vertical exaggeration is 20X.**

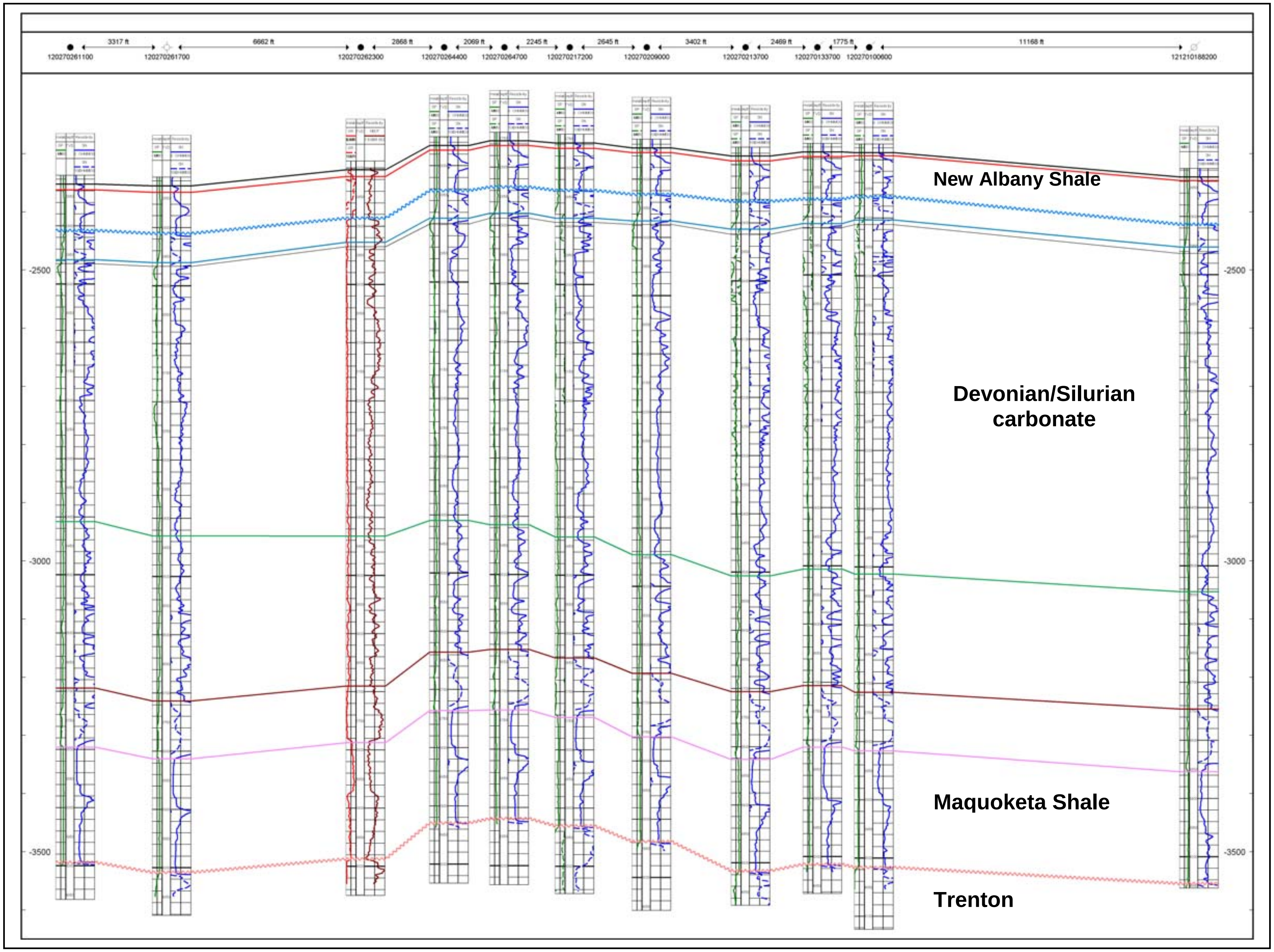


**Figure 20. Structural cross section parallel to the fold axis. Note elongation of Devonian structure compared to the Trenton structure. See figure 12 for map view of cross section. Vertical exaggeration is 20X.**

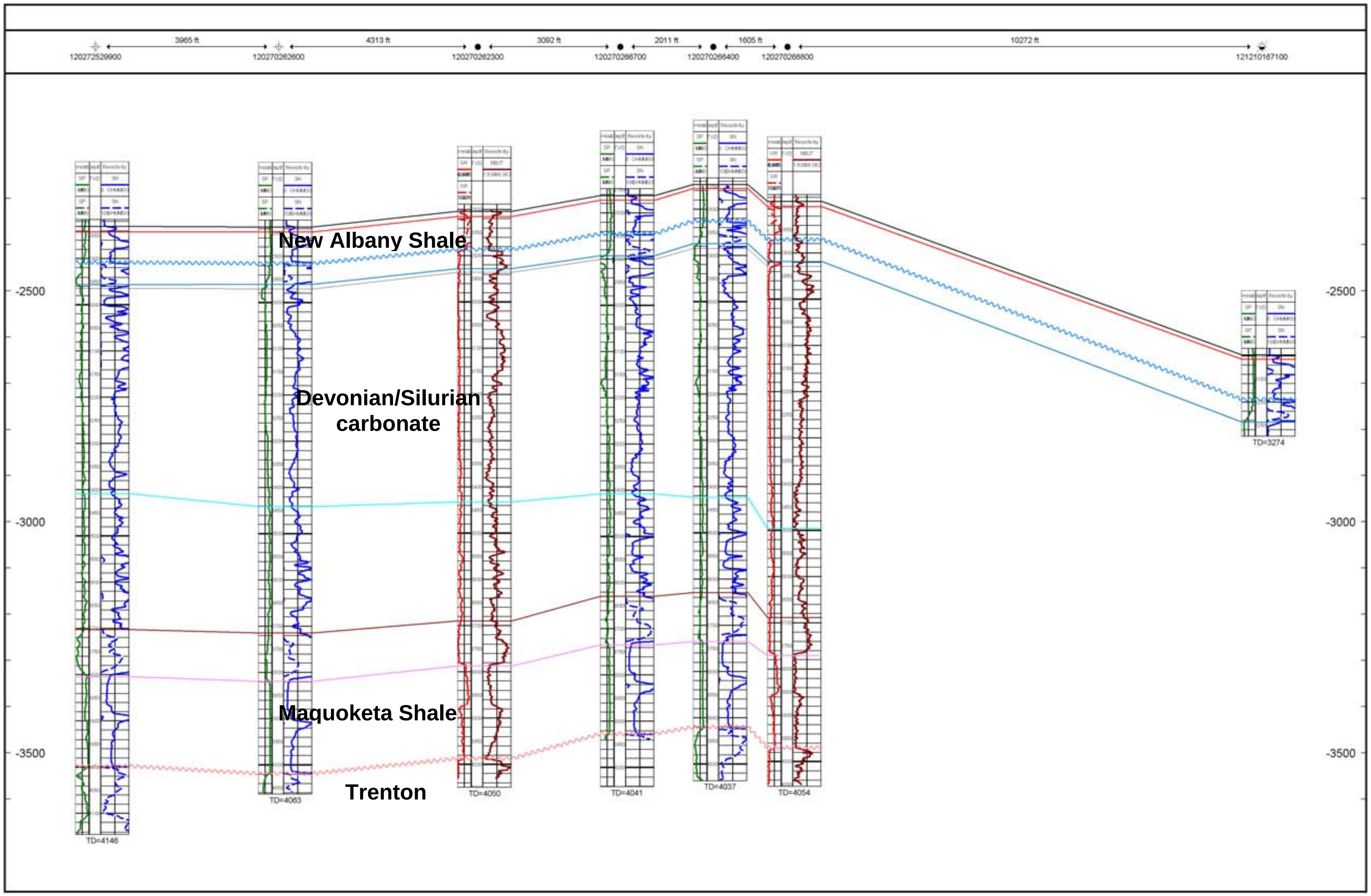


**Figure 21. Cross-axial structural cross-section. The Rock Hill & Pure Oil #8 Buehler well is the farthest Trenton well to the east within the northern end of the field. Cross section indicates a steeper drop off than the contour model on the structural map.**

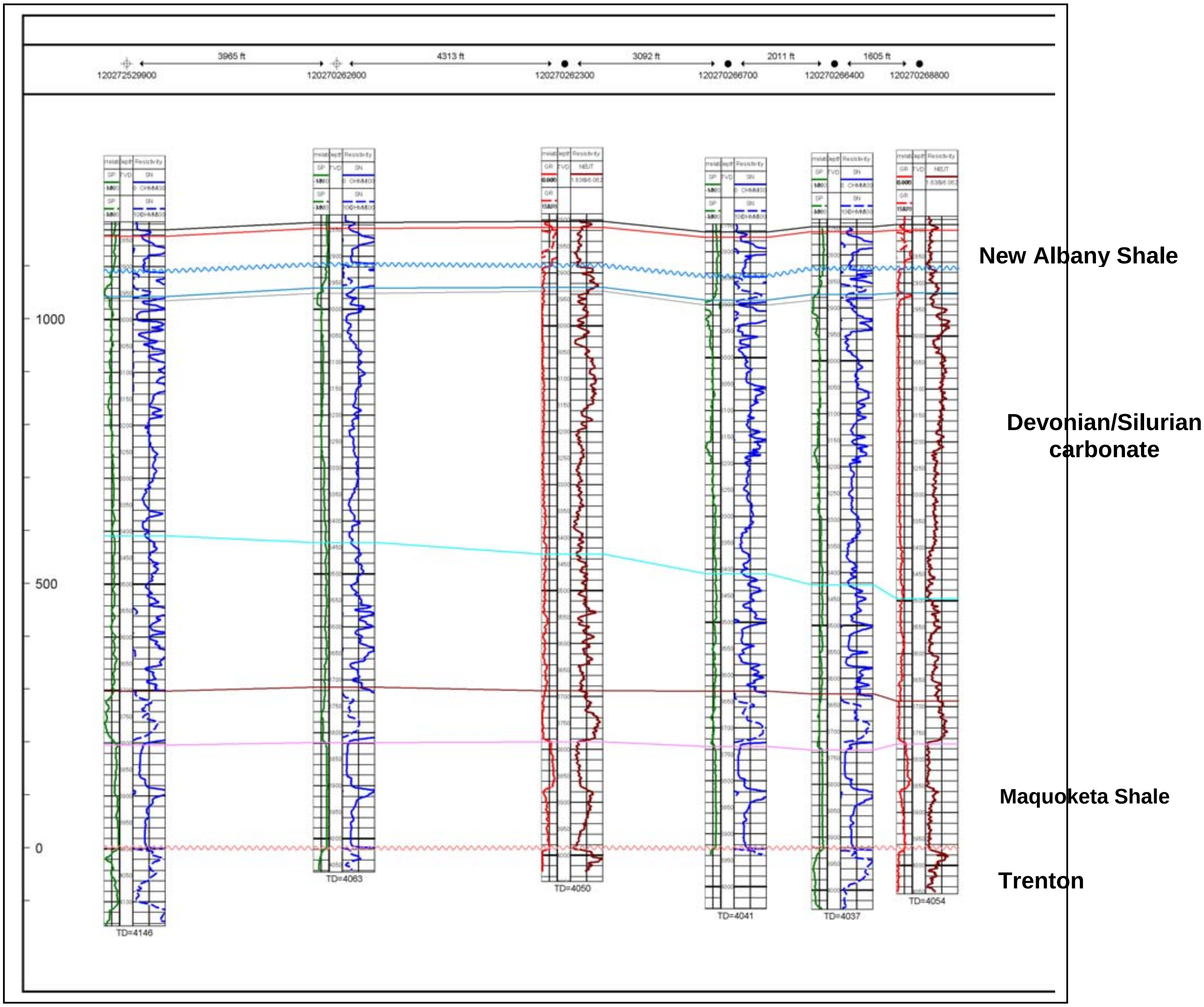


Figure 22. Cross-axial stratigraphic cross-section. The Murvin, John B. #1 Bridges P well is not displayed because it was drilled to the base of the Geneva. The Hunton is visibly thinned over the top of the cross section, but the individual Silurian units do not show the same correlation as in the axial cross-section.

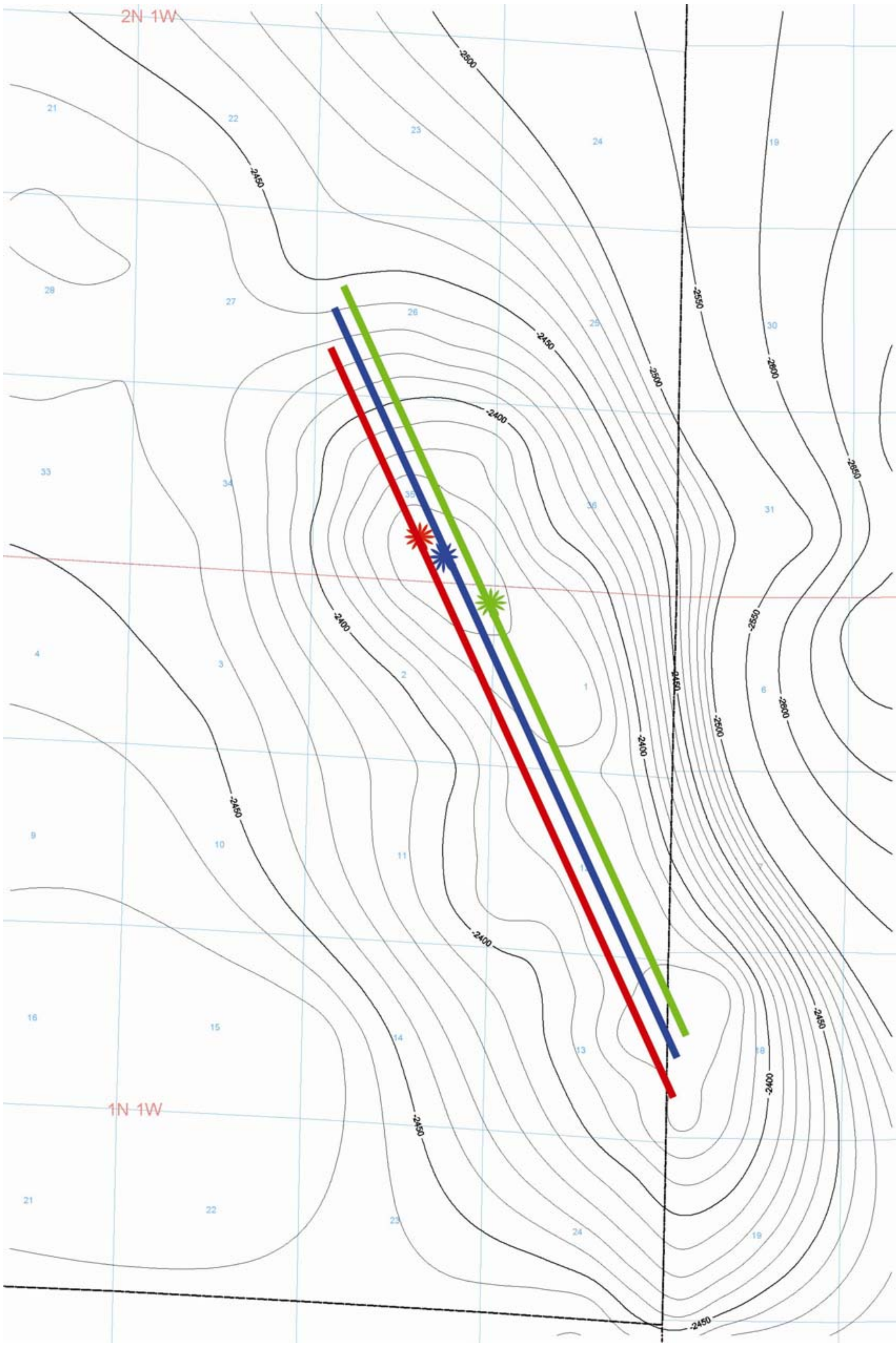


**Figure 23. Map showing the structure on the top of the Lingle formation (blue line is the fold axis). Axis of the Trenton (red) and Ste. Genevieve (green) structures are shown for comparison.**

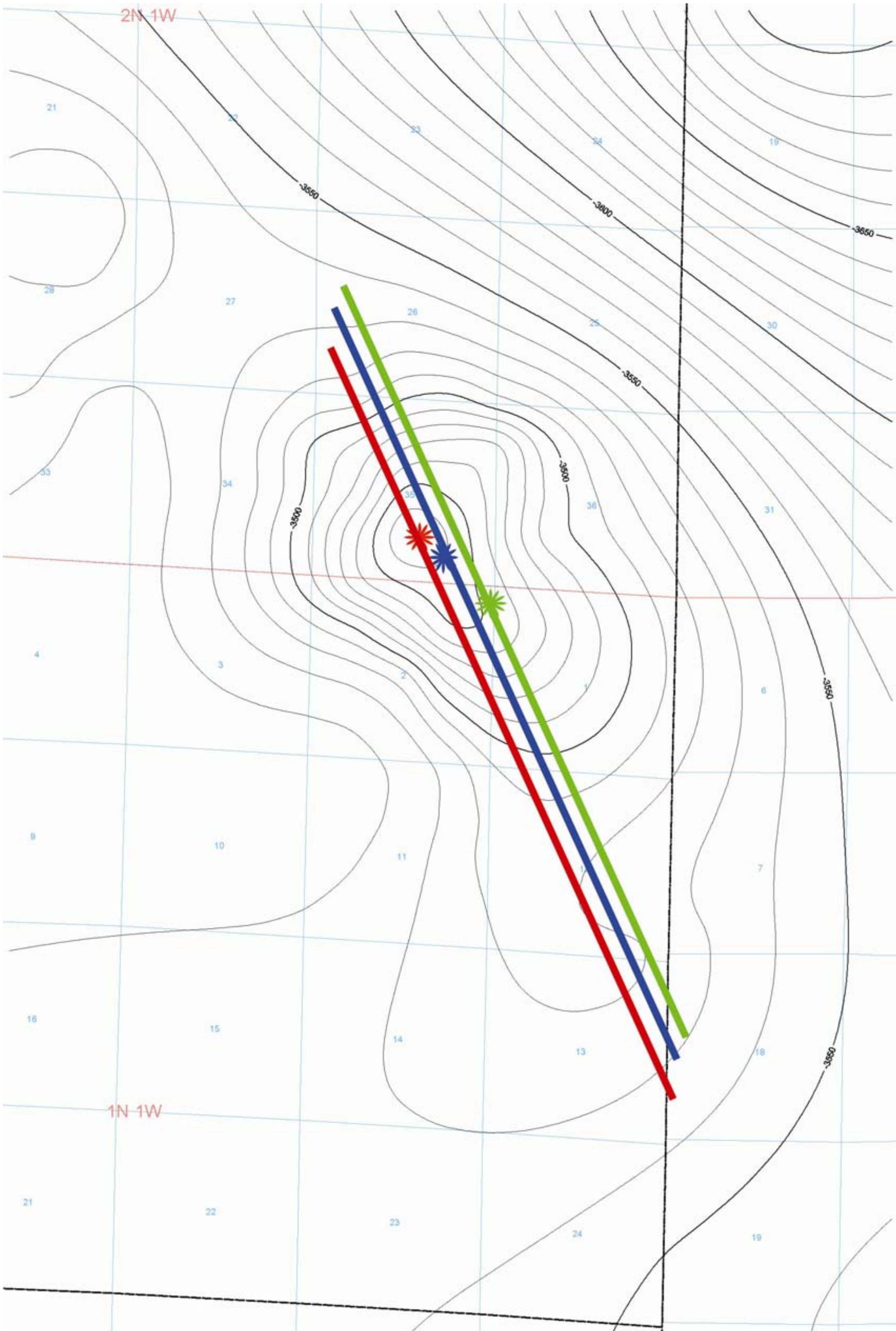


**Figure 24. Map showing the structure of the top of the Trenton (Red line is the fold axis). Axis of Lingle (blue) and Ste. Genevieve (green) are shown for comparison.**

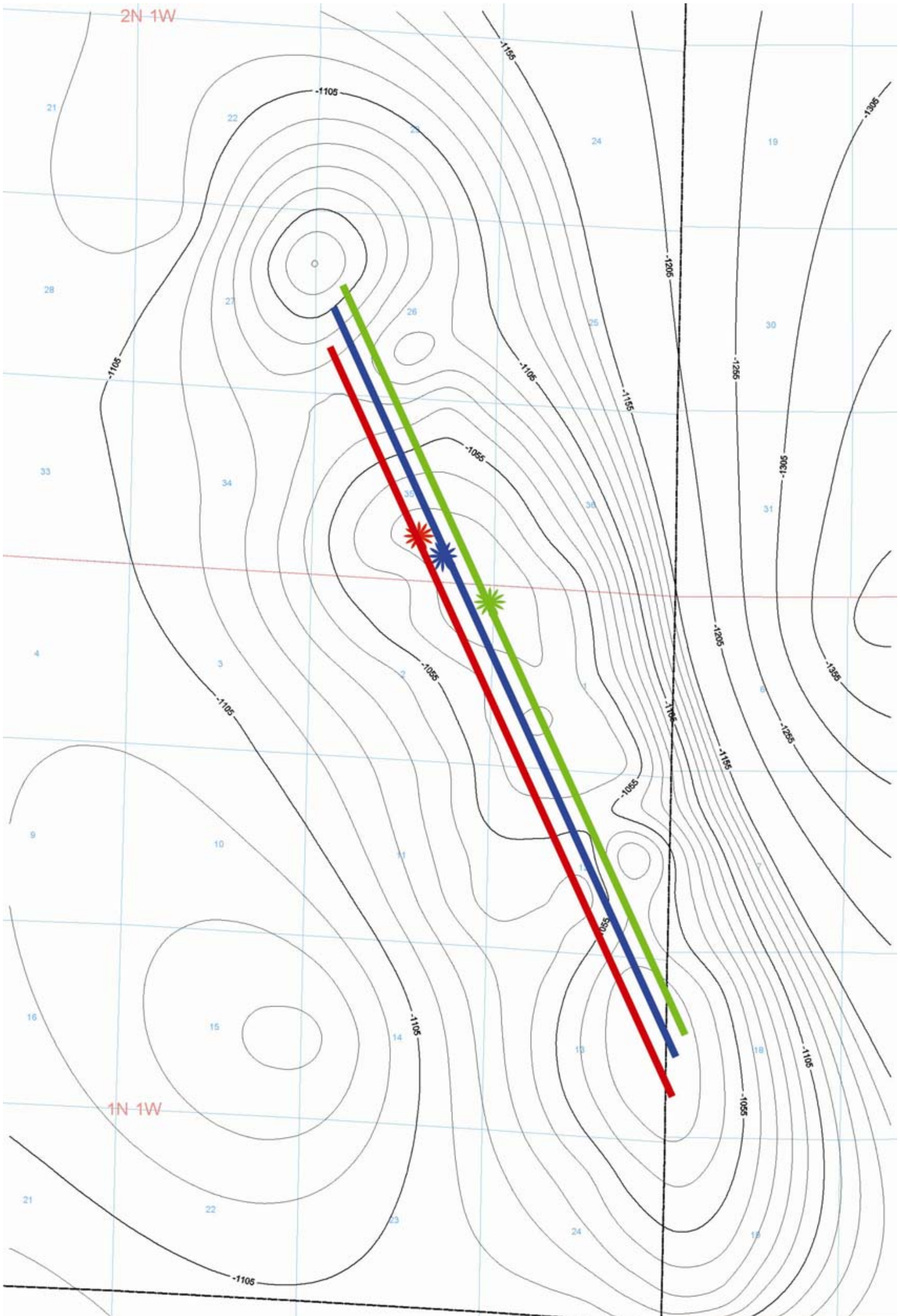


**Figure 25. Map showing the structure on the Ste. Genevieve Formation (green line is the fold axis). Trenton (red) and Lingle (blue) fold axes are shown for comparison.**


**Figure 26. Core from the Shell #37-T Criley well. Note the three oil stained interval, upper interval (3968-3978 ft) is the most productive from this well. Middle oil stained zone is from 3988-3991 ft, and the lower zone is the fractured portion from 3998-4000 ft.**


**Figure 27. Sample of the Trenton Reservoir from the Criley 37-T well. Note the contact between the less porous layer below and the more porous grainstone above.**

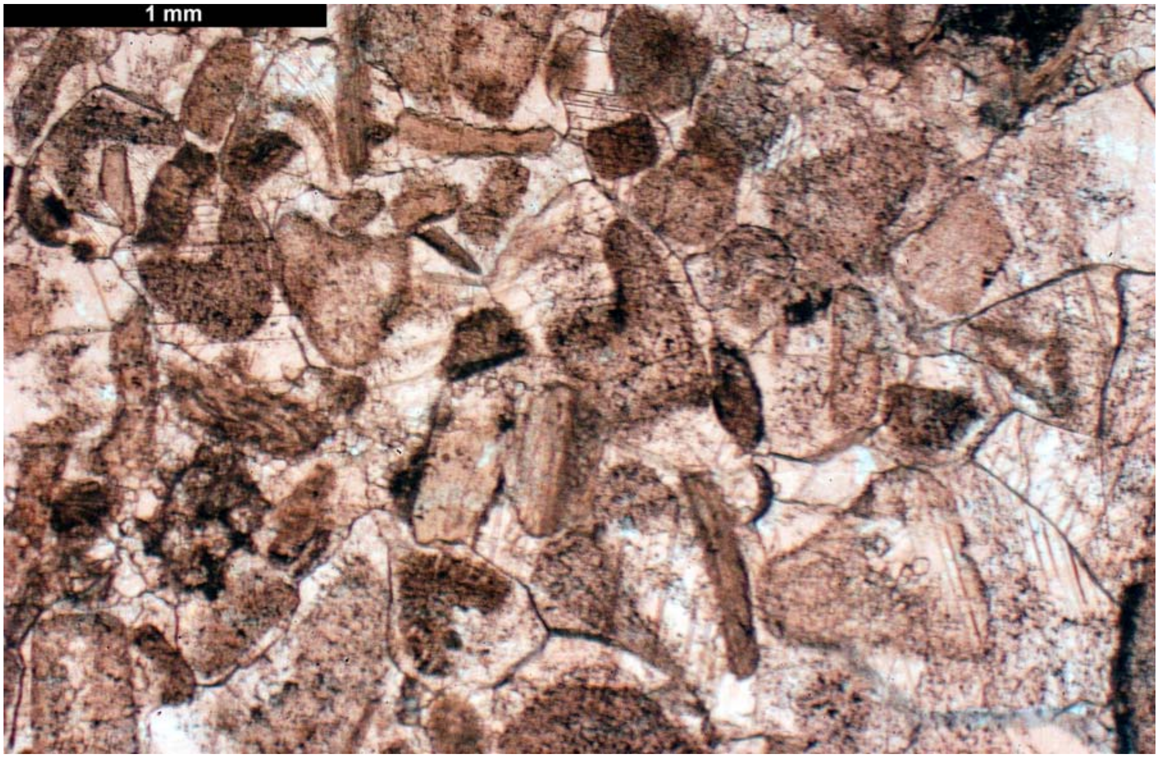


**Figure 28. Thin section from the Criley 37-T well. This sample is from 3966ft, and is representative of the tight grainstones within the Trenton. Fossils are mainly crinoid fragments with lesser amounts of brachiopod and bryozoan fragments.**

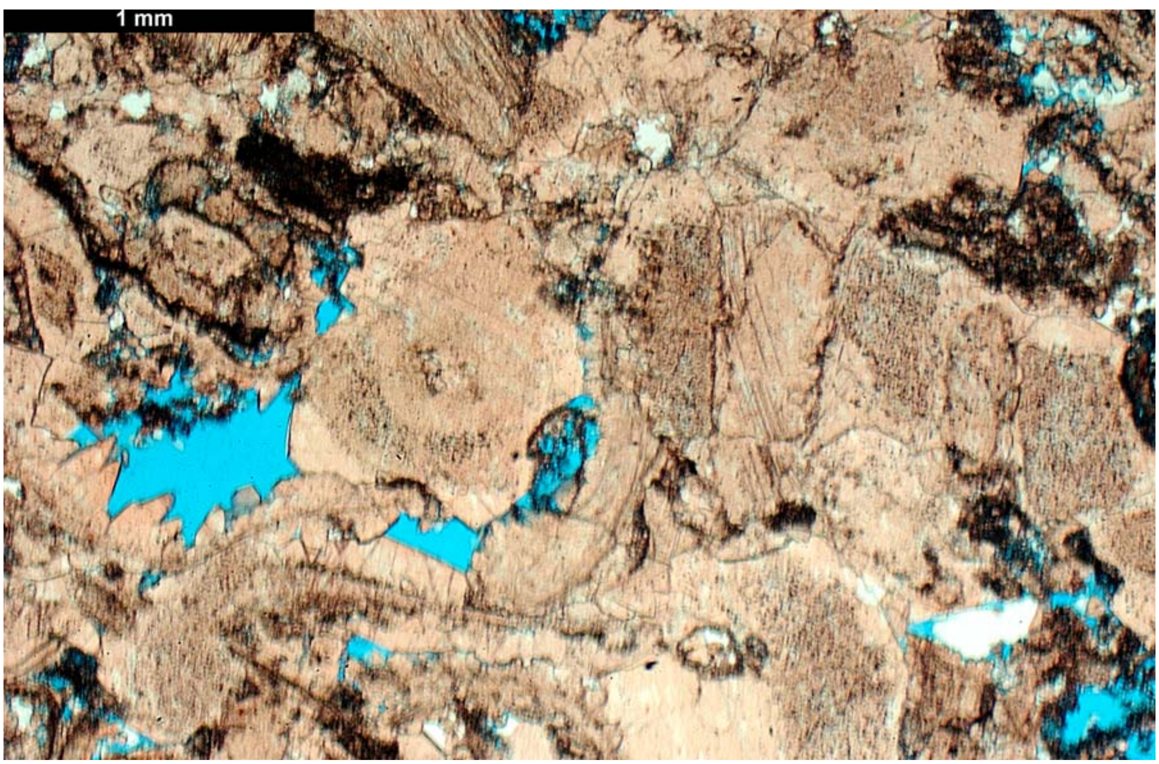


**Figure 29. Thin section from the Criley 37-T well. This sample is from 3976 ft, and is representative of the reservoir units within the Trenton. Porosity is enhanced by dissolution of fossil grains.**

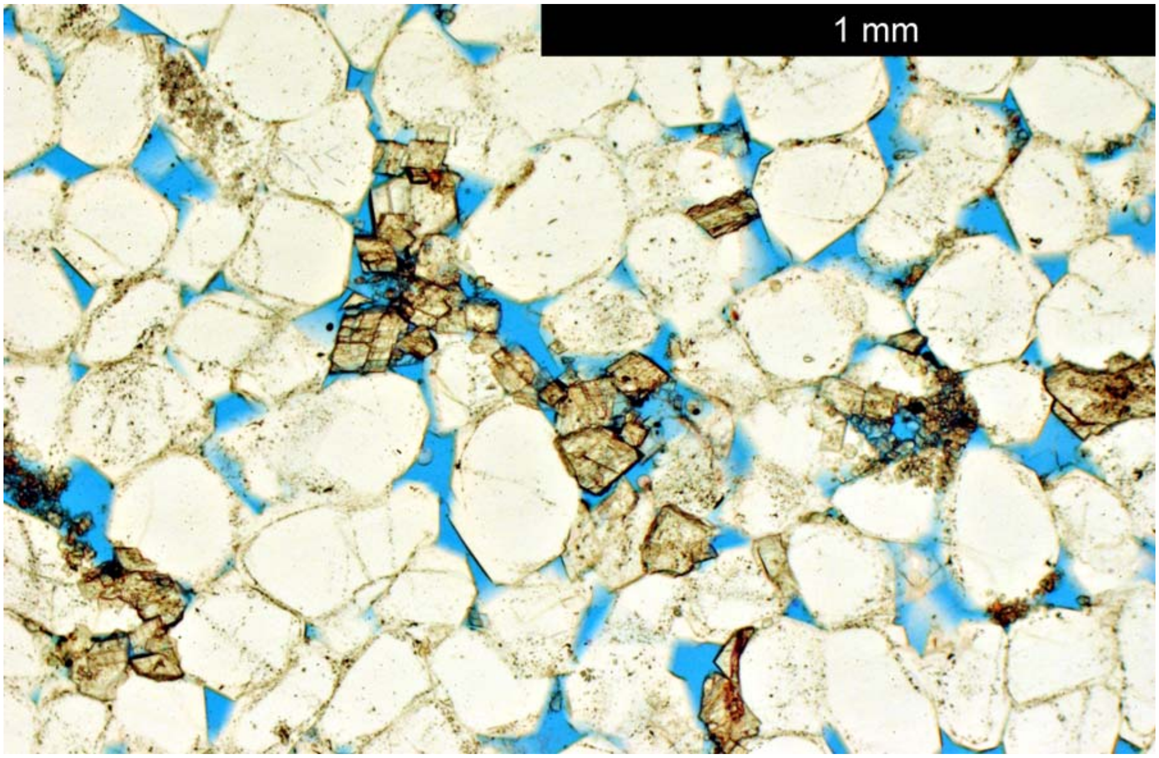

**Figure 30. Devonian Sandstone from the Rothemeyer #2 well. Note high porosity and presence of dolomite crystals in this sample.**

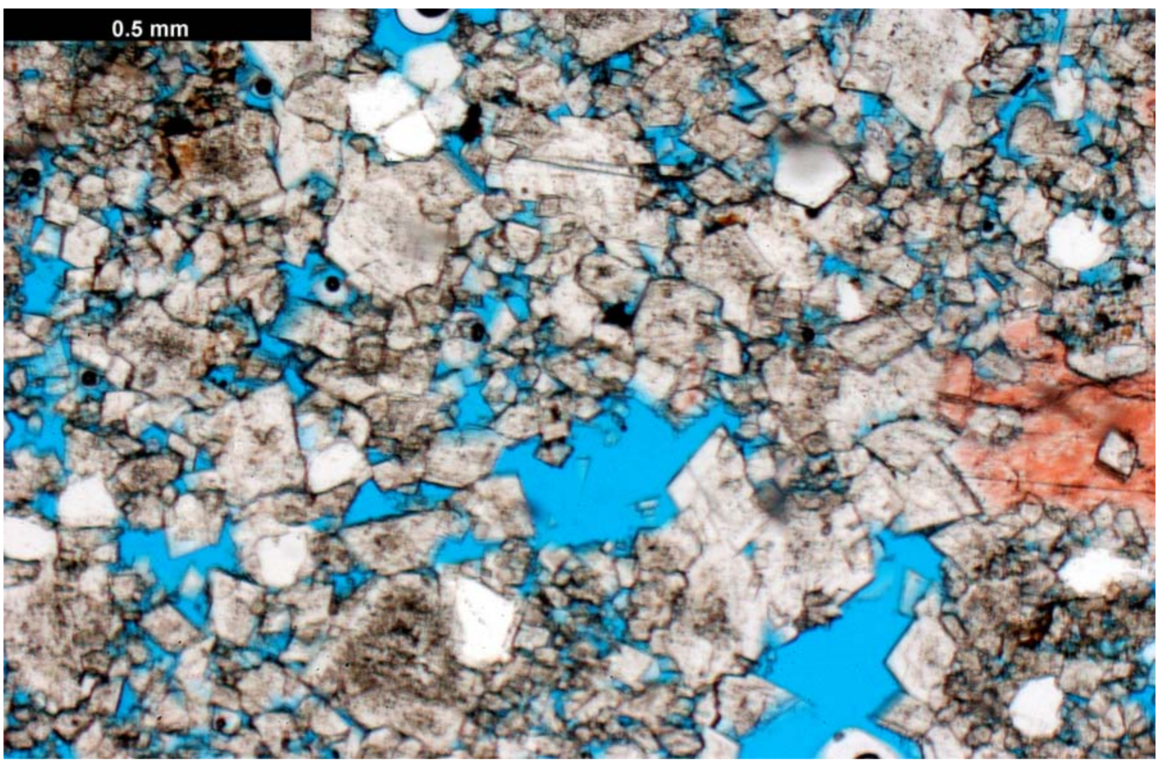

**Figure 31. Devonian dolomite from the Baker #3 well. Note the calcite remaining in the sample which is stained pink. There is also some sand present, which are the bright white rounded grains with no visible cleavage.**

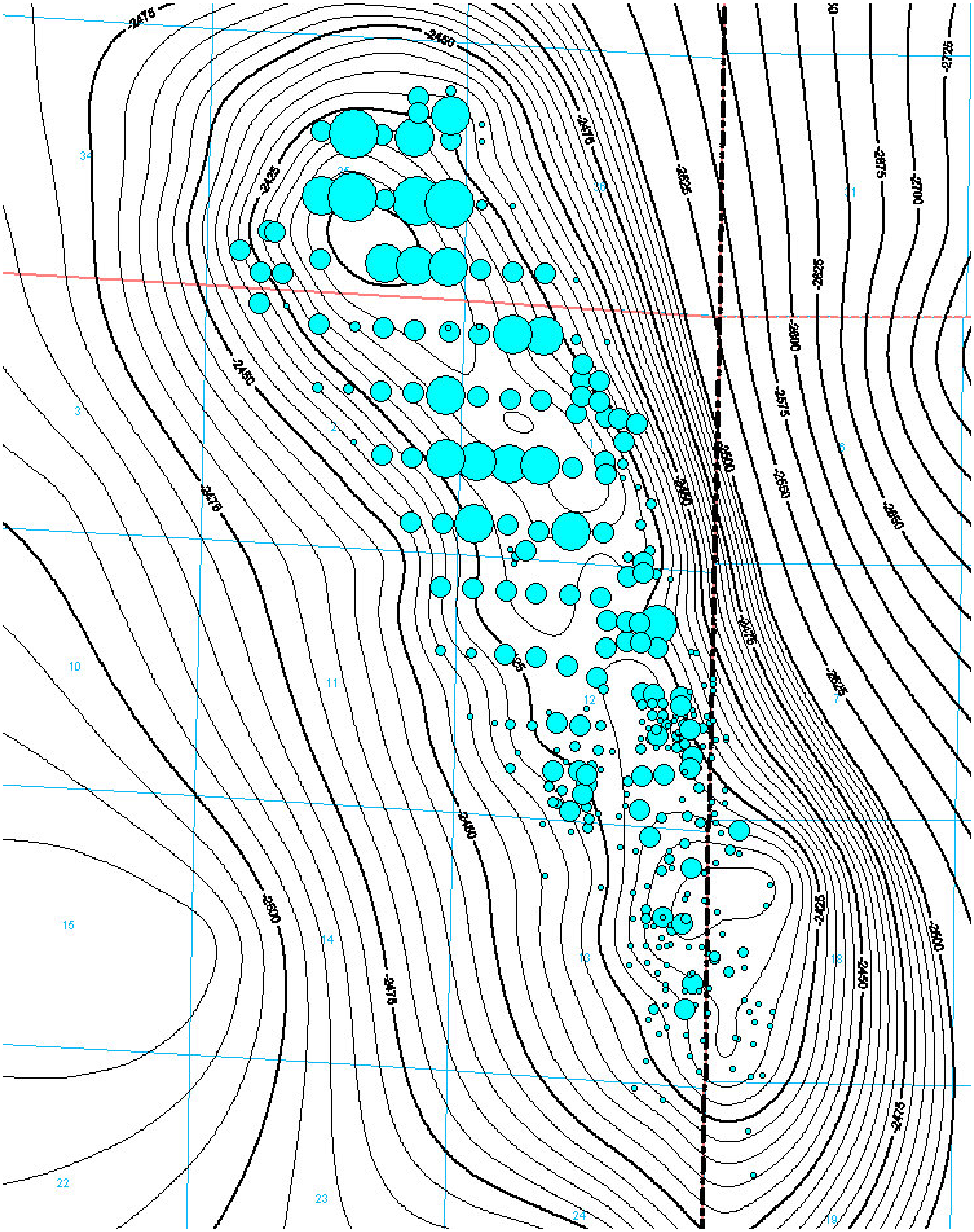

**Figure 32. Map of reported initial production from Devonian wells shown over the Devonian structure. The Largest circles represent wells with rates over 10,000 barrels per day, the next size down represents wells more than 5,000 barrels per day, and the smallest circles represent wells with production less than 500 barrels per day.**

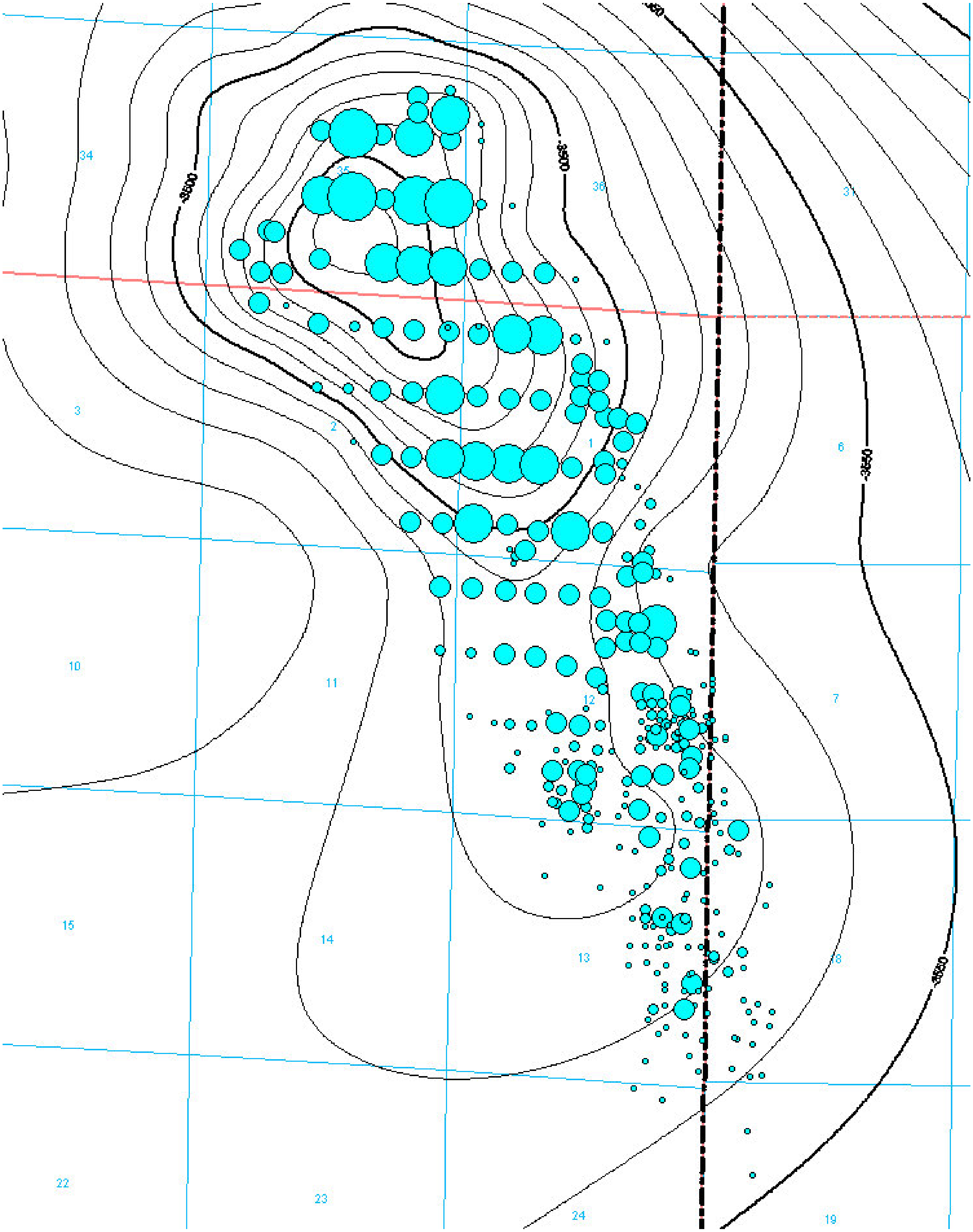


**Figure 33. Map of reported initial production rates from Devonian wells shown on the Trenton structure. Symbol explanation is the same as the previous figure.**

**Westfield Trenton Production**: **Jon Brenizer**

**Geological Setting and Stratigraphy:**

The Westfield field is located on the Westfield dome, a portion of the LaSalle Anticlinorium, in northwestern Clark County and parts of Coles and Cumberland Counties (see Figure 1). A typical log of Westfield is shown in Figure 2, as a guide to the stratigraphy of the field. The Mississippian strata have been eroded down into the Valmeyeran sequence to the base of the St. Genevieve and the top of the St. Louis Limestones. The Borden Siltstone has one or two distinctive lenses of Carper Sandstone which are productive if they are lenticular with no communication with water saturated units. The Chouteau Limestone is easily distinguished on the newer dual induction logs, and is between 12-15 feet thick throughout the area. The New Albany Shale directly underlies the Chouteau, and is 100 feet thick throughout the field. The Devonian limestones are not productive despite showing good porosity in logs. The Ordovician Maquoketa Shale is consistently 250 feet thick throughout the area. The Trenton Limestone is approximately 175 feet thick throughout the field and is comprised mainly of fossiliferous grainstones.

**Production history:**

Oil in the Trenton was discovered very early at Westfield with the first confirmed production coming from the Ohio Oil Company #79 Young, K&E well that was completed in 1910. Development of the field was slow with only 4 additional producers completed between 1922 and 1942 (Figure 3). In late 1948 through 1949, the first new wells were completed in the Trenton. There was no further Trenton development between 1949 and 1957, but 1957 marked the start of extensive drilling targeting the Trenton. Seventy-two wells were completed in the Trenton from 1957-1963, 64 being producers. This period also marked the beginning of water-flooding of the Trenton, which met with mixed success due to the proximity of some wells to large fracture systems. In 1983, a second round of development began and 52 production wells were drilled with no additional injection wells drilled. Development continued through the 1990's at a much slower pace, and in the mid-1990's horizontal drilling began. While the initial production of the wells has varied (from 909 bpd in the Lindley #5 to 32 bpd in the Huisinga 2-18), the average IP is about 50 barrels per day (excluding the Lindley #5) and the average water produced is less than 20 barrels per day. These values are remarkable because they are similar to the production level from 1957-1961, when the field was initially developed (Figure 4). Tests of the Devonian strata have produced no oil, but significant amounts of water.

**Structural History:**

The structure does not significantly change in shape or dimensions between Ordovician through Early Mississippian times (Figures 5, 6, 7, 8 and 9). The top of the bedrock in the area is in the middle of the Valmeyeran section, due to erosion. Much of this upper section has been highly altered and is difficult to recognize in logs. The Westfield Dome was described by Nelson (1995). "an asymmetrical box-fold with a long steep western limb (the Charleston Monocline), a gently dipping eastern limb, and a slightly domed crest."

The structure drops off drastically to the west of the mapped areas and there are no wells drilled to the Trenton in the next township to the west. Variations on the structure mapped on different stratigraphic units are relatively minor. Deeper stratigraphic units have less well density than the shallower units,  all of the maps and data for this project were based on the data available from wells penetrating the Trenton Limestone (Figure 10).

Cross sections were drawn along the lines shown in Figure 11.  The East-West cross sections in Figures 12 and 13 show the structure and the particularly flat stratigraphic section with the Trenton as the datum.  The North-South cross sections (Figures 14 and 15) show similar results to the East-West sections.  The uniform thickness of the strata and the uniformity of the shape and size of the structure at each structural interval indicate that the uplift occurred both before and after the beginning of Pennsylvanian sedimentation (Nelson, 1995).

**Reservoir Characterization:**

The reservoir units of the Trenton in Westfield are similar to many Trenton reservoirs throughout the basin.  The producing horizons are composed of porous grainstones (Crews, 1985). There are non porous tight grainstone intervals interbedded with the porous zones. After burial hydrothermal fluids may have moved through the porous units, dissolving mainly calcite cement, but also the brachiopods and bryozoans (Figure 16).  Later, the fracturing occurred with additional fluids within the pore spaces resulted in partial dissolution of the carbonates along the fractures. Some time after the onset of fracturing formation of dolomite, probably of hydrothermal origin, began. There are several fractures that are filled with dolomite, and several instances where fractures cut through the dolomite and the dolomite bridged the fractures (Figure 17).  The dolomite was precipitated more heavily in the larger fractures, indicating the best conduits for fluid migration and formation of porous intervals (Figure 18).  A still later event deposited some calcite cement, and although it is not as pervasive as the dolomite, it is still present in most samples (Figure 19).  This could be in part due to the reduction in magnesium concentration in the initial fluid due to the precipitation of dolomite.

On the basis of trends in initial production two fracture trends have been identified (Figure 20).  These define fracture trends wider than the radius of a single well.  The lack of oriented core makes it impossible to verify the orientation of field scale fractures, but they do indicate significant numbers, with openings up to 2 cm and significant dolomite mineralization. In the area of these trends, initial production values are 2-10 times higher than the areas of the field located outside of the fracture trends. The Lindley 5 well sits near the junction of two of the trends, and the two laterals cut across both of the trends.  This would explain the remarkable initial production from this single well (909 barrels of oil, no water).

**Completion methods:**

All of the wells drilled prior to 1981 were completed as open holes.  The main method of completing these wells was a fracture treatment with 40,000-80,000 gallons of water and 30,000-40,000 pounds of sand, with several of them flushed with acid.  There were a very small number of wells that combined the two, but this was rare prior to the 1980s.  Several fracture treatments were carried out using nitrogen after 1980.  The wells with the fracture treatments initially produced more oil and water (8 barrels of oil and 13 barrels of water per day respectively) compared with the wells with combined treatments. The wells treated only with an acid flush made much less water (2 barrels per day on average) but produced about half of the oil compared to the wells with fracture treatment.

In the 1980's and later the preferred method was to case the entire well and then perforate the pay zones in the Trenton. The well treatments also changed, with combined acid and fracture treatments being used in 35 out of 61 completions. The combined treated wells made an average initial production of 66 barrels of oil and 14 barrels of water with a water cut of 18%. This is consistent with the combined treatments from the earlier development, but is much better than the single treatment method in modern wells (43% water cut for acid only and 47% water cut for fracture only wells).

Horizontal drilling also improves the recovery of oil with an average of 57 barrels per day recovered initially (not including the Lindley #5 well, including the Lindley #5 the average jumps to 178 barrels per day). Vertical wells drilled in the 1980's and 1990's averaged 44 barrels of oil initially. The vertical wells drilled before 1980 averaged 58 barrels per day initially. Horizontal drilling resulted in producing as much oil as the preceding 100 years of producing from the field.

**Conclusions:**

Several findings from this study can be applied to Trenton exploration and development throughout the Illinois Basin. First, the completion technique used in the Trenton must be carefully controlled, because fracturing the well too heavily or flushing the well with too much acid will ruin the well or increase the water cut. A moderate fracture treatment with a small acid flush will serve to better connect the existing fracture network without destroying it, and a light acid flush will remove the finer grained calcite, while leaving the calcite and dolomite bridges of existing fractures intact. Second, the presence of any fractures will improve production. Whether these fractures are caused by faulting, regional stress, or the stresses along the crest of the anticline, they directly increase the permeability directly. Finally, horizontal drilling in a fractured reservoir will increase production by 10 or 20%, even on a relatively short horizontal well.

**Reference:**

Nelson, J.W. *Structural Features in Illinois*. Bulletin 100, Illinois State Geological Survey, 1995.

Crews, G.A. *Carbonate Facies of the Kimmswick Limestone (Trenton/Galena) in Southwestern Illinois – Their Relations as Oil Reservoirs and Traps.* Thesis, University of Missouri-Rolla, 1985.

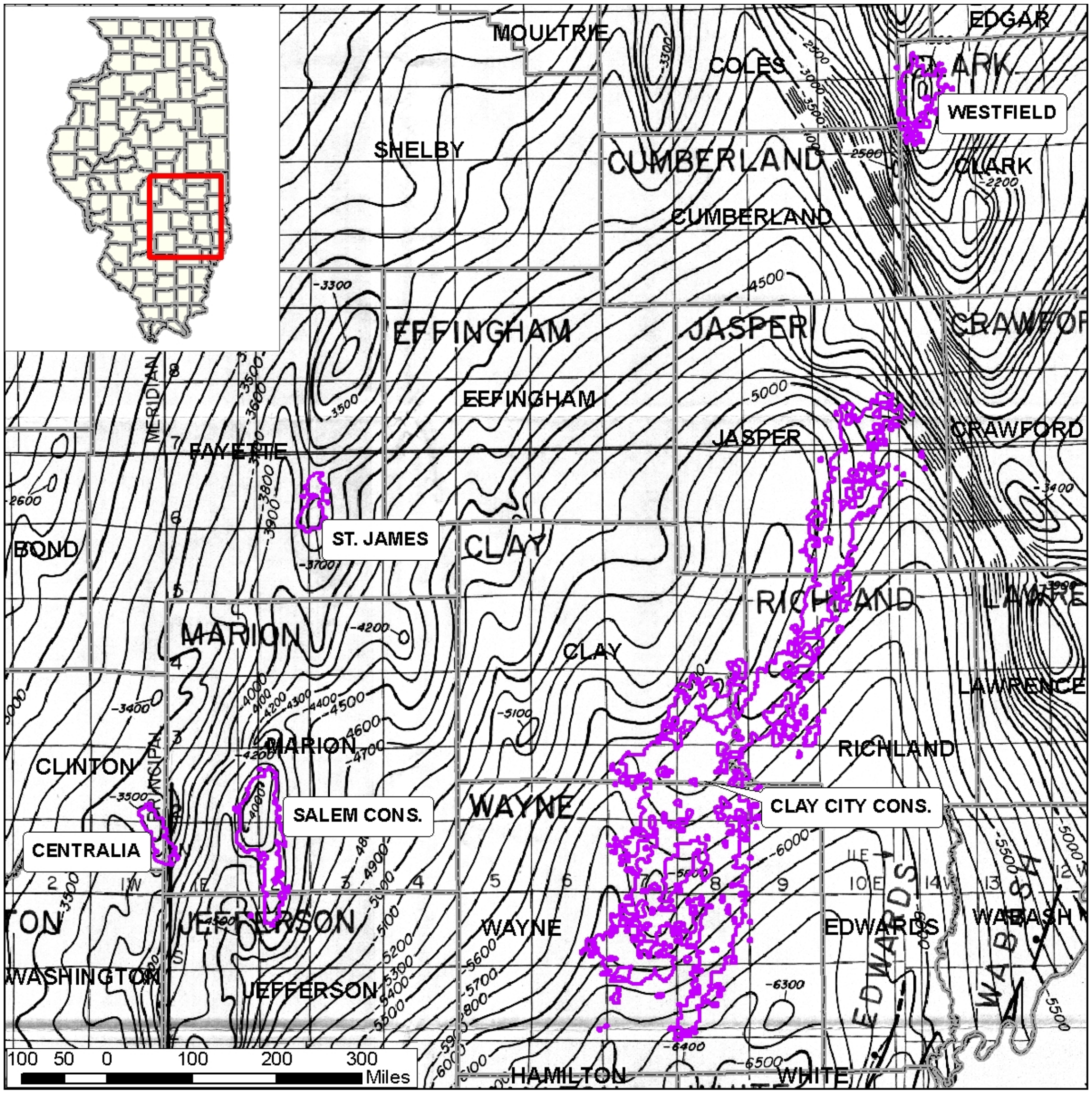


**Figure 1.** Map showing the location of Westfield (upper right corner). The map is contoured on the top of the Trenton Limestone and the contour interval is 100 feet (Bristol and Buschbach, 1973).

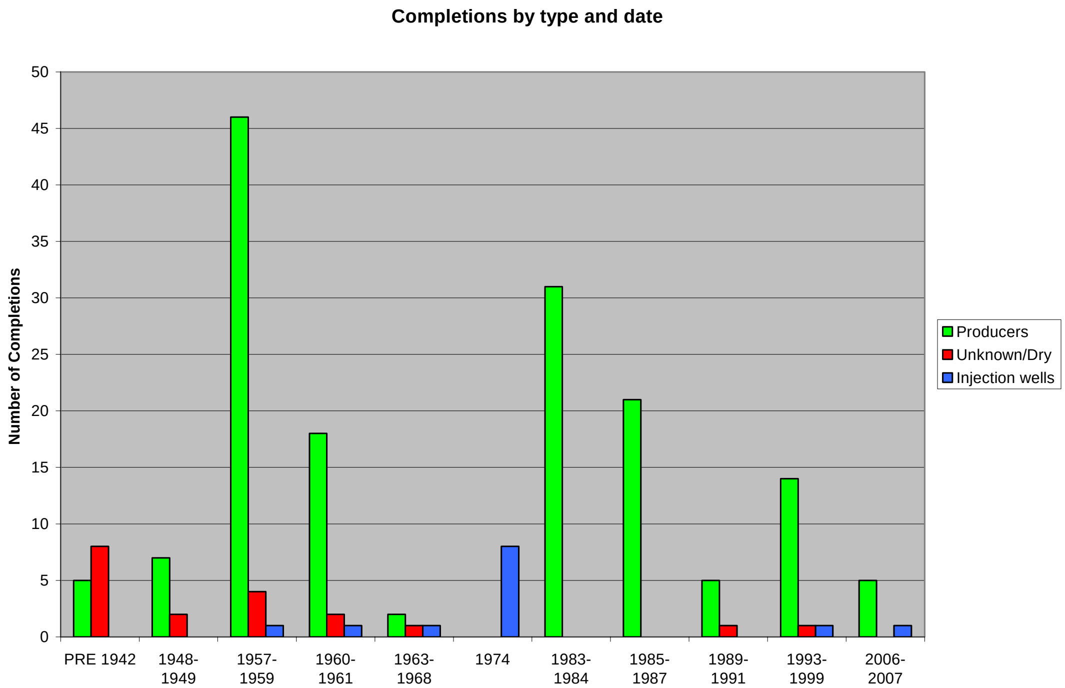


**Figure 2.** Graph of completions by type and date. Notice the three main periods of development within the field in the late 1950's -early 1960's, the mid 1980's and the late 1990's and early 2000's.

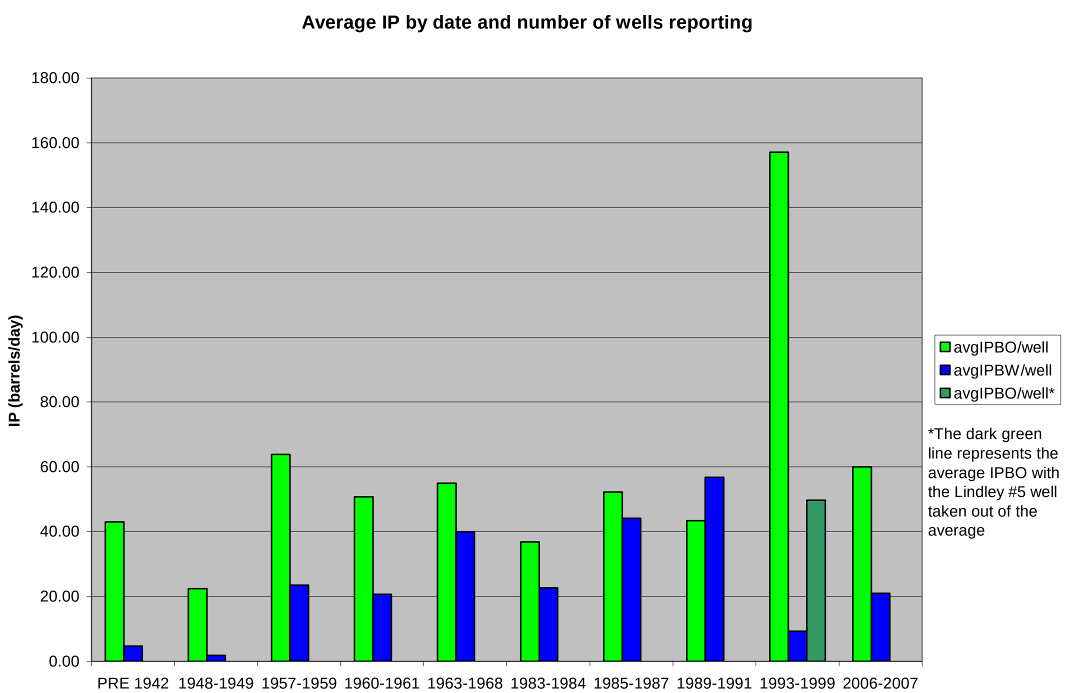


**Figure 3.** Graph showing average IP values per well drilled. The higher values from the late 1990's and early 2000's are due to the completion of several horizontal wells, which produce as much oil as the wells drilled in the 1950s.

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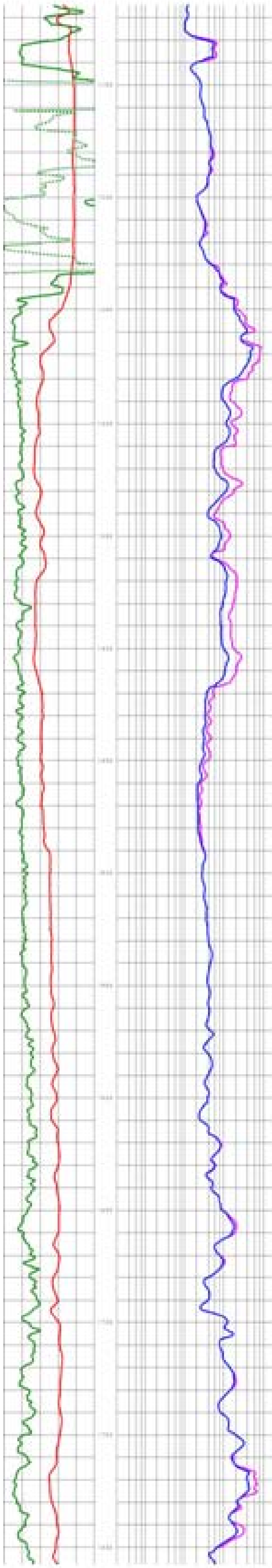
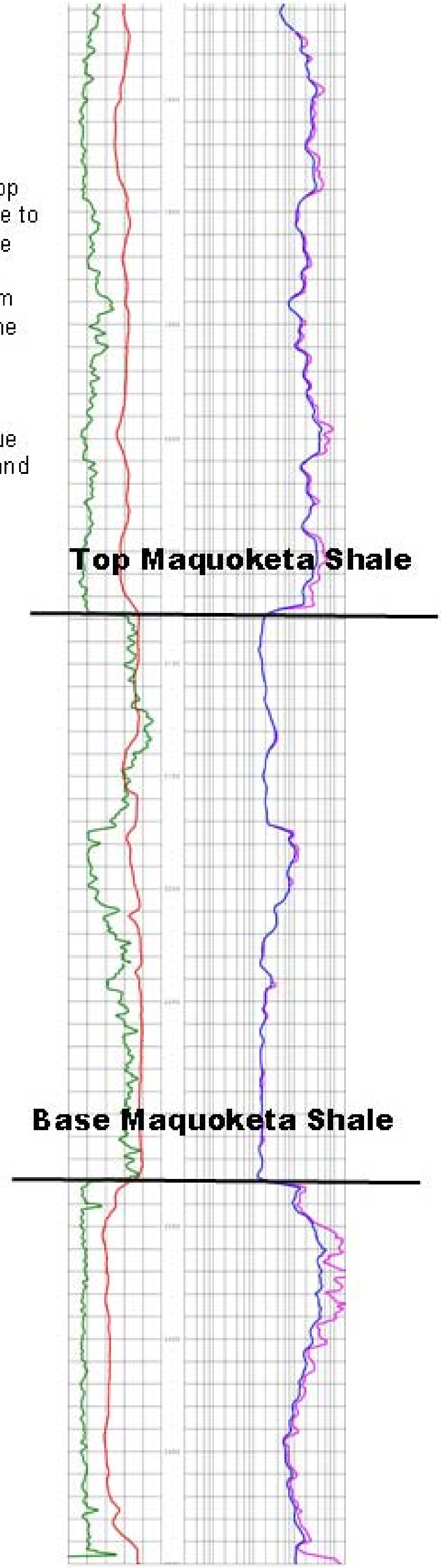


**Figure 23.** Left column shows a typical log from Westfield in Clark County Illinois, the Ashley Oil Husinga-McVey No. 4T in Sec. 6-T11N-R14W API 120232483800 from the top of the Chouteau Limestone to the top of the Silurian. The right column shows the continuation of the log from the top of the Silurian to the base of the Guttenberg Shale. The green line is gamma log, the red is the spontaneous potential, blue is the medium induction, and the pink line is the deep induction curve



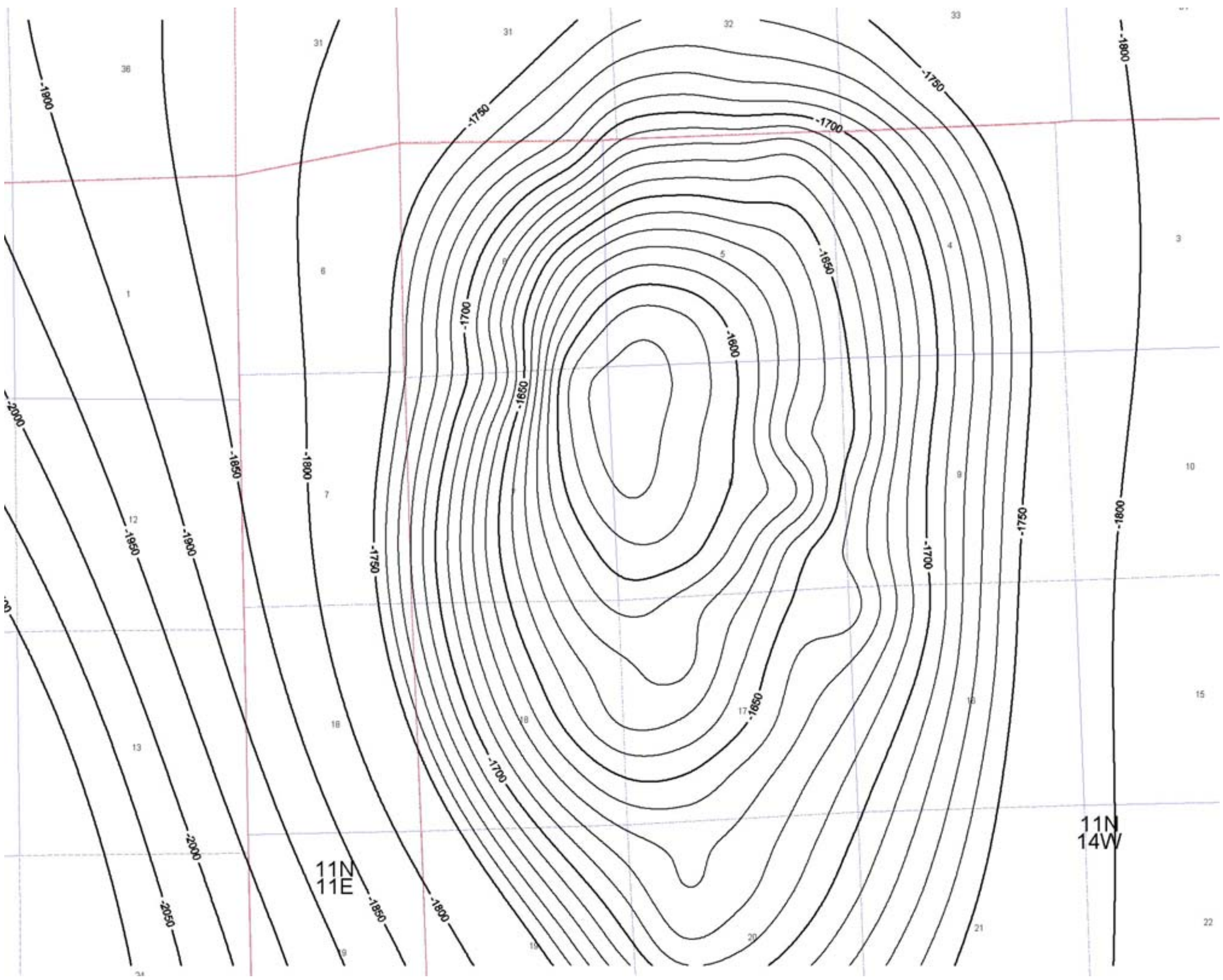



**Figure 5.** Map of the structure of the top of the Trenton Limestone.

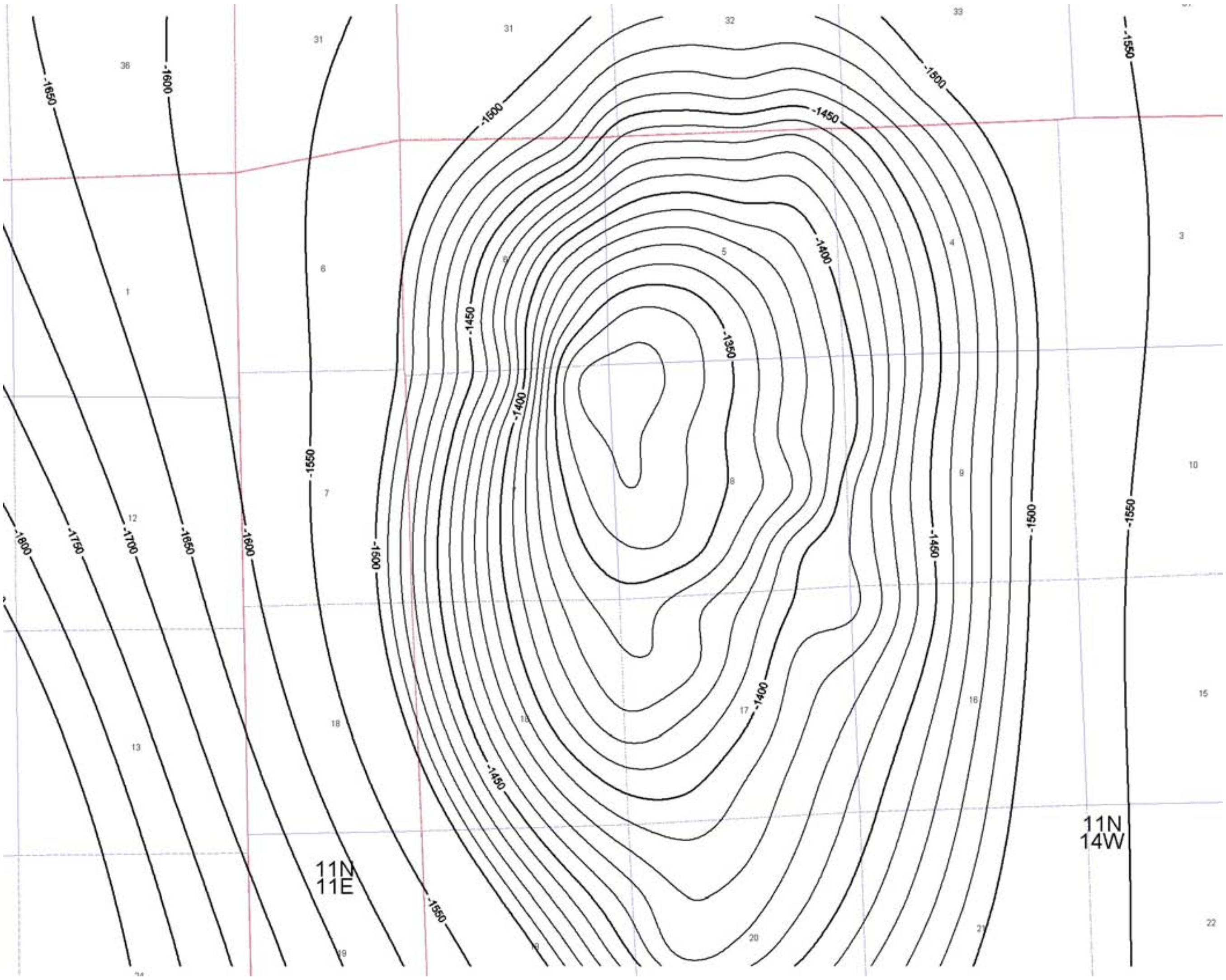



**Figure 6.** Map  the structure on the top of the Maquoketa Shale.

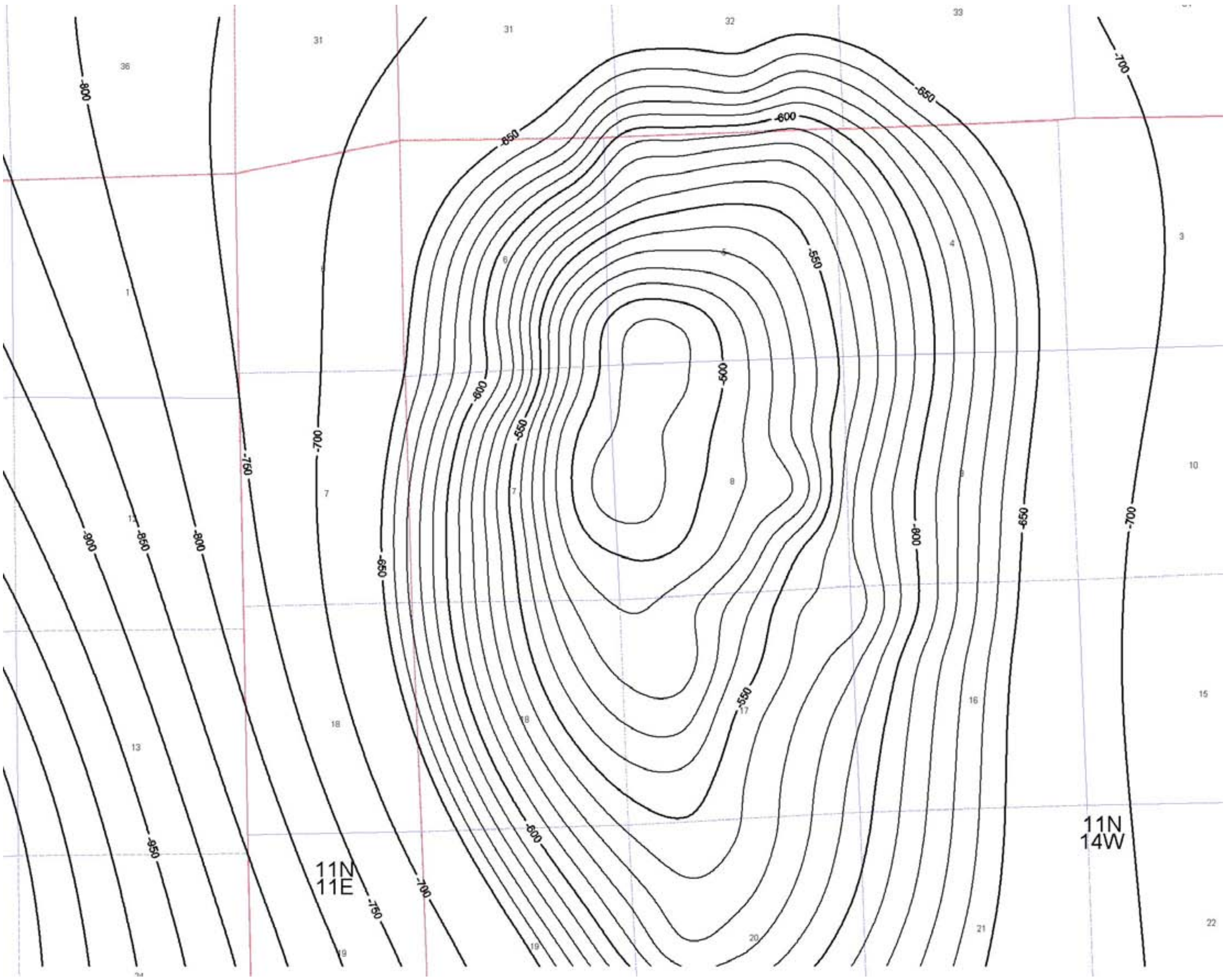



**Figure 7.** Structure on the top of the New Albany Shale.

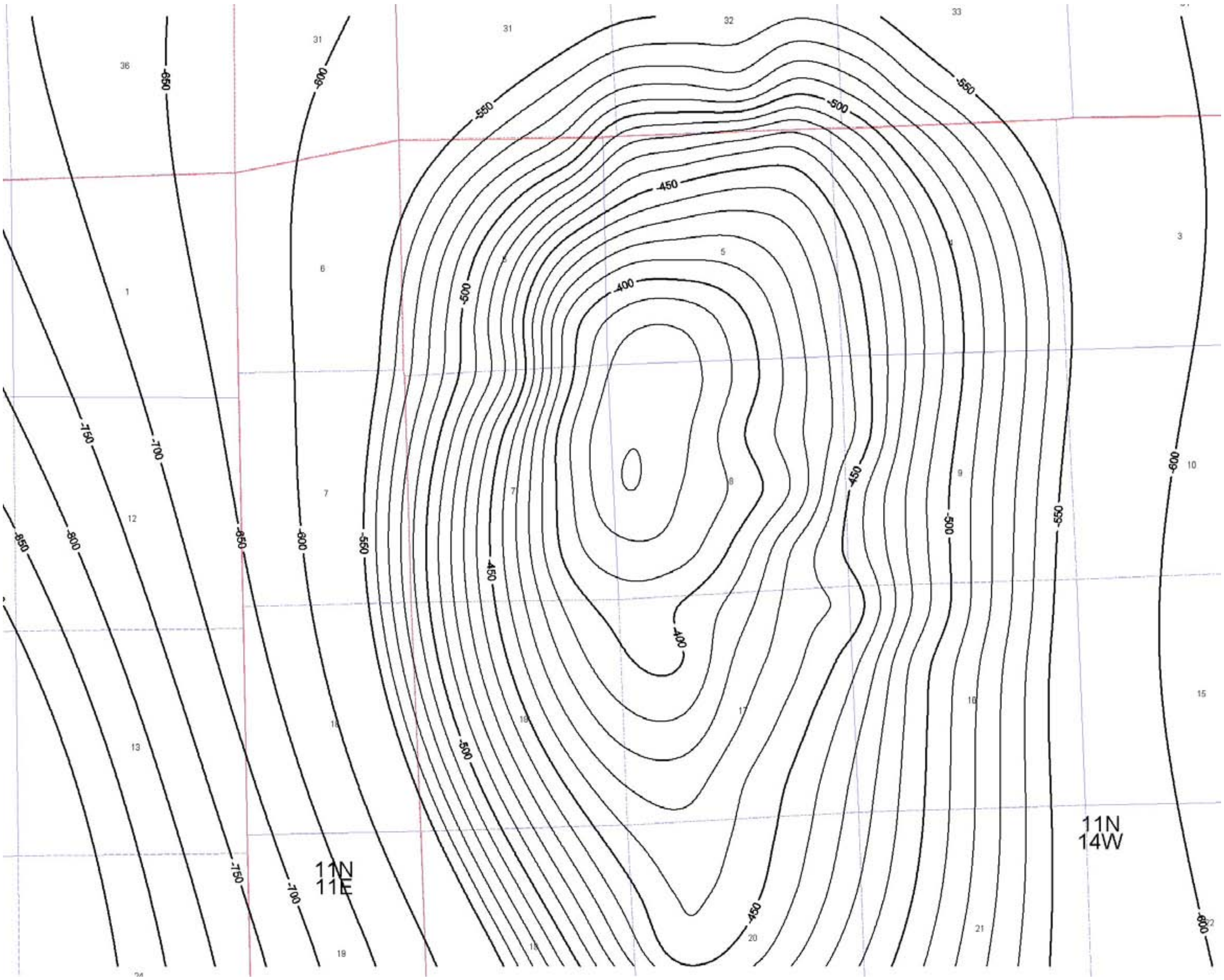



**Figure 8.** Map of the structure on the top of the Chouteau Limestone.

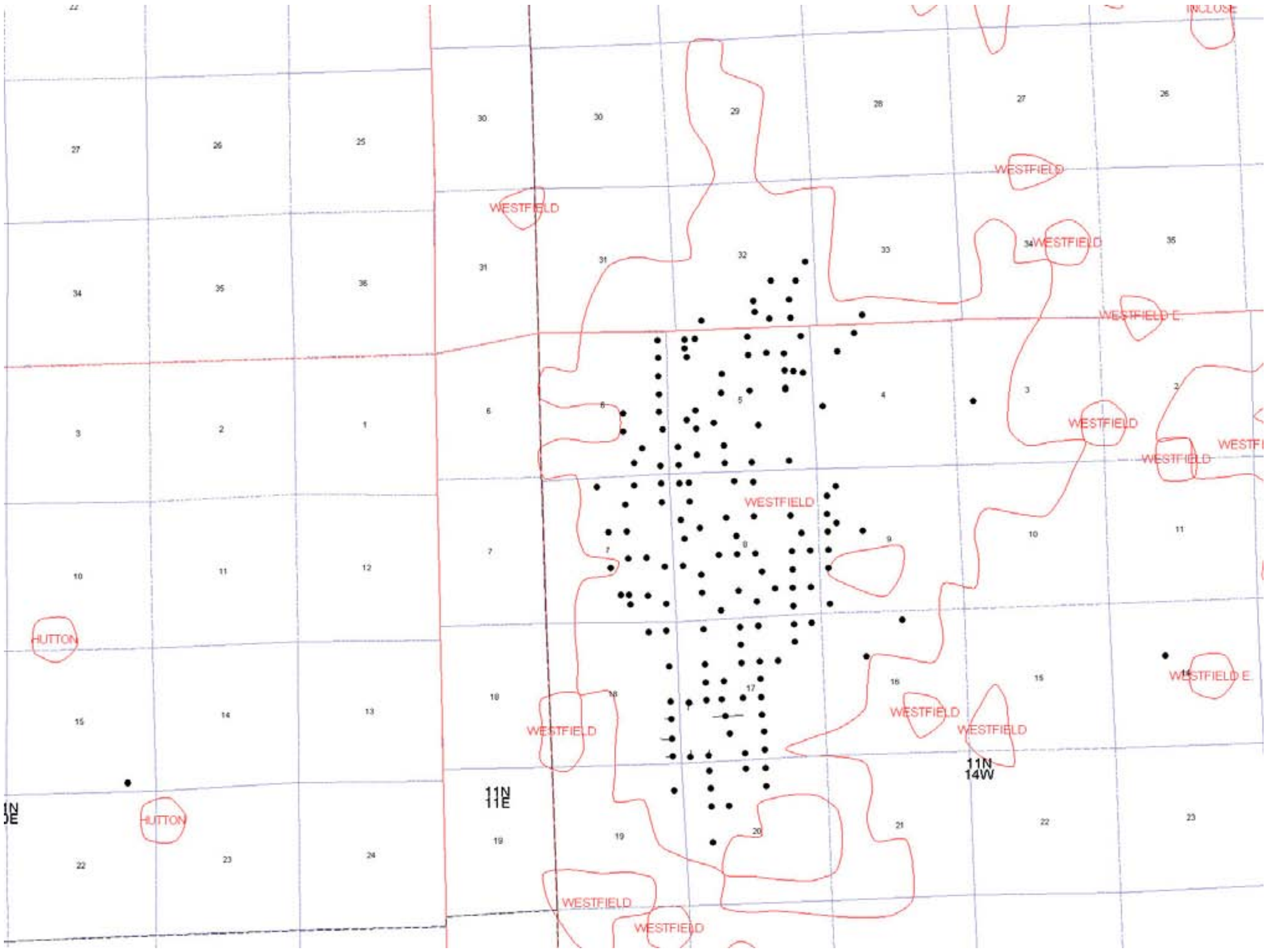



Figure 9. Map showing the location of logged wells penetrating the Trenton Limestone.

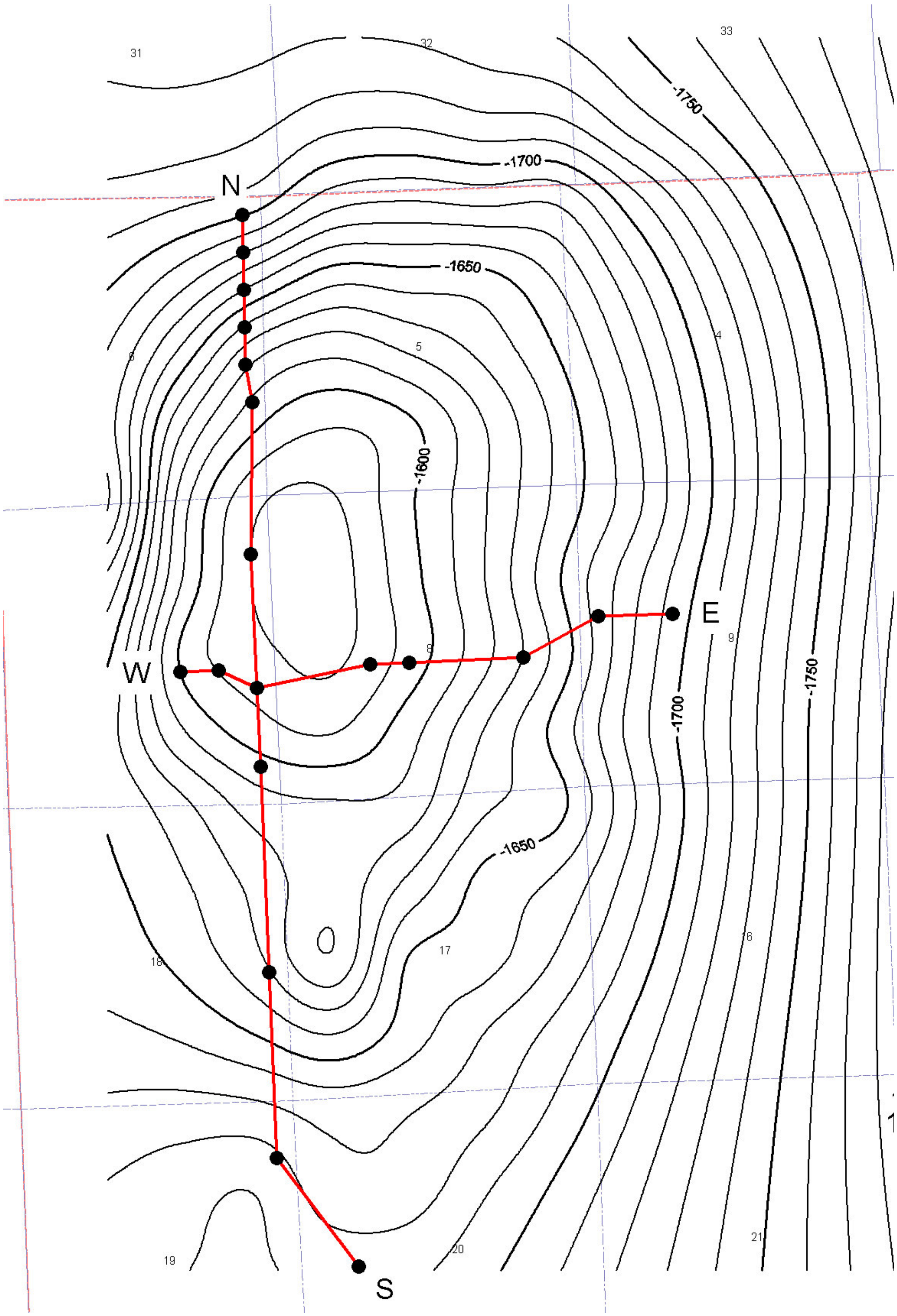



**Figure 10.** Map of cross sections shown on a contour map of the structure on the top of the Trenton Formation.

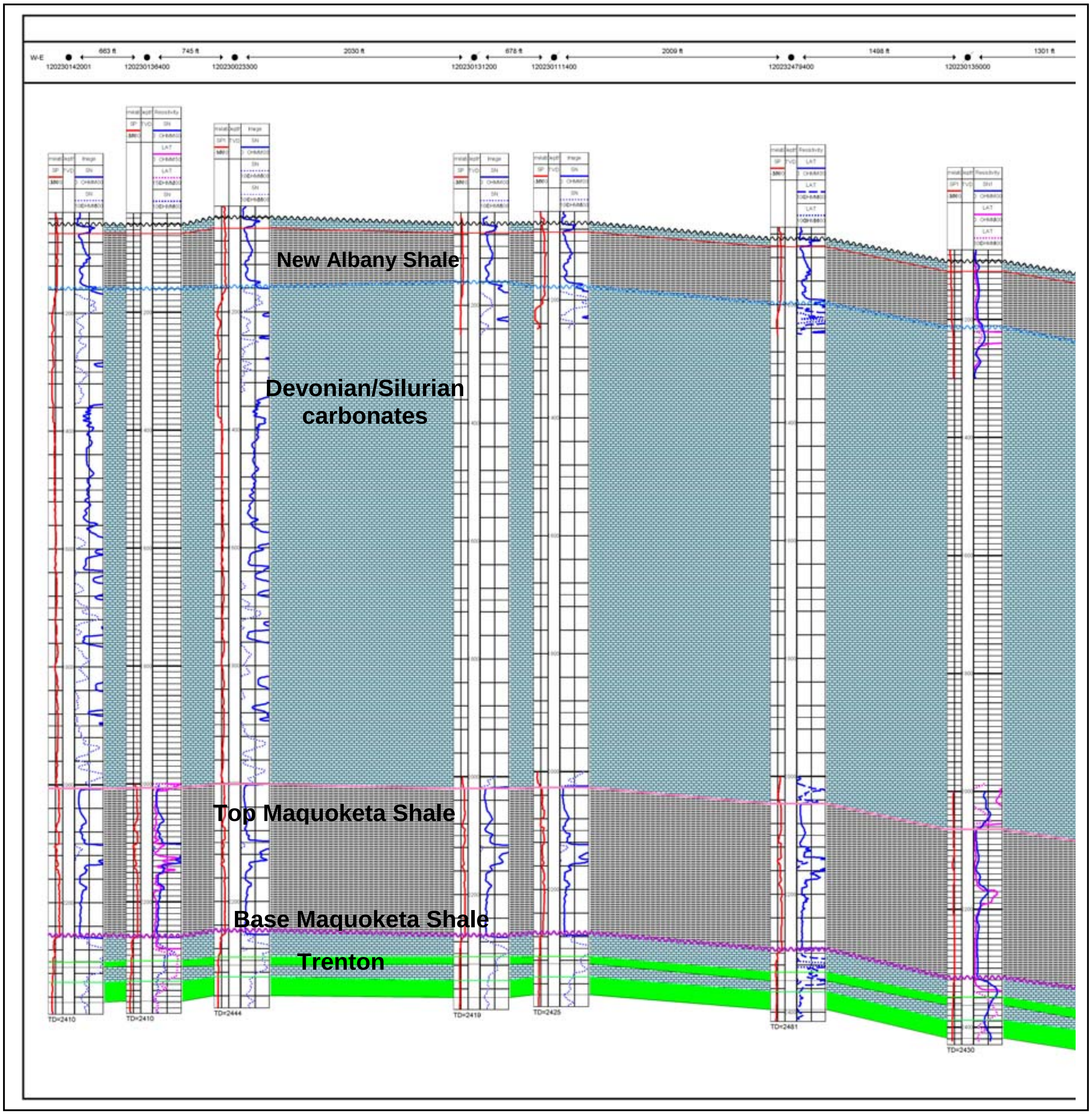



Figure 11.East- West structure cross section of Westfield. Vertical exaggeration is 5X. Index map is shown in Figure 7.

