UMR Journal -- V. H. McNutt Colloquium Series

Volume 3

Article 4

December 1982

The Michigan Basin

L. L. Sloss

The Michigan Basin

L. L. SLOSS*

ABSTRACT

The Michigan basin is widely acknowledged to be the archetype among those basins of cratonic interiors whose subsidence is dominated by flexure rather than faulting. Broadly ovate in plan over an area of some hundreds of thousands of square kilometers, with a preserved Phanerozoic sediment thickness exceeding 4 km accumulated during distinct episodes of subsidence over a 500-million year span, the basin is endowed with significant fossil-fuel resources.

The basin area is crossed, from north-northwest, by a rift zone filled with mafic igneous rock and great thickness of sedimentary rock resting on Archean and Middle Proterozoic crystallines. Rifting is presumably of Keweenawan age, but the igneous rocks cannot be dated more explicitly than "older than 600 myBP". The ill-defined Grenville Front lies near the eastern basin margin.

The basin area, along with the whole of the cratonic interior, suffered intensive erosion before Late Cambrian time when renewed sedimentation began; probably as a northern extension of the Illinois basin-Mississippi Embayment.

Basinal subsidence conforming to the present architecture of the Michigan basin began in mid-Ordovician time, to be followed by further pulses of significant downwarp in the Middle and Late Silurian, Middle Devonian, and Middle Mississippian. Minor accumulations of Pennsylvanian, Jurassic, and Pleistocene sediments are preserved; the Pennsylvanian episode appears to have been accompanied by basement faulting during which the greater part of deformation of the basin fill occurred.

Each of the major episodes of basinal subsidence is marked by changes in the geometry of the basin, such as changes in the position of the depocenters and degree of confinement of expansion of the basin interior.

Episodes of more rapid subsidence of the Michigan basin, times of change in basin geometry, and intervening episodes of stability (commonly accompanied by erosion) are synchronous with similar basins of the North American and other cratonic interiors.

INTRODUCTION

The Michigan basin is an appropriate subject for study. Long considered to be the archetype of sedimentary basins of continental interiors, its exposed margins have been investigated for well over a century. It has been penetrated by thousands of boreholes in the past several decades and has had its magnetic, gravitational, and seismic pulse taken many times, and yet we do not know what makes it tick as a tectonic element or as a repository of oil and gas.

In the course of this colloquium, audiences have been exposed to a variety of basins of the North American craton; of these, only the Williston (see Gerhard, this volume) joins the Michigan basin in being recognizable as a genuine *interior basin*. Interior basins are those entirely surrounded by continental crust, lacking extensions to contemporary continental margins, and are essentially free of major syndepositional effects of faulting. Interior basins are also among those for which we have no adequate theory in geodynamics.

Acknowledgment.—Many of the thoughts contained in this report were developed while the writer was being supported by the following National Science Foundation grants: DES 74-22337, EAR 76-22499, and 80-19315.

GEOLOGY

The surface form of the Michigan basin is well shown by the areal geology (Fig. 1). It is roughly circular, several hundred kilometers across, and confined within encircling outcrops of Ordovician and Silurian platform carbonates. (Lakes Michigan and Ontario occupy glacially-enlarged valleys marking the subcrop of Silurian salt and related collapse breccias.) The basin interior bears a thin and deeply-eroded record of Pennsylvanian and Jurassic sediments. Preservation of these strata is indicative of continued subsidence (or less elevation) during sub-Zuni and younger episodes of erosion that scarred surrounding terrains. In fact, the Phanerozoic subsidence history of the basin can be extended to well over 400 million years by noting that the pre-glacial surface is depressed significantly below sea level near the basin's center, presumably in response to ice loading.

The net effect of long-continued subsidence is shown by the structure of the Precambrian surface (Fig. 2), which reveals a bowl-shaped depression centered near the end of Saginaw Bay where a maximum of about 4.7 km relative to the adjacent Wisconsin arch is attained.

What else do we know about the gross features of the basin? For one thing, the southern peninsula of Michigan is crossed from northwest to

*Department of Geological Sciences, Northwestern University, Evanston, Illinois 60201.

