The North American Midcontinent and the Genesis Flood

Part I: Mapping Surfaces

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Abstract

Maps of diluvial boundaries for the North American midcontinent are presented by state and by sedimentary basin. The upper diluvial boundary is the base of Ice Age sediments. For most of the study area, the basal diluvial boundary is the erosional unconformity between Precambrian crystalline rock and the Phanerozoic sedimentary record. The exceptions are Proterozoic to Cambrian rifts: the Midcontinent, East Continent, Fort Wayne, Reelfoot, Rough Creek Graben, and Rome Trough rifts. These are remnants of severe crustal disruption at the onset of the Flood, with varying ratios of volcanic and sedimentary fill. This paper focuses on the basal marine diluvial boundary and the upper diluvial boundary, excluding the rifts, showing the volume and distribution of sediments of the Ice Age. Deep Proterozoic rifts will be addressed in Part II. Detailed state maps of the basal diluvial boundary are shown in the appendix. Maps of the study area reveal cratonic basins of varying size, show a thickening of diluvial strata toward the south, and show the extent of Ice Age deposition. All these aid in understanding the work of the Flood in this region.

Key Words: Early Flood, Illinois Basin, Michigan Basin, Midcontinent, Precambrian, sedimentary basin, Williston Basin

Introduction

Scripture and science tell us that the Flood was a catastrophic global event. Details of these processes in any given locale are open only to forensic investigation and could include: vertical and horizontal tectonics, overthrusting, the formation of rifts and sedimentary basins, powerful earthquakes, huge tsunamis, volcanism, impacts, and associated erosion, transport, and deposition, which included the burial of trillions of organisms. Many geological questions confront an understanding of the Genesis Flood, and skeptics challenge us on these issues.

One of the most basic products of the Flood is the sedimentary record. Sediments raise may questions. How much sediment exists on the continents

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today? How much sediment is in the oceans? How much ocean sediment was eroded off the continents? How much of the record is from the Flood? How much sediment accumulated on the continents at the peak of the Flood, approximately 150 days (Boyd and Snelling, 2014)? Where did this sediment originate? How was it transported?

The Flood Sediment Research Project

In order to answer the above questions and spur research, we have started the *Flood Sediments Research Project*. This is primarily a mapping project because we consider maps to be the language of geology. Thanks to the GlobSed project, we have a good estimate of the sediments in the oceans (Reed et al, 2022). The GlobSed goal was to map the distribution and thickness of ocean sediments. A rough estimate for the total sediment thickness and volume for the ocean sediments was published in 2003 and in 2013. These two attempts contained uncertainties that were addressed by Straume et al. (2019). Version 3 of GlobSed (Straume et al., 2019) increased the projected volume of oceanic sediments by an astounding 29.7% over earlier versions. New data for the northeast Atlantic, the Mediterranean Sea, and the Arctic and Antarctica continental margins were largely responsible for this change.

The next logical step is to determine the volume and distribution of continental sediments and to link that to continental margin sediments (GlobSed maps stop at the coastlines) to assess Flood runoff. One challenge is to map at a sufficient level of detail relative to the available data. Once complete, we can better estimate the amount of sediment eroded and transported from somewhere onto the continents and try to assess its place in the Flood. Several wide-ranging estimates have been made in the past (Reed et al., 2022). Clarey (2020) has compiled sediment thickness, but he used oceanic sediments from the margin and some Precambrian sediment. Therefore, we have concluded that we need to do our own estimate of continental sediments. We are mapping on a state-by-state level because state sources best provide a sufficient level of detail without becoming overwhelmed by data. States provide well data, some seismic profiles, gravity data, and reports and maps by local experts. Using these data, we compile GIS maps of the lower and upper diluvial boundaries which yield volumes for basins, states, or any other geographic boundary. Colorado served as a pilot study (Reed et al., 2023). Of course, data quantity and quality vary by state. Our ultimate goals are to provide maps and volumes for North America and to develop a GIS mapping method that can easily be applied to other continents. Each state and region also provides more concrete and detailed data to support Flood models.

The Midcontinent Rift and Surrounding States

The North American midcontinent region has been geologically well studied for more than a century. Mining, oil and gas, water resource discovery and conservation, and environmental concerns have driven robust data acquisition and interpretation, and a correspondingly robust understanding of this region's surface and subsurface geology. If maps are the language of geology, then mapping within the diluvial paradigm is of utmost importance. For that reason, we present regional maps showing diluvial boundaries and derivative volumes of diluvial and Ice Age strata, as well as their distribution. The study area (Figure 1) is a broad cratonic surface, punctuated by rifting and large sedimentary basins. The North American Midcontinent Rift is the largest single feature of this study area and one of great interest to geologists. For diluvialists, it illustrates crustal disruption at the beginning of the Flood (Reed, 2000; Clarey, 2020). Though many studies continue to be published (i.e., Miller and Nicholson, 2013; Stein et al., 2015; Woelke and Hinze, 2015; Stein et al., 2016; Fairchild et al., 2017; Stein et al., 2018a, 2018b; Grauch et al., 2020; Hinze and Chandler, 2020), maps of the Midcontinent Rift are limited to its surface or bedrock (sub-glacial) two-dimensional extent, both in terms of volcanism and sedimentation. Horst-top and flanking basins have been characterized (e.g., Anderson, 1990; Jirsa et al., 2011; Woelke and Hinze, 2015), but no map of the base of the rift is available. We will present such a map in Part II, as well as integrating maps of the basement beneath the East Continent Basin, the Reelfoot Rift, the Rough Creek Graben, and the Rome Trough. Three-dimensional maps of the basal diluvial boundary of the entire study area are a prerequisite of any forensic investigation of the Flood. Crystalline basement is exposed in uplifts of the Black Hills of South Dakota and the St. Francois Mountains of Missouri. Proterozoic quartzites (Sioux, Baraboo) are also exposed in South Dakota, Minnesota, and Wisconsin. Both crystalline basement and these quartzites immediately underlie glacial sediments in large parts of Wisconsin, Minnesota, and Michigan. Otherwise, the basement is known from deeper well penetrations, seismic lines, and maps of gravity (Kucks, 1999) and magnetic anomalies (Bankey et al., 2002). In a few parts of the rifts, notably the Rough Creek Graben and Rome Trough, well penetrations are helpful, as are outcrops of the Midcontinent Rift around Lake Superior, but the Midcontinent Rift, the East Continent Basin, the Reelfoot Rift-Rough Creek