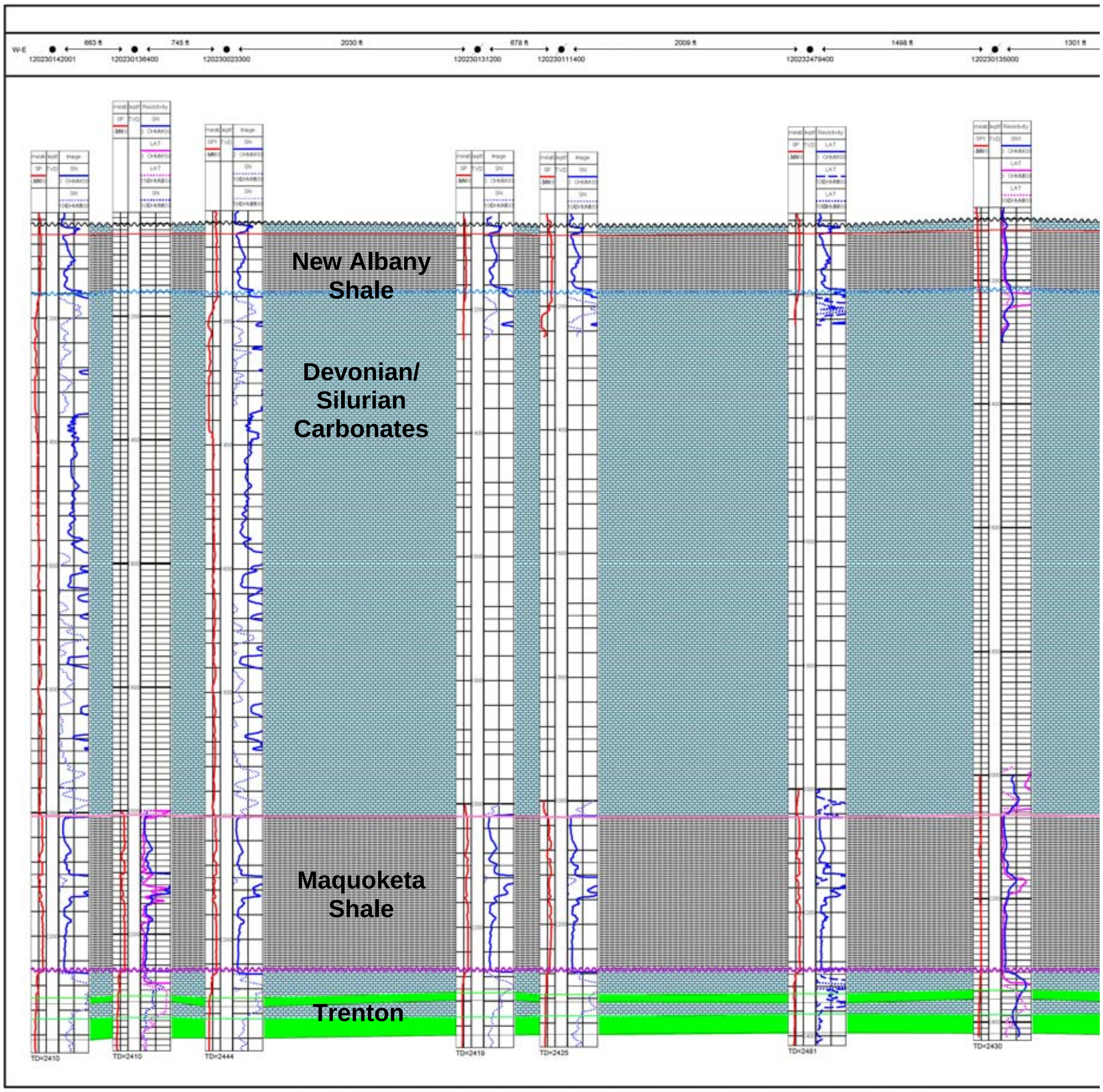



**Figure 12.** East-West stratigraphic cross section in Westfield. Vertical exaggeration is 5X. Index map is shown in figure 7. Green layers are reservoir intervals. Note the layers are all of relatively uniform size across the cross section

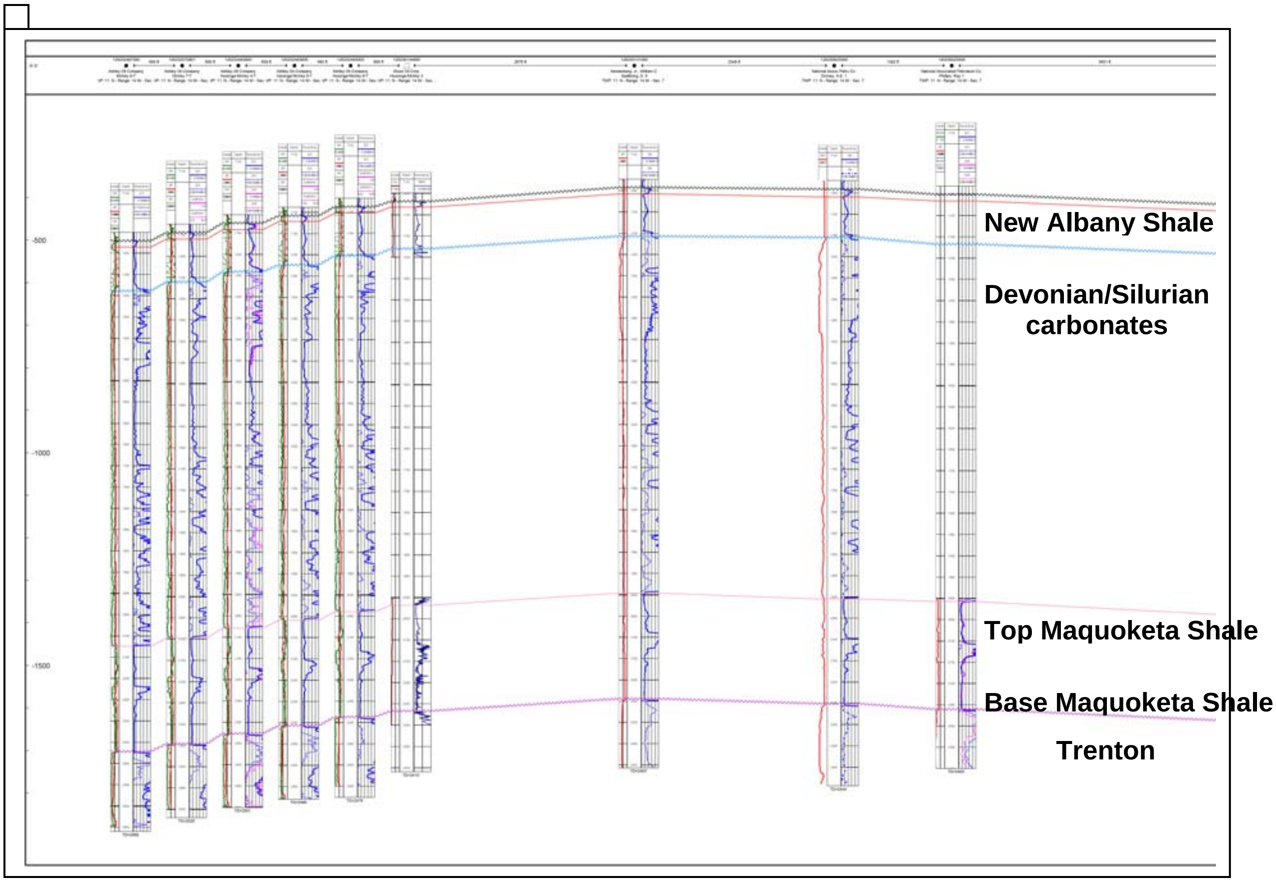



**Figure 13.** North-South structural cross section across the Westfield field. Vertical exaggeration is 5X.

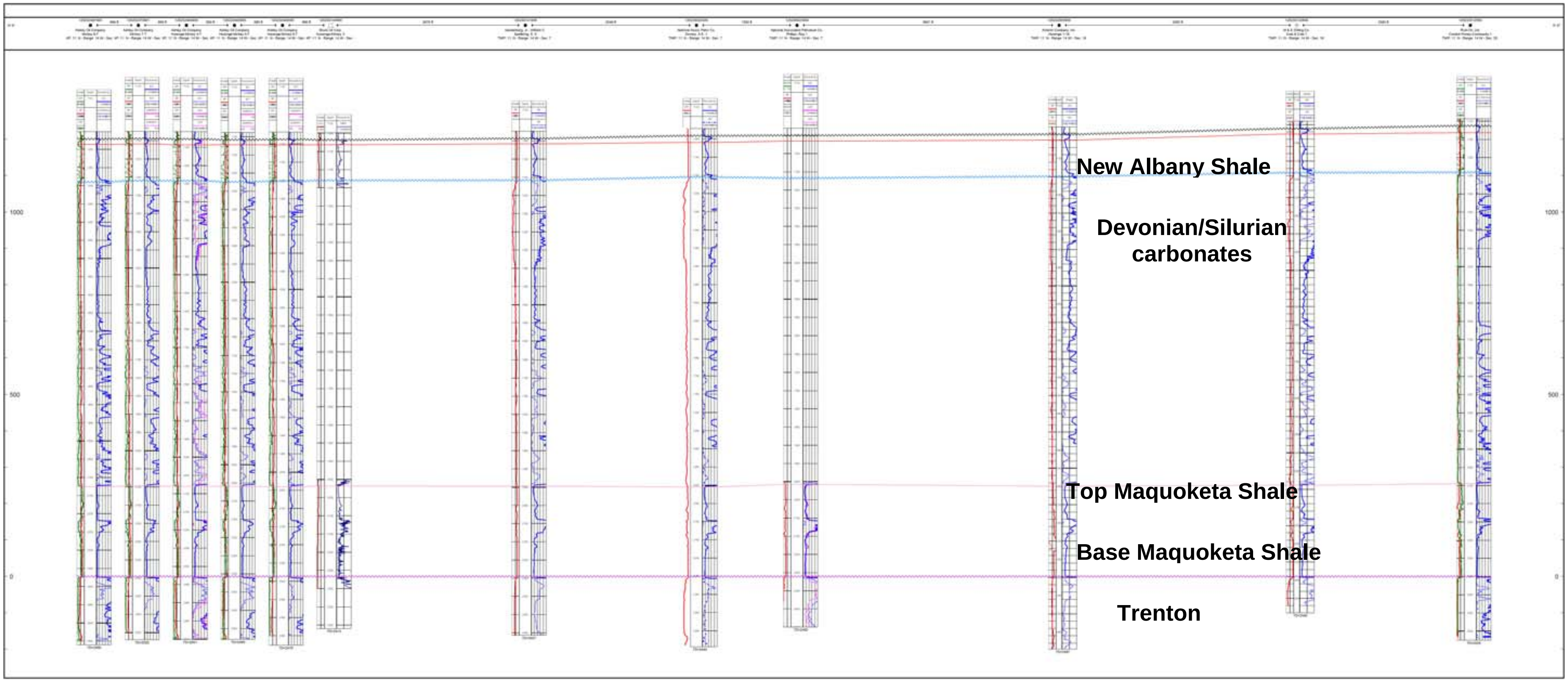



**Figure 14. North-South stratigraphic cross section across Westfield. Vertical exaggeration is 5X. The Hunton section thickens towards the south along the "tongue" shaped feature along the southern end of the fold axis.**

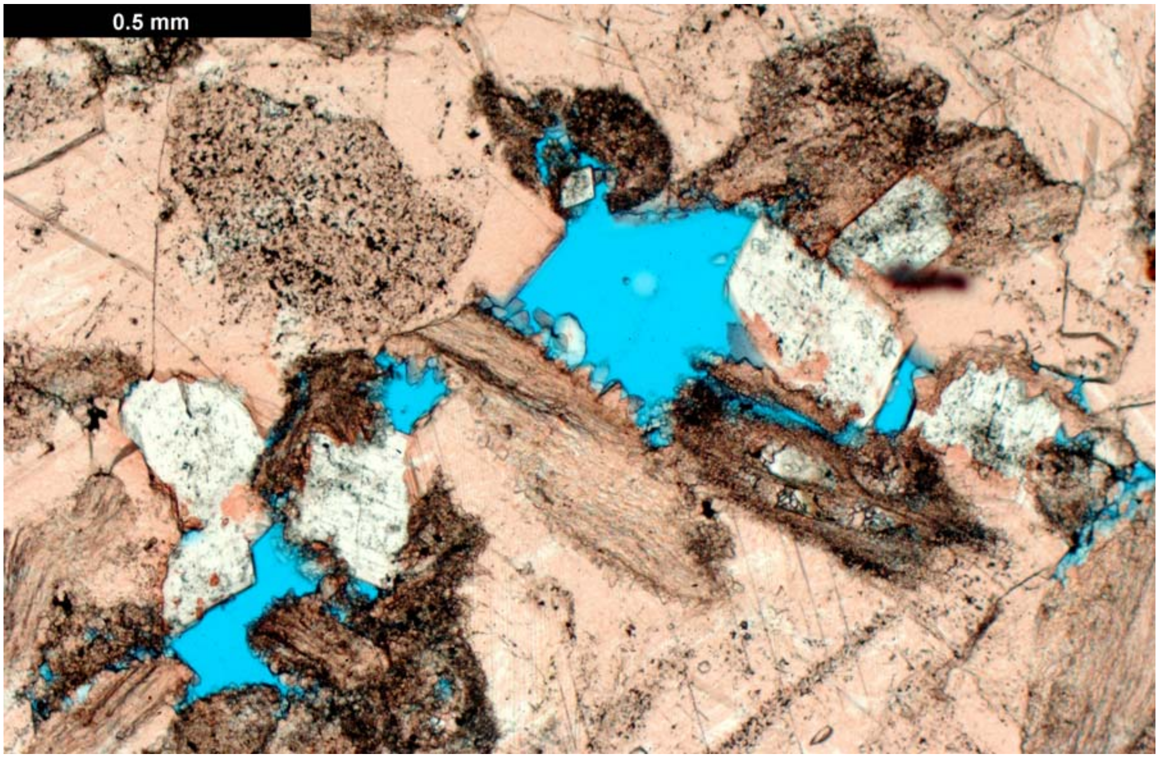



**Figure 15. Picture of pore spaces present within parts of the Trenton. Note the sharp euhedral boundaries in several of the cement crystals, porosity appears to be the result of dissolution of carbonate grains and cement**

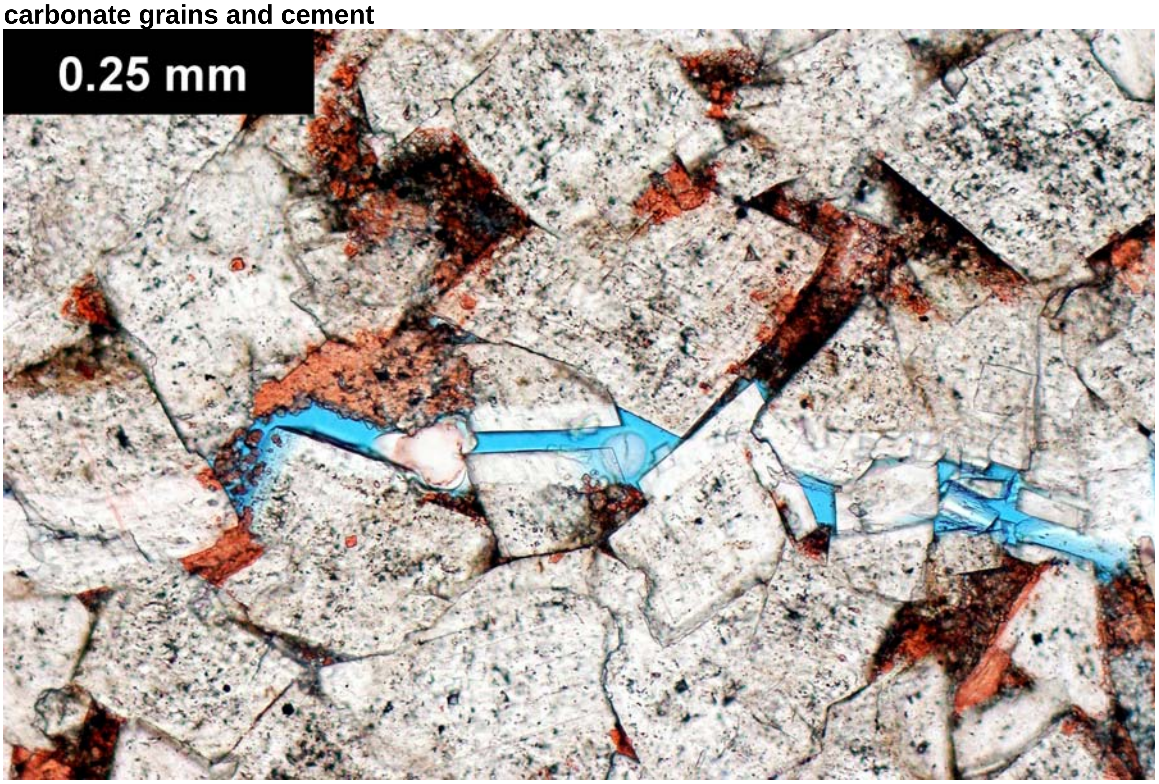



**Figure 16.** Fracture cutting though dolomite which was formed in a larger fracture (aperture of the larger fracture is about 1.5cm). Notice how the dolomite has grown into the space formed by the fracture.

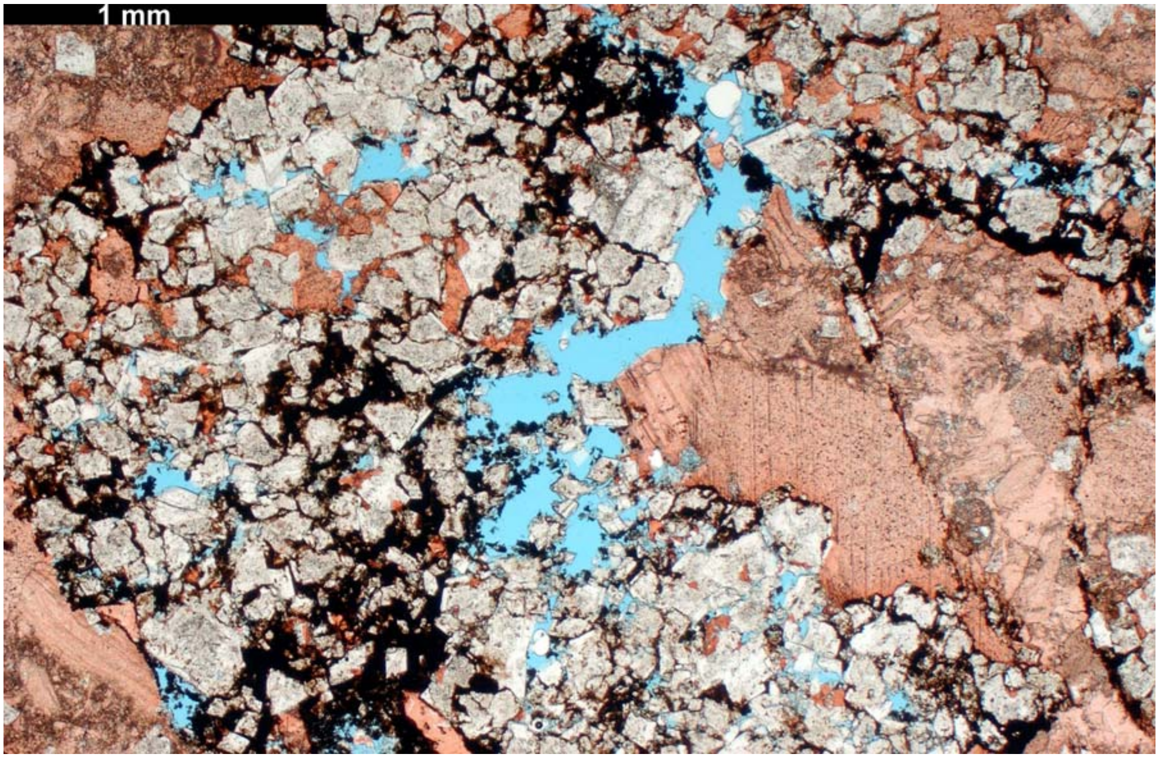



**Figure 17.** Dolomite filled fracture into a tightly cemented unit. The fracture has been enlarged due to dissolution prior to dolomite precipitation.

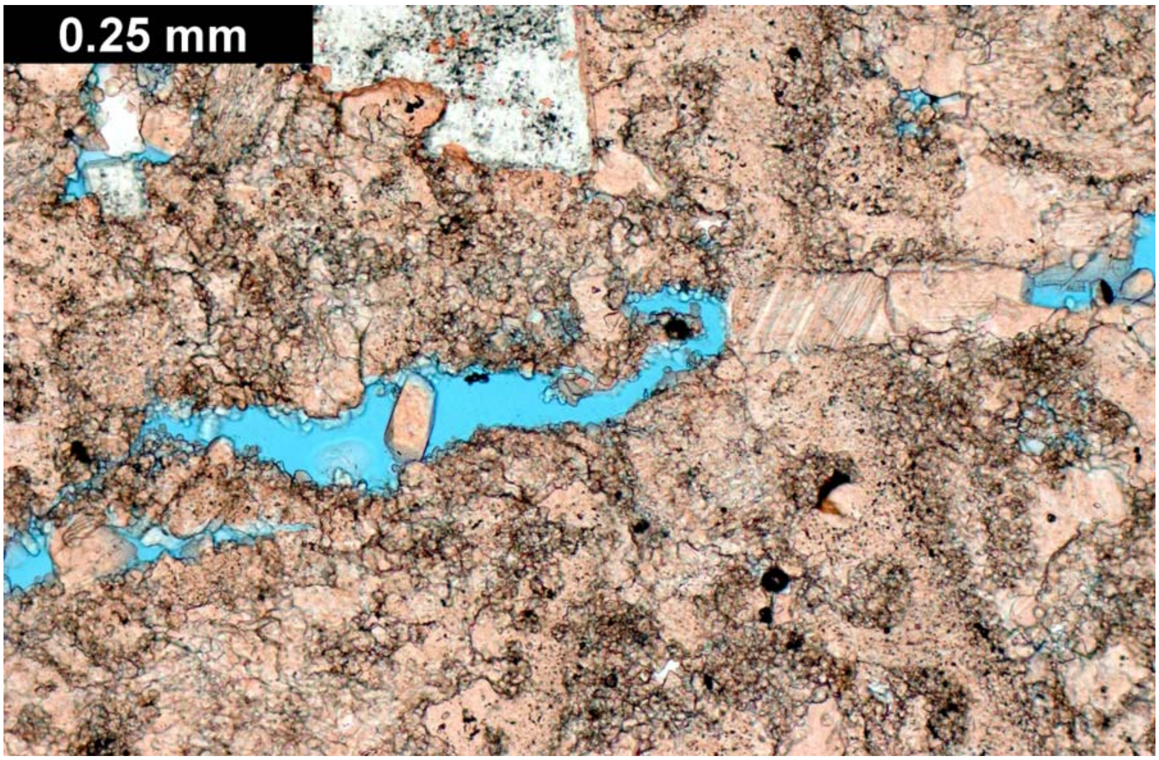



**Figure 18.** Calcite cement forming in fractures. The calcite cement is present in both a very fine grained lining, but also as a larger blocky cement that has completely bridged part of the fracture.

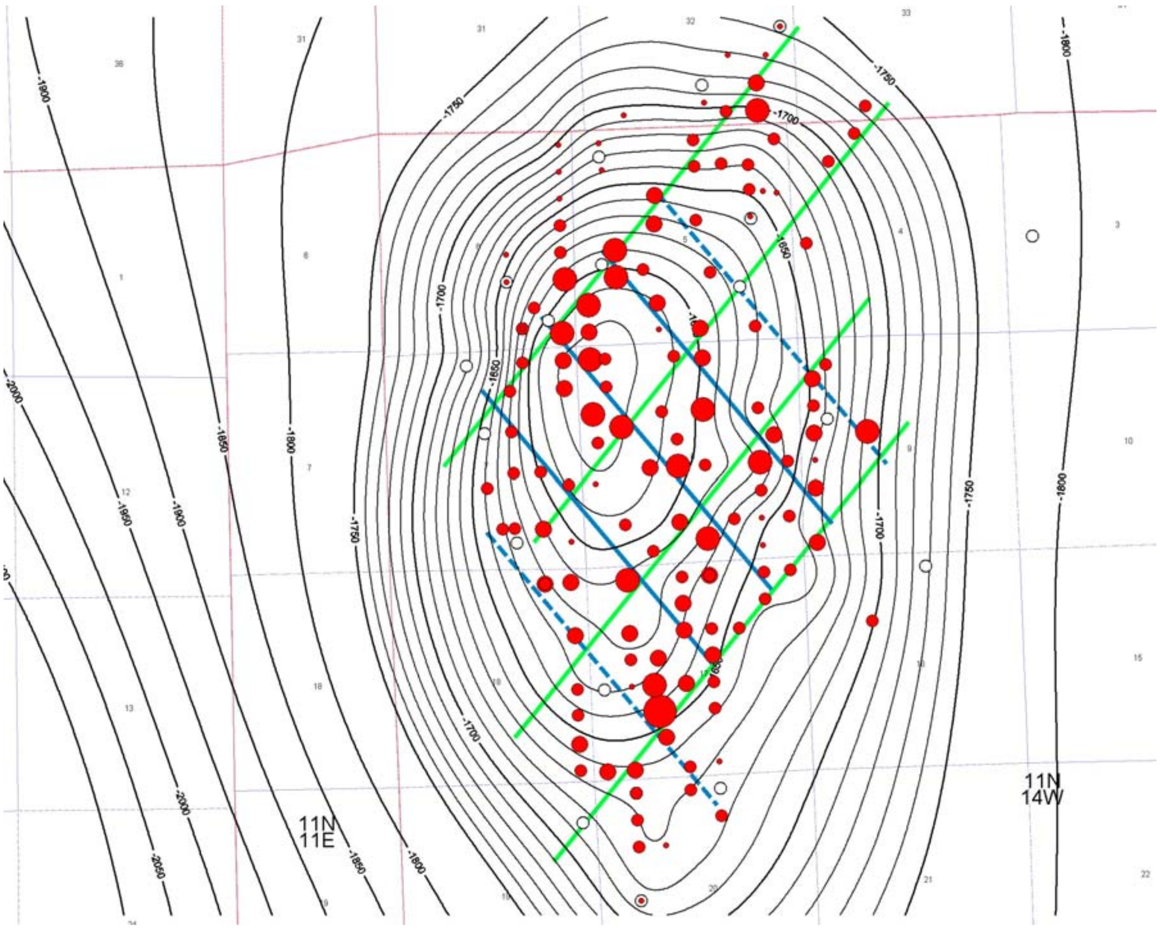



**Figure 19.** Fracture trends as determined by trends in Initial Production. Dashed lines represent possible fracture zones that lack significant data, but have similar spacing and a few data points.

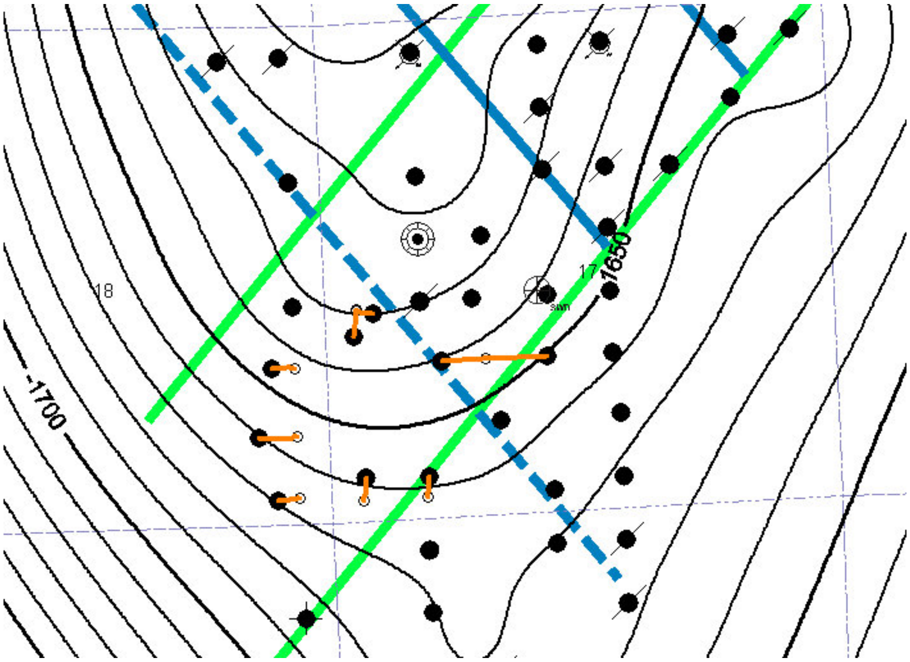



**Figure 20.** Fracture traces with horizontal wells shown. Well in section 17 with two long West-East horizontal legs is the Lindley #5 well.

## Conclusions

Diagenetic alteration of carbonate accumulations to highly porous and permeable dolomite is a key factor in forming many Devonian, Silurian and Ordovician reservoirs in the Illinois Basin. This is not an important factor in younger Middle Mississippian carbonate reservoirs which are typically limestones that display little alteration. Prominent alteration is associated with unconformity surfaces related to the sub-Kaskaskia and sub-Tippecanoe unconformities although hydrothermal fluid alteration within the Ordovician may be widespread and a stratified brine reflux mechanism may be a significant component in the development of the Geneva Dolomite.

Many existing Lower Paleozoic fields in the Illinois Basin have pronounced structural closure, some are associated with differential compaction of younger strata over Silurian reefs which may themselves be related to paleotectonic features. Many of the major structures in the basin are also expressed in Lower Paleozoic strata and are likely to have expression as basement features.

There is a shift of closure with depth observed in some structural features. The location of the crest of structures changes with depth and structurally closed areas mapped on younger Middle Mississippian strata are not the same areas as those mapped on older Lower Paleozoic Devonian, Silurian and Ordovician strata. Therefore, the established exploration practice of drilling shallow structures to deeper depths is a strategy that must be refined to successfully explore for Lower Paleozoic reservoirs.

There is potential in the Illinois Basin for the discovery of hydrothermally altered fault/fracture based plays in the Ordovician Trenton Limestone similar to those found in the Michigan and Appalachian Basins. Analysis of porosity and permeability data from Trenton rocks shows generally low porosity in most samples however there is a smaller distribution of samples with very high porosity and permeability indicating sporadic development of intervals of excellent reservoir quality.

There are examples of combination traps with a strong stratigraphic component e.g. the Niagaran age Silurian production along the Sangamon Arch. The alteration of fossiliferous limestones to dolomites with moldic and vuggy porosity is a major factor in developing petroleum reservoirs in these units.

There is potential to more fully develop the subcrop play of Lower Devonian reservoirs in the deeper Fairfield portion of the Illinois Basin. Interpretation and analysis of available data for these units will assist exploration for stratigraphic traps.

Existing reservoirs in lower Paleozoic units in the Illinois Basin produced from pronounced structural closures. Recent research on the structural evolution of major features in the Illinois Basin suggests that the Illinois Basin was influenced by nearby late Paleozoic events related to the nearby Appalachian – Ouachita Orogenies (Kolata and Nelson 1991) as well as Ancestral Rockies events associated with compressive block style deformation (Marshak et al., 2003). These findings suggest the potential for fracture and fault related reservoir discoveries within lower Paleozoic units.

There has been a significant increase in permits issued to drill to Lower Paleozoic since the inception of this study. Staff at all three participating surveys have fielded numerous requests for information and advice regarding exploration and development in Lower Paleozoic units. Numerous test wells have been drilled with significant discoveries in the Mt. Auburn trend in Illinois and in other areas.

**Source Rocks**

It has been established by previous workers that Silurian and younger reservoirs in the Illinois Basin are sourced from the Devonian New Albany Black Shale. While the New Albany Shale contains intervals that exceed 10 percent Total Organic Carbon and some regions are in the oil window, there has been sparse exploration in this unit as a petroleum reservoir. The New Albany Shale has potential to become a producing horizon in the Illinois Basin.

The Upper Devonian New Albany Shale is a widespread, thick, organically-rich source rock that is present virtually everywhere that oil and gas are produced in the Illinois Basin. It is thickest in southern Illinois and western Kentucky, where it is more than 400 feet thick. The source rock is predominantly Type II Oil Prone material and is the major source of oil in Silurian through Pennsylvanian reservoirs in the Illinois Basin. Numerous studies of the New Albany Shale in Illinois (by Cluff et al., 1981, Cluff and Byrnes, 1991) describe an organic rich source rock that is generally in the oil window with some areas of intense generation that likely produced gas in the deep basin and in the Fluorspar District in southeastern Illinois. There has been recent gas exploration in the New Albany in Illinois, most gas discoveries to date have been marginal and are located on anticlinal structure domes, along the LaSalle Anticline trend, at Russellville and Westfield, and on the Clay City Anticline. Although the original gas wells drilled are vertical wellbores, it is believed that production can be improved using horizontal drilling programs, such as one recently undertaken at Russellville. In Indiana, exploration of the New Albany is predominantly on reef-drape structures along the Terre Haute Reef Bank and has resulted in several gas discoveries.

Gas chromatography analyses of oil from 4 Trenton reservoirs, 4 Silurian reservoirs and 3 Devonian reservoirs have been completed for the source rock-oil correlations studies. Interpretation of these gas chromatographs show strong similarities among Trenton samples and similarities among Silurian age oil but Silurian age oils are very different from Trenton age oils. Trenton age oils are largely devoid of n-C17 and higher components while the heavy end of the Silurian age oils taper off gradually.

**Upper Middle Devonian Production**

Lingle and Cedar Valley limestone reservoirs are the youngest Middle Devonian producing strata in Illinois. Lingle production is primarily associated with regional anticlinal structures (Assumption Field in Christian Co., at the northern toe of Louden Field in Fayette Co., and Woburn Field in Bond Co.). Hoing Sandstone occurs in the basal Cedar Valley limestone and is a prolific shallow pay at Colmar-Plymouth Field in western Illinois. The Hoing Sandstone lies at the sub-Kaskaskia unconformity and is composed of well rounded, highly porous, dolomite cemented sandstone similar to the Dutch Creek Sandstone.

**Lower Middle Devonian Geneva Dolomite Miletus Field**

The Geneva Dolomite is one of the most prolific reservoir units in the Illinois Basin. It produces from reef-drape areas (Miletus, Lillyville, and Tonti) and on regionally-extensive anticlines with strong elements of closure (Centralia, Salem, and Louden). It is formed from regional dolomitization of fossiliferous limestone deposits. Middle Devonian strata commonly have sand grains distributed throughout the predominantly carbonate lithology, but only occur as bedded layers in limited areas of the basin.

Production in Miletus Field in Marion County Illinois increased from 10,000 barrels per year to 100,000 barrels per year after the Geneva Dolomite discovery. A total of 2 million barrels of oil were produced from the Geneva Dolomite in the first 2.5 years of production. Miletus is a typical example of a Geneva Dolomite field with closure created by differential compaction over an underlying Silurian Reef. Younger Devonian strata thin 20 feet or more over the top of the reef due to less deposition over the paleo-high. 3-D seismic exploration was successfully used to define this prolific extension reservoir beneath Forbes Lake to the south. Horizontal/directional drilling beneath Forbes Lake was also an element to the success at Miletus/Forbes Lake.

**Middle Devonian Dutch Creek Sandstone Pays**

Dutch Creek Sandstone reservoirs are located at the base of the Middle Devonian, at or just above the Sub-Kaskaskia unconformity. The reservoirs are quartz sand with dolomite cement. Sands are lenticular and grade laterally and vertically into sandy dolomite or limestone. The distribution of Dutch Creek reservoirs has been expanded in recent years to include production in Clay and Jasper Counties. Sands may be deposited in lows, sinkholes, or fractures on the unconformable Lower Devonian carbonate surface, and sand is not uncommon throughout the Grand Tower. All established fields are located on positive structural features. Although the deposits are thin (usually less than 15 feet), they may be prolific reservoirs. One Dutch Creek well in Aden Field has produced over 2.4 million barrels of oil from the Dutch Creek and shallower Mississippian pays.

**Lower Devonian Reservoirs Sesser Field**

The sequence of events leading to development of reservoir quality rock in Lower Devonian strata in central Illinois started with deposition of carbonates containing abundant sponges. Followed by dissolution of silica in some sponge spicules; re-precipitation of silica as microcrystalling chalcedony and quartz (chert nodules and bedded chert) leading to formation of porous chert. In Sesser Field uplift and erosion at sub-Kaskaskia unconformity has apparently removed upper Clear Creek deposits. All Clear Creek Fields have strong element of structural closure. The Clear Creek and the Grassy Knob Formations contain cherty intervals that are under-explored plays. All established Lower Devonian fields have a strong element of structural closure, there is indication that there is potential for a stratigraphic subcrop play in the region.

**Lower Silurian Reservoir at Buckhorn Field in Western Illinois**

Buckhorn Consolidated Field in Adams and Brown counties in Illinois is one of the most productive Lower Silurian fields in the Illinois Basin. The field was discovered in 1961 with a substantial field extension discovery in 1981 and has produced over 2 million barrels of oil from a depth of 650 feet. The producing horizon is a sucrosic dolomite located at the base of the Silurian carbonate section in the Kankakee Formation and directly overlies the sub-Kaskaskia unconformable surface on the Ordovician Maquoketa Shale. Kankakee carbonates accumulated in a regional drainage system eroded into the underlying Maquoketa Shale in response to the initial Silurian marine transgression. Later diagenetic events led to preferential dolomitization and dissolution of fossils to form moldic and vuggy porosity in the basal Silurian carbonates. Structure played a minor role in petroleum accumulation at the Buckhorn Consolidated Field. The Devonian New Albany Shale is the ultimate seal for the field.

**Silurian Pinnacle Reef Play**

Most of the Silurian reefs were discovered in the 1940s and 1950s, using traditional seismic and subsurface mapping to identify favorable positive structures for drill sites. The New Albany Shale is in close contact with the reef and is the source rock as well as the reservoir seal. Production occurs from both fossil framework build-ups and flank deposits, as well as younger porous strata draped over the reefs. Most reef production occurs on the west side of the DuQuoin Monocline, in a region known as the Sparta Shelf. Diagenetic alteration and microfracturing likely contribute to reservoir quality. New reef production has been discovered as recently as 2002, when Vintage Resources re-entered an old test well and found oil in the Stone Church field. The Stone Church reef was discovered in 1994 using gravity, magnetics and 2-D seismic in addition to linear trend interpretation and lithology studies. The reef is associated with an underlying basement fault that dies out in the Maquoketa shale beneath the reef. East of the Du Quoin Monocline, the reefs are covered by thicker layers of Middle Devonian sediments, which is may prevent the Silurian reef from being charged with oil. These reefs have, however, contributed to the formation of several prolific Devonian reservoirs.

**Sangamon Arch**

The Sangamon Arch is a broad southwest-trending structure in west-central Illinois, which was formed as a result of upward warping during Late Silurian through Early-Middle Devonian times. The Silurian deposits of the Sangamon Arch are bounded by the pre-Middle Devonian (sub-Kaskaskia) and post Ordovician interregional unconformities. Oils are sourced from the New Albany shale, and reservoirs are charged where the Devonian sediments are absent due to erosion or non-deposition. Some reservoirs have been enhanced by hydrothermal and meteoric dissolution of fossils and dolomitization of sediments. Oil production from Silurian strata along the Sangamon Arch, includes two field study areas, the Springfield East Field and the Mt Auburn trend. The two fields depict the two main types of plays in the area. The channelized patch reefs such as Springfield East and the patchy barrier type reefs of the Mt. Auburn Consolidated field.

**Silurian Patch Reefs: Springfield East**

The Springfield East Field was discovered in 1960, and has produced 684,000 barrels of oil. Production correlates with deposition of Devonian sands, although the production is from the Silurian inter-reef sediments. Channels formed between reefs because reefs were more resistant to erosion. Payzone sediments are dolomitized, transported bioclasts have been dissolved, creating significant porosity and permeability. Silurian sediments underlying sands were karstified during the deposition of the Devonian sands, which served as a conduit for hydrothermal fluids and further alteration after burial by the New Albany Shale.

**Silurian Carbonate Reservoirs: Mount Auburn Trend Along the Sangamon Arch:**

The Silurian deposits of the Sangamon Arch are bounded by the pre-Middle Devonian (sub-Kaskaskia) and post Ordovician interregional unconformities. As a result of pre-Upper Devonian erosion, no Lower and Middle Devonian rocks are present on the Sangamon Arch. The Silurian rocks of the Sangamon Arch have produced for over 60 years with cumulative production being more than 20 million barrels of oil from dolomitized carbonates in the upper part of the Silurian succession. In the Mount Auburn trend, production thus far has been chiefly from the uppermost part of the Niagaran Series; most wells did not test the deeper reservoirs. This study identified permeability pinch outs at several horizons along the Mount Auburn trend in Macon, Christian and Sangamon Counties. The reservoirs display shallowing-upward cycles and include dolomitized bioclastic grainstone facies in the upper part and dolomitized coral reef/rudstone facies in the lower part of the Niagaran succession. The reservoirs are of limited lateral extent. The highest production is associated with these lower reservoirs that most wells have not tested.

**Trenton Oil Fields and Potential Production in Illinois**

Trenton production in Illinois is confined to areas with pronounced structural closure at the base of the Ordovician Maquoketa Shale. Several fields produce from permeable grainstone intervals in which oil is trapped by overlying dense limestone. Production from dolomitized fractured intervals has been reported in other fields. There are 35 separate Trenton pools, most having been discovered from the early 1940s to the late 1960s. Size ranges from 20 – 2,000 acres at depths up to 4,000 feet. Up to 5 million barrels per field has been produced. All fields produce on structures and are most likely fractured. Most reservoirs have low porosity. Some reservoirs are dolomitic. There is potential for fault-based Trenton reservoirs in Illinois similar to the Albion Scipio Field 200 miles to the north in the Michigan Basin.

**Trenton Production at Centralia and Westfield**

In Centralia Oil field there is a shift in structural closure with depth. The Mississippian Barlow Limestone contoured structure map shows an elongate anticline with north and south regions of closure separated by a small saddle. The Trenton Limestone contoured structure map has closure on the north end of the anticline and the crest as mapped on Barlow has shifted to the south. Trenton production is confined to the anticlinal closure mapped on the Trenton. The reservoir interval is composed of grainstone containing dissolution-enhanced porosity.

There is potential for deeper Trenton grainstone reservoirs throughout the Illinois Basin. Trenton structural closure may not be reflected by shallower horizons. Westfield in eastern Illinois produces on a dome with 100 feet of closure on the Trenton. The reservoir is fractured limestone with dolomite reported in some intervals. There are three porous intervals in Westfield. Major fracture trends based on alignment of high initial production show fractures oriented northeast-southwest and another set oriented perpendicular to the primary set. Many wells exhibit flush production associated with fractures. Horizontal Trenton wells at Westfield generally have much higher production rates than surrounding vertical wells. East-west horizontal legs have higher production rates than north-south legs. Major fracture trends may be caused by basement faults. There is the potential for significant fault related oil discoveries on the flanks of structures.

**Secondary Porosity in the Trenton (Galena) Dolomite of Northern Illinois**

Outcrop study of the Trenton in Northern Illinois shows karstification along fractures. The porosity models and fracture patterns developed for the outcrop have application for exploration of Trenton reservoirs in the subsurface. Karstification in the Trenton occurred in the following sequence: Galena deposition (mid-Ord), uplift and meteoric karstification (mid-Ord), Maquoketa through Devonian deposition (mid-Ord thru Dev), hydrothermal karstification (late Paleozoic), uplift, erosion, and further meteoric karstification (late Paleozoic thru present). Secondary porosity occurs as conduits, fractures, and matrix vugs. Fractures and conduits are arranged in an orthogonal pattern with conduits forming at the fracture junctions. Primary fluid flow occurs through conduits, followed by flow from fractures, with fluid storage occurring in the matrix.

Source beds for the Trenton are the overlying Maquoketa shale and the underlying Guttenberg (Decorah) shale. Hydrocarbon can be trapped in faulted karst domes.

## Technology Transfer

### Website Development

Over 100 publications in the Illinois State Geological Survey Circular Series and 128 publications in the Illinois Petroleum series related to petroleum exploration and development in Illinois have been scanned and linked to the ISGS website for the public to view. Information is continually added to the website. To date over 140,00 scanned log images are available on the ILoil website, including all lower Paleozoic geophysical logs in Illinois. Data and previous studies pertaining to the New Albany Shale are available on line through the ISGS website which can be accessed at isgs.uiuc.edu. Much new data has been added to the ILoil website.

### Presentations and Publications:

J.P. Grube, Seyler B., Huff, B. G. and Crockett, J. E., 2004, Trenton Oil Fields and Potential Production in Illinois, Program with Abstracts 2004 American Association of Petroleum Geologists 33rd Annual Eastern Section Meeting, p. 78-79.

H. E. Leetaru, 2005 Trend Surface analysis of the Trenton, presented at the Illinois Oil and Gas Association Meeting March, 2005 at Evansville, Indiana

Seyler B., J. P. Grube, J. E. Crockett, P. M. Johanek, B. G. Huff, R. A. Knepp., S. R. Gustison, R. D. Lipking, 2005, Petroleum Potential for the Lower Paleozoic Strata in the Illinois Basin, Eastern Section American Association of Petroleum Geologists Annual Meeting, Morgantown WV, Sept. 18-20, Abstracts Volume, p. 32-33

AAPG National Meeting Houston, Texas April 11, 2006
B. Seyler, J. P. Grube, J. E. Crockett, P. M. Johanek, B. G. Huff, R. A. Knepp, S. R. Gustison, and R. Lipking, 2006, Petroleum Potential of Under Explored Lower Paleozoic Strata in the Mature Illinois Basin, AAPG Program with Abstracts.

### Eastern Section AAPG in Buffalo New York October 2006

J. E. Crockett and R. Lipking, Petroleum Potential of Lower Devonian Subcrop Play, Eastern AAPG Program with abstracts

B. Seyler, J. P. Grube, J. E. Crockett, P. M. Johanek, B. G. Huff, R. A. Knepp, S. R. Gustison, R. D. Lipking, Under Explored Lower Paleozoic Strata in Illinois, Eastern Section AAPG Program with abstracts

J. P. Grube, B. Seyler, B. G. Huff, J. E. Crockett, Selected Illinois Basin Lower Paleozoic Cores, Eastern Section AAPG Program with abstracts

### Eastern Section AAPG in Lexington, Kentucky September 2007

Dean W. Ekberg, John P. Grube, and Joan E. Crockett, 2007, Secondary Porosity Development in the Galena (Trenton) Dolomite of Northern Illinois: Implications for Regional Fluid Flow and Hydrocarbon Accumulation, Program with abstracts 2007 Eastern Section American Association of Petroleum Geologists Annual Meeting, Lexington, Kentucky

B. Seyler and J. Crockett, 2007, Update of New Albany Shale Potential in Illinois, Program with abstracts 2007 Eastern Section American Association of Petroleum Geologists Annual Meeting, Lexington, Kentucky

**Workshop March 5, 2008: Following Presentations were given at the Preconvention Illinois Oil and Gas Association PTTC Workshop in Evansville, Indiana**

Secondary Porosity Development in the Galena/Trenton Dolomite of Northern Illinois Dean Ekberg

Trenton Oil Fields and Potential Production in Illinois: John Grube, Joan Crockett and Beverly Seyler

Trenton Production at Westfield and Centralia Fields Jon Brenizer

Siluro-Devonian Carbonates in Illinois: Play Analysis Hannes Leetaru

Western Illinois Shallow Silurian and Devonian Reservoirs at Buckhorn Consolidated and Colmar-Plymouth Fields Beverly Seyler and Joan Crockett

Sesser Oil Field Franklin County, IL Lower Devonian Clear Creek Chert Joan Crockett

Silurian Carbonate Reservoirs of the Mount Auburn Trend Along the Sangamon Arch Yaghoob Lasemi

Springfield East Oil Field Sangamon County, Illinois Bryan Huff

The Origin of Prolific Reservoirs in the Geneva Dolomite (Middle Devonian), West-Central Illinois Basin Beverly Seyler, John Grube and Zak Lasemi

Update of New Albany Shale Potential in Illinois Beverly Seyler and Joan Crockett

Tuscola Stone Quarry Fieldtrip and Core Workshop of Lower Paleozoic Reservoirs held April 17, 2008 at the Tuscola Stone Quarry in Tuscola, Illinois: Core Workshop held at the Illinois State Geological Survey Core Annex.

**AAPG Presentations April 2008**

Illinois Basin: Potential of Underexplored Lower Paleozoic Strata Beverly Seyler, Joan Crockett, Bryan Huff, Yaghoob Lasemi, Zoreh Askari, Jon Brenizer, John Grube

Ekberg, D.W. & Grube, J.P., 2008, Secondary Porosity Development in the Galena (Trenton) Dolomite of Northern Illinois: Implications for Regional Fluid Flow and Hydrocarbon Accumulation

**GSA Presentation**

Lasemi, Yaghoob and Seyler, B., 2008, Sangamon Arch Reef Play: An Important Exploration Target in Central Illinois

## Kentucky Geological Survey subcontract

**David Harris and John Hickman, Kentucky Geological Survey**

**A Systems Approach to Identifying Exploration and Development Opportunities in the Illinois Basin: Digital Portfolio of Play in Underexplored Lower Paleozoic Rocks**

Kentucky Geological Survey subcontract from the Illinois State Geological Survey
Ms. Bev Seyler, Principal Investigator, Illinois State Geological Survey
Dave Harris and John Hickman, Kentucky Geological Survey

Interim Report: Nov. 19, 2008

## Project Status

The western Kentucky portion of the Lower Paleozoic study has been delayed due to several reasons. Some of the final products resulting from this work are not complete. These delays have resulted partly from the interruption in DOE funding, which caused staff to be reassigned to other projects. In addition, the later renewal of the final year of funding coincided with the Kentucky Geological Survey (KGS) receiving significant state funding for a major carbon sequestration project resulting in delays for this project. KGS plans to continue work on this project to complete the various tasks defined at the start of the project. We plan to complete this work by June 30, 2009.

## Project Outline

The work at KGS has focused on gaining a better understanding of the regional structure and stratigraphy in the Illinois Basin. The following tasks were proposed for the project at KGS:

1) **Interpretation of reflection seismic data.** Interpretation of 2D seismic data from western Kentucky available at KGS. This work was the primary task for KGS in the project, and was completed during the first phase of the project. A report is included below. Seismic data is not included in the report due to licensing restriction. Digital data derived from the seismic interpretation (horizon picks) are include with this report. The task was originally planned to include seismic data from Illinois and Indiana, but these data had not been received when funding was cut.
2) **Regional pre-New Albany stratigraphic interpretation.** This task involved interpretation of formation tops and construction of regional cross sections using digitized and scanned well logs. A subcrop map on the pre-Middle Devonian unconformity is an important part of this task. Key cores will be included. This task is still in progress.
3) **Catalog of Devonian, Silurian, and Upper Ordovician oil fields.** This task involves compiling a summary of fields and data for pools producing from the Devonian New Albany Shale down through the top of the Ordovician Knox Group. Some of this work is complete, but final pool summaries are in progress.
4) **Characterization of pre-New Albany hydrocarbon source rocks.** Compilation of existing source rock data for pre-Upper Devonian rocks.

Task summaries follow:

## Interpretation of reflection seismic data, western Kentucky

### Overview

The seismic/geophysics portion of this project included the interpretation of 41 regional 2-D seismic lines across southernmost Illinois Basin (Figure 1a-f). After a review of the seismic characteristics of the regional geology within the project area, six major reflection horizons were interpreted. These seismic reflections correspond to the stratigraphic horizons of the:

1) Top of the Devonian New Albany Shale
2) Base of the Devonian New Albany Shale
3) Top of the Upper Ordovician Maquoketa Shale
4) Top of the Middle Ordovician Trenton Formation
5) Top of the Middle Ordovician Black River Group
6) Top of the Lower Ordovician Knox Supergroup

Attempts were made to interpret shallower horizons, but due to data quality and "muting" of the near-surface data to remove interfering surface waves, this was not feasible within our area of data. Fault-cut maps also proved impractical to create due to both the data quality/spacing and the highly complex Rough Creek Graben fault zones that have been exposed to numerous periods of tectonic reactivization.

### General Observations

The overall shape and orientation of the Rough Creek Graben and southernmost Illinois Basin can be observed from this data. The asymmetric patterns of stratigraphic packages become thicker and deeper to the west-northwest, away from western Kentucky and towards southern Illinois. While this is also evident from an analysis of the local well data (Figure 2), reflection seismology provides a 2-D view of regional trends, fault zones, etc.

The complicated, inverted nature of the Rough Creek Fault Zone (RCFZ) is also evident in the shallower (Devonian) horizons in this data. Even though the RCFZ is considered to be a down-to-south normal fault system, the top and base of the New Albany Shale horizons are dramatically elevated along and immediately south of the fault zone.

Although the extensional, basement-rooted faults of the Rough Creek Graben formed during the Early – Mid. Cambrian Era, this region of the Midcontinent has been exposed to regional tectonic stresses numerous times since then. The individual orogenies Taconic, Acadian, and Alleghanian that formed the Appalachian Mountains created far-field tectonic compressive stresses. These stresses reactivated this (and other) normal fault zones and created localized reverse faulting and inversion structures along the fault zone trend. The RCFZ was then further deformed during the regional extensional tectonics during the opening of the Gulf of Mexico (Triassic-Jurassic) and the creation of the Atlantic Ocean (L. Triassic – E. Cretaceous). The current RCFZ displays the deformation and offsets created through all six of these orogenies (3 compressive and 3 extensional).

**Data Results**

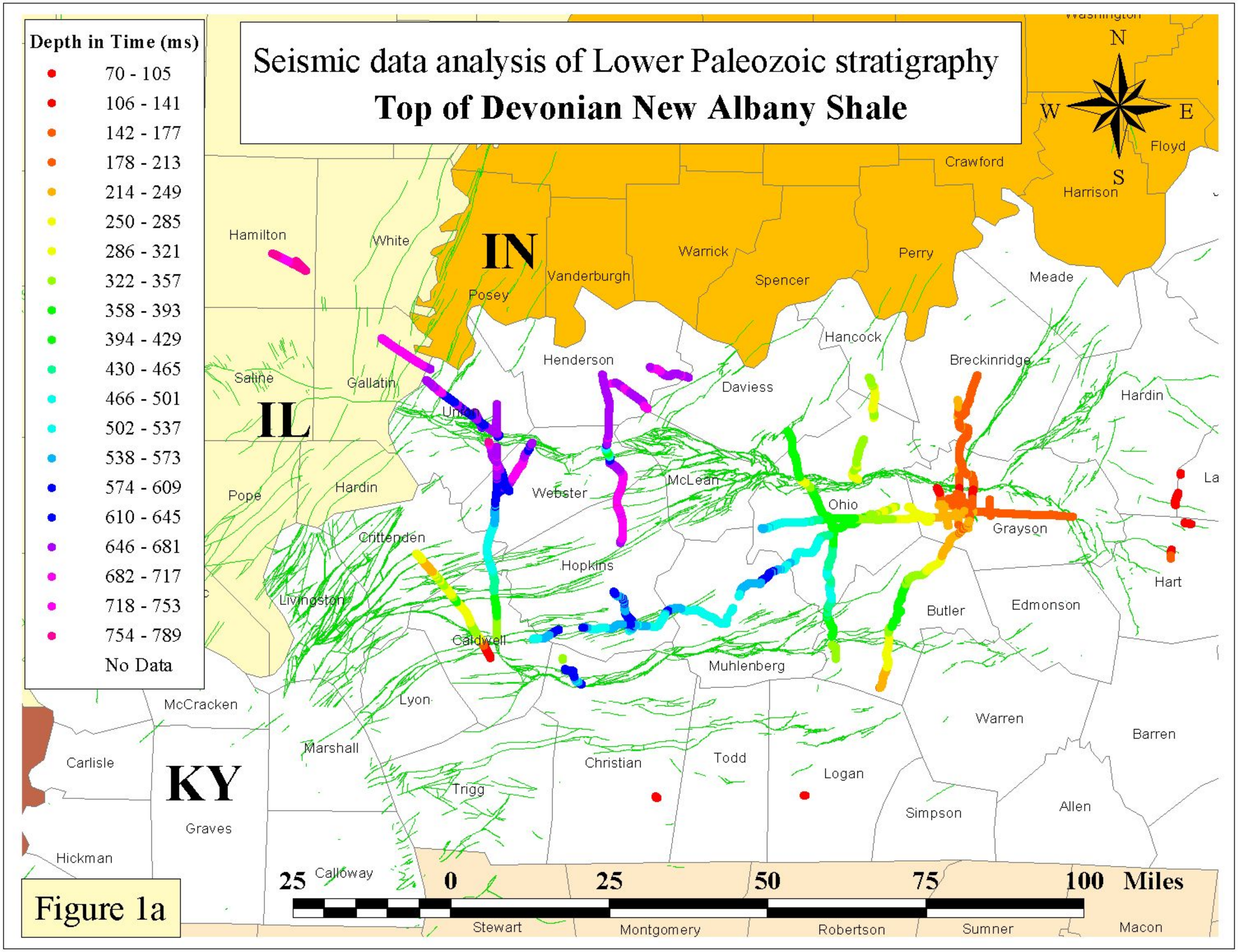
The file "LPIB_hrz.asc" comprises our seismic interpretations for this project. This file is an ASCII, column delimited data file with X, Y, and multiple Z values, grouped by individual seismic line names. Lines beginning with "!" are header and/or comment fields. X and Y values are Longitude and Latitude in decimal degrees based upon the NAD-83 datum. Z values are in milliseconds below a 500' above mean sea level datum. Lines processed with other datums were bulk shifted to a 500' datum before exporting. A null Z value of -999.25 is used if the horizon was absent and/or otherwise uncorrelatable. Locations (X, Y) w/o listed horizons (all nulls) were skipped from this output file.

Data file format:

Column 1 Latitude{(NAD83- Decimal Degrees, North)}
Column 2 Longitude{(NAD83- Decimal Degrees, East)}
Column 3 NALB [New Albany Sh]{Time (ms)}
Column 4 NALB_B [Base of New Albany Sh]{Time (ms)}
Column 5 MQKT [Maquoketa Sh]{Time (ms)}
Column 6 TRNT [Trenton Fm]{Time (ms)}
Column 7 BKRV [Black River Gp]{Time (ms)}
Column 8 KNOX [Knox SGp]{Time (ms)}

Also included are related GIS files for Kentucky. These include county outlines, 1:24K mapped surface faults, and oil and gas field outlines (both merged and separated by production type). All files are in Lat/Lon decimal degrees, based upon the NAD83 datum.

If you have any questions or comments, feel free to call me at 859-257-5500 ext.171, or email me at jhickman@uky.edu.



Seismic data analysis of Lower Paleozoic stratigraphy
Top of Devonian New Albany Shale
Depth in Time (ms)
70 - 105
106 - 141
142 - 177
178 - 213
214 - 249
250 - 285
286 - 321
322 - 357
358 - 393
394 - 429
430 - 465
466 - 501
502 - 537
538 - 573
574 - 609
610 - 645
646 - 681
682 - 717
718 - 753
754 - 789
No Data
N
S
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E
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KY
Hamilton
White
Posey
Vanderburgh
Warrick
Spencer
Perry
Crawford
Harrison
Floyd
Meade
Hancock
Breckinridge
Henderson
Daviess
Saline
Gallatin
Union
Hardin
Pope
Webster
McLean
Ohio
Grayson
Crittenden
Hopkins
Livingston
Caldwell
Butler
Edmonson
Hart
Muhlenberg
McCracken
Lyon
Marshall
Christian
Todd
Logan
Warren
Barren
Carlisle
Graves
Trigg
Simpson
Allen
Hickman
Calloway
Stewart
Montgomery
Robertson
Sumner
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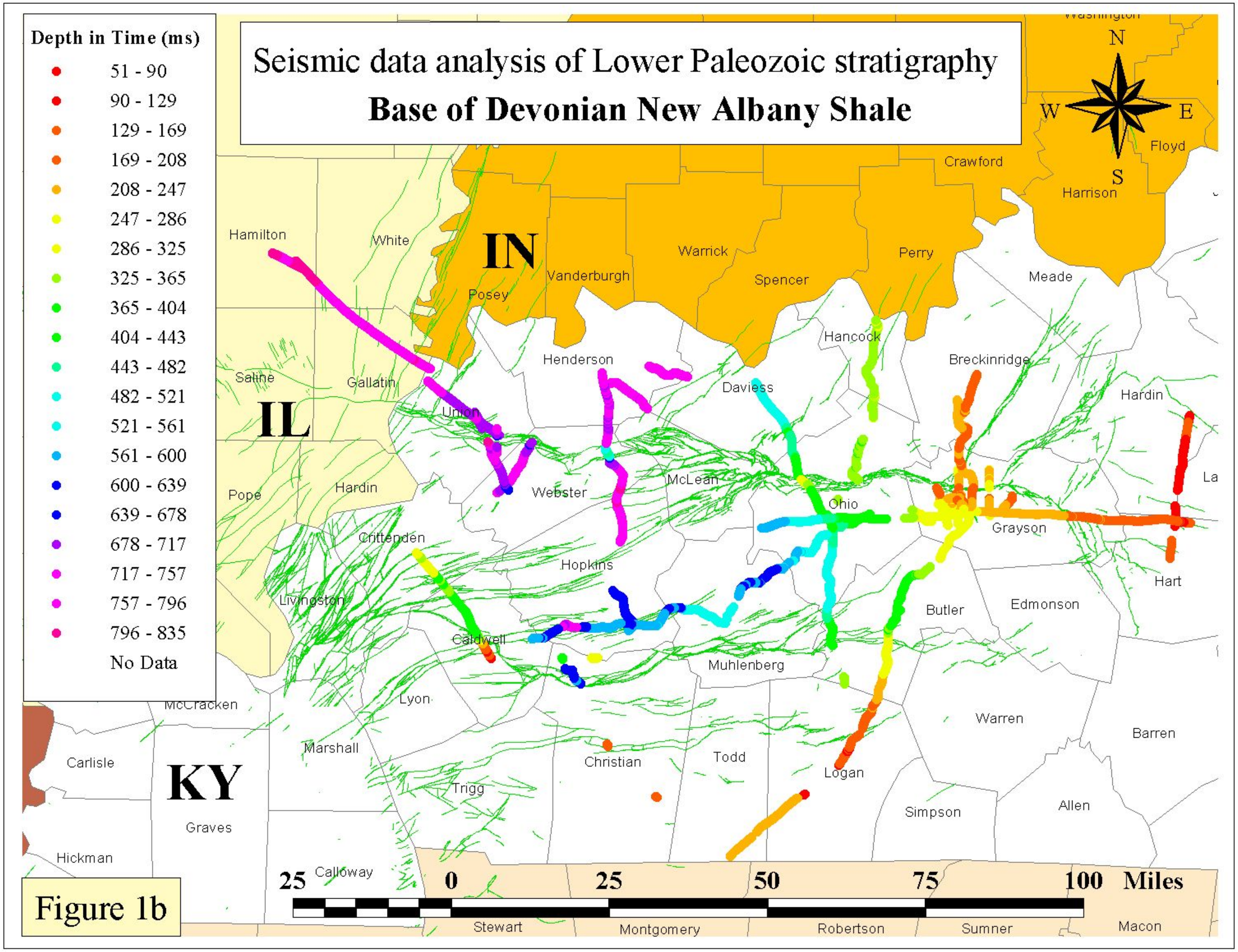
Miles

Figure 1a



Seismic data analysis of Lower Paleozoic stratigraphy
Base of Devonian New Albany Shale
Depth in Time (ms)
51 - 90
90 - 129
129 - 169
169 - 208
208 - 247
247 - 286
286 - 325
325 - 365
365 - 404
404 - 443
443 - 482
482 - 521
521 - 561
561 - 600
600 - 639
639 - 678
678 - 717
717 - 757
757 - 796
796 - 835
No Data
IN
IL
KY
N
S
E
W
Hamilton
White
Posey
Vanderburgh
Warrick
Spencer
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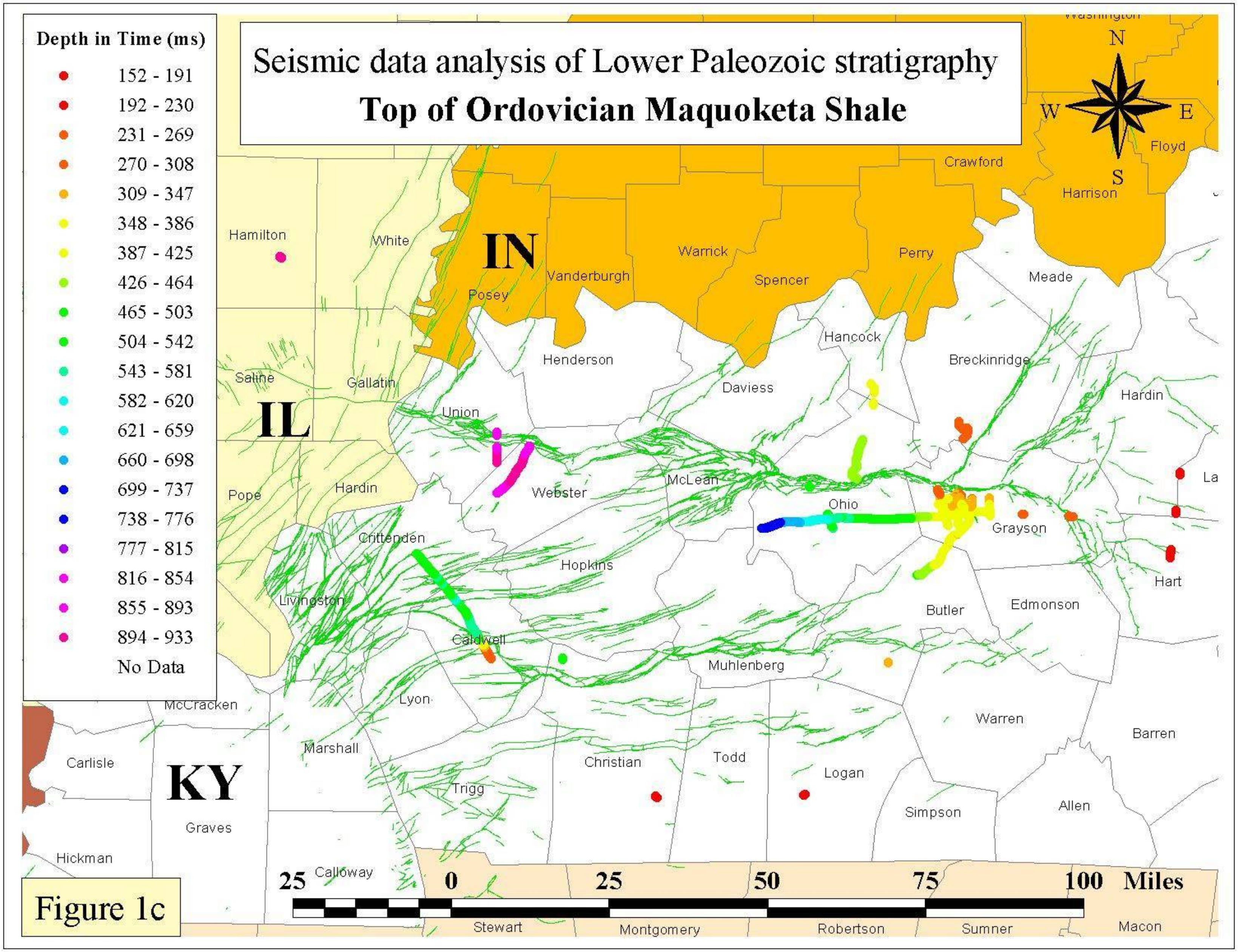
Miles


Figure 1b


Depth in Time (ms)
152 - 191
192 - 230
231 - 269
270 - 308
309 - 347
348 - 386
387 - 425
426 - 464
465 - 503
504 - 542
543 - 581
582 - 620
621 - 659
660 - 698
699 - 737
738 - 776
777 - 815
816 - 854
855 - 893
894 - 933
No Data
Seismic data analysis of Lower Paleozoic stratigraphy
Top of Ordovician Maquoketa Shale
N
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KY
Hamilton
White
Posey
Vanderburgh
Warrick
Spencer
Perry
Crawford
Harrison
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Figure 1c

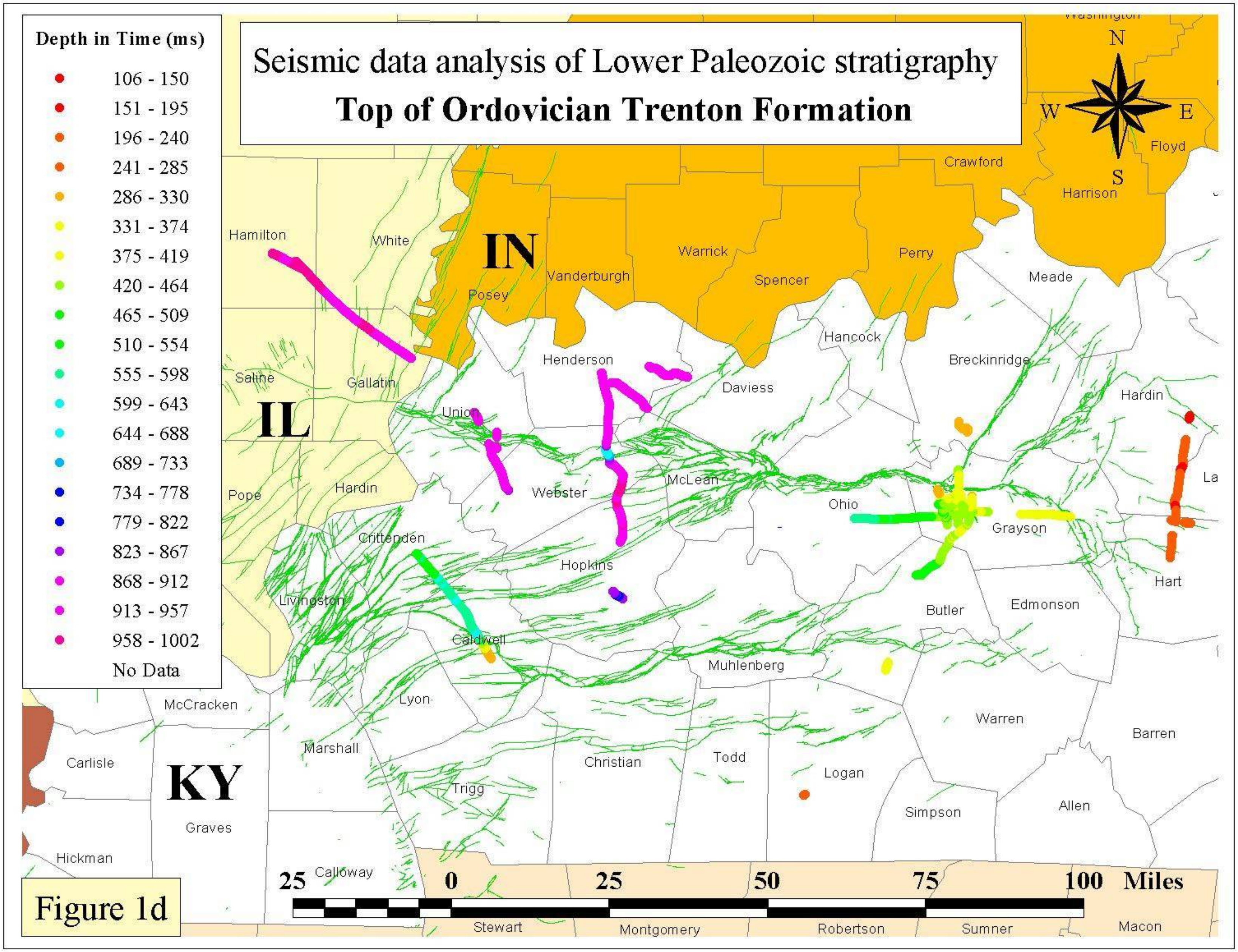
Seismic data analysis of Lower Paleozoic stratigraphy
Top of Ordovician Trenton Formation
Depth in Time (ms)
106 - 150
151 - 195
196 - 240
241 - 285
286 - 330
331 - 374
375 - 419
420 - 464
465 - 509
510 - 554
555 - 598
599 - 643
644 - 688
689 - 733
734 - 778
779 - 822
823 - 867
868 - 912
913 - 957
958 - 1002
No Data
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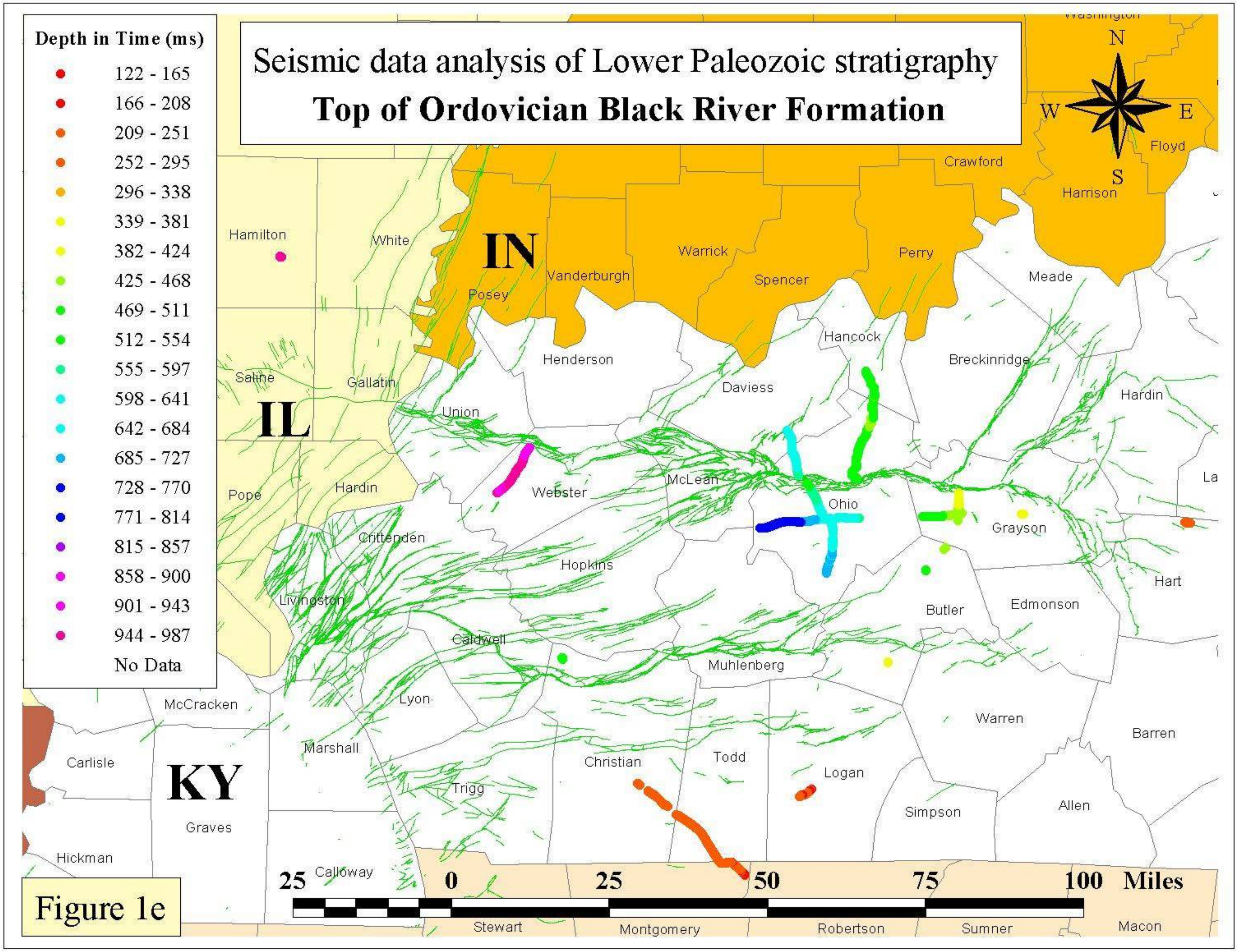
Figure 1d



Seismic data analysis of Lower Paleozoic stratigraphy
Top of Ordovician Black River Formation
Depth in Time (ms)
122 - 165
166 - 208
209 - 251
252 - 295
296 - 338
339 - 381
382 - 424
425 - 468
469 - 511
512 - 554
555 - 597
598 - 641
642 - 684
685 - 727
728 - 770
771 - 814
815 - 857
858 - 900
901 - 943
944 - 987
No Data
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Figure 1e
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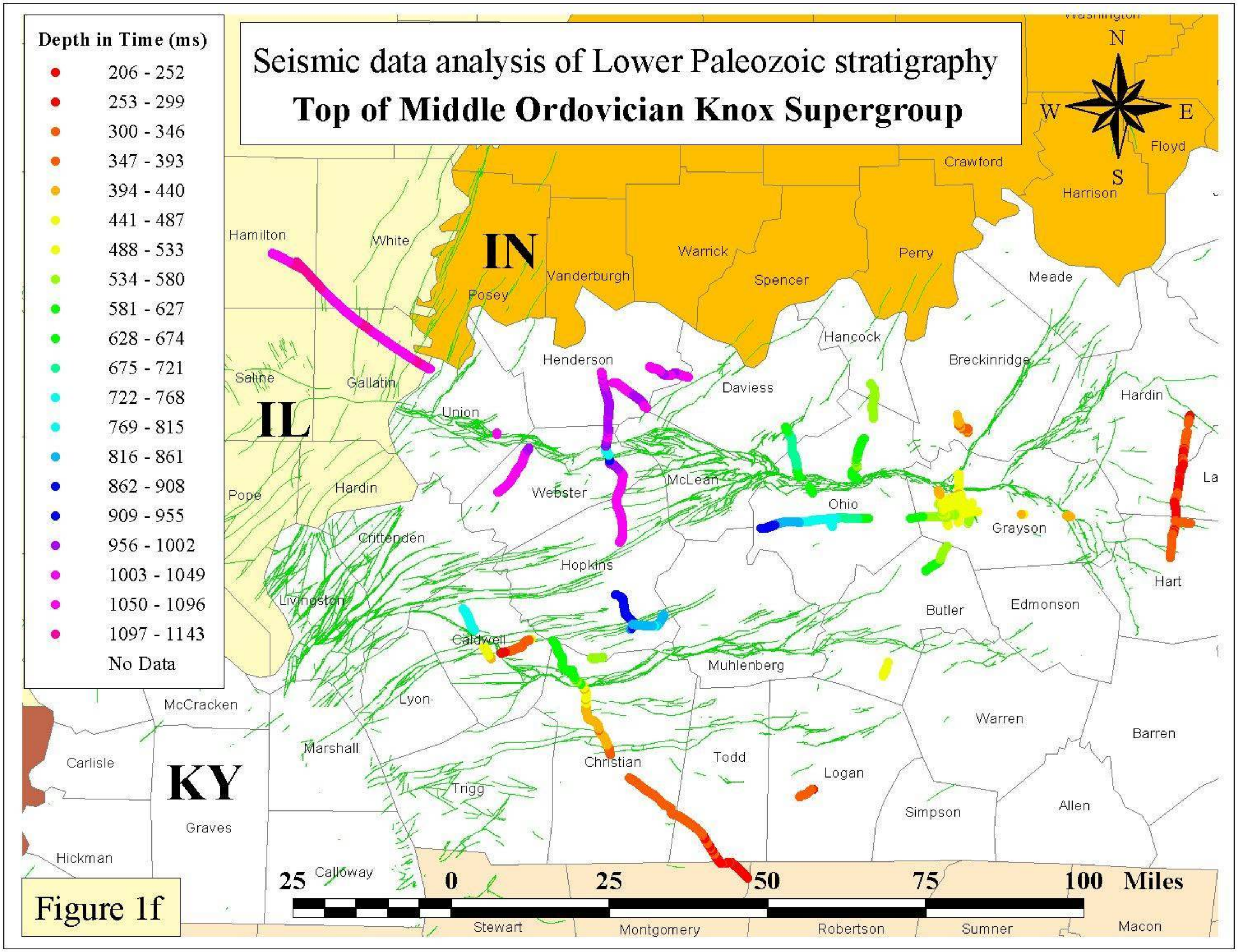

Seismic data analysis of Lower Paleozoic stratigraphy
Top of Middle Ordovician Knox Supergroup
Depth in Time (ms)
206 - 252
253 - 299
300 - 346
347 - 393
394 - 440
441 - 487
488 - 533
534 - 580
581 - 627
628 - 674
675 - 721
722 - 768
769 - 815
816 - 861
862 - 908
909 - 955
956 - 1002
1003 - 1049
1050 - 1096
1097 - 1143
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Figure 1f

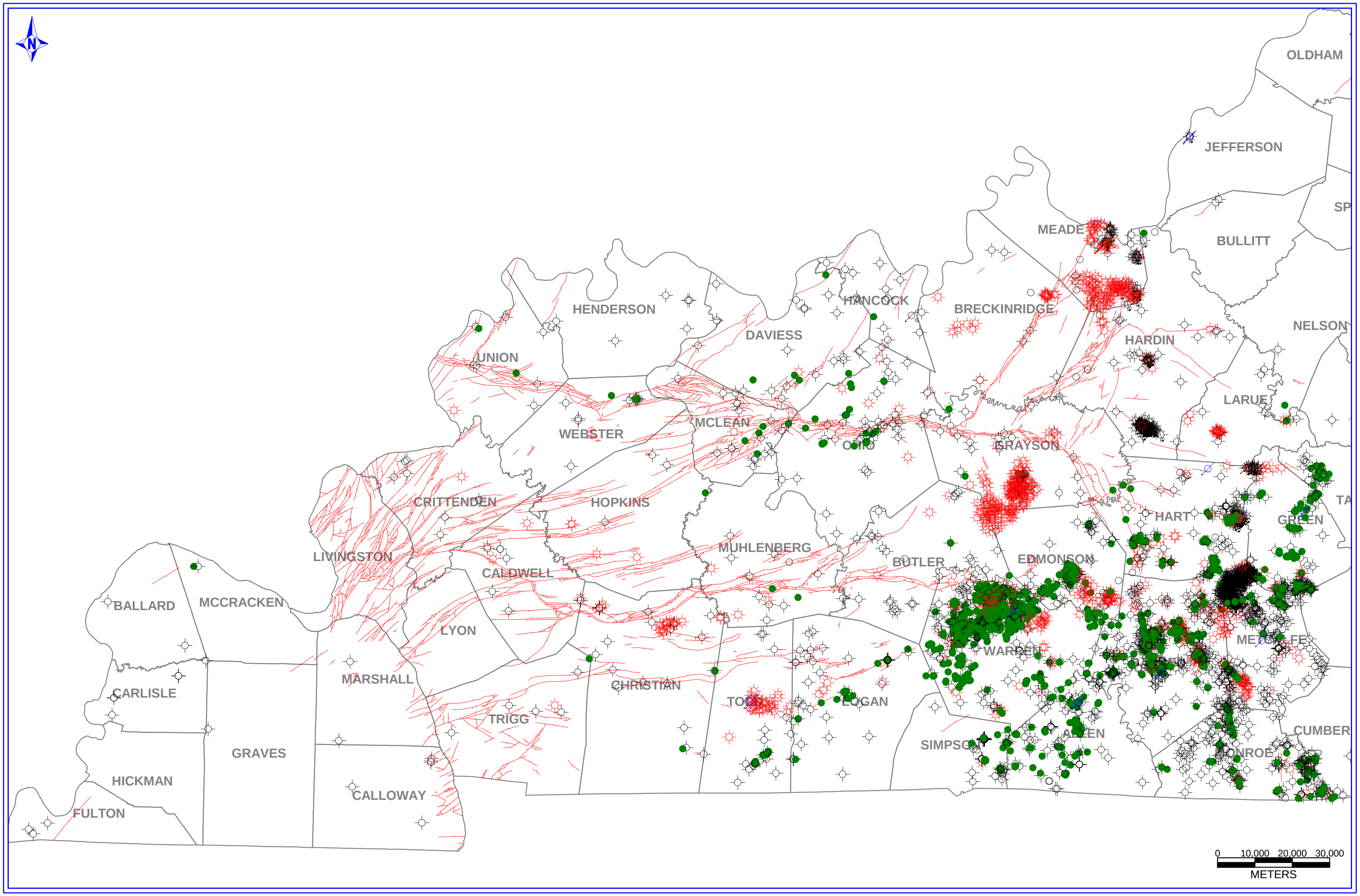


**Figure 2.** Location of wells with data used in this study. Dataset includes all wells deeper than the New Albany Shale with geophysical log data available at KGS.

**Regional Pre-New Albany Stratigraphic Interpretation**

The stratigraphic interval of interest in this study lies below the Upper Devonian New Albany Shale and the Lower Ordovician Knox Group. The work in Kentucky has focused on the Silurian and Devonian section, commonly referred to as “Corniferous” by drillers. Stratigraphic relationships in this interval, containing multiple unconformities, are not well understood. Most drilling records do not recognize individual formations, but lump everything below the New Albany Shale into the Corniferous. A main goal of this study is to resolve the distribution of Silurian-Devonian units and regional unconformities in the western Kentucky area.

Almost all of the oil production in the Silurian-Devonian section in western Kentucky has been from shallow carbonate fields on the west flank of the Cincinnati Arch (Fig. 3). Many of these pools are stratigraphic traps associated with unconformity truncations. The Cincinnati Arch was a positive feature during the Silurian and Devonian, and affected depositional and erosional patterns (Freeman, 1951). Multiple stacked unconformities occur along this eastern margin of the Illinois Basin, resulting in complex stratigraphic relationships. These stratigraphic correlations are difficult due to the similarity of log response of many of the carbonate units. A better understanding of the stratigraphy will be an important exploration tool, due to the subtle nature of many of the fields.

Header data and locations for 4,927 wells were obtained from the KGS oil and gas database and loaded into Petra, a geological interpretation program. Wells were selected for the study if they were drilled below the New Albany Shale and had at least one geophysical log. Existing digital well logs were loaded into the project and considerable additional geophysical well logs were digitized for the study. A total of 366 digital wells logs are now available (Fig. 4). In addition to digital logs, scanned logs (raster images) were used to fill in cross sections.

Eleven regional cross sections have been defined to interpret the stratigraphic framework for this interval (Figure 5). Stratigraphic correlations in this interval are continuing. Stratigraphic picks used in the study are illustrated in Table 1. A database of formation tops will be produced after cross sections are completed and correlations verified.

Once correlations are completed a new map of the pre-Middle Devonian unconformity surface (lower Kaskaskia sequence boundary) will be constructed. This subcrop map will be a valuable tool for visualizing stratigraphic patterns at this important unconformity.

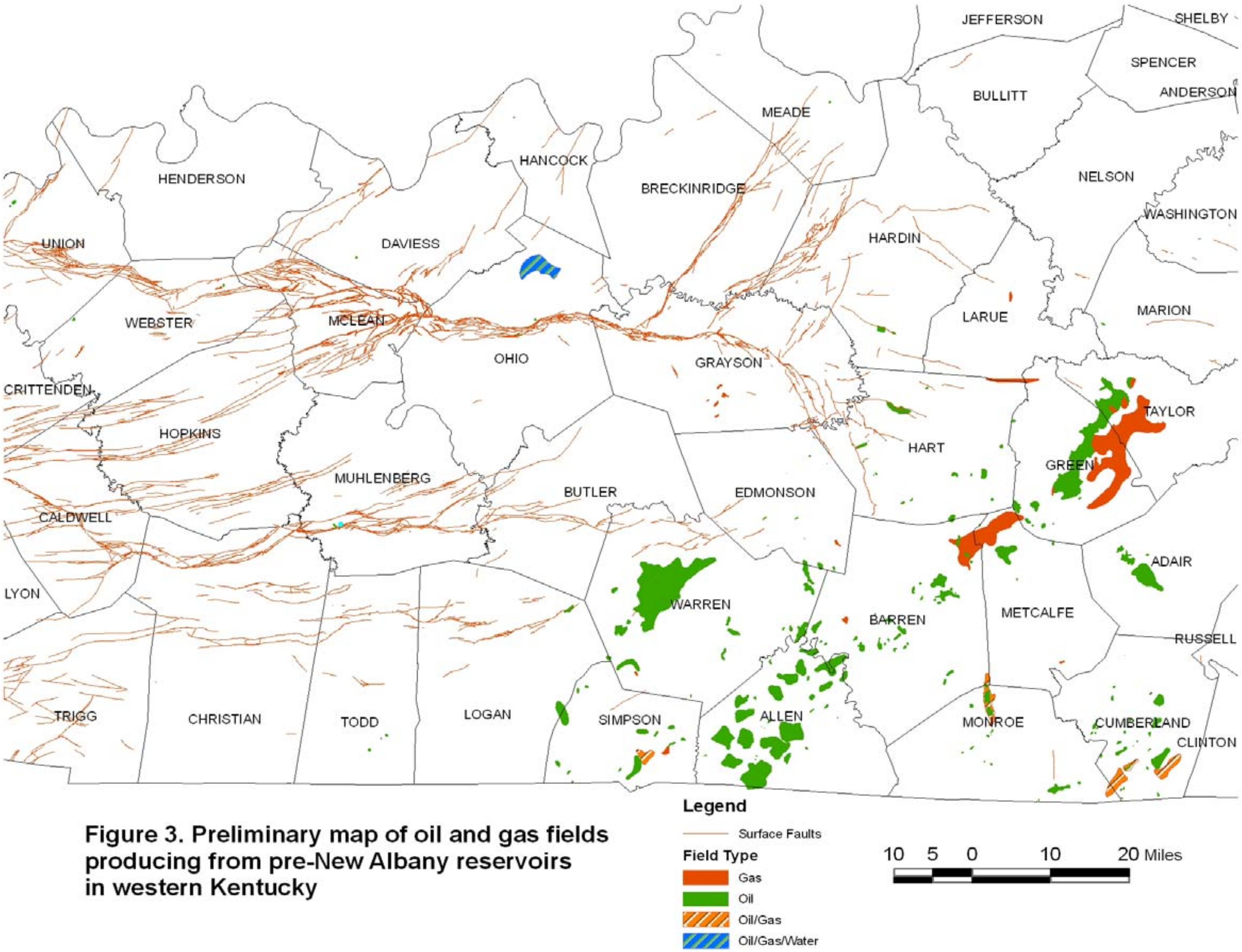


**Figure 3. Preliminary map of oil and gas fields producing from pre-New Albany reservoirs in western Kentucky**

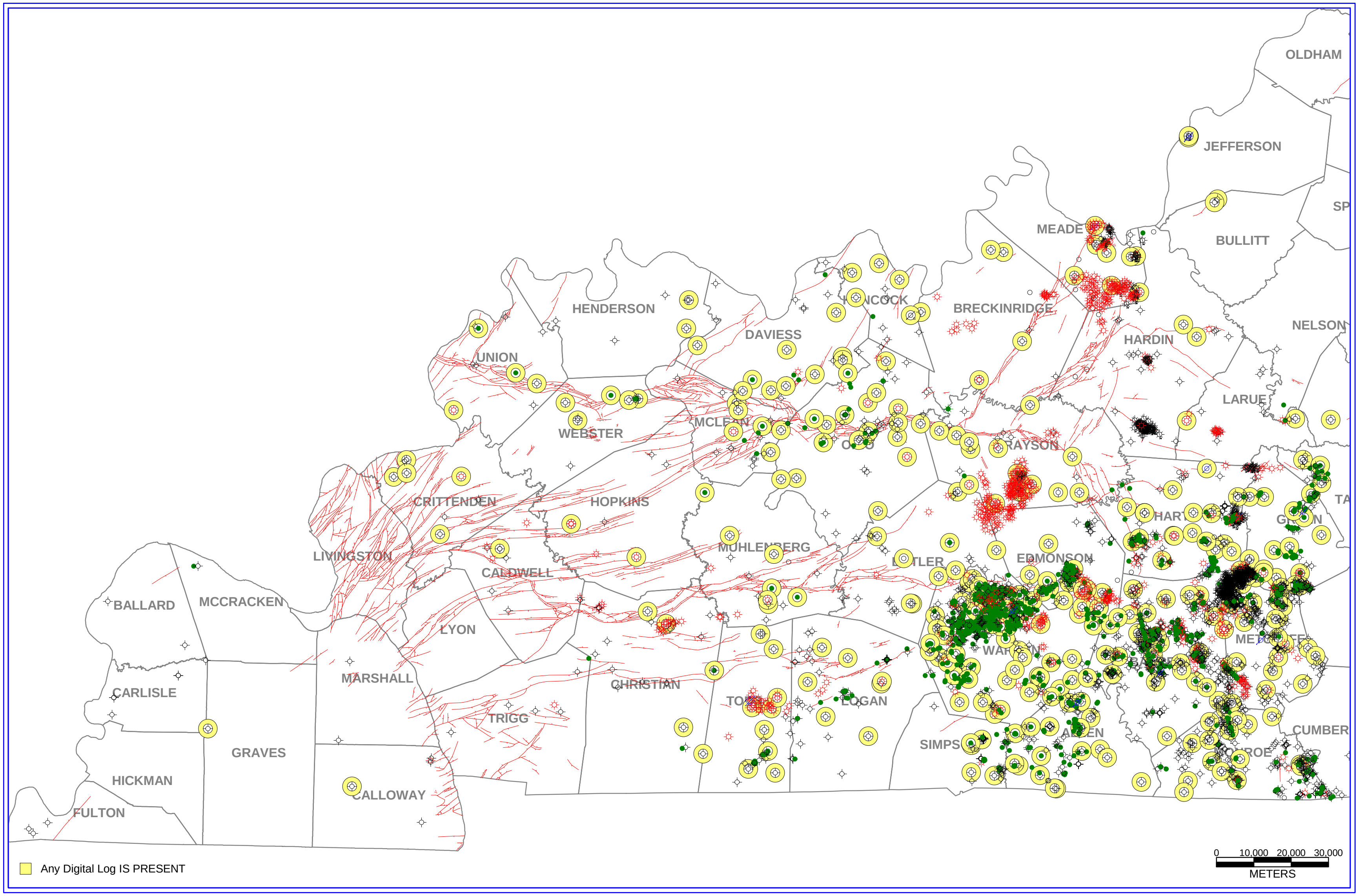


Figure 4. Locations of wells (highlighted in yellow) with digital well logs used in correlation and cross sections.