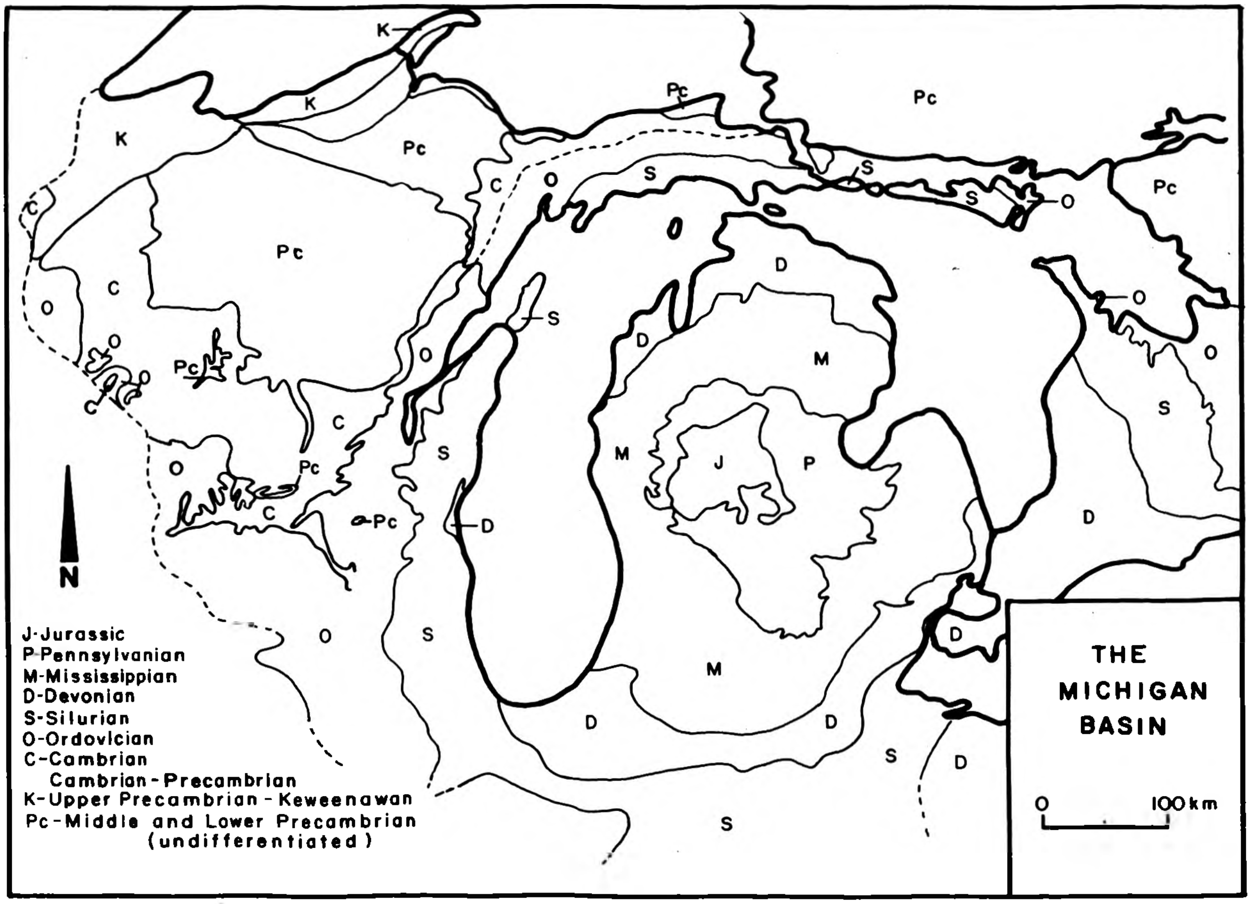

Fig. 1. Areal geology of preglacial chronostratigraphic units of the Michigan basin. After Stonehouse (1969), with permission of the Michigan Basin Geological Society.

southeast by a profound gravity anomaly (Hinze and others, 1975) featuring a well-defined curvilinear positive flanked by more diffuse Bouguer-negative borders. Deep drilling (Sleep and Sloss, 1978, and accompanying detailed papers) on the eastern margin of the anomaly penetrated about 1.5 km of firmly lithified sub-Sauk clastic sediments floored by metabasic igneous rock. It is presumed that these rocks, as in the case of the similar Midcontinent Gravity High, are Keweenawan, but no isotopic "ages" have been obtained; paleomagnetic data suggest involvement with a 600 myBP thermal event. A COCORP deep seismic reflection line, not yet fully evaluated (at least to my knowledge), appears to confirm the rift origin of the Central Michigan anomaly. In any case, the anomaly and its contributing rocks do not conform to the geometry of the basin, and the time of emplacement is at least 150 my earlier than the initiation of basinal subsidence.