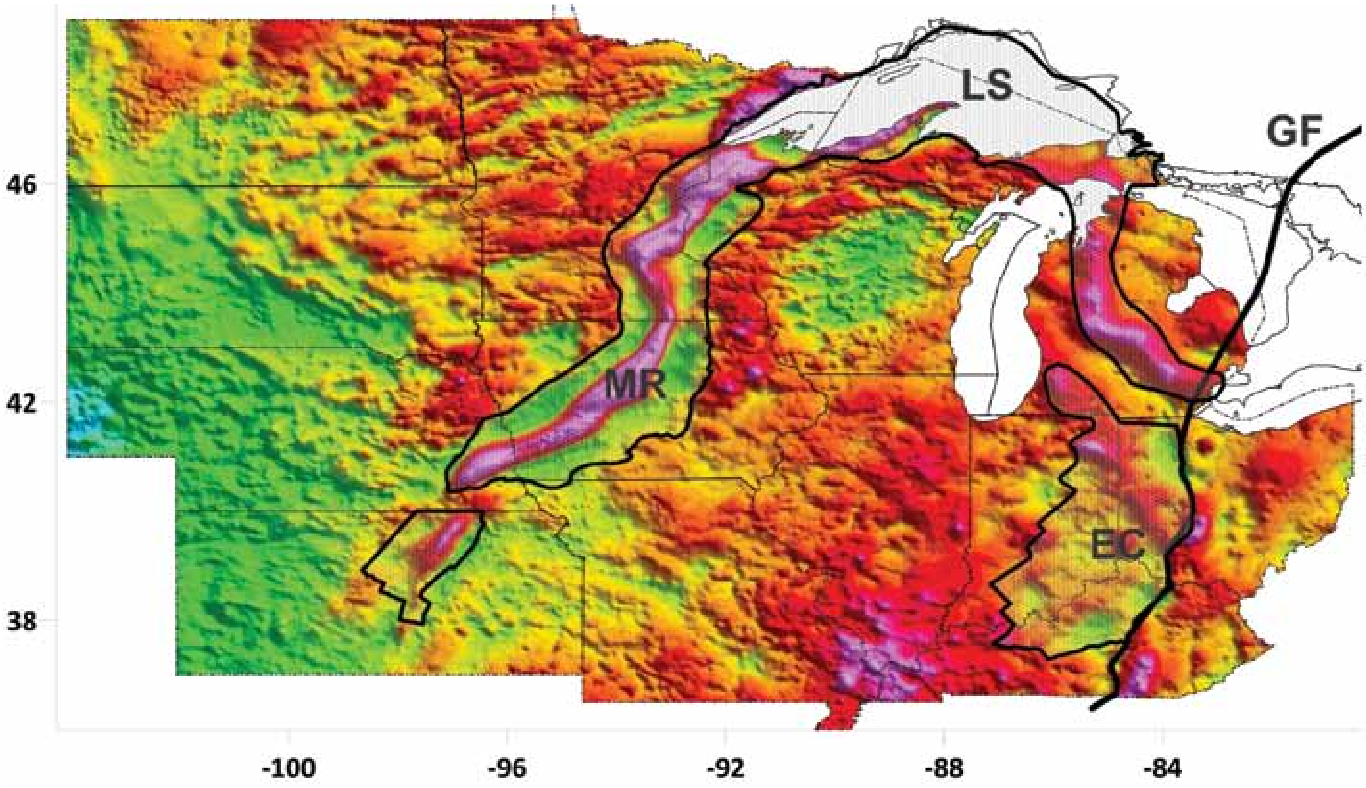

Figure 1. Study area of this paper shown on the Bouguer Gravity Anomaly map (Kucks, 1999), showing the Midcontinent Rift (MR), East Continent Basin (EC), and Grenville Front (GF). The largest, deepest part of the Midcontinent Rift is in the Lake Superior Basin (LS). Pink, purple, and red are positive gravity anomalies, while green colors are negative gravity anomalies. Notice in the MR that high gravity anomalies, representing horsts of uplifted denser rocks, are found in the center. They are surrounded by low gravity anomalies, representing sedimentary basins along the edge.

Graben, the Rome Trough, and even a proposed Illinois Graben (Freiburg et al., 2022)—are known largely by geophysical investigation.

Relationships between these rifts are discounted by secular geologists due to different dates (e.g., Drahovzal and Harris, 1998 vs. Moecher et al., 2018). Although the Midcontinent and East Continent rifts are roughly age equivalent, ~1.1 Ga, southern rifts in the study area are dated nearly 600 million years later, as Early Cambrian, in Ohio, Kentucky, and Indiana (Drahovzal et al., 1992); at the boundary of Missouri, Arkansas, Tennessee, and Kentucky (Dart, 1995; Hickman, 2011, 2013); in eastern Kentucky, West Virginia, and Pennsylvania (Drahovzal and Noger, 1995; Gold et al., 2005). Although outside the study area, the nearby Oklahoma Aulacogen (Reed, 2004) is also dated as Early Cambrian. However, a Biblical paradigm might suggest that large similar tectonic features reflecting a significant disruption of the antediluvian crust would be of similar age and related in their genetic cause.

Method

We mapped a rectangular study area (Figure 1) to show regional context and minimize gridding anomalies. It covers 13 states and a small part of Ontario. Our goal is to define three volumes: (1) Ice Age (and Recent) sediments, (2) diluvial marine strata, and (3) diluvial rift fill. These require four gridded surfaces: (1) a digital elevation model (DEM), to represent surface topography; (2) the base of glacial deposits; (3) the base of the marine diluvial; and (4) the base of the diluvial rifts (Figure 2). The volume and distribution of these stratal packages provides fundamental information about the Flood and Ice Age and facilitates volume and thickness comparisons to other regions. For the study area, diluvial marine strata are those between the Precambrian crystalline basement and the erosional unconformity underlying Ice Age sediments. Subglacial strata are commonly called "bedrock" to differentiate them from glacial sediments.

It is worth noting that the Ice Age and Recent sediments are probably reworked diluvial deposits. Using regional-scale maps and DEMs, differentiation of very thin sediments draping irregular surfaces can introduce isopach mapping and volume calculation errors. That is why we calculated Ice Age volumes and then subtracted them from the total volumes to derive the Flood totals. As will be shown, the Ice Age volumes are quite small in proportion, especially when factoring in the rift fill. Exceptions are found in Minnesota and Wisconsin, which have thin diluvial and thick Ice Age strata. Our maps (in the appendix) were developed from those published by state geological surveys, supported by publicly-available well data and published geophysical data. To a lesser degree, we use other publications from journals and state surveys, USGS sources, and dissertations. Many of the state maps were modified, often to rectify them with surrounding states.

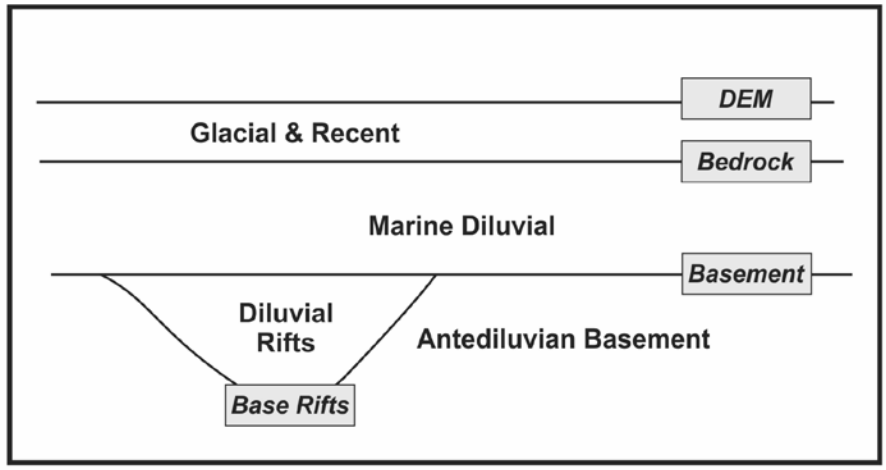

Figure 2. Schematic of three volumes to be assessed and four map horizons to define them. DEM = Digital Elevation Model (representing surface topography).

