RESERVOIRS RESULTING FROM FACIES-INDEPENDENT DOLOMITIZATION: CASE HISTORIES FROM THE TRENTON AND BLACK RIVER CARBONATE ROCKS OF THE GREAT LAKES AREA

Brian D. Keith
Indiana Geological Survey
611 N. Walnut Grove Avenue
Bloomington, IN 47405

ABSTRACT: Reservoirs in the Trenton Limestone and the Black River Group (Limestone) (both Upper Ordovician) in Indiana, Michigan, and Ohio formed a major oil province that increased rapidly in importance beginning in 1884. This province became America's first giant oilfield and has yielded more than 600 MBO, including that produced from the giant Albion-Scipio Trend (120 MBO), which was discovered in 1956. Trenton and Black River carbonates have always excited exploration interest, but very little was known about the nature and distribution of their reservoirs. Recent research on the nature of reservoir development in these units indicates that they do not contain any depositional porosity in the Great Lakes area. Reservoirs are found only where there has been dolomitization or fracturing or some combination of the two.

Dolomitization of Trenton and Black River limestones does not conform to facies-related models, such as the sabkha model, but must be related either to fluid movement along fractures associated with tectonic features or to burial dolomitization by some process that is not well understood. The importance of these two general types of dolomitization models can be shown by a comparison of fields where there has been dolomitization and fluid movement along a linear fault (or fracture) zone, and the Lima-Indiana Trend in Ohio and Indiana, where there has been a regional pattern of burial dolomitization. The range of oil recovery of the former is 12,000 to 2500 barrels per acre, and that of the latter is only 1,000 to 540 barrels per acre.

INTRODUCTION

There is a certain mystique in the petroleum industry associated with the idea of finding production from the Trenton Limestone and the Black River Group (Limestone in Ohio) in Indiana, Ohio and Michigan (Fig. 1). (It should be noted that in exploration discussions the Black River has often been included as part of the Trenton, therefore, the mystique is associated only with the name Trenton but actually applies to both units in many cases.) This mystique has developed primarily for two reasons. The first was the discovery of natural gas in the Trenton just east of Findlay, Ohio, in 1884, which was followed by the discovery of oil near Lima, Ohio, a year later. These discoveries initiated America's first major petroleum boom. The drilling fever quickly spread into Indiana and into New York. During this period, in Ohio and Indiana, nearly 500 million barrels of oil was produced, and about 100,000 wells were drilled (Buehner, 1971) in what came to be known as the Lima-Indiana Trend (Fig. 1). The second reason was the discovery in 1956 of the Albion-Scipio Trend in southern Michigan (Fig. 1). This trend, which is about 35 miles long and generally less than a mile wide, had yielded more than 120 million barrels of oil as of 1981 (Michigan Geological Survey, 1983) from the Trenton and Black River reservoirs combined.

Early in the development history of the Lima-Indiana Trend, geologists recognized that the Trenton Limestone was porous only where it was a dolomite and that the dolomite was probably altered from the original limestone (Orton, 1888; Phinney, 1891). Subsequently, virtually nothing new appeared in the literature regarding dolomite in the Trenton, although Landes (1946) proposed that the dolomitization occurred after burial of the Trenton, and Gutstadt (1958) did include a map showing the thickness

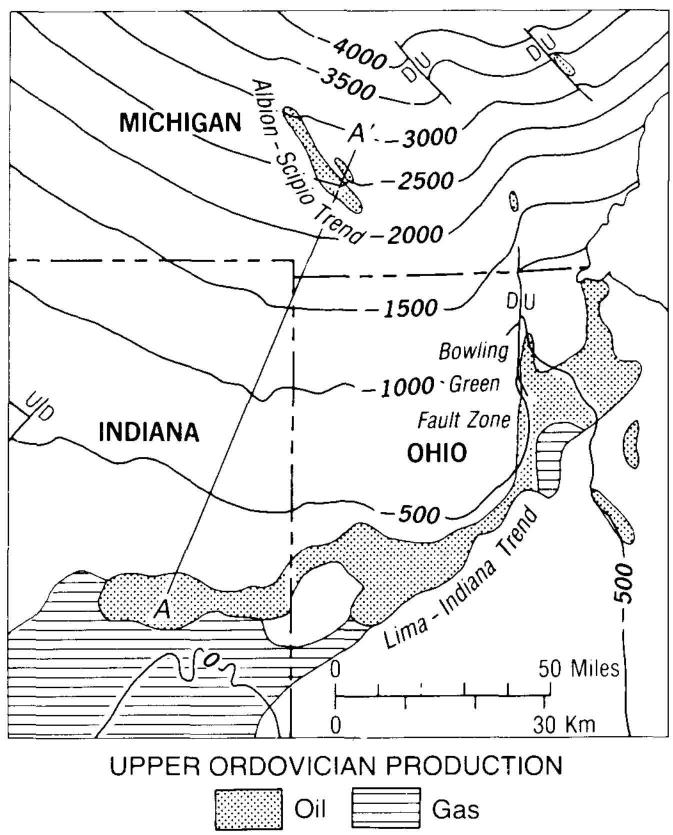

FIG. 1 — Map showing structure on top of the Trenton Limestone and location of Lima-Indiana Trend, the Bowling Green Fault Zone, and the Albion-Scipio Trend and other unlabeled fields in Michigan. The south edge of the Lima-Indiana Trend marks the north flank of the Findlay Arch referred to in the text.