Thanks in large part to a series of basin-wide isopach and facies studies by James Fisher and his students at Michigan State University, the subsurface record of the Michigan basin has been integrated to reveal the most intimate details of basin evolution. These maps, plus augmentation from other sources, show that there was little basinal behavior during Sauk (Cambrian-Early Ordovician) deposition. (Interested readers should consult Catacosinos, 1973.) The present form of the basin dates from Middle Ordovician and, with a few notable exceptions, has remained remarkably constant since. That is, successive depocenters tended to remain southwest of Saginaw Bay. Subsidence departed widely from a constant rate with the passage of time, however, and the positions of hingelines defining the basin interior were similarly variable.

Middle Ordovician basinal subsidence was followed by Late Ordovician and Early Silurian episodes of alternating basinal and platformal behavior. Middle and Late Silurian history is beset with major controversies created by differences of opinion as to the relationships of platform carbonates, pinnacle reefs, and evaporites (see for example, Mesolella and others, 1974), but regardless of interpretation, late Middle and Late Silurian were times of very rapid downwarp of the basin interior with concomitant effects on sedimentary facies. This period of subsidence gave way to broad Early Devonian stabilization leading to and accompanying development of the craton-wide sub-Kaskaskia erosion surface.

The course of renewed deposition in the Middle Devonian has been magnificently documented by Gardner (1974). He shows early Middle-Devonian basinal subsidence centered over the Saginaw Bay depocenter followed by times of platform absence of a well-defined basin and then by accelerated depression and salt deposition but now centered well to the northwest of Saginaw Bay. Immediately after the salt episode, the depocenter returned to its traditional position, and the basin broadened until, at the close of Middle Devonian time, although truncated to the north by Pennsylvanian (?) erosion, it appears to have extended over the now-exposed Shield toward the James Bay lowlands.

Late Devonian and earliest Mississippian time presents no record of significant basinal development; instead, the region was covered by a blanket of black shale in concert with much of the Midcontinent area. Genuine basinal behavior, including salt accumulation, recurred yet again in the Middle Mississippian, ending the functional life of the Michigan basin—but do not forget that the basin stirred again in Late Paleozoic, mid-Mesozoic, and Pleistocene death throes.

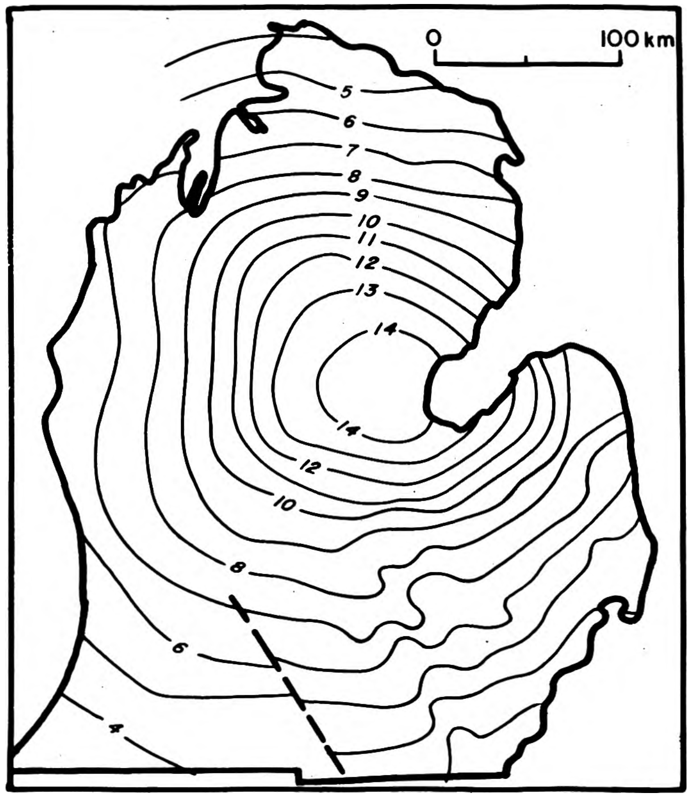

Fig. 2. Structure contours, in thousands of feet, on the top of the Precambrian in the Lower Peninsula of Michigan. After Hinze and Merritt (1969), with permission of the Michigan Basin Geological Society.