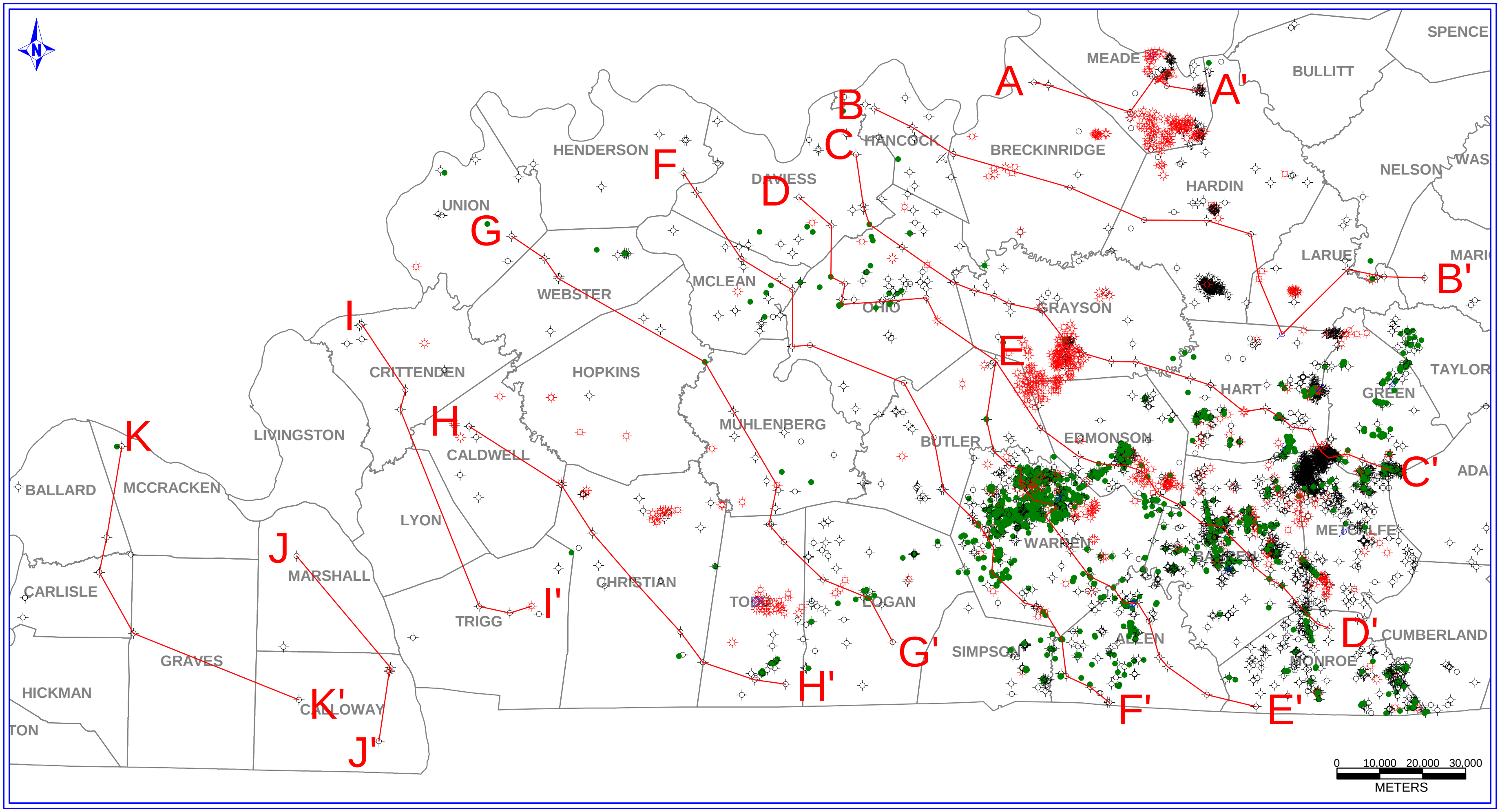


**Figure 5.** Cross section location map, western Kentucky.

| Age | Primary Stratigraphic Units | | Equivalent Units | | Basinal Equivalents | |
|---|---|---|---|---|---|---|
| | Fm Code | Name | Fm Code | Name | Fm Code | Name |
| Upper Devonian | 341NALB | New Albany Shale | | | | |
| Middle Devonian | 344SLBG | Sellersburg Ls | | | | |
| | 344JFVL | Jeffersonvlle Ls | | | | |
| | 344DCCK | Dutch Creek Ss | | | | |
| Lower Devonian | 347CCEK | Clear Creek Fm | 347CCGK | Clear Creek/Grassy Knob Undiff | | |
| | 347BKBN | Backbone Ls | | | | |
| | 347GRKB | Grassy Knob Ls | | | | |
| | 347FLGP | Flat Gap Ls | | | | |
| Upper Silurian | 351BILY | Bailey Ls | 351DCTR | Decatur Ls | | |
| Middle Silurian | 355BRPT | Brownsport Fm | 355LBLV | Lobelville Ls. Mbr Brownsport Fm | 355MSPG | Mocassin Springs Fm |
| | | | 355BOB | Bob Ls. Mbr Brownsport Fm | | |
| | | | 355BCRV | Beech River Ls. Mbr Brownsport Fm | | |
| | 355DIXN | Dixon Ls | | | | |
| | 355LSVL | Louisville Ls | 355LEGO | Lego Ls | 355SCLR | St. Clair Ls |
| | 355WLDR | Waldron Sh | | | | |
| | 355LAUR | Laurel Dol | | | | |
| Lower Silurian | 357OSGD | Osgood Sh | | | | |
| | 357BRSF | Brassfield Dol | 357SXCK | Sexton Creek Ls | | |
| U. Ord. | 361MQKT | Maquoketa Sh | | | | |
| Middle Ordovician | 365TRNT | Trenton Ls | | | | |
| | 365BKRV | Black River Group | | | | |
| | 365DTCN | Dutchtown Fm | | | | |
| | 365STPR | St. Peter Ss | | | | |
| | 365EVRN | Everton Fm | | | | |
| L. Ord. | 368KNOX | Knox Group | | | | |

**Table 1**. Stratigraphic nomenclature used for western Kentucky study area. Unconformities are indicated by wavy red boundaries.

**Catalog of Devonian, Silurian, and Upper Ordovician oil field data**

This task has begun to compile available information on the major oil fields producing from pre-New Albany reservoirs in western Kentucky. Over 350 oil and gas pools produce from reservoirs below the New Albany Shale. While data is not available for all these fields, KGS is compiling summaries of the larger pools to serve as a reference. This will include scanned copies of published studies and data, as well as internal reservoir data at KGS.

Core Analysis Database

Part of this effort has been to build a comprehensive database of core analysis data for cores from pre-New Albany formations. Porosity and permeability data for 115 cored wells have been entered into a Microsoft Excel spreadsheet file and is included with this report. These data include a wide range of Devonian, Silurian and Ordovician cores. Cored intervals have been identified by specific formation, rather than the more generic "Corniferous" designation that was listed on most of the core reports. This reservoir data is now available for analysis by reservoir zone, which will help to delineate regional porosity trends as wells as reservoir characterization for enhanced oil recovery projects.

It is hoped that this pool data can be put in an interactive format and made available on the KGS or ISGS web site in the future.

**Characterization of pre-New Albany hydrocarbon source rocks**

Much of the oil production from pre-New Albany rocks in western Kentucky occurs along the flank of the Cincinnati Arch, where due to unconformity truncations the reservoirs are in close proximity to the organic-rich New Albany Shale. The New Albany is a known source rock for much of the oil produced in western Kentucky, particularly from Mississippian reservoirs. Even oils from Ordovician reservoirs on the crest of the Cincinnati Arch have been shown to be derived from Devonian source rocks (KGS data). The interpretation of a viable source rock below the New Albany would define a new petroleum system in this area, and make the deeper parts of the southern Illinois Basin much more prospective.

KGS is compiling what little source rock data is available from rocks older than the Devonian New Albany Shale. The most likely candidate for hydrocarbon source potential is the Upper Ordovician Maquoketa Shale. Very little data exists from the Maquoketa, but we recently obtained permission to release some analyses done by Conoco Inc. after they drilled 3 deep wells in the Rough Creek Graben. In a technical services report dated March 1993 (authorship redacted), Conoco reports a moderate total organic carbon value (TOC) of 0.44% in the Maquoketa Shale from 4,190-4,210 ft in the Conoco Turner well in McLean County. Conoco reported a calculated vitrinite reflectance (Ro) of 0.64 and determined the Maquoketa contained primarily Type III kerogen (gas prone, with some waxy oils). Based on the RockEval analysis, organic matter in the Maquoketa in the Turner well is mature. This suggests the Maquoketa has hydrocarbon source potential in western Kentucky and could have charged reservoirs in the Silurian and Lower/middle Devonian.

Additional source rock data is being sought from published and unpublished sources.

Selected References


Conoco Exploration and Research Services, 1993, Organic geochemistry of shales, crude oils, oil stains, and a natural gas from southern Illinois Basin, 49 p.

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# Lower Paleozoic Fields in the Illinois Basin of Indiana

## Oil, Natural Gas, and Gas Storage Fields in Devonian and Deeper Reservoirs

**Prepared for U. S. DOE under subcontract to Illinois State Geological Survey**

**By Kuldeep Chaudhary and Brian D. Keith, Indiana Geological Survey at Indiana University**

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October 2008

## Introduction

This atlas is intended as a comprehensive listing of fields in southwestern Indiana that are part of the Illinois Basin and which contain wells with Devonian or deeper reservoirs that were completed for the production of oil and/or natural gas or as gas storage fields (Fig. 1). In some cases producing fields were converted to gas storage fields some time after discovery. Of the 70 fields listed (Table 1), all but Chrisney South have reservoirs in Middle Devonian rocks of the Muscatatuck Group (Fig. 2). Only three, Chrisney South, Portersville, and White Rose produce from the Lower Devonian New Harmony Group (Fig. 2). Three fields, Bartlettsville, Heltonville, and Unionville that all are along the Mt. Carmel Fault contain reservoirs in the Ordovician Trenton Limestone (Fig. 2). Only one field, Griffin Consolidated, produces from Cambrian/Ordovician Knox Super Group (Fig. 2). Fields or areas producing solely from the Devonian/Mississippian New Albany Shale (Fig. 2) were not included in this study.

Each field has a summary page report. For 13 fields information and well control was not adequate to compile any additional material beyond the summary report. Fields with sufficient well control have one or more of the items listed below in addition to the summary report.

Well location map showing Devonian wells, field outline, and line of cross section, if present.
Structure map on top of Muscatatuck Group.
Structure map on top of Jeffersonville Limestone.
Structure map on top of Geneva Dolomite Member of Jeffersonville Limestone.
Structure map on top of Silurian rocks.
Isopach map of North Vernon Limestone.
Isopach map of Vernon Fork Member of Jeffersonville Limestone.
Type log for field.
Structural cross section.
Porosity vs. permeability cross-plot.
Cumulative oil production curve.
List of wells used for structure maps.
Core description and photographs of Devonian section.

The amount of available information is highly variable from field to field. For two fields, Plummer and Simpson Chapel, more extensive reports were produced. Where information is not available or does not apply “na” has been used. It is also worth noting that cumulative gas production information is not available for Indiana, and is thus not shown for any natural gas fields. The structural closure mentioned on the summary report page may differ from that shown on structure maps. This is because county maps showing regional well control beyond the field limits were consulted for the summary report, and can show greater closure for the field structure than the more limited control in the immediate field area used for the report maps.

Table 1. List of fields and locations that are included in the atlas. Wells marked with * have insufficient well control for information beyond a summary report. Multiple ID numbers are for fields with gas storage designation in addition to oil or natural gas production.

| Field | County & Location | IGS ID |
|---|---|---|
| Alfordsville Southwest* | Daviess 1N-5W | 10008 |
| Arlington* | Monroe 9N-1W | 10011 |
| Arney | Owen 9N-5W | 10013 |
| Arney North* | Owen 9N-5W | 10014 |
| Art | Clay 11N-7W | 10015 |
| Ashboro East | Clay 11N-6W | 10019 |
| Bartlettsville | Monroe & Lawrence 6&7N-1E | 10032 |
| Bartlettsville North* | Monroe, 7N-1E | 10033 |
| Blackhawk | Vigo 10N-8W | 10050 |
| Bowling Green | Clay 11N-6W | 10057 |
| Bowling Green South | Clay 11N-6W | 10058 |
| Carbon | Clay & Parke 13&14N-6W | 10091 |
| Carlisle North | Sullivan 6N-9&10W | 10093 |
| Carlisle West* | Sullivan 6N-10W | 10094 |
| Chrisney South | Spencer, 6S-5W | 10109 |
| Clay City North | Clay 10N-6W | 10110 |
| Coal City | Owen 9N-6W | 10114 |
| Coalmont West | Sullivan 9N-8W | 10117 |
| Cory Consolidated | Clay 11N-7W | 10127 |
| Cory South | Clay 10&11N-7W | 10128 |
| Dixon | Greene 7N-6W | 10803 |
| Dodds Bridge | Sullivan 8&9N-10W | 10159 |

| | | |
|---|---|---|
| Dubois | Dubois County, 1S&1N-4W | 10163 |
| Elnora Central | Daviess 5N-6W | 10185 |
| Fairbanks | Sullivan 9N-10W | 10196 |
| Glendale | Daviess 2N-6W | 10253 |
| Griffin Consol. | Gibson &Posey 3S-13&14 W | 10277 |
| Heltonville* | Lawrence 6N-1E | 10300 |
| Howesville | Greene 8N-7W | 10310, 10832 |
| Leesville | Lawrence 5N-1&2E | 10373, 10810 |
| Leesville South* | Lawrence 4N-2E | 10374 |
| Lewis | Sullivan 9N-8W | 10375 |
| Linton | Greene 7N-7W | 10382, 10812 |
| Lonetree | Greene 8N-6&7W | 10384, 10813 |
| Lyons | Greene 6N-6W | 10393 |
| Lyons West* | Greene 7N-6W | 10394 |
| Marts | Sullivan 9N-9W | 10409 |
| Mineral City | Greene 6N-5W | 10429, 10816 |
| Montgomery North* | Daviess 3N-6W | 10447 |
| Newberry* | Daviess 5N-5&6W | 10479 |
| Oakland City Consol.* | Pike 2S-8W | 10488 |
| Odon East | Daviess 5N-5W | 10495, 10820 |
| Odon North | Daviess 5N-5W | 10496 |
| Odon South | Daviess 5N-5&6W | 10497 |
| Pennyville | Daviess 2N-5W | 10532 |
| Plainville | Daviess 4N-7W | 10543 |
| Plummer | Greene 6N-5W | 10546 |

| | | |
|---|---|---|
| Portersville* | Daviess 1N-5W | 10549 |
| Portersville West | Daviess 1N-5W | 10551 |
| Prairie Creek | Vigo 10N-10W | 10556 |
| Riley | Vigo 11N-8W | 10581 |
| Riley South | Vigo 11N-8W | 10582 |
| Saline City | Clay 11N-7W | 10605 |
| Sandborn North | Greene 6N-7W | 10608 |
| Shelburne Consol. | Sullivan 8&9N-9&10W | 10624 |
| Simpson Chapel | Greene 6N-4&5W | 10631, 10825 |
| Siosi | Sullivan & Vigo 9&10N-10W | 10632 |
| South Martin* | Martin1N-4W | 10645 |
| Spencer Consol. | Posey 7&8S-14W | 10649 |
| Spring Hill | Vigo 11N-9W | 10651 |
| State Line | Vigo 12N-10W | 10685, 10826 |
| Staunton | Clay 12N-7W | 10686 |
| Switz City | Greene 7N-6W | 10704, 10827 |
| Terre Haute* | Vigo 12N-9W | 10712 |
| Terre Haute East | Vigo 12N-9W | 10713 |
| Terre Haute South | Vigo 11N-9W | 10714 |
| Unionville (Hindustan) | Monroe 9N-1E & 10N-1W | 10734, 10829 |
| White Rose | Greene 7N-7W | 10783 |
| Wilfred | Sullivan 9N-8W | 10786, 10830 |
| Worthington | Greene 8N-5W | 10793 |

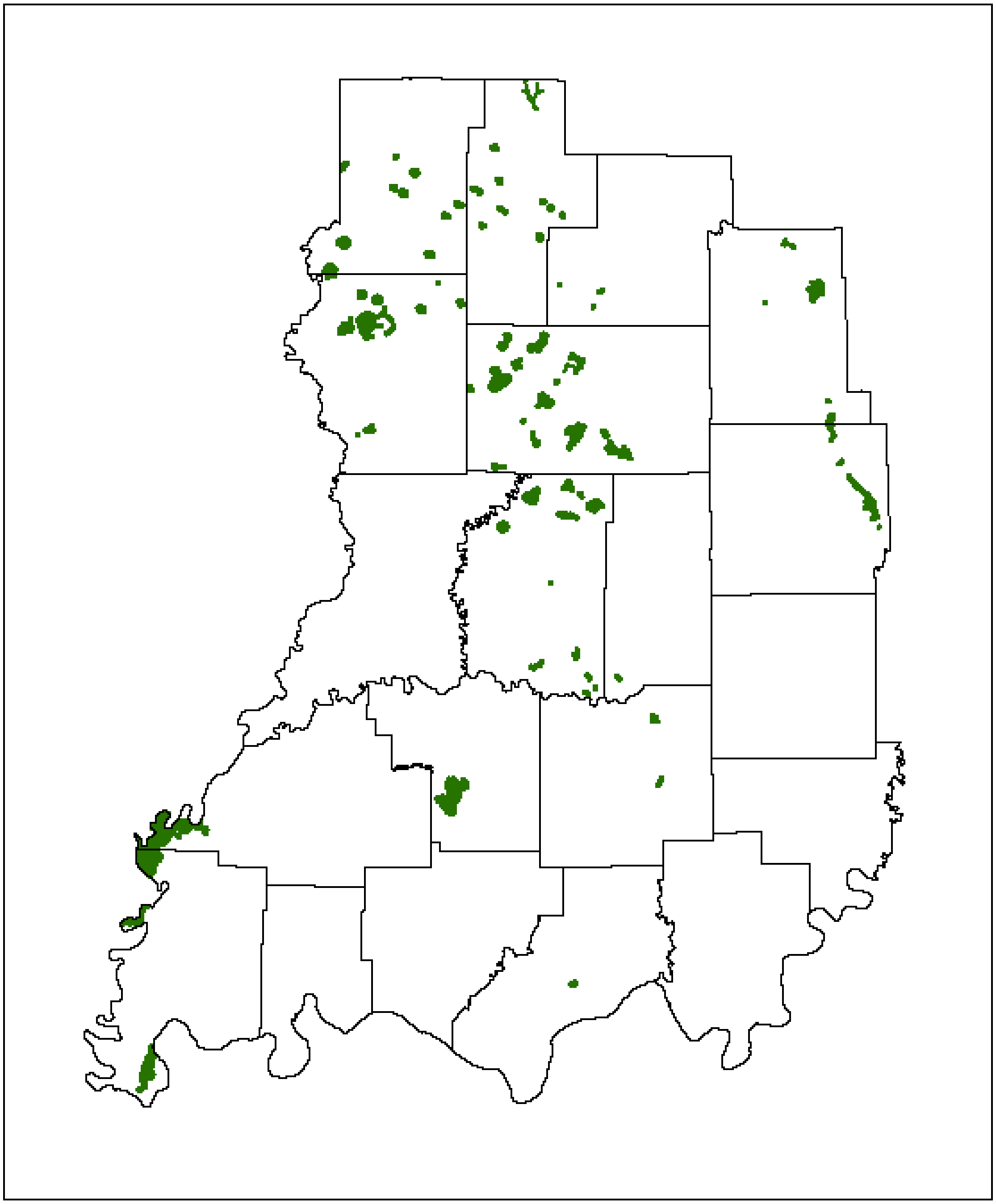

Figure 1. Map of southwestern Indiana showing oil, natural gas, and gas storage fields included in atlas.

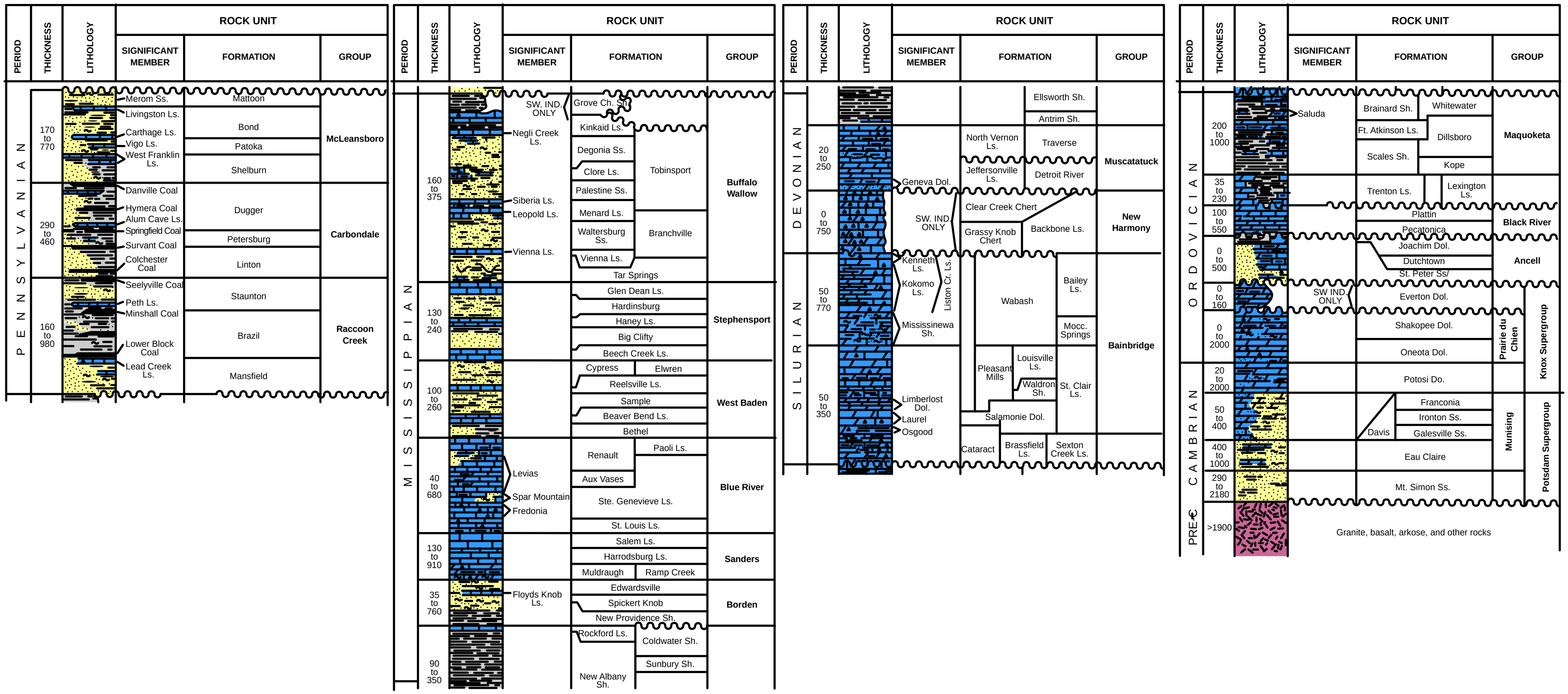


Figure 2. Generalized stratigraphic column for southern Indiana.

**Field name:** Alfordsville Southwest

**IGS ID:** 10008

**DOE ID:** 9650

**Location:** Daviess County, 1N-5W

**Discovery date:** 1973

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls., (1,870 ft.)

**Field type:** natural gas

**Total number production wells:** 2

**Area:** na

**Cumulative production:** na

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Silurian (2,750 ft.)

**Field characteristic:** No structural closure observable.

**Reservoir characteristics:**

Porosity – 6.2 %

Permeability – 1.5 md

Reservoir thickness: 15 ft.

**Field name:** Arlington

**IGS ID:** 10011

**DOE ID:** na

**Location:** Monroe County, 9N-1W

**Discovery date:** 1960

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, na (873 ft.)

**Field type:** natural gas

**Total number production wells:** 1

**Area:** na

**Cumulative production:** na

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Muscatatuck (957 ft.)

**Field characteristic:** No structural closure observable.

**Reservoir characteristics:**

**Field name:** Arney

**IGS ID:** 10013

**DOE ID:** na

**Location:** Owen County, 9N-5W

**Discovery date:** 1951

**Lower Paleozoic reservoir unit and depth:** Devonian, Muscatatuck Group, na (1,314 ft.)

**Field type:** natural gas

**Total number production wells:** 2

**Area:** na

**Cumulative production:** na

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Silurian (1,467 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 40 ft. at top of Muscatatuck.

**Reservoir characteristics:**

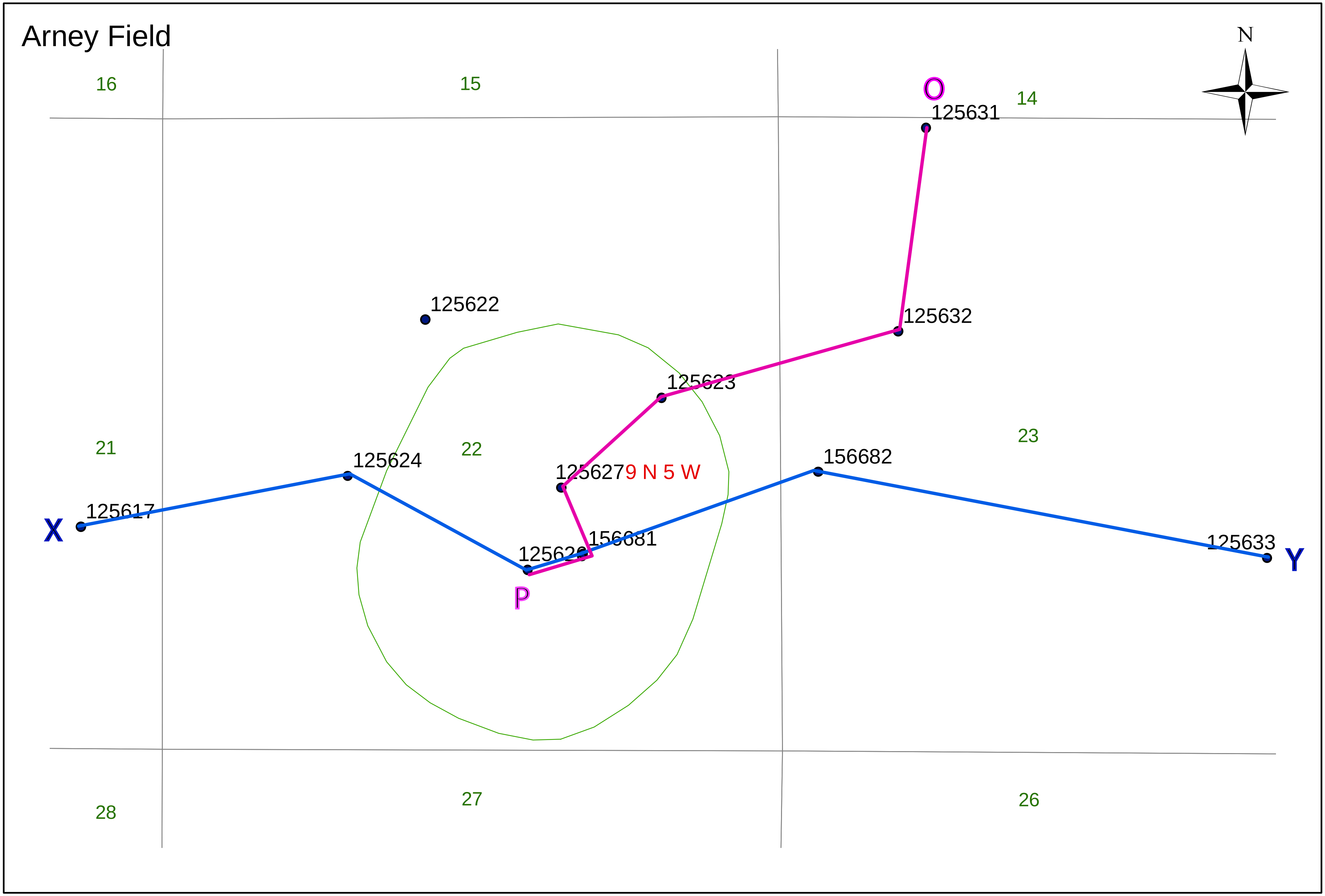


Figure 1: Map showing location and wells at Arney Field, Owen County. X-Y and P-O are the locations of the cross sections that show the subsurface Devonian structure in Figures 5 and 6.

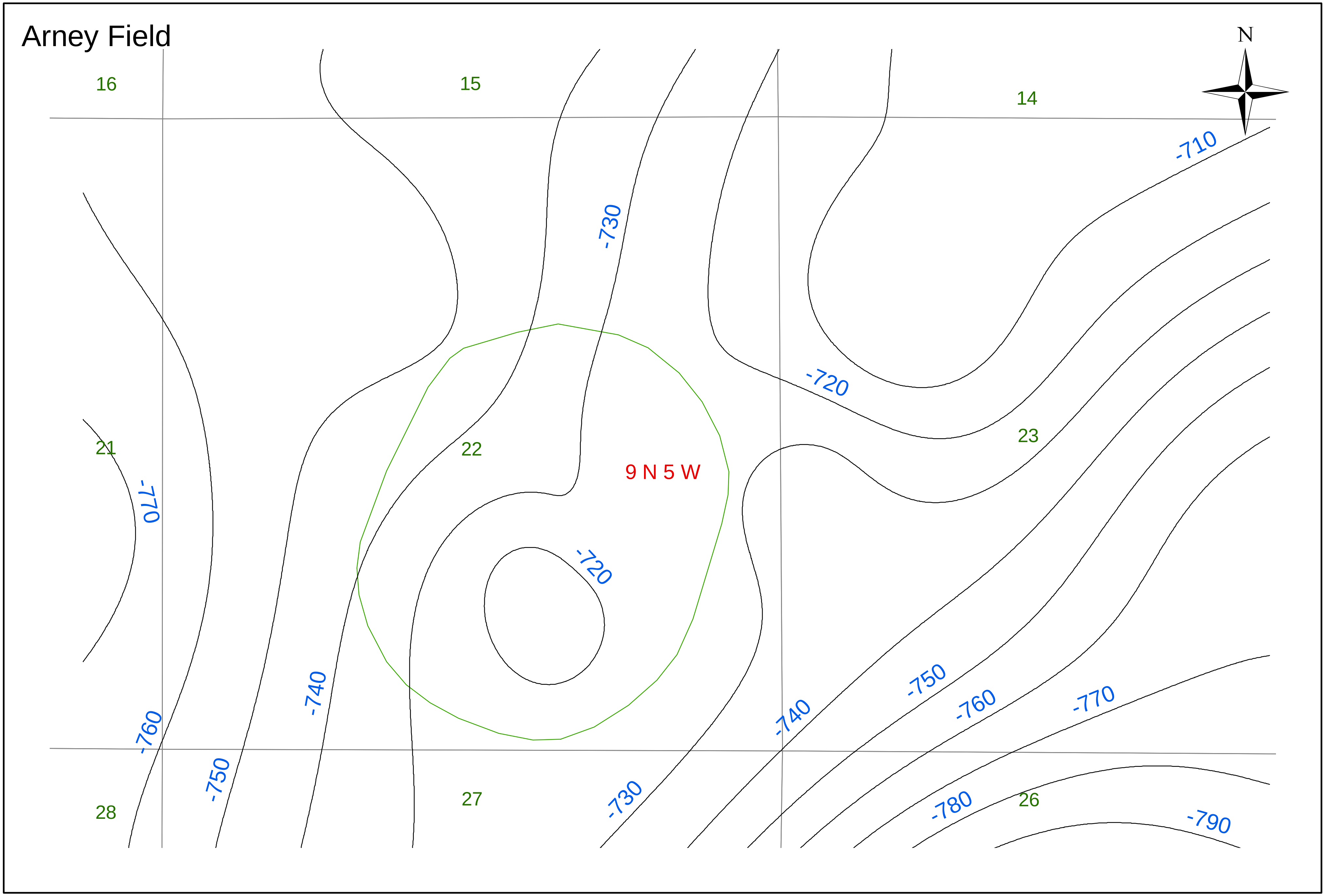


Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in ArneyField, Owen County. Contours show values below sea level, contour interval is 10 ft .

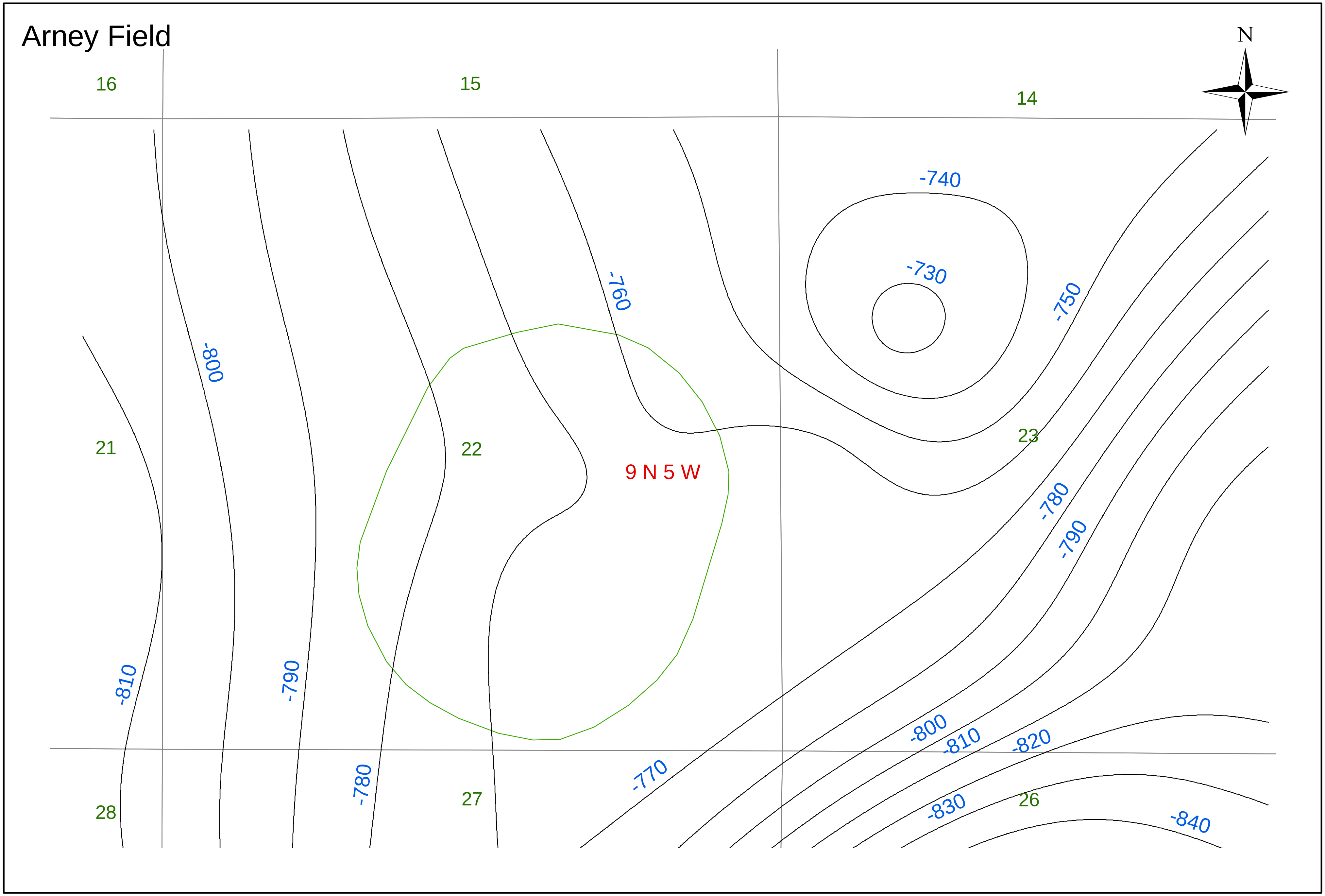


Figure 3: Structure map showing the top of subsurface Jeffersonville Limestone in Arney field, Owen County. Contours show values below sea level, contour interval is 10 ft .

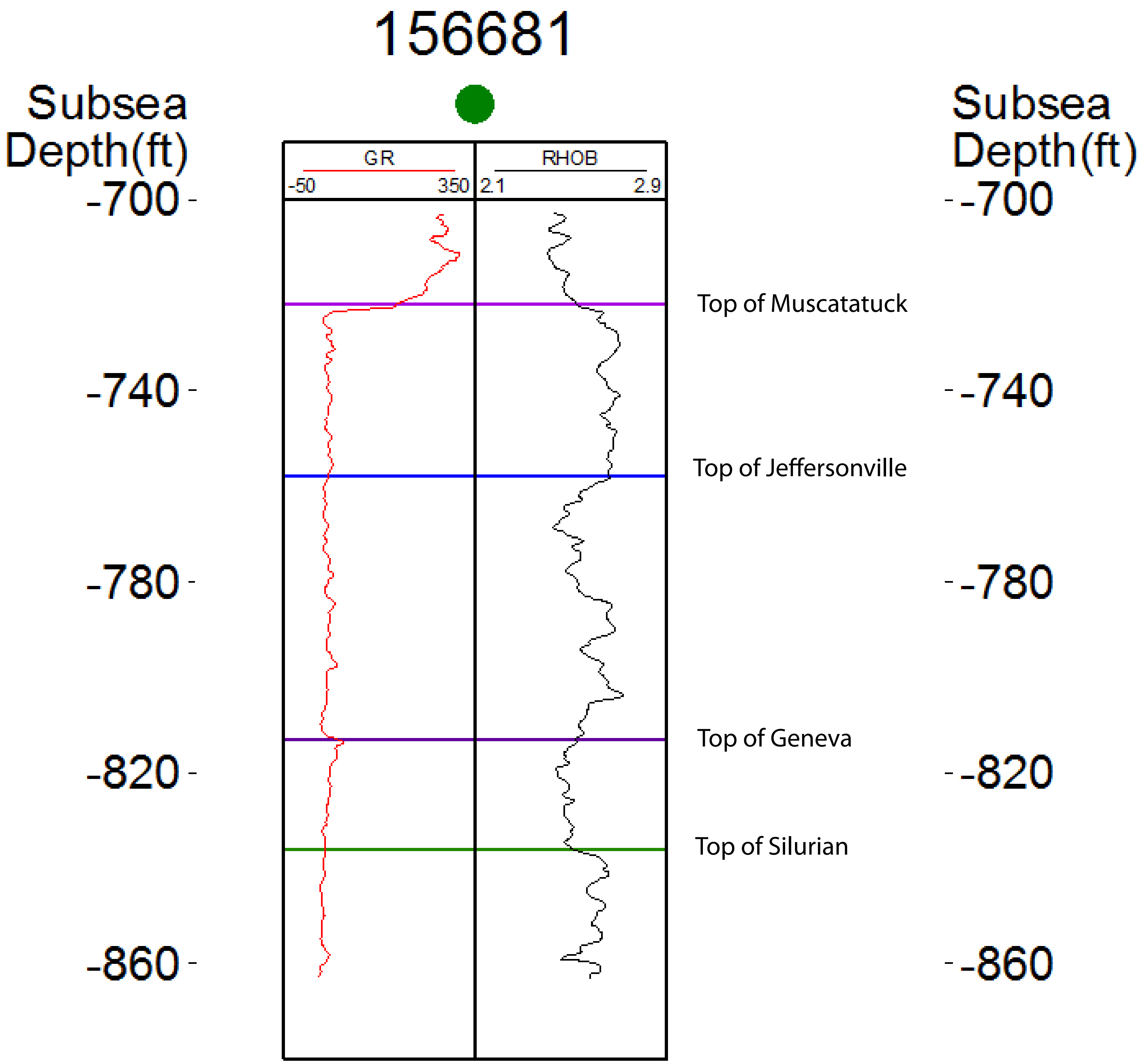


Figure 4: Type log section showing the Devonian formations at Arney Field, Owen County.



HS=1

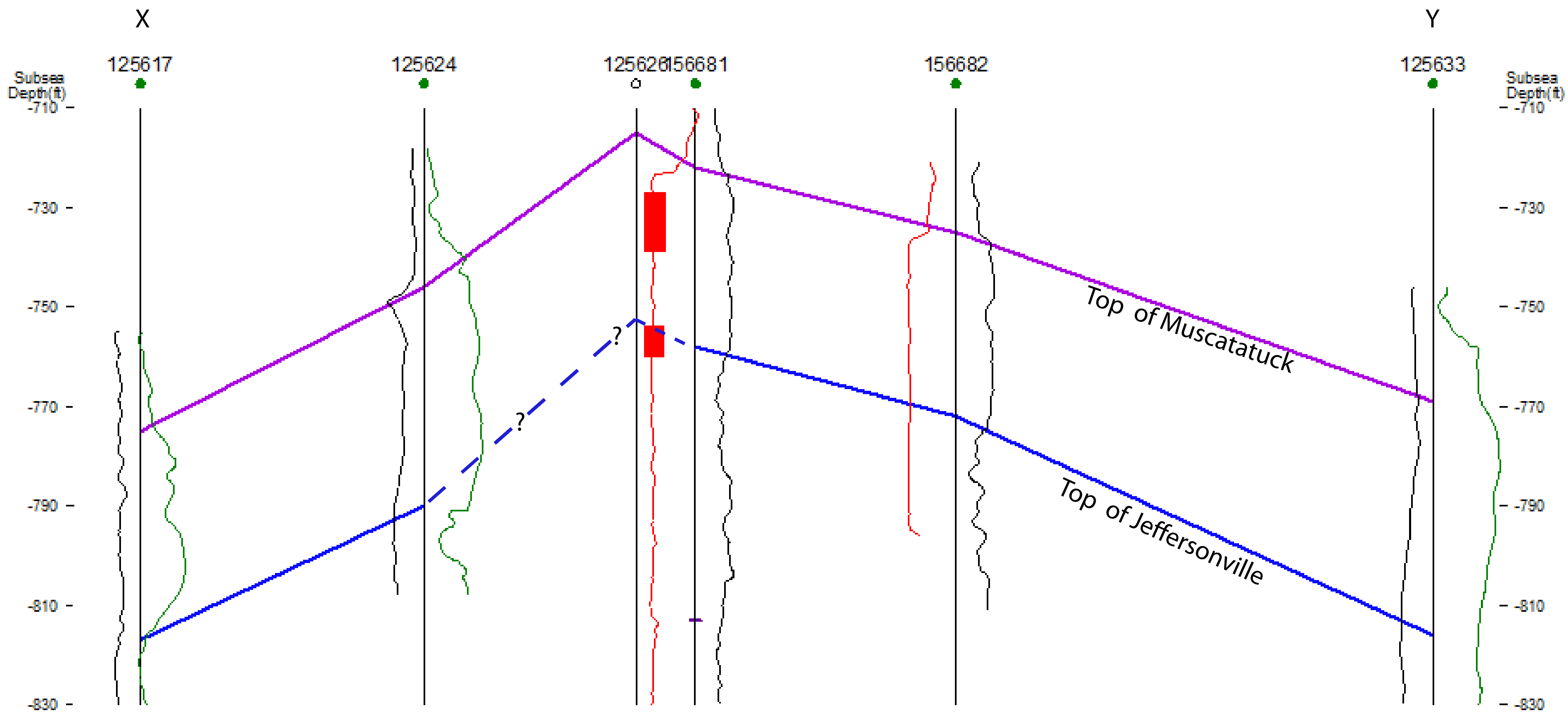


Figure 5: X-Y Cross section showing the Devonian subsurface structure across Arney Field, Owen County. The red color box shows the completion intervals for the gas production. For location of the cross section refer to Figure 1.



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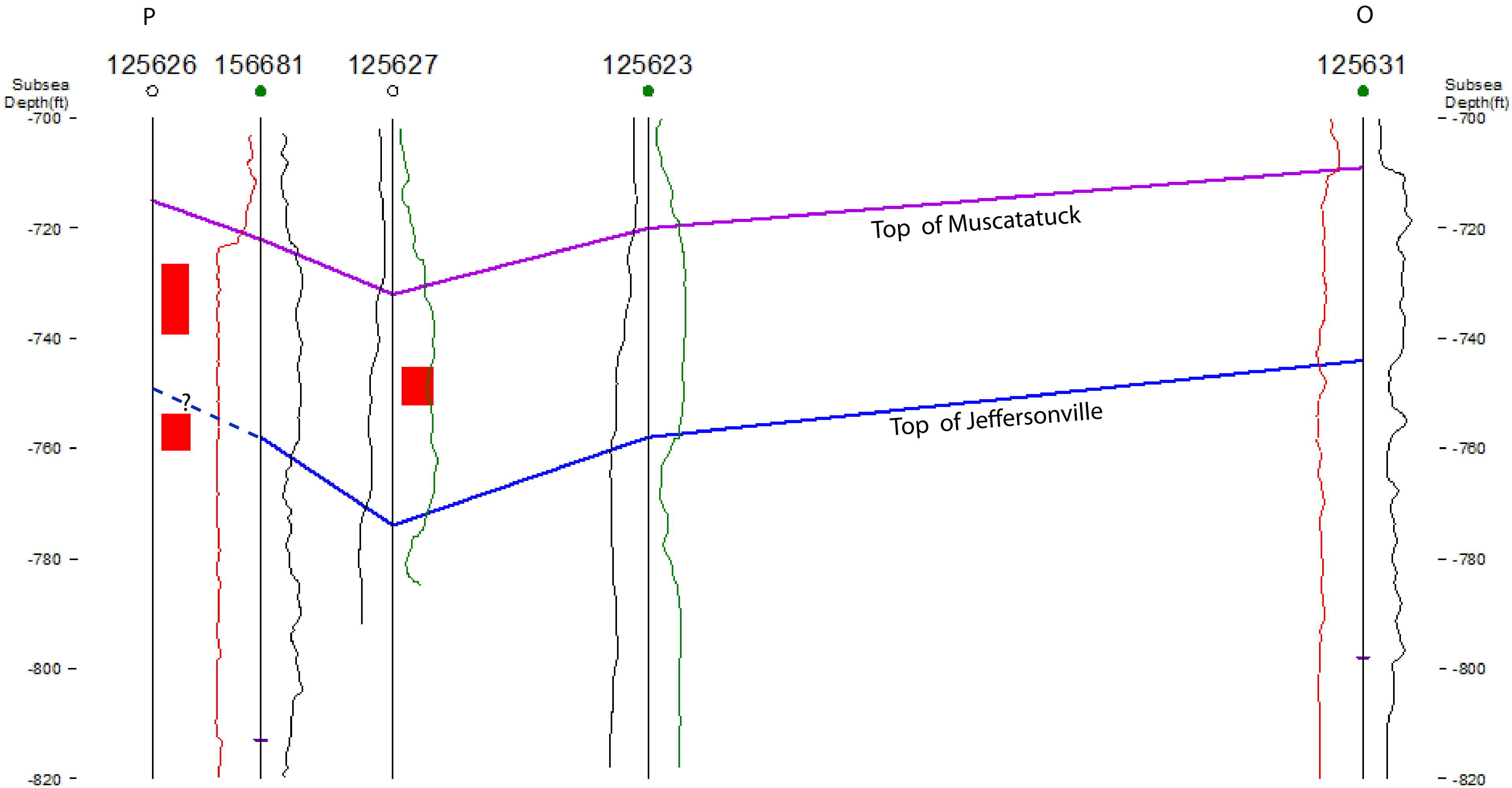


Figure 6: P-O Cross section showing the Devonian subsurface structure across Arney Field, Owen County. The red color box shows the completion intervals for the gas production. For location of the cross section refer to Figure 1.



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Table-1: List of the wells used for subsurface structure mapping in Arney Field, Owen County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125617 | 9 | N | 5 | W | 21 | 670 | 1445 | 1487 | 1530 | 1596 | | |
| 125622 | 9 | N | 5 | W | 22 | 642 | 1395 | | | | | |
| 125623 | 9 | N | 5 | W | 22 | 632 | 1354 | 1390 | | | | |
| 125624 | 9 | N | 5 | W | 22 | 652 | 1398 | 1440 | | | | |
| 125626 | 9 | N | 5 | W | 22 | 559 | 1274 | | | | | 1000 |
| 125627 | 9 | N | 5 | W | 22 | 568 | 1299 | 1342 | | | | 1000 |
| 156681 | 9 | N | 5 | W | 22 | 597 | 1319 | 1358 | 1410 | 1433 | | |
| 125631 | 9 | N | 5 | W | 23 | 668 | 1377 | 1412 | 1466 | | | |
| 125632 | 9 | N | 5 | W | 23 | 664 | 1364 | 1390 | 1440 | 1473 | | |
| 125633 | 9 | N | 5 | W | 23 | 634 | 1403 | 1450 | 1520 | 1562 | | |
| 156682 | 9 | N | 5 | W | 23 | 619 | 1354 | 1386 | | | | |
| 156683 | 9 | N | 5 | W | 26 | 637 | 1446 | 1494 | | | | |

**Field name:** Arney North

**IGS ID:** 10014

**DOE ID:** na

**Location:** Owen County, 9N-5W

**Discovery date:** 1977

**Lower Paleozoic reservoir unit and depth:** Devonian, Muscatatuck Group, na (1,330 ft.)

**Field type:** natural gas

**Total number production wells:** 2

**Area:** na

**Cumulative production:** na

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Silurian (1,700 ft.)

**Field characteristic:** Limited data available, but possible domal anticline with closure in excess of 60 ft.

**Reservoir characteristics:**

**Field name:** Art

**IGS ID:** 10015

**DOE ID:** 26716

**Location:** Clay County, 11N-7W

**Discovery date:** 1963

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls., (1,450 ft.)

**Field type:** oil

**Total number production wells:** 15

**Area:** 90 acres

**Cumulative production:** 71,885 bbls. (2002)

**Other reservoir units:** Mississippian, Borden Group, Carper Ss.

**Deepest unit penetrated (depth):** Silurian (1,677 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 40 ft. at top of Muscatatuck.

**Reservoir characteristics:**

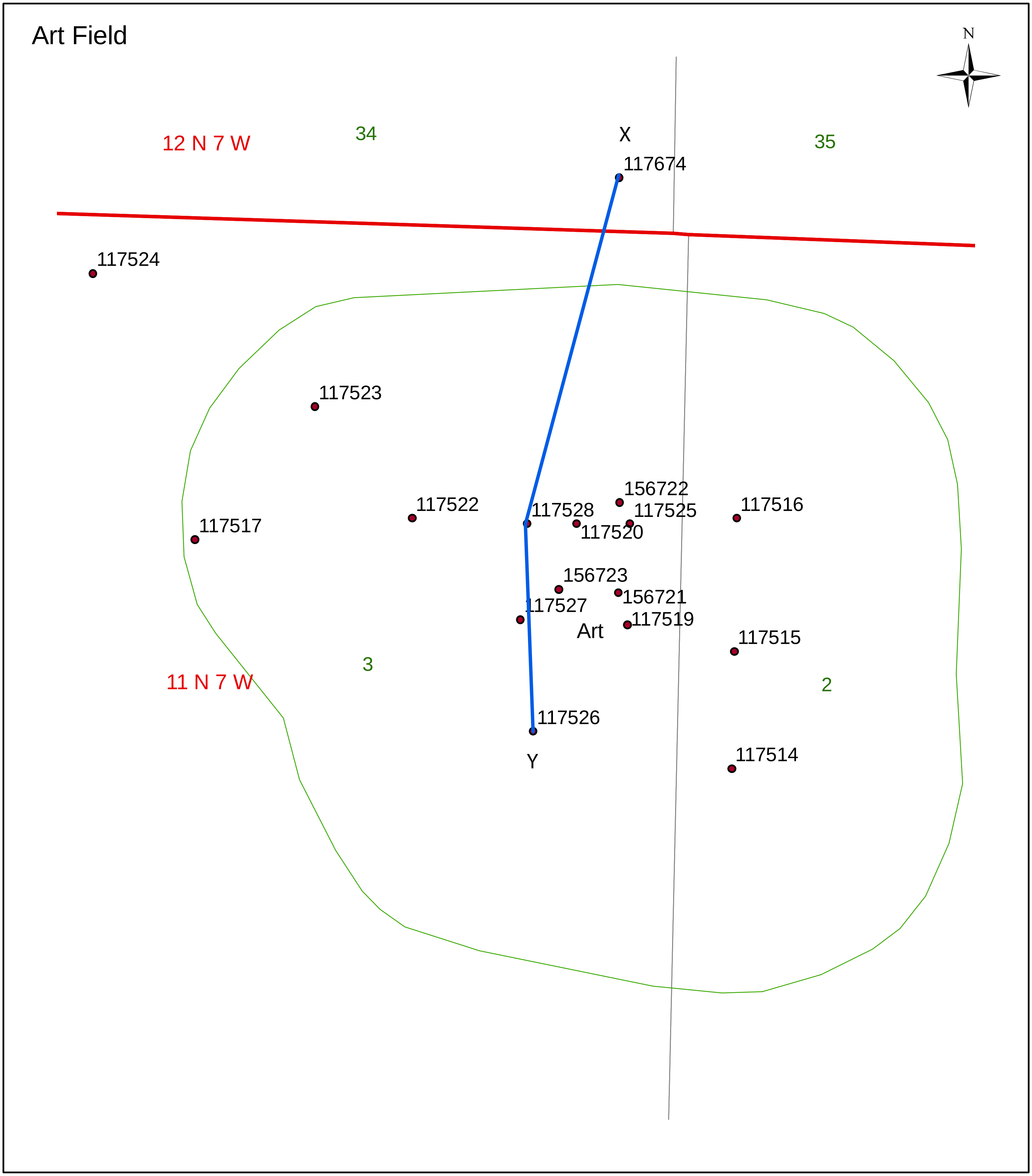


Figure 1: Map showing the location and wells at Art field, Clay County. X-Y is the location of cross section that showing the subsurface Devonian structure in Figure 4.

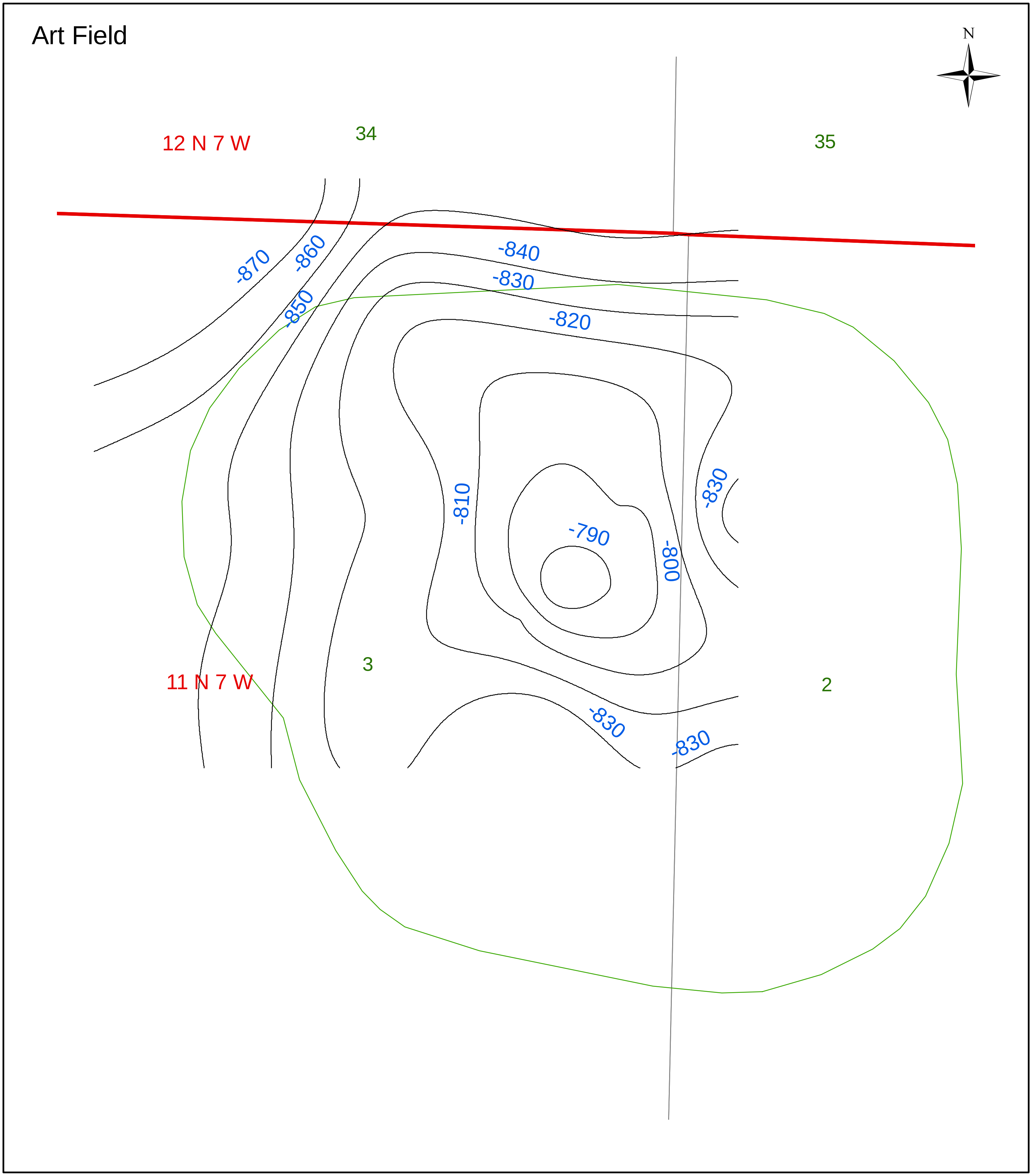


Figure 2: Structure map showing the top of Muscatatuck Limestone at Art Field, Clay County. Contours show values below sea level, contour interval is 10 ft .

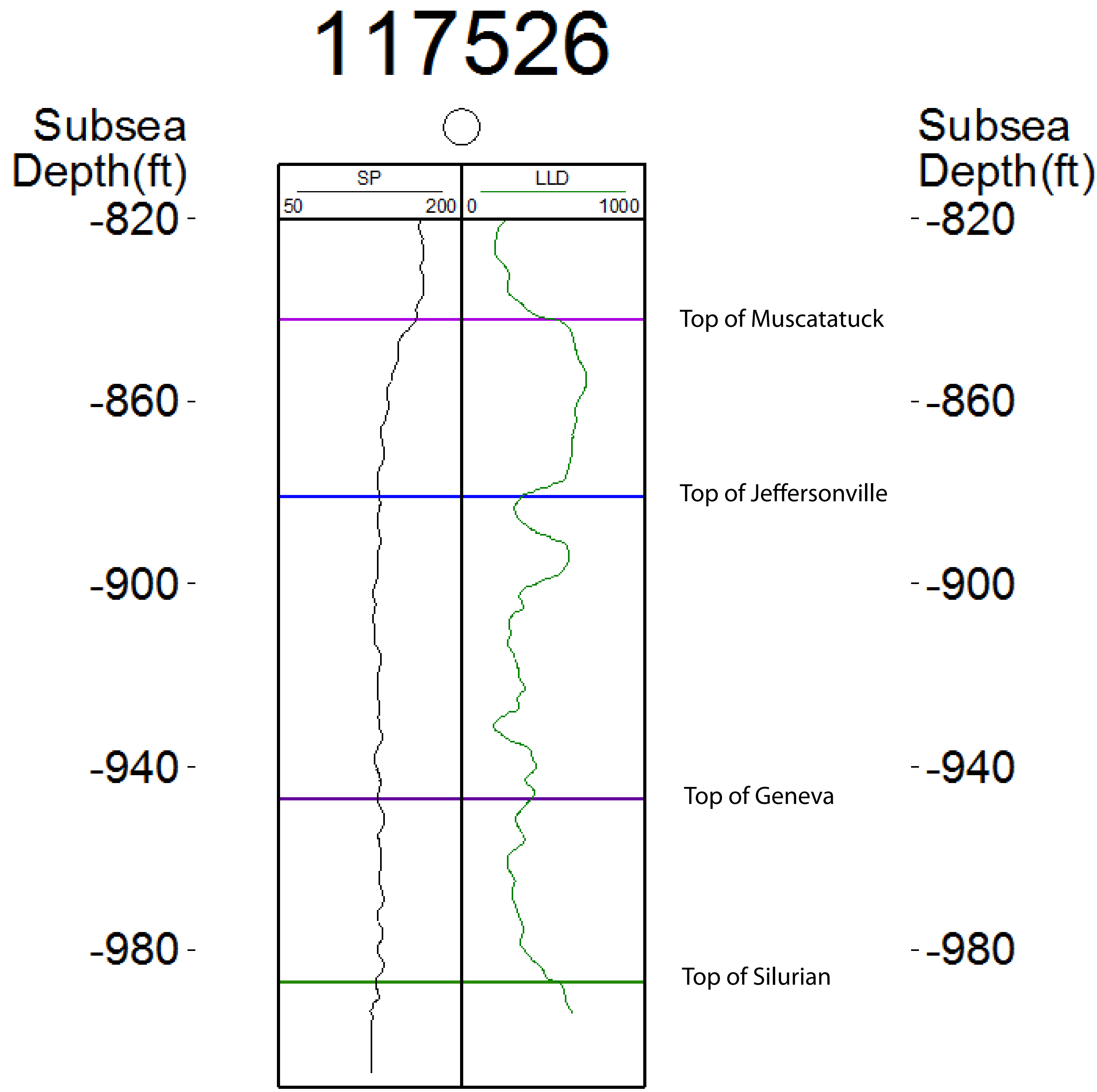


Figure 3: Type log section showing Devonian formations at Art Field, Clay County.

HS=216

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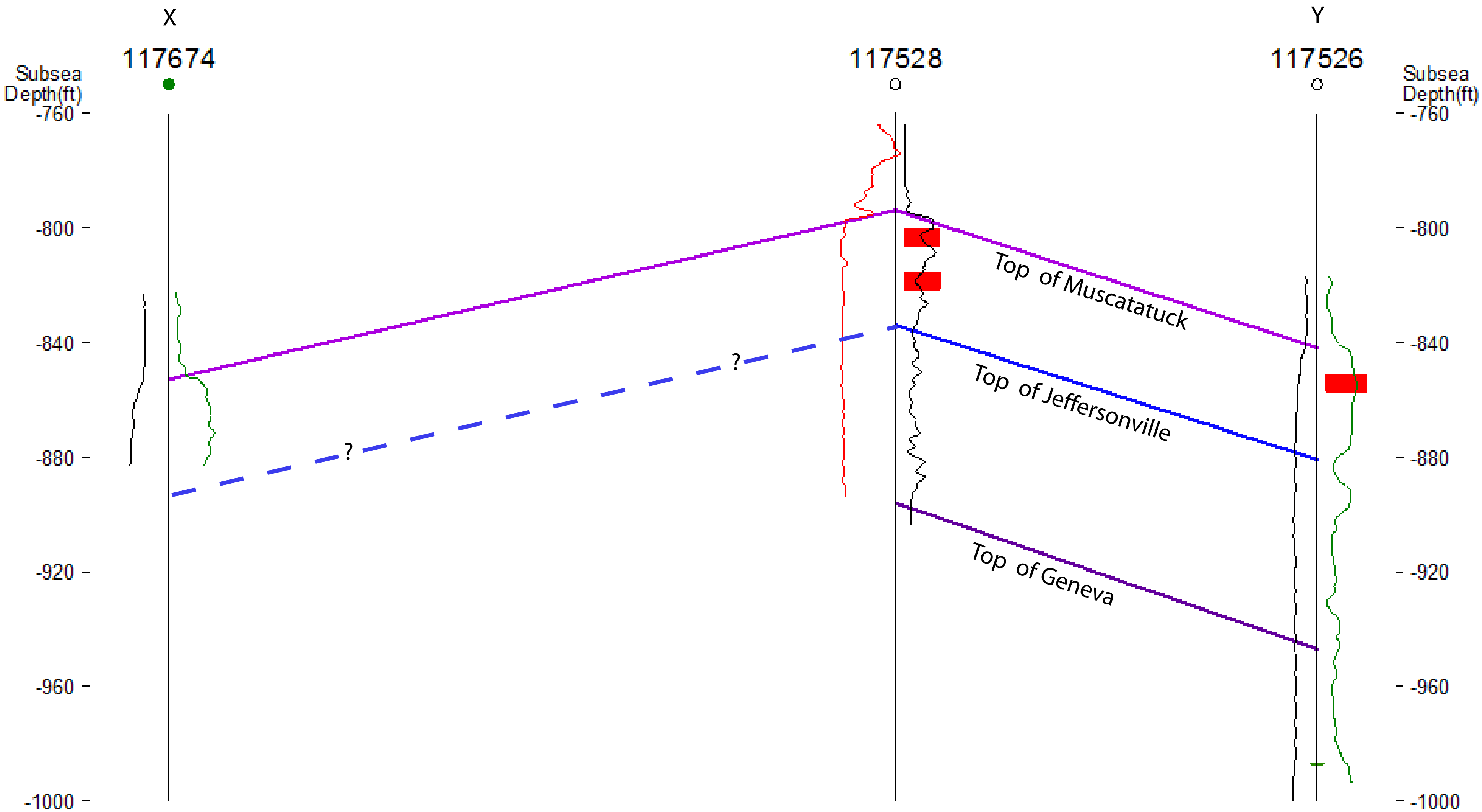


Figure 4: X-Y Cross section showing Devonian subsurface structure across Art Field, Clay County. The red color box shows the completion intervals for the oil production. For location of the cross section refer to Figure 1.



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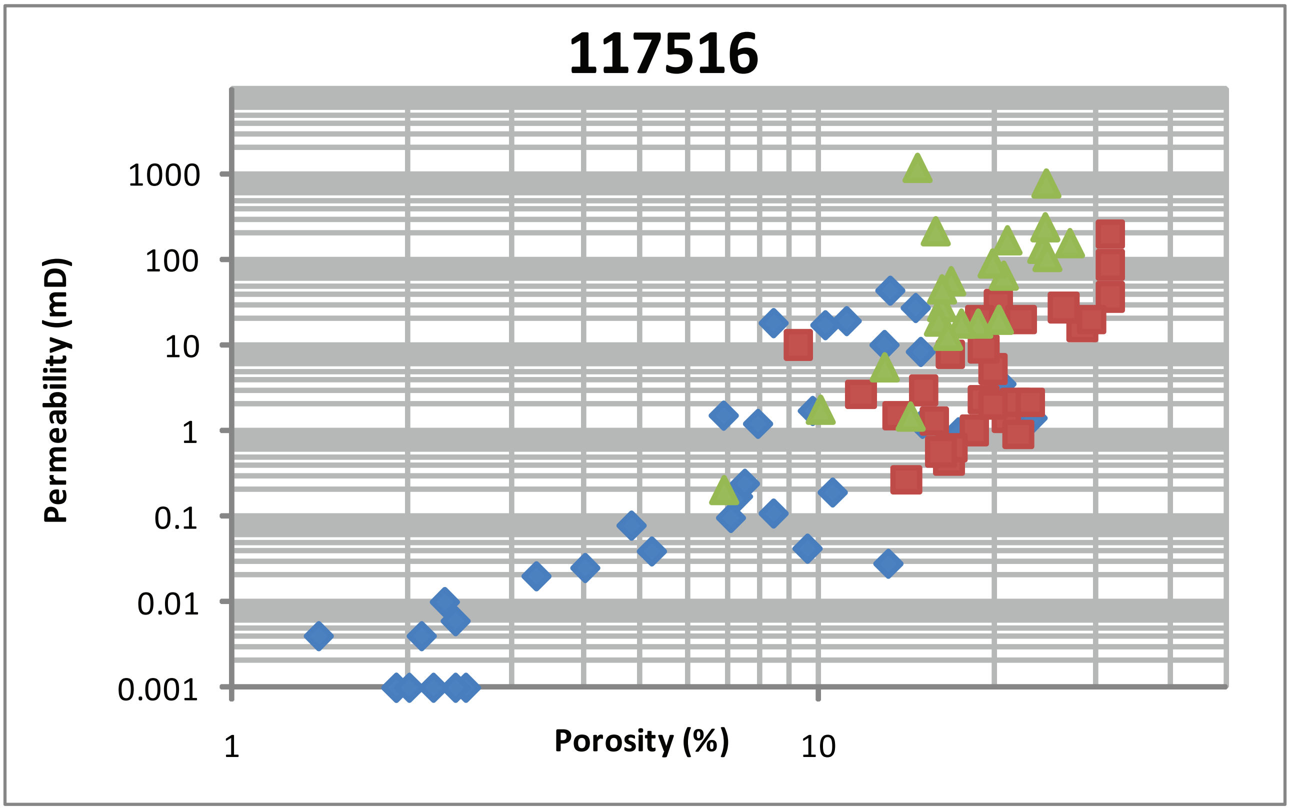


Figure 5: Porosity and permeability from core analysis from Art Field, Clay County. The blue points are from North Vernon, the red points from the Vernon Fork, the green triangles from the Geneva Dolomite. The chart title lists the IGS Well ID. For well location see Figure 1.

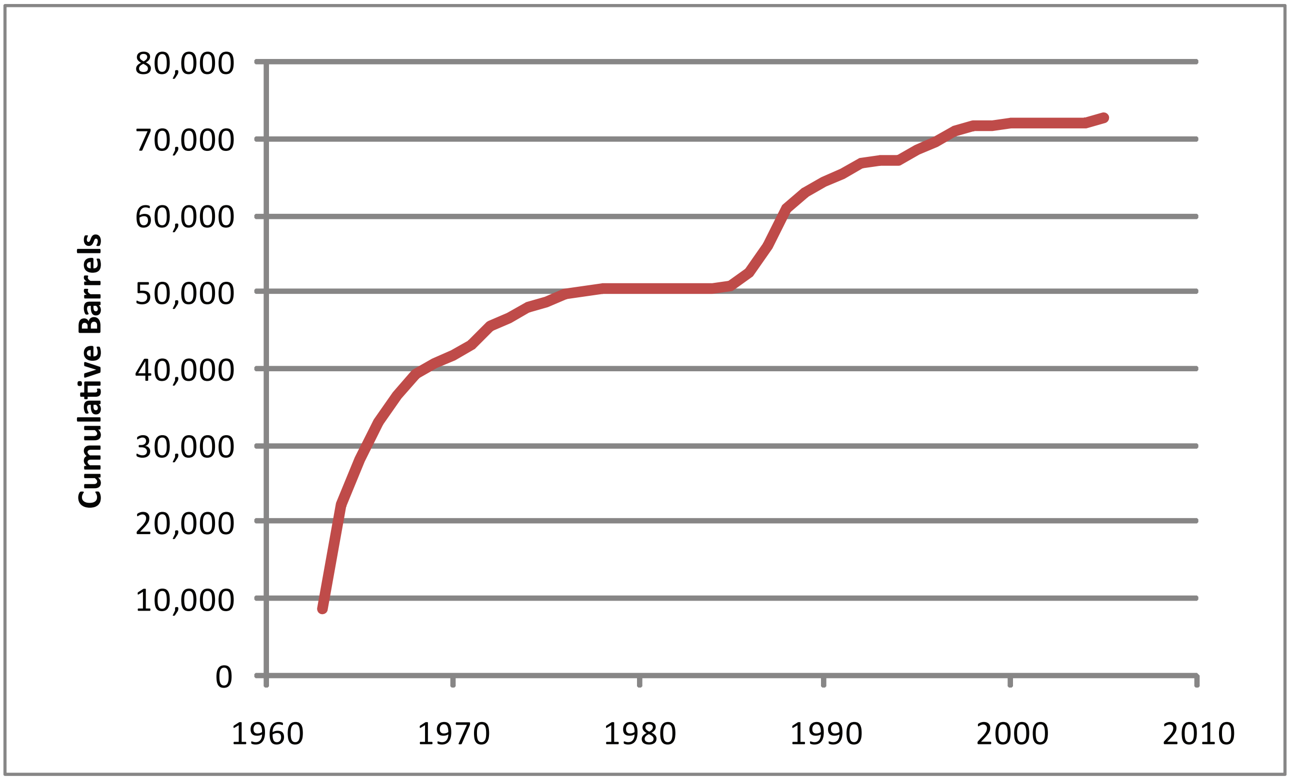


Figure - 6: Cumulative oil production history for Art Field, Clay County since 1963.

Table-1: List of the wells used for subsurface structure mapping in Art Field, Clay County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 117513 | 11 | N | 7 | W | 1 | 603 | 1458 | 1498 | 1570 | 1629 | | |
| 117514 | 11 | N | 7 | W | 2 | 630 | 1464 | | | | 11 | |
| 117515 | 11 | N | 7 | W | 2 | 613 | 1426 | | | | 26 | |
| 117516 | 11 | N | 7 | W | 2 | 629 | 1464 | 1500 | | | | |
| 117517 | 11 | N | 7 | W | 3 | 636 | 1488 | 1520 | 1576 | 1620 | 10 | |
| 117519 | 11 | N | 7 | W | 3 | 620 | 1418 | | | | 50/100 | |
| 117520 | 11 | N | 7 | W | 3 | 630 | 1423 | | | | 85 | |
| 117522 | 11 | N | 7 | W | 3 | 629 | 1457 | | | | 40 | |
| 117523 | 11 | N | 7 | W | 3 | 638 | 1496 | | | | | |
| 117524 | 11 | N | 7 | W | 3 | 654 | 1530 | | | | | |
| 117525 | 11 | N | 7 | W | 3 | 636 | 1430 | | | | | |
| 117526 | 11 | N | 7 | W | 3 | 633 | 1475 | 1514 | 1580 | 1620 | 36 | |
| 117527 | 11 | N | 7 | W | 3 | 614 | 1424 | | | | 20 | |
| 117528 | 11 | N | 7 | W | 3 | 636 | 1432 | 1472 | 1532 | | 48 | |
| 156721 | 11 | N | 7 | W | 3 | 623 | 1414 | | | | 5 | |
| 156722 | 11 | N | 7 | W | 3 | 629 | 1430 | | | | 8 | |
| 156723 | 11 | N | 7 | W | 3 | 618 | 1400 | | | | 10 | |
| 117673 | 12 | N | 7 | W | 34 | 643 | 1509 | | | | | |
| 117674 | 12 | N | 7 | W | 34 | 617 | 1470 | | | | | |

**Field name:** Ashboro East

**IGS ID:** 10019

**DOE ID:** 3000

**Location:** Clay County, 11N-6W

**Discovery date:** 1980

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,338 ft.)

**Field type:** oil

**Total number production wells:** 6

**Area:** 110 acres

**Cumulative production:** 57,040 bbls. (2002)

**Other reservoir units:** Mississippian, Borden Group, Carper Ss.

**Deepest unit penetrated (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,400 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 40 ft. at top of Muscatatuck.

**Reservoir characteristics:**

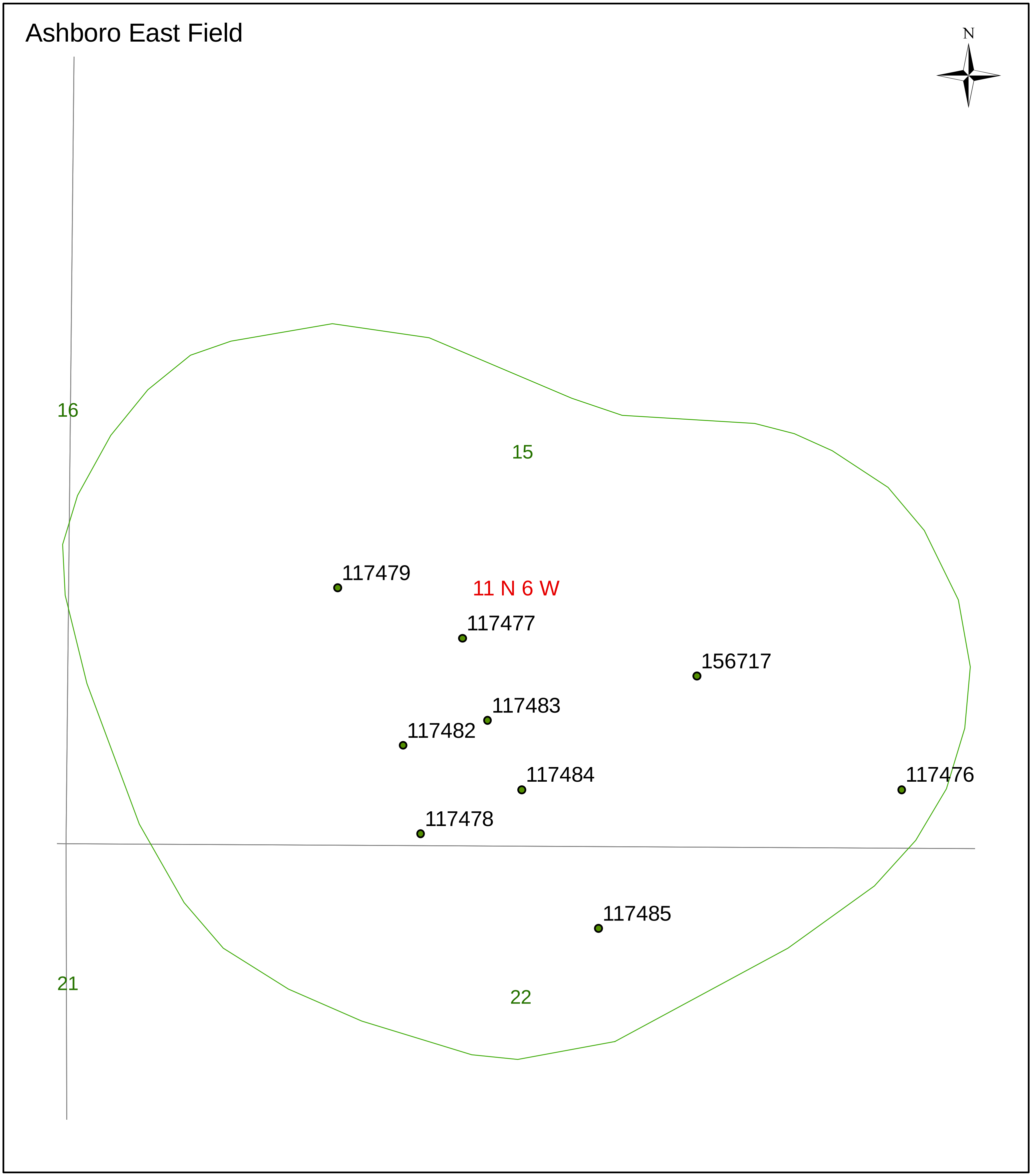


Figure 1: Map showing location and wells at Ashboro East Field, Clay County. The green points are the location of wells in the field.

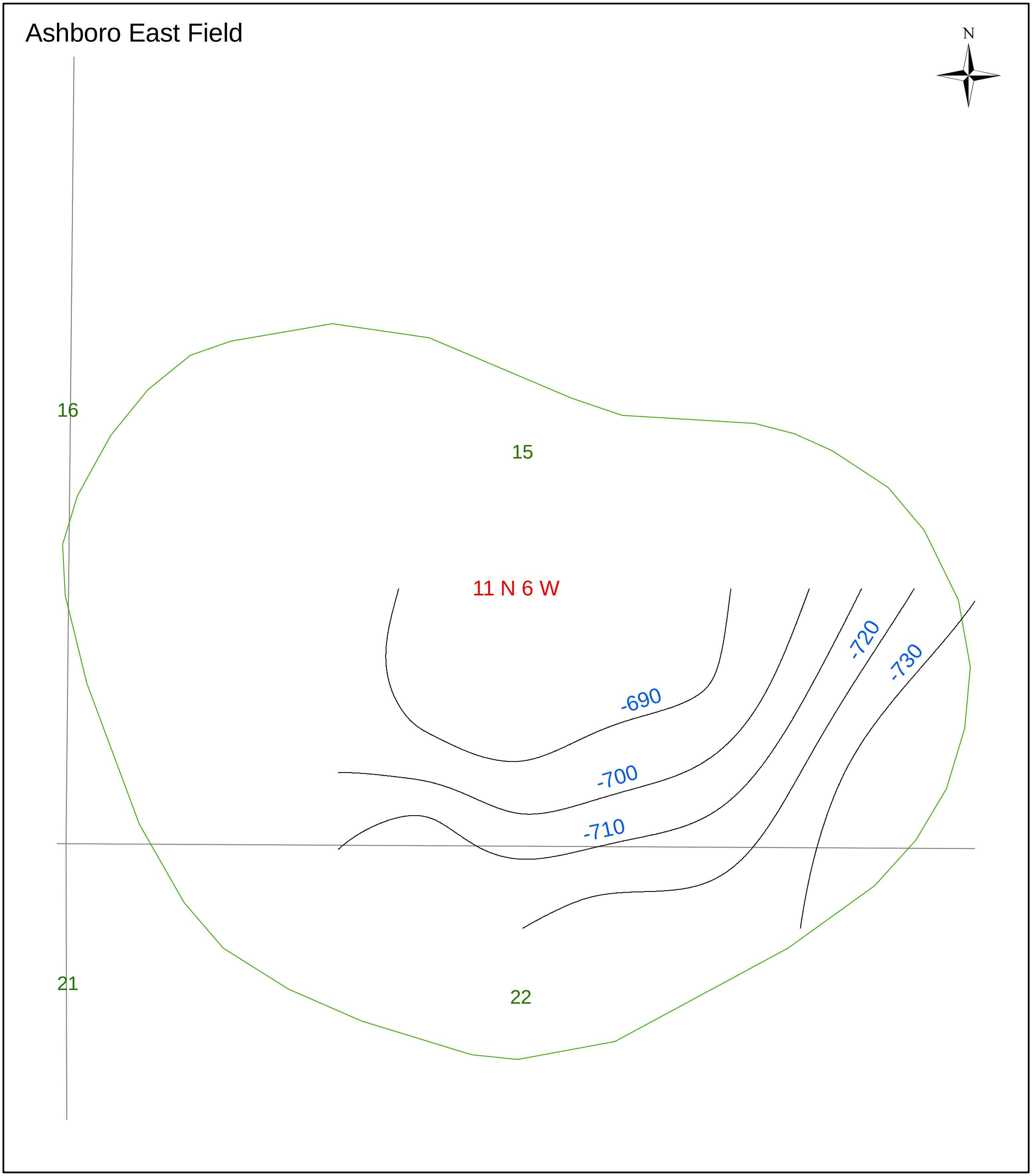


Figure 2: Structure map showing the top of Muscatatuck Limestone in Ashboro East Field, Clay County. Contours show values below sea level, contour interval is 10 ft .

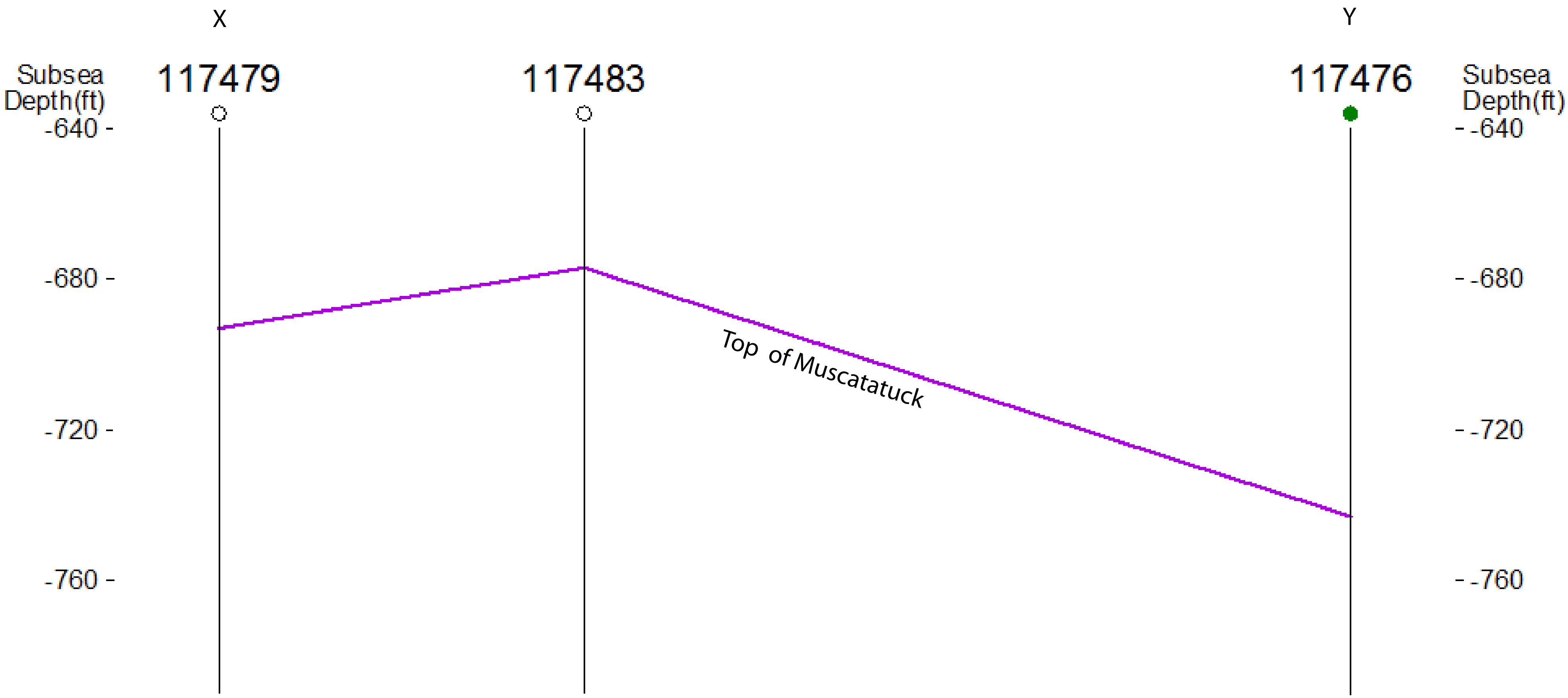


Figure 3: X-Y Cross section showing Devonian subsurface structure across Ashboro East field, Clay County. For location of the cross section refer to Figure 1.



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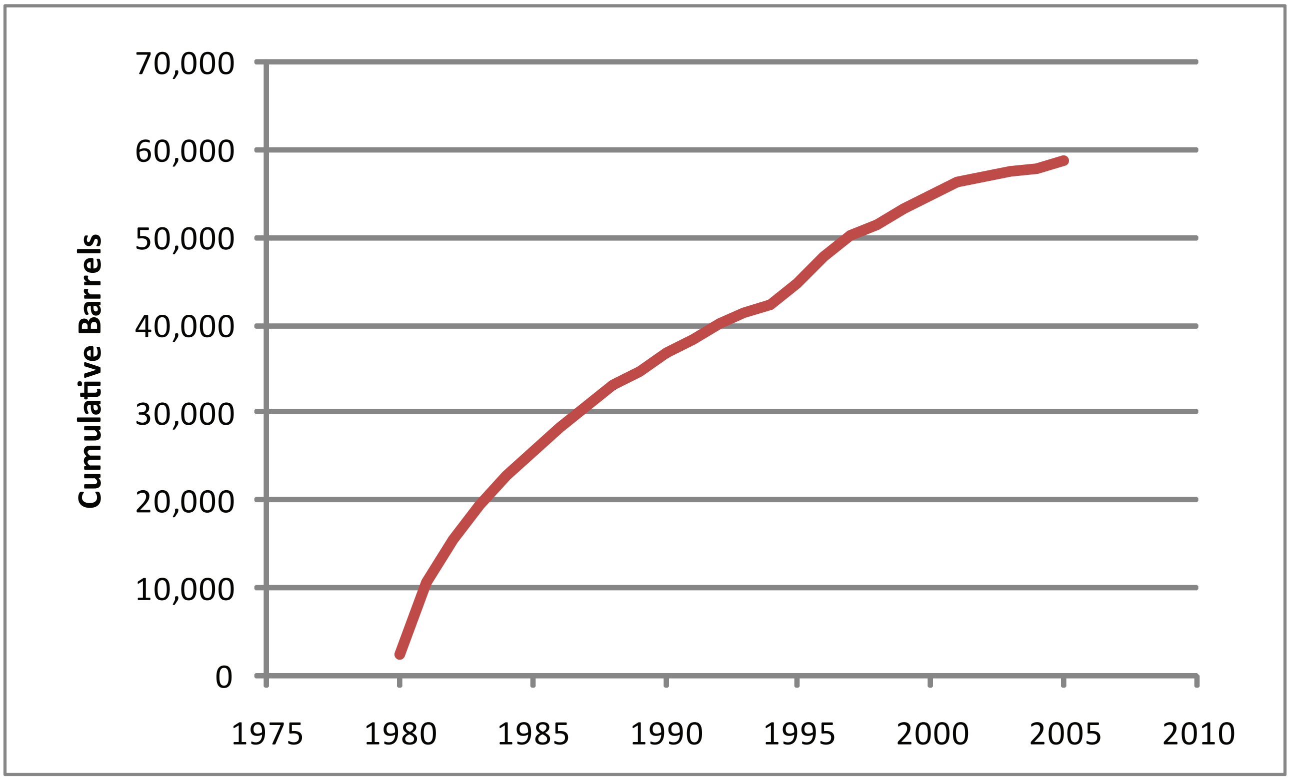


Figure - 3: Cumulative oil production history for Ashboro East Field, Clay County since 1980.