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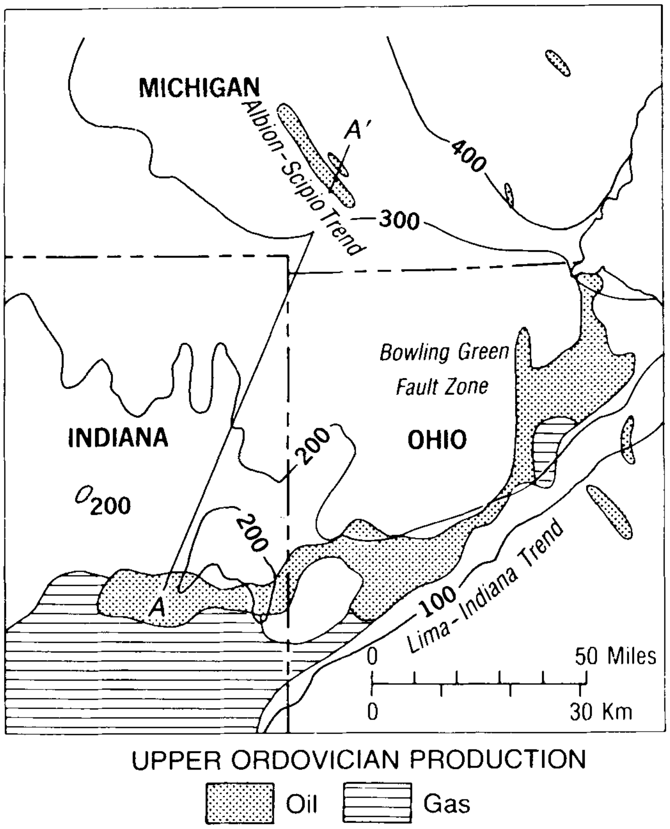

FIG. 2—Map showing thickness of the Trenton Limestone. Map is compiled from Keith (1985b) for Indiana, Wilson and Sengupta (1985) for Michigan, and Wickstrom and Gray (in preparation) for Ohio.

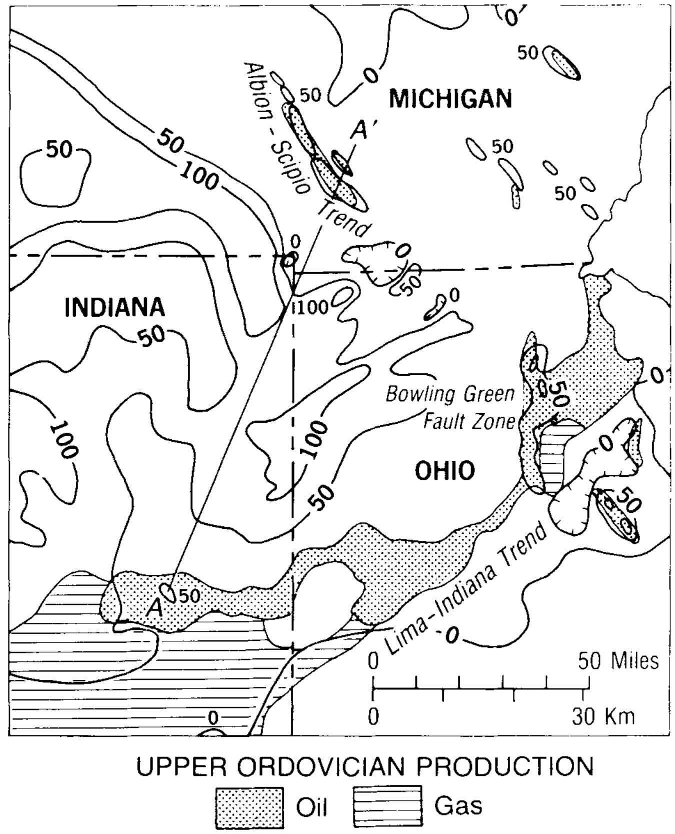

FIG. 3—Map showing percentage of thickness of the Trenton Limestone that is dolomite. Data are based on unpublished maps from various sources for all three states.

distribution of dolomite in the Trenton in Indiana in his report. With the discovery of the Albion-Scipio Trend, where dolomite occurred in a linear trend, there was renewed interest in the origin of Trenton and Black River dolomites. Burgess (1960) stated that the dolomite found at present in a large area in northwestern Ohio and northern Indiana (referred to as regional dolomite) formed soon after deposition of the original limestone, as opposed to the dolomite in linear trends in southern Michigan and southwestern Ontario (of which the Albion-Scipio Trend was the only major oilfield). According to Burgess (1960), these linearly occurring dolomites consisted of a later secondary dolomite forming along fracture trends. Burgess (1960) also observed that the Lima-Indiana Trend was a large-scale stratigraphic trap where the Trenton as a whole thinned to the south (Fig. 2) and where the porous dolomite pinched out to the south along the north flank of the Findlay Arch in Ohio and Indiana (Figs. 1 and 3). These basic observations still stand, but debate continues about the origin of the regional dolomite and the linear dolomite bodies. It is this question of origin and the consequences of the type of dolomite for reservoir quality that is the focus of discussion in this paper.