DEM

The USGS (https://www.usgs.gov/faqs/what-digital-elevation-model-dem) defines a digital elevation model (DEM) as "a representation of the bare ground (bare earth) topographic surface of the Earth excluding trees, buildings, and any other surface objects." Newer DEMs are the product of lidar, or aerial laser pulses bouncing off the ground and back to aerial sensors. These produce detailed, accurate pictures of ground topography. The level of detail is a function of the scale, representing a balance of detail and file size. Detailed DEMs are often available but unworkable at our scale due to computational limits. The extent of current data and their downloads can be found at the National Map downloader at https://apps.nationalmap.gov/downloader/. We tested three workable options: (1) NASA's Shuttle Radar Tomography Mission (SRTM) in 1 arc-second resolution, (2) NOAA's ETOPO global relief model in 15, 30, and 60 arc-second resolutions, and (3) the USGS 3-D Elevation Program (3DEP) dataset. We found that ETOPO provided similar resolution to the slower 3DEP, with fewer problems than SRTM. For finer scale work, we would recommend the 3DEP surface or DEMs from state sources. This is especially true of areas with thin or irregular sediment cover and abrupt topography.

Sub-Glacial Bedrock Surface

During the Ice Age, sediment was transported and deposited by glaciation and by associated processes, such as glacio-fluvial processes (Oard, in press). Their extent has been mapped (Figure 3) and covers much of the study area. Thicknesses rarely exceed a few hundred feet and are thin at the margins. These thicknesses are small compared to the total diluvial sedimentary record. Exceptions are found in Minnesota and Wisconsin, and beneath Lake Superior, where they exceed 1,700 ft. (518 m) per Soller and Garrity (2018) or 2,500 ft. (762 m) per Hamilton (2020). However, the average thickness over all of Minnesota is only 195 ft. (59 m). But the thin marine diluvial record makes the glacial fraction of the total sedimentary record more significant: 57% of the total in Minnesota and 19% in Wisconsin. Other states range from < 1% to 7%. Ice Age thicknesses are significant in Michigan but still small compared to the Michigan Basin fill. Once rift fill is factored in, these percentages drop precipitously. In Minnesota, they drop to 5.48%, Wisconsin, to 1.36%, and Michigan to 0.9%. The other states range from 0.09% to 4.48%. For the study area as a whole, the percentage of Ice Age sediments drops from nearly 2.66% to 1.36%. Even with mapping uncertainties, the Ice Age record is still very small.

The bedrock (Figure 4) is a rough, well-incised erosional surface, probably reflecting the post-Flood, and perhaps even Late Flood, drainage system development. Figure 4 was constructed from a variety of state sources

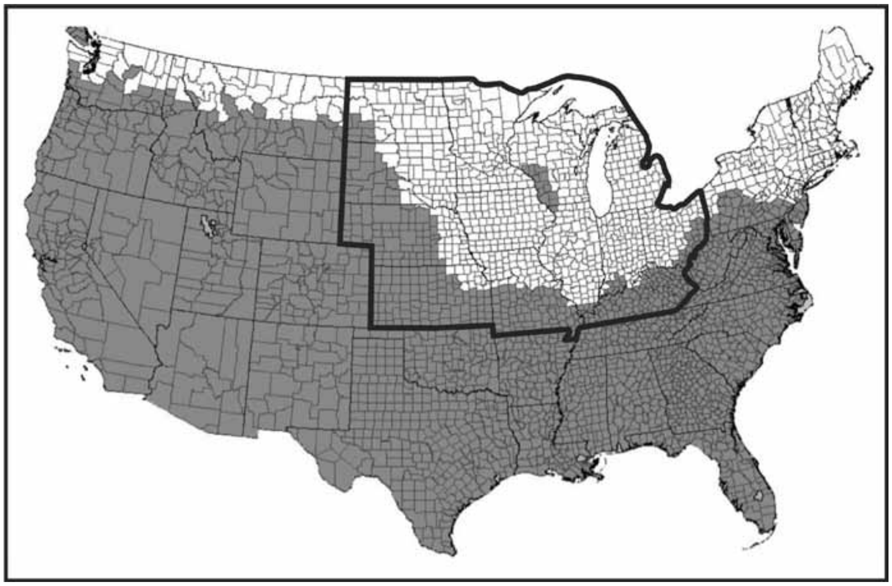

Figure 3. Glacial extent in upper Midwest. Note that every state in the study area has some Ice Age sediments. Modified from https://mapsontheweb.zoom-maps.com/post/78118597495/extent-of-glacial-ice-sheets-in-the-united-states.

(Hansen, 1972, 1973, 1975, 1978, 1985, 1986, 1992; Cagle, 1973; Gray, 1982; Hansen and Runkle, 1986; Herzog et al., 1994; Denne et al., 1998; Tomhave and Schulz, 2004; Hamilton, 2020) and sources from the USGS (Soller, 1997; Soller and Garrity, 2018). Maps from the Minnesota, Illinois, Indiana, Ohio, and South Dakota surveys are the most detailed. Michigan, Nebraska, North Dakota, and Wisconsin offer no maps, though Wisconsin is working on detailed maps at the county scale. For that reason, we used the less detailed contours of Soller and Garrity (2018) to create a unified map of the bedrock topography. A large portion of southwestern Wisconsin has no glacial sediment (note darker gray counties on Figure 3 and white area in Figure 4). The outline of this "driftless region" in Wisconsin, Minnesota, and Iowa is well-defined (Carson et al., 2023).

