With the obvious erratic deposition which took place in the area in the Miocene, it is easy to understand why multiple stratigraphic reservoirs exist in the University field. It is also generally known from other studies that the Miocene formation in the Gulf Coast of Texas and Louisiana has been erratically deposited, and it is apparent from this knowledge that any known structure in the Miocene belt would be susceptible to stratigraphic reservoirs such as exist in the University field. Greater attention should be employed in the study of small electric-log uncored "kicks" that may be present in the Miocene formation at shallower depths than the producing sands.

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SHOESTRING GAS FIELDS OF MICHIGAN[1]

MAX W. BALL,[2] T. J. WEAVER,[3] H. D. CRIDER,[4] AND DOUGLAS S. BALL[5]

ABSTRACT

The Michigan Stray sand, from which most of Michigan's gas is produced, consists of sand bars formed on offshore shoals in a shallow Mississippian sea. The shoals that caught the bars are on pre-Mississippian anticlinal trends, the sea-floor topography having been determined partly by structure and partly by erosion during a previous period of emergence. Contour maps of the sand bodies are strikingly similar to those of present-day offshore bars. In a field where the pre-depositional sea-floor topography has been worked out, the sand bars were accurately modelled to the shoals that caused them, and the sand piled up behind a small subsea hill or island and built up on the top of a subsea ridge, and a smaller bar formed on a lower shoal across a narrow channel, through which passed enough current to keep the channel almost, but not quite, free from sand. Isopach and isopore maps show that the cleanest sand was deposited in the thickest parts of the main bar, with muddier sand on the lagoonward side. In another field, successive bars were built across a wide shoal area, each bar inshore from its predecessor, and the channels between them were partially filled to form the whole into a continuous sand body.

The sand bodies are of some magnitude and are important gas reservoirs. The largest so far explored is about 9 miles long and 3 wide, and originally held about 50 billion cubic feet of gas. Twenty-three of these shoestring gas fields have been found, with a total original gas content approximating 150 billion cubic feet. None of the shoestring reservoirs of Kansas and Oklahoma shows more clearly its origin as an offshore bar.

INTRODUCTION

In 1929, gas was discovered in the Clare field, Clare County, Michigan, in a sand in the basal part of the Michigan, the lower member of the Grand Rapids group (Mississippian), and in subsequent years twenty-two other gas fields have been developed in a sand at approximately the same horizon. The total original gas content of these fields appears to have been about 150 billion cubic feet, of which about 45 billion cubic feet had been withdrawn prior to 1941.

Because the gas-bearing sand was a "stray" that was unexpectedly encountered above the top of the upper Marshall or Napoleon sandstone and was only encountered here and there, and because it was in the Michigan formation, it came in time to be called the "Michigan Stray" sandstone, a name now firmly established in the field and in the literature.

By 1934, the nature of the Michigan Stray sand as disconnected sand-

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stone lenses and something of the pattern of the occurrence of these lenses were becoming apparent to the more observant geologists working in the area, but, so far as the writers know, no explanation for the lenses or their pattern had been attempted. One night in August of that year, in an off-duty chat between H. D. Crider and Max W. Ball, Crider raised the question as to why the Michigan Stray lenses seemed generally to be found on the long, narrow, northwest-southeast, complex anticlinal trends that cross the Michigan Basin. Ball, ending his first day in Michigan and blessed with the newcomer's ability to explain everything, suggested that the lenses might be offshore sand bars caught on anticlinal shoals in a subsea topography so young that it still reflected structural deformation. In conversations on subsequent days among Ball, Crider, R. B. Newcombe, E. L. Fischer, H. L. Gentry, and others, the offhand suggestion developed into a theory, and on August 27, 1934, Ball incorporated it in a report to the American Light and Traction Company, as follows.

> As yet we have little evidence as to the manner in which the Michigan Stray sand was distributed or the agencies that determined the location and extent of its lenses. Such evidence as we have, however, suggests a strong probability that the long northwest-southeast anticlines, which had been folded long before Grand Rapids time, were below-water ridges in the shallow Grand Rapids seas, and that waves carried and shoved the sand of the Michigan Stray and deposited it in bars on the shoals which these anticlinal ridges formed.
>
> This is all in the realm of theory, but it fits better than any other explanation with such facts as we have.