REGIONAL SETTING OF UPPER ORDOVICIAN RESERVOIRS

Dolomite reservoirs are only two of the four different types of reservoirs in the Upper Ordovician carbonate rocks of eastern North America (Fig. 4 and Keith, 1986). Reservoirs of the first type are the only ones that have limestone-matrix porosity (Fig. 4), and they are confined to rocks equivalent to the Trenton Limestone. (See Shaver and others, 1985, for regional correlations of units equivalent to the Trenton.) These reservoirs are found as localized shoals, which developed in a predominantly low energy carbonate environment during deposition of the upper part of the Lexington Limestone. This shoaling occurred where the Cincinnati Arch crosses the Tennessee-Kentucky border (Pryor and Sullivan, 1985; Sullivan and Pryor, in preparation). Limestone reservoirs are also found in southern Illinois where depositional porosity has been preserved in grainstone lenses of the Galena Group (Crews, 1985). The second reservoir type is also found only in the Trenton Limestone and consists of tectonic fracture-controlled reservoirs (Fig. 4) that in westernmost Virginia are associated with thrusting along the eastern

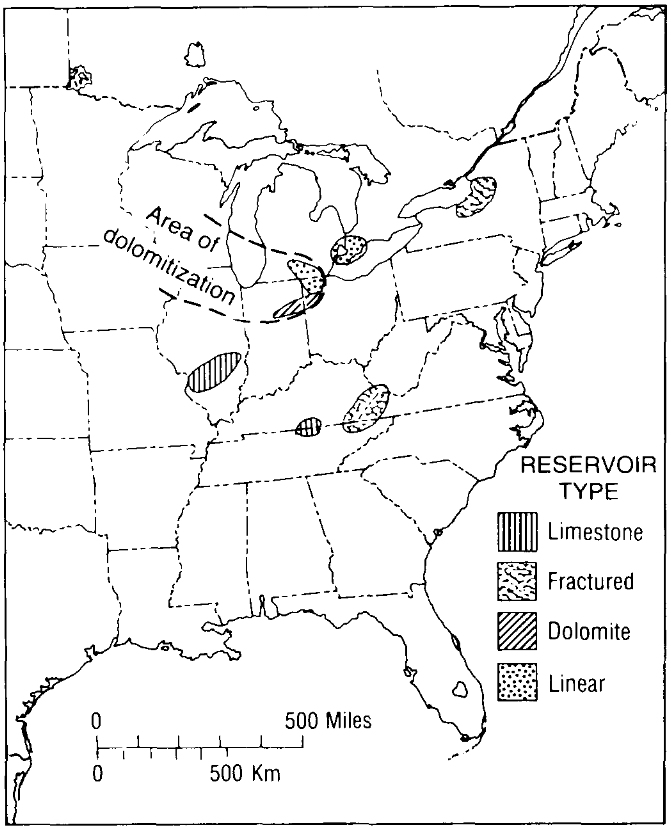

FIG. 4 — Location map for different types of reservoirs in the Trenton Limestone and the Black River Group (Limestone). All types are found in the Trenton, but only the dolomite and linear types are found in the Black River. (See text for more complete description of each reservoir type.)

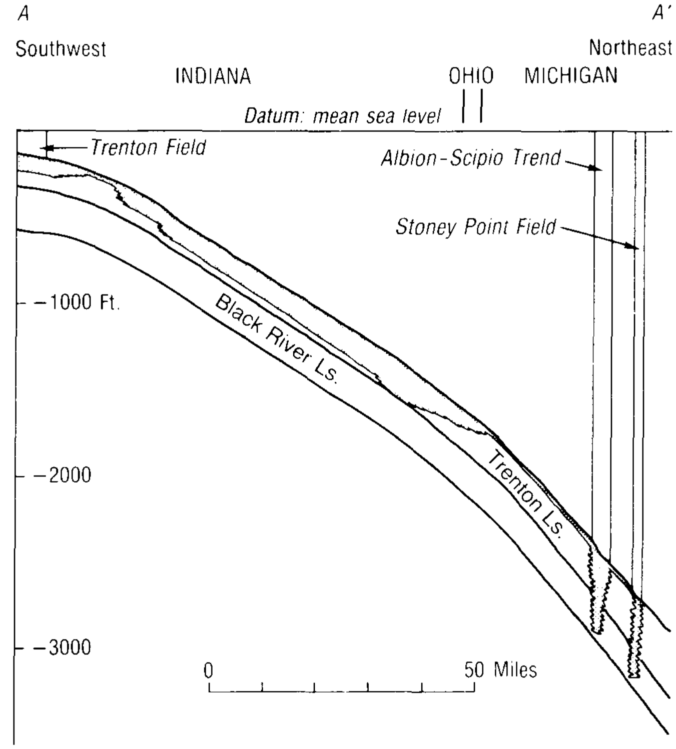

FIG. 5 — Regional structural cross section based on regional maps. (See Figs. 1-3 for location of section.) Thickness of dolomitization is somewhat schematic at this scale.