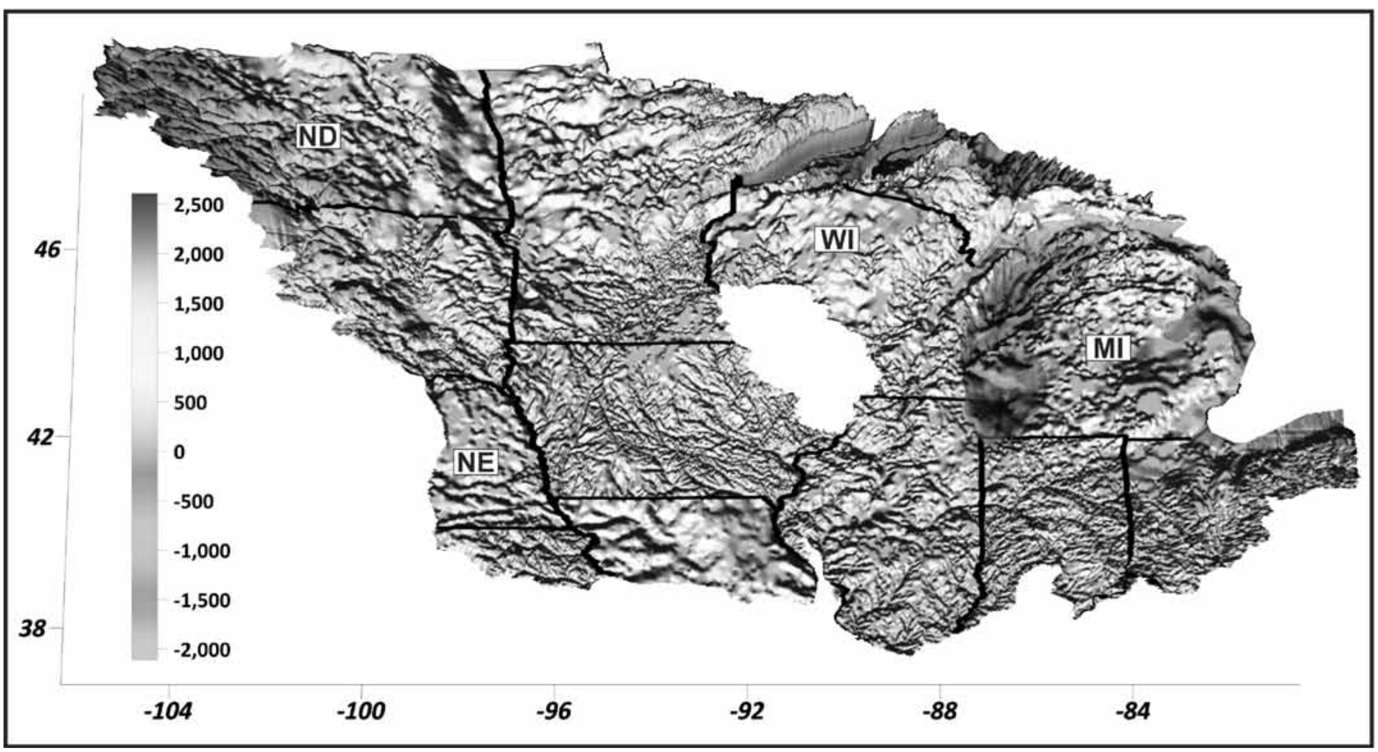

Figure 4. Bedrock topography of study area in feet asl (above sea level). Note irregular topography reflecting channelized erosion and watershed development after the Ice Age. Bedrock maps in labeled states from Soller and Garrity (2018); remainder from state geological surveys. The white area is the driftless area.

To better show the thickness and distribution of Ice Age and Recent sediments (Figure 5), we compared data from state surveys in Ohio, Illinois, Missouri, Minnesota, and North Dakota. Isopach maps of drift thickness were taken from Soller and Garrity (2018) but were compared to state survey maps from Ohio, Illinois, Minnesota, Missouri, and North Dakota. The older USGS Groundwater Atlas maps (Bluemle, 1986, 2003; Olcott, 1992; Lloyd and Lyke, 1995; Soller, 1997; Whitehead, 1997; Grimley, 2015; Hamilton, 2020; Missouri DNR, 2023; Ohio DNR, 2023) are also available for comparison. Thin, patchy glacial sediments in eight counties of northern Kentucky were ignored. Ice Age sediments seldom exceed a few hundred feet. Incised sediment-filled channels reach 800 ft. (244 m) in South Dakota. Thicknesses reach 1,400 ft. (427 m) near Itasca Park, in northwestern Minnesota, and exceed 2,500 ft. (762 m) beneath Lake Superior off Minnesota (Hamilton, 2020). Soller and Garrity (2018) show thick sections in Michigan reaching 1,000 ft. (305 m). Their thicknesses are generally in line with the state surveys, although the newer map in Minnesota (Hamilton, 2020) includes more recent data and shows thicker drift in some areas. The most significant difference was in Missouri, where their Department of Natural Resources map returned a total of 1,814 km^3, while Soller and Garrity's map (2018) only showed 1,141 km^3. The Missouri state map also showed a glaciated *area* approximately 10 percent greater than that of Soller and Garrity (2018). The southern limit of glacial sediments was derived from Soller and Garrity (2018), state survey maps, and the Ground Water Atlas. These limits were simplified in some areas where alluvial sediments stretched south of the main body of glacial sediments in narrow river valleys (e.g., Ohio).

We calculated the volumes by state and for the study area (Table I). The "grid average" is *only* for the areas actually overlain by Ice Age and Recent sediments (cf., Figure 3). That excludes parts of every state. The "state average" is that for the area of the *entire* state. Kansas and Nebraska have very low grid areas, reflecting glacial limits. Michigan and Minnesota have much greater relative coverage. Michigan has the greatest total volume, due to significant thicknesses beneath Lake Superior. The average thickness of Ice Age sediments in the study area is 86 ft. (26 m); that for the states range from 3 ft. (1 m) in Kansas to 195 ft. (59 m) in Minnesota.

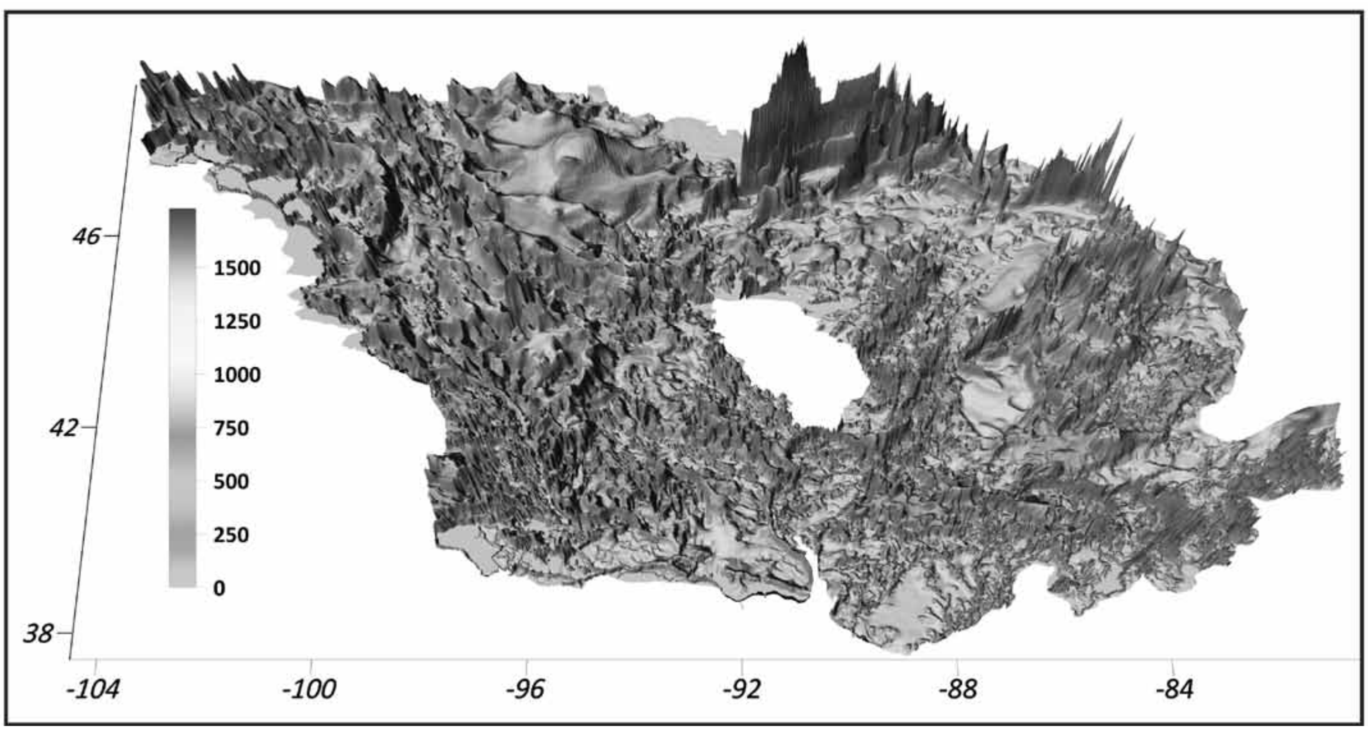

Figure 5. Thickness of glacial and Recent deposits in study area based on Soller and Garrity (2018). State boundaries distorted by overlay on 3D surface. Note maximum thicknesses beneath Lake Superior, in northwestern Minnesota and the northwestern part of Michigan's southern peninsula. For the study area, the thickness averages 86 ft. (26 m). White area is the driftless area that was never glaciated. See Table I.