Since that time, hundreds of wells have been drilled in Michigan Stray fields, a great mass of information has been built up concerning the Michigan Stray lenses, and the theory that they are offshore bars similar in character and origin to the shoestring sands of Kansas and Oklahoma, so well described by Bass and others,[6] has come to be taken as proved by many geologists working in Michigan, though it is not accepted by all.[7]

Acknowledgments

Most of the data on which this paper is based have been gathered

[6] N. Wood Bass, "Origin of the Shoestring Sands of Greenwood and Butler Counties, Kansas," *Univ. Kansas Bull. 23* (1936).

N. Wood Bass, Constance Leathercock, W. Reese Dillard, and Luther E. Kennedy, "Origin and Distribution of Bartlesville and Burbank Shoestring Oil Sands in Parts of Oklahoma and Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 1 (January, 1937), p. 30.

[7] B. F. Hake, "Geologic Occurrence of Oil and Gas in Michigan," *ibid.*, Vol. 22, No. 4 (April, 1938), pp. 393–415.

E. W. Hard, "Mississippian Gas Sands of Central Michigan Area," *ibid.*, Vol. 22, No. 2 (February, 1938), pp. 129–74.

in work done for the American Light and Traction Company, the Michigan Consolidated Gas Company, the Grand Rapids Gas Light Company, the American Production Company, the Consumers Power Company, and Taggart Bros., Incorporated, from 1934 to the present. The writers are indebted to these companies for permission to make use of the data, and particularly to Glenn R. Chamberlain, first vice-president of the Michigan Consolidated Gas Company and president of the American Production Company, for permission to use the illustrations. They are also indebted to E. L. Fischer, J. E. Spindle, H. J. Gabel, W. C. Taggart, C. K. Wirth, R. B. Newcombe, E. L. Hess, Jr., Lee S. Miller, and many others for information and ideas furnished during the years the data have been accumulating, and to R. G. Fortier for helpful service in the preparation of the illustrations. They have drawn freely, moreover, on Newcombe's "Oil and Gas Fields of Michigan,"[8] the indispensable text for anyone studying Michigan geology.

The Michigan Basin

The Michigan Basin is a true depositional basin which occupies the Lower Peninsula of Michigan, parts of the adjoining Great Lakes, and a small part of northern Indiana. The following classical description by Winchell,[9] written in 1860, is quoted from Newcombe.[10]

> It appears, therefore, that the Lower Peninsula of Michigan is surrounded on all sides by ancient axes of elevation; and . . . we must expect to find the strata dipping from all sides toward the center. Every rocky stratum of the Lower Peninsula is, therefore, dish shaped. All together, they form a nest of dishes. The highest strata are near the center of the peninsula; and passing from this point in any direction we travel successively over the outcropping edges of older and older strata.

What this description fails to note is that the "outcropping edges" of the strata are for the most part buried beneath a mantle of glacial drift, which in some parts of the basin is as much as 800 feet thick. Nearly all that is known about the geology of the basin is derived from well records, for outcrops are absent throughout most of the basin, and no geophysical method has yet been found that will reliably penetrate the glacial drift.

The outline of the basin is more nearly circular than most geosyn-

[8] R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Div. Pub. 38* (1933).

[9] Alexander Winchell, "First Biennial Report of Progress," *Michigan Geol. Survey* (1861), p. 44; also *Proc. Amer. Assoc. Advancement of Science*, Pt. 2 (1876), p. 27.

[10] R. B. Newcombe, *op. cit.*, p. 10.

clines, with the lowest known structural portion located in southeast Clare and southwest Gladwin counties. This low point roughly coincides with the geographic center of the Lower Peninsula.

The Michigan Stray sand is found in the central part of the basin in an area about 110 miles north and south by 75 miles east and west.