overthrust region (Bartlett, 1985 and in preparation). Fracture reservoirs also occur in central New York along local structural features possibly related to uplift of the Adirondack Mountains (Robinson, 1985). The third and fourth types of reservoirs, which are the subject of this paper, occur in both the Trenton and Black River and their equivalent units in Ontario (Keith, in preparation). The third reservoir type is related to regional dolomitization in east-central Indiana and northwestern Ohio (Fig. 4), and the fourth type developed because of localized dolomitization and solution along linear structural features (Figs. 3, 4, and 5) in northwestern Ohio, southern Michigan, and southwestern Ontario.

DOLOMITIZATION OF TRENTON AND AND BLACK RIVER LIMESTONES

Because the only porosity found in the Great Lakes area is associated with dolomitization, an understanding of the dolomitization process (or processes) is the key to understanding the nature of these reservoirs. For the most part, evidence to support dolomitization interpretations is indirect because no systematic geochemical and petrographic study of the dolomite over the whole area has been made.

Several key issues should be considered in discussing the origin of dolomite in the Trenton. Sabkha-related dolomitization was proposed by Coogan and Parker (1984 and in preparation). No evidence of such an interpretation was presented by the authors, and no such evidence has been seen in Indiana or reported by anyone else. Deposition of the Trenton in the tri-state area occurred in normal open-marine subtidal conditions on a carbonate platform (Keith, in preparation) that deepened from northwestern Ohio and northeastern Indiana to the south into southwestern Ohio (Wickstrom and Gray, in preparation) and to the north into central Michigan (Wilson and Sengupta, 1985). Highest energy conditions appear to have been in northern Indiana (Fara and Keith, in preparation).

This leads to a proposal for dolomitization about which much has been said but about which little has actually been published. This interpretation for dolomitization of the Trenton in Michigan is based on the concept of subaerial exposure of the Trenton surface before deposition of the overlying Utica Shale (DeHaas, 1986; and DeHaas and Jones, in preparation). Ver Wiebe (1929) first proposed the idea of exposure of the Trenton to explain solution porosity in the Trenton, although he mistakenly stated that the reservoirs in the Trenton of the Lima-Indiana Trend were limestone. The most detailed and most often quoted discussion of the idea is by Rooney (1966), whose evidence has been rebutted elsewhere (Keith, 1985c).

Only recently have more detailed studies been made on the dolomites in the Trenton (Fara and Keith, 1984 and in preparation; Budai and Wilson, 1986, and Taylor and Sibley, 1986). None of these studies, however, has been able to provide conclusive evidence of the origin of dolomites in the Trenton, but the evidence can be summarized.

Four types of dolomite have been described in these and other studies. First, a cap dolomite occurs only at the top of the Trenton, immediately beneath the overlying shale. It ranges in thickness from 1.5 to 15 m. It is generally finely crystalline and ferroan in composition, and recognizable fossils are common. This type of dolomite is found in southern Michigan (Taylor and Sibley, 1986), northern Indiana (Fara and Keith, in preparation), and northwestern Ohio (L. H. Wickstrom, 1986, written communication) and seems to be the only kind of dolomite about which there is some consensus.

Next, what has been described as a fracture-related dolomite occurs in linear features associated with fracture zones such as are found in the area of the Albion-Scipio Trend in Michigan (Figs. 5 through 8) and in the Dover Field in southwestern Ontario (Figs. 9 and 10). It is coarsely crystalline, ferroan (Budai and Wilson, 1986), or only slightly ferroan (Taylor and Sibley, 1986), shows no original limestone texture, and can have slightly undulose extinction. This type of dolomite has been decribed as occurring only in Michigan, but it probably also occurs in southwestern Ontario and in Ohio.

The third type of dolomite has even more confusion associated with it. It has been called regional dolomite by many authors and petroleum geologists. This dolomite was described by Taylor and Sibley (1986) as having essentially the same texture as the cap dolomite but without any iron. Regional dolomite as described by Fara and Keith (in preparation) is texturally very much like the fracture dolomite of Taylor and Sibley (1986), and it is nonferroan. Taylor and Sibley (1986) showed that in Michigan the regional dolomite was present only in the southwestern part of that state. There are large areas, however, where the Trenton is nearly to completely dolomitized across northern Indiana and into northwestern Ohio (Fig. 3). Whether this dolomite has the same texture and chemistry and, therefore, presumably the same origin everywhere is questionable. The regional dolomite described by Taylor and Sibley (1986) was interpreted by them as having formed very early and before the cap dolomite. Budai and Wilson (1986), using petrographic and geochemical evidence, believed that the regional dolomite (although they did not use that term), and the cap dolomite were formed during early diagensis by early mixed water dolomitization, which appeared to support Taylor and Sibley's (1986) conclusions. None of the authors actually called on subaerial exposure of the Trenton in Michigan for dolomitization, and both papers clearly stated that the dolomite associated with fractures was a later event.