Table I. Ice Age and Recent sediment volume and average thicknesses of study area. Average thicknesses are divided into the area gridded and the entire extent of the state. From Soller and Garrity (2018).

STATE	TOTAL AREA (km²)	GRID AREA (km²)	VOLUME (km³)	AVG THICKNESS GRID		AVG THICKNESS STATE	
				(M)	(FT)	(M)	(FT)
Illinois	149,995	142,330	3,744	26	86	25	82
Indiana	94,326	78,973	2,758	35	115	29	96
Iowa	145,756	136,254	6,528	48	157	45	147
Kansas	213,100	18,584	178	10	31	1	3
Michigan	250,487	248,214	13,160	53	174	53	172
Minnesota	225,163	214,957	13,378	62	204	59	195
Missouri	180,540	60,620	1,141	19	62	6	21
Nebraska	200,330	45,904	2,163	47	155	11	35
North Dakota	183,108	129,814	5,964	46	151	33	107
Ohio	116,098	87,065	1,899	22	72	16	54
South Dakota	199,729	90,625	5,498	61	199	28	90
Wisconsin	169,635	140,005	3,936	28	92	23	76
Total	2,232,918	1,393,345	60,347	43	142	26	86

The next surface is the base of the marine diluvial package, with its base at the erosional unconformity between Precambrian crystalline rocks/rift fill and the overlying Phanerozoic sedimentary sequence. Due to the irregularity of the bedrock surface (Figure 4), we derive volume and thicknesses for the entire sedimentary sequence and then subtract the Ice Age volume by state. The exception was in Minnesota, where thin, diluvial sediments and irregular topography degraded the grid differencing operation. However, Minnesota has published excellent bedrock topography and drift thickness maps (Hamilton, 2020). We used the bedrock topography map to derive the diluvial thicknesses and added the drift thicknesses of Soller and Garrity (2018) to derive a total sediment volume.

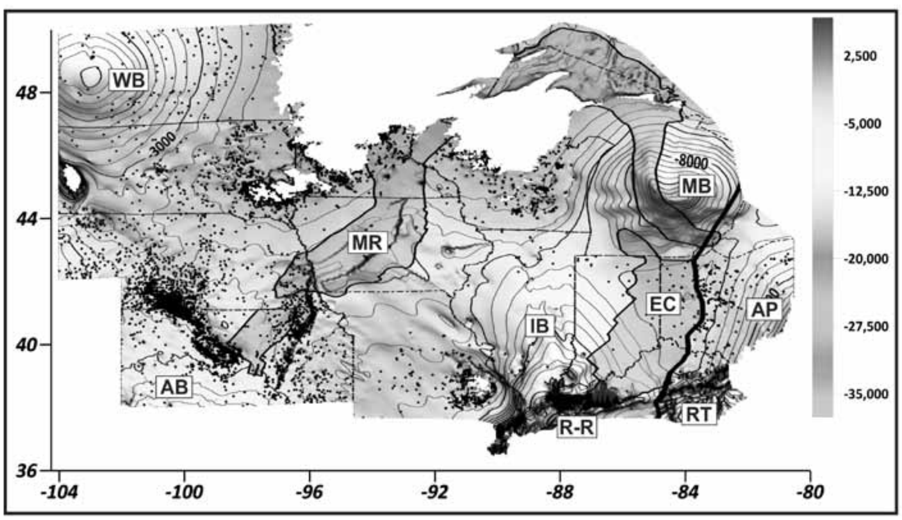

Figure 6. Configuration of the Precambrian surface in the upper midcontinent in feet asl. Contour interval is 1,000 feet. White areas are those of exposed or subglacial Precambrian crystalline and metamorphic rock: the Sioux Ridge in southeastern South Dakota, the Black Hills in southwestern South Dakota, the Baraboo quartzites in Wisconsin, and the St. Francois Mountains in southeastern Missouri. Major sedimentary basins in the study area include the Anadarko (AB), Williston (WB), Illinois (IB), Michigan (MB), and Appalachian (AP) Basins. This surface also forms the top of the Proterozoic Midcontinent Rift (MR) and East Continent Basin (EC), both shaded darker. The Reelfoot Rift-Rough Creek Graben (R-R) and Rome Trough (RT) are deep rift grabens along the southern boundary of the study area; the Rome Trough continues northeast through West Virginia and Pennsylvania. Black dots show well control.

Top Precambrian Surface

For most of the study area, the unconformity atop the Precambrian (Figure 6) is interpreted as forming the lower diluvial boundary because it is an erosional surface atop crystalline basement at the base of the sedimentary record. The Midcontinent Rift, found beneath seven states and part of Ontario, and the East Continent Basin, found beneath Indiana, Kentucky, Michigan, and Ohio are the major exceptions. Other cratonic rifts in the study area are dated as Cambrian, have much less volcanic fill, and contain fossiliferous marine sediments. These include the Reelfoot Rift, the Rough Creek Graben, and Rome Trough, all partly in Kentucky. Lacking any hard data, we did not attempt to map the recently-proposed Illinois Graben (Freiburg et al., 2022).

The North American craton is well known for its large marine sedimentary basins—the Williston, Illinois, and Michigan Basins. Smaller basins include the Salina, Forest City, and