Table-1: List of the wells used for subsurface structure mapping in Ashboro East field, Clay County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 117475 | 11 | N | 6 | W | 14 | 586 | 1324 | 1360 | | | | |
| 117476 | 11 | N | 6 | W | 15 | 629 | 1372 | | | | | |
| 117477 | 11 | N | 6 | W | 15 | 633 | 1320 | | | | | |
| 117478 | 11 | N | 6 | W | 15 | 631 | 1355 | | | | 20 | |
| 117479 | 11 | N | 6 | W | 15 | 658 | 1351 | | | | 10 | |
| 117482 | 11 | N | 6 | W | 15 | 631 | 1320 | | | | 6 | |
| 117483 | 11 | N | 6 | W | 15 | 623 | 1300 | | | | 2 | |
| 117484 | 11 | N | 6 | W | 15 | 626 | 1318 | | | | 10 | |
| 156717 | 11 | N | 6 | W | 15 | 627 | 1312 | | | | 8 | |
| 117485 | 11 | N | 6 | W | 22 | 626 | 1356 | | | | | |

**Field name:** Bartlettsville

**IGS ID:** 10032

**DOE ID:** 41675

**Location:** Monroe & Lawrence Counties, 6&7N-1E

**Discovery date:**

1929 (oil)

1935 (natural gas)

**Lower Paleozoic reservoir units (depth):**

Devonian, Muscatatuck Group (na) (natural gas)

Ordovician, Trenton Ls. (1691 ft.) (oil)

**Field type:** oil & natural gas

**Total number production wells:** 15 (oil), 4 (natural gas)

**Area:** 260 acres

**Cumulative production:** 56,413 bbls. (2002)

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Cambrian/Ordovician Knox Supergroup (2,842 ft.)

**Field characteristic:** Anticline adjacent to Mt. Carmel Fault with structural closure in excess of 20 ft..

**Reservoir characteristics:**

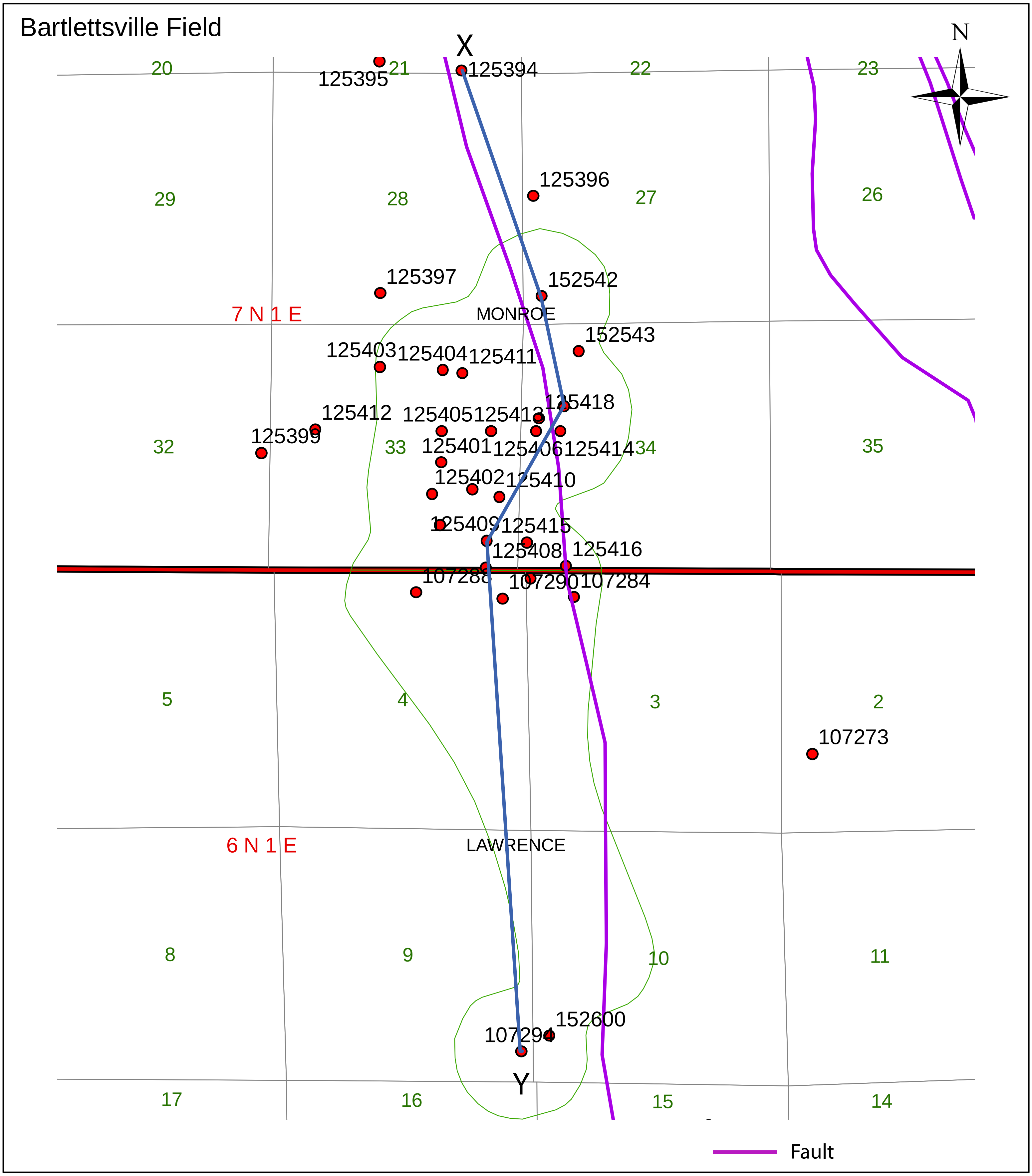


Figure 1: Map showing location and wells at Bartlettsville Field, Monroe County. X-Y is the location of the cross section that shows the subsurface Devonian structure in Figure 5. Mt. Carmel Fault traces are also shown.

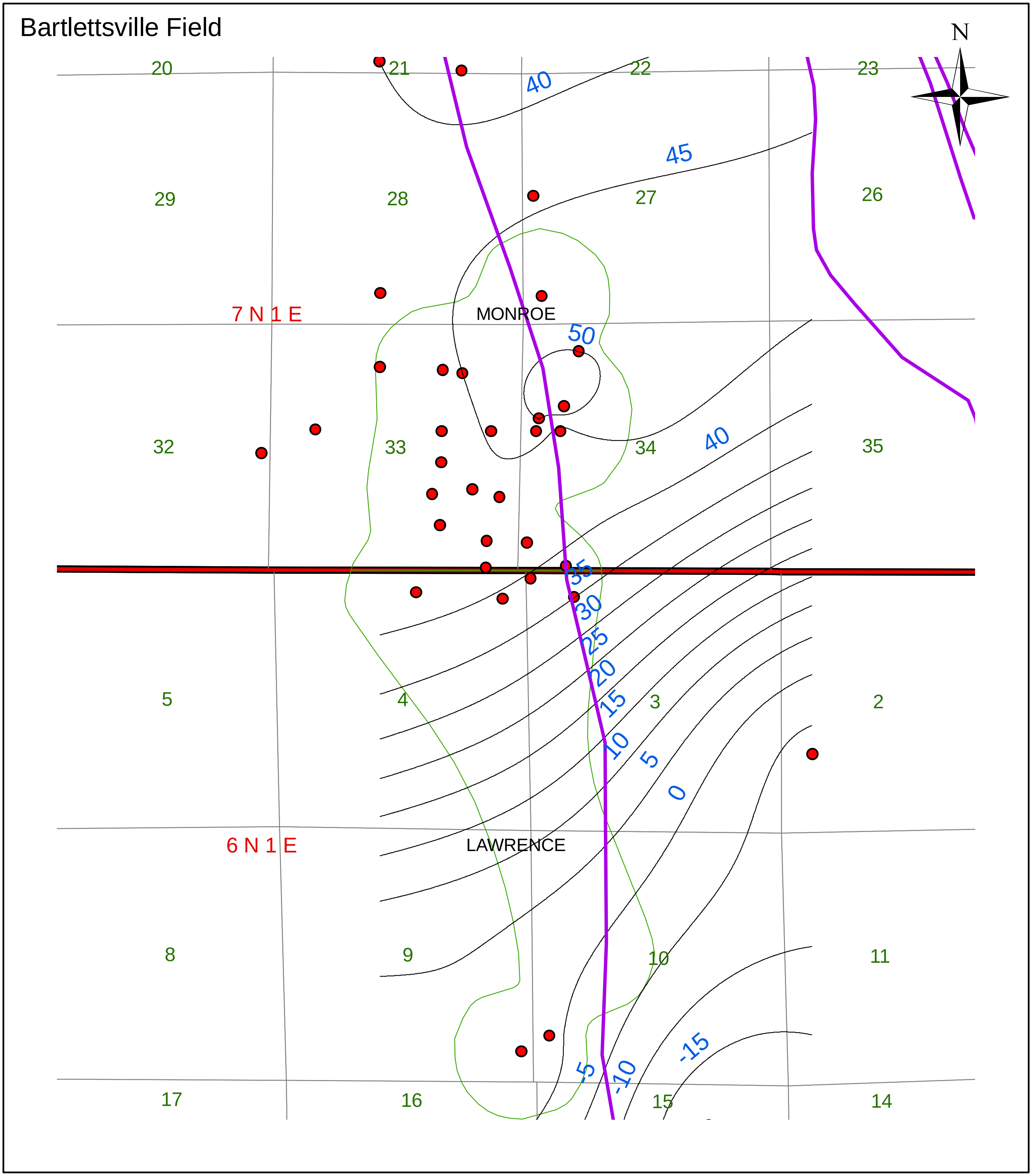


Figure 2: Structure map showing top of the Muscatatuck Limestone in the Bartlettsville Field, Monroe County. Contours show values below sea level, contour interval is 5 ft .

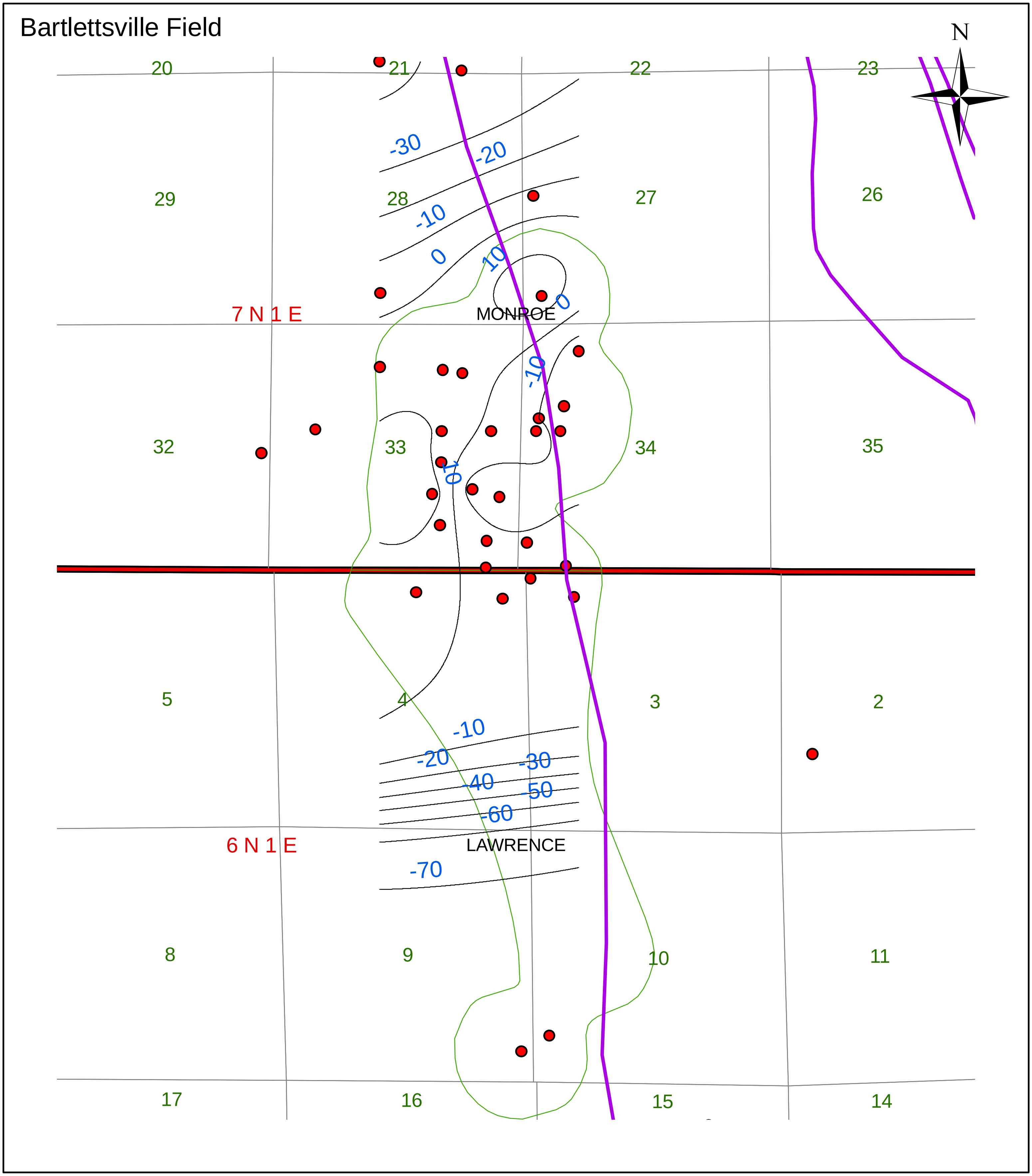


Figure 3: Structure map showing top of the Jeffersonville Limestone in Bartlettsville Field, Monroe County. Contours show values below sea level, contour interval is 10 ft .

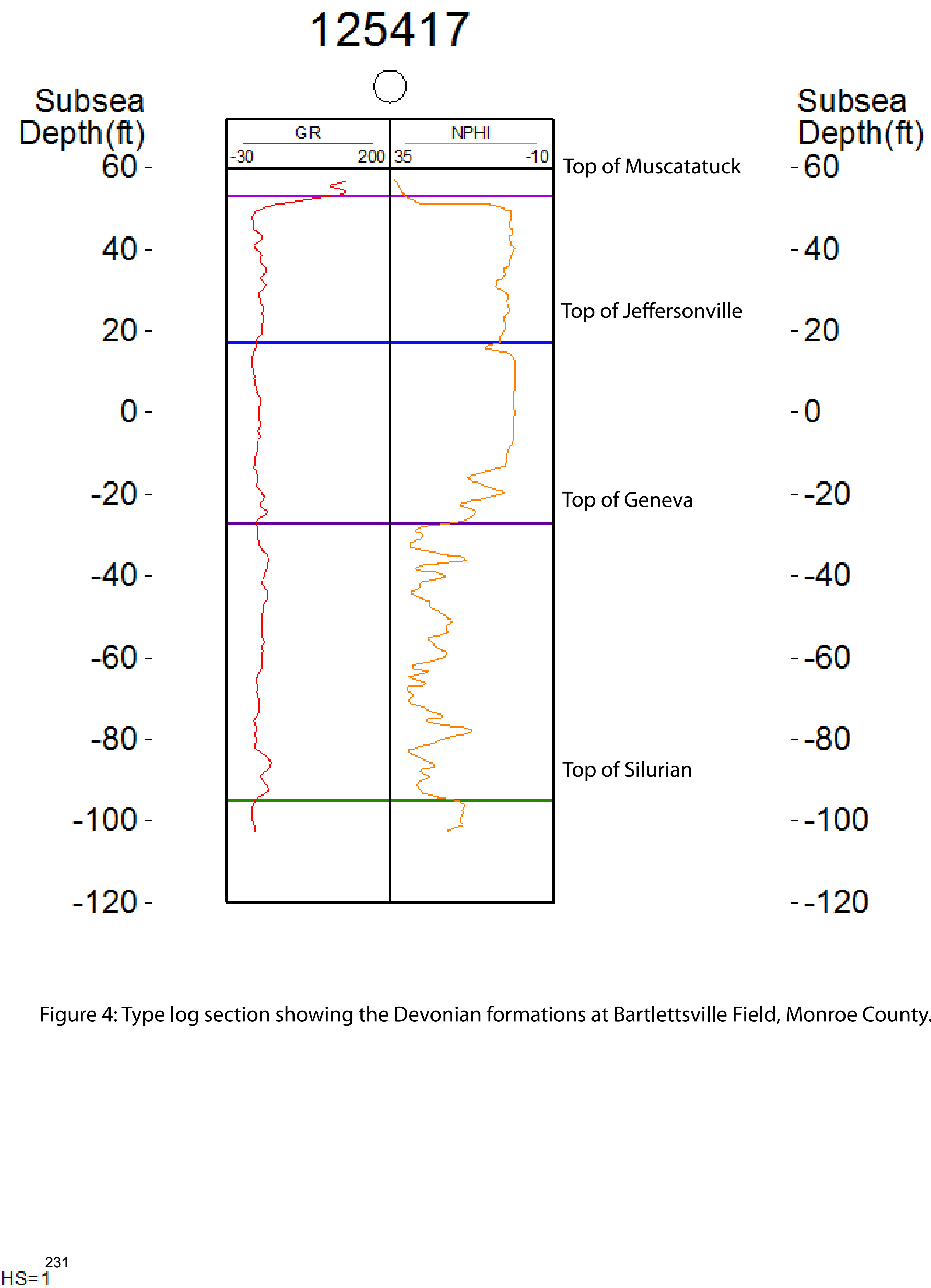


Figure 4: Type log section showing the Devonian formations at Bartlettsville Field, Monroe County.

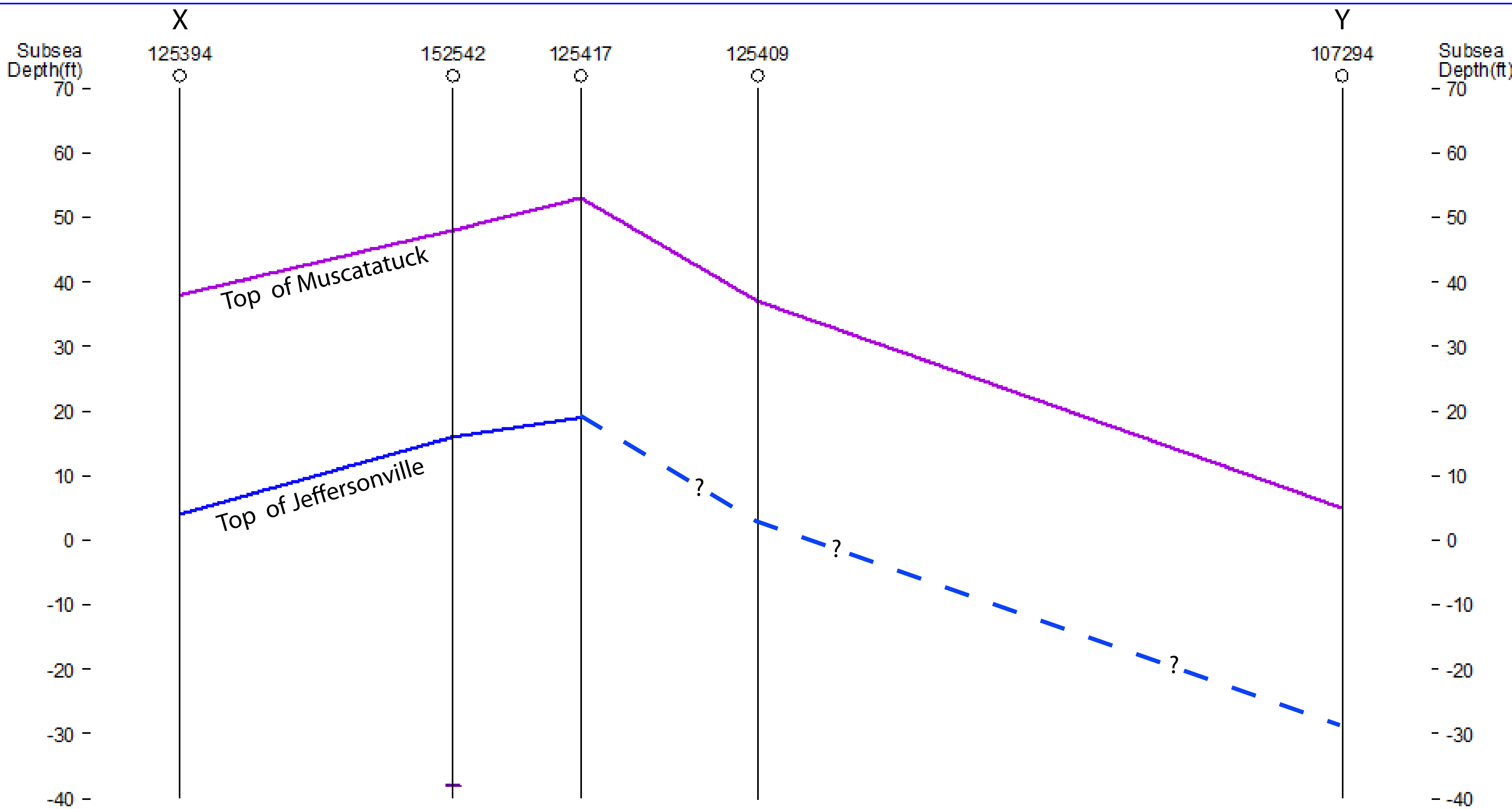


Figure 5: X-Y Cross section shows the Devonian subsurface structure across Bartlettsville Field, Monroe County. For location of the cross section refer to Figure 1.

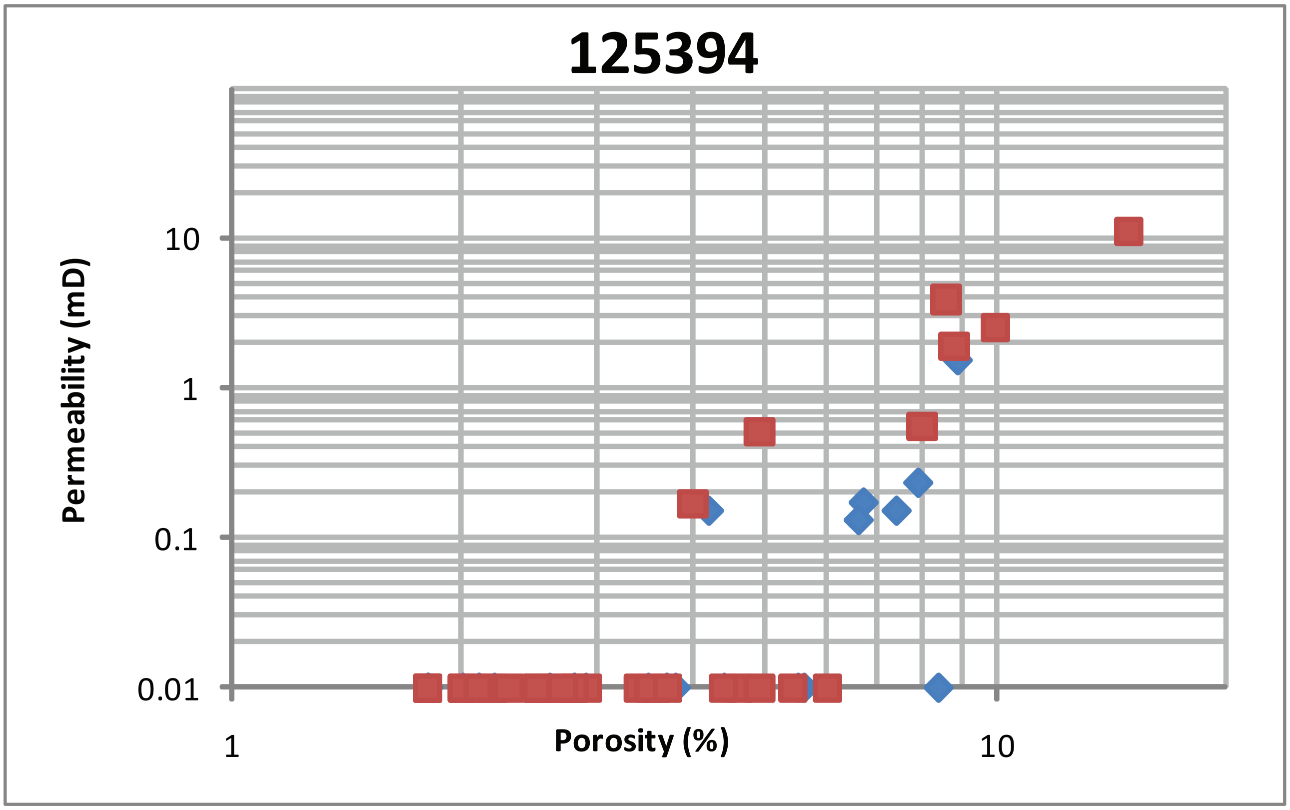


Figure 6: Porosity-permeability plot from core analysis from Bartlettsville Field, Monroe County. The blue points are from the North Vernon, the red points from the Vernon Fork. The chart title lists the IGS Well ID. For the well location see Figure 1.

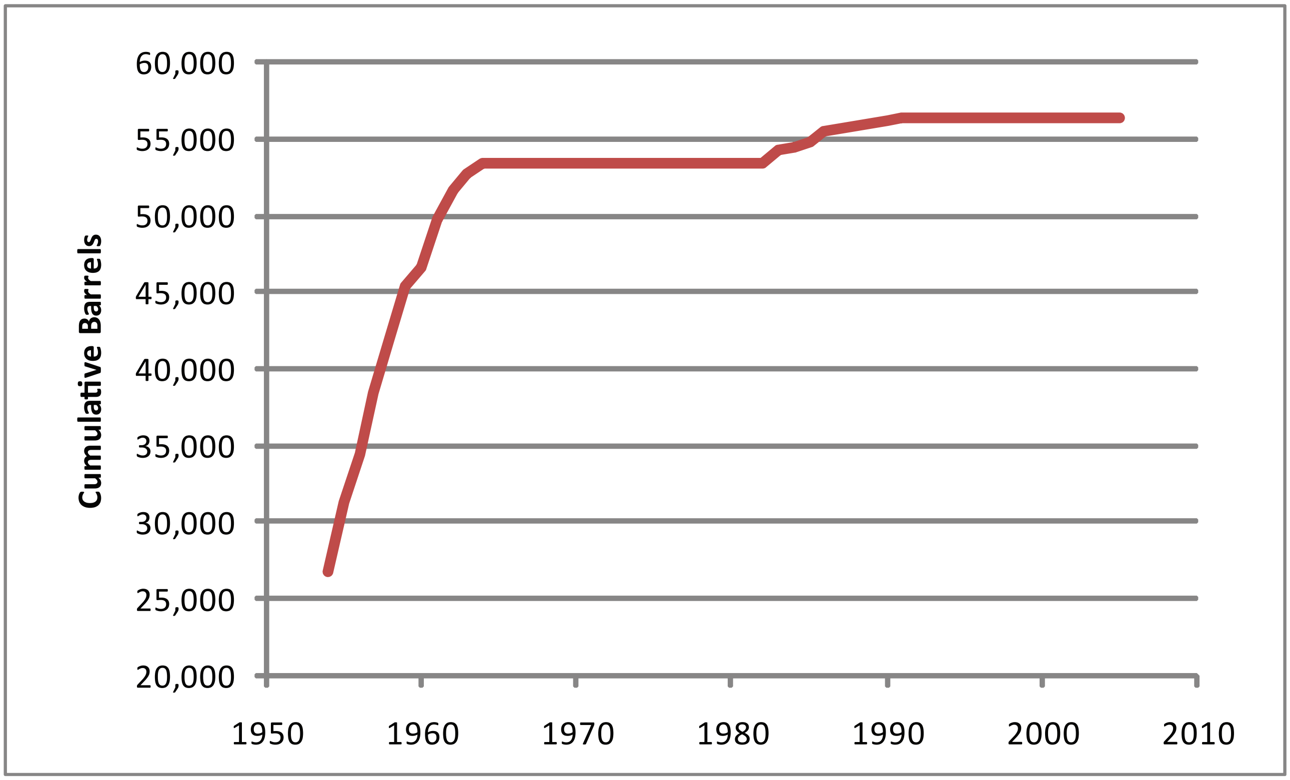


Figure - 7: Cumulative oil production history for Bartlettsville Field, Monroe County since 1954.

Table-1: List of the wells from Bartlettsville Field, Monroe County.

| County | IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lawrence | 107273 | 6 | N | 1 | E | 2 | 770 | 777 | | | 905 | | |
| Lawrence | 107284 | 6 | N | 1 | E | 3 | 628 | 610 | | | | | |
| Lawrence | 107285 | 6 | N | 1 | E | 3 | 765 | | | | | | |
| Lawrence | 107288 | 6 | N | 1 | E | 4 | 776 | 780 | | | | 8 | |
| Lawrence | 107290 | 6 | N | 1 | E | 4 | 653 | | | | | | 700 |
| Lawrence | 107294 | 6 | N | 1 | E | 9 | 567 | 562 | 638 | 710 | 770 | 5 | 3 |
| Lawrence | 152600 | 6 | N | 1 | E | 10 | 574 | 573 | | | | | |
| Lawrence | 107272 | 6 | N | 1 | E | 15 | 531 | | | | | | |
| Lawrence | 152601 | 6 | N | 1 | E | 15 | 535 | 555 | | | 669 | | |
| Monroe | 125391 | 7 | N | 1 | E | 15 | 804 | 788 | | | 922 | | |
| Monroe | 125392 | 7 | N | 1 | E | 16 | 797 | 755 | | | | | |
| Monroe | 125394 | 7 | N | 1 | E | 21 | 802 | 764 | 840 | | | | |
| Monroe | 125395 | 7 | N | 1 | E | 21 | 824 | 784 | 866 | | 943 | | |
| Monroe | 152540 | 7 | N | 1 | E | 21 | 699 | 670 | | | | | |
| Monroe | 125396 | 7 | N | 1 | E | 27 | 796 | 741 | | | | | |
| Monroe | 152542 | 7 | N | 1 | E | 27 | 823 | 775 | 807 | 861 | 900 | | |
| Monroe | 125397 | 7 | N | 1 | E | 28 | 790 | 747 | | | 875 | | |
| Monroe | 125399 | 7 | N | 1 | E | 32 | 625 | 612 | | | | | |
| Monroe | 125400 | 7 | N | 1 | E | 33 | 755 | 746 | 770 | 848 | 874 | 30 | |
| Monroe | 125401 | 7 | N | 1 | E | 33 | 809 | 766 | | | | 25 | |
| Monroe | 125402 | 7 | N | 1 | E | 33 | 805 | 760 | 790 | 848 | 892 | 35 | |
| Monroe | 125403 | 7 | N | 1 | E | 33 | 800 | | | | | | |
| Monroe | 125404 | 7 | N | 1 | E | 33 | 700 | 743 | | | | 28 | |
| Monroe | 125405 | 7 | N | 1 | E | 33 | 797 | 755 | 788 | 846 | 900 | 23 | |
| Monroe | 125406 | 7 | N | 1 | E | 33 | 819 | 768 | | | | 14 | |
| Monroe | 125407 | 7 | N | 1 | E | 33 | 785 | 748 | | | | 30 | |
| Monroe | 125408 | 7 | N | 1 | E | 33 | 658 | 597 | | | | | |
| Monroe | 125409 | 7 | N | 1 | E | 33 | 671 | 634 | | | | | |
| Monroe | 125410 | 7 | N | 1 | E | 33 | 710 | | | | | | |
| Monroe | 125411 | 7 | N | 1 | E | 33 | 805 | 776 | | | | | |
| Monroe | 125412 | 7 | N | 1 | E | 33 | 734 | 729 | | | | | |
| Monroe | 125413 | 7 | N | 1 | E | 34 | 802 | 764 | 810 | 855 | 894 | | |
| Monroe | 125414 | 7 | N | 1 | E | 34 | 801 | 758 | | | | | |
| Monroe | 125415 | 7 | N | 1 | E | 34 | 768 | | | | | | |
| Monroe | 125416 | 7 | N | 1 | E | 34 | 649 | | | | | | |
| Monroe | 125417 | 7 | N | 1 | E | 34 | 797 | 744 | 810 | 858 | 892 | 6 | |
| Monroe | 125418 | 7 | N | 1 | E | 34 | 820 | 770 | 830 | 868 | 896 | 10 | |
| Monroe | 152543 | 7 | N | 1 | E | 34 | 824 | 774 | 840 | | | | |

**Field name:** Bartlettsville North

**IGS ID:** 10033

**DOE ID:** na

**Location:** Monroe County, 7N-1E

**Discovery date:** 1986

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, na (693 ft.)

**Field type:** natural gas

**Total number production wells:** 1

**Area:** na

**Cumulative production:** na

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Devonian, Muscatatuck Group, na (768 ft.)

**Field characteristic:** Insufficient data available.

**Reservoir characteristics:**

**Field name:** Blackhawk

**IGS ID:** 10050

**DOE ID:** 69081

**Location:** Vigo County, 10N-8W

**Discovery date:** 1949

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,856 ft.)

**Field type:** oil

**Total number production wells:** 20

**Area:** 350 acres

**Cumulative production:** 584,406 bbls. (2002)

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Silurian (2,110 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 40 ft. at top of Muscatatuck.

**Reservoir characteristics:**

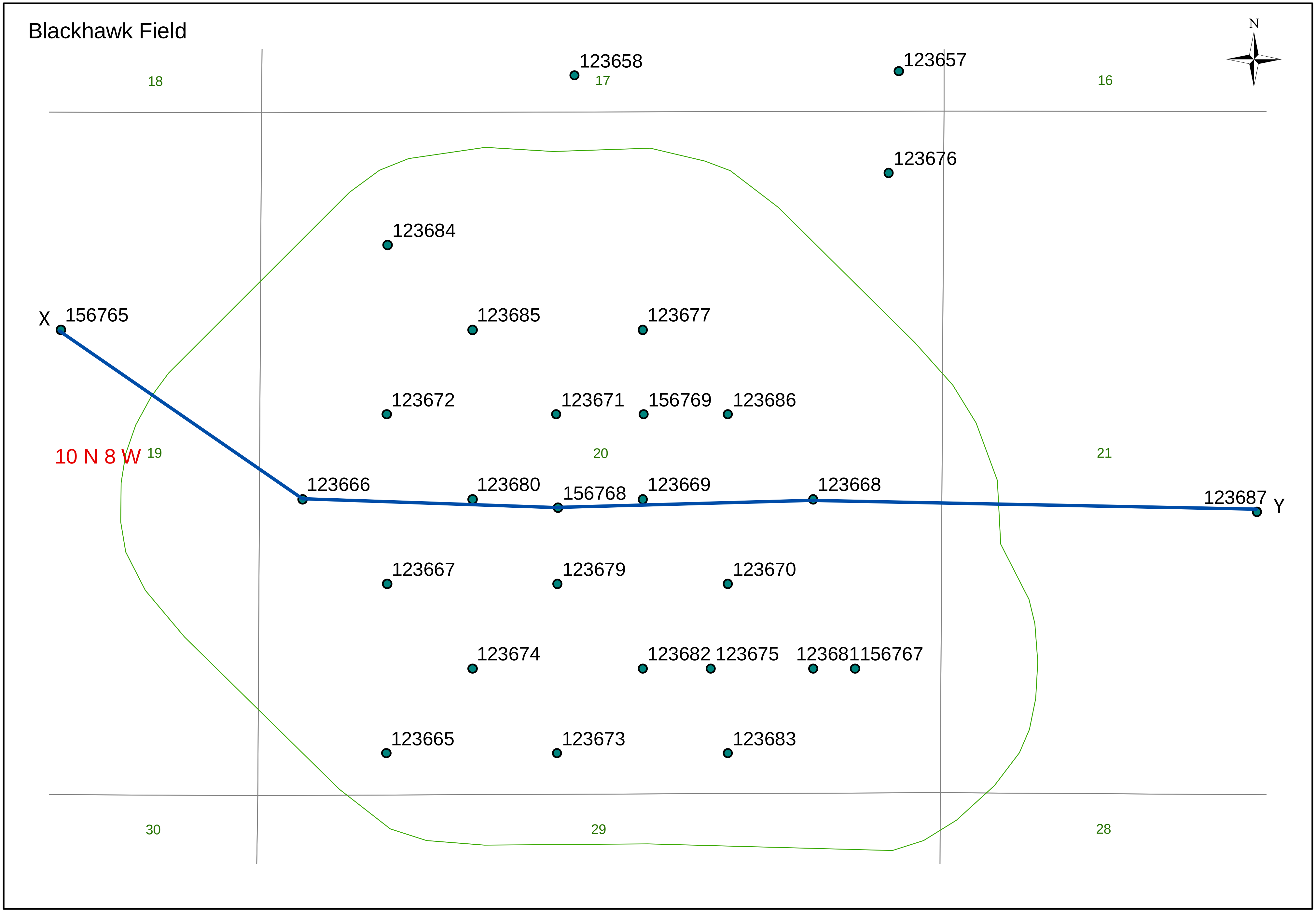


Figure 1: Map showing the location and wells at Blackhawk Field, Vigo County. X-Y is the location of the cross sections that shows the subsurface Devonian structure (Fig. 4).

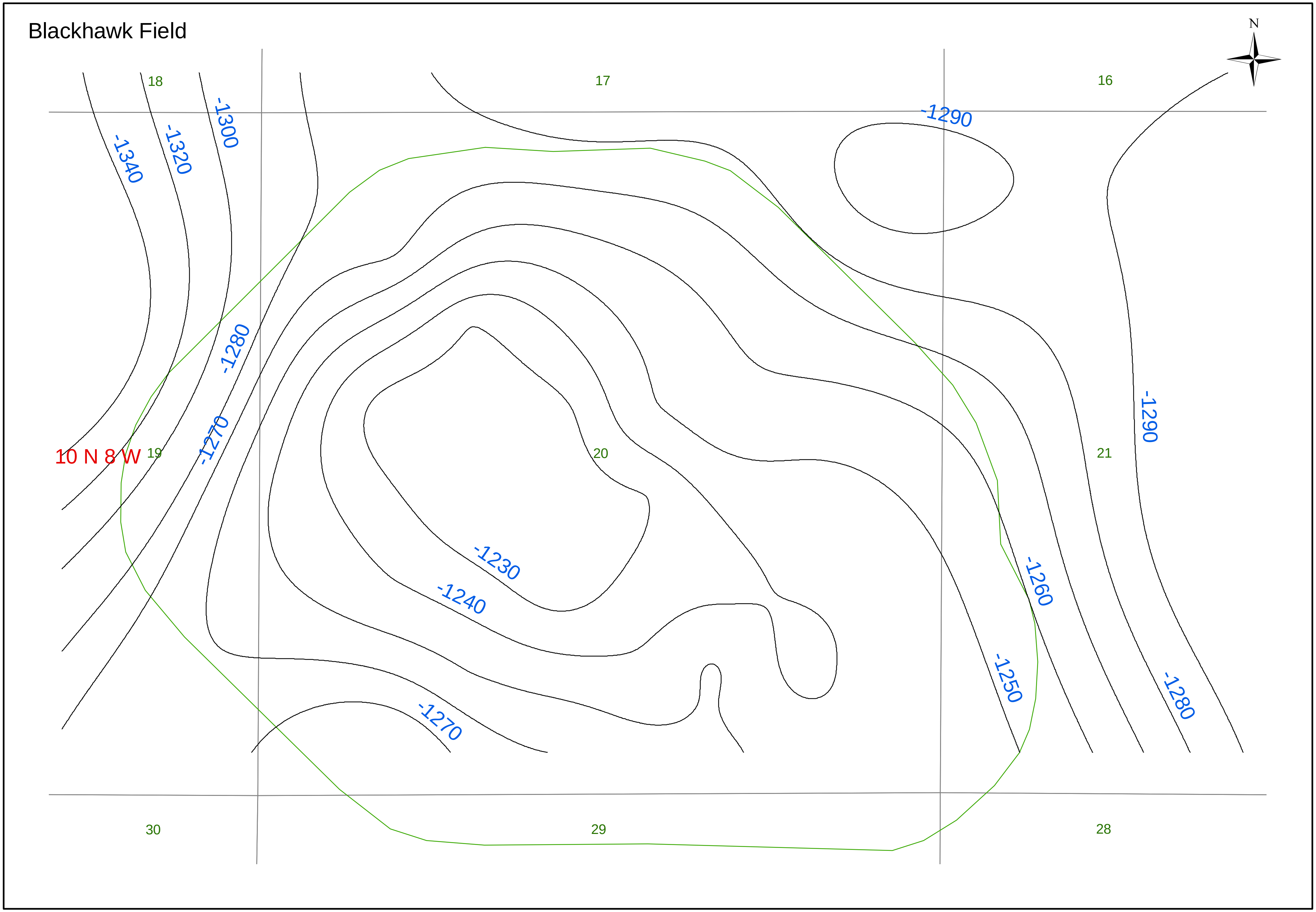


Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Blackhawk Field, Vigo County. Contours show values below sea level, contour interval is 10 ft .

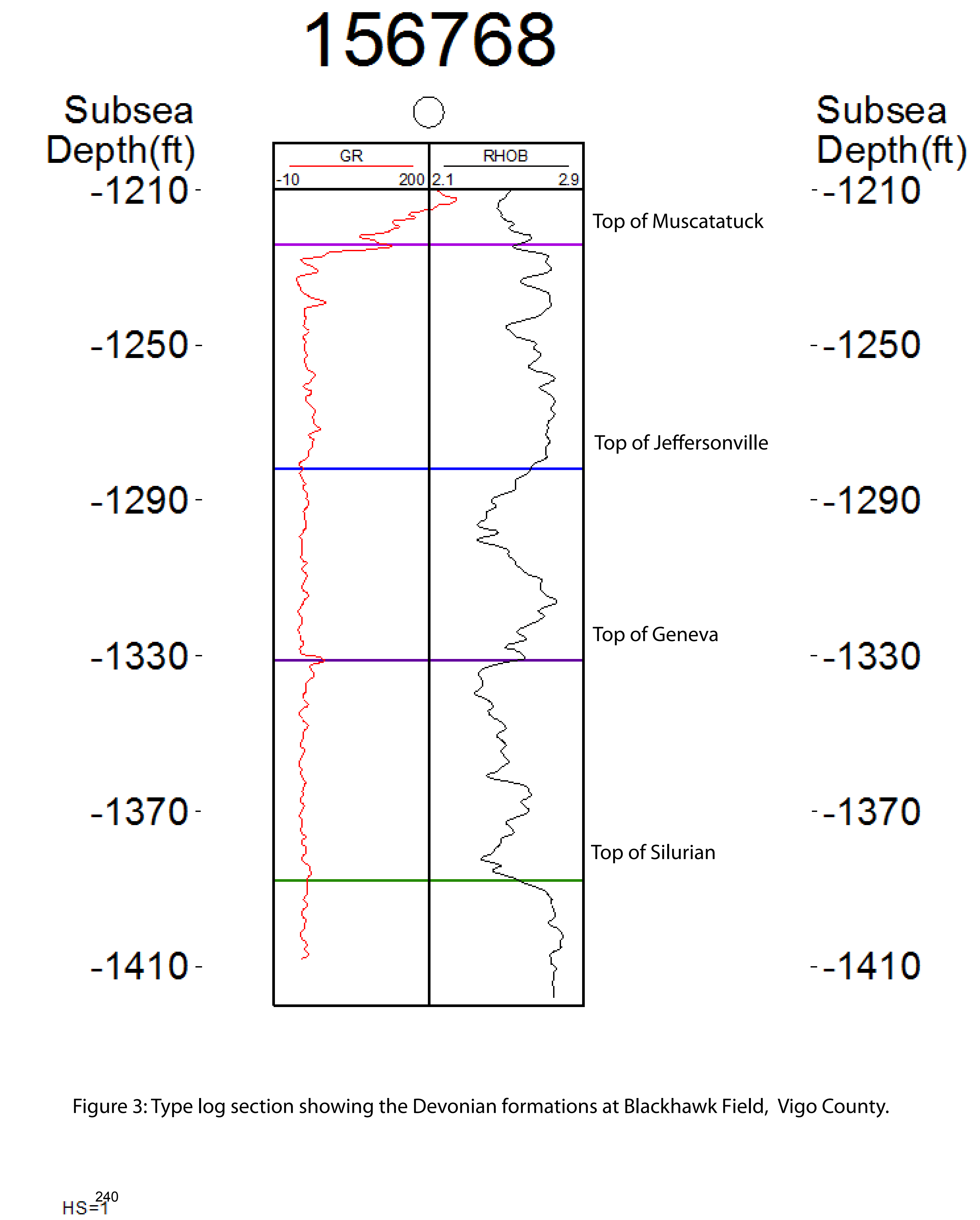


Figure 3: Type log section showing the Devonian formations at Blackhawk Field, Vigo County.

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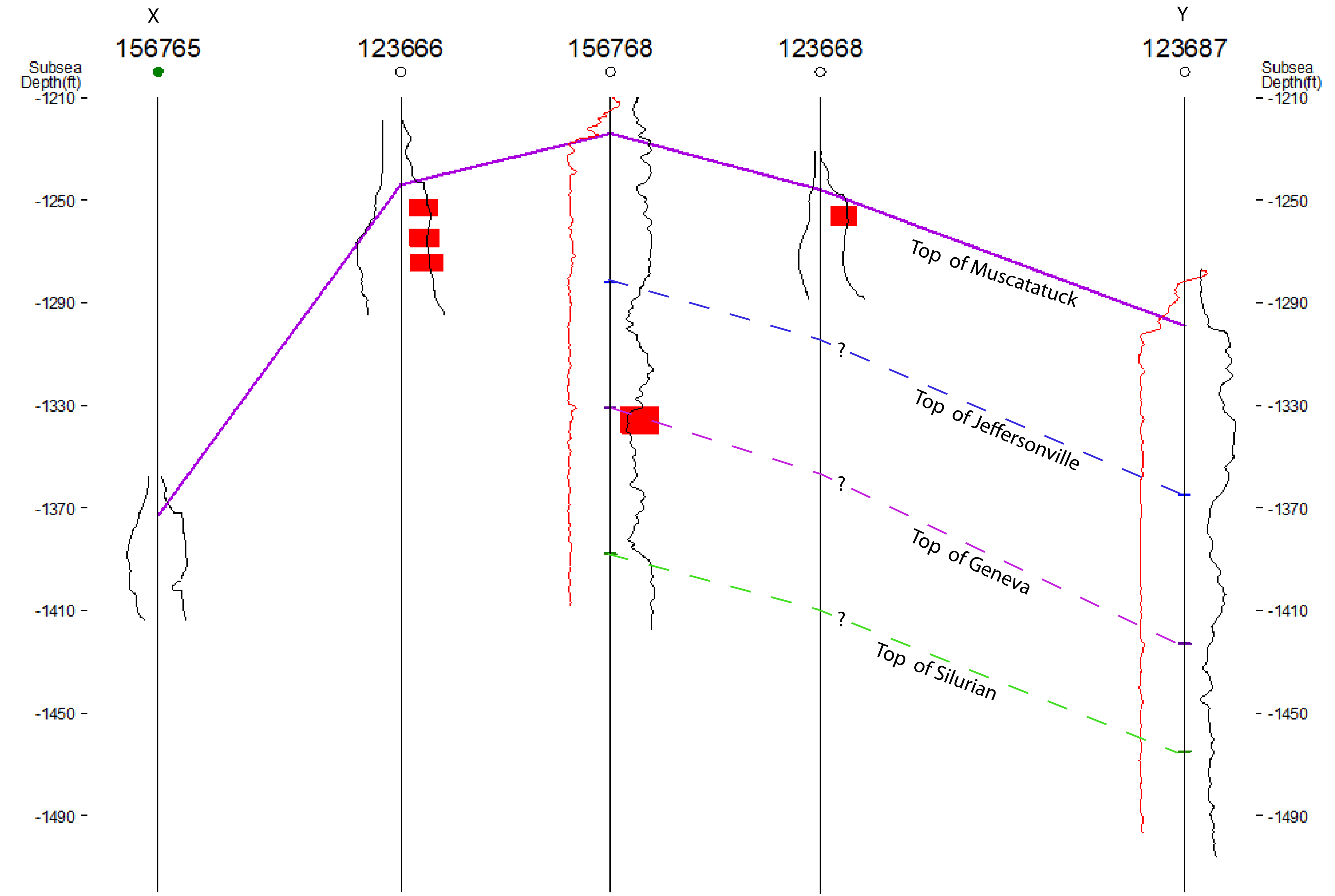
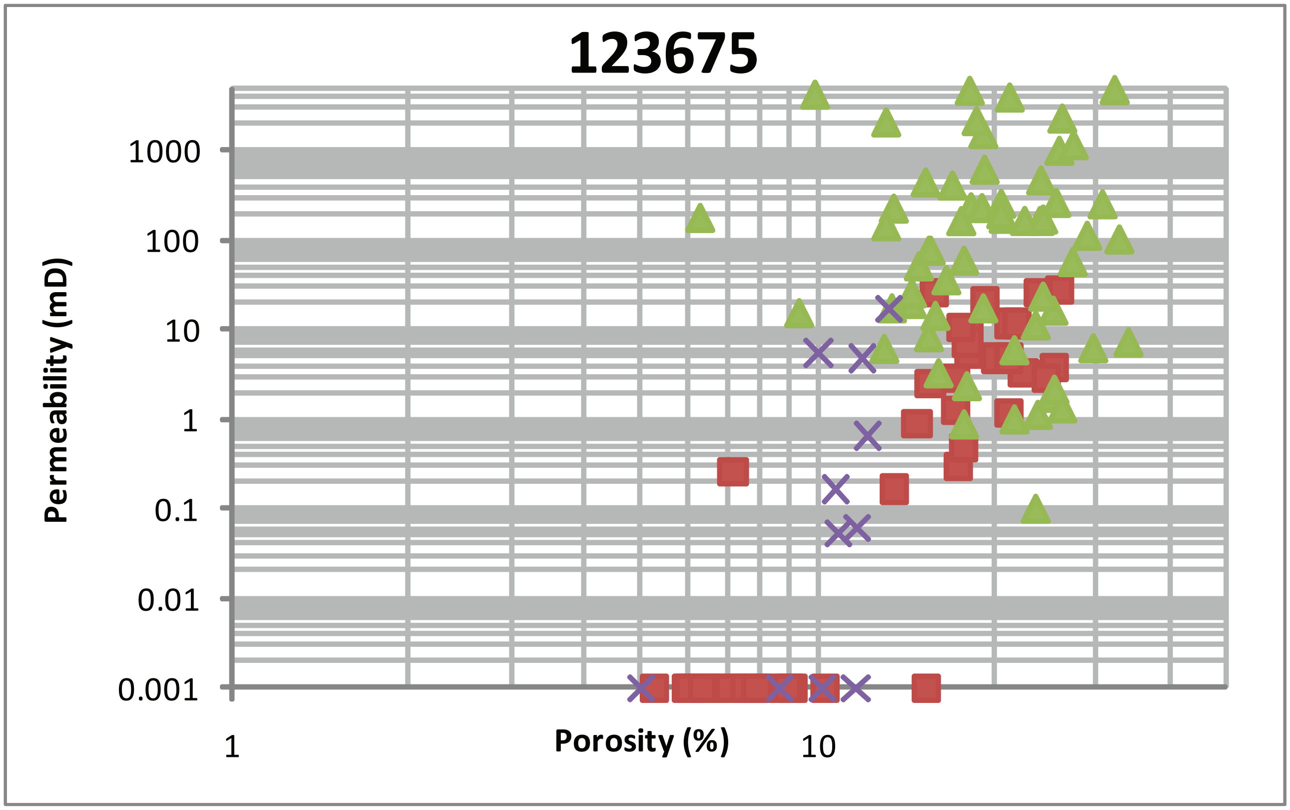



Figure 4: X-Y Cross section showing the Devonian subsurface structure across the Blackhawk Field, Vigo County. The red color box shows the completion intervals for the oil production. For location of the cross section refer to Figure 1.



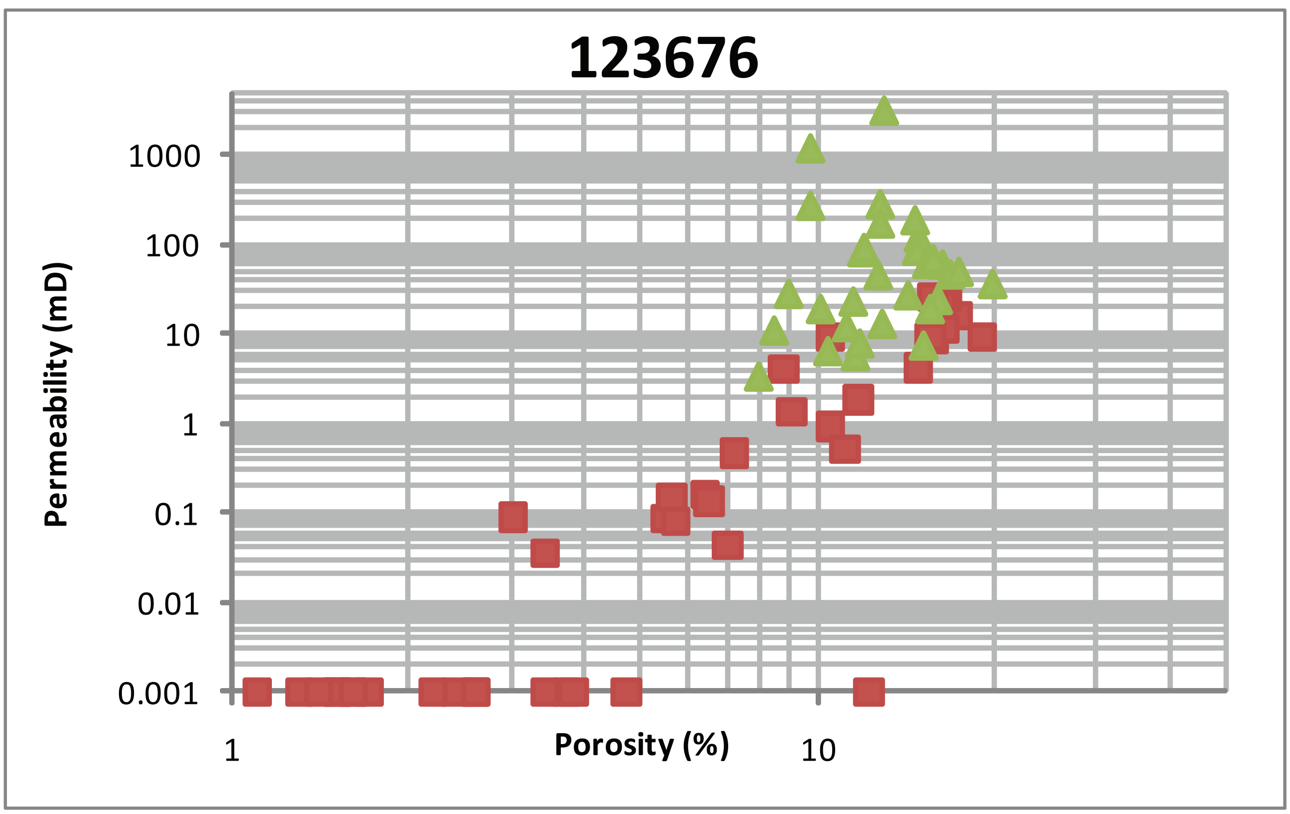
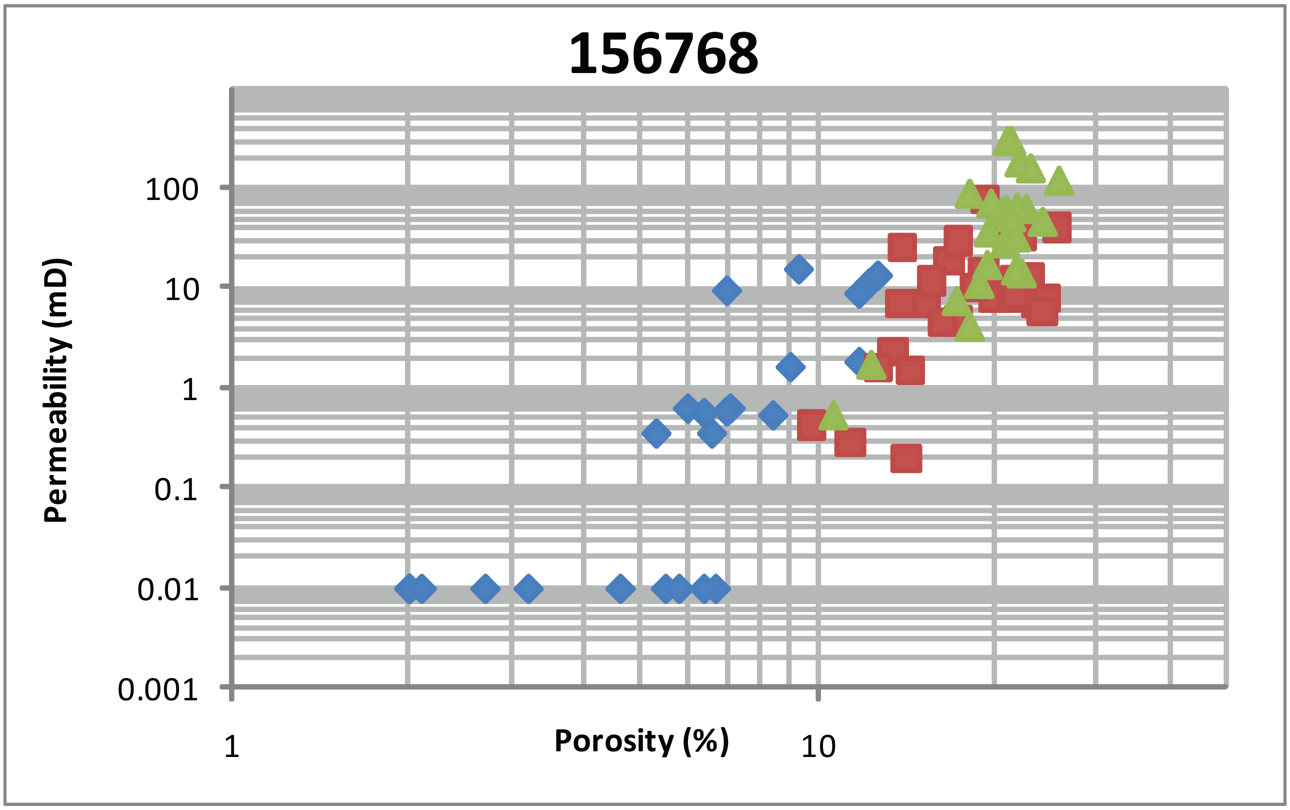




Figure 5: Porosity-permeability plots from core analysis from Blackhawk Field, Vigo County. The blue points are from North Vernon, the red points from the Vernon Fork, the green triangles from the Geneva Dolomite, and the crosses from the Silurian. The chart title lists the IGS Well ID. For the well locations see Figure 1.

Figure 5: Continued....



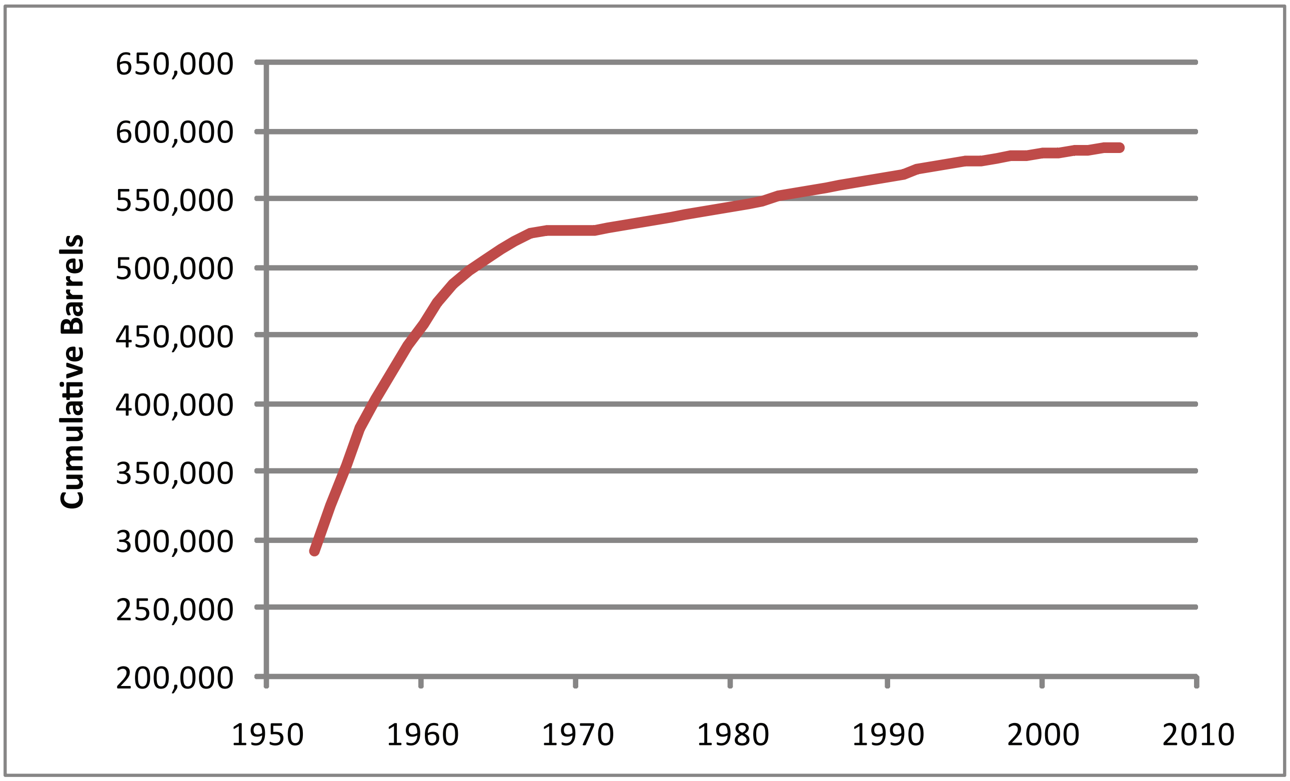



Figure - 6: Cumulative oil production history for Blackhawk Field, Vigo County since 1953.

Table-1: List of the wells used for subsurface structure mapping in Blackhawk Field, Vigo County. The wells selected have TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) | Core (P/A) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 123657 | 10 | N | 8 | W | 17 | 619 | 1902 | | | | | | |
| 123658 | 10 | N | 8 | W | 17 | 653 | 1943 | 2006 | 2071 | 2115 | | | |
| 156765 | 10 | N | 8 | W | 19 | 632 | 2005 | | | | | | |
| 123665 | 10 | N | 8 | W | 20 | 629 | 1912 | | | | | | |
| 123666 | 10 | N | 8 | W | 20 | 631 | 1875 | | | | 100 | | |
| 123667 | 10 | N | 8 | W | 20 | 633 | 1874 | | | | 20 | | |
| 123668 | 10 | N | 8 | W | 20 | 609 | 1855 | | | | 61 | | Present |
| 123669 | 10 | N | 8 | W | 20 | 620 | 1849 | 1906 | | | 100 | | |
| 123670 | 10 | N | 8 | W | 20 | 596 | 1834 | | | | 104 | | Present |
| 123671 | 10 | N | 8 | W | 20 | 632 | 1858 | 1920 | | | 77 | | Present |
| 123672 | 10 | N | 8 | W | 20 | 647 | 1872 | | | | 161 | | |
| 123673 | 10 | N | 8 | W | 20 | 638 | 1898 | | | | | | |
| 123674 | 10 | N | 8 | W | 20 | 639 | 1888 | | | | 36 | | |
| 123675 | 10 | N | 8 | W | 20 | 619 | 1870 | 1922 | 1980 | 2040 | 5 | | Present |
| 123676 | 10 | N | 8 | W | 20 | 612 | 1909 | 1968 | 2028 | 2065 | | | Present |
| 123677 | 10 | N | 8 | W | 20 | 648 | 1900 | | | | 10 | | |
| 123679 | 10 | N | 8 | W | 20 | 621 | 1845 | | | | 70 | | |
| 123680 | 10 | N | 8 | W | 20 | 635 | 1857 | | | | 94 | | |
| 123681 | 10 | N | 8 | W | 20 | 606 | 1841 | | | | 144 | | |
| 123682 | 10 | N | 8 | W | 20 | 633 | 1875 | | | | 78 | | |
| 123683 | 10 | N | 8 | W | 20 | 635 | 1886 | | | | | | |
| 123684 | 10 | N | 8 | W | 20 | 662 | 1936 | | | | | | |
| 123685 | 10 | N | 8 | W | 20 | 648 | 1877 | | | | 103 | | |
| 123686 | 10 | N | 8 | W | 20 | 617 | 1874 | 1936 | 2006 | 2049 | 45 | | Present |
| 156767 | 10 | N | 8 | W | 20 | 598 | 1842 | | | | | | |
| 156768 | 10 | N | 8 | W | 20 | 622 | 1847 | 1902 | 1944 | 2010 | 7 | | Present |
| 156769 | 10 | N | 8 | W | 20 | 629 | 1877 | | | | | | |
| 123687 | 10 | N | 8 | W | 21 | 583 | 1884 | 1948 | 2006 | 2048 | | | |

**Field name:** Bowling Green

**IGS ID:** 10057

**DOE ID:** 84600

**Location:** Clay County, 11N-6W

**Discovery date:** 1973

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, Jeffersonville Ls. (1,274 ft.)

**Field type:** oil

**Total number production wells:** 10

**Area:** 120 acres

**Cumulative production:** 245,652 bbls. (2002)

**Other reservoir units:** Mississippian, Borden Group, carper Ss.

**Deepest unit penetrated (depth):** Silurian (1,505 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 40 ft. at top of Muscatatuck.

**Reservoir characteristics:**

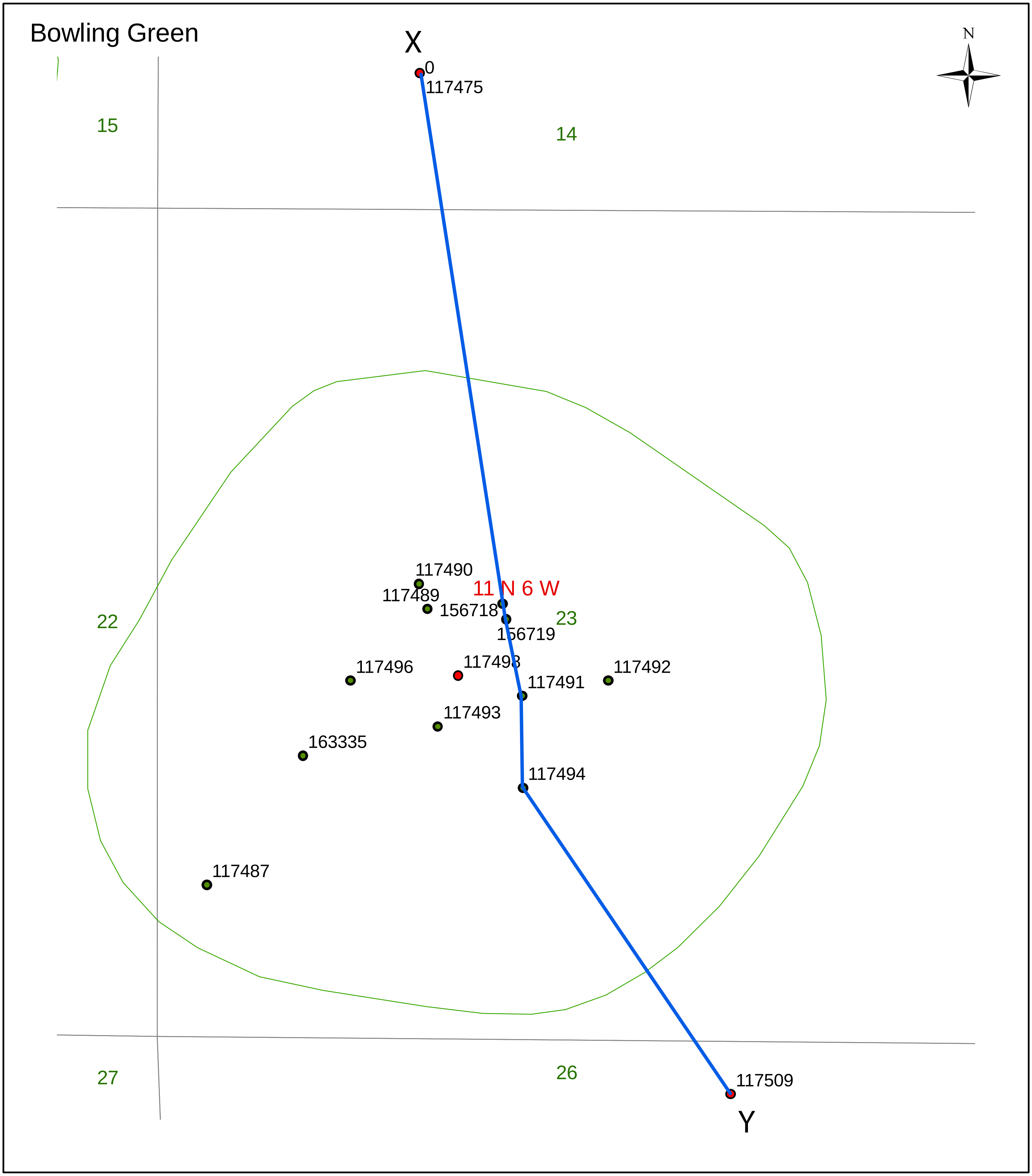



Figure 1: Map showing location and wells at Bowling Green Field, Clay County. X-Y is the location of cross section showing subsurface Devonian structure in Figure 4.

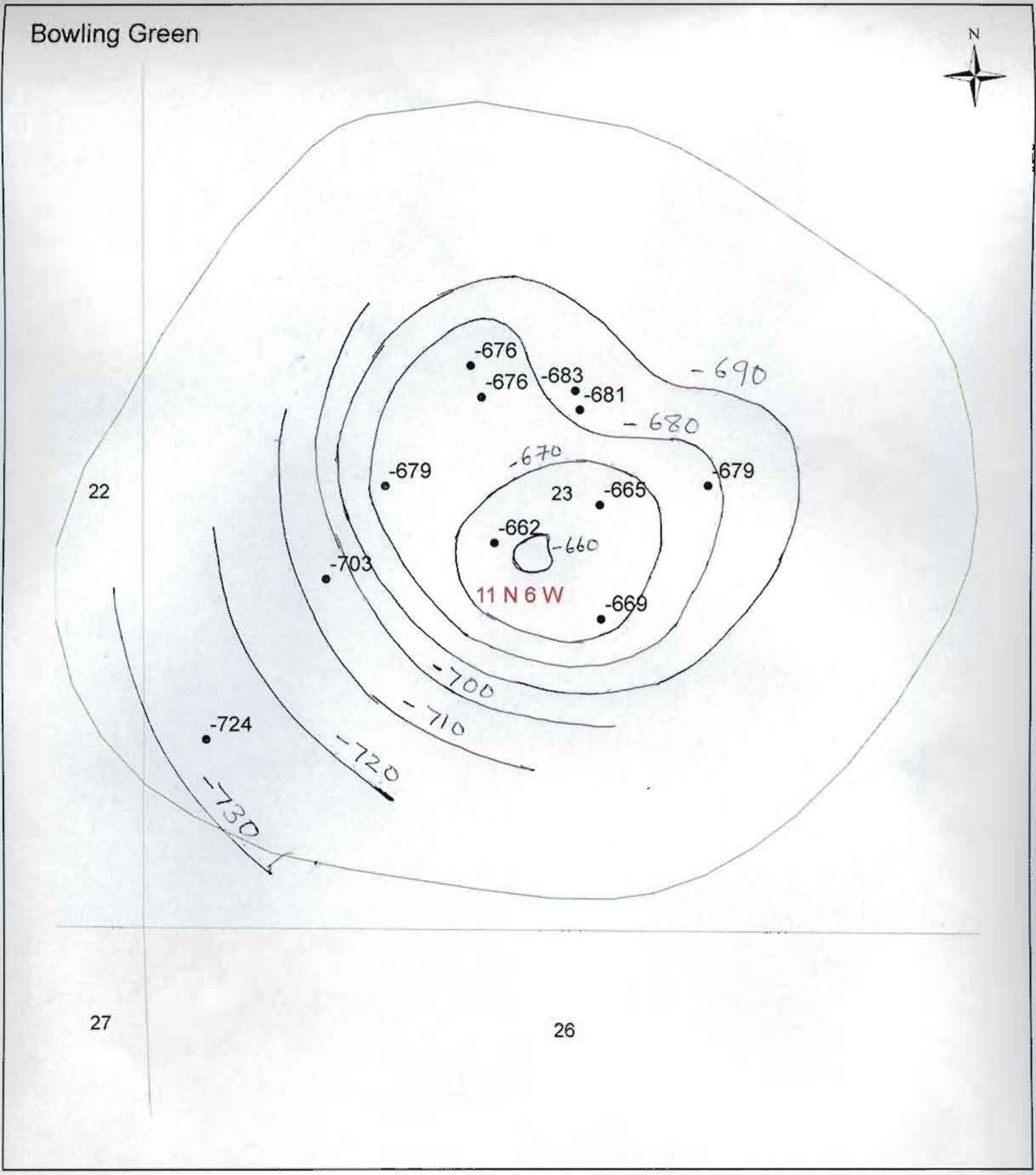



Figure 2: Structure map showing top of Muscatatuck Limestone in Bowling Green field, Clay County. Contours show values below sea level, contour interval is 10 ft .

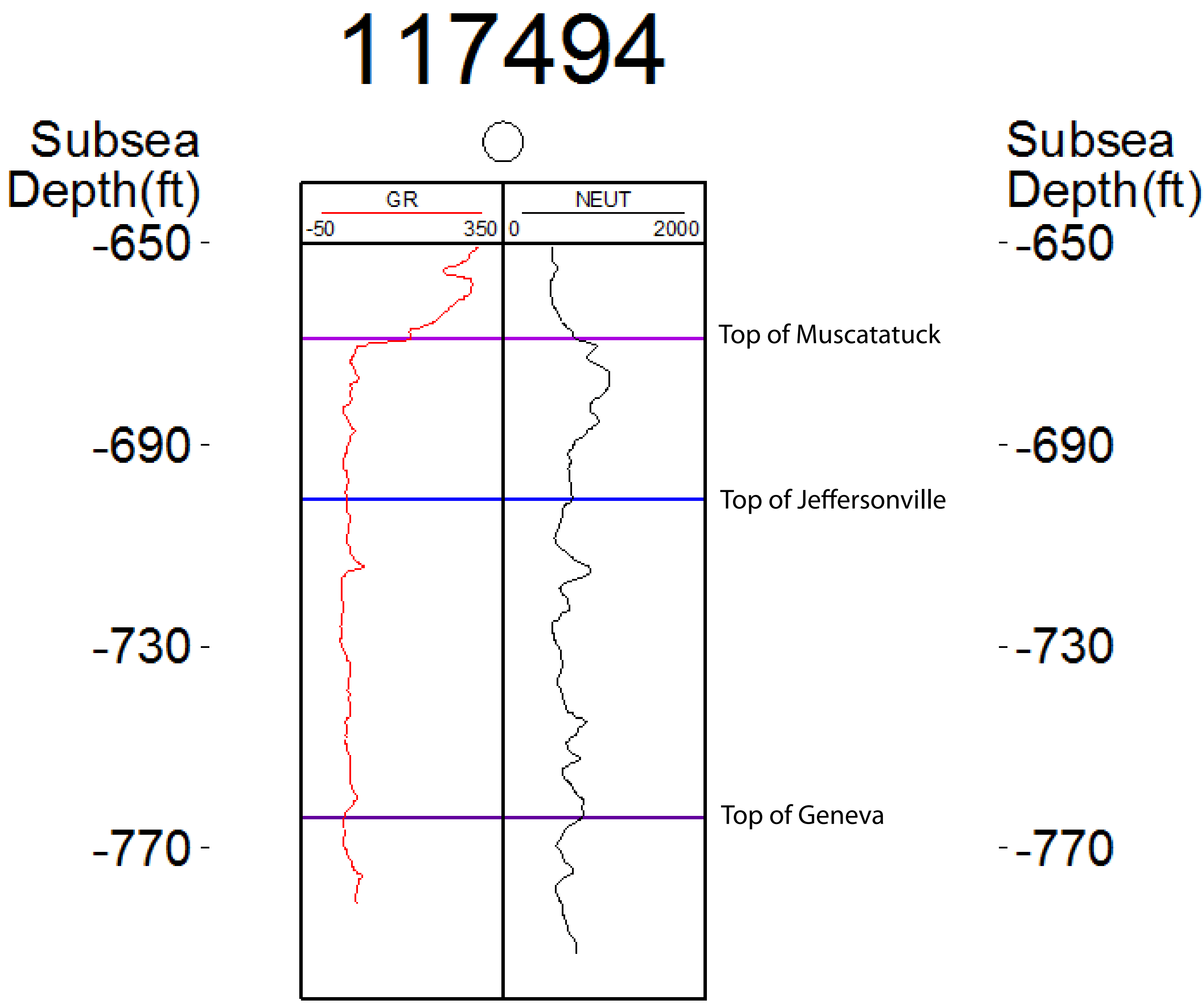



Figure 3: Type log section showing the Devonian formations from Bowling Green Field, Clay County.

HS=1 249

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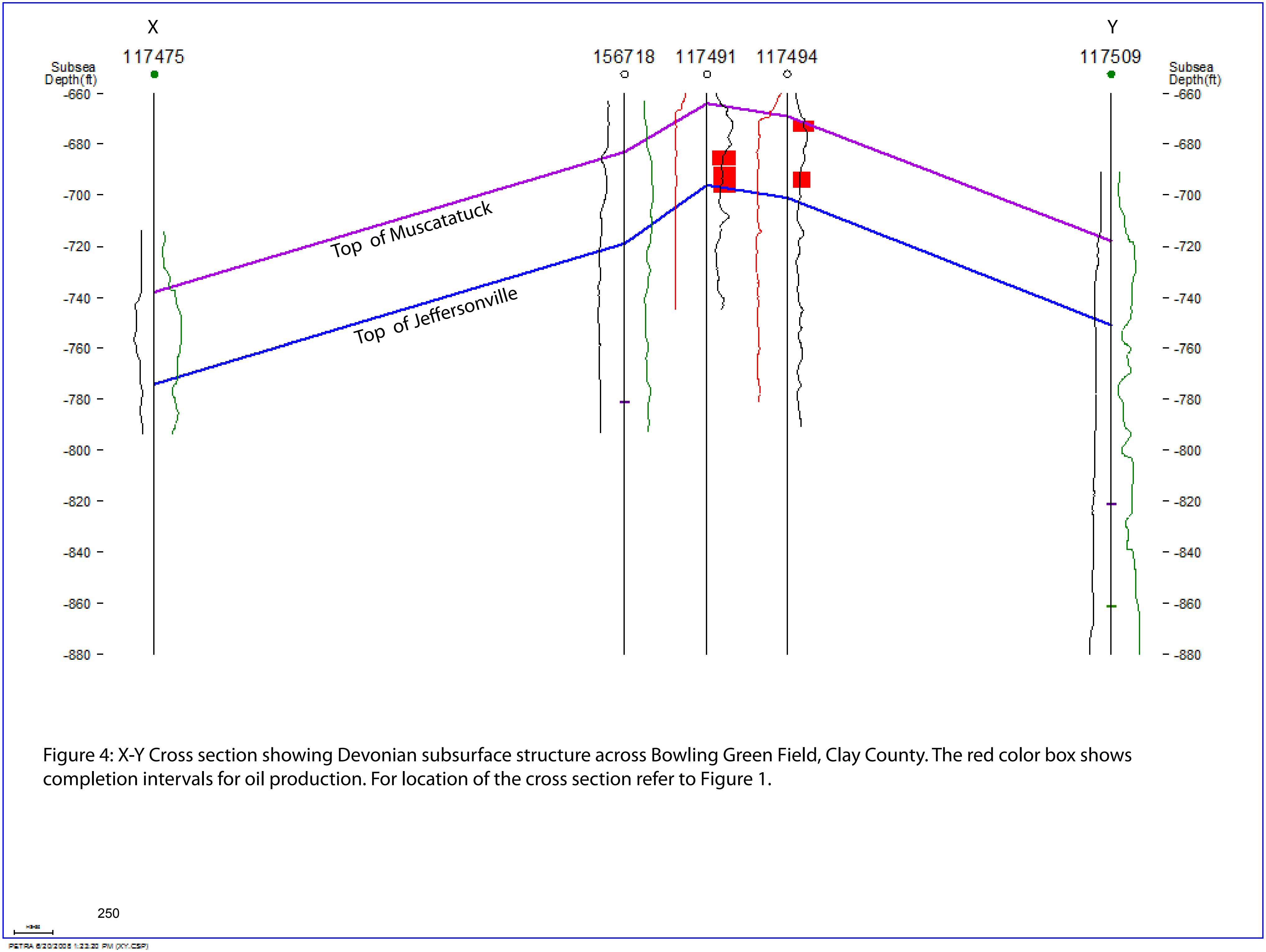


Figure 4: X-Y Cross section showing Devonian subsurface structure across Bowling Green Field, Clay County. The red color box shows completion intervals for oil production. For location of the cross section refer to Figure 1.

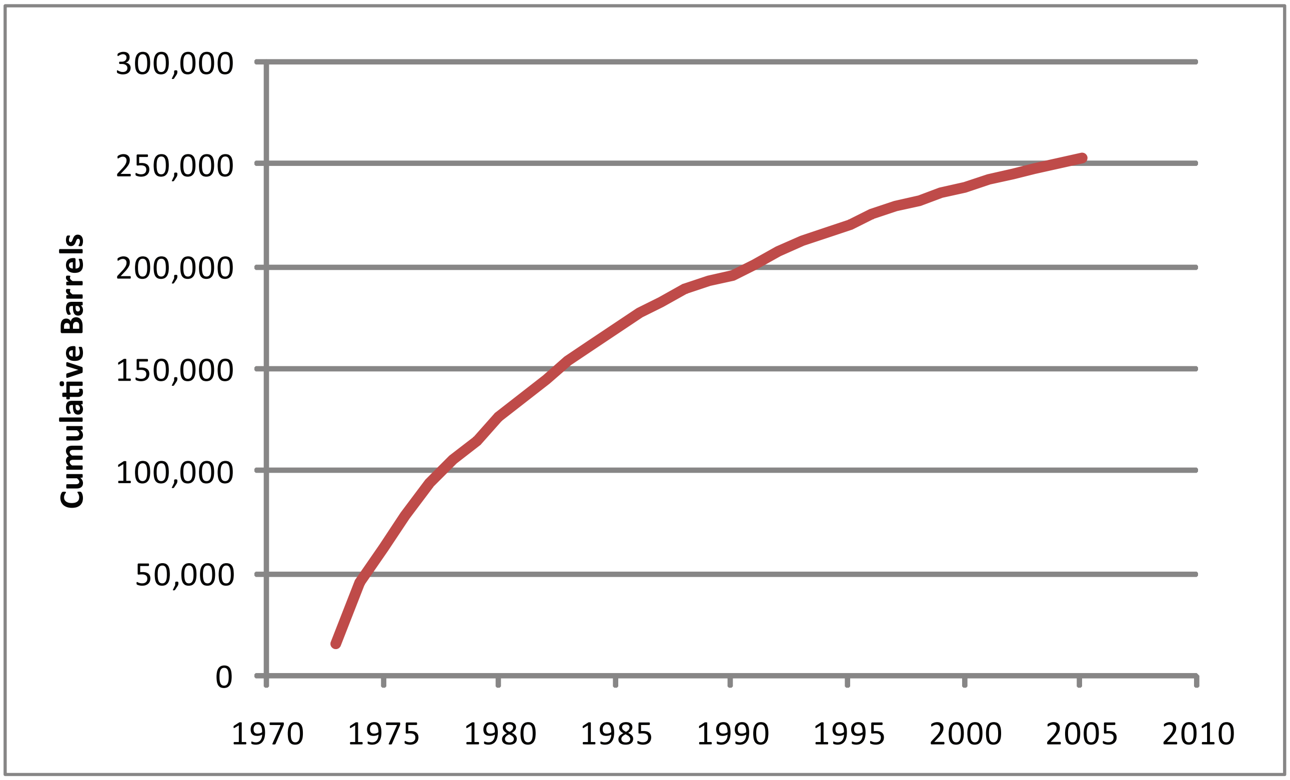


Figure - 5: Cumulative oil production history from Bowling Green Field, Clay County since 1973.

Table-1: List of the wells used for subsurface structure mapping in Bowling Green Field, Clay County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 117475 | 11 | N | 6 | W | 14 | 586 | 1324 | | | | | |
| 117487 | 11 | N | 6 | W | 23 | 628 | 1352 | 1390 | 1462 | | | |
| 117489 | 11 | N | 6 | W | 23 | 623 | 1299 | | | | | |
| 117490 | 11 | N | 6 | W | 23 | 622 | 1298 | | | | | |
| 117491 | 11 | N | 6 | W | 23 | 625 | 1290 | 1336 | | | 160 | |
| 117492 | 11 | N | 6 | W | 23 | 595 | 1274 | | | | 45 | |
| 117493 | 11 | N | 6 | W | 23 | 637 | 1299 | | | | 90 | |
| 117494 | 11 | N | 6 | W | 23 | 649 | 1318 | 1340 | | | 15 | |
| 117496 | 11 | N | 6 | W | 23 | 637 | 1316 | | | | 30 | |
| 117498 | 11 | N | 6 | W | 23 | 614 | 1297 | | | | 2 | |
| 156718 | 11 | N | 6 | W | 23 | 607 | 1290 | 1324 | 1388 | | | |
| 156719 | 11 | N | 6 | W | 23 | 609 | 1290 | | | | 8 | |
| 163335 | 11 | N | 6 | W | 23 | 632 | 1335 | 1368 | 1424 | 1482 | | |
| 117509 | 11 | N | 6 | W | 26 | 579 | 1297 | 1330 | 1400 | 1440 | | |

**Field name:** Bowling Green South

**IGS ID:** 10058

**DOE ID:** 84604

**Location:** Clay County, 11N-6W

**Discovery date:** 1973

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,241 ft.)

**Field type:** oil

**Total number production wells:** 7

**Area:** 70 acres

**Cumulative production:** 78,997 bbls. (2002)

**Other reservoir units:** Mississippian, Borden Group, Carper Ss.

**Deepest unit penetrated (depth):** Silurian (1,480 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 40 ft. at top of Muscatatuck.

**Reservoir characteristics:**

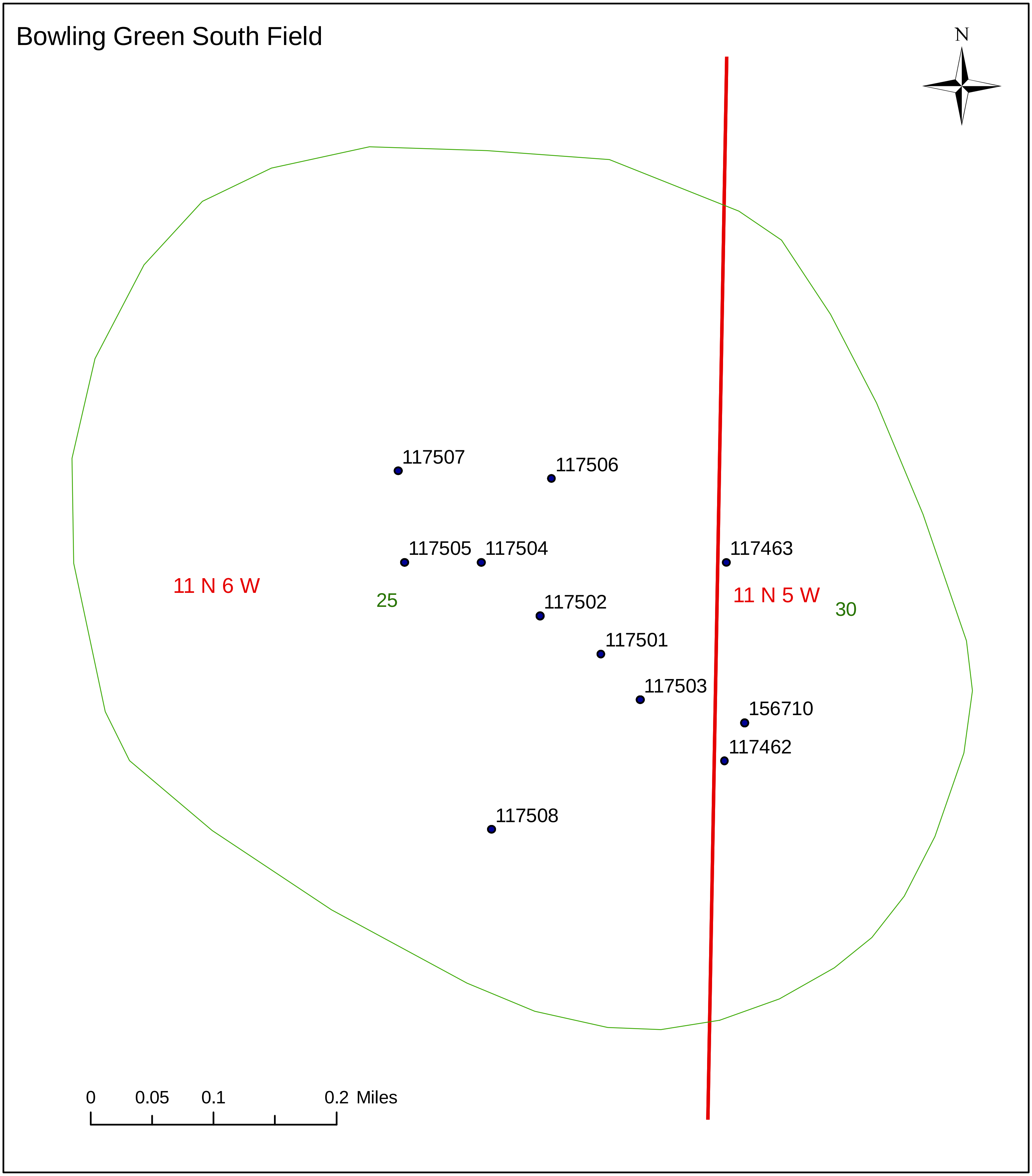


Figure 1: Map showing location aand wells at Bowling Green South Field, Clay County. Black circles are the location of  wells in the field.