A fourth kind of dolomite is found in the Trenton. It is a white, very coarsely crystalline baroque or saddle dolomite that has been found associated with fractures in Michigan (DeHaas and Jones, in preparation) and along the Bowling Green Fault Zone and other areas in Ohio (Stieglitz, 1975). It is also seen as a vug filling in Indiana. In all examples it appears to be a product of late diagenesis.

In summary, all of the Trenton and Black River dolomitization can be interpreted as a series of postdepositional diagenetic events. The exact nature of these events, however, is not well documented but would have to be related to fluid movement some time after burial. The composition of the fluids and the timing of their movement are not really understood. The idea of subaerial exposure of the Trenton before deposition of the overlying shale does not readily fit with the regional evidence (Keith, 1985c) and does not appear to be required to fit the geochemical data, although much work still needs to be done before a satisfactory interpretation can be made. Fracture-related dolomite in producing fields in Michigan is the product of a still later event (Budai and Wilson, 1986; Taylor and Sibley, 1986). DeHaas and Jones (1984 and in preparation) believed that karstification associated with subaerial exposure was vital in creating the solution porosity associated with these fields, but Keith (1985c) proposed that such solution could have resulted from hydrothermal solutions instead of meteoric waters. This question also needs detailed geochemical study.

DOLOMITE RESERVOIRS IN THE INDIANA-OHIO-MICHIGAN AREA

Hydrocarbon productivity of Trenton and Black River reservoirs is directly controlled by the type of dolomitization that formed the reservoir. Porosity in the Lima-Indiana Trend developed at the southern updip pinchout of the regional dolomite into nonporous limestone and argillaceous limestone. Some porosity is localized on small positive structural features north of the trend in northwestern Ohio and northeastern Indiana (Keith, 1985a). The porosity in this dolomite is intercrystalline to vuggy (Fara and Keith, in preparation), and individual zones appear to have very poor lateral continuity as would be expected from porosity of this type. Visual examination and commercial core analyses for porosity and permeability from wells in Indiana indicate that vertical communication of fluids in the reservoirs would be virtually nonexistent. The Lima-Indiana Trend is actually broken up into many small pools, and when the total acreage drilled is taken into account, the actual productivity proves to be quite low (Table 1). The productivity does appear to have been higher in Ohio than in Indiana.

Fractured-related solution reservoirs are locally developed where the Bowling Green Fault Zone cuts across the Lima-Indiana Trend in Ohio (Figs. 1, 2, and 3). More than 500 million barrels of oil has been produced from the Lima-Indiana Trend, but possibly as much as 45 percent of this has been associated with the Bowling Green Fault Zone (derived from Wickstrom and Gray, in preparation). Actual oil recovery figures are not