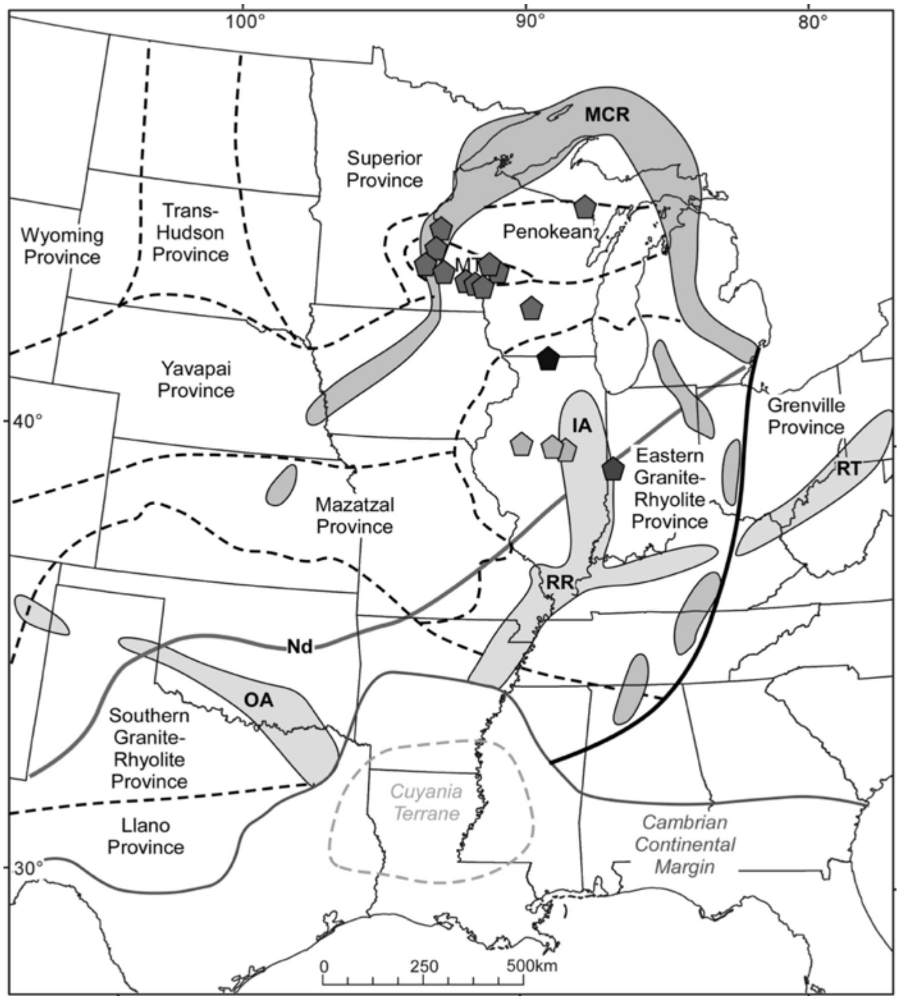

Figure 7. Interpretation of Precambrian basement provinces and features from Freiburg et al. (2022). Pentagons are drill and sample sites discussed in their paper. Cambrian rifts, including the Oklahoma Aulacogen (OA), Illinois Aulacogen (IA), Reelfoot Rift complex (RR), and Rome Trough (RT) are shown in light gray and Proterozoic rifts in darker gray. Terranes are interpreted by gravity and magnetic signatures, limited lithologic samples, and radiometric dating.

Cherokee Basins. The Anadarko and Appalachian Basins are large but lie primarily outside the study area. Marine Phanerozoic strata of the Williston, Illinois, Michigan, and smaller basins are separated stratigraphically from the Midcontinent Rift and East Continent Basin by the Precambrian/Cambrian unconformity. State maps in Figure 6 that comprise this figure are described and shown in the appendix. White areas show where Precambrian crystalline rocks are either exposed at the surface or immediately underlie glacial deposits. The Sioux Quartzite was also blanked. Although we suspect it is an Early Flood deposit (Oard et al., 2023a), there are no available maps of its base. Mapping it and the other Proterozoic quartzites is a separate study, so we mapped the basal diluvial boundary across their tops. Though barely visible in Figure 6, the Baraboo Hills exposures in south-central Wisconsin are likewise blanked. The current uniformitarian interpretation of the underlying Precambrian terranes is shown in Figure 7.

Interpretation of Rifts, Troughs, and Basins

We interpret the Precambrian (and Cambrian) rifts in the study area as products of the Flood (Reed, 2000; Clarey, 2020). The largest two, the Midcontinent Rift and East Continent Basin, dwarf the others. In the study area, there is a clear contrast between north and south. In the south, rifting was less intense, less volcanic, and the rifts were infilled by mostly marine sediments. Farther north, rifts are larger and were filled by volcanics (primarily basalt) and unfossiliferous terrigenous sediments. On top of the rift fills, Phanerozoic marine sediments occur. We created two volumes of diluvial rock in the study area: one for the Phanerozoic and one for the rift fills. We discovered that the top of the Precambrian is a heavily eroded surface. Because of dense well control, we have mapped the presence of interesting large erosional remnants, such as in the Kansas basement (Figure A-4 in the appendix). That 3D surface was then subtracted from NOAA's 2022 30-arc second ETOPO DEM. The resulting volumes (base Phanerozoic to surface) include Flood, Ice Age, and Recent deposits. The Ice Age/Recent sediments, shown in Table I, were subtracted as shown in Table II to yield diluvial volumes outside the Midcontinent Rift and East Continent Basin. Volumes for the Reelfoot Rift, Rough Creek Graben, and Rome Trough are included since they are filled with Phanerozoic marine sediments. Differencing of grids typically returns both "cut" and "fill" volumes and areas. We used the cut volume and area. Uncertainties in estimating volume estimates can be obtained from the lead author. Average

Table II. Volume and average thickness of Phanerozoic strata in the study area. Glacial data from Table I. Average thicknesses exclude areas of exposed or subglacial Precambrian basement. No Ice Age thickness was assigned to Kentucky, which has patchy, thin glacial sediments in only eight counties.

		Base Phanerozoic to Surface			Ice Age and Recent Sediment			Marine Diluvial		
STATE	AREA (km^2)	VOLUME (km^3)	AVG THICK (m)	AVG THICK (ft.)	VOLUME (km^3)	AVG THICK (m)	AVG THICK (ft.)	VOLUME (km^3)	AVG THICK (m)	AVG THICK (ft.)
Illinois	149,995	260,913	1,734	5,688	3,744	25	82	257,169	1,709	5,606
Indiana	94,321	146,479	1,552	5,093	2,758	29	96	143,721	1,523	4,997
Iowa	145,756	97,300	686	2,251	6,528	45	147	90,772	640	2,100
Kansas	213,100	203,523	964	3,162	178	1	3	203,345	963	3,159
Kentucky	104,656	289,485	2,788	9,146	0	0	0	289,485	2,788	9,146
Michigan	250,487	363,527	1,682	5,517	13,160	53	172	350,367	1,621	5,318
Minnesota	225,163	23,382	415	564	13,378	59	195	10,004	177	582
Missouri	180,540	111,913	621	1,361	1,141	6	21	110,772	624	2,046
Nebraska	200,330	127,818	642	2,105	2,163	11	35	125,655	631	2,070
North Dakota	183,108	332,712	1,952	6,405	5,964	33	107	326,748	1,917	6,290
Ohio	116,098	169,096	1,460	4,790	1,899	16	54	167,197	1,444	4,737
South Dakota	199,729	122,714	748	2,452	5,498	28	90	126,538	634	2,079
Wisconsin	169,635	21,216	294	965	3,936	23	76	17,280	240	786
Ontario (SA)	65,833	UNK	–	–	–	–	–	–	–	–
TOTAL	2,295,682	2,270,078	1,212	3,975	60,347	26	86	2,209,731	1,179	3,870

thicknesses were calculated using only the areas without exposed Precambrian (see Appendix). Minnesota and Wisconsin show the greatest proportion of Ice Age and Recent sediments to diluvial marine strata. In addition to higher volumes of Ice Age strata, these states showed lower volumes and thicknesses of diluvial strata. Figure A-6 shows that much of the subglacial area of both states is crystalline basement, resulting in large areas of zero Flood thickness. This suggests that either this area was high during the entire Flood and/or that there was significant erosion during the Recessive Stage of the Flood.