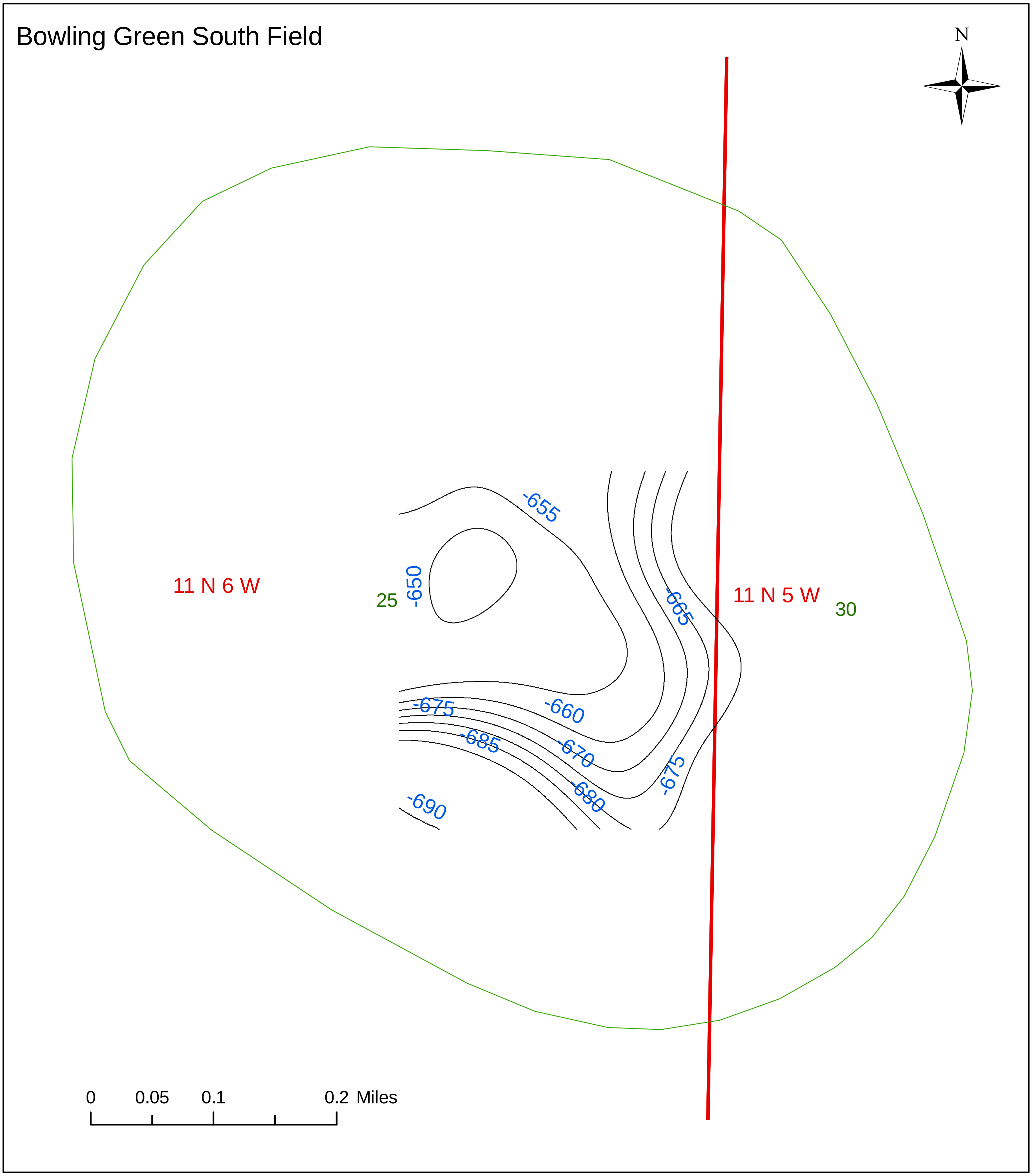


Figure 2: Structure map showing the top of Muscatatuck Limestone in Bowling Green South Field, Clay County. Contours show values below sea level, contour interval is 5 ft .

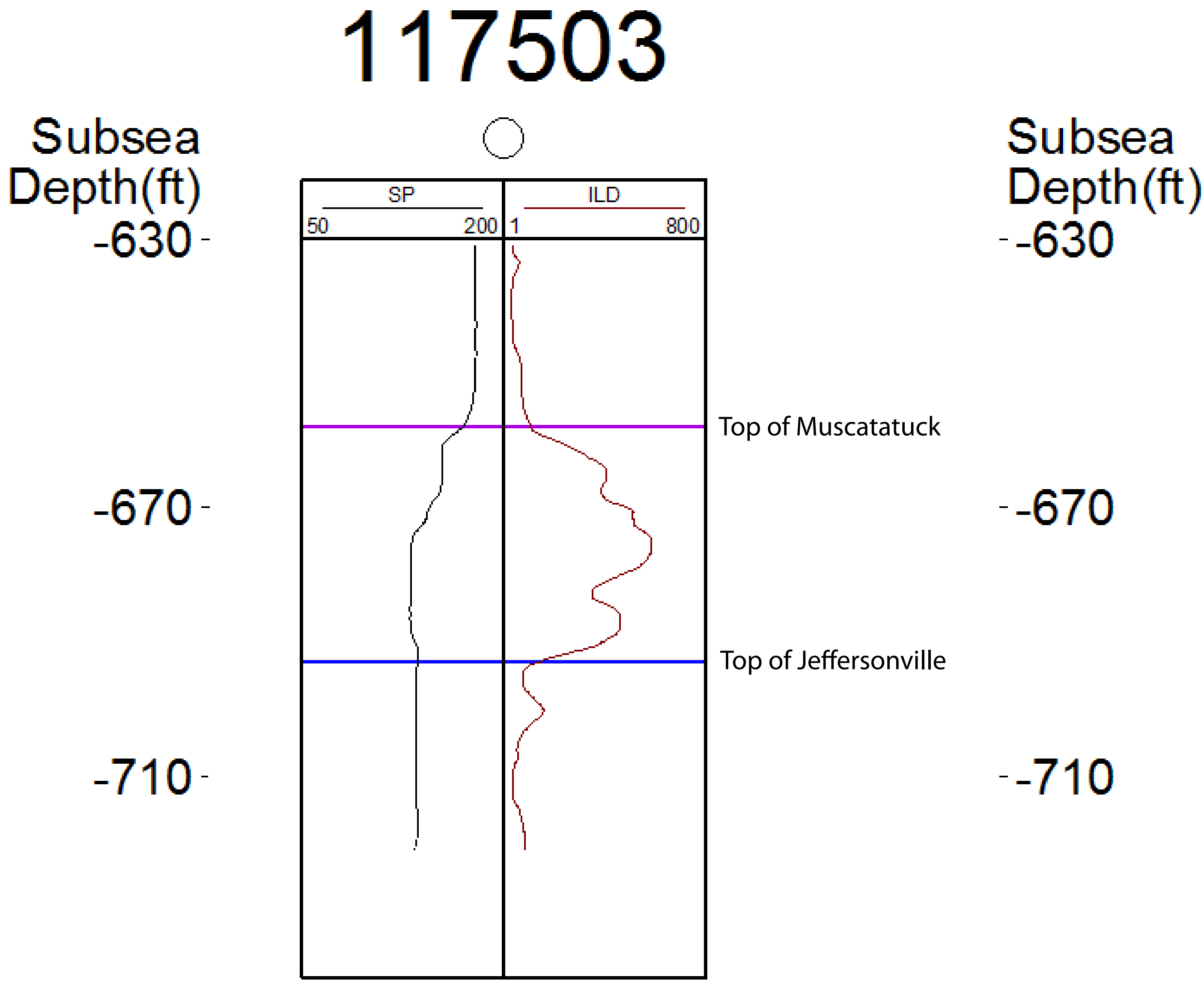


Figure 3: Type log section showing the Devonian formations from Bowling Green South Field, Clay County.

HS=1 256

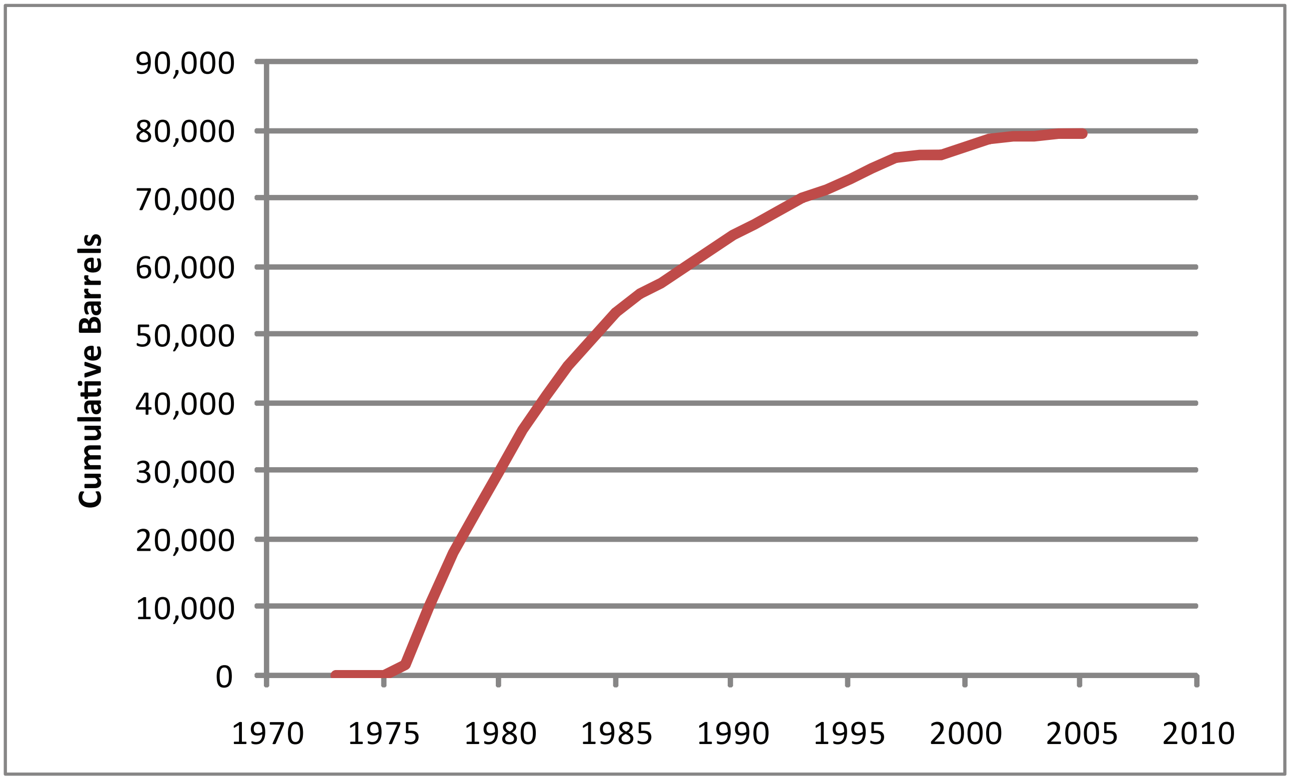


Figure - 4: Cumulative oil production history from the Bowling Green South Field, Clay County since 1976.

Table-1: List of the wells used for subsurface structure mapping in Bowling Green South Field, Clay County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp _D | Rng | Rng_ D | Land _N | Elevation/ Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 156708 | 11 | N | 5 | W | 19 | 659 | 1362 | | | | | |
| 117460 | 11 | N | 5 | W | 29 | 640 | 1348 | 1386 | 1456 | 1496 | | |
| 117462 | 11 | N | 5 | W | 30 | 572 | 1251 | | | | | |
| 117463 | 11 | N | 5 | W | 30 | 565 | 1245 | | | | | |
| 117464 | 11 | N | 5 | W | 30 | 705 | 1398 | | | | | |
| 156710 | 11 | N | 5 | W | 30 | 567 | 1244 | | | 1380 | | |
| 117501 | 11 | N | 6 | W | 25 | 563 | 1216 | | | | 42 | |
| 117502 | 11 | N | 6 | W | 25 | 563 | 1216 | | | | 62 | |
| 117503 | 11 | N | 6 | W | 25 | 569 | 1226 | 1262 | | | 200 | |
| 117504 | 11 | N | 6 | W | 25 | 563 | 1210 | | | | 42 | |
| 117505 | 11 | N | 6 | W | 25 | 562 | 1213 | | | | 12 | |
| 117506 | 11 | N | 6 | W | 25 | 563 | 1222 | | | | 6 | |
| 117507 | 11 | N | 6 | W | 25 | 562 | 1221 | | | | 42 | |
| 117508 | 11 | N | 6 | W | 25 | 597 | 1287 | | | | | |
| 117512 | 11 | N | 6 | W | 36 | 634 | 1383 | | | | | |

**Field name:** Carbon

**IGS ID:** 10091

**DOE ID:** na

**Location:** Clay & Parke Counties, 13&14N-6W

**Discovery date:** 1994 (storage initiation)

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,275 ft.)

**Field type:** natural gas storage

**Total number production wells:** 19 storage, 16 observation

**Area:** na

**Total capacity:** na

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Cambrian/Ordovician, Knox Supergroup (2,895 ft.)

**Field characteristic:** Subtle anticlinal feature with less than 20 ft. closure.

**Reservoir characteristics:**

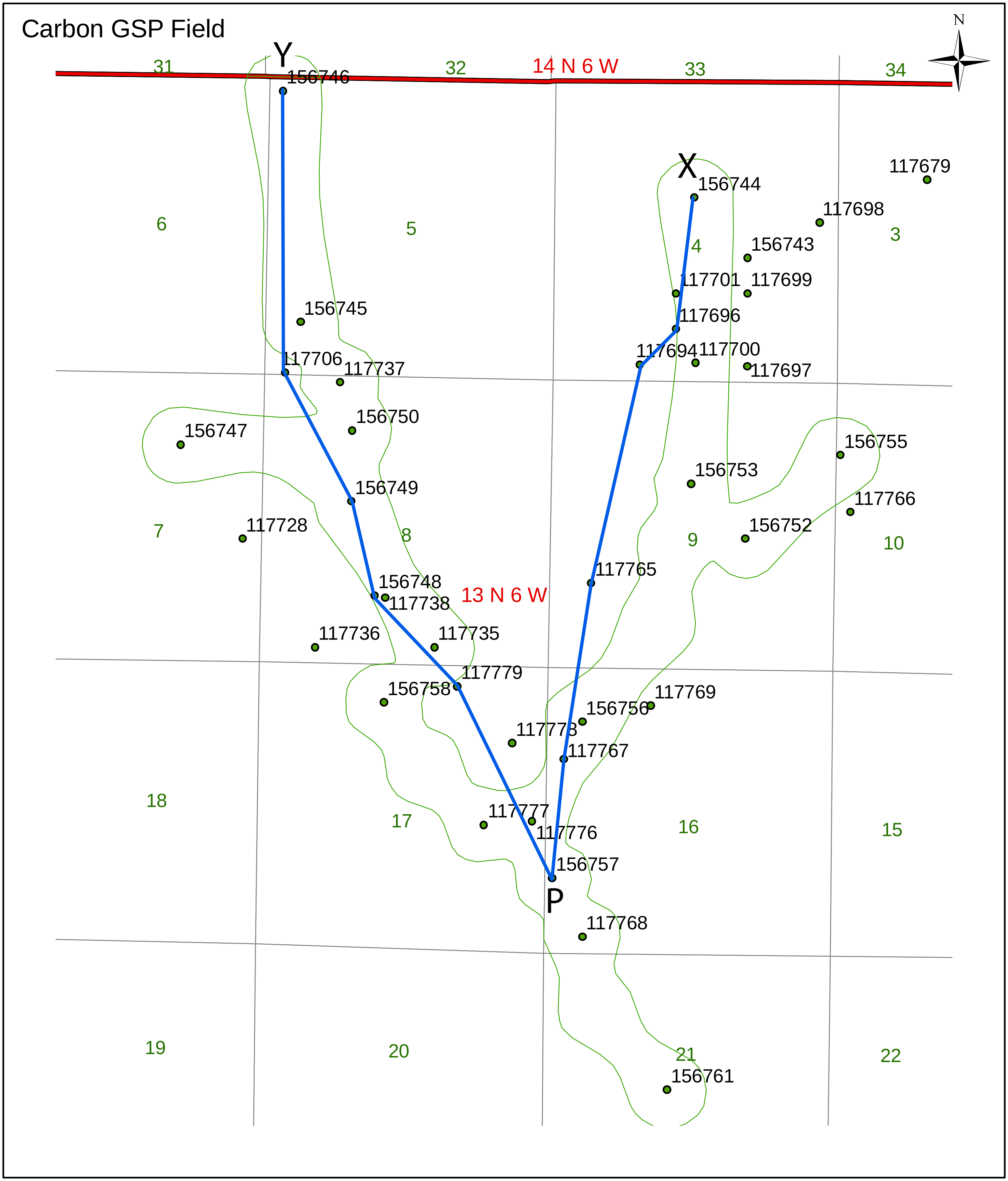


Figure 1: Map showing location and wells at Carbon GSP Field, Clay County. X-P and Y-P are the locations of the cross sections that show the subsurface Devonian structure in Figures 10 and 11.

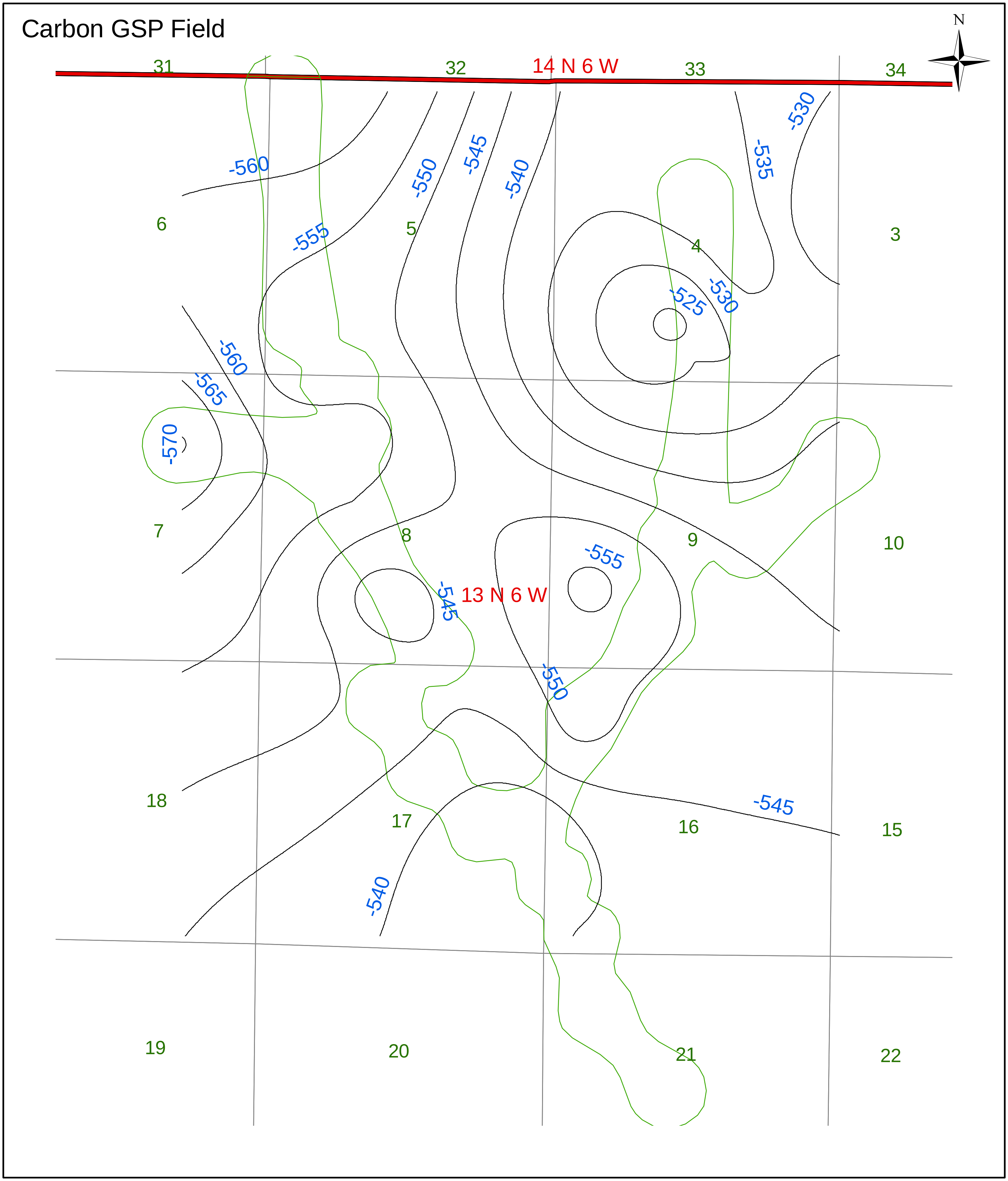


Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Carbon GSP field, Clay County. Contours show values below sea level, contour interval is 5 ft .

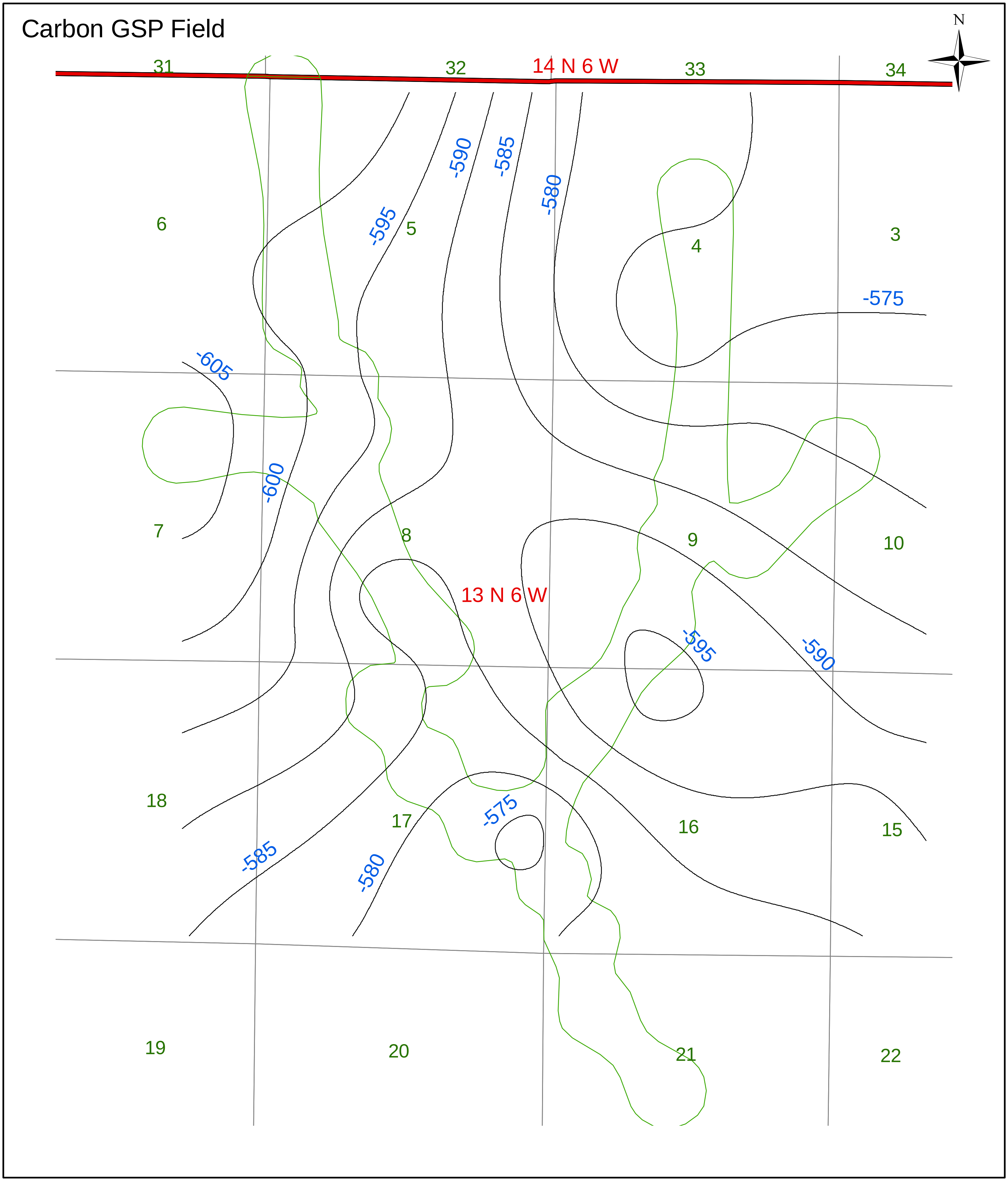


Figure 3: Structure map showing the top of subsurface Jeffersonville Limestone in Carbon GSP field, Clay County. Contours show values below sea level, contour interval is 5 ft .

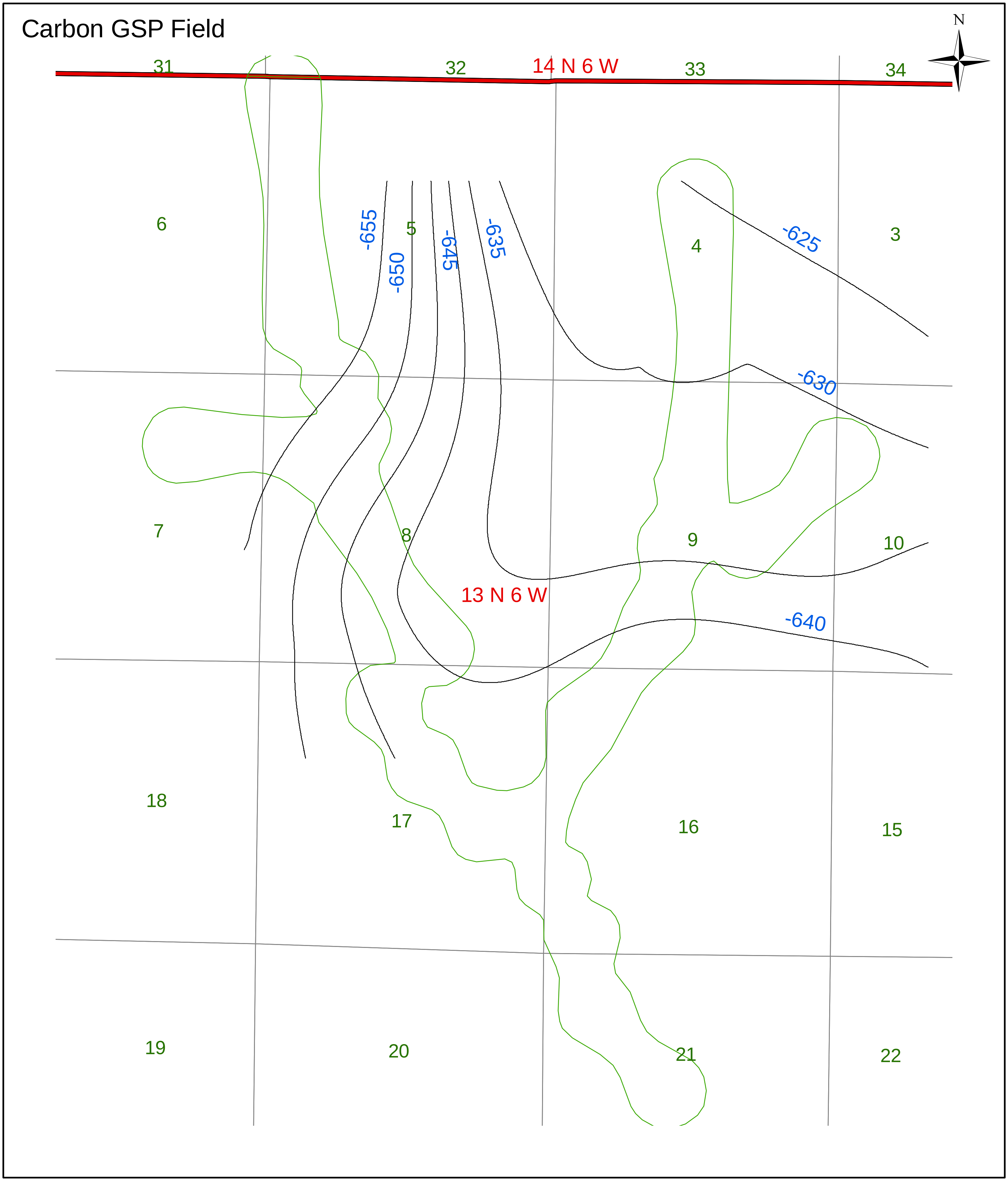


Figure 4: Structure map showing the top of subsurface Geneva Dolomite Member in Carbon GSP field, Clay County. Contours show values below sea level, contour interval is 5 ft .

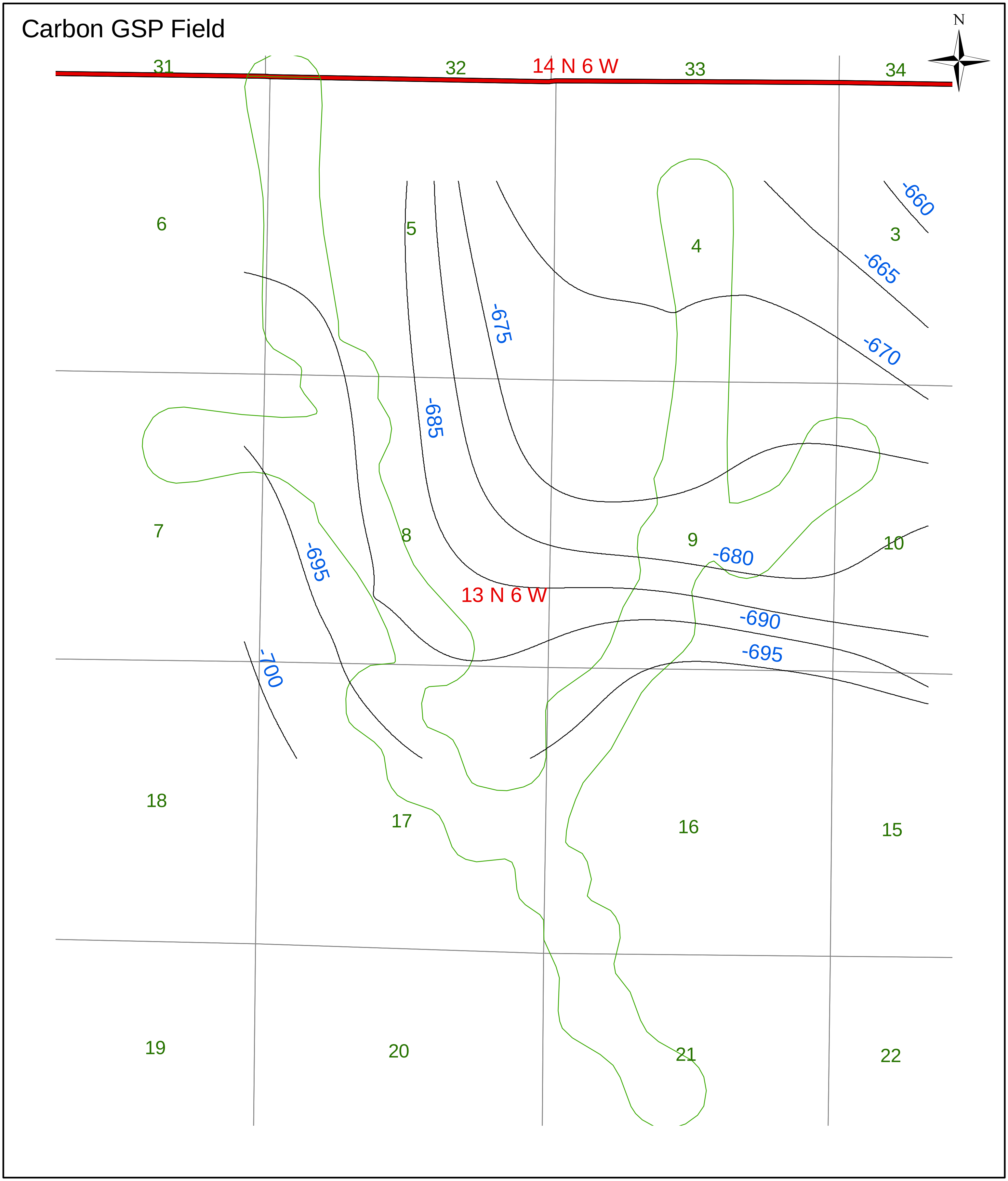


Figure 5: Structure map showing the top of subsurface Silurian formation in Carbon GSP field, Clay County. Contours show values below sea level, contour interval is 5 ft .

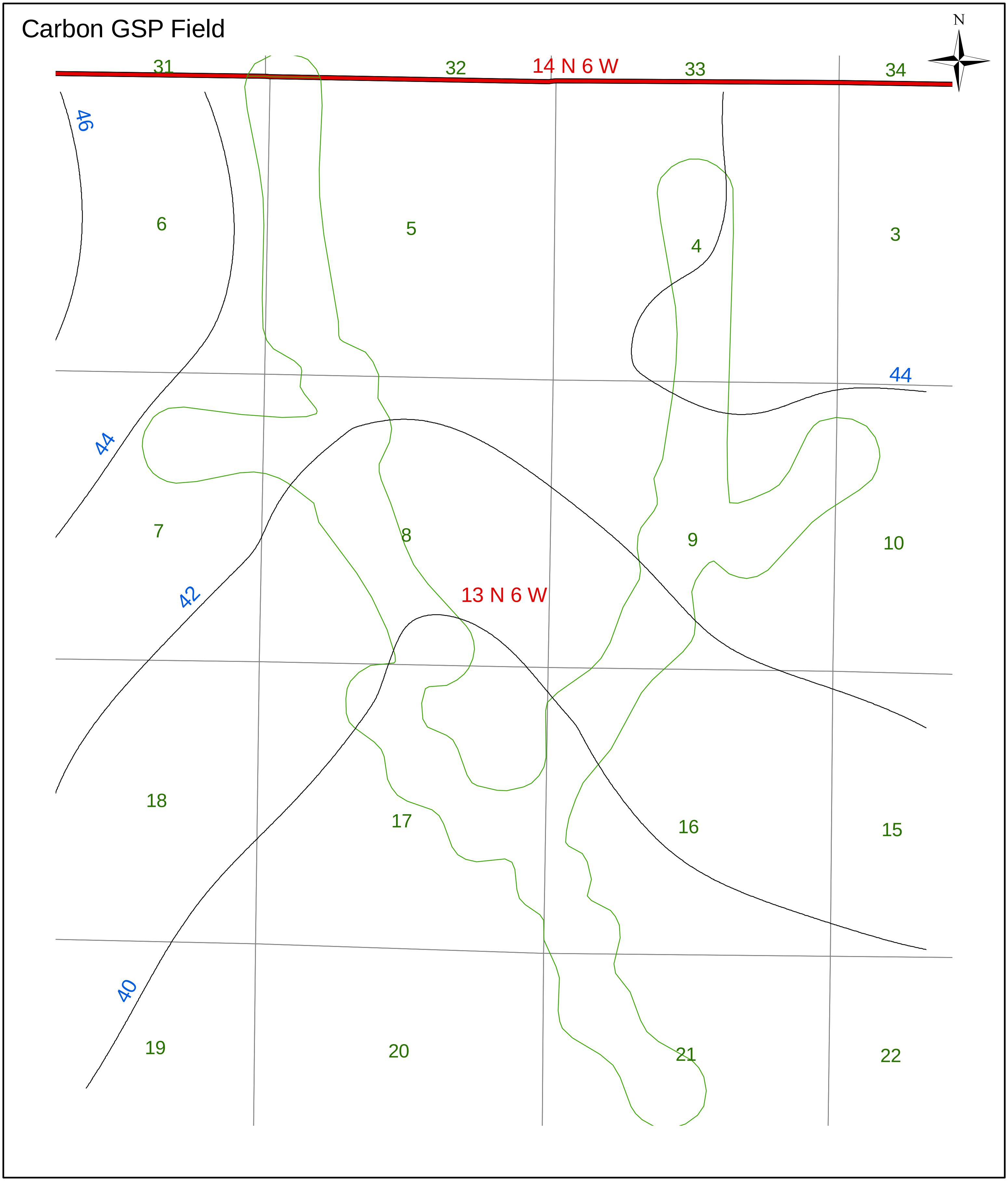


Figure 6: Isopach map of the North Vernon formation from Carbon GSP Field, Clay County. Contour interval is 2 ft.

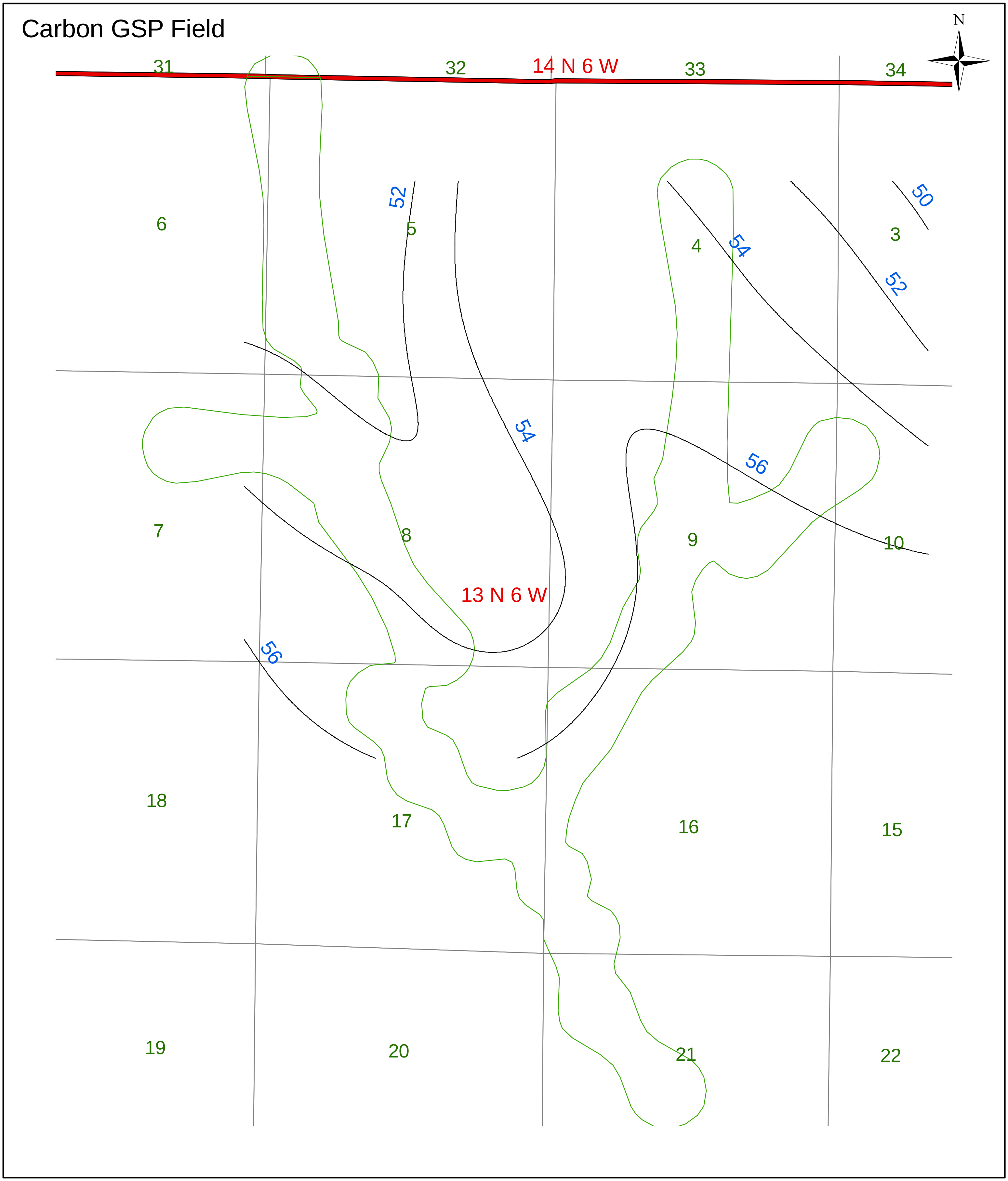


Figure 7: Isopach map of the Vernon Fork Member from Carbon GSP Field, Clay County. Contour interval is 2 ft.

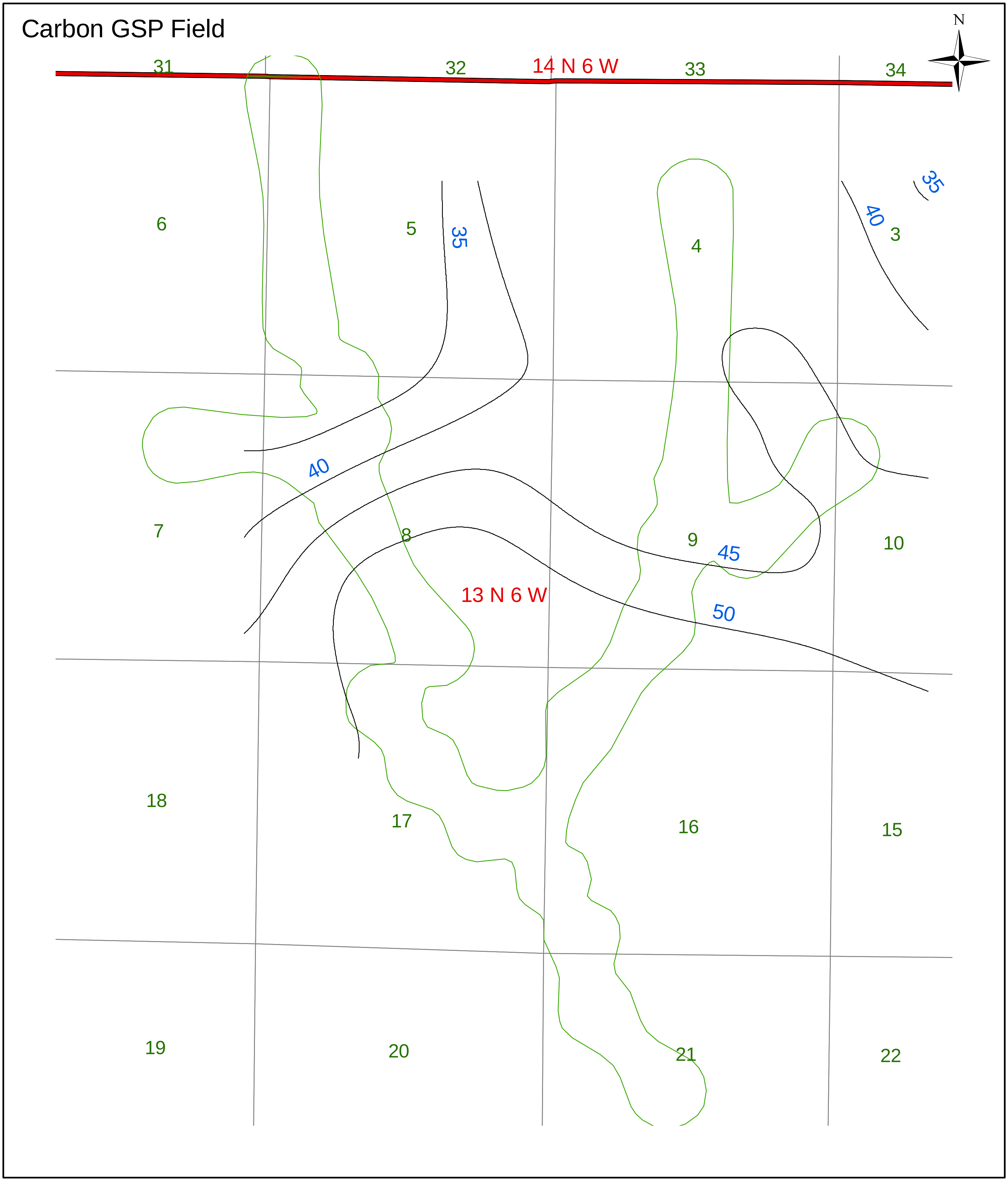


Figure 8: Isopach map of the Geneva Dolomite Member from Carbon GSP Field, Clay County. Contour interval is 5 ft.

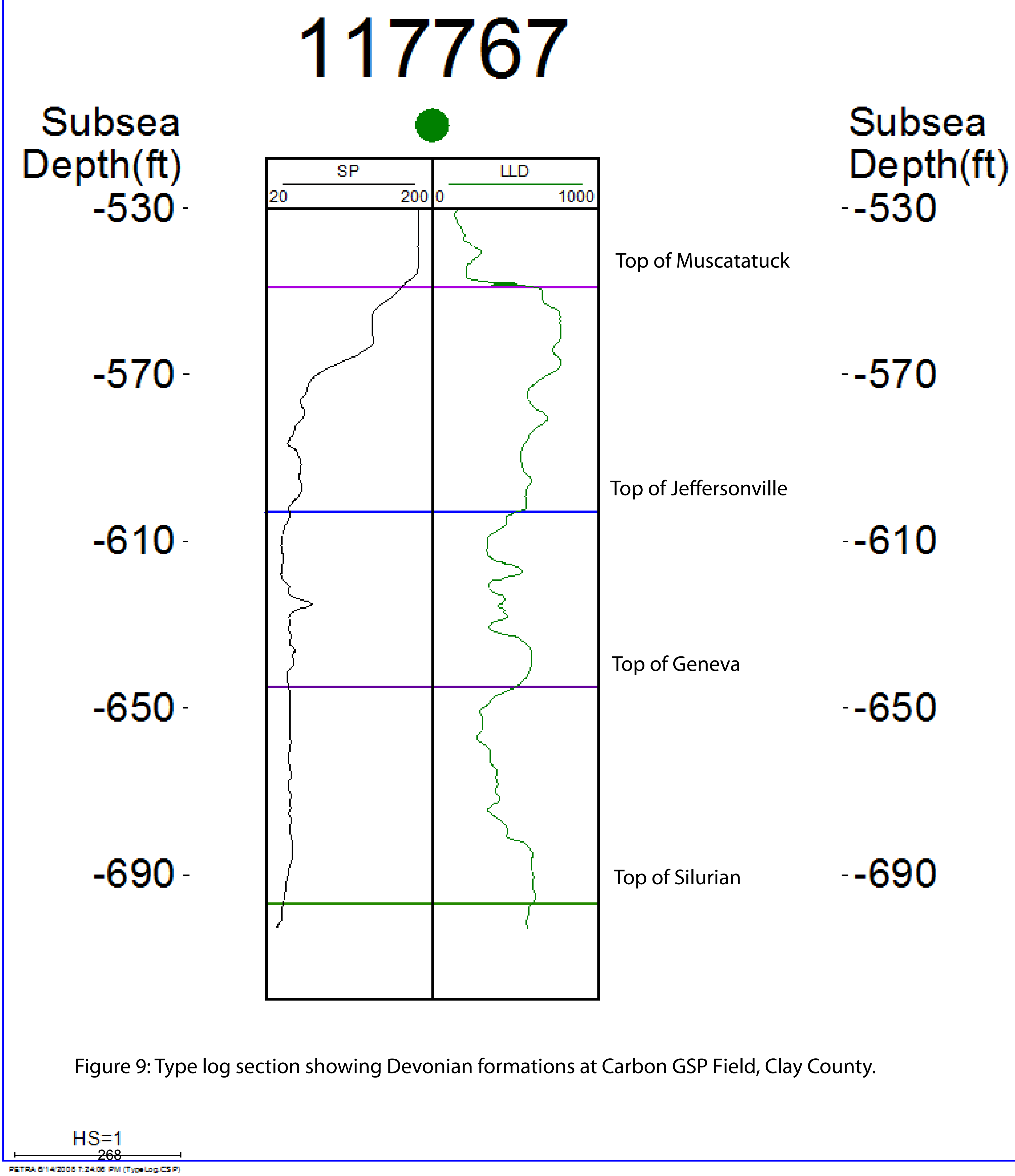


Figure 9: Type log section showing Devonian formations at Carbon GSP Field, Clay County.

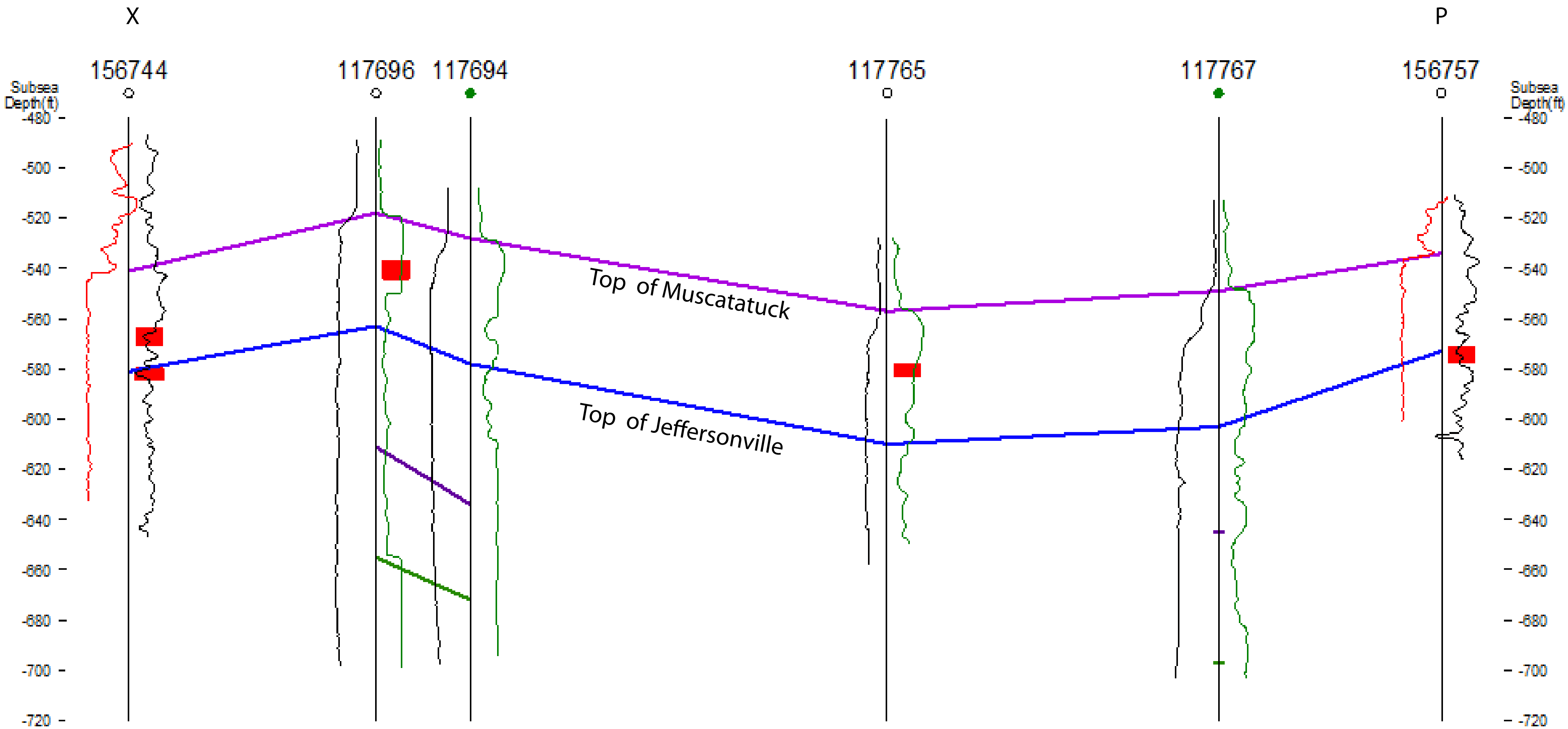


Figure 10: X-P Cross section showing the Devonian subsurface structure across Carbon GSP Field, Clay County. The red color box shows the completion intervals for the gas storage. For location of the cross section refer to Figure 1.

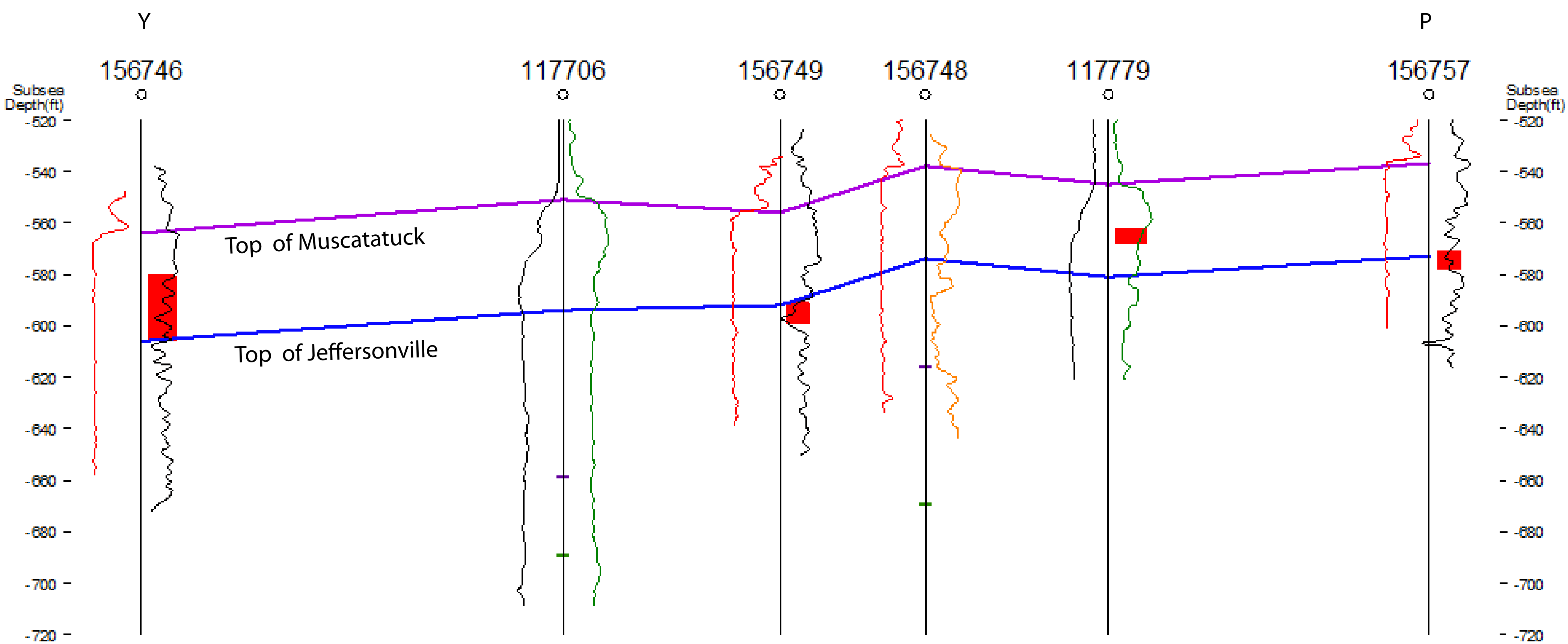


Figure 11: Y-P Cross section showing Devonian subsurface structure across Carbon GSP Field, Clay County. The red color box shows the completion intervals for the Gas storage. For location of the cross section refer to Figure 1.

Table-1: List of the wells used for subsurface structure mapping in Carbon GSP Field, Clay County.

| IGS_ID | Twp | Twp _D | Rng | Rng _D | Land _N | Eleva tion/ Kb | Top of Musca- tatcuk | Top of Jeffer- sonville | Top of Geneva | Top of Silurian | Core (P/A) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 117679 | 13 | N | 6 | W | 3 | 747 | 1271 | 1320 | 1366 | 1400 | Present |
| 117694 | 13 | N | 6 | W | 4 | 702 | 1230 | 1280 | 1342 | 1380 | |
| 117696 | 13 | N | 6 | W | 4 | 701 | 1219 | 1264 | 1312 | 1356 | Present |
| 117697 | 13 | N | 6 | W | 4 | 691 | 1219 | 1274 | 1330 | 1376 | |
| 117698 | 13 | N | 6 | W | 4 | 721 | 1243 | 1292 | 1340 | 1383 | |
| 117699 | 13 | N | 6 | W | 4 | 693 | 1229 | 1264 | 1324 | 1366 | |
| 117700 | 13 | N | 6 | W | 4 | 689 | 1222 | | | | |
| 117701 | 13 | N | 6 | W | 4 | 702 | 1227 | | | | |
| 156743 | 13 | N | 6 | W | 4 | 698 | 1241 | | | | |
| 156744 | 13 | N | 6 | W | 4 | 713 | 1254 | 1292 | | | |
| 117706 | 13 | N | 6 | W | 5 | 691 | 1242 | 1300 | 1350 | 1380 | |
| 156745 | 13 | N | 6 | W | 5 | 691 | 1244 | 1284 | | | |
| 156746 | 13 | N | 6 | W | 5 | 692 | 1256 | 1298 | | | |
| 117723 | 13 | N | 6 | W | 6 | 674 | 1241 | 1294 | | | |
| 117728 | 13 | N | 6 | W | 7 | 681 | 1239 | 1288 | 1346 | 1386 | Present |
| 156747 | 13 | N | 6 | W | 7 | 676 | 1250 | 1286 | | | |
| 117735 | 13 | N | 6 | W | 8 | 687 | | | | | |
| 117736 | 13 | N | 6 | W | 8 | 642 | 1195 | 1240 | 1305 | 1354 | |
| 117737 | 13 | N | 6 | W | 8 | 688 | 1238 | 1280 | | | |
| 117738 | 13 | N | 6 | W | 8 | 690 | 1232 | 1270 | | | |
| 156748 | 13 | N | 6 | W | 8 | 696 | 1234 | 1270 | 1312 | 1365 | |
| 156749 | 13 | N | 6 | W | 8 | 656 | 1212 | 1248 | | | |
| 156750 | 13 | N | 6 | W | 8 | 686 | 1248 | 1286 | | | |
| 117765 | 13 | N | 6 | W | 9 | 692 | 1251 | 1290 | | | |
| 156752 | 13 | N | 6 | W | 9 | 703 | | | | | |
| 156753 | 13 | N | 6 | W | 9 | 692 | | | | | |
| 117766 | 13 | N | 6 | W | 10 | 704 | | | | | |
| 156755 | 13 | N | 6 | W | 10 | 690 | 1234 | 1270 | | | |
| 117767 | 13 | N | 6 | W | 16 | 697 | 1246 | 1284 | 1342 | 1394 | |
| 117768 | 13 | N | 6 | W | 16 | 731 | 1272 | 1316 | | | |
| 117769 | 13 | N | 6 | W | 16 | 705 | 1252 | 1306 | | | |
| 156756 | 13 | N | 6 | W | 16 | 699 | 1254 | 1290 | | | |
| 156757 | 13 | N | 6 | W | 16 | 699 | 1236 | 1272 | | | |
| 117776 | 13 | N | 6 | W | 17 | 694 | 1226 | 1260 | | | |
| 117777 | 13 | N | 6 | W | 17 | 691 | 1228 | 1266 | | | |
| 117778 | 13 | N | 6 | W | 17 | 686 | 1229 | 1270 | | | |
| 117779 | 13 | N | 6 | W | 17 | 689 | 1234 | 1270 | | | |
| 156758 | 13 | N | 6 | W | 17 | 686 | 1236 | 1278 | | | |
| 156761 | 13 | N | 6 | W | 21 | 738 | 1310 | 1346 | | | |

**Field name:** Carlisle North

**IGS ID:** 10093

**DOE ID:** 9021

**Location:** Sullivan County, 6N-9&10W

**Discovery date:** 1982

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, Jeffersonville (2,567 ft.)

**Field type:** oil

**Total number production wells:** 8

**Area:** 100 acres

**Cumulative production:** 41,355 bbls. (2002)

**Other reservoir units:** Mississippian, Blue River Group, Ste. Genevieve Ls.

**Deepest unit penetrated (depth):** Devonian, New Harmony Group (2,806 ft.)

**Field characteristic:** Subtle anticlinal nose with no observable closure at top of Muscatatuck.

**Reservoir characteristics:**

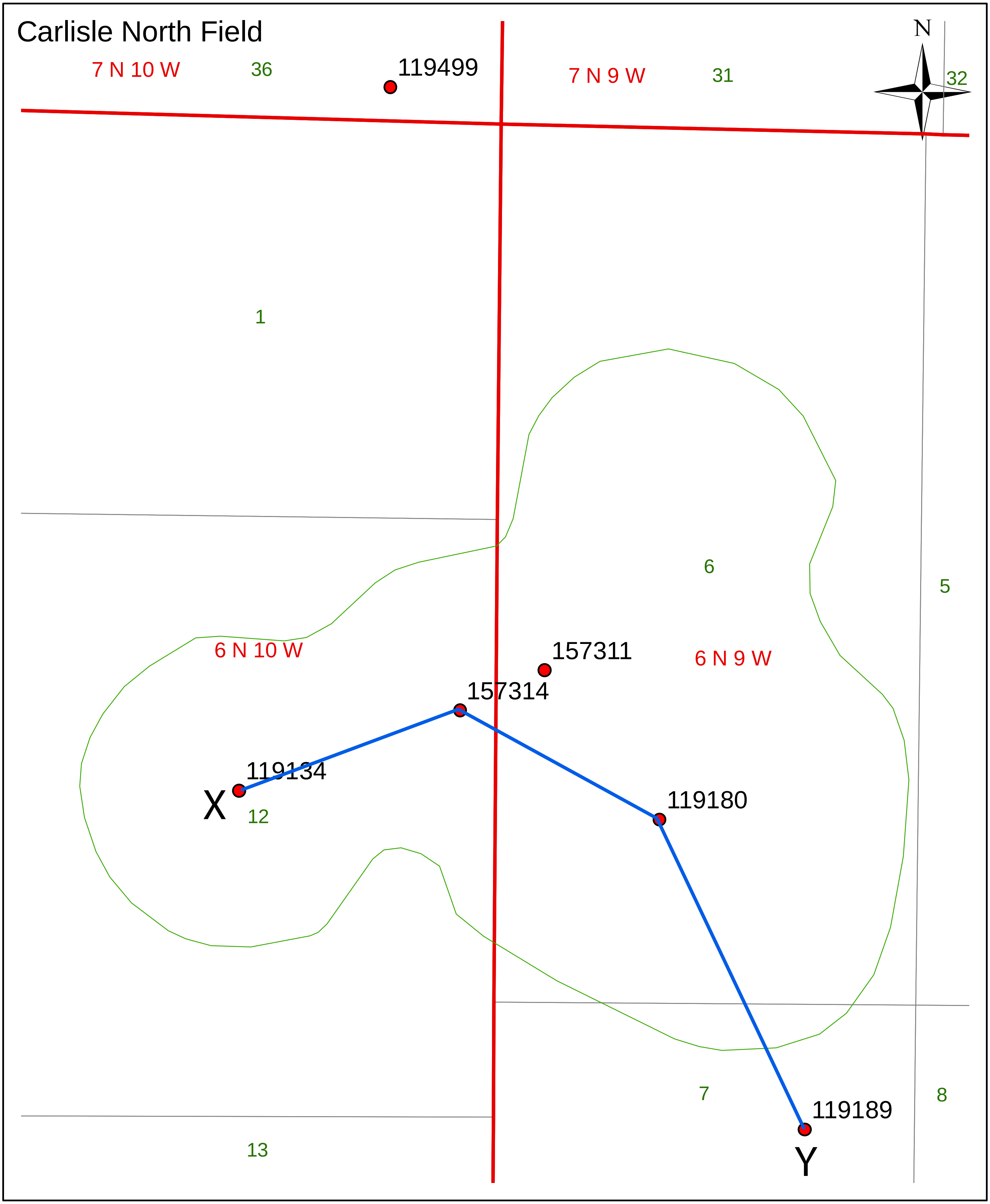


Figure 1: Map showing the location and wells at Carlisle North Field, Sullivan County. X-Y is the location of the cross section that shows the subsurface Devonian structure in Figure 4.

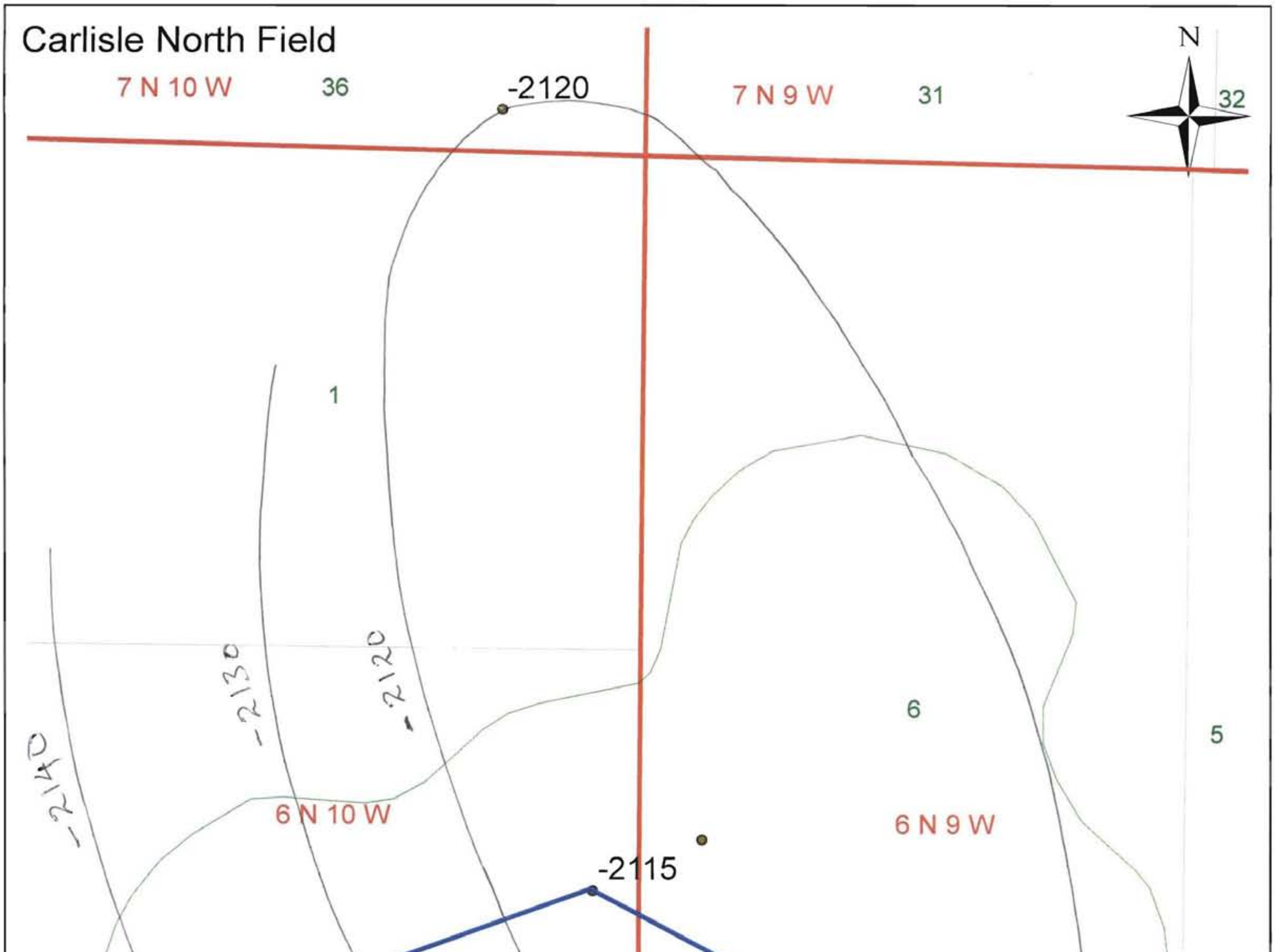


Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Carlisle North Field, Sullivan County. Contours show values below sea level, contour interval is 10 ft .

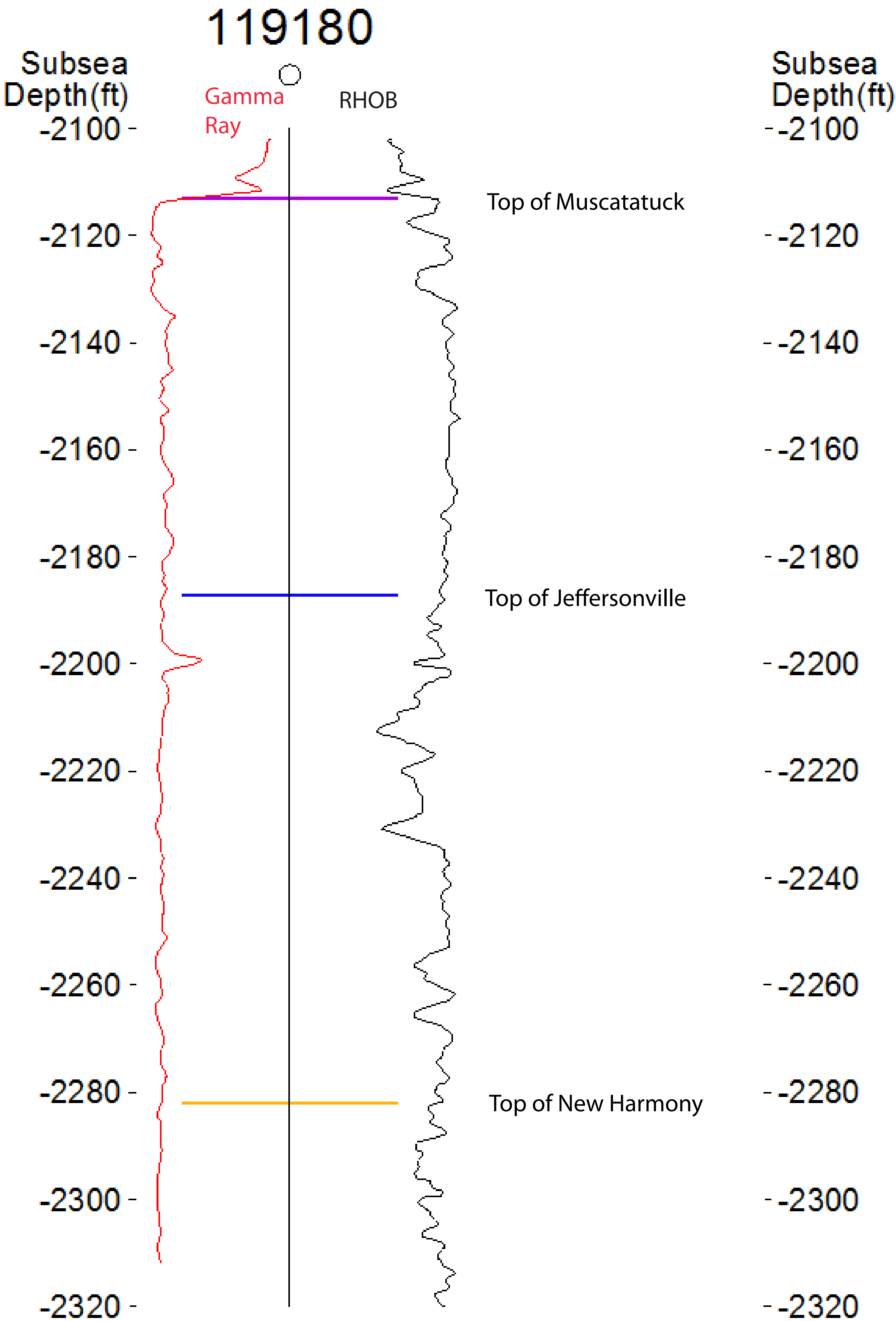


Figure 3: Type log section showing the Devonian formations at Carlisle North Field, Sullivan County.



HS=1

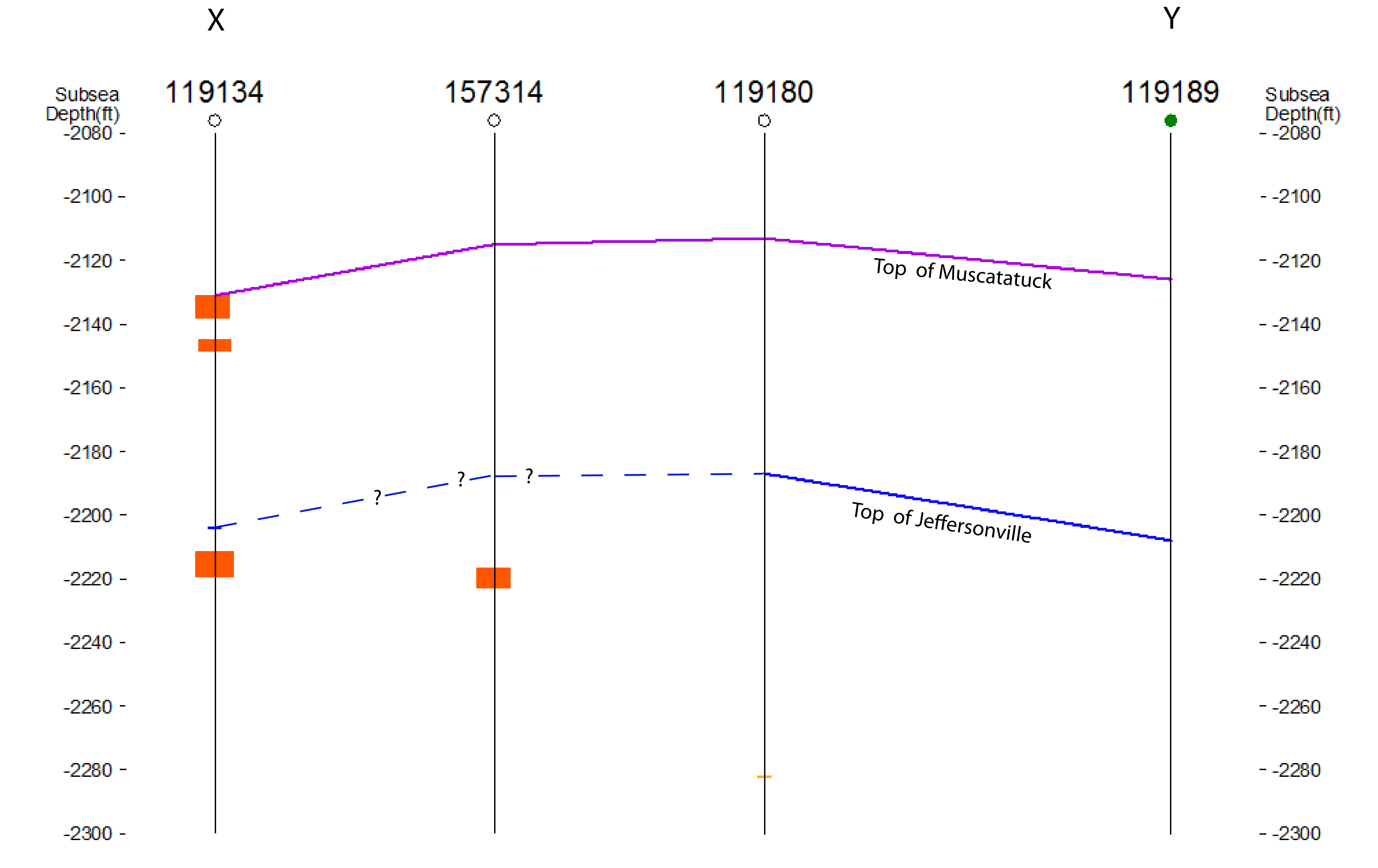


Figure 4: X-Y Cross section showing the Devonian subsurface structure across Carlisle North Field, Sullivan County. For location of the cross section refer to Figure 1. Red box indicates the completion interval for oil and gas production.



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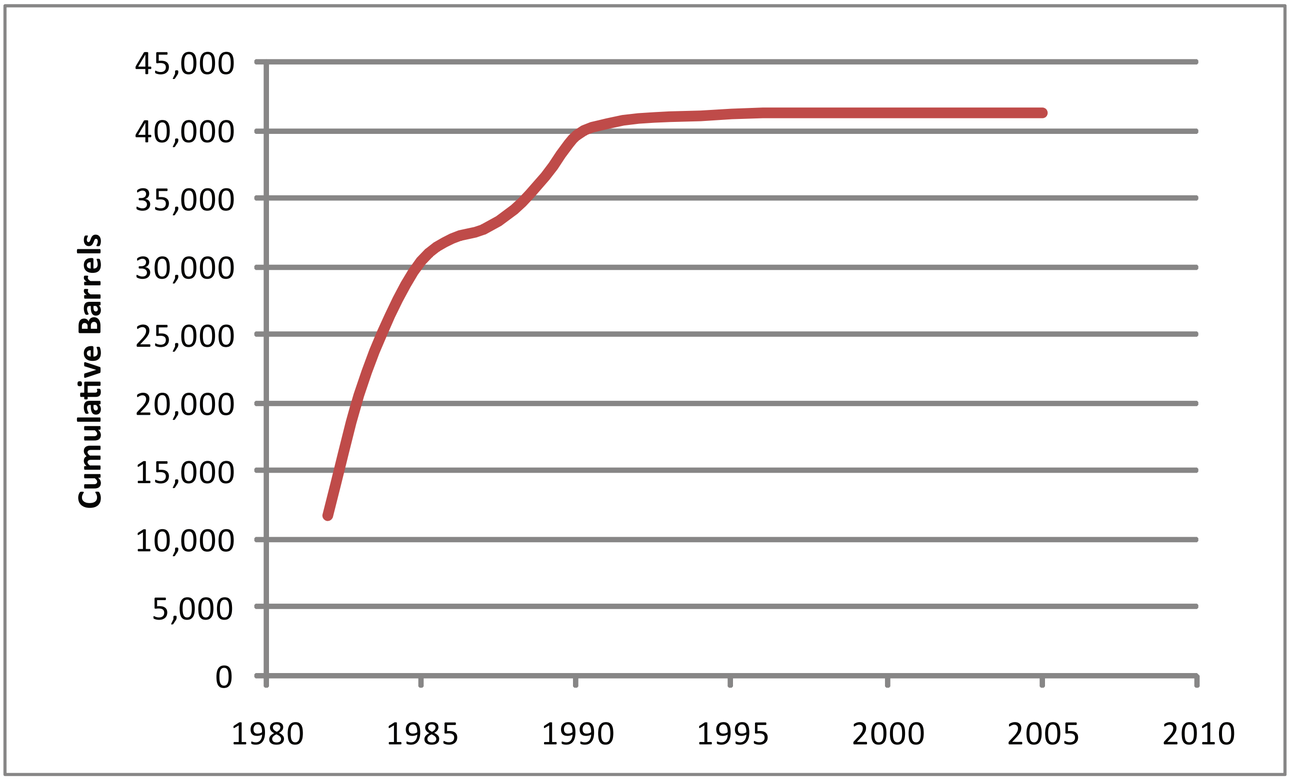


Figure - 5: Cumulative oil production history for Carlisle North Field, Sullivan County since 1983.

Table-1: List of the wells used for subsurface structure mapping in Carlisle North field, Sullivan County.

| IGS_ID | Twp | Twp _D | Rng | Rng _D | Land_ N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of New Harmony | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 119180 | 6 | N | 9 | W | 6 | 468 | 2581 | 2655 | 2740 | | 288 | |
| 157311 | 6 | N | 9 | W | 6 | 470 | | | | | | |
| 119189 | 6 | N | 9 | W | 7 | 442 | 2568 | 2650 | | | | |
| 119134 | 6 | N | 10 | W | 12 | 436 | 2567 | 2640 | 2758 | | 2 | |
| 157314 | 6 | N | 10 | W | 12 | 462 | 2577 | | | | | |
| 119499 | 7 | N | 10 | W | 36 | 460 | 2580 | 2670 | | | | |

**Field name:** Carlisle West

**IGS ID:** 10094

**DOE ID:** 102204

**Location:** Sullivan County, 6N-10W

**Discovery date:** 1976

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, Jeffersonville (2,719 ft.)

**Field type:** oil (abandoned)

**Total number production wells:** 1

**Area:** 20 acres

**Cumulative production:** 674 bbls. (2002)

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Devonian, New Harmony Group (2847 ft.)

**Field characteristic:** Subtle anticlinal nose with no observable closure at top of Muscatatuck.

**Reservoir characteristics:**

**Field name:** Chrisney South

**IGS ID:** 10109

**DOE ID:** 141370

**Location:** Spencer County, 6S-5W

**Discovery date:** 1958

**Lower Paleozoic reservoir unit (depth):** Devonian, New Harmony Group, Backbone (2,771ft.)

**Field type:** oil

**Total number production wells:** 9

**Area:** 100 acres

**Cumulative production:** 100,292 bbls. (2002)

**Other reservoir units:**

Mississippian, West Baden Group, Elwren (Cypress) & Sample Fms.

Mississippian, Sanders Group, Harrodsburg Ls.

**Deepest unit penetrated (depth):** Silurian (3,420 ft.)

**Field characteristic:** Complex domal anticline over probable Silurian reef with structural closure in excess of 120 ft. at top of Muscatatuck.

**Reservoir characteristics:**

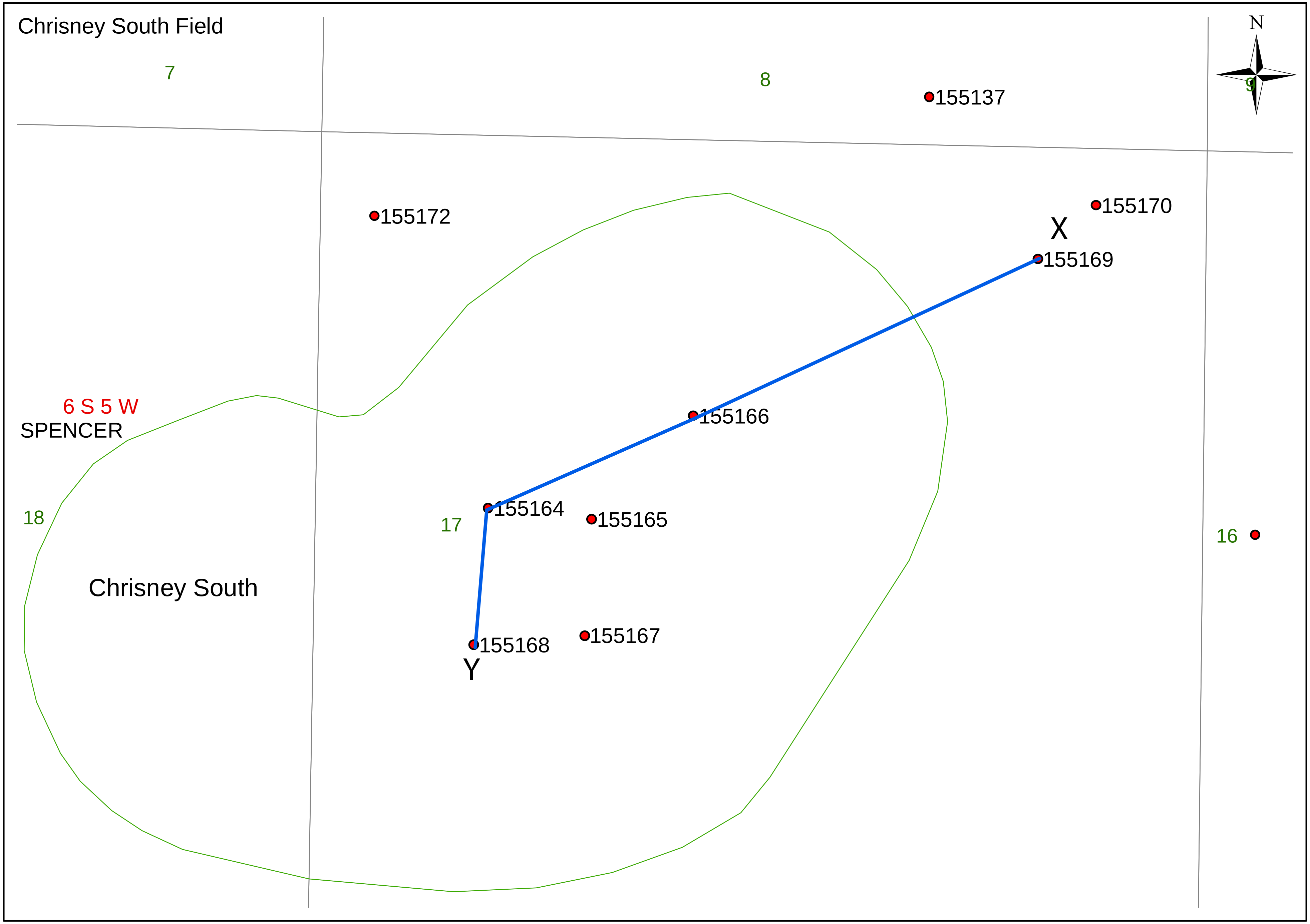


Figure 1: Map showing the location and wells at Chrisney South Field, Spencer County. X-Y is the location of the cross section that shows the subsurface Devonian structure in Figure 8.

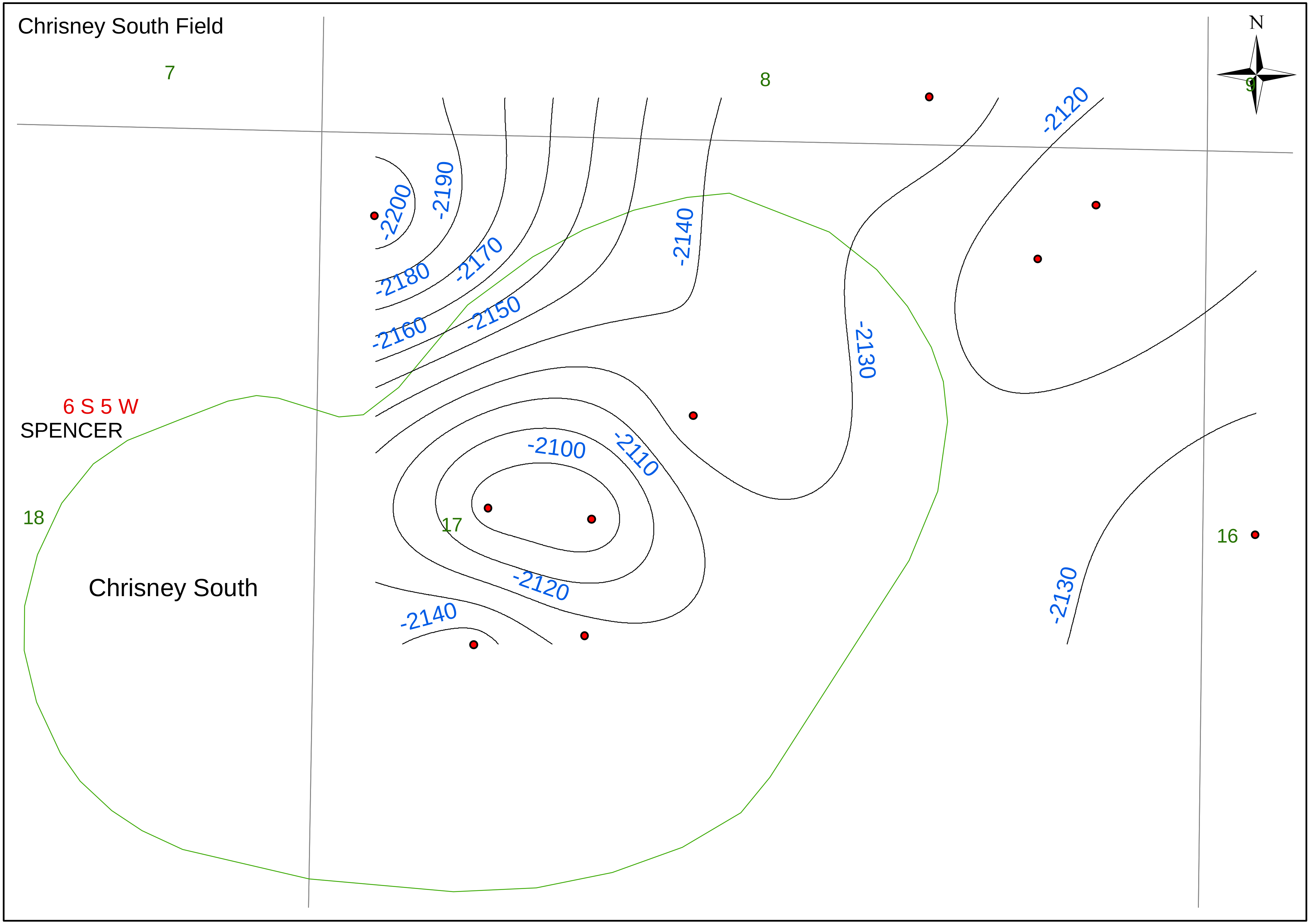


Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Chrisney South Field, Clay County. Contours show values below sea level, contour interval is 10 ft .