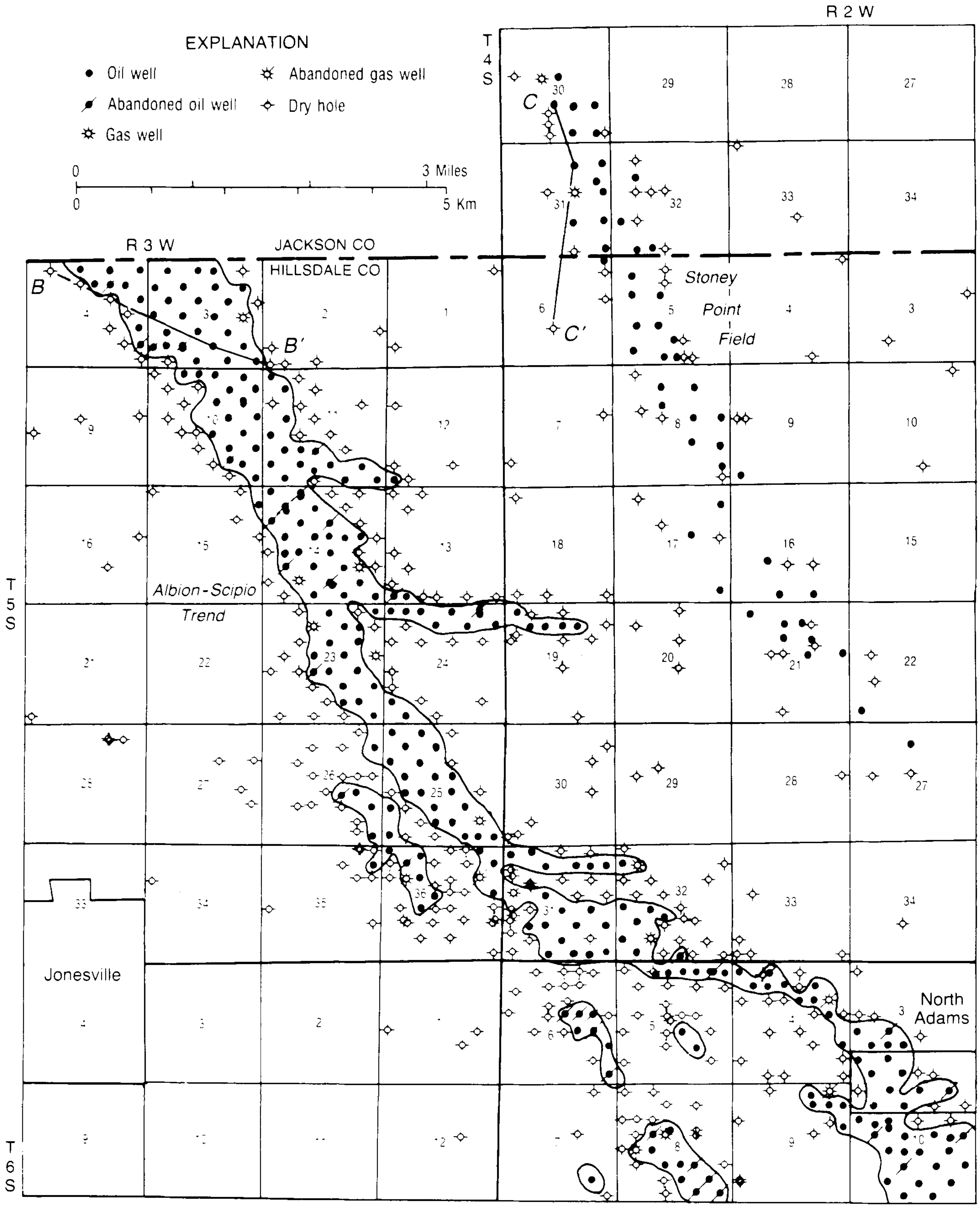

FIG. 6 — Map of a part of Hillsdale County, Michigan, showing the southern part of the Albion-Scipio Trend and the Stoney Point Field. Locations of log cross sections are also shown. (See regional maps for location of area.)

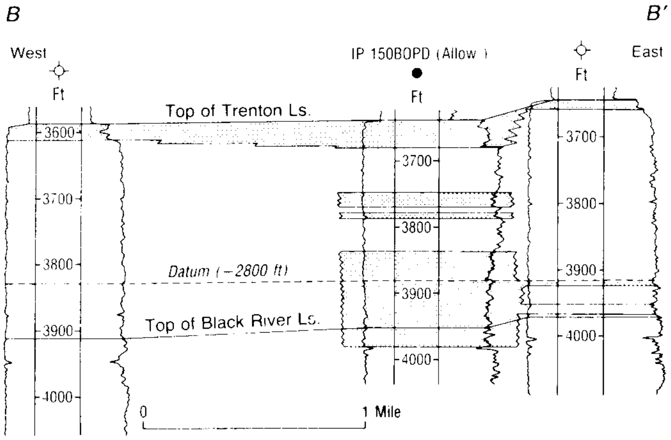

FIG. 7 — Structural cross section of the Albion-Scipio Trend showing pattern of dolomitization as interpreted from geophysical logs.

really available for this old production but are estimated to be either 1,000 or 840 barrels of oil per acre in Ohio and only 540 barrels per acre as an average for Indiana (Table 1). This gives an overall range of 2,700 to 10,000 barrels per well, depending on whether 5- or 10-acre units are used in the calculations.

This productivity contrasts with that from reservoirs related to dolomitization along local tectonic features, such as faults or fracture zones, that commonly contain solution porosity (Table 1). These reservoirs have been documented in southwestern Ontario (Sanford, 1961; Bailey and Cochrane, 1984), southern Michigan (DeHaas and Jones, 1984 and in preparation; Prouty, 1984 and in preparation), and northern Ohio (Wickstrom and others, 1984; Wickstrom and Gray, in preparation). All of these reservoirs in their different areas are found where the Trenton is a limestone and the dolomitization is very much localized around a tectonic feature (Figs. 6 through 10). This kind of feature appears to be one of two types: (1) a normal fault of either small-scale (Deerfield Field in southern Michigan) or large-scale (Bowling Green Fault Zone) displacement or (2) a linear fracture zone that might be related to a fault. The latter shows very little displacement at the Trenton stratigraphic level, although a local synclinal feature coinciding with the area of greatest dolomitization is usually present, as seen at Dover Field in southwestern Ontario (Figs. 9 and 10) and at the Albion-Scipio Trend and Stoney Point Field in southern Michigan. Reservoir quality appears to depend on the amount of solution porosity that is present, and actual oil-filled caverns are present in some places (DeHaas and Jones, 1984 and in preparation).

The Bowling Green Fault Zone was discovered through drilling in the Lima-Indiana Trend. Wells in the area of the fault zone were recognized at the time as the most prolific part of the trend with recoveries of about 12,000 barrels of oil per acre (Table 1). This amounts to 120,000 barrels for a 10-acre unit. The Dover Field in Ontario, discovered in 1917, had recoveries of about 2,500 barrels of oil per acre as of 1958 (Table 1). the Albion-Scipio Trend, discovered in 1956, had an average recovery of 15,000 barrels per acre as of 1981 (Table 1), or 300,000 barrels per 20-acre drilling unit. The Stoney Point Field was discovered in 1983 as a feature parallel to the Albion-Scipio Trend, and potentials of about 200 barrels per day indicate that recoveries from this field will probably be significant.