The greatest volumes of Phanerozoic marine diluvial rocks were emplaced in Michigan (Michigan Basin), North Dakota (Williston Basin), Kentucky (Early Cambrian grabens and Appalachian Basin), Illinois (Illinois Basin), and Kansas (Salina and Anadarko Basins). Kentucky has the greatest average thickness of sediments, followed by North Dakota, Illinois, and Michigan. We modified the outline of the Reelfoot Rift and Rough Creek Graben from Coleman and Cahan (2012) based on our own basement map and adopted Coleman and Cahan's (2012) outline of the Rome Trough. Both the Reelfoot Rift and Rome Trough extend beyond the study area, but within the study area, the three features occupy 43,573 km^2. In that area, 187,147 km^3 of sediment were deposited between the basement unconformity and the ground surface. Their average thickness of 14,091 ft. (4,295 m) of fill is predominantly Cambrian to Early Ordovician arkoses to carbonates. Hickman (2013) notes that the maximum thickness of the Late Cambrian/Early Ordovician Knox Group alone exceeds 11,500 ft. (3,505 m) in the Rough Creek Graben. Sediment accumulations are typically characterized by basins, so we calculated the volume and thickness by basin (Table III), with the caveat that some basins extend outside the study area and those volumes were not included. For basin boundaries, we used those of Evenick (2021). However, we found his boundaries very general, and our delineation of his Lake Superior and Midcontinent Basins, based on more detailed mapping, are significantly more accurate (see Part II). For that reason, we compared the results from his outlines (Figure 8) to the more conservative ones of Coleman and Cahan (2012), from the USGS (Table III). Average thicknesses by basins are shown in Figure 9.

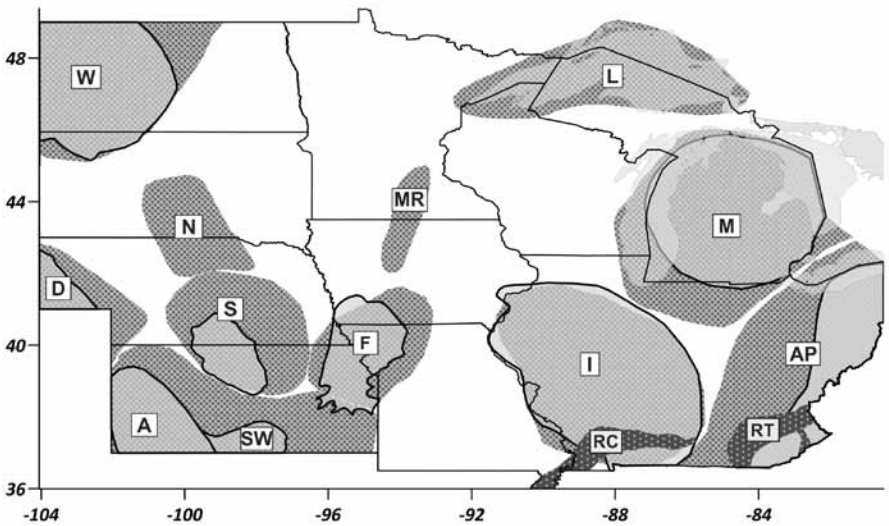

Figure 8. Sedimentary basins in the study area from Evenick (2021) = stippled, and Coleman and Cahan (2012) = lighter gray. RC = Reelfoot Rift/Rough Creek Graben, RT = Rome Trough, AP = Appalachian Basin, I = Illinois Basin, M=Michigan Basin, L = Lake Superior Basin, MR = Midcontinent Basin, F = Forest City Basin, A = Anadarko Basin, S = Salina Basin, SW = Sedgewick Basin, D = Denver Basin, N = Central Nebraska Basin, W = Williston Basin. Evenick's (2021) boundaries are consistently larger than those of Coleman and Cahan (2012). The Lake Superior and Midcontinent Basins are Proterozoic basins.

The basin volumes and average thicknesses show a picture matching that of a regional isopach map (Figure 10). The southern rifts were included on this isopach because they were infilled with mostly Phanerozoic marine fossiliferous sediments rather than unfossiliferous sediments in the East Continent Basin and Midcontinent Rift sedimentary basins. The cratonic basins represented here are sags in the surface relative to the rifts. The Rough Creek Graben reaches more than 38,000 ft. (11,582 m) below sea level. This is comparable to the Appalachian and Anadarko Basins, but much deeper than the Michigan, Illinois, and Williston Basins. The cratonic basins' origins are unclear, although the Michigan Basin, the Anadarko Basin, the Illinois Basin, and the Appalachian Basin all overlie rifts to some extent. The basins with the greatest volume in the study area are the Il-

Table III. Total volume (marine diluvial and Ice Age) and average thickness of sedimentary basins based on boundaries from Figure 8. Basins extending outside the study area were cropped at the study area margin and the volume shown here is *only* that within the study area. No numbers were derived here for the Proterozoic Lake Superior and Midcontinent Basins; they will be done in Part II.

	EVENICK (2021)				COLEMAN AND CAHAN (2012)			
SEDIMENTARY BASIN	AREA (km^2)	VOLUME (km^3)	AVG THICK (m)	AVG THICK (ft.)	AREA (km^2)	VOLUME (km^3)	AVG THICK (m)	AVG THICK (ft.)
Williston	121,576	326,955	2,689	8,823	100,027	294,489	2,944	9,659
Central NE	51,182	19,310	377	1,238	—	—	—	—
Denver	36,108	40,265	1,115	3,659	13,160	19,129	1,454	4,769
Salina	97,025	68,850	710	2,328	27,816	25,149	904	2,966
Anadarko	142,994	153,275	1,072	3,517	45,678	64,800	1,419	4,654
Forest City	73,006	96,623	773	2,537	48,754	38,018	780	2,558
Illinois	202,648	463,243	2,286	7,500	207,129	459,869	2,220	7,284
Appalachian	178,364	304,163	1,705	5,595	70,464	175,888	2,496	8,189
Michigan	222,795	417,905	1,876	6,154	148,459	344,176	2,318	7,606
TOTAL	1,125,698	1,850,410	1,644	5,393	760,471	1,512,702	1,989	6,526

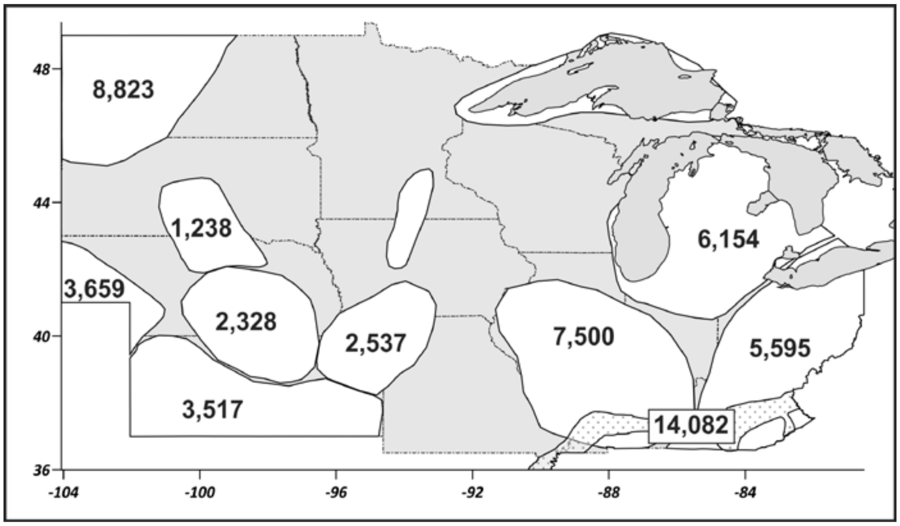

Figure 9. Average thickness in feet of sedimentary basins in the study area based on volumes calculated between our basement map and ETOPO. Outlines and numbers follow Evenick's definitions (2021). See Table III for varying numbers using outlines of Coleman and Cahan (2012). Number for Reelfoot Rift/Rough Creek Graben/Rome Trough (lower right) based on our work.

linois and Michigan Basins, although the Williston, Anadarko, Denver, and Appalachian Basins would be greater if shown in whole.