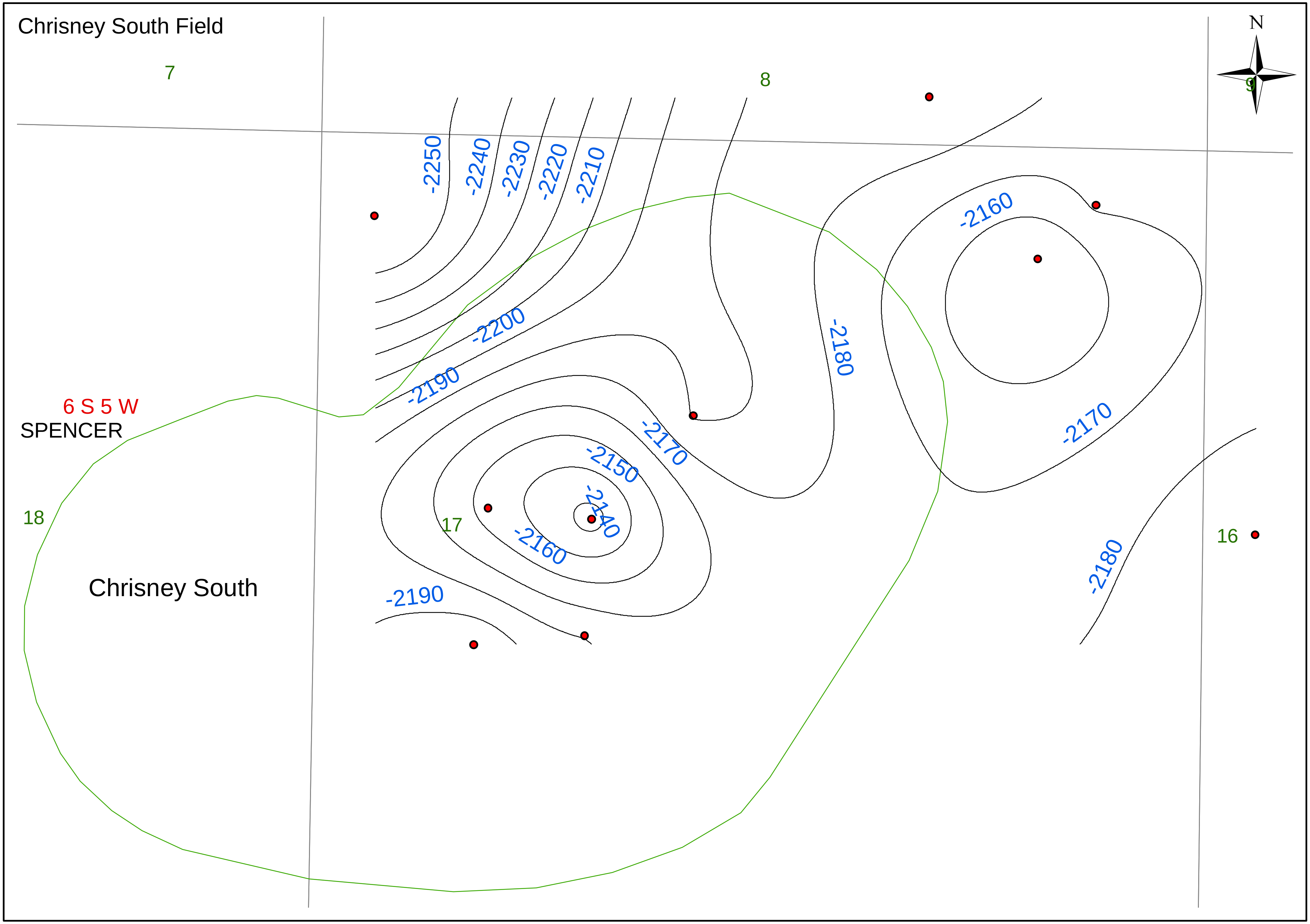


Figure 3: Structure map showing top of the Jeffersonville Limestone in Chrisney South Field, Spencer County. Contours show values below sea level, contour interval is 10 ft .

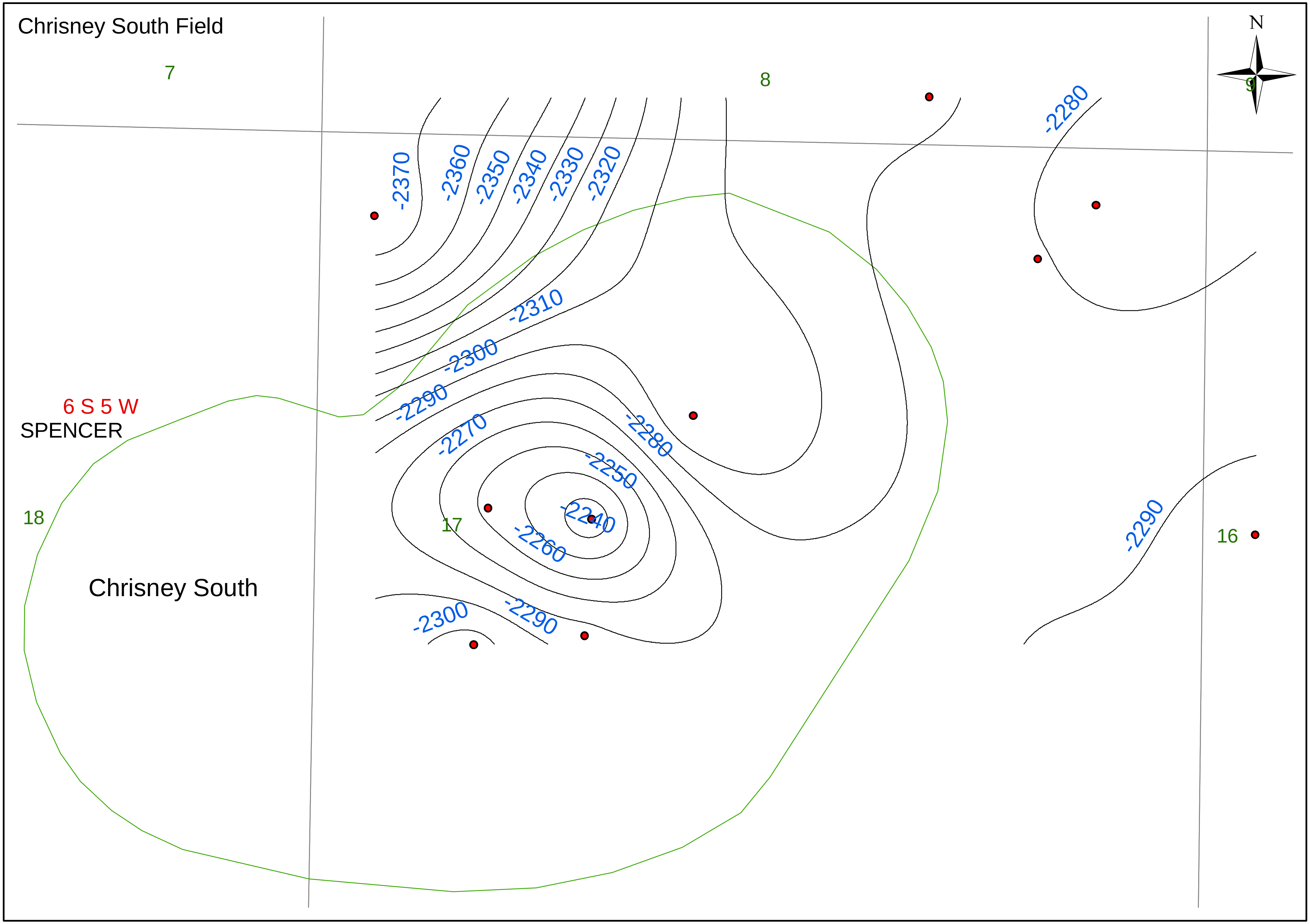


Figure 4: The structure map showing top of the New Harmony Limestone in the Chrisney South field, Spencer County. Countour shows values below sea level, contour interval is 10 ft .

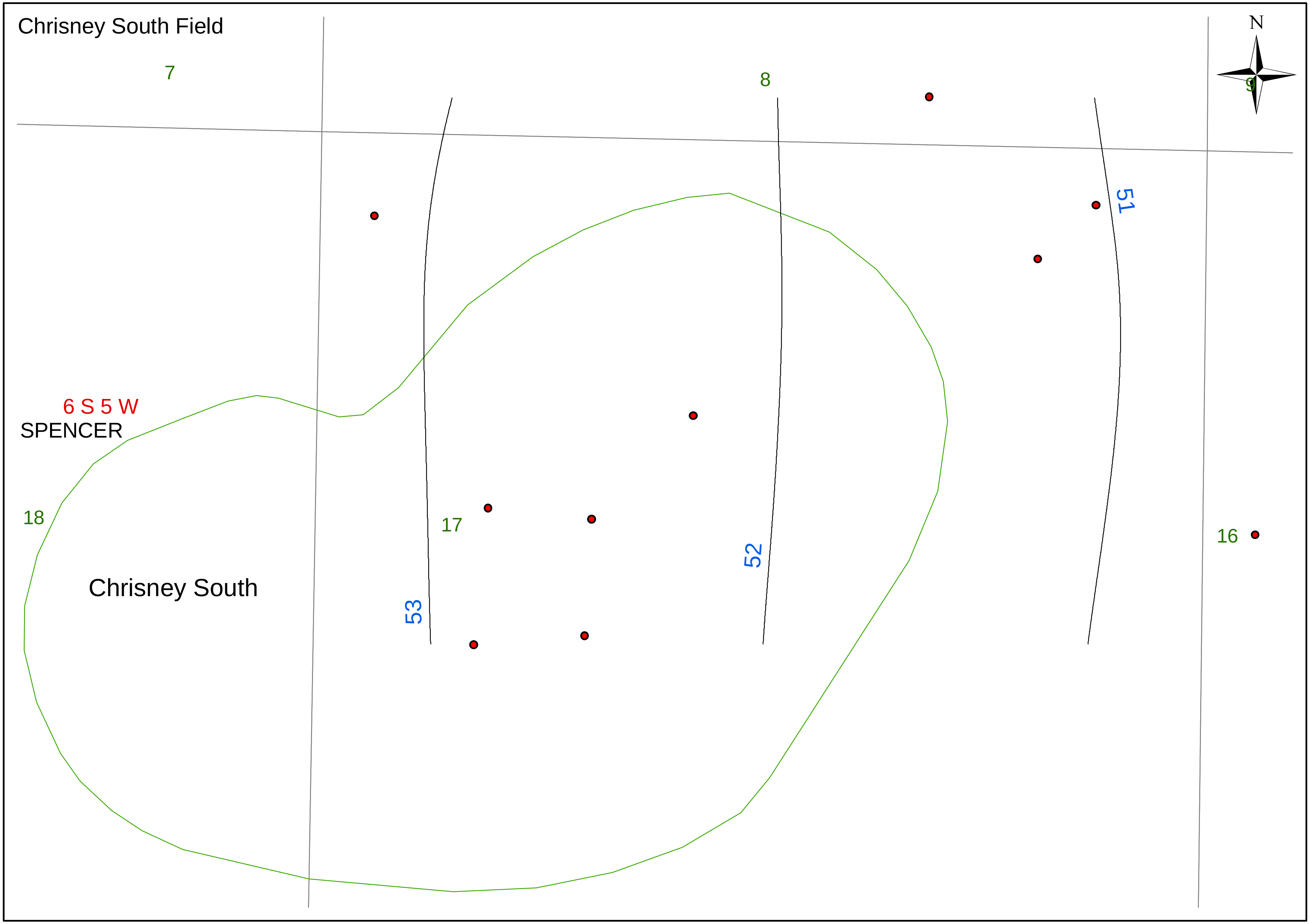


Figure 5: Isopach map showing the thickness of North Vernon Member in Chrisney South Field, Spencer County. Contour interval is 1 ft .

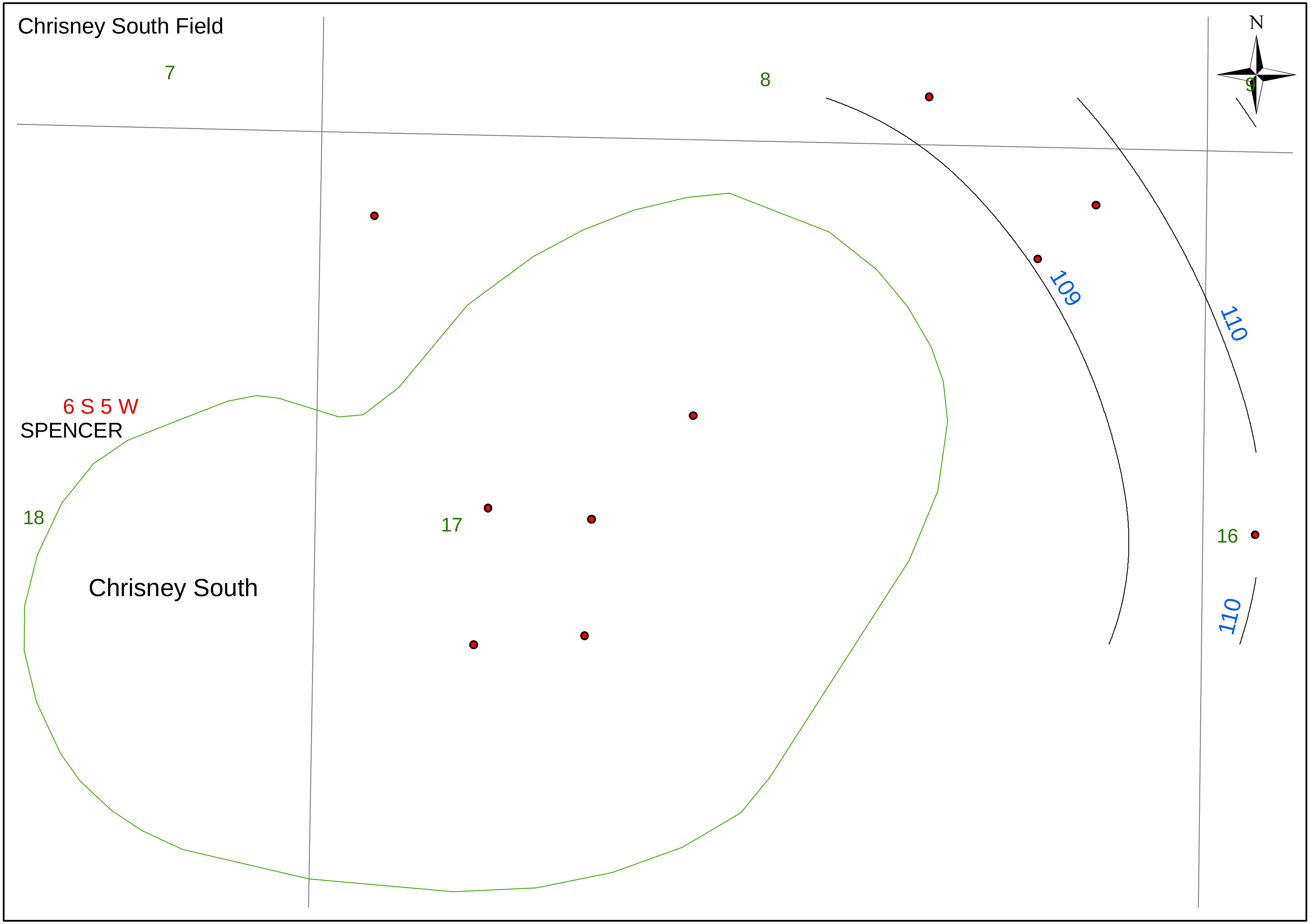


Figure 6: Isopach map showing the thickness of Jeffersonville Limestone in Chrisney South Field, Spencer County. Countour interval is 1 ft .

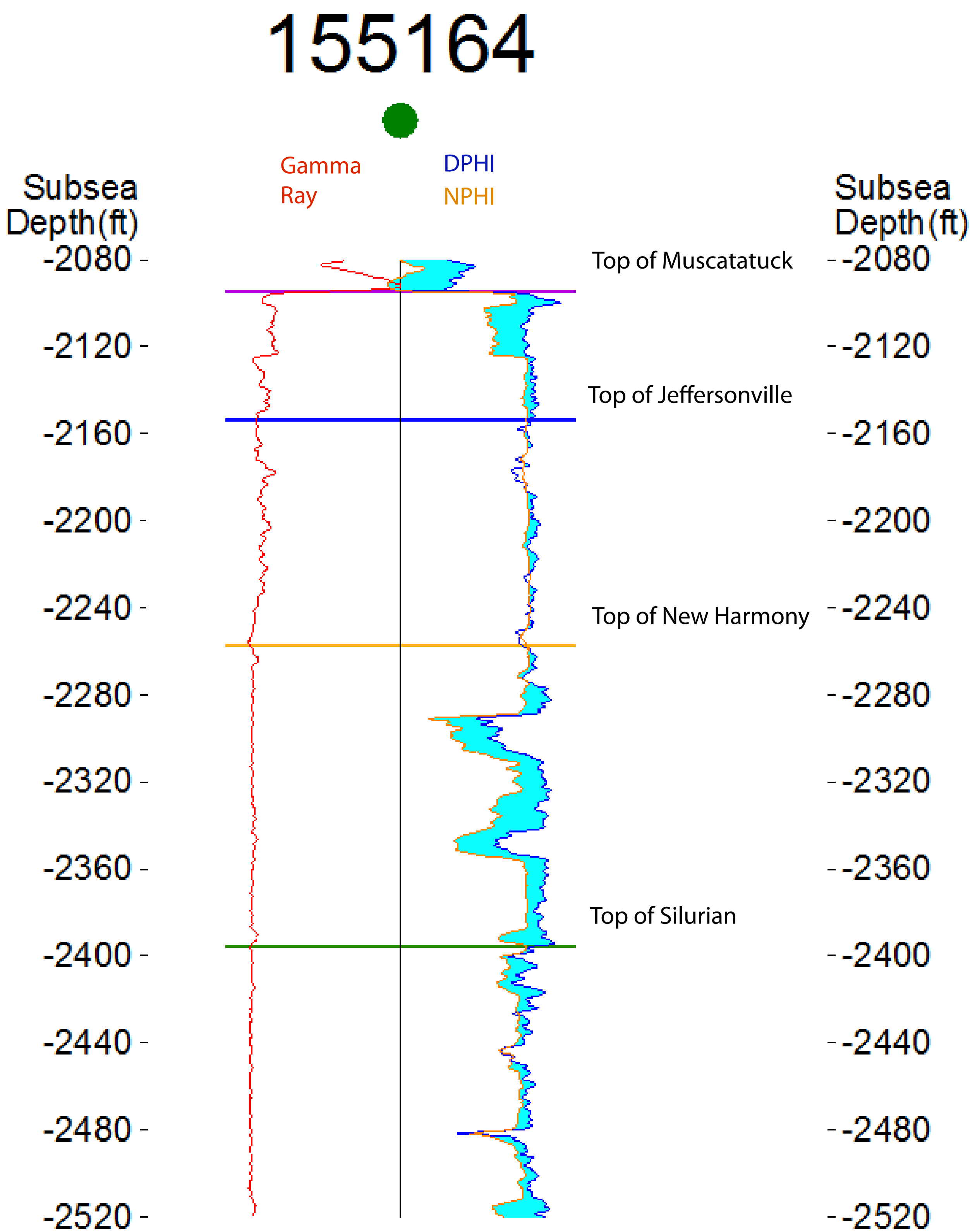


Figure 7: Type log section showing the Devonian formations at Chrisney South Field, Spencer County.



HS=1

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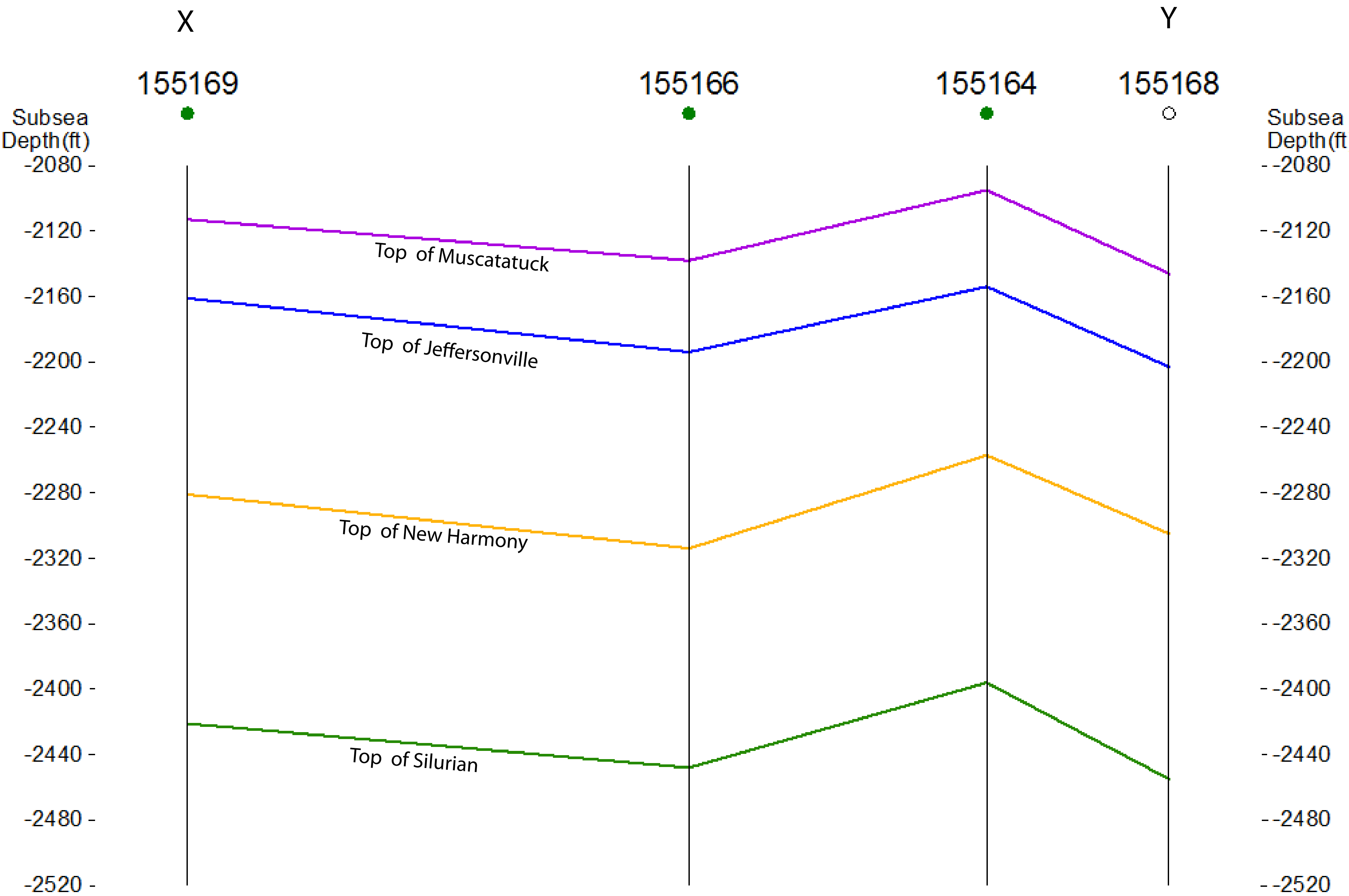


Figure 8: X-Y Cross section showing the Devonian subsurface structure across Chrisney South Field, Spencer County. For location of the cross section refer to Figure 1.

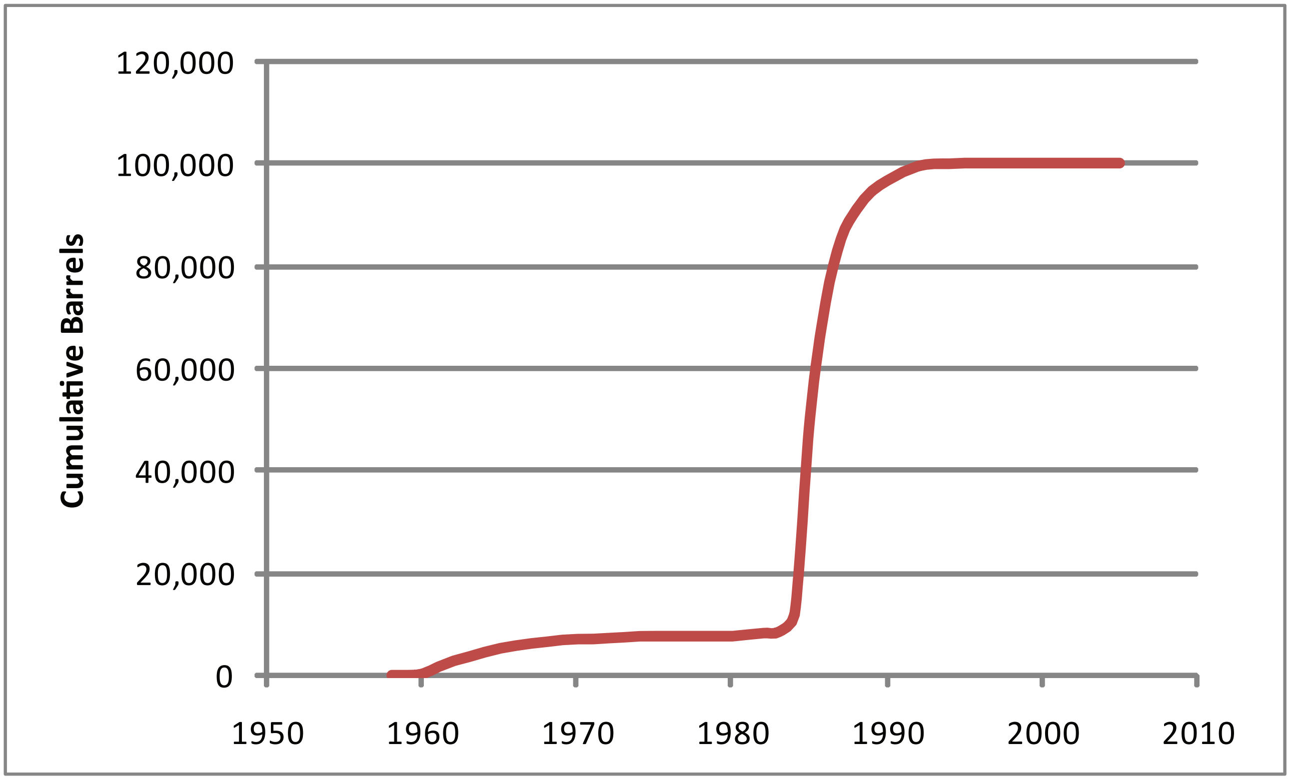


Figure - 9: Cumulative oil production history from Chrisney South Field, Spencer County since 1958.

Table-1: List of the wells used for subsurface structure mapping in Chrisney South Field, Spencer County.

| IGS_ID | Twp | Twp _D | Rng | Rng _D | Land _N | Elevation/ Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of New Harmony | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 155137 | 6 | S | 5 | W | 8 | 408 | 2546 | 2600 | 54 | | | |
| 155163 | 6 | S | 5 | W | 16 | 413 | 2550 | 2600 | 50 | 2920 | | |
| 155164 | 6 | S | 5 | W | 17 | 468 | 2563 | 2622 | 59 | 2864 | | |
| 155165 | 6 | S | 5 | W | 17 | 482 | 2573 | 2610 | 37 | | 120 | |
| 155166 | 6 | S | 5 | W | 17 | 516 | 2654 | 2710 | 56 | 2964 | | |
| 155167 | 6 | S | 5 | W | 17 | 487 | 2612 | 2668 | 56 | | 60 | |
| 155168 | 6 | S | 5 | W | 17 | 495 | 2641 | 2698 | 57 | 2950 | 8 | |
| 155169 | 6 | S | 5 | W | 17 | 449 | 2562 | 2592 | 30 | 2870 | | |
| 155170 | 6 | S | 5 | W | 17 | 416 | 2527 | 2590 | 63 | 2860 | | |
| 155172 | 6 | S | 5 | W | 17 | 421 | 2629 | 2690 | 61 | | | |

**Field name:** Clay City North

**IGS ID:** 10110

**DOE ID:** 146439

**Location:** Clay County, 10N-6W

**Discovery date:** 1978

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,359 ft.)

**Field type:** oil

**Total number production wells:** 16

**Area: 200** acres

**Cumulative production:** 260,420 bbls. (2002)

**Other reservoir units:** Mississippian, Borden Group, Carper Ss.

**Deepest unit penetrated (depth):** Silurian (1,613 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 40 ft. at top of Muscatatuck.

**Reservoir characteristics:**

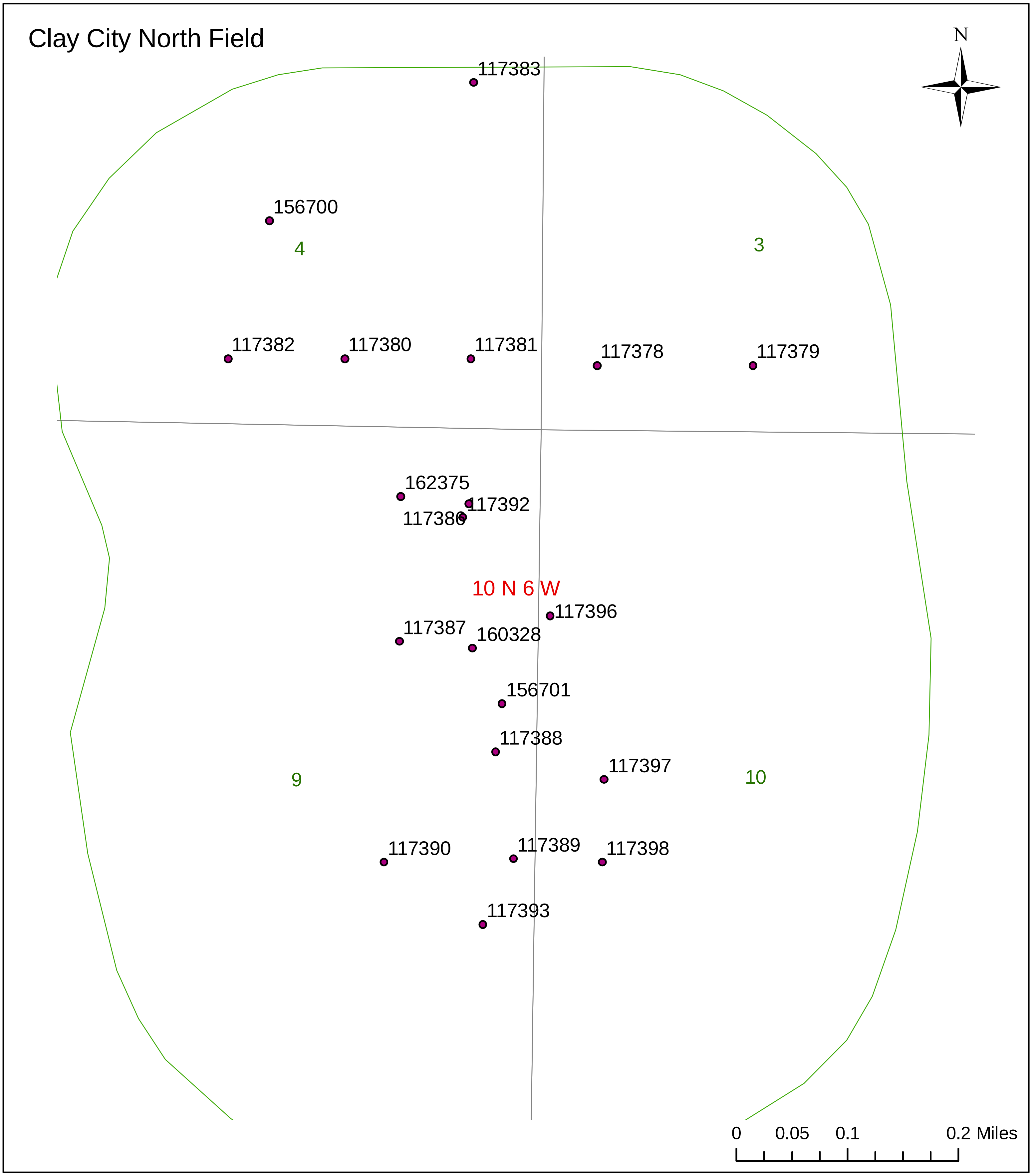


Figure 1: Map showing the location and wells at Clay City North Field, Clay County. Red points are the location of wells in the field.

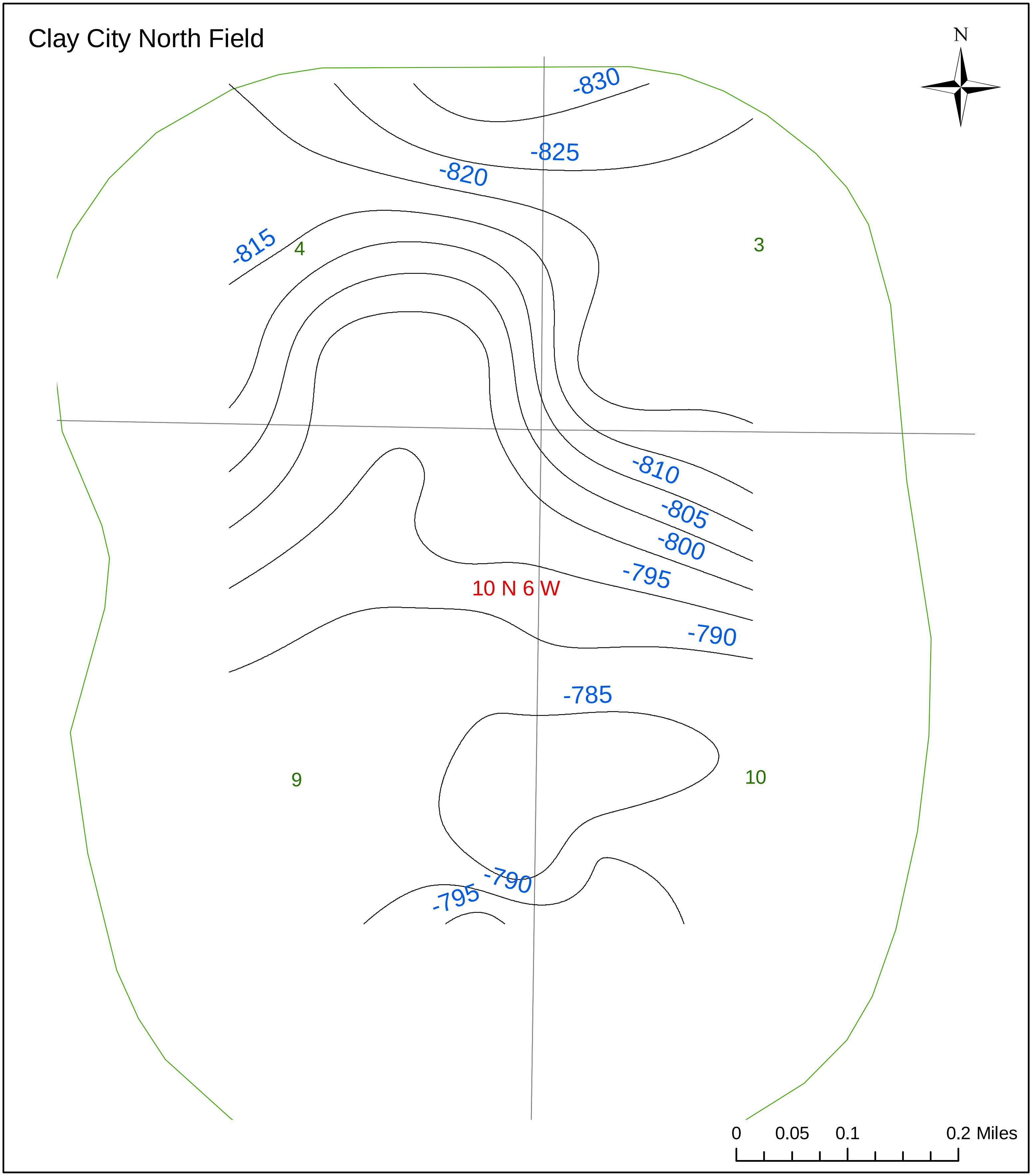


Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Clay City North Field, Clay County. Contours show values below sea level, contour interval is 5 ft .

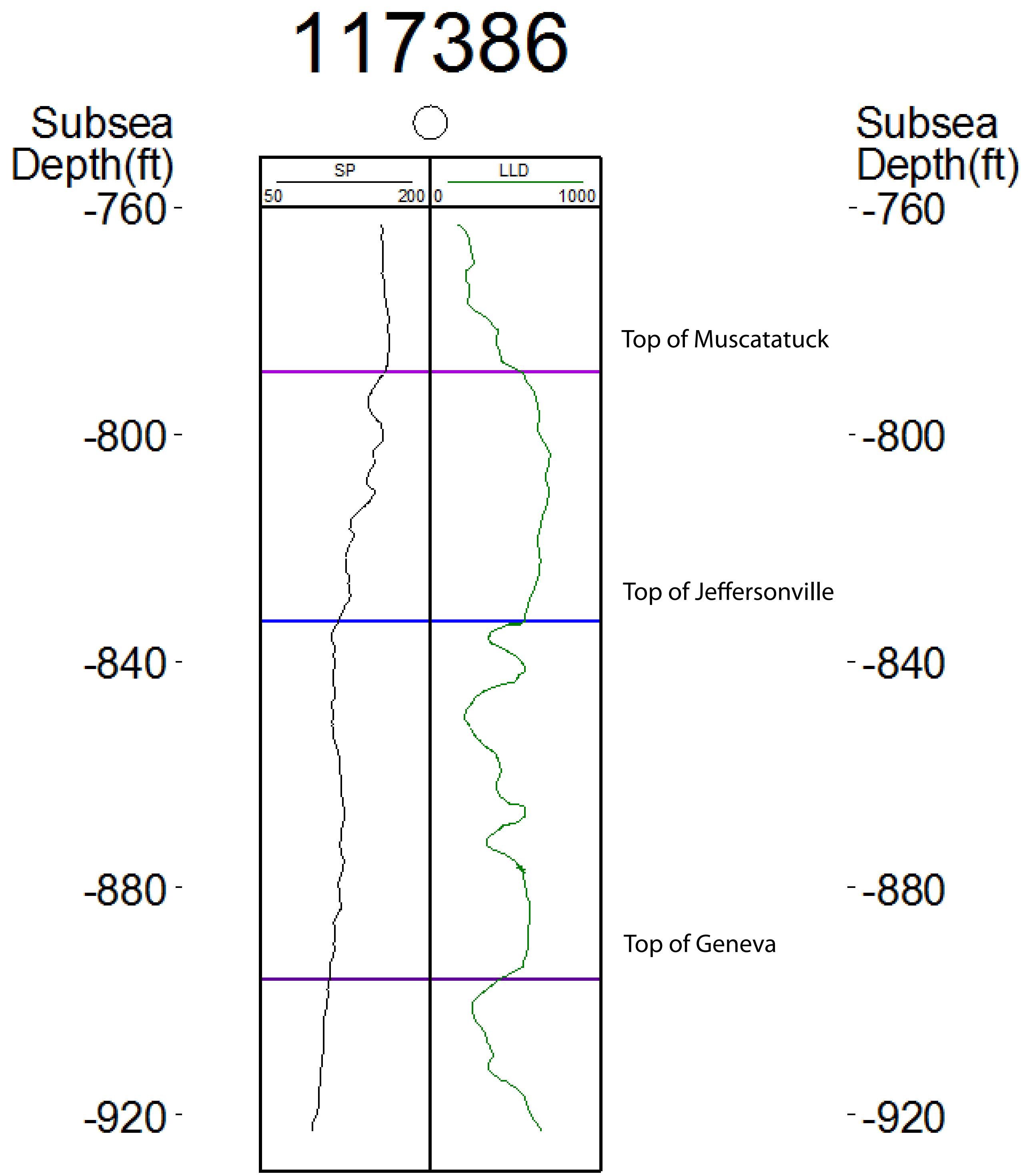


Figure 3: Type log section showing the Devonian formations from Clay City North Field, Clay County.

HS=1294

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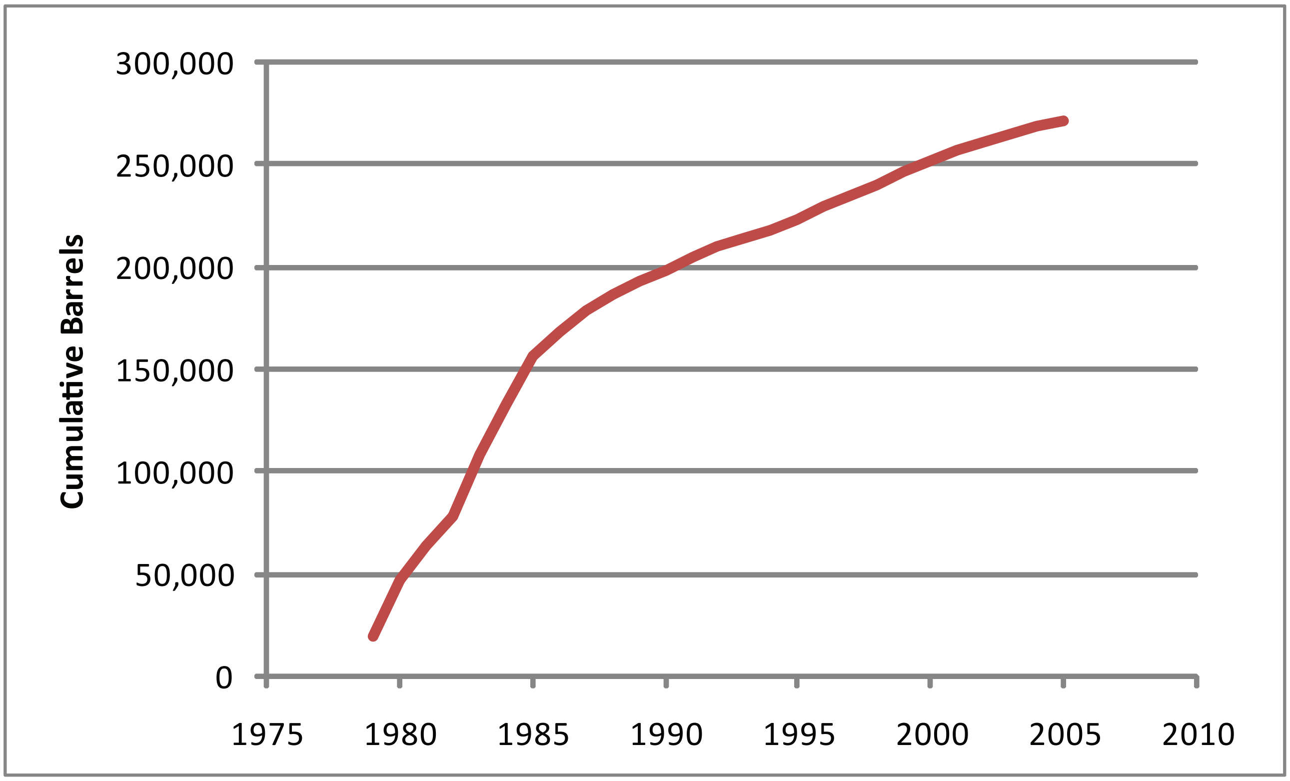



Figure - 4: Cumulative oil production history from Clay City North Field, Clay County since 1979.

Table-1: List of the wells used for subsurface structure mapping in Clay City North Field, Clay County. The wells selected have TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/ Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 117378 | 10 | N | 6 | W | 3 | 558 | 1385 | | | | 4 | |
| 117379 | 10 | N | 6 | W | 3 | 565 | 1386 | | | | | |
| 117380 | 10 | N | 6 | W | 4 | 555 | 1349 | | | | 6 | |
| 117381 | 10 | N | 6 | W | 4 | 557 | 1352 | | | | 12 | |
| 117382 | 10 | N | 6 | W | 4 | 555 | 1370 | 1408 | | | | |
| 117383 | 10 | N | 6 | W | 4 | 567 | 1400 | | | | | |
| 156700 | 10 | N | 6 | W | 4 | 554 | 1373 | | | | | |
| 117386 | 10 | N | 6 | W | 9 | 577 | 1366 | 1410 | 1474 | | | |
| 117387 | 10 | N | 6 | W | 9 | 567 | 1355 | 1406 | | | 20 | |
| 117388 | 10 | N | 6 | W | 9 | 571 | 1343 | | | | 35 | |
| 117389 | 10 | N | 6 | W | 9 | 586 | 1361 | | | | 3\20 | |
| 117390 | 10 | N | 6 | W | 9 | 597 | 1384 | | | | 10 | |
| 117392 | 10 | N | 6 | W | 9 | 572 | 1379 | | | | 10 | |
| 117393 | 10 | N | 6 | W | 9 | 594 | 1396 | | | | 10 | |
| 156701 | 10 | N | 6 | W | 9 | 575 | 1360 | | | 1520 | | |
| 160328 | 10 | N | 6 | W | 9 | 575 | 1360 | | | | 20 | |
| 162375 | 10 | N | 6 | W | 9 | 578 | 1371 | | | | 15 | |
| 117396 | 10 | N | 6 | W | 10 | 581 | 1374 | | | | 15 | |
| 117397 | 10 | N | 6 | W | 10 | 589 | 1369 | | | | 5\12 | |
| 117398 | 10 | N | 6 | W | 10 | 587 | 1380 | | | | 15 | |

**Field name:** Coal City

**IGS ID:** 10114

**DOE ID:** na

**Location:** Owen County, 9N-6W

**Discovery date:** 1973

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,448 ft.)

**Field type:** natural gas

**Total number production wells:** 2

**Area:** na

**Cumulative production:** na

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Silurian (1,695 ft.)

**Field characteristic:** Insufficient data.

**Reservoir characteristics:**

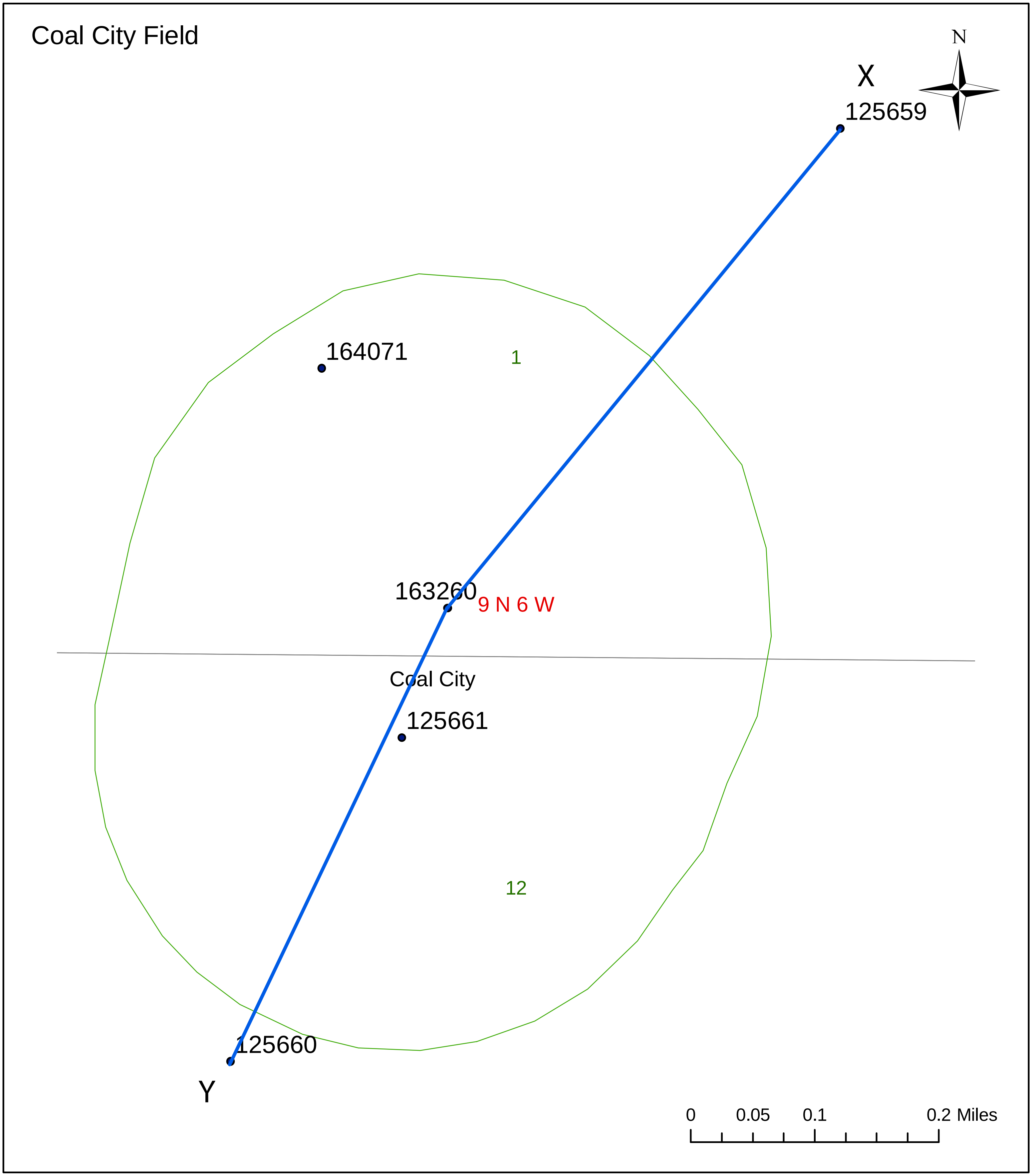



Figure 1: Map showing the location and wells at Coal City Field, Owen County. X-Y is the location of the cross section that shows the subsurface Devonian structure in Figure 4.

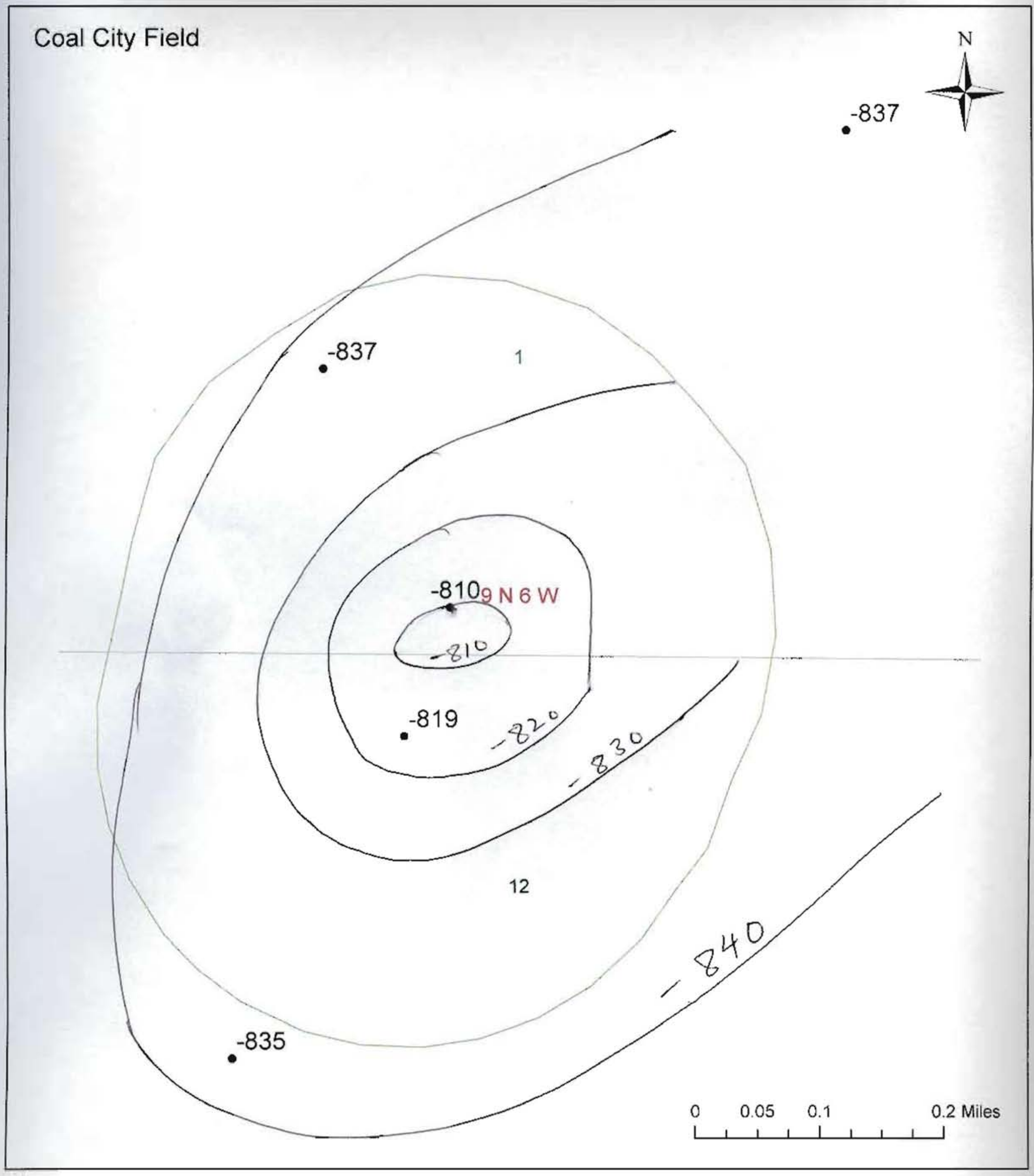



Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Coal City Field, Owen County. Contours show values below sea level, contour interval is 10 ft .

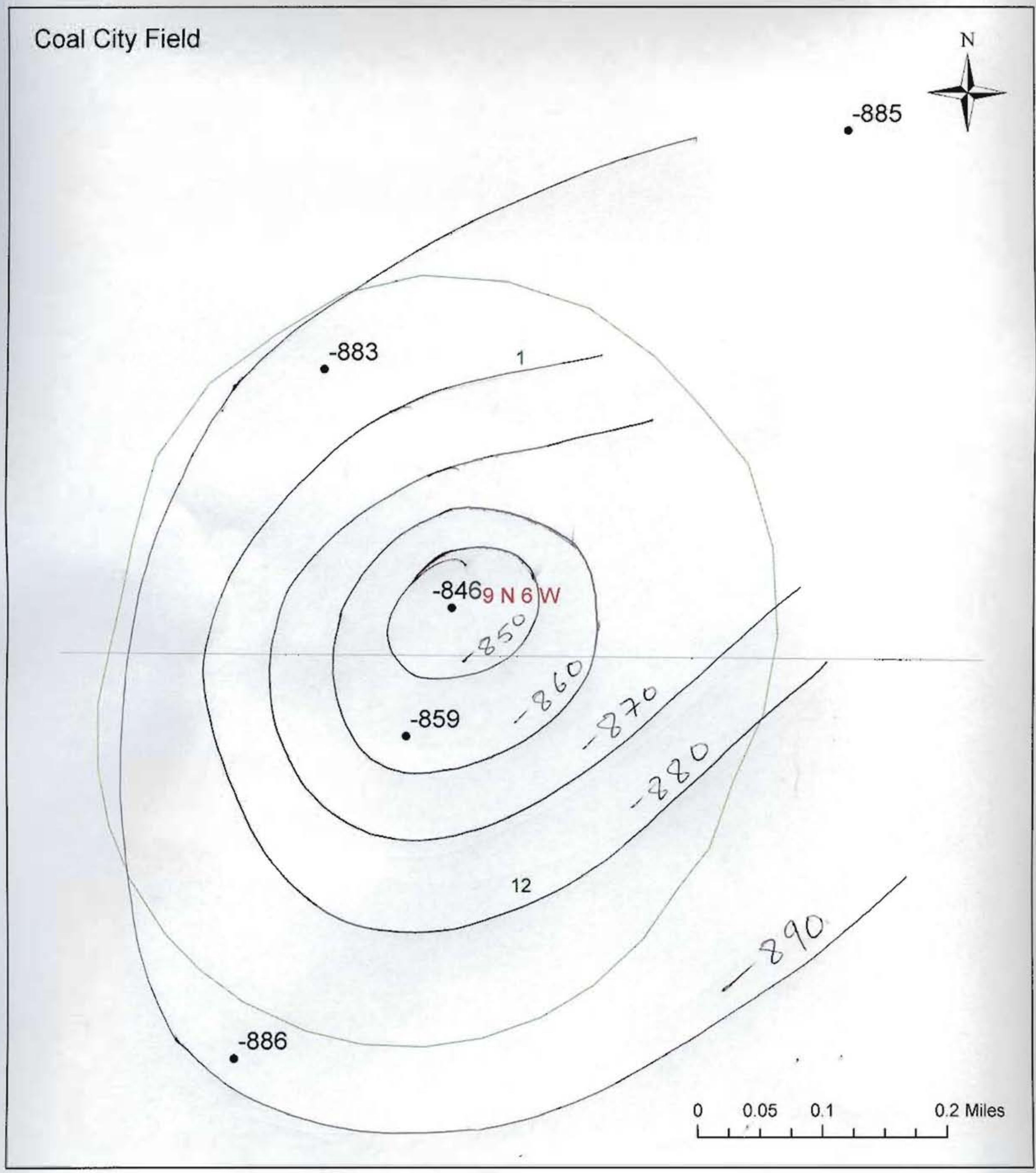



Figure 3: Structure map showing the top of subsurface Jeffersonville Limestone in Coal City Field, Owen County. Contours show values below sea level, contour interval is 10 ft .

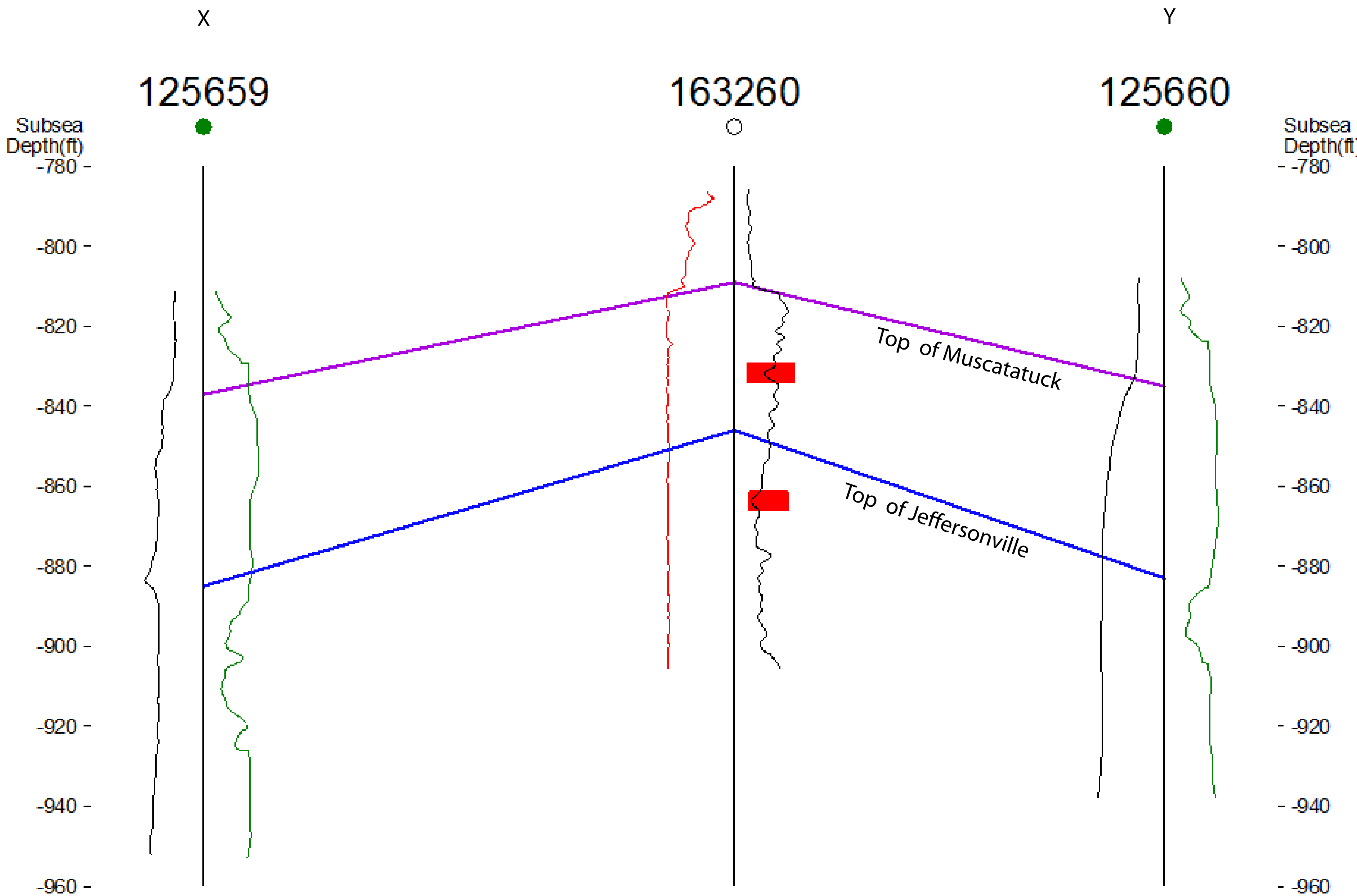



Figure 4: X-Y Cross section showing the Devonian subsurface structure across Coal City Field, Owen County. The red color box shows the completion intervals for the oil production. For location of the cross section refer to Figure 1.

Table-1: List of the wells used for subsurface structure mapping in Coal City Field, Owen County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125659 | 9 | N | 6 | W | 1 | 539 | 1376 | 1424 | | | | |
| 163260 | 9 | N | 6 | W | 1 | 644 | 1454 | 1490 | | | | |
| 164071 | 9 | N | 6 | W | 1 | 617 | 1454 | 1500 | 1570 | | | 1500 |
| 125660 | 9 | N | 6 | W | 12 | 612 | 1447 | 1498 | | | | |
| 125661 | 9 | N | 6 | W | 12 | 611 | 1430 | 1470 | 1532 | | | 112 |

**Field name:** Coalmont West

**IGS ID:** 10117

**DOE ID:** 13356

**Location:** Sullivan County, 9N-8W

**Discovery date:** 1988

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,863 ft.)

**Field type:** oil & natural gas

**Total number production wells:** 7 oil, 3 natural gas

**Area:** na

**Cumulative production:** na

**Other reservoir units:** Devonian/Mississippian, New Albany Sh.

**Deepest unit penetrated (depth):** Devonian, Muscatatuck Group, Jeffersonville Ls. (1,988 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 20 ft. at top of Muscatatuck.

**Reservoir characteristics:**

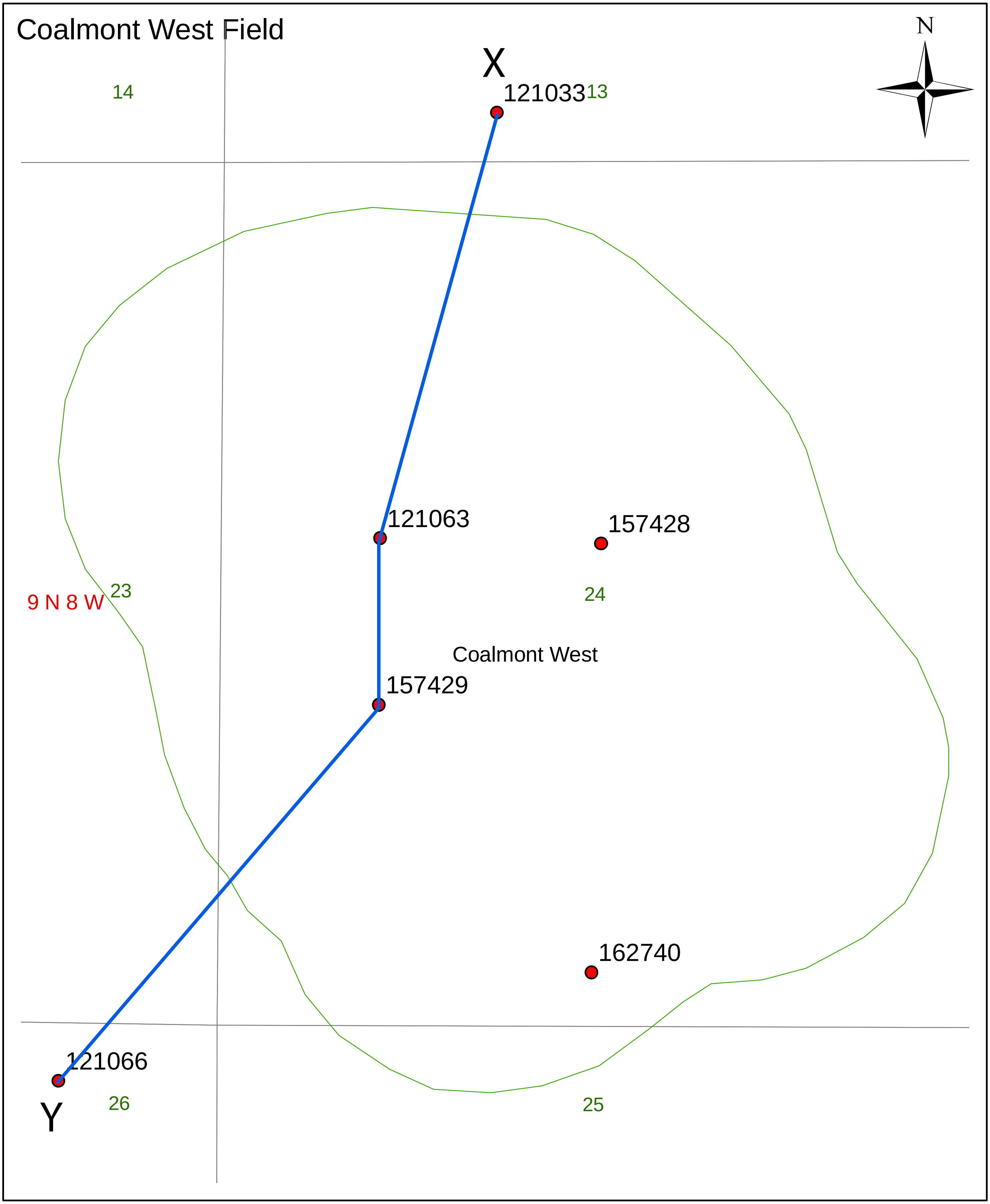



Figure 1: Map showing the location and wells at Coalmont West Field, Sullivan County. X-Y is the location of the cross section that shows the subsurface Devonian structure in Figure 4.

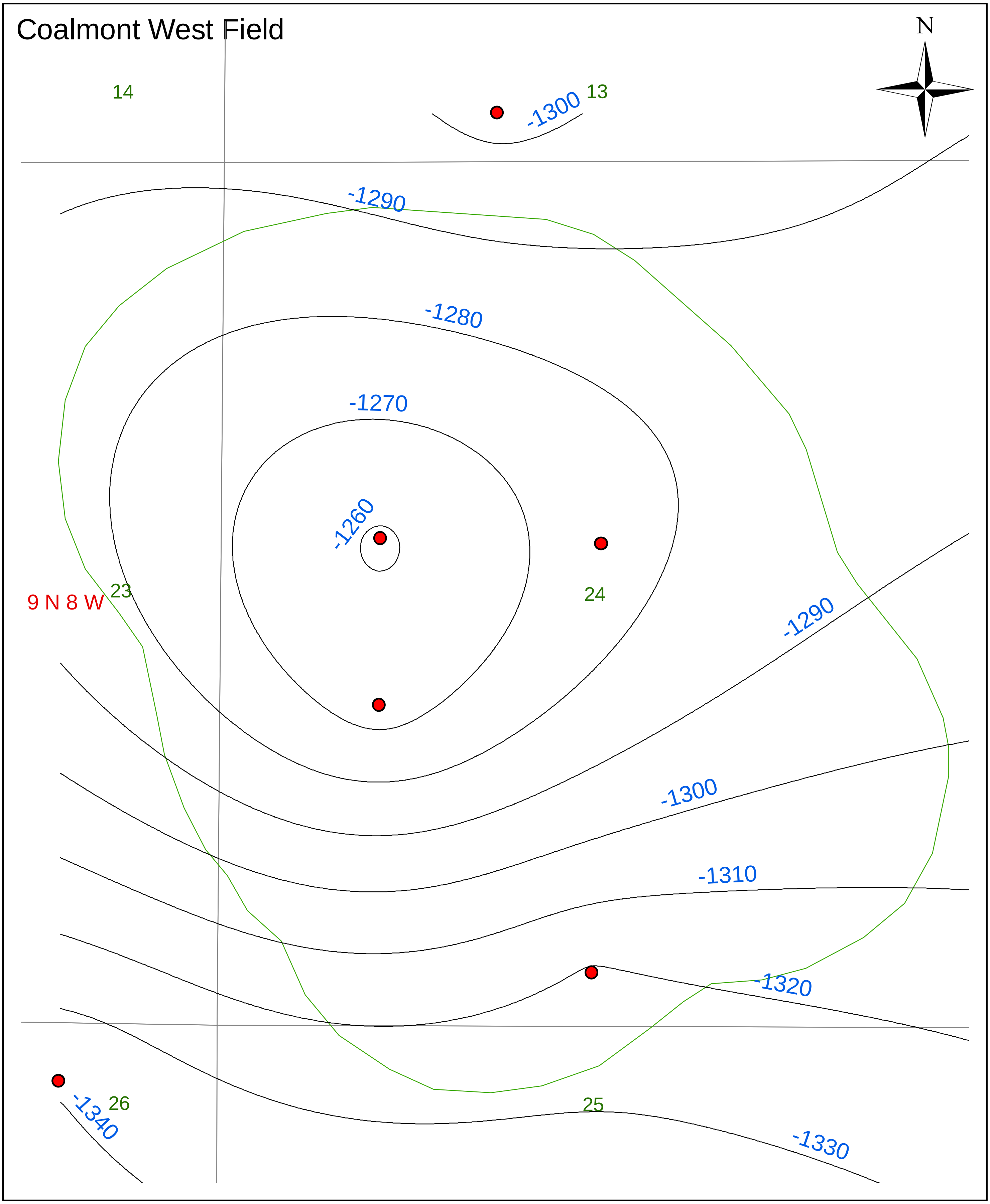



Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Coalmont West Field, Sullivan County. Contours show values below sea level, contour interval is 10 ft .

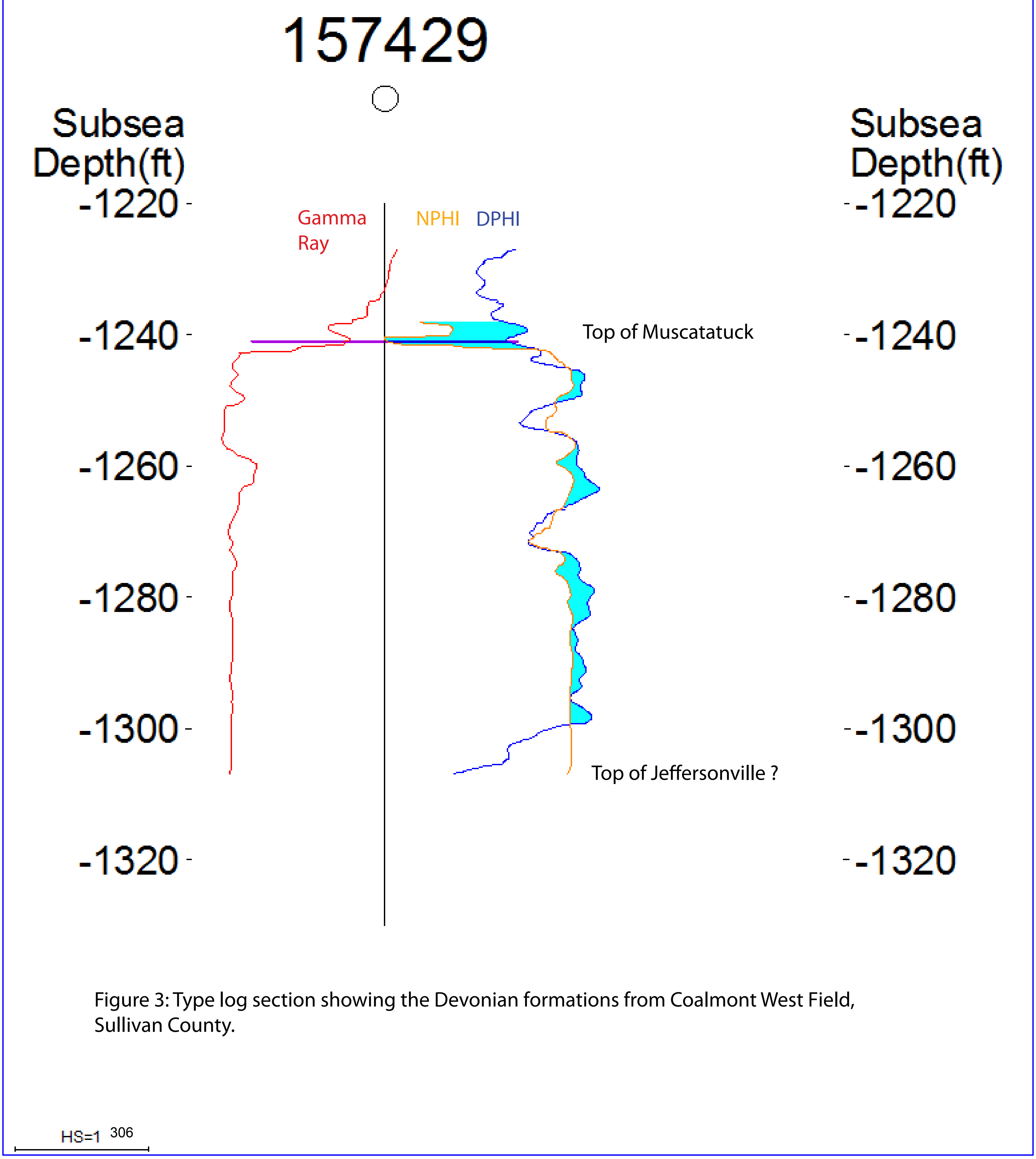



Figure 3: Type log section showing the Devonian formations from Coalmont West Field, Sullivan County.

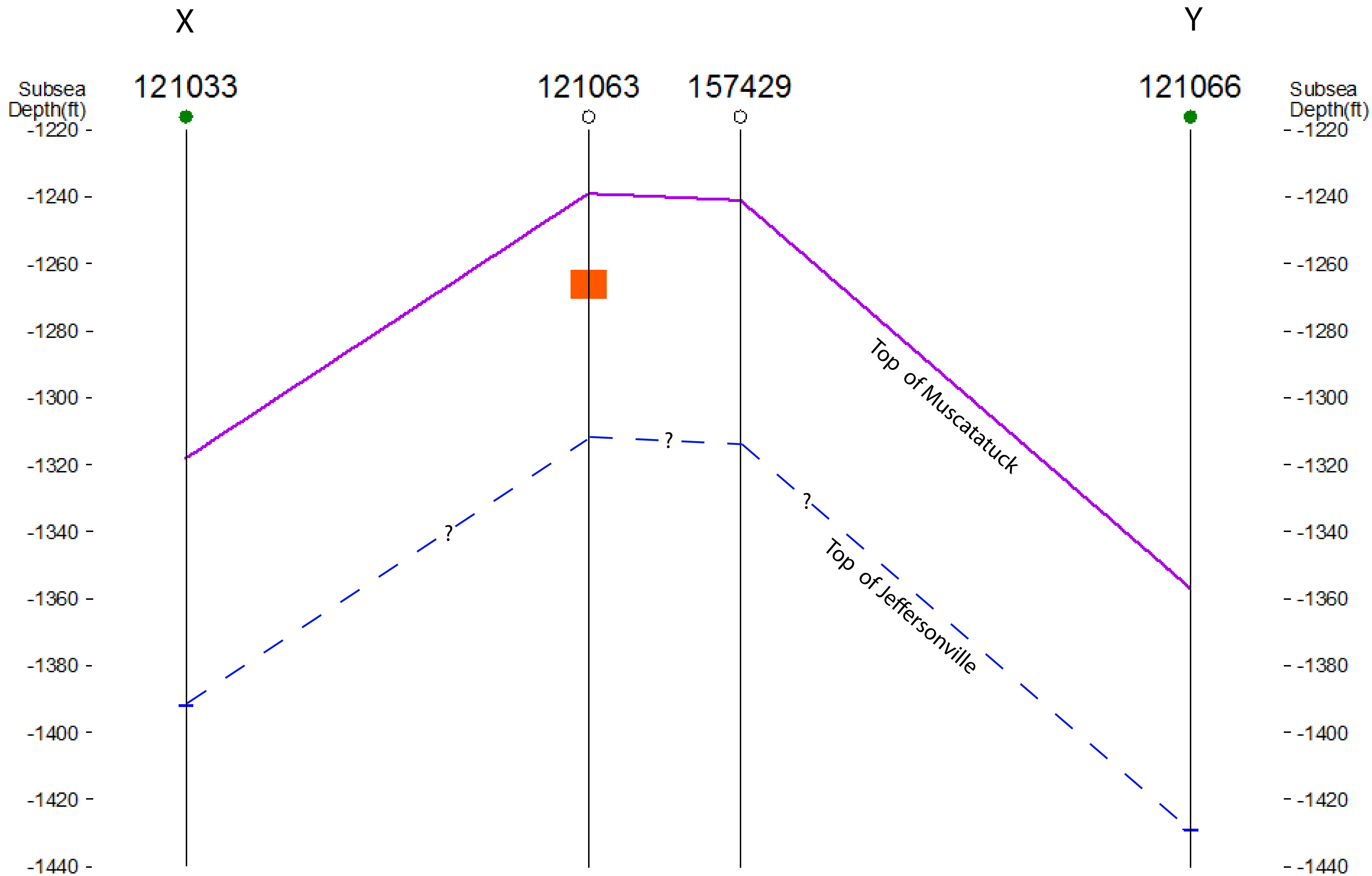



Figure 4: X-Y Cross section showing the Devonian subsurface structure across Coalmont West Field, Sullivan County. For location of the cross section refer to Figure 1. Red box indicates the completion interval for gas production.

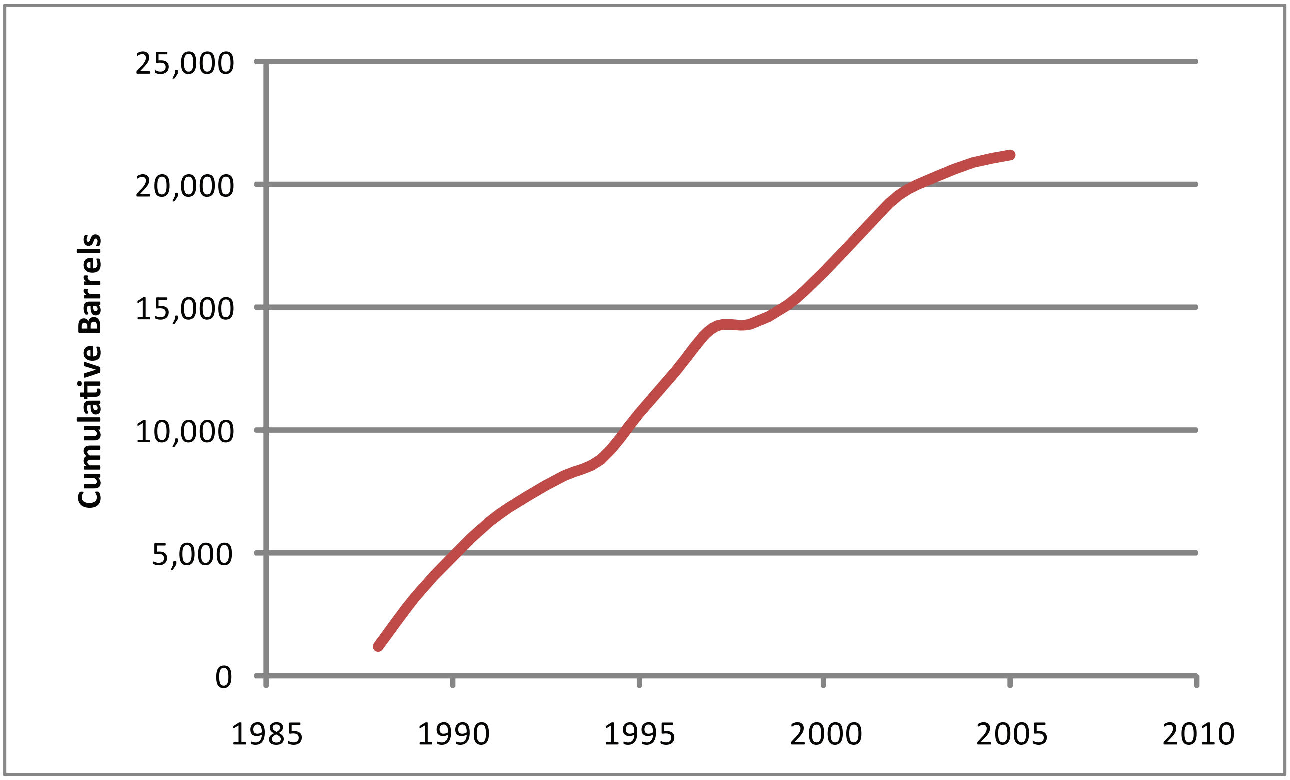



Figure - 5: Cumulative oil production history for Coalmont West Field, Sullivan County since 1988.

Table-1: List of the wells used for subsurface structure mapping in Coalmont West Field, Sullivan County.

| IGS_ID | Twp | Twp _D | Rng | Rng_ D | Land _N | Elevation/ Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 121033 | 9 | N | 8 | W | 13 | 608 | 1926 | 2000 | | | | |
| 121062 | 9 | N | 8 | W | 24 | 614 | 1896 | | | | | |
| 121063 | 9 | N | 8 | W | 24 | 599 | 1838 | | | | | 400 |
| 157428 | 9 | N | 8 | W | 24 | 596 | 1872 | | | | | 454 |
| 157429 | 9 | N | 8 | W | 24 | 593 | 1834 | | | | | 115 |
| 162740 | 9 | N | 8 | W | 24 | 591 | 1928 | | | 2130 | | |
| 121065 | 9 | N | 8 | W | 25 | 590 | 1947 | 2024 | | | | |
| 121066 | 9 | N | 8 | W | 26 | 551 | 1908 | 1980 | | | | |

**Field name:** Cory Consolidated

**IGS ID:** 10127

**DOE ID:** 163102

**Location:** Clay County, 11N-7W

**Discovery date:** 1958

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,521 ft.)

**Field type:** oil (abandoned)

**Total number production wells:** 17

**Area:** 250 acres

**Cumulative production:** 177,151 bbls. (2002)

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Silurian (1,738 ft.)

**Field characteristic:** Irregular domal anticline over probable Silurian reef with structural closure in excess of 20 ft. at top of Muscatatuck.

**Reservoir characteristics:**

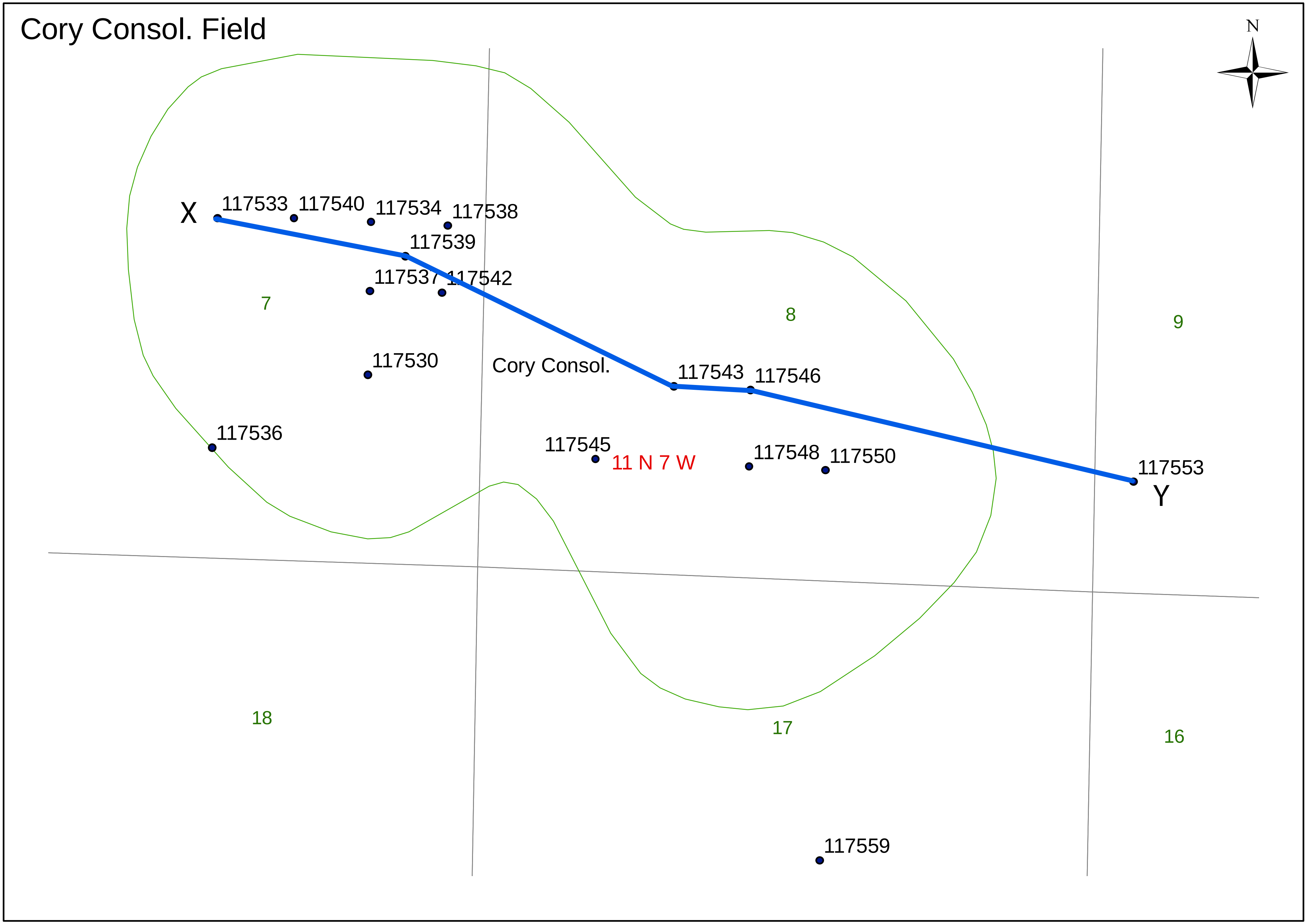



Figure 1: The map shows the location and wells at Cory Consolidated Field, Clay County. X-Y is the location of the cross section that shows the subsurface Devonian structure in Figure 4.

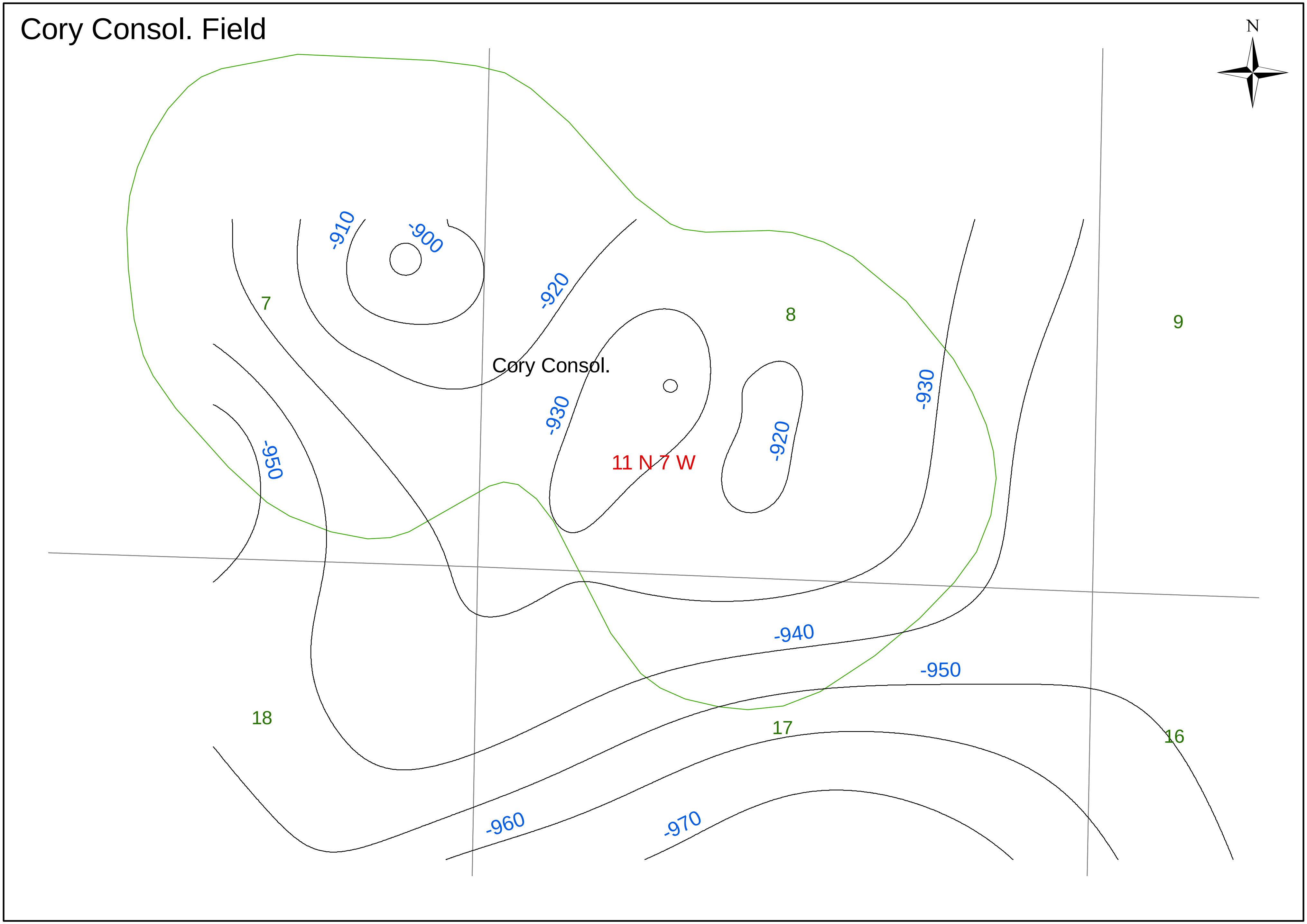



Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Cory Consol. Field, Clay County. Contours show values below sea level, contour interval is 10 ft .

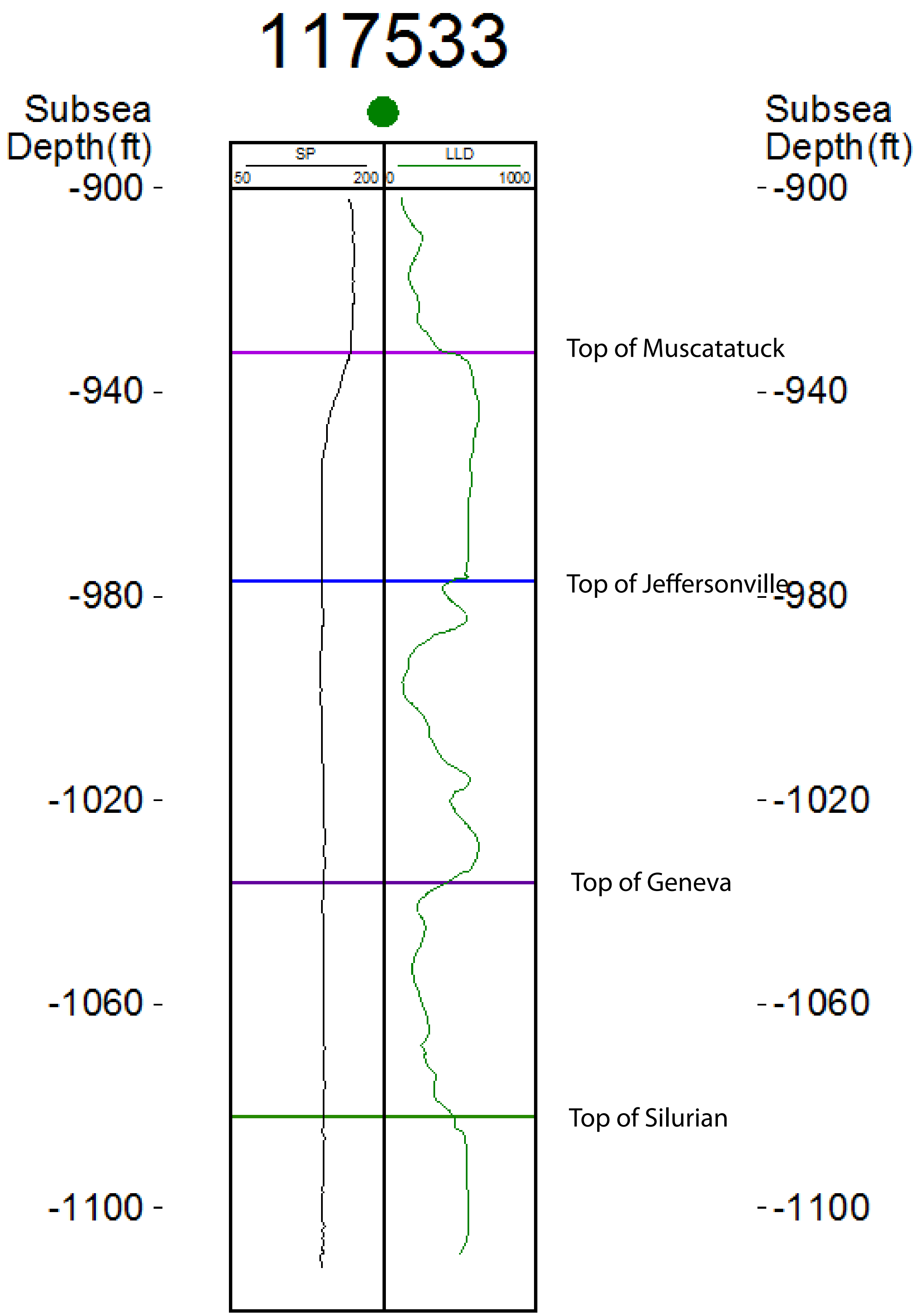



Figure 3: Type log section showing the Devonian formations from Cory Consol. Field, Clay County.