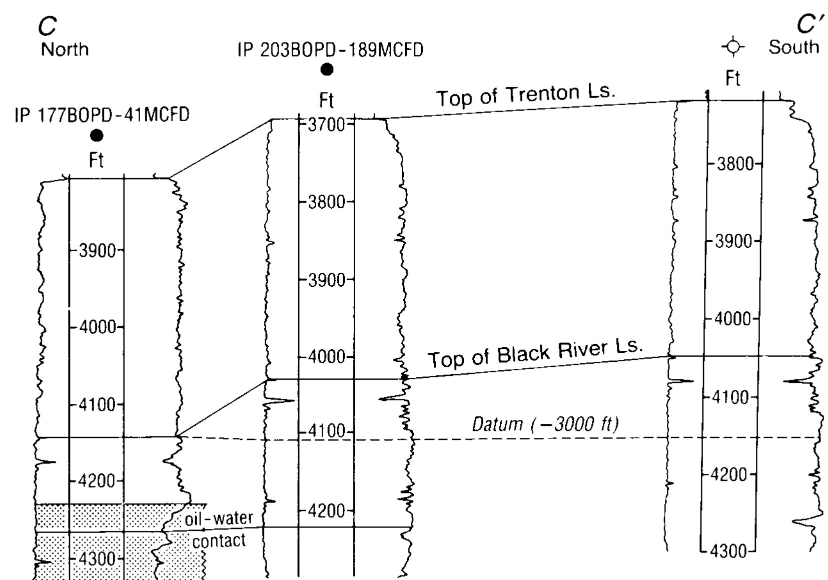

FIG. 8 — Structural cross section of the Stoney Point Field showing pattern of dolomitization as interpreted from geophysical logs. The oil well without any dolomite as indicated by the log was given a large hydraulic-fracture treatment after initially being drilled as a dry hole. The fracture apparently connected with the reservoir in the field, as can be seen by the initial potential. This illustrates the very local nature of the dolomitization in these features.

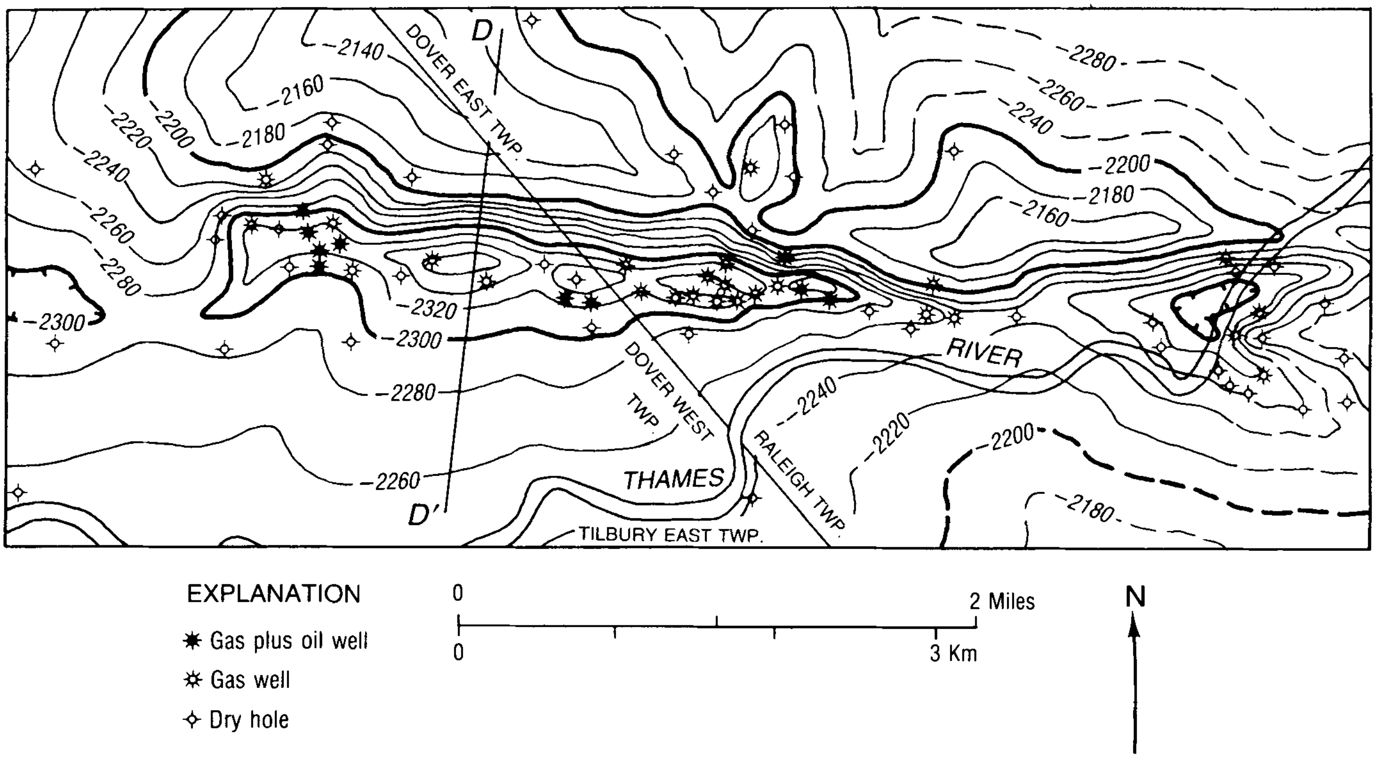

FIG. 9 — Map showing structure on top of the Trenton Limestone at the Dover Field in Ontario. Line of cross section is also shown. (Modified from Stanford, 1961.)