OIL AND GAS

Oil and gas are distributed widely, geographically and stratigraphically, in the Michigan basin. The greatest concentration is at Albion-Scipio near the southern margin of the basin. Here, a very narrow, northwest-trending strip produces from locally dolomitized Middle Ordovician carbonates. Enhanced porosity/permeability appear to be the product of alteration along a fracture zone. Efforts to duplicate the rich productive potential of Albion-Scipio have resulted in little beyond extreme frustration. Greater satisfaction among geologists and geophysicists (and significantly greater profit) derives from exploration of Silurian pinnacle reefs that produce handsomely in a narrow zone basinward of the encircling platform carbonates and associated barrier reefs. Pinnacle-reef production has been exploited for years in the Detroit area and in an adjoining patch in Ontario, but attempts to expand the producing area were inhibited by dry holes in more basinal sites where reefs tend to be salt plugged and by inability to locate reefs by seismic methods below thick glacial drift in sections of low acoustic-impedance contrast. Once the geophysical problems were solved, reef exploration expanded explosively and very successfully around the northern rim of the basin, impeded only by environmental constraints and by Lakes Michigan and Huron at either end of the northern fairway. Note that both "Trenton" (Middle Ordovician) and Silurian reef production involve areas near the periphery of the basin. These sites raise problems of source and migration as will be discussed in a later paragraph.

The long-term, traditional hunting ground of the Michigan basin has been nearer the basin's center in Middle Devonian sebkha related (?) dolomites, commonly on readily identifiable major structural trends. Here, the Dundee Formation has been the major productive interval. Modest gas reserves have been exploited in shallow stratigraphic traps among lensing Lower Mississippian sands. In the past year, deep drilling near the basin's center discovered an encouraging volume of gas in sub-Trenton sandstones, presumably Cambrian or Early Ordovician Sauk units. With the exception of a few small pools in Ohio and on the Niagara Peninsula of Ontario, Sauk strata have not been shown to have a significant production potential north and east of Kansas; thus, confirmation of the deep Michigan discovery would have important implications for the future.

These, then, are the contributors to the Michigan basin oil and gas picture. The sum is not great by world standards but is a much-prized and welcome addition to the energy-poor resources of a heavily-populated and intensively-industrialized region. It is clear that the tectonic evolution of the basin is responsible for the character and distribution of traps and reservoir rocks. Inasmuch as the basin has been so thoroughly studied, it has become a model for consideration of like basins elsewhere. What is less obvious is the linkage between subsidence history and the maturation and migration of hydrocarbons.

Nunn (1980) modeled the subsidence and thermal histories of the Michigan basin and found that appropriate temperatures for the maturation of kerogens have been attained only in Middle Ordovician and older strata and only in the central, most deeply subsident, area of the basin. These findings fit the distribution of significant production and reserves in Middle Devonian reservoirs, if one assumes vertical (fault-controlled?) migration from Ordovician source beds. Similarly, the enigmatic Albion-Scipio trend of Middle Ordovician production is not contradicted by Nunn's model, given a modest distance of lateral migration. However, the northern Silurian pinnacle-reef trend would require seemingly excessive migration paths from the basin's interior; further, the chemistry of the Silurian reef oil is reported to be such as to preclude derivation from Ordovician source strata near the basin's depocenter. To add yet another complication, there is evidence that oil migration into Niagaran/Salinan reefs preceded salt crystallization that plugs pores. If this were to be verified and if, as some maintain, the salt plugging is the product of Late Silurian desiccation, then we have real problems. Either the threshold of the oil-maturation "window" must be lowered to include lesser temperatures, or Nunn's subsidence/thermal model (and all similar calculations) are seriously in error, or the Michigan basin was buried by a much thicker section of the Pennsylvanian and younger strata than has been assumed. The latter suggestion appears to be in fatal conflict with preliminary vitrinite-reflectance data that indicate no more than a few hundred meters of post-Pennsylvanian burial.