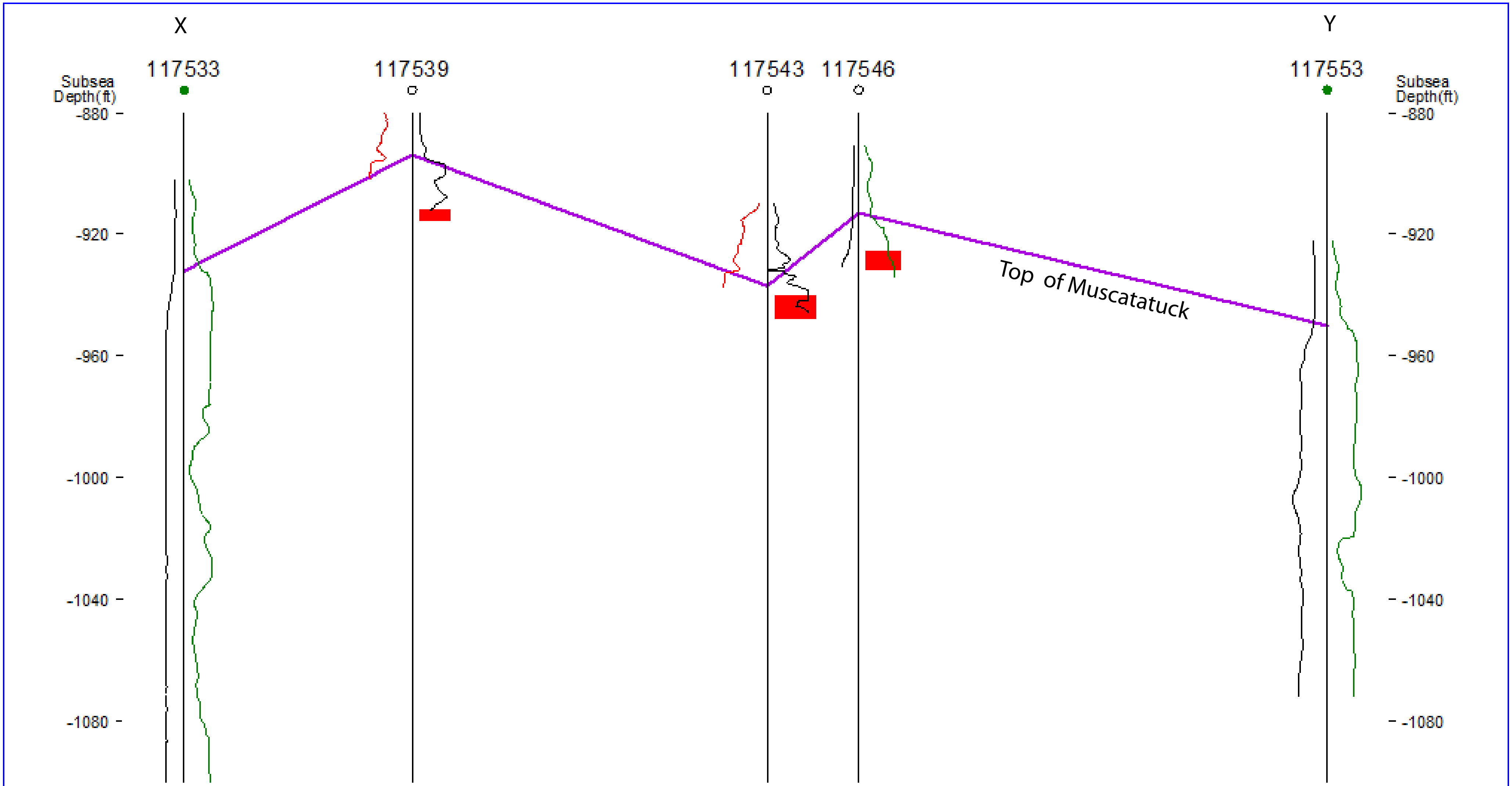
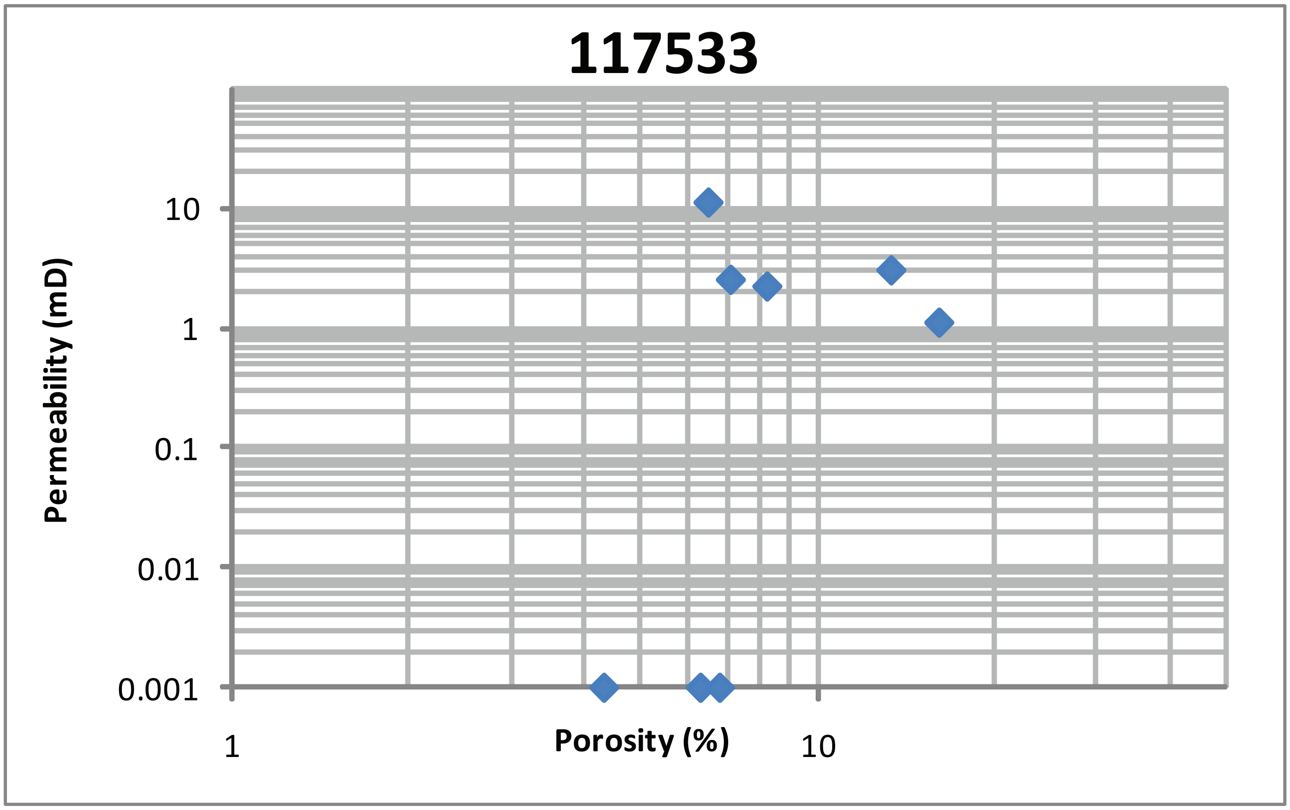



Figure 4: X-Y Corss section showing the Devonian subsurface structure acorss the Cory Consol. field, Clay County. The red colour box shows the completion intervals for oil production. For location of the cross section refer to Figure 1.



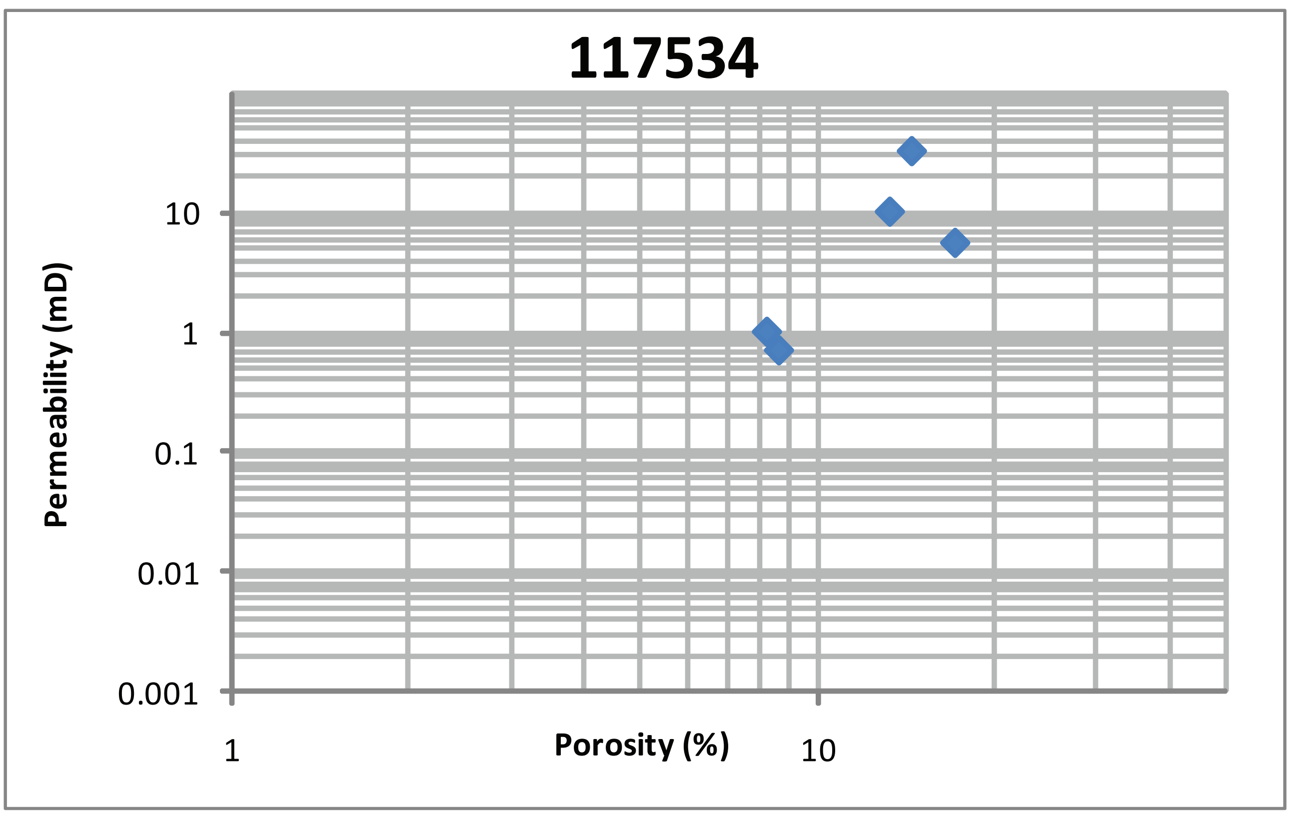




Figure 5: Porosity and permeability plot from core analysis from Cory Consol. Field, Clay County. The blue points are from North Vernon. The chart title lists the IGS Well ID. For the well locations see Figure 1.

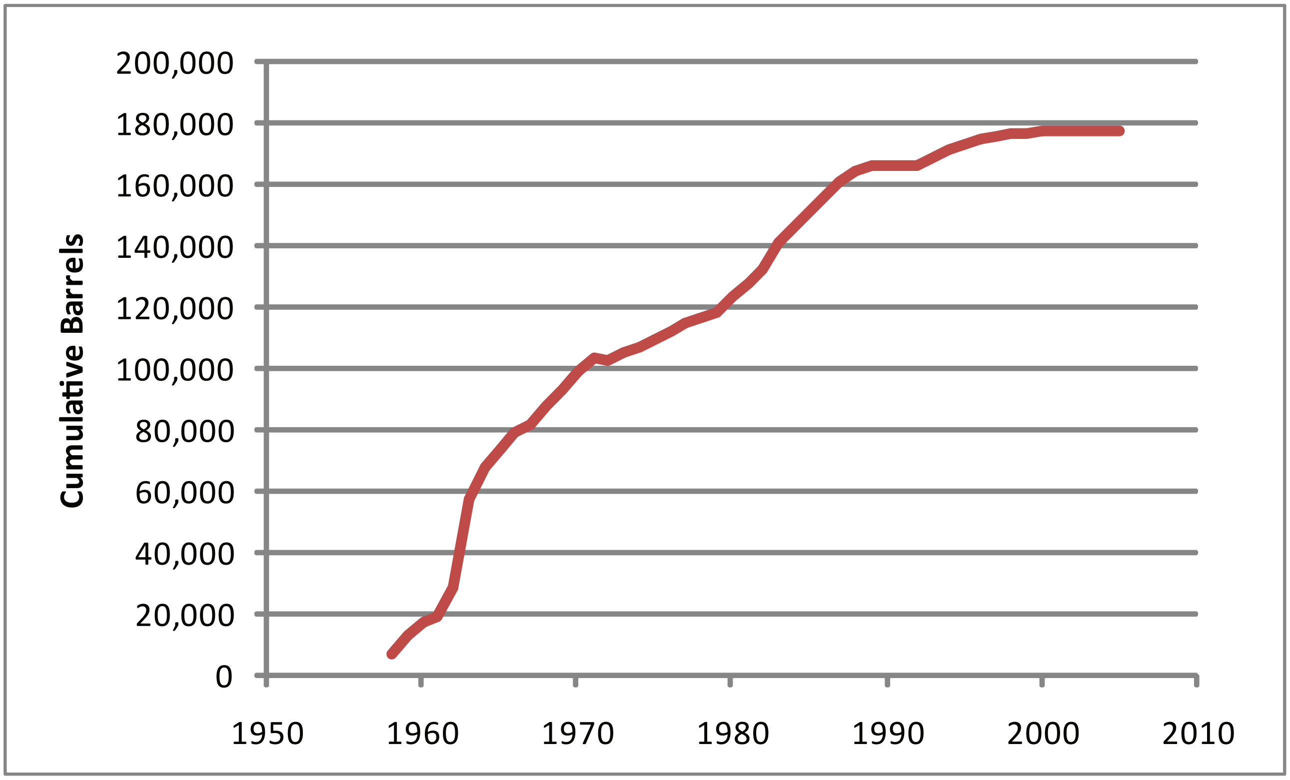



Figure - 6: Cumulative oil production history from Cory Consol. Field, Clay County since 1958.

Table-1: List of the wells used for subsurface structure mapping in Cory Consol. Field, Clay County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 117530 | 11 | N | 7 | W | 7 | 605 | 1528 | | | | 10 | |
| 117531 | 11 | N | 7 | W | 7 | 617 | | | | | | |
| 117533 | 11 | N | 7 | W | 7 | 628 | 1560 | 1605 | 1664 | 1710 | | |
| 117534 | 11 | N | 7 | W | 7 | 611 | 1520 | | | | 62 | |
| 117535 | 11 | N | 7 | W | 7 | 599 | | | | | 34 | |
| 117536 | 11 | N | 7 | W | 7 | 636 | 1593 | | | | | |
| 117537 | 11 | N | 7 | W | 7 | 598 | 1504 | | | | 16 | |
| 117538 | 11 | N | 7 | W | 7 | 608 | 1518 | | | | 42 | |
| 117539 | 11 | N | 7 | W | 7 | 608 | 1504 | | | | 10 | |
| 117540 | 11 | N | 7 | W | 7 | 615 | 1536 | 1578 | | | 60 | |
| 117542 | 11 | N | 7 | W | 7 | 603 | 1509 | | | | 10 | |
| 156724 | 11 | N | 7 | W | 7 | 618 | | | | | | |
| 117543 | 11 | N | 7 | W | 8 | 610 | 1551 | | | | 36 | |
| 117544 | 11 | N | 7 | W | 8 | 615 | | | | | 10 | |
| 117545 | 11 | N | 7 | W | 8 | 638 | 1570 | 1614 | 1686 | 1720 | | |
| 117546 | 11 | N | 7 | W | 8 | 639 | 1557 | 1620 | | | 15 | |
| 117547 | 11 | N | 7 | W | 8 | 628 | | | | | | |
| 117548 | 11 | N | 7 | W | 8 | 611 | 1527 | | | | 175 | |
| 117549 | 11 | N | 7 | W | 8 | 629 | | | | | 35 | |
| 117550 | 11 | N | 7 | W | 8 | 633 | 1557 | | | | 2 | |
| 117551 | 11 | N | 7 | W | 8 | 614 | | | | | 8 | |
| 117552 | 11 | N | 7 | W | 8 | 638 | | | | | 7 | |
| 117553 | 11 | N | 7 | W | 9 | 648 | 1598 | 1636 | | | | |
| 117556 | 11 | N | 7 | W | 16 | 638 | 1586 | | | | | |
| 117559 | 11 | N | 7 | W | 17 | 638 | 1613 | | | | | |

**Field name:** Cory South

**IGS ID:** 10128

**DOE ID:** 163133

**Location:** Clay County, 10&11N-7W

**Discovery date:** 1973

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,543 ft.)

**Field type:** oil (abandoned)

**Total number production wells:** 5

**Area:** 100 acres

**Cumulative production:** 31,664 bbls. (2002)

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Silurian (1,717 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 20 ft. at top of Muscatatuck.

**Reservoir characteristics:**

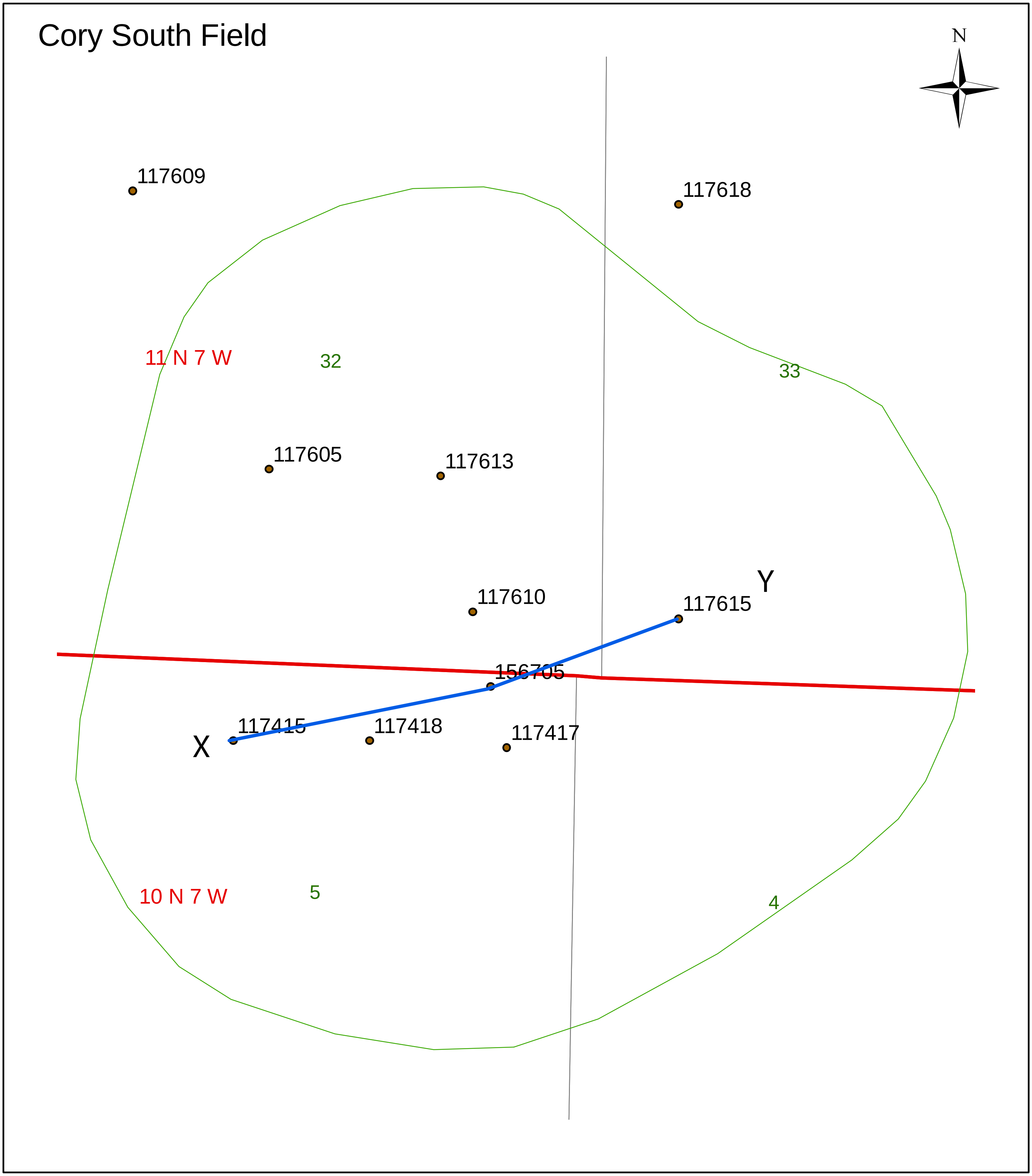



Figure 1: Map showing the location and wells at Cory South Field, Clay County. X-Y is the location of cross section that shows the subsurface Devonian structure in Figure 4.

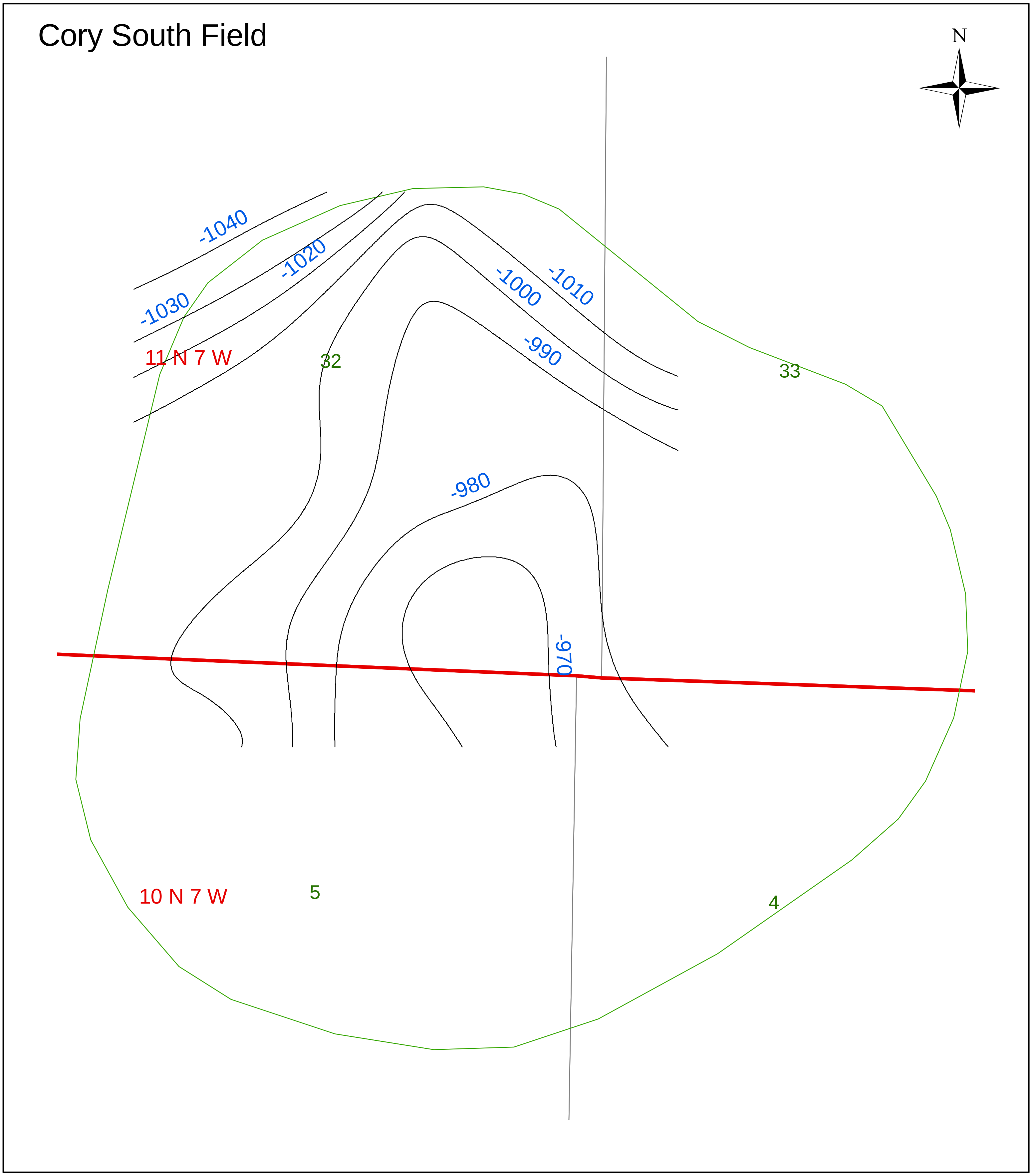



Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in the Cory South Field, Clay County. Contours show values below sea level, contour interval is 10 ft .

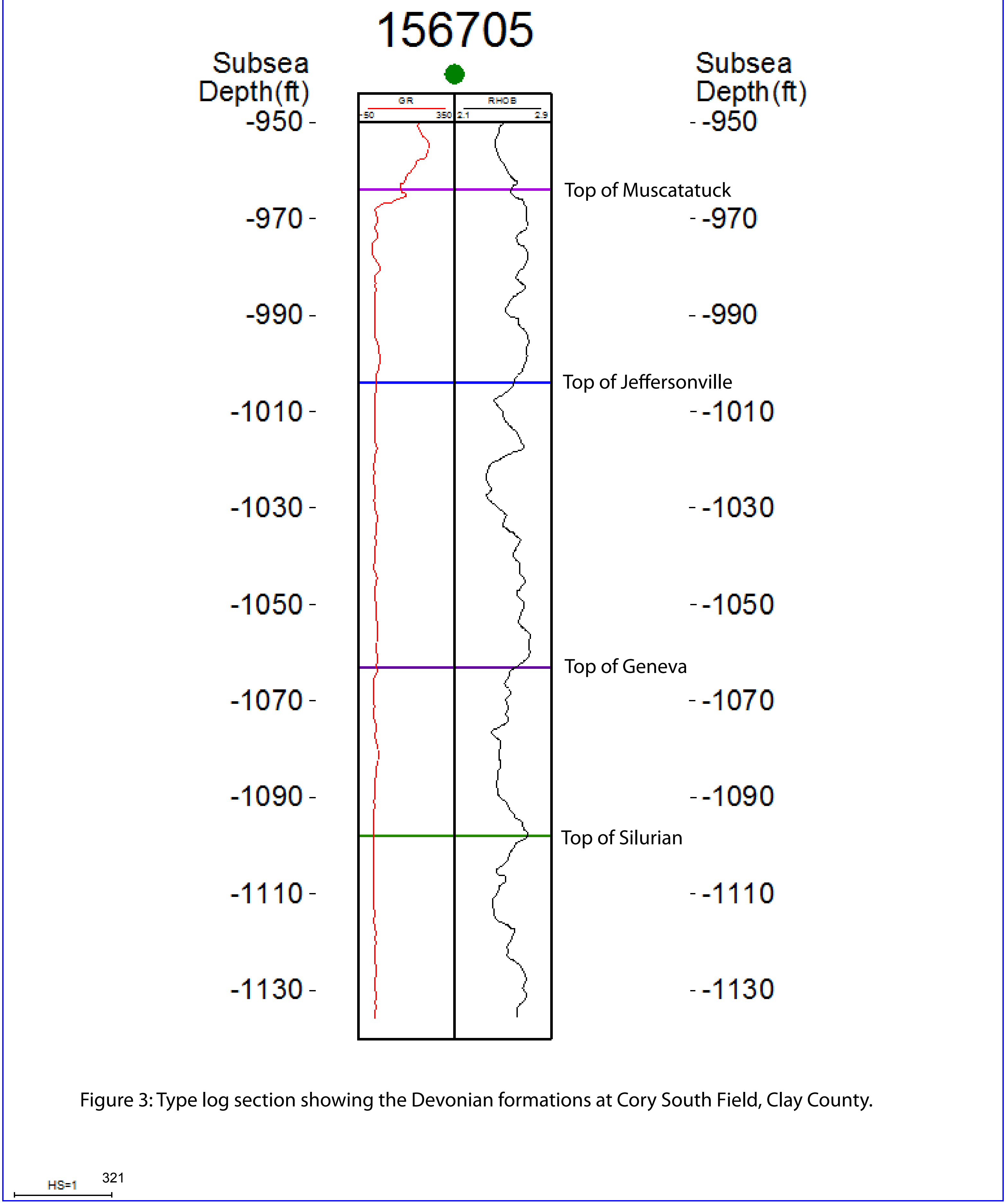



Figure 3: Type log section showing the Devonian formations at Cory South Field, Clay County.

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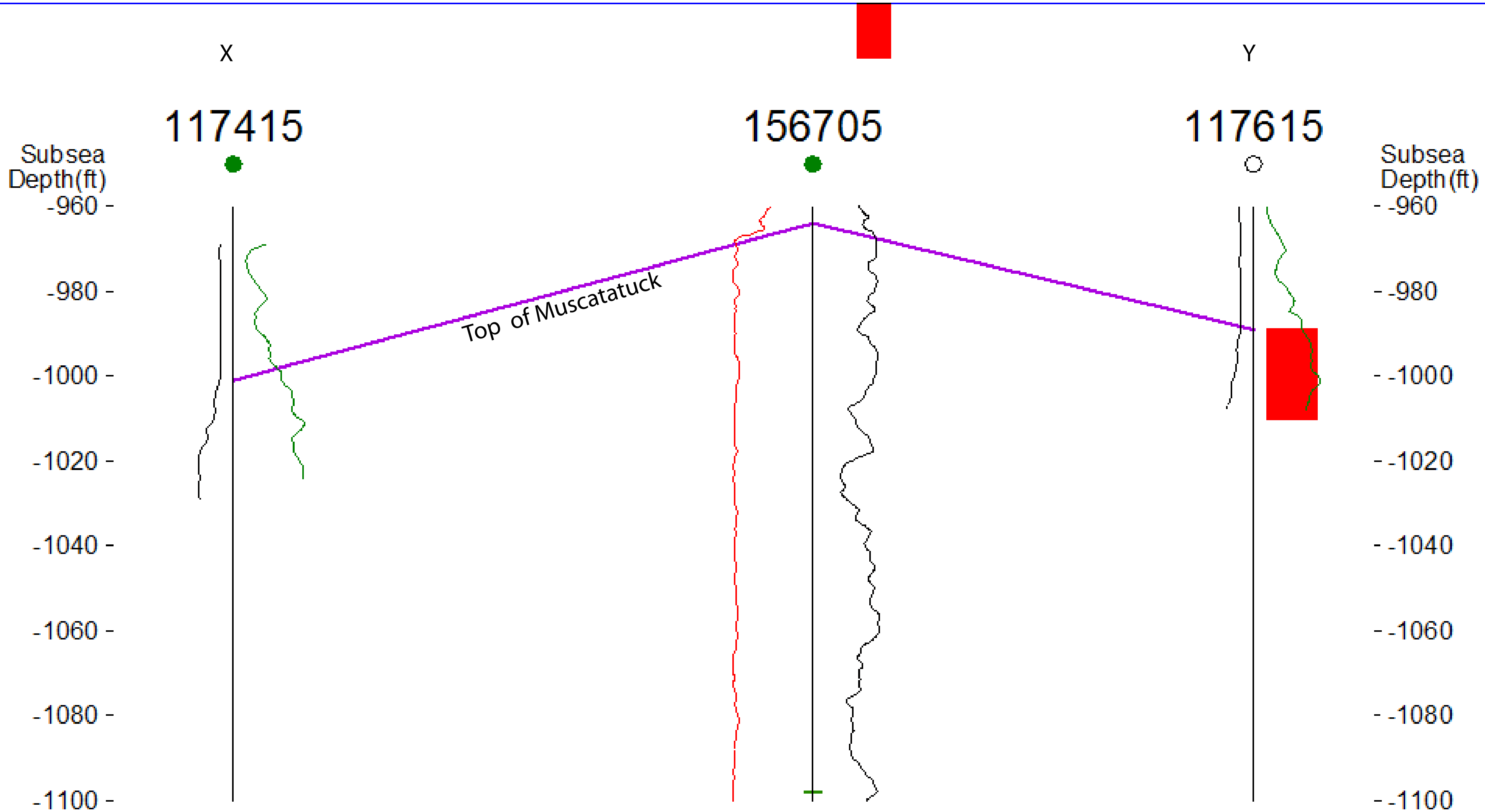


Figure 4: X-Y Cross section showing the Devonian subsurface structure across Cory South Field, Clay County. The red color box shows the completion intervals for the oil production. For location of the cross section refer to Figure 1.

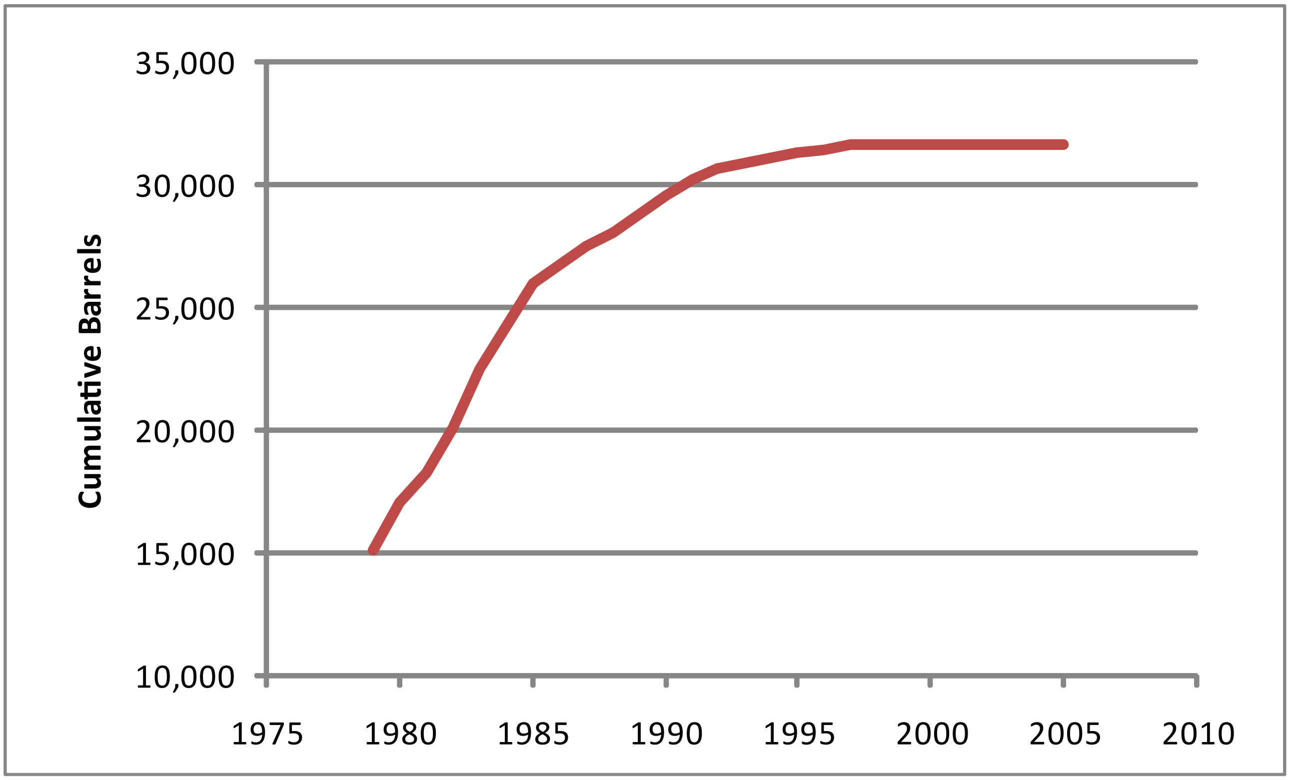


Figure - 5: Cumulative oil production history from Cory South Field, Clay County since 1979.

Table-1: List of the wells used for subsurface structure mapping in the Cory South Field, Clay County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_ D | Rng | Rng_ D | Land_ N | Elevation/ Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 117413 | 10 | N | 7 | W | 4 | 555 | 1590 | | | | | |
| 117415 | 10 | N | 7 | W | 5 | 581 | 1582 | | | | | |
| 117417 | 10 | N | 7 | W | 5 | 586 | 1555 | | | | 35 | |
| 117418 | 10 | N | 7 | W | 5 | 566 | 1541 | | | | 10 | |
| 156705 | 10 | N | 7 | W | 5 | 582 | 1549 | 1586 | 1645 | 1680 | | |
| 117423 | 10 | N | 7 | W | 9 | 571 | 1662 | | | 1839 | | |
| 117602 | 11 | N | 7 | W | 29 | 599 | | | | | | |
| 117605 | 11 | N | 7 | W | 32 | 596 | 1601 | | | | | |
| 117609 | 11 | N | 7 | W | 32 | 609 | 1652 | | | | | |
| 117610 | 11 | N | 7 | W | 32 | 582 | 1544 | | | | 10 | |
| 117613 | 11 | N | 7 | W | 32 | 593 | 1577 | | | | 25 | |
| 117615 | 11 | N | 7 | W | 33 | 592 | 1581 | | | | 2 | |
| 117616 | 11 | N | 7 | W | 33 | 574 | 1604 | | | | | |
| 117617 | 11 | N | 7 | W | 33 | 621 | 1642 | | | | | |
| 117618 | 11 | N | 7 | W | 33 | 596 | 1613 | 1652 | | | | |

**Field name:** Dixon

**IGS ID:** 10803

**DOE ID:** na

**Location:** Greene County, 7N-6W

**Discovery date:** 1965 (gas storage initiated 1966)

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, Jeffersonville Ls. (1,850 ft.)

**Field type:** natural gas & gas storage

**Total number production wells:** 15 storage, 6 observation

**Area:** 362 acres

**Total capacity:** 2,827,500 mcf

**Other reservoir units:** na

**Deepest unit penetrated (depth):** Silurian (1,780 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 100 ft. at top of Muscatatuck.

**Reservoir characteristics:**

Average porosity – 16 %

Average permeability – 35 md

Approximate reservoir thickness: 43 ft.

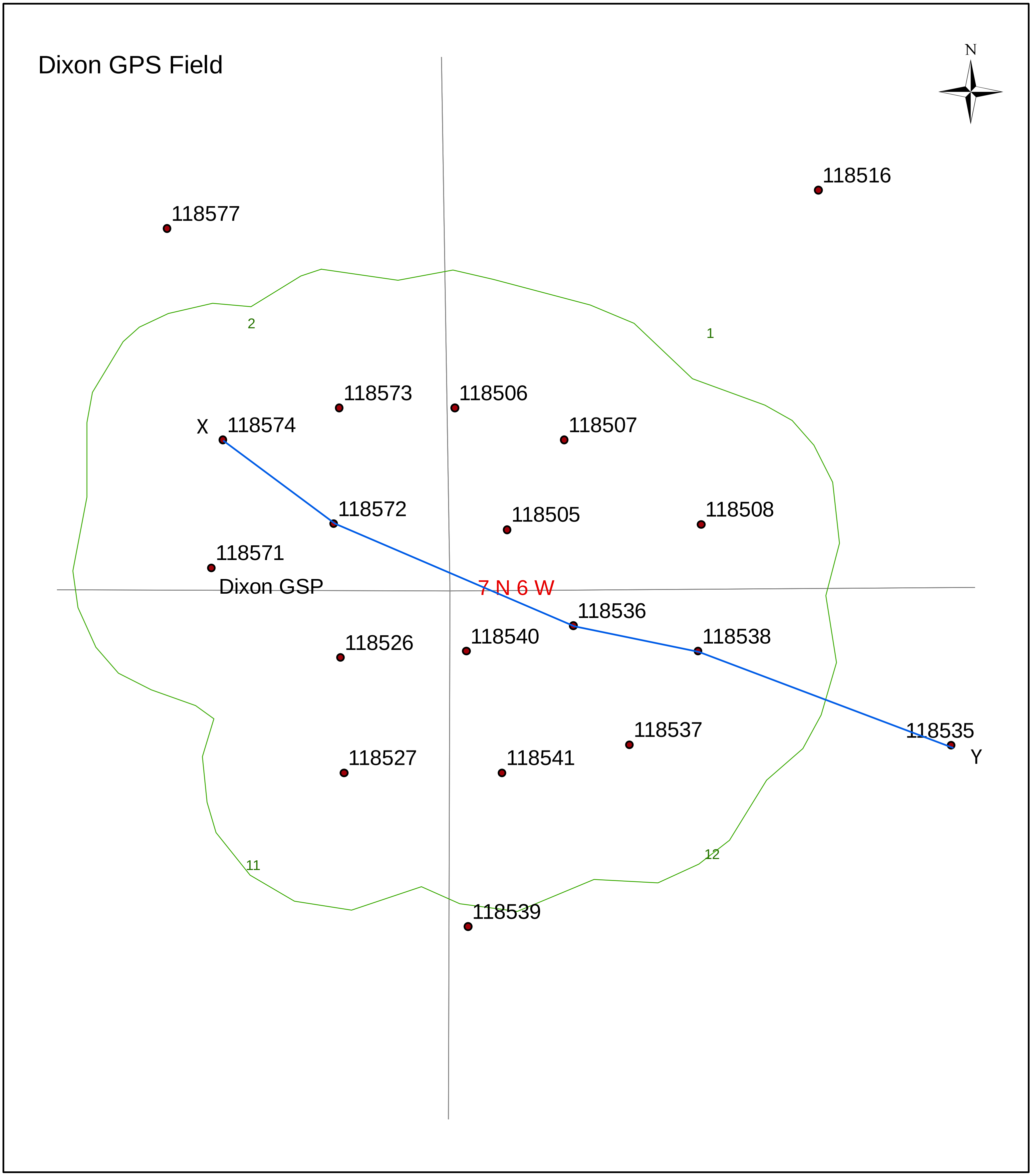


Figure 1: Map showing the location and wells at Dixon GSP Field, Greene County. X-Y is the location of the cross sections that shows the subsurface devonian structure (Fig. 11). The wells depicted were used for subsurface maping and had a total depth (TD) of Devonian or deeper.

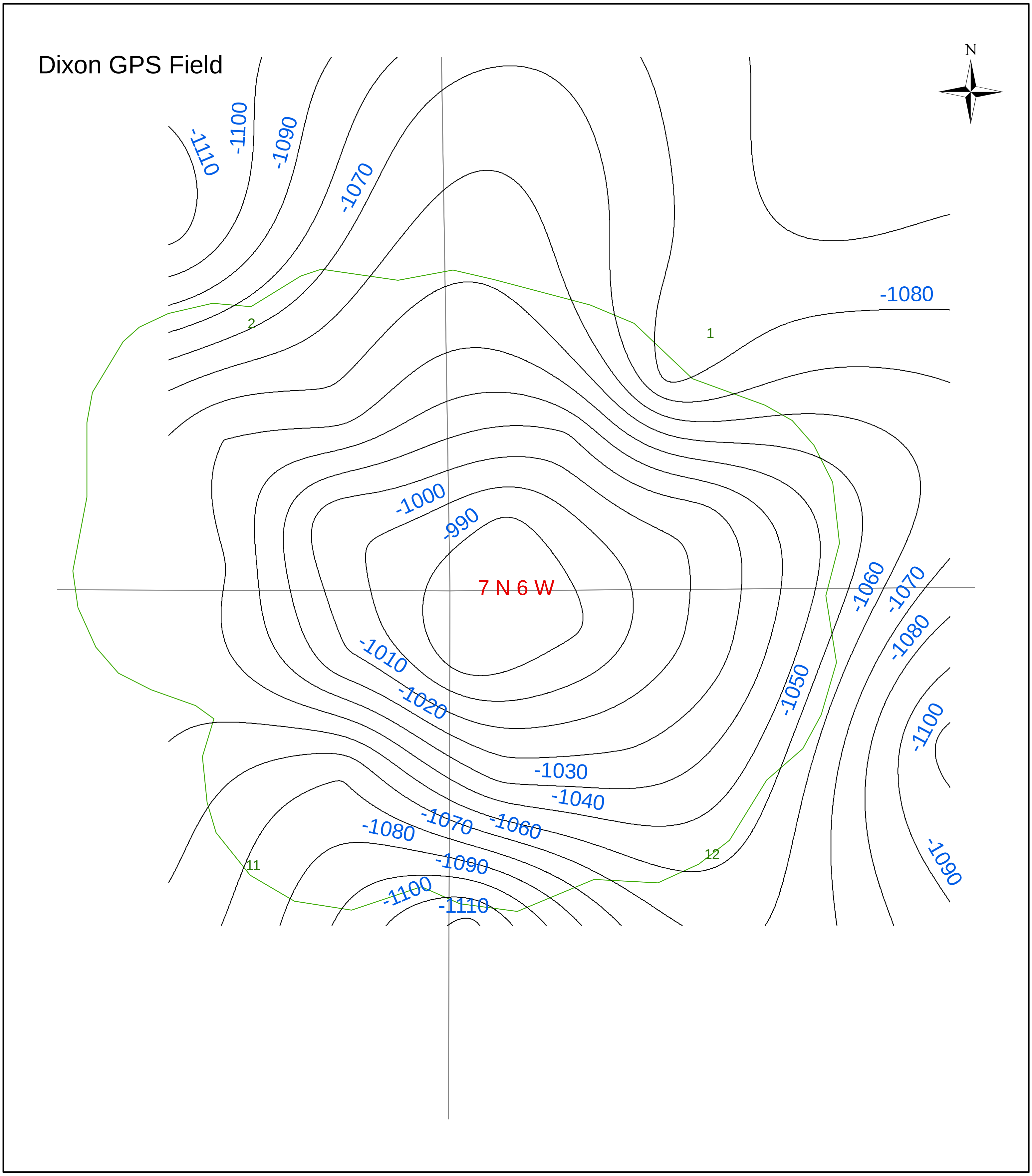


Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Dixon GSP Field, Greene County. Contours show values below sea level, contour interval is 10 ft .

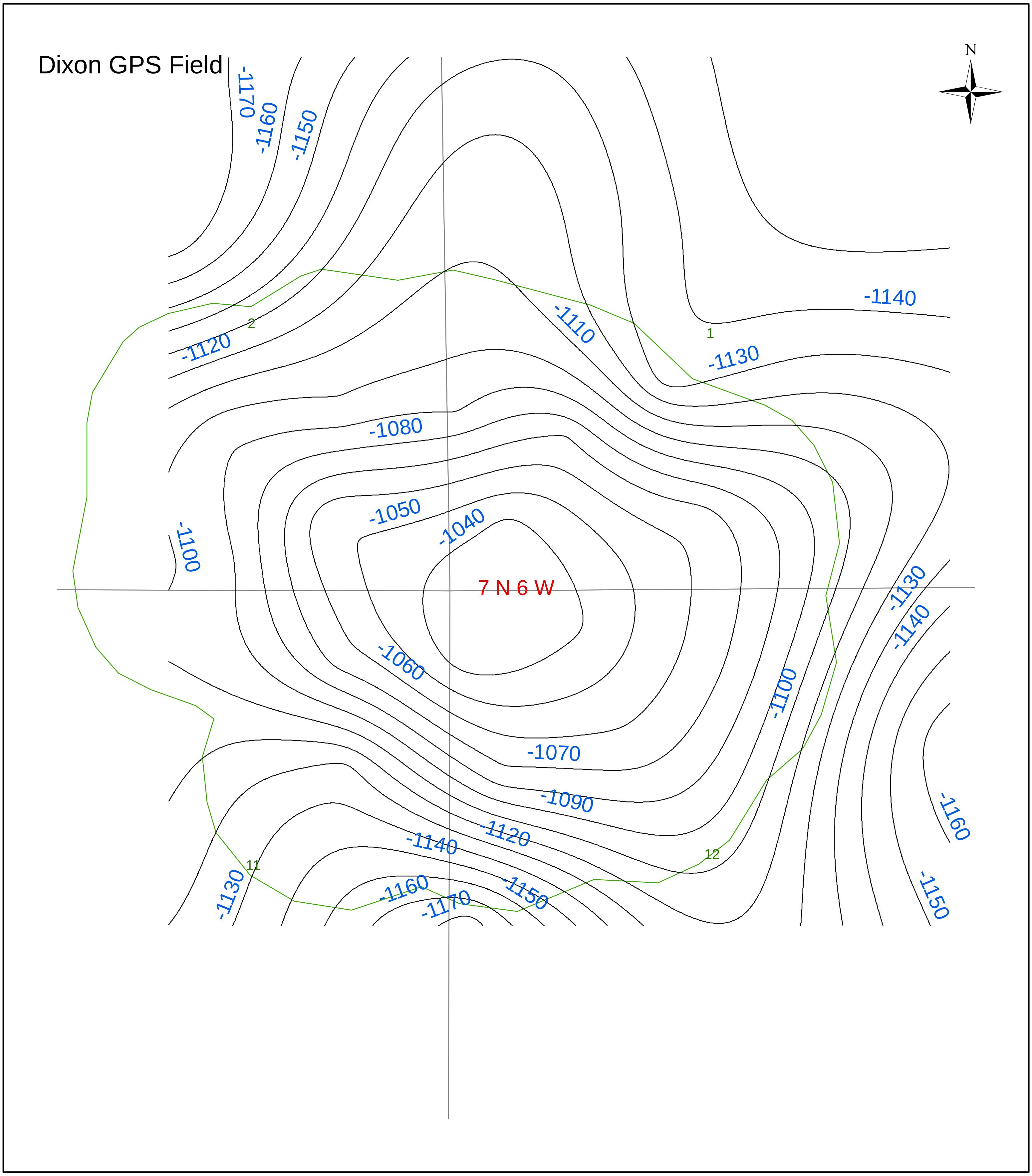


Figure 3: Structure map showing the top of subsurface Jeffersonville Limestone in Dixon GSP Field, Greene County. Contours show values below sea level, contour interval is 10 ft .

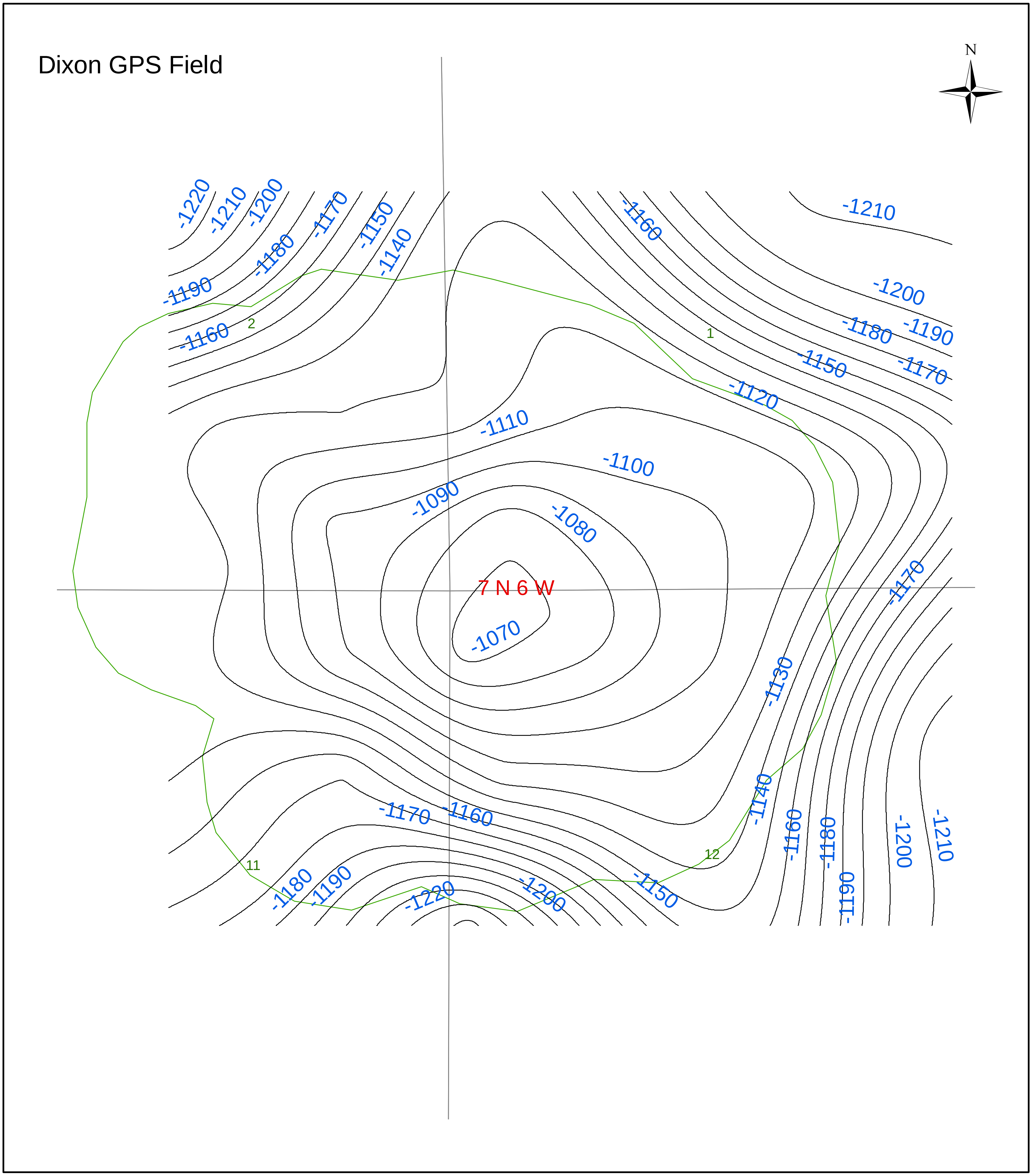


Figure 4: Structure map showing the top of the subsurface Geneva Dolomite Mbr. in Dixon GSP Field, Greene County. Contours show values below sea level, contour interval is 10 ft .

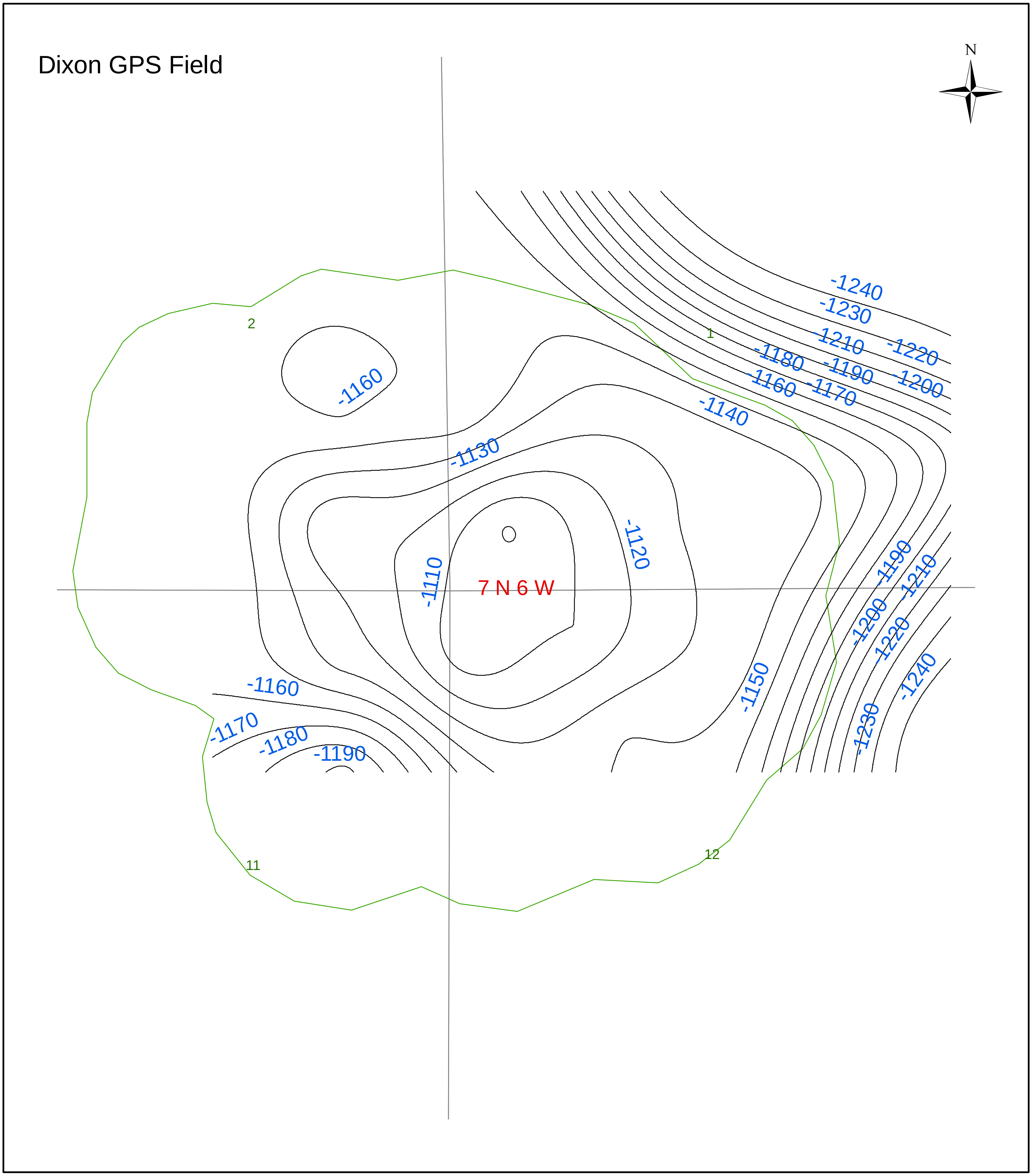


Figure 5: Structure map showing the top of the subsurface Silurian formation in Dixon GSP Field, Greene County. Contours show values below sea level, contour interval is 10 ft .


Figure 6: Map showing isopach of the North Vernon Limestone at Dixon GSP Field, Greene County. Contour interval is 4 ft.

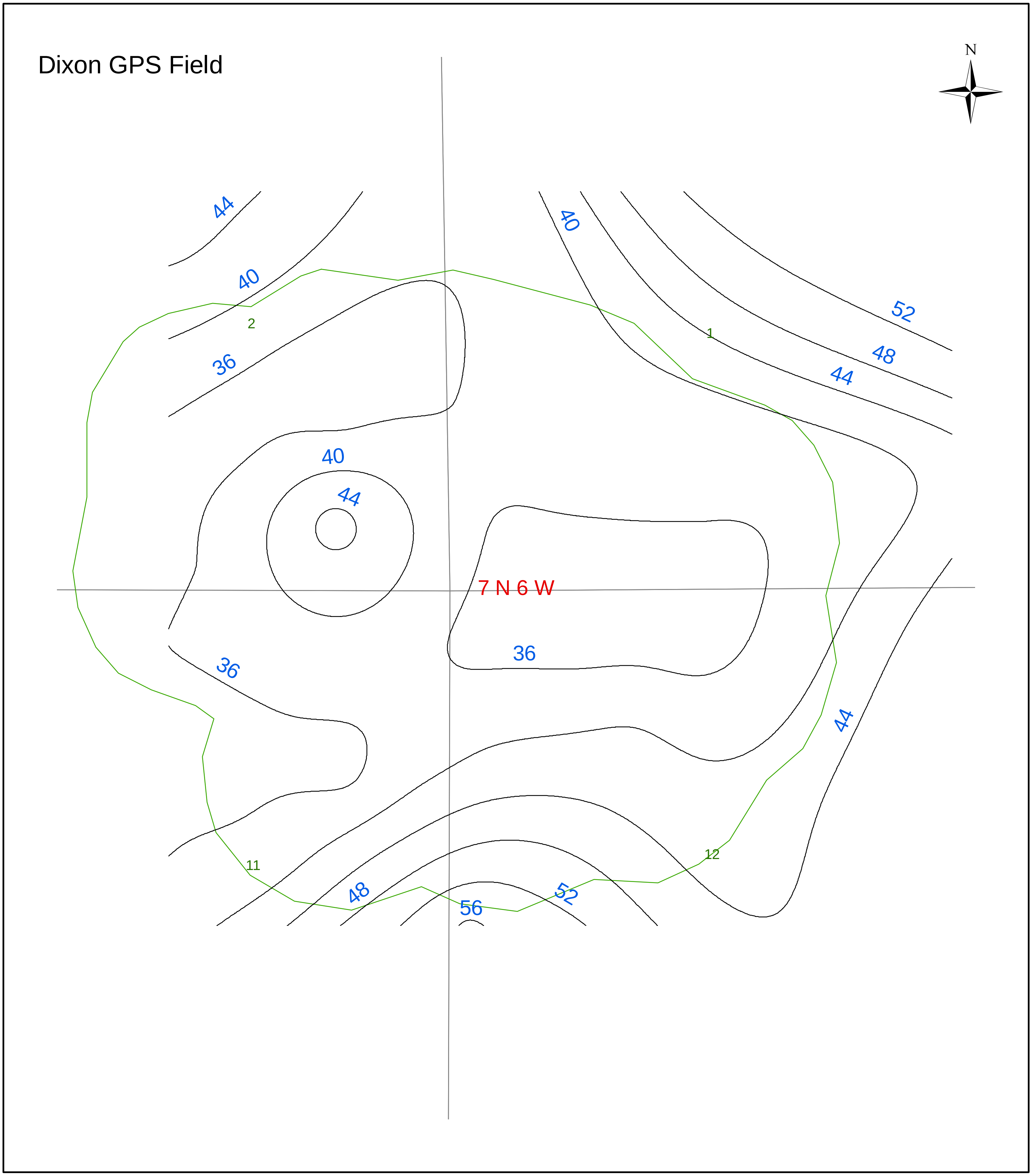


Figure 7: Map showing isopach of the Vernon Fork Member from Dixon GSP Field, Greene County. Contour interval is 4 ft.

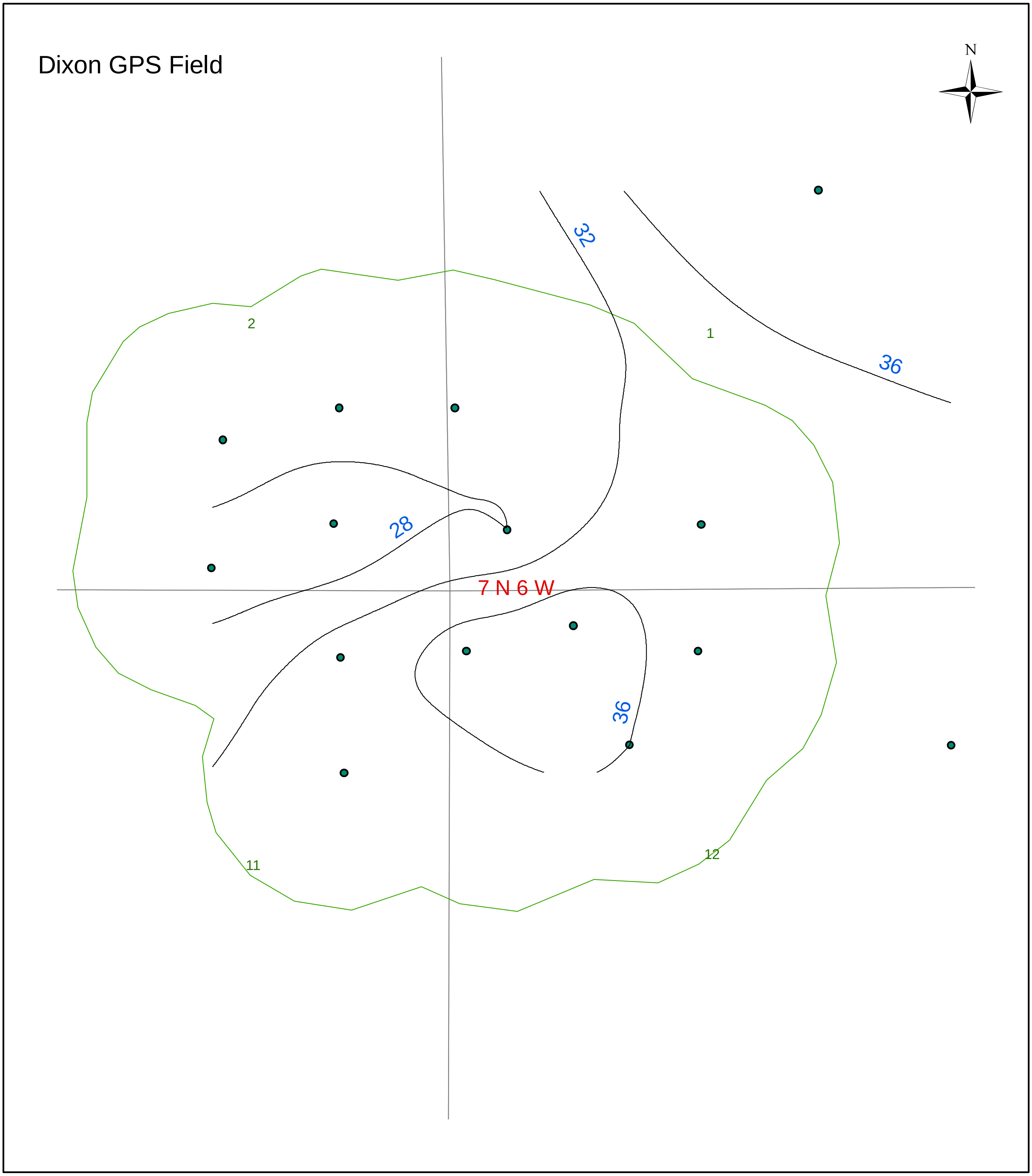


Figure 8: Map showing isopach of the Geneva Dolomite Member in Dixon GSP Field, Greene County. Contour interval is 4 ft.

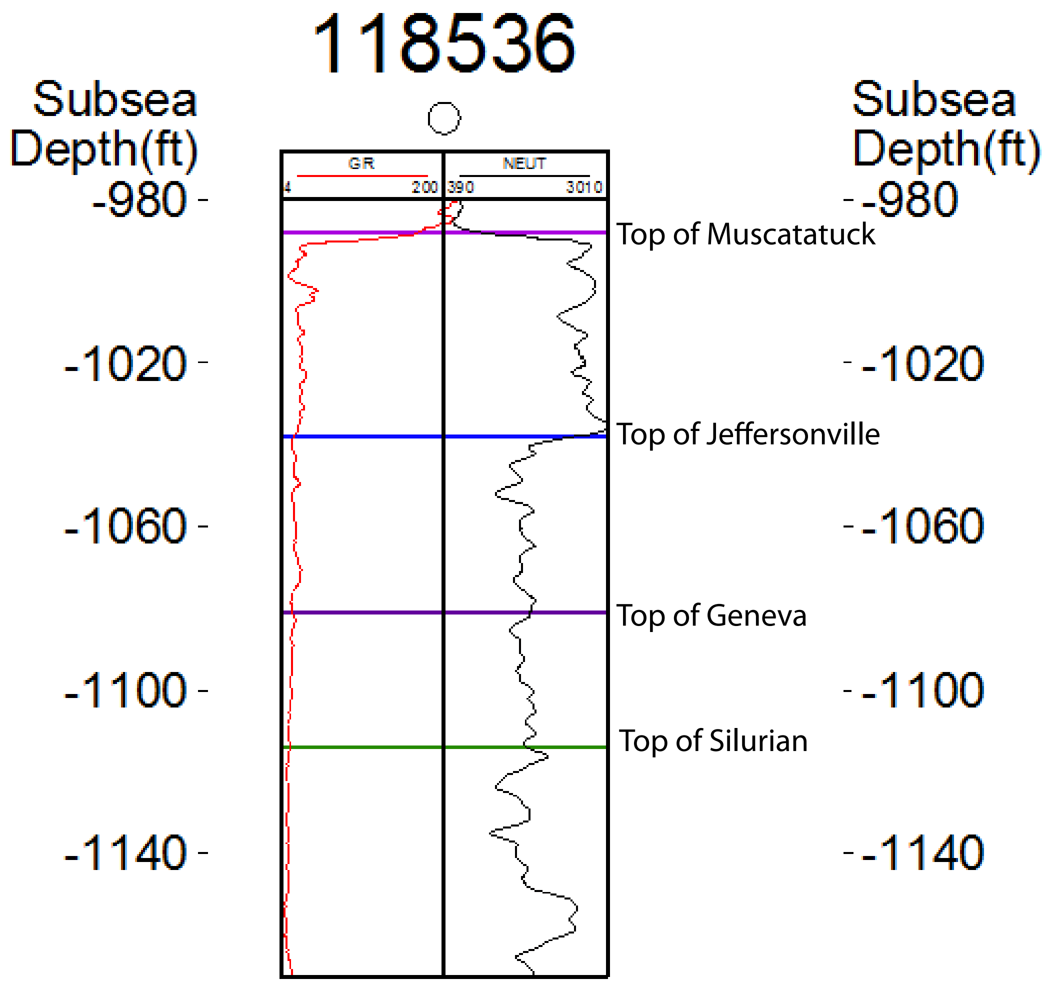


Figure 9: Type log section showing the Devonian formations at Dixon GSPField, Greene County.

HS=1 334

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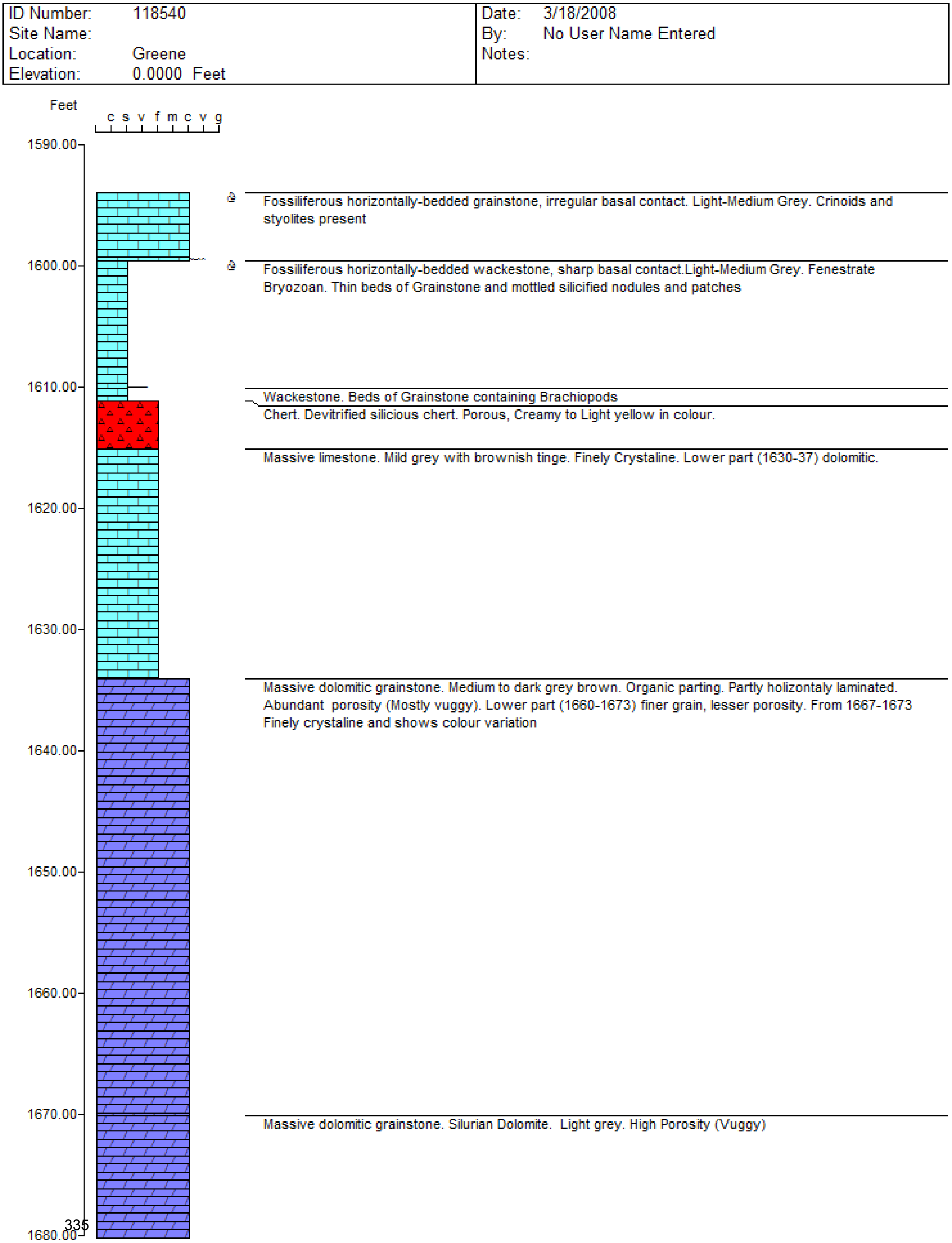
Figure 10: Core description and the litholog of IGS well ID 118540, Dixon GSP Field, Greene County.



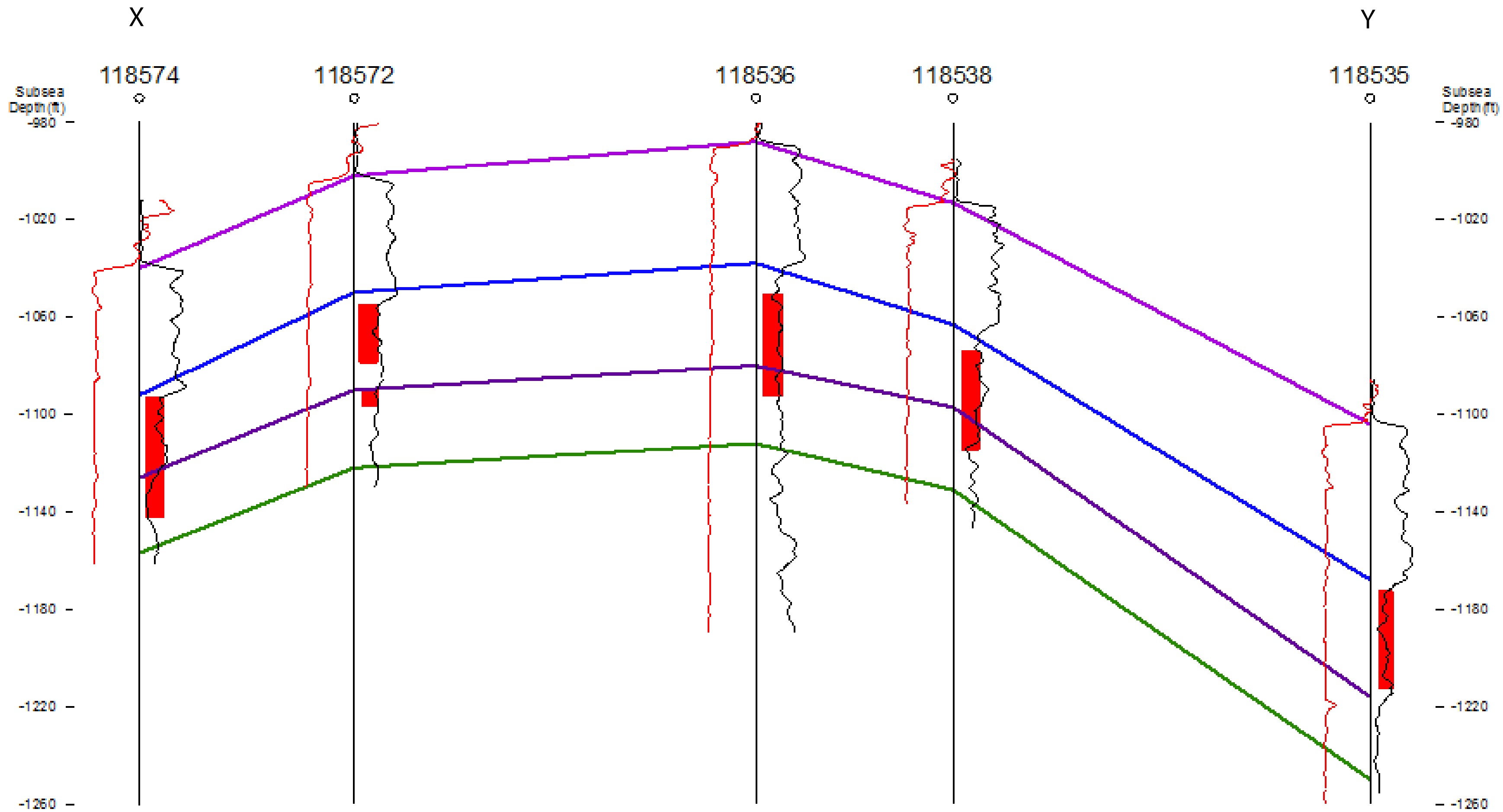



Figure 11: X-Y Cross section showing the Devonian subsurface structure across Dixon GSP Field, Greene County. The red color box shows the completion intervals for the gas storage, production or observation. For location of the cross section refer to Figure 1.



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Table-1: List of the wells used for subsurface structure mapping in Dixon GSP Field, Greene County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Core |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 118505 | 7 | N | 6 | W | 1 | 591 | 1577 | 1627 | 1662 | 1690 | |
| 118506 | 7 | N | 6 | W | 1 | 602 | 1630 | 1694 | 1730 | 1760 | |
| 118507 | 7 | N | 6 | W | 1 | 583 | 1600 | 1651 | 1690 | | |
| 118508 | 7 | N | 6 | W | 1 | 609 | 1622 | 1672 | 1708 | 1741 | |
| 118509 | 7 | N | 6 | W | 1 | 566 | 1650 | 1703 | | | |
| 118516 | 7 | N | 6 | W | 1 | 551 | 1646 | 1708 | 1762 | 1800 | |
| 118571 | 7 | N | 6 | W | 2 | 566 | 1610 | 1664 | 1700 | 1726 | |
| 118572 | 7 | N | 6 | W | 2 | 570 | 1572 | 1620 | 1668 | 1692 | |
| 118573 | 7 | N | 6 | W | 2 | 600 | 1647 | 1698 | 1731 | 1762 | |
| 118574 | 7 | N | 6 | W | 2 | 588 | 1628 | 1680 | 1714 | 1745 | |
| 118576 | 7 | N | 6 | W | 2 | 610 | 1720 | 1787 | | | |
| 118577 | 7 | N | 6 | W | 2 | 580 | 1695 | 1760 | 1806 | | |
| 118526 | 7 | N | 6 | W | 11 | 554 | 1566 | 1618 | 1656 | 1690 | |
| 118527 | 7 | N | 6 | W | 11 | 541 | 1610 | 1666 | 1700 | 1734 | |
| 118535 | 7 | N | 6 | W | 12 | 514 | 1618 | 1682 | 1730 | 1764 | |
| 118536 | 7 | N | 6 | W | 12 | 560 | 1548 | 1598 | 1631 | 1670 | |
| 118537 | 7 | N | 6 | W | 12 | 537 | 1556 | 1600 | 1642 | 1678 | |
| 118538 | 7 | N | 6 | W | 12 | 575 | 1588 | 1638 | 1672 | 1706 | |
| 118539 | 7 | N | 6 | W | 12 | 520 | 1634 | 1696 | 1754 | | Present |
| 118540 | 7 | N | 6 | W | 12 | 569 | 1549 | 1600 | 1635 | 1673 | |
| 118541 | 7 | N | 6 | W | 12 | 536 | 1561 | 1608 | 1650 | | |

Figure 1: Photo of the core ID 317, IGS ID # 118540 from Dixon GSP Field, Greene County.

Figure 12: Continued....



Figure 12: Continued....



1618 ft

Figure 12: Continued....



1628 ft


1639 ft

1639 ft




1649 ft

Figure 12: Continued....



1650 ft


1657 ft

Figure 12: Continued....

1650 ft

7




1657 ft

Figure 12: Continued....

1668 ft




1681 ft

Figure 12: Continued....



1684 ft 1686 ft 1690 ft 1692 ft




1682 ft 1684 ft 1687 ft 1690 ft


1695 ft
1697 ft
INDIANA
GEOLOGICAL
SURVEY
1695 ft
1692 ft

**Field name:** Dodds Bridge

**IGS ID:** 10159

**DOE ID:** 194507

**Location:** Sullivan County, 8&9N-10W

**Discovery date:** c.1913 (oil), c.1915 (natural gas)

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, Jeffersonville Ls. (2,265 ft.)

**Field type:** oil & natural gas

**Total number production wells:** 126 oil, 3 natural gas

**Area:** 960 acres

**Cumulative production:** 2,554,506 bbls. (2002)

**Other reservoir units:**

Pennsylvanian

Mississippian, Sanders Group, Salem Ls.

**Deepest unit penetrated (depth):** Silurian (2,600 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 20 ft. at top of Muscatatuck.

**Reservoir characteristics:**

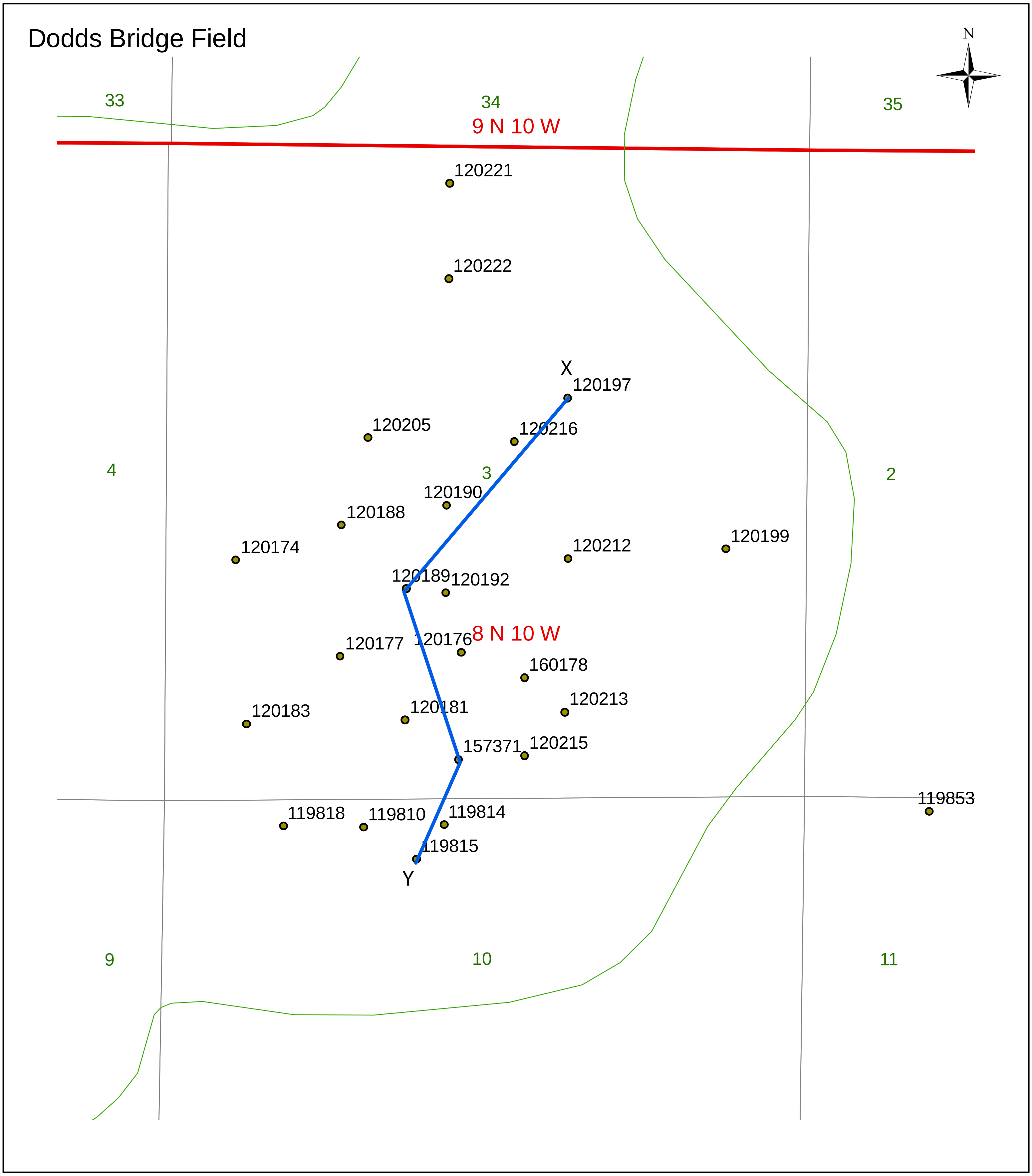


Figure 1: Map showing the location and wells at Dodds Bridge Field, Sullivan County. X-Y is the location of the cross section that shows the subsurface Devonian structure (Fig. 9).

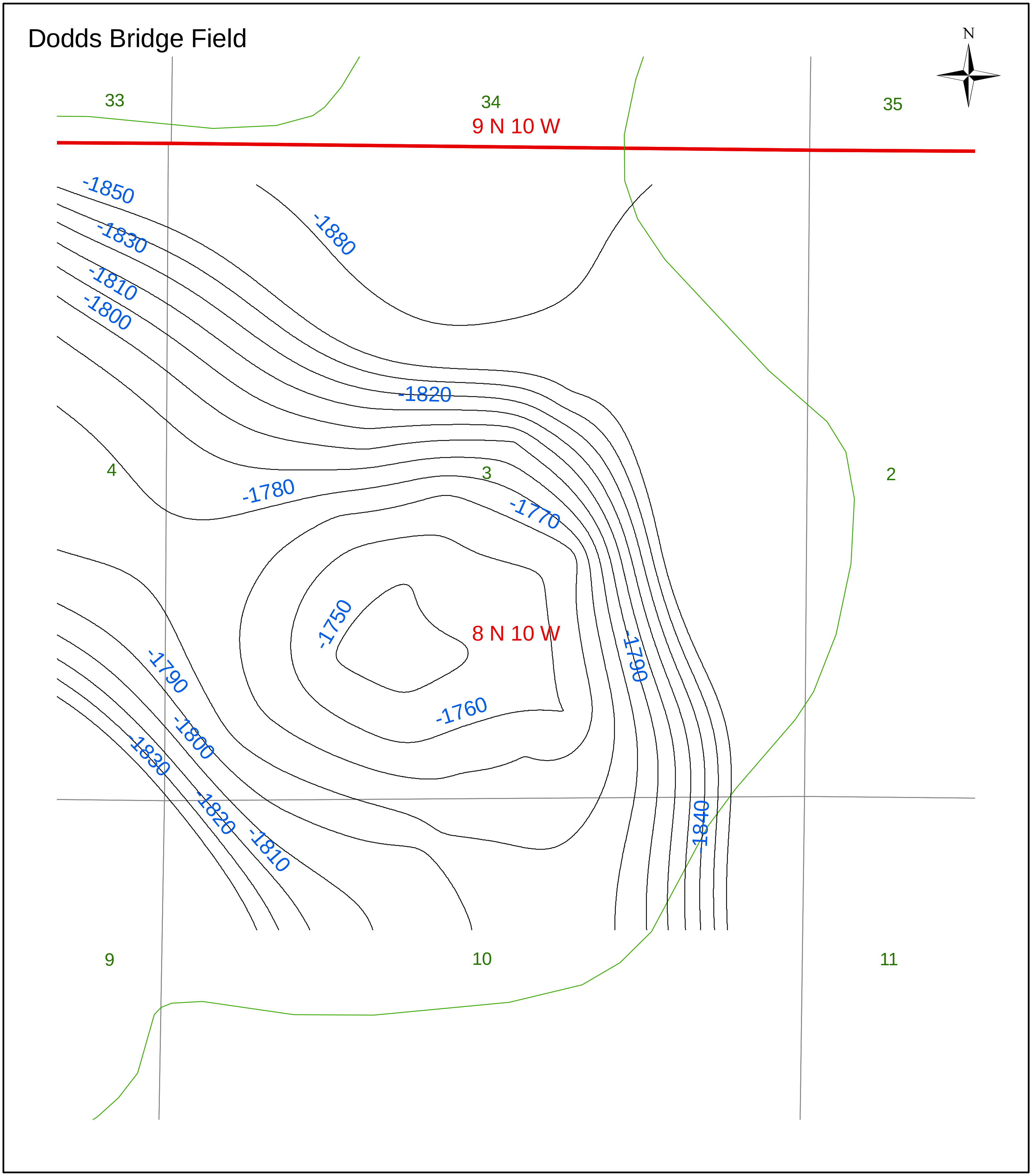


Figure 2: Structure map showing the top of subsurface Muscatatuck Limestone in Dodds Bridge Field, Sullivan County. Contours show values below sea level, contour interval is 10 ft .