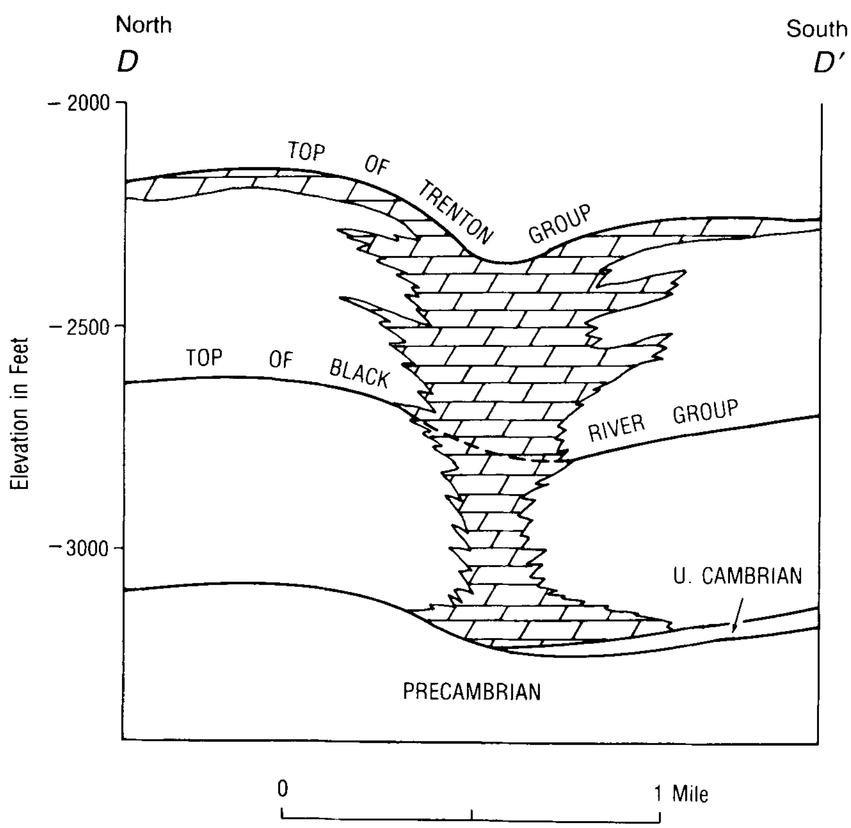

FIG. 10 — Diagrammatic cross section of the Dover Field showing general structure and pattern of dolomitization. (Modified from Sanford, 1961.)

Table 1. *Oil Productivity for Trenton and Black River Dolomite Reservoirs*

Type of reservoir, location, and field name	Source of data (listed below)	Acres	Total production (in barrels of oil)	Productivity (in barrels per acre)
Regional dolomite				
Lima-Indiana Trend,* Ohio	5	NA		1,000†
Lima-Indiana Trend,* Ohio	1	NA		840†
Trenton Field, Indiana	2	195,150	105,313,218	540
Fracture-related				
Bowling Green Fault Zone,** Ohio	5	NA		12,000†
Albion-Scipio Trend,* Michigan	3	13,220	120,066,223	9,082
Dover Field, Ontario	4	100	249,855	2,499

Data Sources
1. Beuhner (1971)
2. Carpenter and Keller (1984)
3. Michigan Geol. Survey (1983)
4. Sanford (1961)
5. Wickstrom and Gray (in preparation)

*Trend is composed of several individual fields that are not differentiated.
**Does not have field status, but consists of an area considered separately for purposes of productivity.
†Estimated value.
NA Published acreage and total production values not available.

SUMMARY

Despite a long history of exploration interest covering almost a century, relatively little is really known about the origin of dolomite reservoirs in the Trenton Limestone and in the Black River Group (Limestone). No evidence has been presented in the literature to indicate that the dolomites are particularly related to any depositional facies, other than on a very local basis where dolomitizing fluids may have followed zones of slightly higher initial permeability in fracture-related reservoirs (Sanford. 1961).

Clearly, several dolomitization events resulted in: (1) a ferroan cap dolomite at the top of the Trenton Limestone over much of the area, (2) one or more types of pervasive regional dolomite that extend from northwestern Ohio, through northern Indiana and southern Michigan, and into northern Illinois and southern Wisconsin, and (3) one or more types of dolomite that occur locally and are associated with fractures at local structural features or as fillings in vugs. The geochemistry and petrography of these dolomites have not been systematically studied on a regional basis, and many questions regarding the dolomitization processes and timing of dolomitization remain.

Undoubtedly, the nature of the dolomitizing process has had a profound effect on reservoir quality. The fracture- and solution-related dolomite along tectonic features has resulted in very high quality petroleum reservoirs, but reservoirs in the regional dolomite have been of much poorer quality.

ACKNOWLEDGEMENTS

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