BASIN GENESIS

A number of questions relating to the Michigan basin and its hydrocarbon resources could be approached more systematically if there were an acceptable basis in geodynamic theory to explain the tectonic evolution of the basin and its sedimentary fill. One segment of conventional wisdom attributes subsidence to the load imposed by the accumulation of sediment, which, in turn, is a reflection of global sea-level changes. It can be demonstrated (e.g., Watts and Steckler, 1981) that loading is inadequate to account for the amplitude of subsidence, and it is popular to appeal to thermal contraction as the root cause. Heating and subsequent subsidence of a rifted continental margin is readily acceptable and, indeed, the subsidence curves of such margins can be fit to the predicted decay of rates of subsidence that would result from thermal contraction. Turcotte and associates have applied thermal models to interior basins (e.g., Haxby and others, 1976) but founder on the disconcerting observation that the subsidence history of cratonic basins records stops and starts and changes of pace that do not fit a simple negative exponential expression. Norman Sleep and his students (e.g., Sleep and Snell, 1976) have combined thermal contraction with eustatic events to tiptoe around the irregularities of basin subsidence, but, at least in the case of the Michigan basin, there is no record of a heating event of appropriate date to initiate subsidence and no evidence of the uplift that would precede downwarping. Falvey (1974) has invoked thermally related phase changes in the crust to create subsidence, and the postulate has been applied to cratonic basins by Middleton (1980), but here, again, the evidence for localized heating events and their consequences is lacking. It has been shown (e.g., Sloss, 1978, 1981) that there is a remarkable degree of global synchroneity in the times of rapid subsidence of sedimentary basins, whether these be on cratonic interiors or at continental margins. Beyond some quite unsupported thoughts on the subject (Sloss and Speed, 1974), I have no explanation for these observations, but they stand as currently insurmountable barriers to the acceptance of popular concepts on the origin and evolution of sedimentary basins. What remains clear is that answers must be found before the Michigan basin can fulfill its promise to become a natural textbook for the exploration of similar basins throughout the world.

REFERENCES

Catacosinos, P. A., 1973, Cambrian lithostratigraphy of Michigan Basin: Amer. Asso. Petroleum Geologists Bull. v. 57, p. 2404-2418.

Falvey, D. A., 1974, The development of continental margins in plate tectonic theory: Aust. Petroleum Expl. Assoc. Jour., v. 14, p. 95-106.

Gardner, W. C., 1974, Middle Devonian stratigraphy and depositional environments in the Michigan basin: Mich. Basin Geol. Soc., Spec. Papers 1, p. 1-132.

Haxby, W. F., Turcotte, D. L., and Bird, J. M., 1976: Thermal and Mechanical evolution of the Michigan basin: Tectonophysics, v. 36, p.57-75.

Hinze, W. J., and Merritt, D. W., 1969, Basement rocks of the Michigan basin: Studies of the Precambrian of the Michigan basin, H. B. Stonehouse, ed., Mich. Basin Geol. Soc., 1969 Ann. Field Excursion, p. 28-59.

________________, **Roy, R. F., and Davidson, D. M.,** 1975, Geophysical studies of basement geology of southern peninsula of Michigan: Amer. Assoc. Petroleum Geologists Bull., v. 59, p. 1562-1584.

Mesolella, K. J. and others, 1974, Cyclic deposition of Silurian carbonates and evaporites in Michigan basin: Amer. Assoc. Petroleum Geologists Bull., v. 58, p. 34-62.

Middleton, M. F., 1980, A model of intracratonic basin formation, entailing deep crustal metamorphism: Geophys. Jour. R. Astr. Soc., v. 62, p. 1-14.

Nunn, J. A., 1980, Thermal contraction and flexure of intracratonic basins: A three-dimensional study of the Michigan basin: unpubl. Ph.D. thesis, Northwestern University, Evanston, IL.

Sleep, N. H., and Sloss, L. L., 1978, A deep borehole in the Michigan basin: Jour. Geophys. Res., v. 83, p. 5815-5819.

________________, **and Snell, N.,** 1976, Thermal contraction and flexure of Midcontinent and Atlantic marginal basins: Geophys. Jour. R. Astr. Soc., v. 45, p. 125-154.

Sloss, L. L., 1978, Global sea level change: a view from the craton: Amer. Assoc. Petroleum Geologists Mem. 29, p. 461-467.

________________, 1981, Subsidence of continental margins: the case for alternatives to thermal contraction *in* Geodynamics of seismically inactive continental margins: Inter-Union Comm. on Geodynamics, Working Group 8, R. A. Scrutton, ed., Geodynamics Series, Amer. Geophys. Jour. and Geol. Soc. America.

________________, **and Speed, R. C.,** 1974, Relationships of cratonic and continental margin tectonic episodes: Soc. Econ. Paleontologists and Mineralogists, Spec. Publ. 22, p. 92-119.

Stonehouse, H. B., 1969, Studies of the Precambrian of the Michigan basin, H. B. Stonehouse, ed.: Mich. Basin Geol. Soc., 1969 Ann. Field Excursion (map inside front cover).

Watts, A. B., and Steckler, M. S., 1981, Subsidence and tectonics of Atlantic-type margins: Oceanologica Acta, Supplement to v. 4, p. 143-153.