Structure within the Basin

Much is yet to be learned about the folding that lies beneath the glacial drift of the basin, and what is said must be confined to the folds now known. In the northeast part of the basin are pronounced folds with clearly defined northwest-southeast axes. The folds become less pronounced toward the center of the basin, and in the basin's central part they consist of long, rather narrow, and somewhat sinuous anticlinal zones or trends, with individual anticlines spaced irregularly along them. The irregularity of spacing is both lateral and longitudinal; the individual anticlines are not in perfect alignment, but may lie to right or left of the center of the trend or zone, and they are not spaced at regular intervals along the trends or zones. Broad, shallow synclinal basins appear to lie between the anticlinal trends or zones, though further exploration may show some or all of these to contain other anticlinal trends. Like the more clearly defined structures of the northeast, these folds of the central part of the basin have a northwest-southeast arrangement. Indeed, the folding of the northeast and central parts exhibits a striking parallelism, giving the basin a gently corrugated effect.

In the southwest part of the basin, the folds are poorly developed and have no pronounced pattern. A few folds trend northeast-southwest, and on some of these oil and gas have been found, and there is a suggestion here and there that a northeast-southwest trend may extend into the central part of the basin, influencing the spacing of some of the anticlines on the northwest-southeast trends. As yet, however, this is only a suggestion; there is no present evidence of the existence of a grid pattern such as is found in some of the geosynclines of the Mid-Continent.

The time of the first folding within the basin is not definitely known; it may have been as early as pre-Cambrian. The anticlines of the central part of the basin appear to have attained something comparable with their present development by middle Mississippian time. Post-Mississippian folding is definitely known only in the northeast part of the basin.

The best developed and most productive bodies of Michigan Stray sand so far found are in the central part of the basin and associated with the long, sinuous, irregular anticlinal trends that characterize that area.

Mississippian History of the Basin

The depositional history of the basin has been characterized by frequent emergences and resubmergences, and, especially since the close of the Devonian, by shallow, shifting seas, cut off from, or only imperfectly connected with, deeper and more extensive waters.

In Mississippian time, after the upper Antrim, Bedford, Berea, Sunbury, and Coldwater had been laid down, a series of sediments composed predominantly of sandstone with some shale, and known as the Marshall formation, was laid down. The late Marshall climate must have been rather dry, for the Napoleon sandstone member comprising the upper part of the formation is exceptionally clean, and the late Marshall or Napoleon sea must have been isolated, for the sandstone contains an exceptionally strong brine, the brine for whose development the Dow Chemical Company was originally founded.

After the Marshall was deposited, there was another period of slight uplift, and the top of the Marshall was exposed to erosion. Considered locally, the erosion was comparatively slight; at no place, so far as the writers know, does the surface of the Marshall have a local erosional relief of more than 75 feet. The Marshall shows a definite regional thinning from east to west, but whether this is erosional or depositional is not yet clear. On the north flank of the basin is an extensive tongue of Marshall sandstone that may represent the deposition of reworked Marshall material during this period of general erosion. It has all the characteristics of the true upper Marshall or Napoleon, including the occurrence of gas-producing Michigan Stray sand bodies above it, and its presence has in some areas greatly complicated the identification and correlation of the Marshall top.

In connection with the post-Marshall uplift some further folding probably took place along the old anticlinal axes, for, when the ensuing subsidence came, the anticlines, in places if not everywhere, were marked by low ridges and hills.

The subsidence, which came at the beginning of Michigan (lower Grand Rapids) time, brought a land-locked sea or seas, generally encroaching from east to west, though doubtless with many diversions among the varied topographic features of the early Michigan terrane. In this sea or these seas, the concentration was soon sufficient for the precipitation of calcium carbonate and calcium sulphate. These, with the muds and sands washed in from the adjoining land areas, formed the limestones, anhydrites, shales, and scattered sandstones of the Michigan formation, which in places reaches a thickness of 550 feet.

After the close of the Michigan, there was a new marine invasion, with the deposition of the Bayport (upper Grand Rapids) formation, and another emergence during which the Bayport was removed from some areas. With this emergence the Mississippian was at an end.