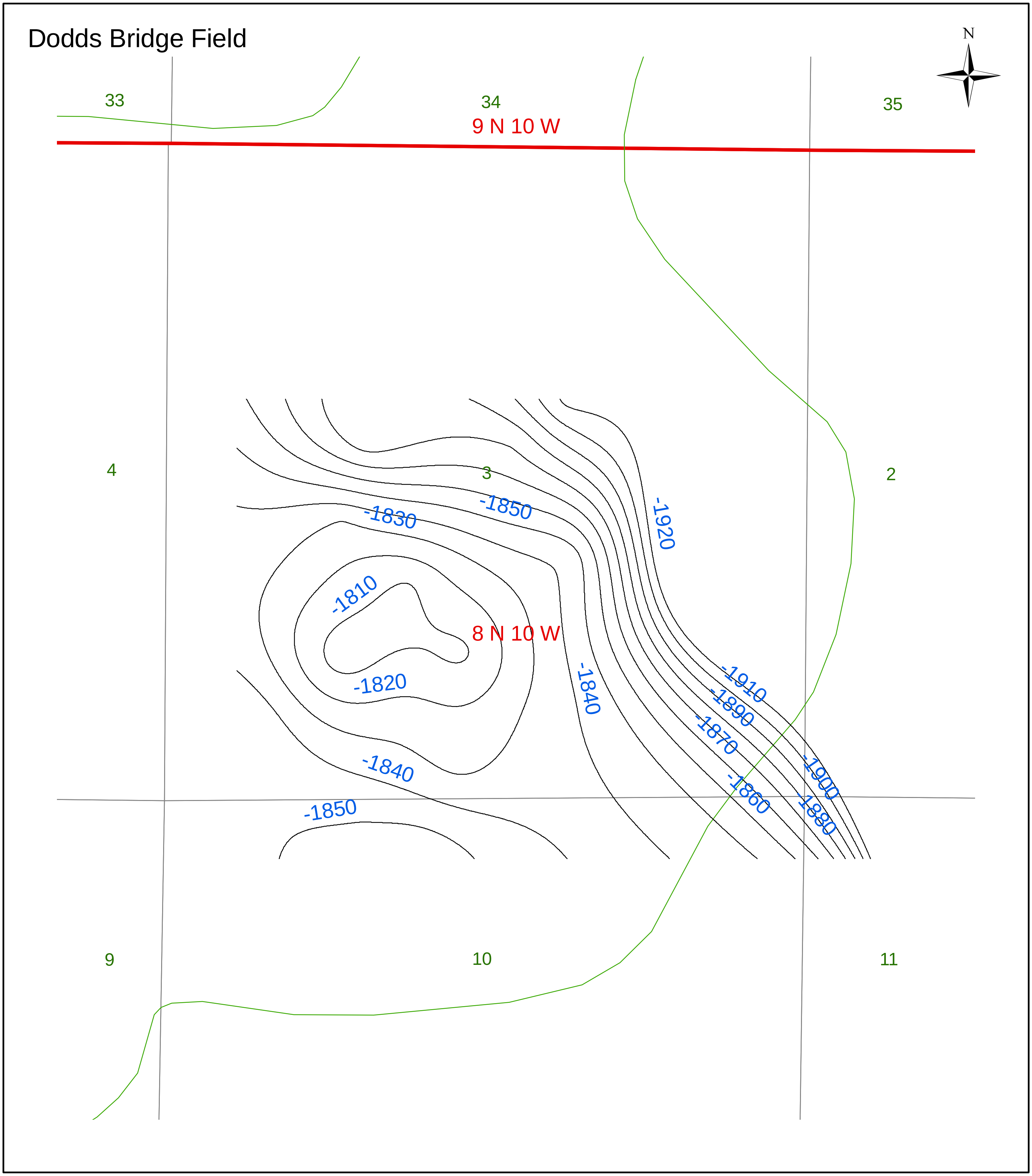


Figure 3: Structure map showing the top of subsurface Jeffersonville Limestone in Dodds Bridge Field, Sullivan County. Contours show values below sea level, contour interval is 10 ft .

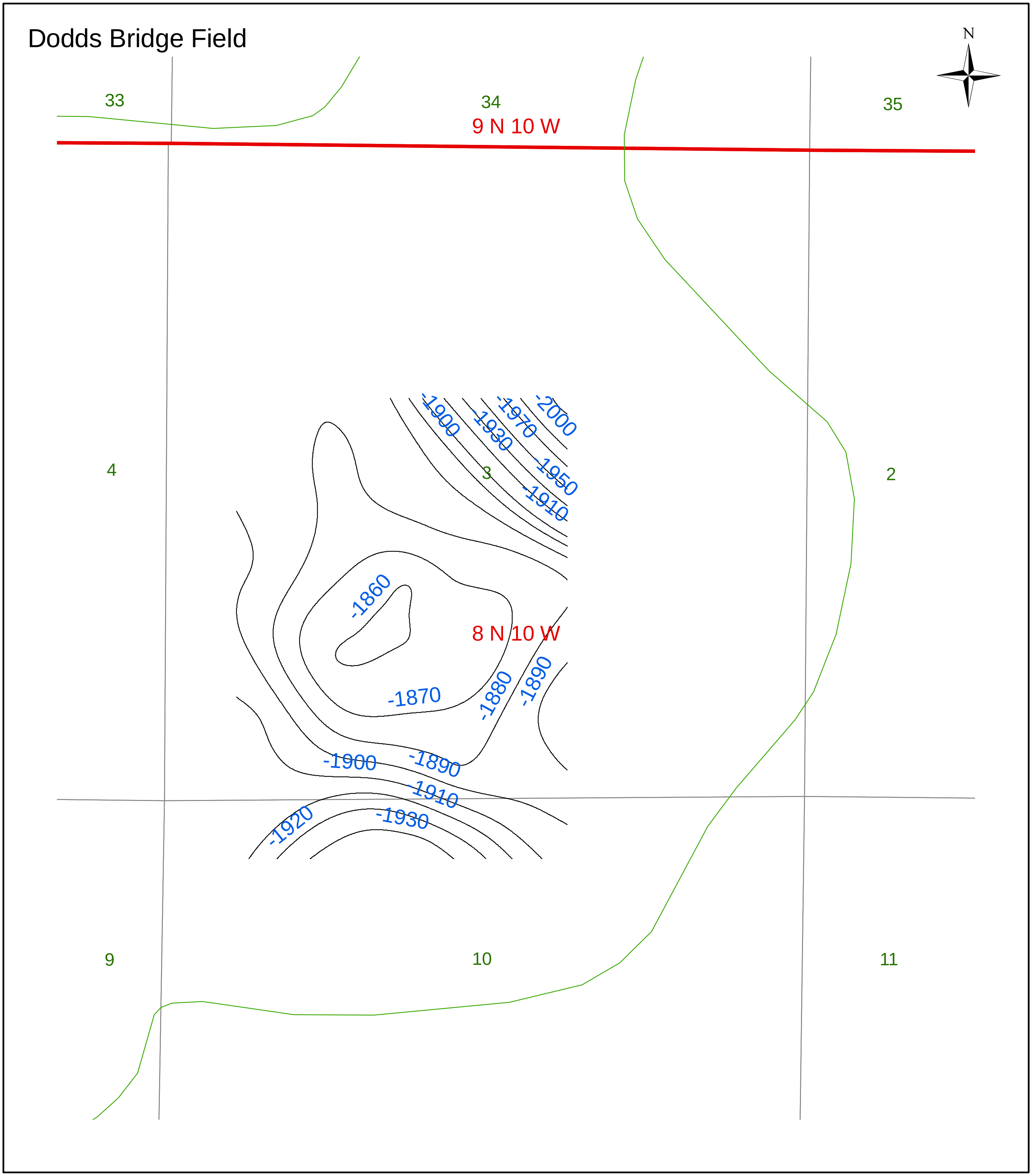


Figure 4: Structure map showing the top of the subsurface Geneva Dolomite Mbr. in Dodds Bridge Field, Sullivan County. Contours show values below sea level, contour interval is 10 ft .

Dodds Bridge Field

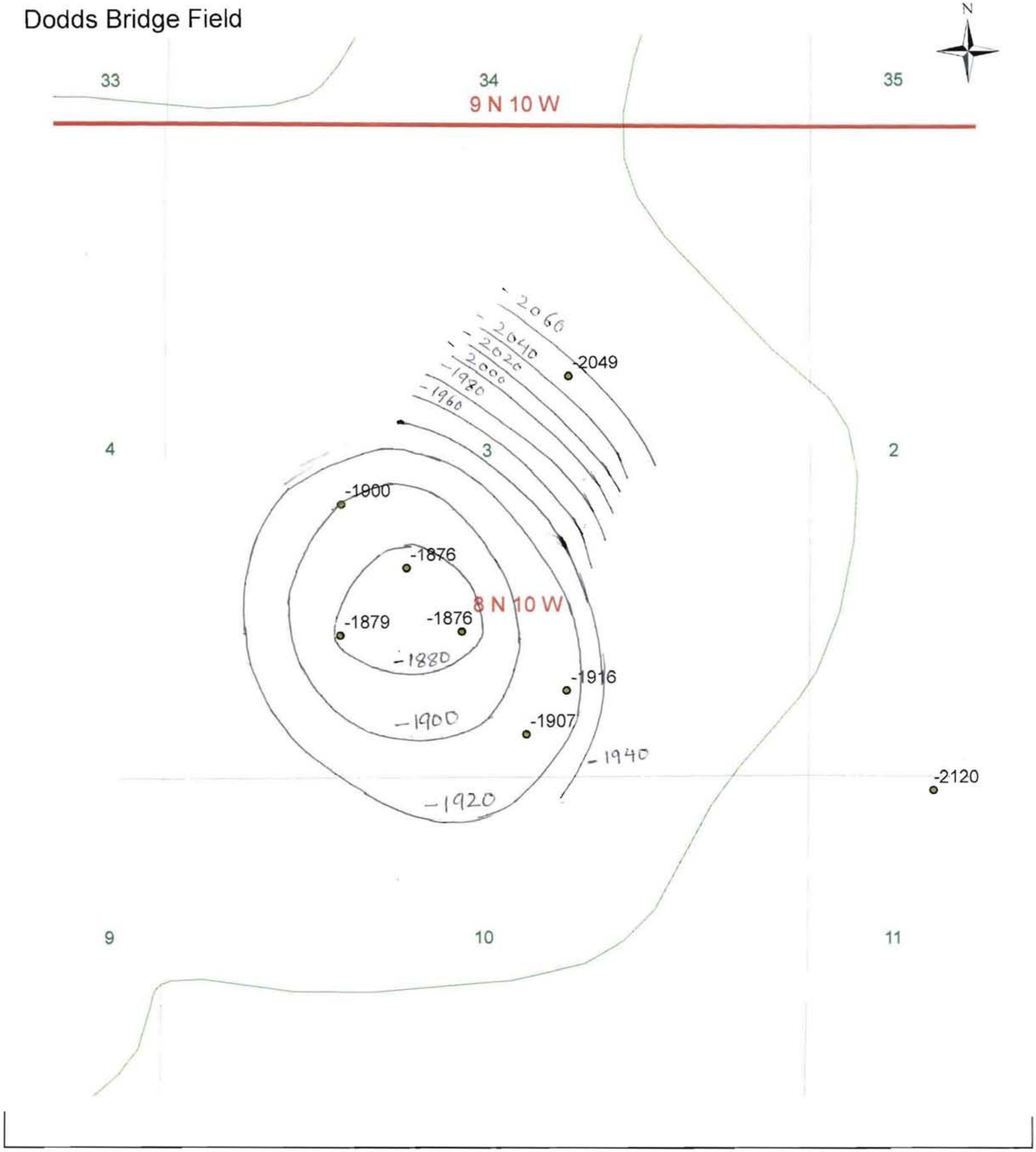


Figure 5: Structure map showing the top of the subsurface Silurian formation in Dodds Bridge Field, Sullivan County. Contours show values below sea level, contour interval is 20 ft .

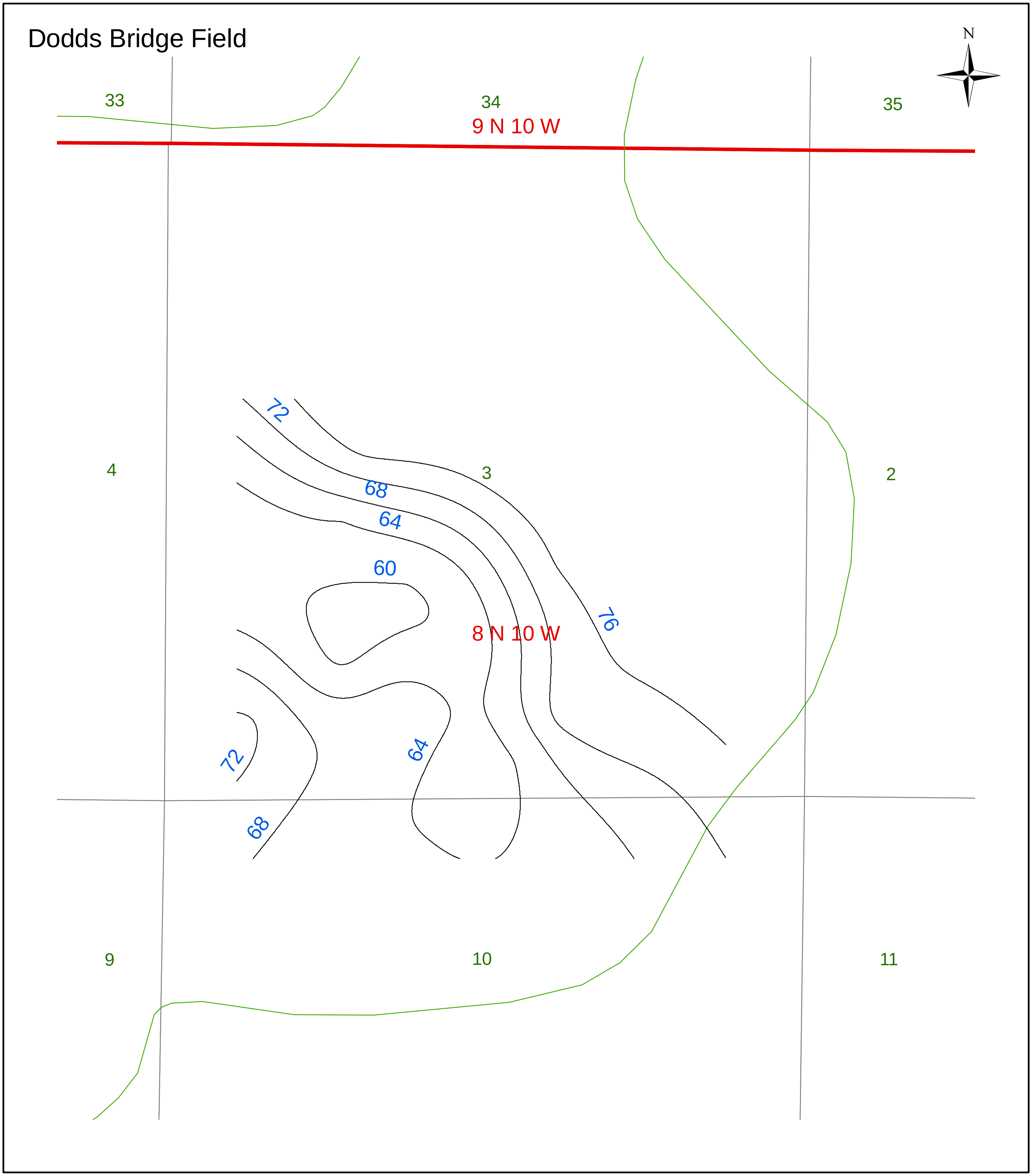


Figure 6: Isopach map showing the thickness of the North Vernon Limestone at Dodds Bridge Field, Sullivan County. Contour interval is 4 ft.

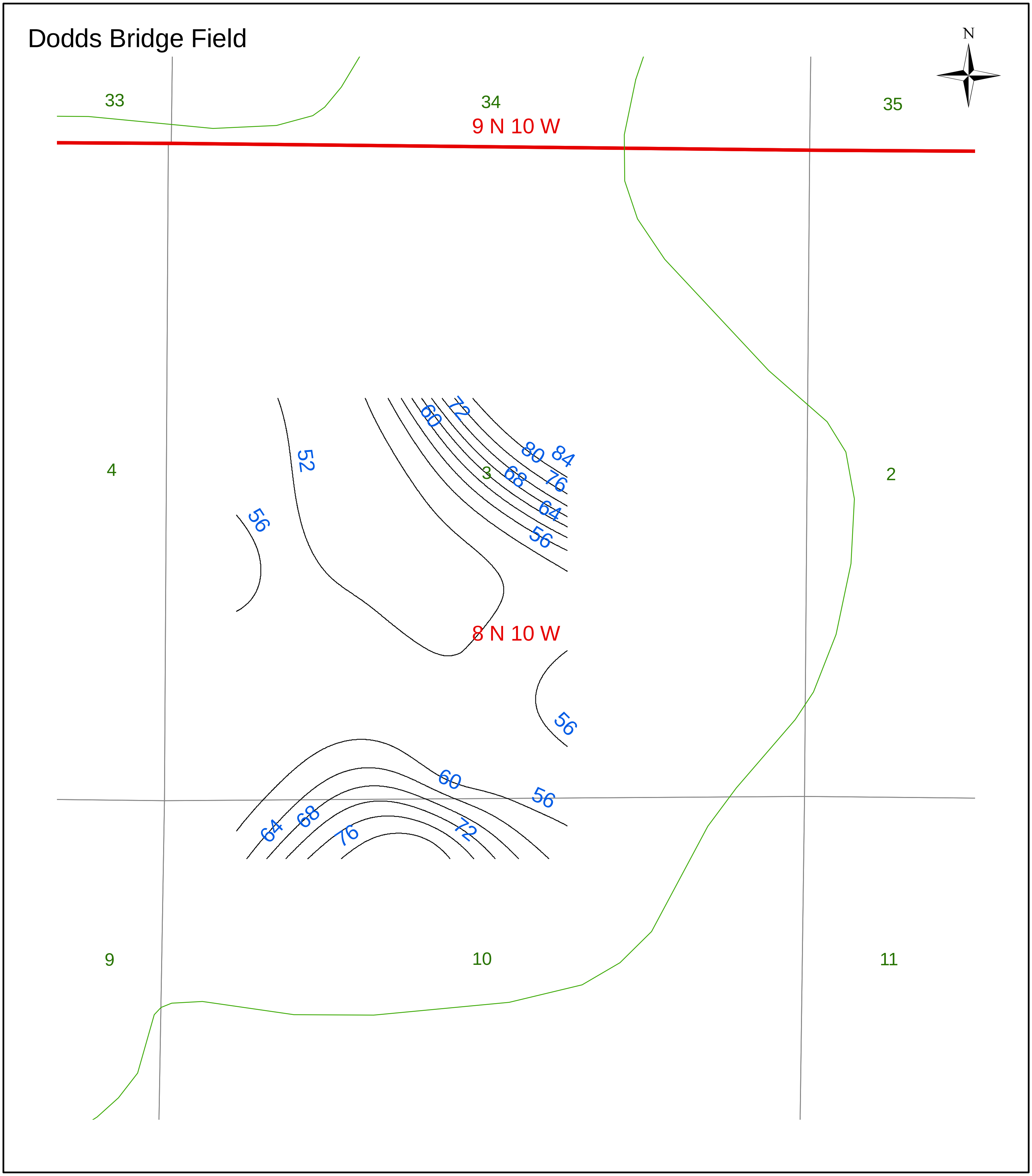


Figure 7: Isopach map showing the thickness of the Vernon Fork Member at Dodds Bridge Field, Sullivan County. Contour interval is 4 ft.

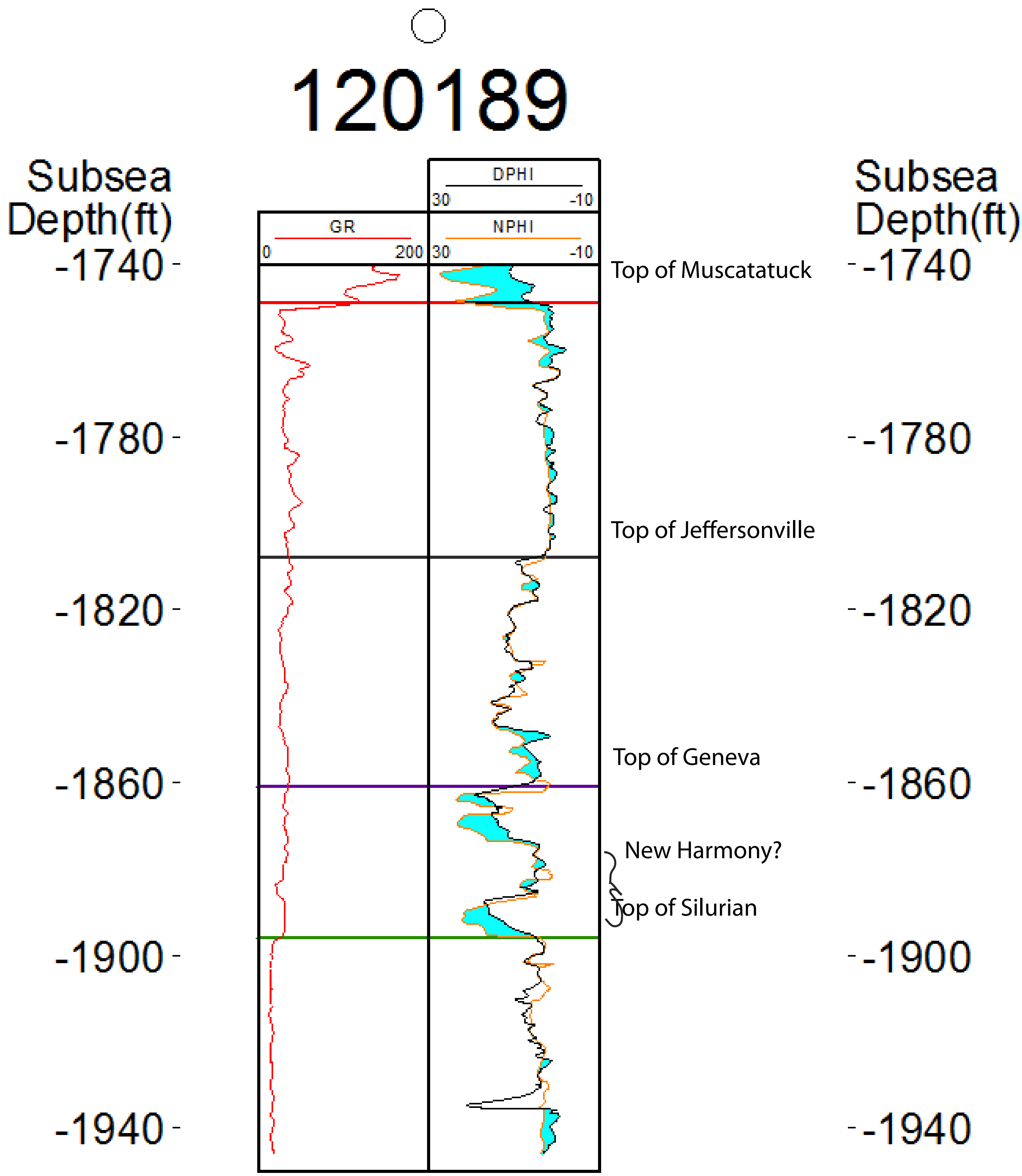


Figure 8: Type log section showing the Devonian formations at Dodds Bridge Field, Sullivan County.



HS=1

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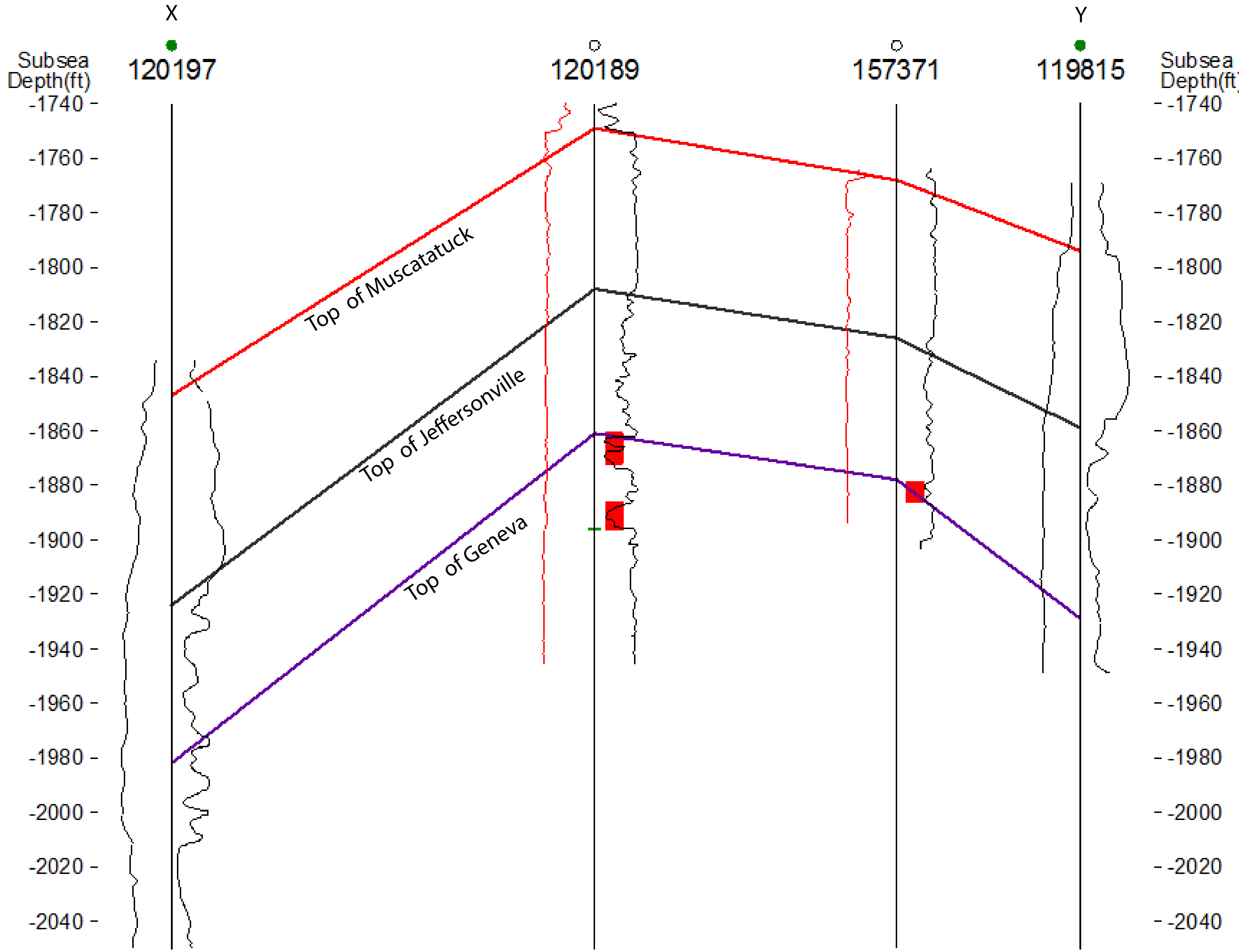



Figure 9: X-Y Cross section showing the Devonian subsurface structure acorss Dodds Bridge Field, Sullivan County. The red color box shows the completion intervals for the oil production. For location of the cross section refer to Figure 1.

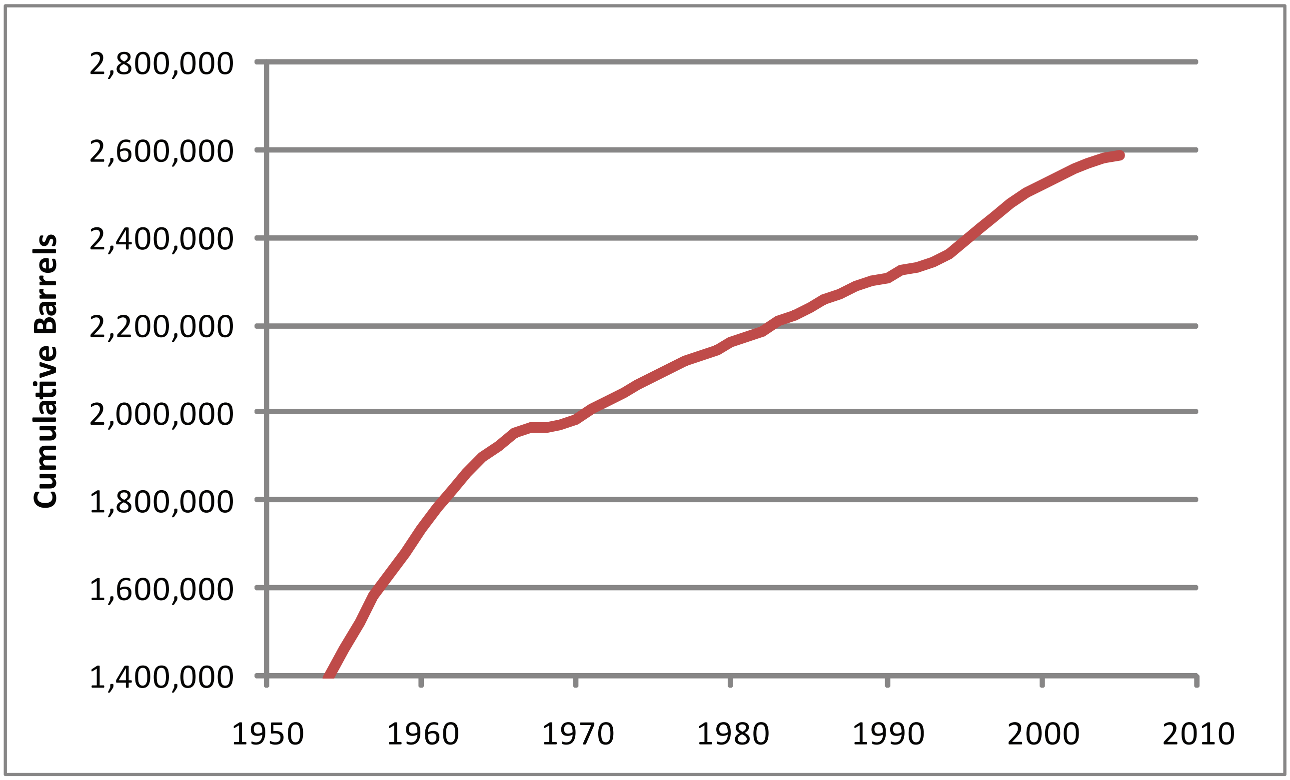
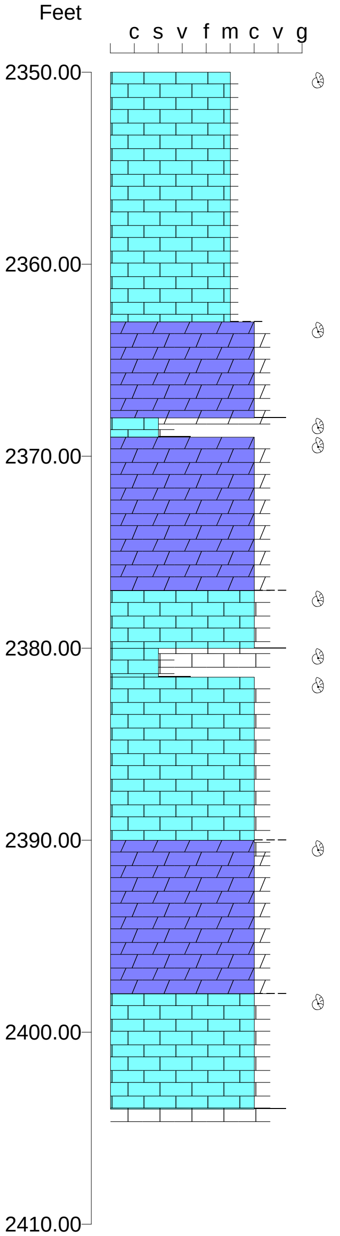



Figure - 10: Cumulative oil production history for Dodds Bridge Field, Sullivan County since 1954.

| | | | |
|---|---|---|---|
| ID Number: | 120189 | Date: | 5/1/2008 |
| Site Name: | | By: | |
| Location: | Dodds Bridge | Notes: | |
| Elevation: | 0.0000 Feet | | |




Fossiliferous massive packstone, gradational basal contact.Light Grey to brown. Organic laminations.stromatoporoid present in lower part near the contact

Fossiliferous massive dolomitic grainstone, sharp basal contact. Brown to buff color. Rugos and Horn coral present

Fossiliferous cryptalgal laminated wackestone, sharp basal contact.Grey-Black. stromatoporoid fossil present with others

Fossiliferous massive dolomitic grainstone, gradational basal contact. Brown to Buff color.Finger, Stick corals present. Horn and Rugos aswell. resembles uper Jeffersonville facies

Fossiliferous massive grainstone, sharp basal contact.light Grey. Fine laminations present. stromatoporoid, spine coral present Brachiopod pieces present.

Fossiliferous cryptalgal laminated wackestone, sharp basal contact.stromatoporoid present. Grey-Black

Fossiliferous massive grainstone, gradational basal contact. Light grey-light buff color.some laminations. Brachiopod, stromatoporoid coral fossil debris. structure like soft sediment deformation.colonial coral.

Fossiliferous massive dolomitic grainstone, gradational basal contact.Brown. Brachiopod shells preserved.

Fossiliferous massive grainstone, sharp basal contact. White-light grey. Horn and colonial corals.

Figure 11: Core description of IGS well ID 120189, Dodds Bridge Field, Sullivan County.

Table-1: List of the wells used for subsurface structure mapping in Dodds Bridge Field, Sullivan County. The wells selected have a TD of Devonian or deeper.

| IGS_ID | Twp | Twp_D | Rng | Rng_D | Land_N | Elevation/Kb | Top of Musca-tatcuk | Top of Jeffer-sonville | Top of Geneva | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 120174 | 8 | N | 10 | W | 3 | 468 | 2243 | 2303 | 2360 | | 143 | |
| 120176 | 8 | N | 10 | W | 3 | 504 | 2253 | 2312 | 2364 | 2380 | 58 | |
| 120177 | 8 | N | 10 | W | 3 | 513 | 2262 | 2318 | 2372 | 2392 | 15 | |
| 120181 | 8 | N | 10 | W | 3 | 489 | 2242 | 2315 | | | 13 | |
| 120183 | 8 | N | 10 | W | 3 | 501 | 2275 | 2350 | 2404 | | | |
| 120188 | 8 | N | 10 | W | 3 | 472 | 2238 | 2300 | 2350 | 2372 | 20 | |
| 120189 | 8 | N | 10 | W | 3 | 504 | 2253 | 2312 | 2363 | 2380 | | |
| 120190 | 8 | N | 10 | W | 3 | 489 | 2254 | | 2376 | | 5 | |
| 120192 | 8 | N | 10 | W | 3 | 497 | 2254 | 2314 | 2365 | | 35 | |
| 120197 | 8 | N | 10 | W | 3 | 466 | 2313 | 2390 | 2478 | 2515 | | |
| 120199 | 8 | N | 10 | W | 3 | 496 | 2404 | 2484 | | | | |
| 120205 | 8 | N | 10 | W | 3 | 462 | 2268 | 2350 | | | 20 | |
| 120212 | 8 | N | 10 | W | 3 | 503 | 2267 | 2346 | | | 385 | |
| 120213 | 8 | N | 10 | W | 3 | 506 | 2266 | 2344 | 2402 | | 16 | |
| 120215 | 8 | N | 10 | W | 3 | 487 | 2257 | 2320 | 2373 | | 33 | |
| 120216 | 8 | N | 10 | W | 3 | 490 | 2290 | 2372 | | | | |
| 120221 | 8 | N | 10 | W | 3 | 469 | 2370 | | | | | |
| 120222 | 8 | N | 10 | W | 3 | 463 | 2373 | | | | | |
| 157371 | 8 | N | 10 | W | 3 | 506 | 2274 | 2332 | 2384 | | 9 | |
| 160178 | 8 | N | 10 | W | 3 | 491 | | | | | 22 | |
| 120547 | 8 | N | 10 | W | 9 | 461 | 2429 | | | 2542 | | |
| 119810 | 8 | N | 10 | W | 10 | 509 | 2296 | 2360 | | | 8 | |
| 119814 | 8 | N | 10 | W | 10 | 483 | 2260 | | | | 235 | |
| 119815 | 8 | N | 10 | W | 10 | 511 | 2305 | 2370 | 2450 | | | |
| 119818 | 8 | N | 10 | W | 10 | 505 | 2299 | | | | | |
| 119853 | 8 | N | 10 | W | 11 | 504 | 2453 | | | 2624 | | |

Figure 12: Photo of the core ID 654, IGS ID # 120189 from Dodds Bridge Field, Sullivan County.

Fig 12: Continued...

Fig 12: Continued...



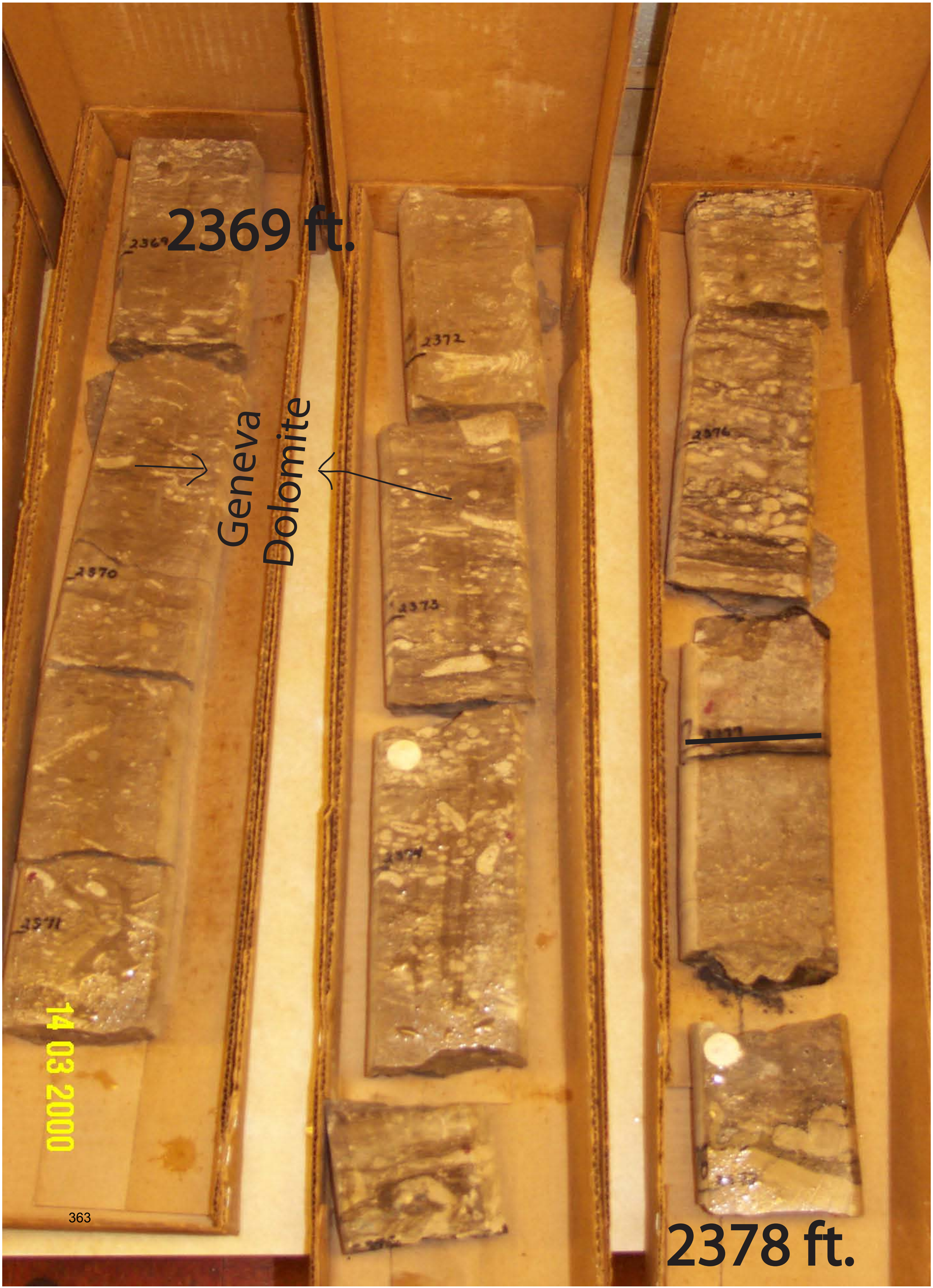


Fig 12: Continued...

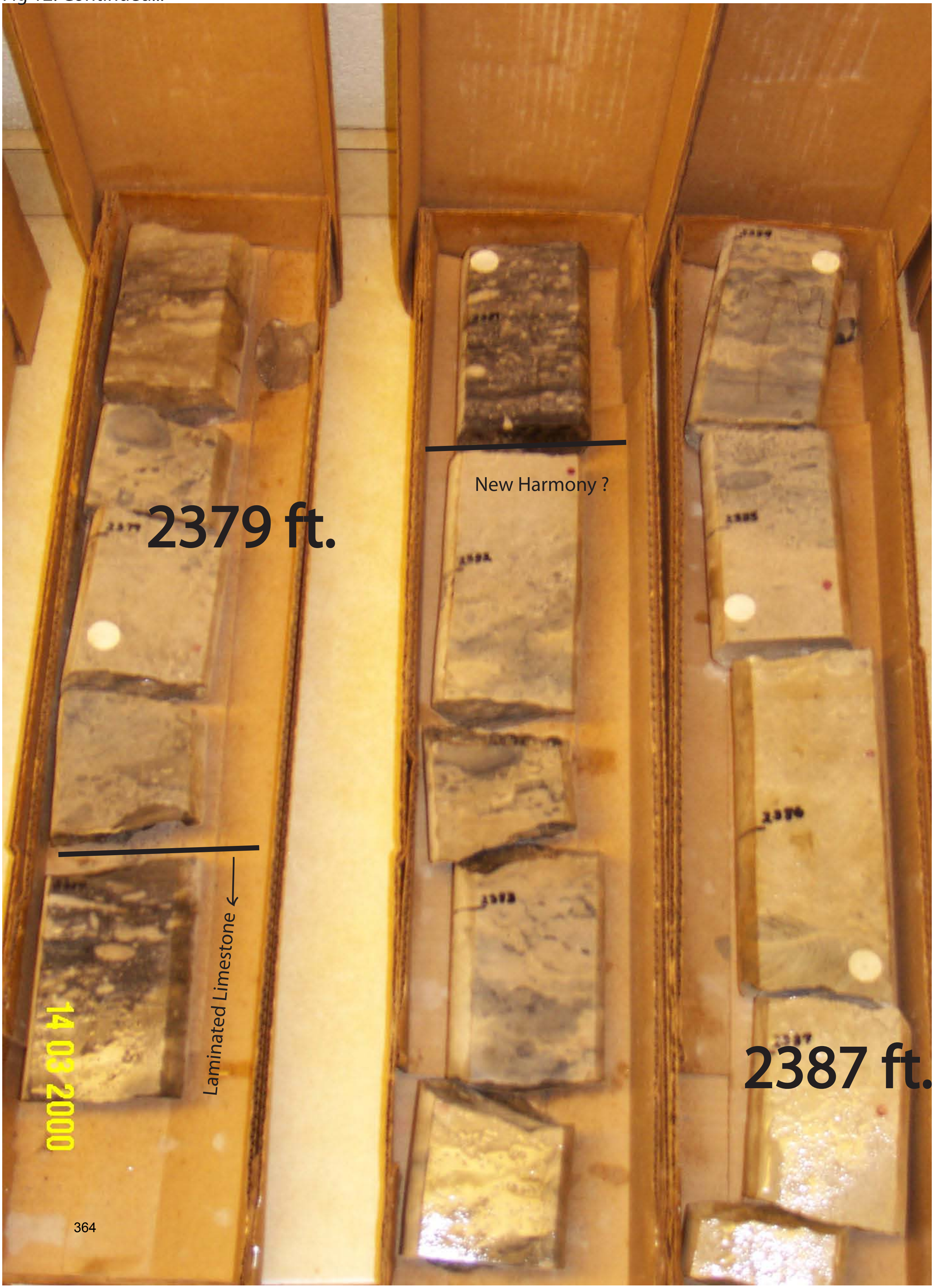


Fig 12: Continued...

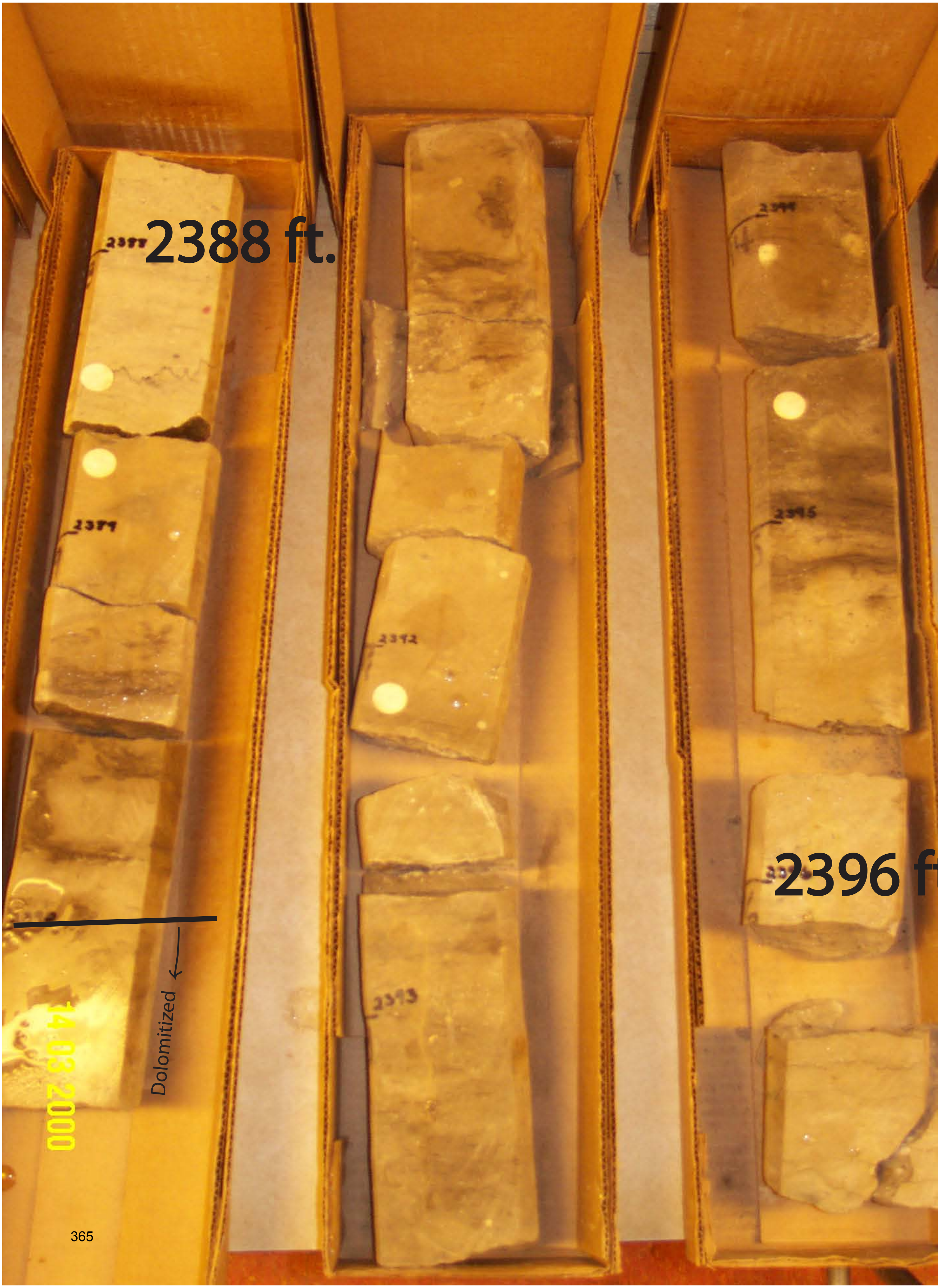


Fig 12: Continued...



**Field name:** Dubois

**IGS ID:** 10163

**DOE ID:** 204114

**Location:** Dubois County, 1S&1N-4W

**Discovery date:** 1987

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, North Vernon Ls. (1,596 ft.)

**Field type:** oil & natural gas

**Total number production wells:** 3 (oil), 1 (natural gas)

**Area:** na

**Cumulative production:** 183 bbls. (2002)

**Other reservoir units:**

Mississippian, Sanders Group, Salem Ls.

Mississippian, Sanders Group, Harrodsburg Ls.

**Deepest unit penetrated (depth):** Ordovician, Black River Group (3,100 ft.)

**Field characteristic:** na

**Reservoir characteristics:**

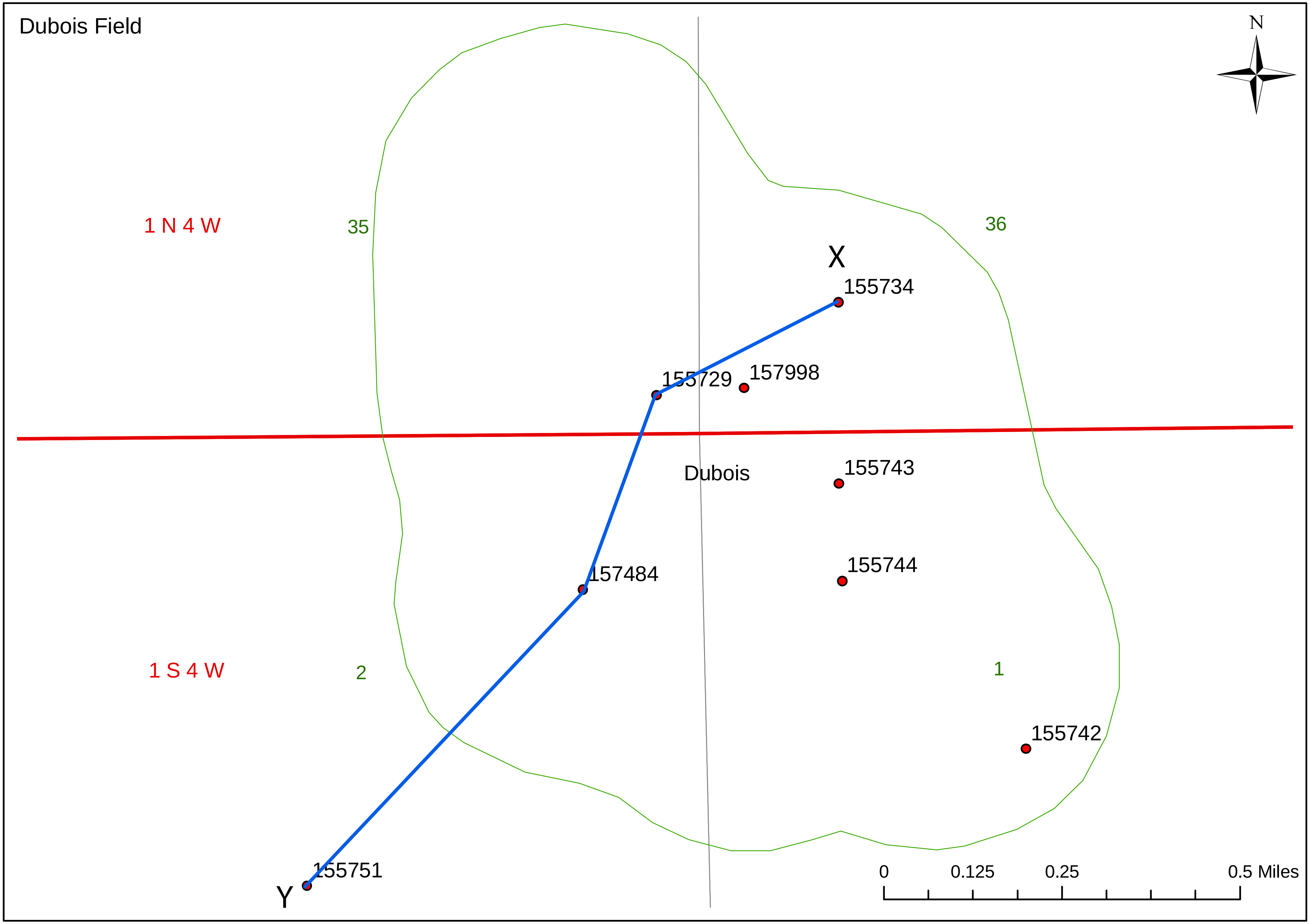



Figure 1: Map showing the location and wells at Dubois Field, Dubois County. X-Y is the location of the cross section that shows the subsurface Devonian structure in Figure 5.

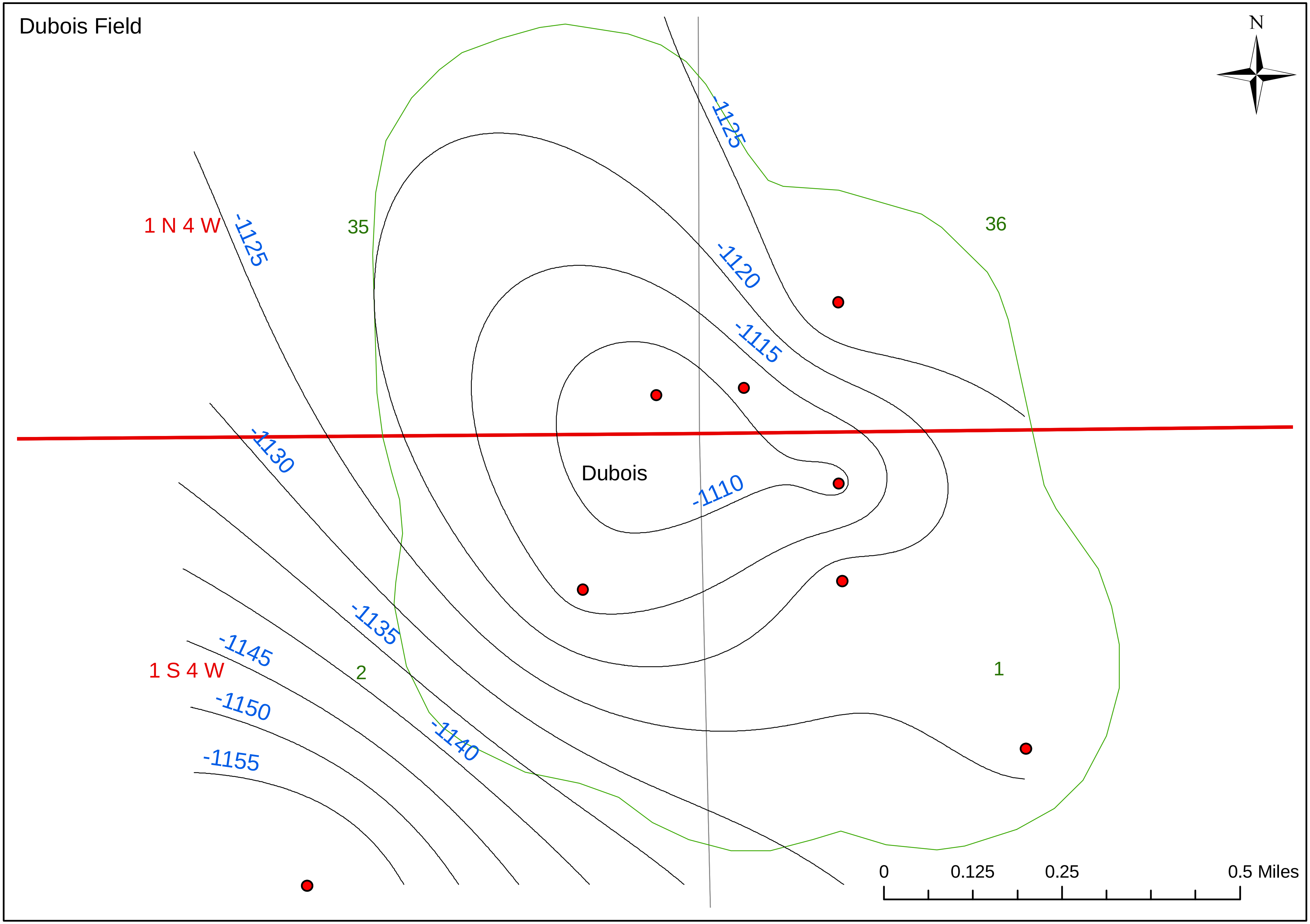



Figure 2: Structure map showing top of the Muscatatuck Limestone in Dubois field, Dubois County. Contours show values below sea level, contour interval is 5 ft .

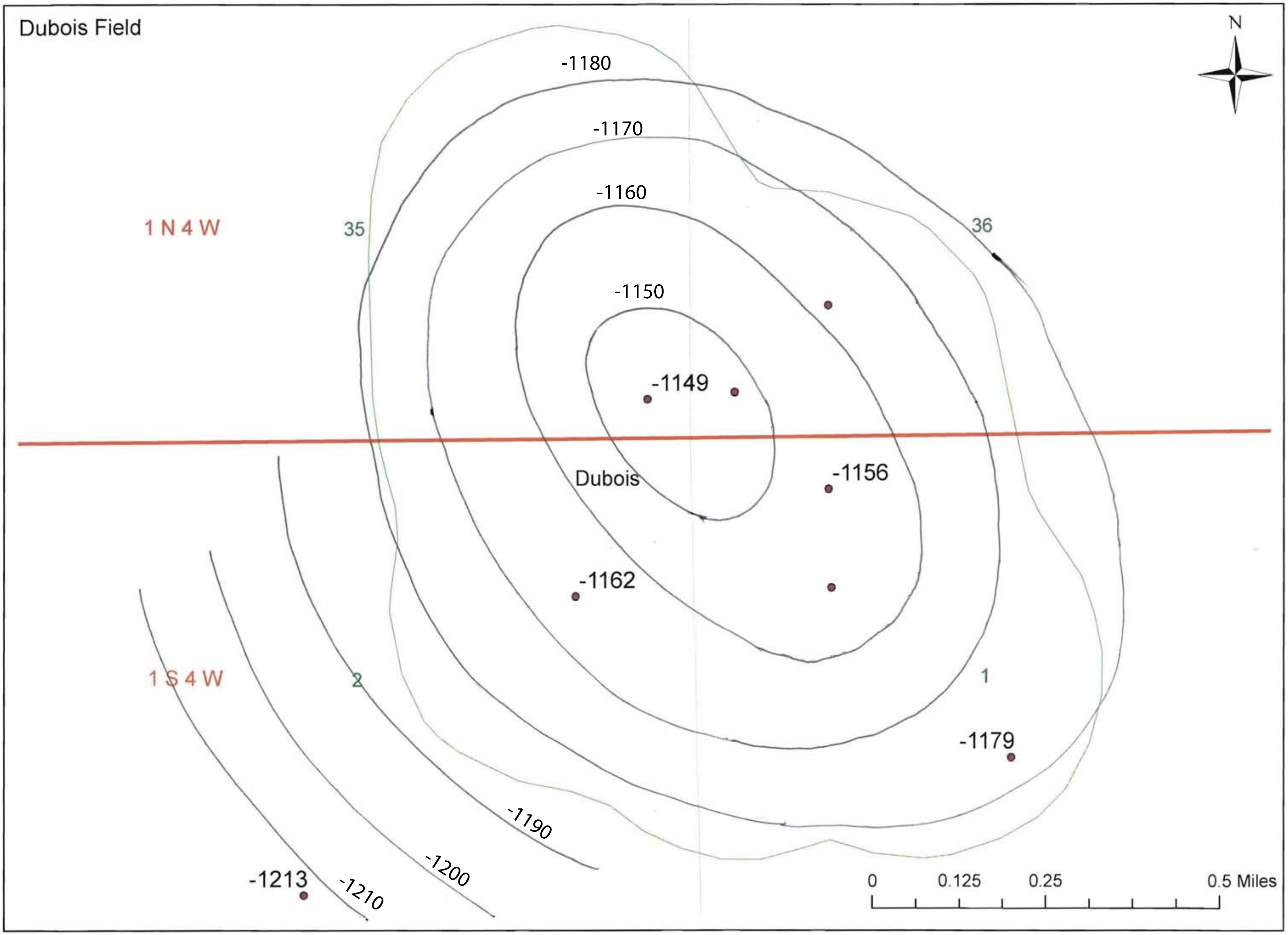



Figure 3: Structure map showing top of the Jeffersonville Limestone in Dubois Field, Dubois County. Contours show values below sea level, contour interval is 10 ft .

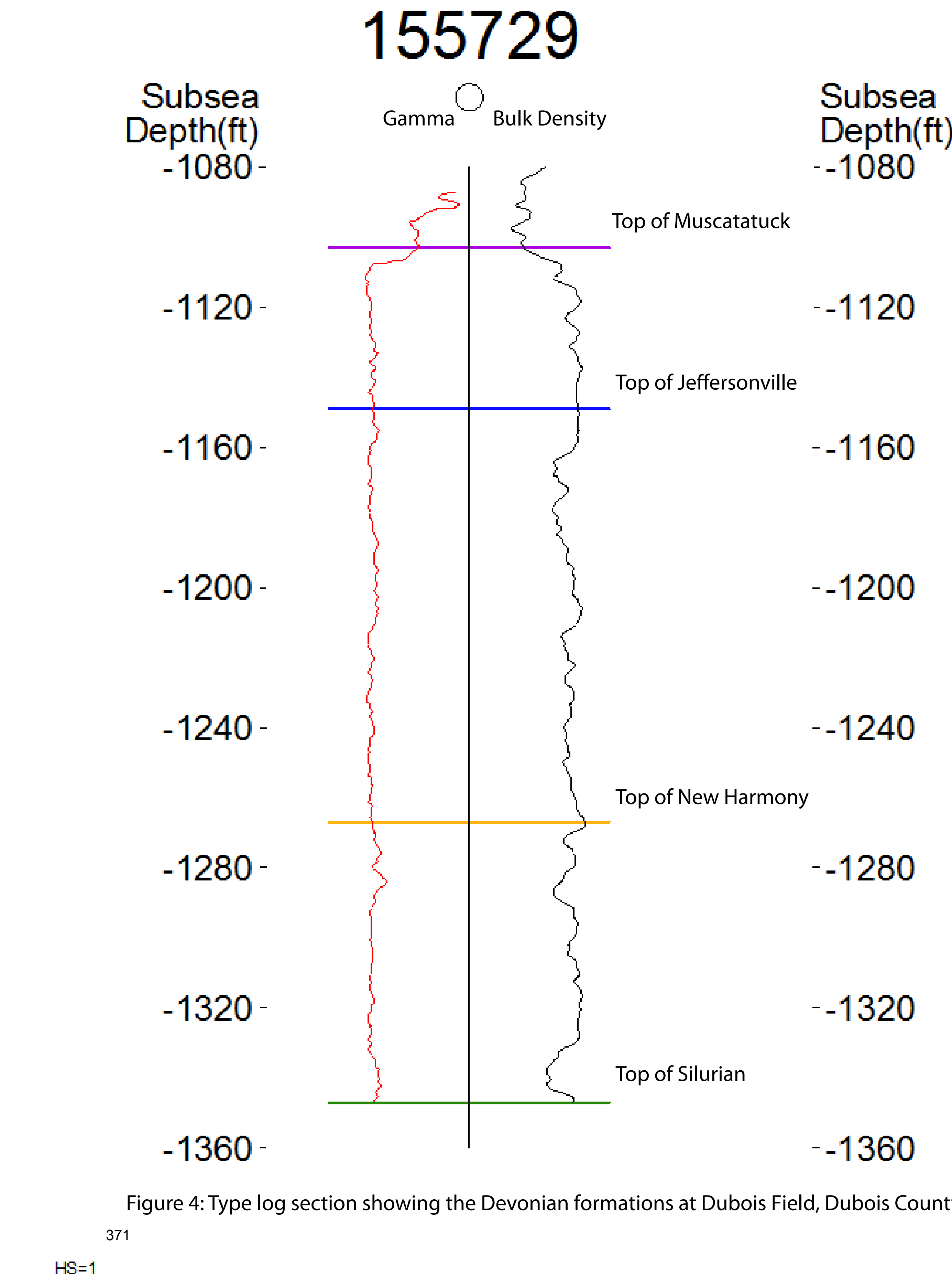



Figure 4: Type log section showing the Devonian formations at Dubois Field, Dubois County.

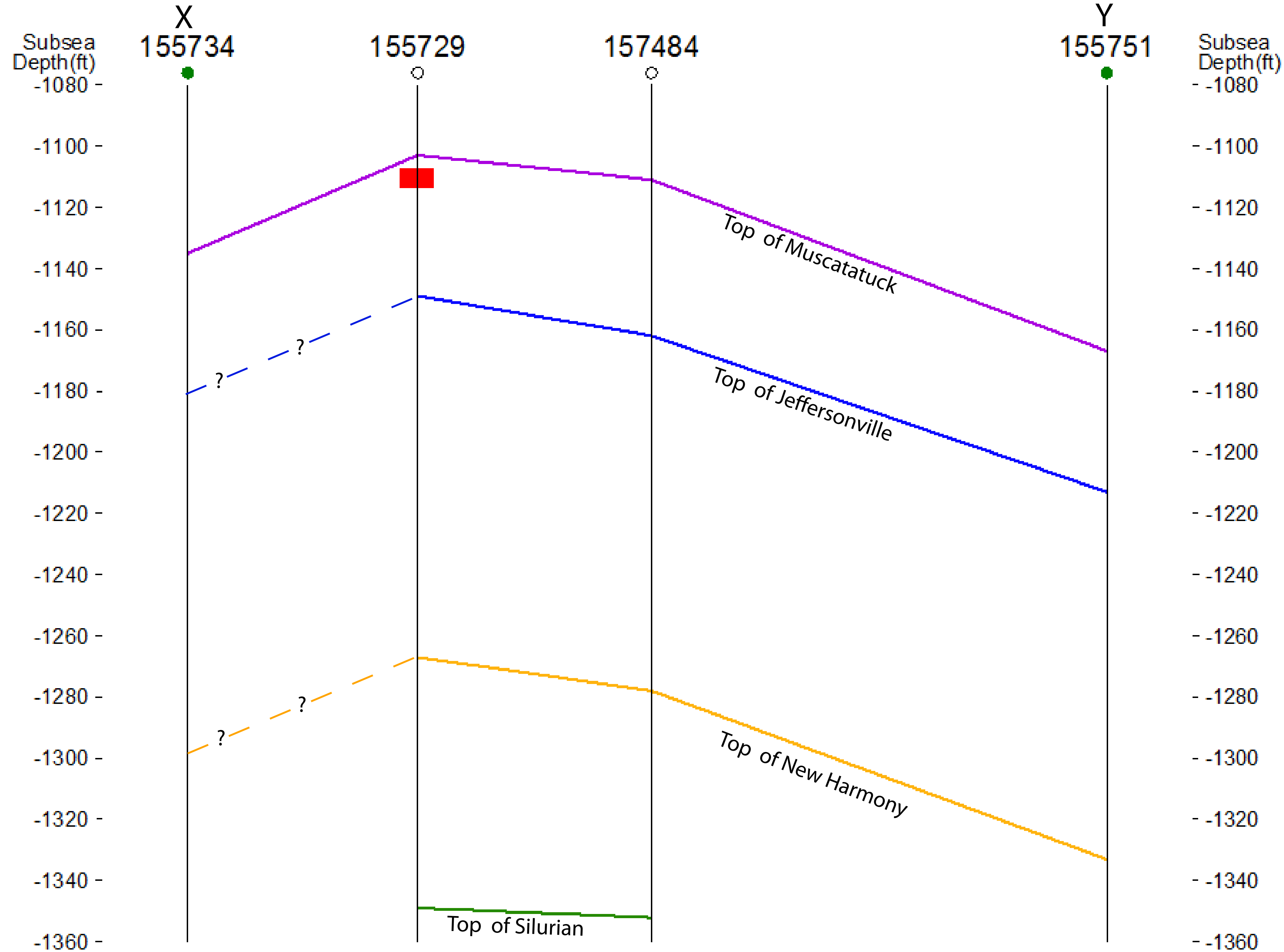



Figure 5: X-Y Cross section showing the Devonian subsurface structure across Dubois Field, Dubois County. For location of the cross section refer to Figure 1. Red box indicates the completion interval for oil and gas production.

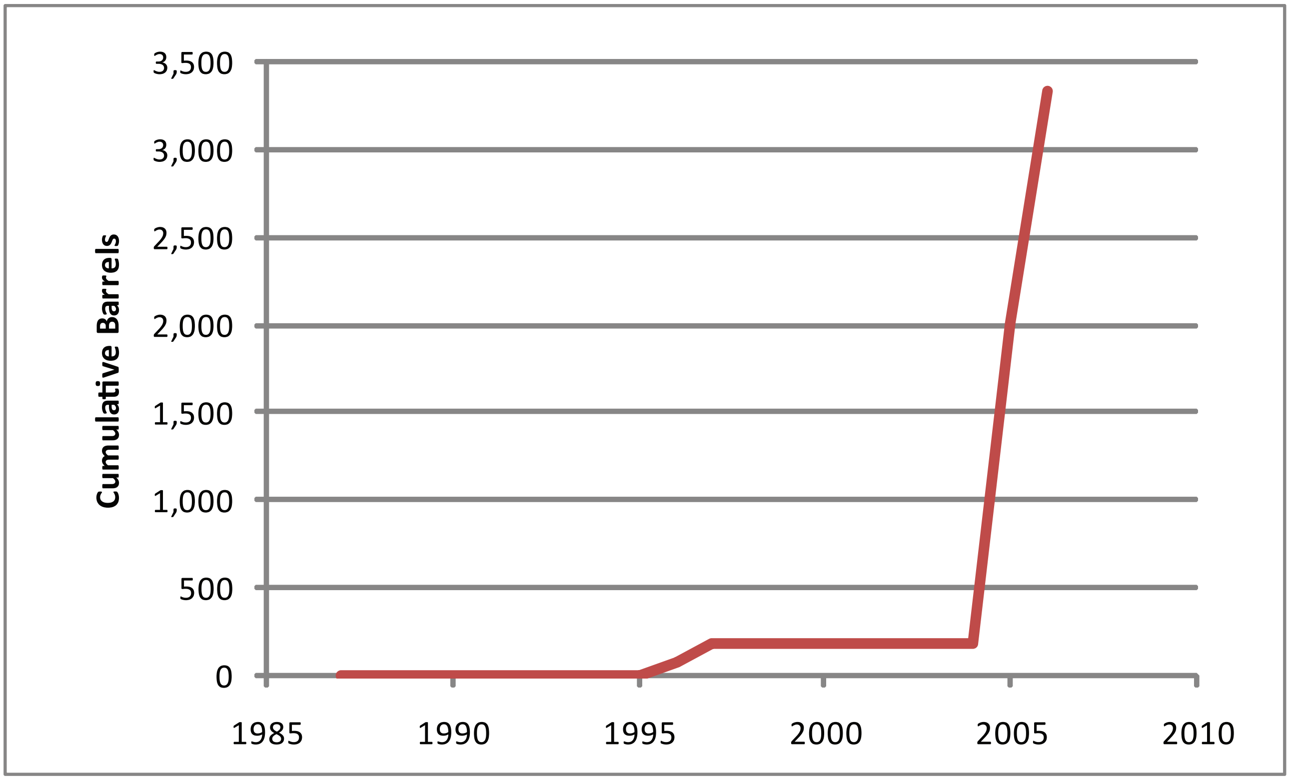



Figure - 6: Cumulative Oil production history from Dubois Field, Dubois County since 1987.

Table-1: List of the wells used for subsurface structure mapping in Dubois Field, Dubois County.

| IGS_ID | Twp | Twp _D | Rng | Rng_ D | Land _N | Elevation/ Kb | Top of Musca- | Top of Jeffer- | Top of New | Top of Silurian | Oil IP (BOPD) | Gas IP (MCF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 155729 | 1 | N | 4 | W | 35 | 503 | 1606 | 1652 | 1770 | 1852 | | |
| 155734 | 1 | N | 4 | W | 36 | 490 | 1625 | | | | | |
| 157998 | 1 | N | 4 | W | 36 | 493 | 1604 | | | | 5 | |
| 155742 | 1 | S | 4 | W | 1 | 551 | 1675 | 1730 | 1840 | 1900 | | |
| 155743 | 1 | S | 4 | W | 1 | 486 | 1590 | 1642 | 1746 | | | 750 |
| 155744 | 1 | S | 4 | W | 1 | 487 | 1614 | | | | | |
| 155751 | 1 | S | 4 | W | 2 | 537 | 1704 | 1750 | 1870 | | | |
| 157484 | 1 | S | 4 | W | 2 | 568 | 1679 | 1730 | 1846 | 1915 | | |

**Field name:** Elnora Central

**IGS ID:** 10185

**DOE ID:** 222134

**Location:** Daviess County, 5N-6W

**Discovery date:** 1972

**Lower Paleozoic reservoir unit (depth):** Devonian, Muscatatuck Group, Jeffersonville Ls. (1,847 ft.)

**Field type:** oil & natural gas

**Total number production wells:** 88 (oil), 3 (natural gas)

**Area:** 1,090 acres

**Cumulative production:** 2,145,984 bbls. (2002)

**Other reservoir units:**

Mississippian, Blue River Group, Aux Vases Fm.

Mississippian, Blue River Group, Ste. Genevieve Ls.

**Deepest unit penetrated (depth):** Silurian (2,030 ft.)

**Field characteristic:** Domal anticline over probable Silurian reef with structural closure in excess of 60 ft. at top of Muscatatuck.

**Reservoir characteristics:**

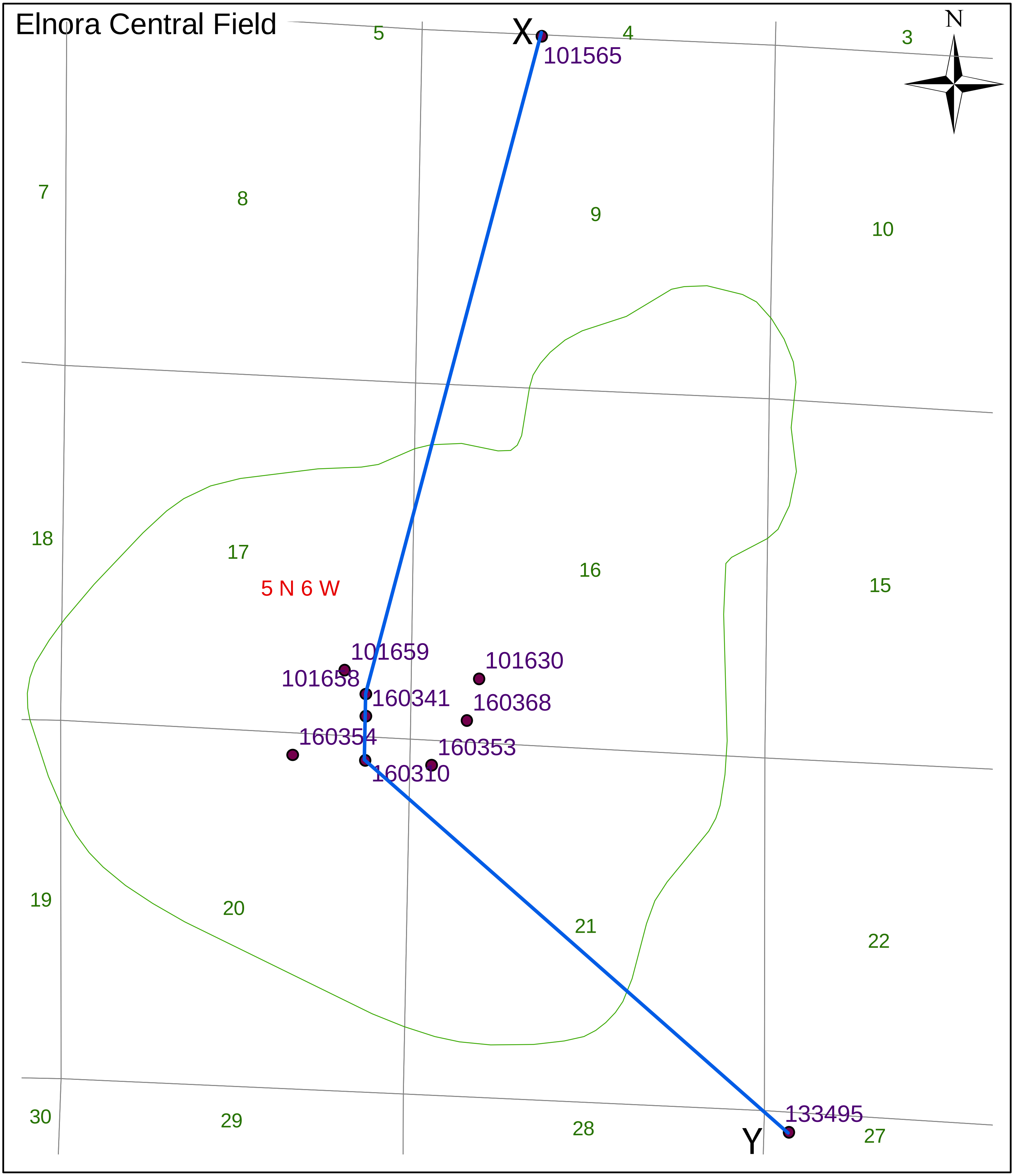



Figure 1: Map showing the location and wells at Elnora Central Field, Daviess County. X-Y is the location of the cross section that shows the subsurface Devonian structure in Figure 4.

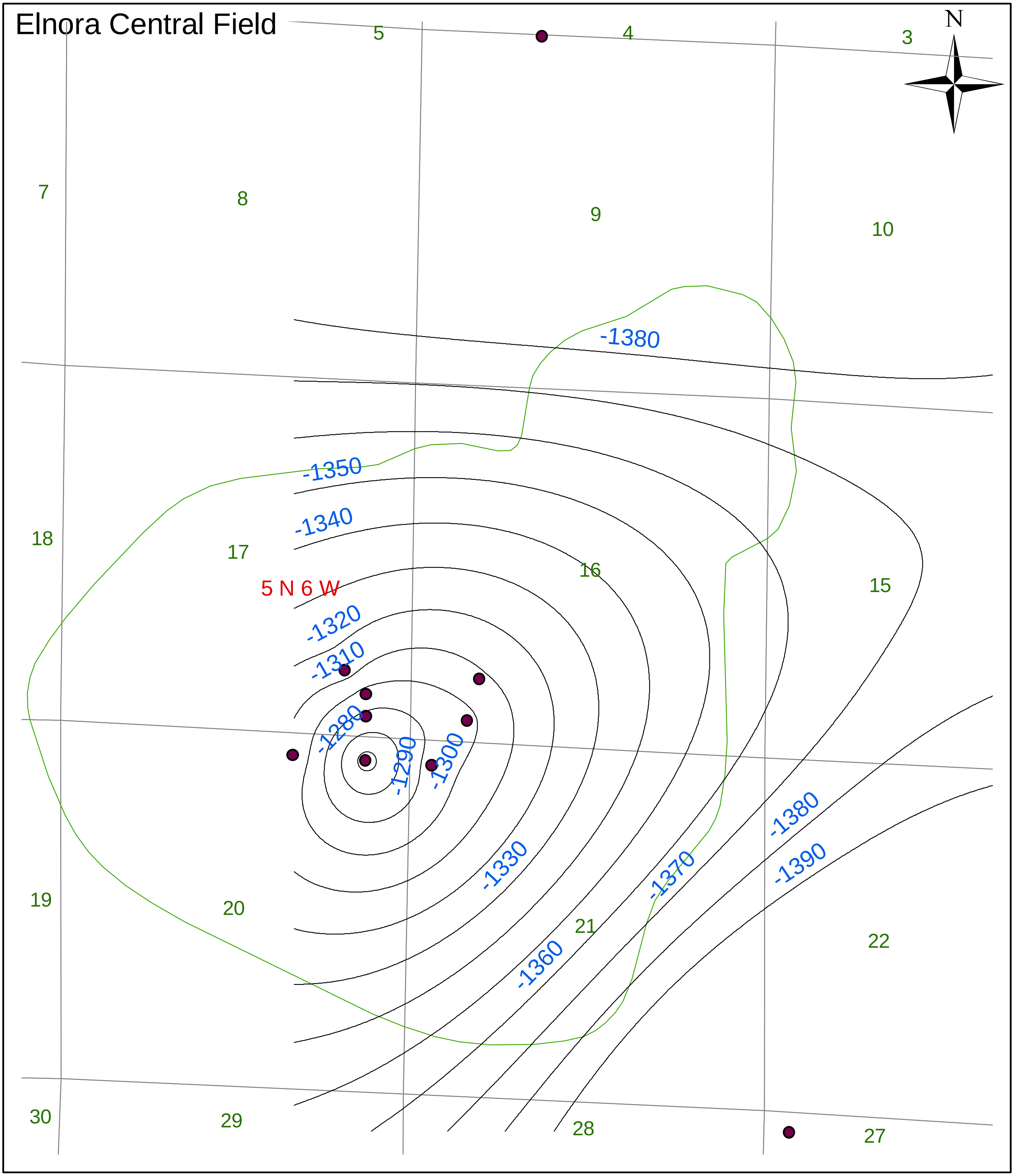



Figure 2: Structure map showing top of the Muscatatuck Limestone in Elnora Central field, Daviess County. Contours show values below sea level, contour interval is 10 ft .

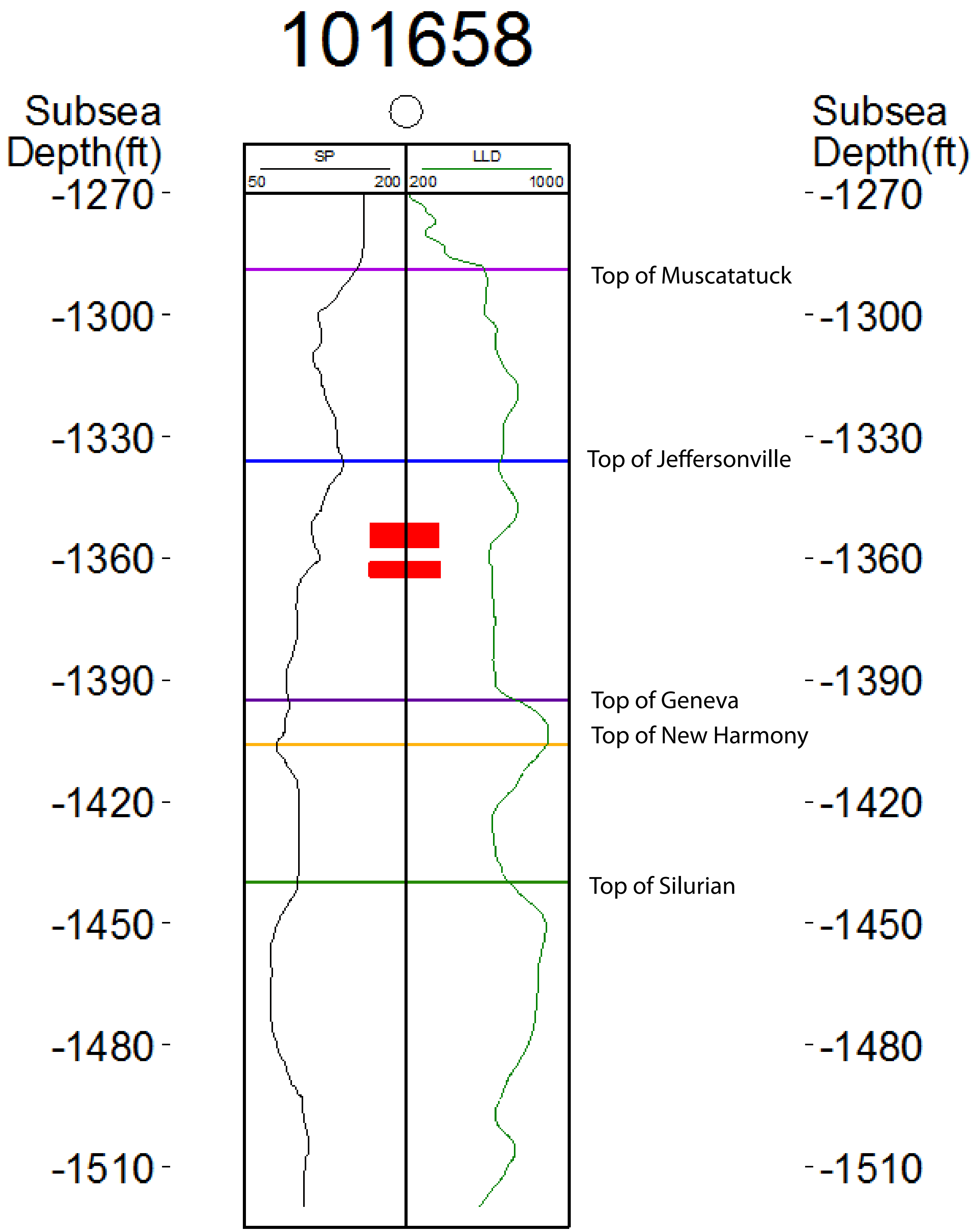



Figure 3: Type log section showing the Devonian formations from Elnora Central Field, Daviess County. Red box show the completion interval for oil production.



HS=1

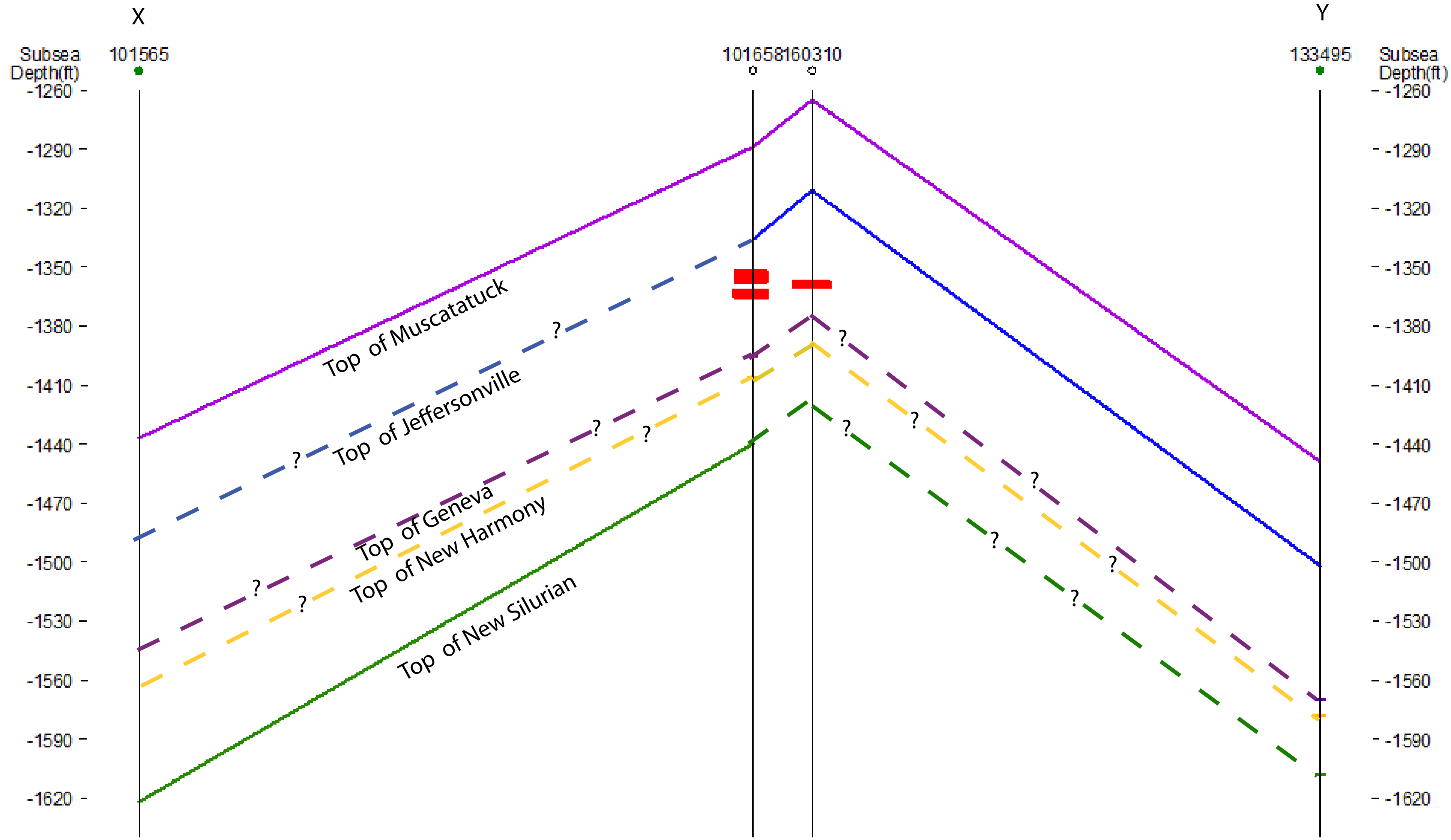



Figure 4: X-Y Cross section showing the Devonian subsurface structure across Elnora Central Field, Daviess County. For location of the cross section refer to Figure 1. Red box indicates the completion interval for oil production.



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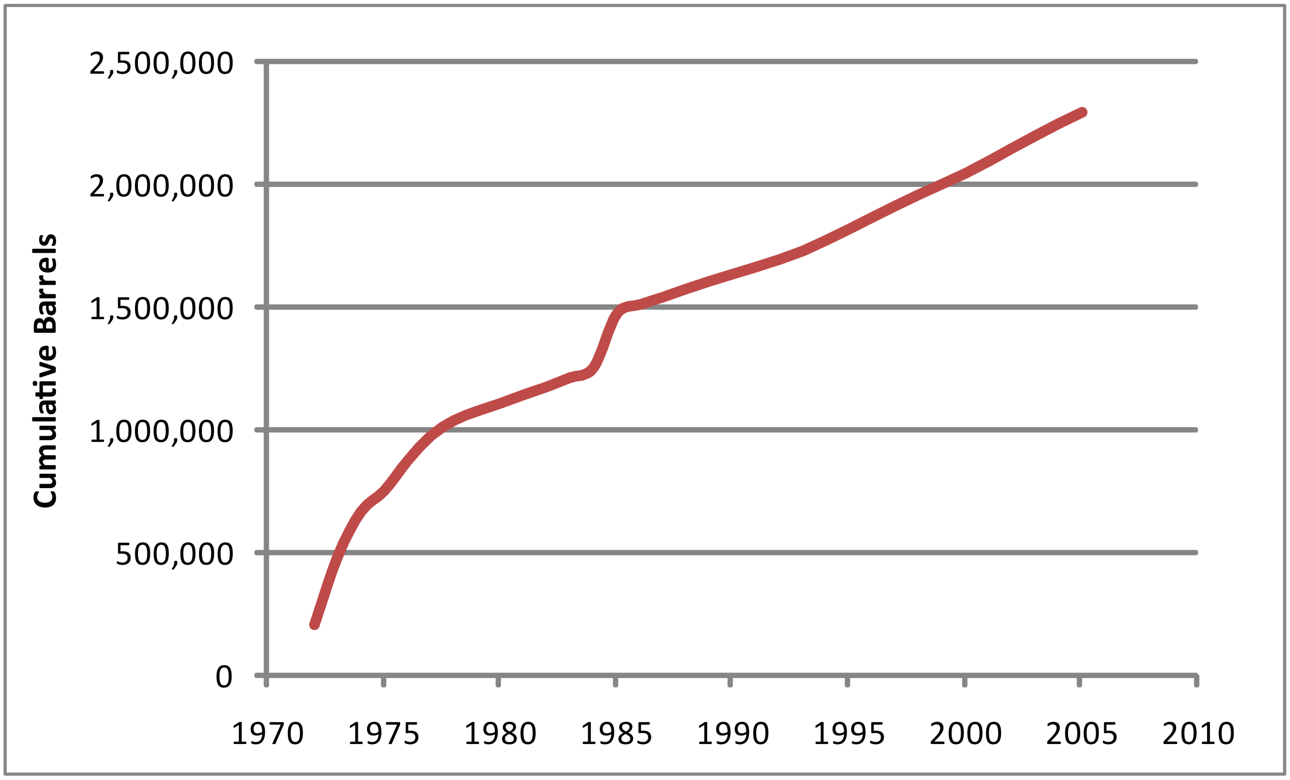


Figure - 5: Cumulative oil production history from Elnora Central Field, Daviess County since 1972.