Deposition of Michigan Stray

Among the materials carried into the shallow sea of early Michigan time was a comparatively small quantity of sand derived from the erosion of the upper Marshall sandstone. There was not enough of it, apparently, to cover even the shoreward part of the sea bottom, or, except in limited areas, to build extensive beaches; practically all of it seems to have been used in building sand bars on offshore shoals, separated from the shore by relatively quiet lagoons that gradually filled with mud. These offshore bars are the Michigan Stray sandstones.

Most, if not all, of the shoals that caught the bars seem to have been slight topographic "highs" on, or related to, the higher undulations on the anticlines. These topographic "highs" were partly structural and partly erosional, the relative influence of structure and erosion doubtless varying from place to place. The structural factor must be considered as dominant, however, for so far as known no bar of any importance has been found except on or near one of the long anticlinal trends.

As the sea or seas progressed westward, each successive anticlinal trend had its turn at furnishing offshore shoals and receiving sand bars, each set being slightly higher stratigraphically in the Michigan than the one east of it, but each bearing the same general relationship to the top of the Marshall.

In the main, the shoals had been covered by mud and calcareous ooze before the bars began to form, but in places they seem to have been clean and bare, so that the sand of the bar was deposited directly on the upper Marshall sandstone from which, though at some distant point, it had been derived. Thus, in most areas, the Michigan Stray is separated from the Marshall by a few feet of shale, limestone, and anhydrite, but here and there the Stray seems to rest on the Marshall. Considering that the Michigan Stray and the upper Marshall are composed of the same material, the one having been derived from the other, it is not surprising that the logging of the contact between them is not everywhere reliable.

Michigan Stray Gas Fields

Figure 1 shows the gas fields found in the Michigan Stray sand. The Riverside, Winterfield, Lincoln-Freeman, Clare, Grant-Sheridan, Wise,

Fig. 1.—Map of southern Michigan, showing location of Michigan Stray sand gas fields (black) and natural-gas pipe lines.

Vernon, and Denver fields comprise the most easterly group so far developed. They appear to be within an anticlinal zone, which may in turn comprise two or more narrower anticlinal trends. The Sheridan and Broomfield fields lie on a more westerly trend. The Austin, Six Lakes, Edmore, New Haven, and a few small intervening fields not noted on the map are in a still more westerly zone which also seems to include two or more trends. Reed City, on the northwest, may be on the Broomfield-Sheridan trend, or on the Austin-Six Lakes-New Haven zone, or on an intermediate trend of its own. Still farther west is Winfield, with no other fields yet found on its trend, but with its axis as definitely northwest-southeast as the others. The eastern group are associated with more pronounced folds, having greater structural relief than the folds associated with the more westerly fields.

As the underlying Marshall and the Michigan Stray itself are unpromising source rocks, it is practically certain that the gas in the Stray originated in the enclosing and overlying shales and limestones of the Michigan. Three wells in the Grant-Sheridan field produced a little 31° A.P.I. mixed-base oil from the Stray for a short period of time; a core taken in the Six Lakes gas field showed moderate oil saturation in the lower part of the sand; and in other isolated areas the Stray has produced small quantities of oil. However, the gas produced in every major Stray gas field is dry.

As a rule, the Marshall brine is excluded from the Stray by a few feet of Michigan shale and limestone, but here and there the Stray lies directly on the Marshall. Few wells encounter Marshall brine in the top few feet of the formation, indicating that these top few feet are relatively impervious, perhaps rendered so by deposition of mineral matter from the brine itself. These seals, whether of relatively impervious Marshall sandstone or of Michigan shale and limestone, are not effective against pronounced differences in pressure. Too heavy a pull on a gas well in the Stray, particularly a well near the edge of the Stray lens or one drilled too deeply into it, will cone up Marshall water and drown out the well. There seems to be little if any encroachment by Marshall water, however, so long as wells are not overproduced.

With these general facts in mind, the easiest way to study the formation of these shoestring fields is to consider a few examples, and the remainder of this paper is devoted chiefly to the two fields that have been most studied, the Austin and Six Lakes fields, with a brief consideration of the Vernon field as an example lying on a different anticlinal trend and showing a poorer degree of sand-bar development.

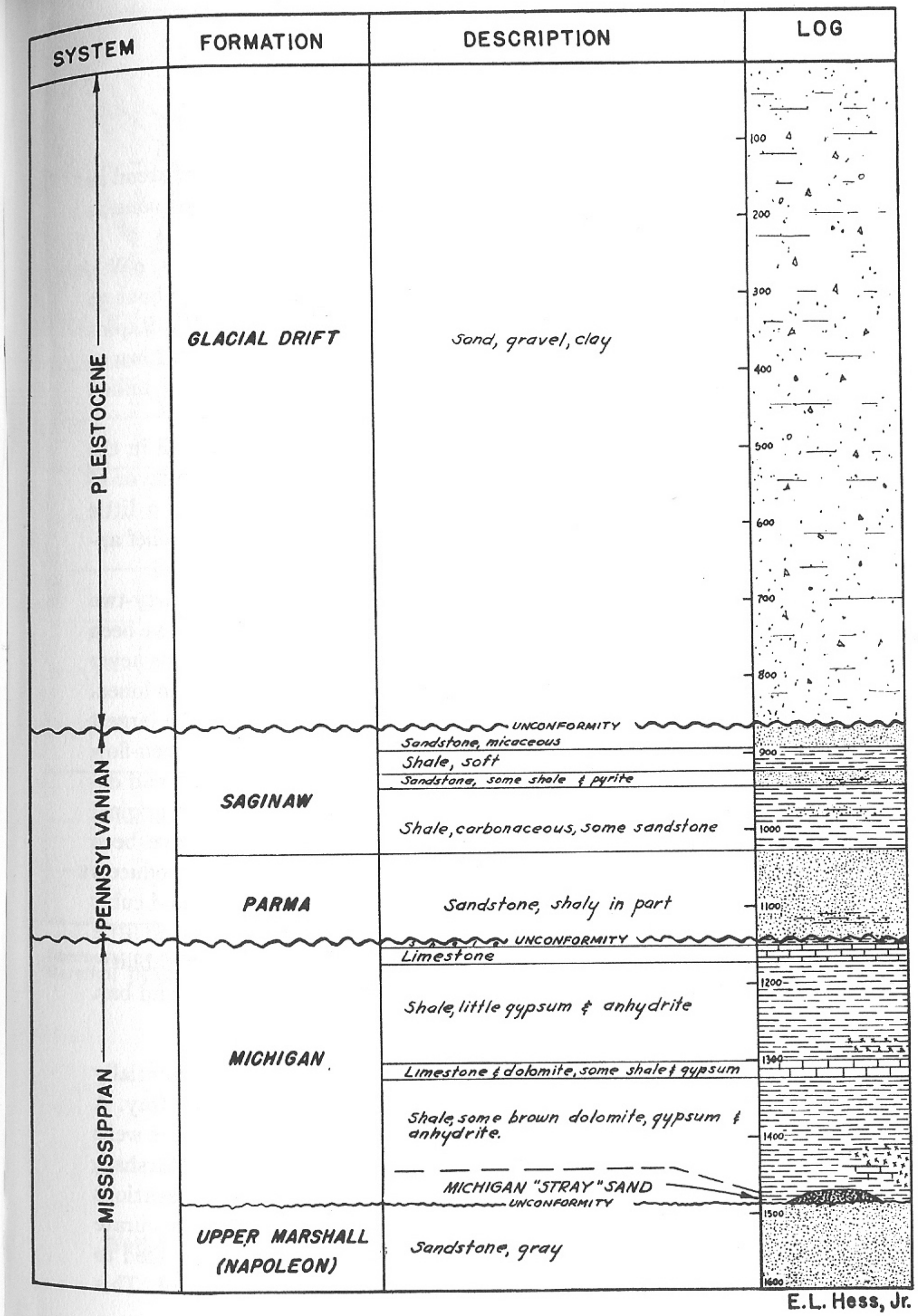

Fig. 2.—Geologic column, Austin locality. Vertical scale in feet.