Discussion

This study seeks to provide basic mapped data as well as investigating some of the mechanics of the Flood. Shape files for the maps used in this study are available to creationist researchers upon request from the lead author. The resulting volume and distribution of sediment therein help explain events of the Early Flood in the northern Midcontinent. Rifting occurred throughout the region. The Oklahoma Aulacogen lies a few hundred miles south of the study area (Figure 7). It is a rift largely containing igneous bimodal rock fill; granite and rhyolite forming over deep and thick mafic gabbros (Reed, 2004). The basement was eroded before being covered by the transgressive sequence of the Timbered Hills Group (Reed, 2005). In this regard, it is similar to the Reelfoot-Rough Creek and Rome Trough structures. The Midcontinent Rift and East Continent Basin rifting have preserved volcanics as predominantly basalt, although significant erosion of these rocks occurred during and after their emplacement. However, the associated large sedimentary basins under Lake Superior and flanking the rift in Minnesota, Iowa, Nebraska, and Kansas are not found in Oklahoma. In the Rough-Creek/Reelfoot Rift/Rome Trough complex, basal Phanerozoic clastic and carbonate sediments dominate over basalt and rhyolite. The characteristics of these rifts will be more closely investigated in Part II, and diluvial explanations of their similarities and differences will be explored. For now, what are we to make of the sequence of the rock record in the study area outside the areas of rifting? Two particular issues arise: (1) the evidence of significant, widespread, and powerful erosion of the crystalline basement, and (2) the evidence of the overwhelming activity of the Flood in shaping the volume and distribution of the rock record in the region. Crystalline basement in the study area was subjected to three episodes of erosion: (1) the Early Flood, (2) the Late Flood regression, and (3) that associated with

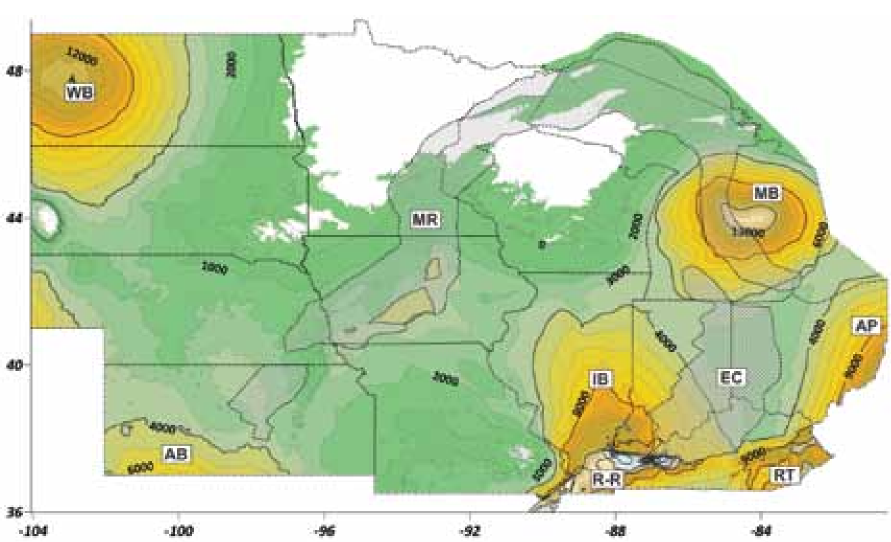

Figure 10. Isopach map of the interval between the ground surface and the unconformity atop crystalline basement for the upper midcontinent region, in feet. Contour interval is 1,000 feet. These thicknesses do not include rift or basin fill in the Midcontinent Rift (MR) and East Continent Basin (EC), shown in outline.

glaciation. Since paleotopography appears to have been higher to the north, based on large-scale sediment patterns, erosion in all three episodes would have increased from south to north. Early Flood erosion left impressive erosional remnants (Figure A-4). As water flowed south, the large channels would have combined into sheets—the opposite of the Late Flood transition from sheet flow to channels (Oard, 2013). At some level of energy, those sheets would have created vast planation surfaces with erosional remnants. The study area was covered by diluvial sediments at the height of the Flood. Oard et al. (2023b) estimated that an average of about 2,000 m (6,560 ft.) of sediment was removed from North America during the Late Flood regression. In other words, nearly 40% of the original record was eroded preferentially from the younger Flood record. Those places where Ice Age sediments directly overlie crystalline basement were probably once covered by significant thicknesses of Flood sediment. Their erosional remnants are seen today in patches atop the crystalline basement beneath glacial rocks in Minnesota and well into Canada (Ambrose, 1964; Jirsa et al., 2011). Therefore, the remaining sedimentary rocks and sedimentary basins are much smaller than they would have been at the highstand of the Flood and those that remain disproportionately represent earlier stages of the Flood. Finally, the most significant Ice Age erosion in the study area occurred in Minnesota, Wisconsin, and Michigan. Subglacial crystalline rock is exposed in small patches in eastern North Dakota (Bluemle, 2003) and along the Sioux Ridge in southeastern South Dakota and southwestern Minnesota (McCormick, 2010c). It is currently unclear as to whether those irregular surfaces are the result of Ice Age erosion only or whether they may also exhibit relicts of the Flood.

Conclusion and Summary

The Midcontinent region of the United States is a well-studied area that provides many insights into the Flood. It includes five major rifts and six major cratonic basins. Based on data from state surveys, the USGS, and from other publications, we mapped four key surfaces in order to derive the thickness and distribution of three significant volumes: (1) Ice Age and Recent sediments, (2) Phanerozoic marine diluvial strata, and (3) rift fill. The first two packages are described in this paper; the rift fill will be addressed in Part II. Ice Age and Recent strata average 86 ft. (26 m) across the study area and marine diluvial strata averages 3,870 ft. (1,179 m). The thickest sediments of that volume are found in the Rough Creek Graben in Kentucky, with depths reaching over 38,000 ft. (11,582 m) and sediment averaging over 14,000 ft. (4,267 m) in the Reelfoot Rift/Rough Creek Graben/Rome Trough rifts. Thick sediments are also found in the Michigan, Illinois, Williston, and Appalachian Basins. However, as we will demonstrate in Part II, these thicknesses are dwarfed by those of the Midcontinent Rift.

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Appendix: Basement of the Upper Midcontinent by State

North Dakota

We obtained well picks of the top Precambrian from 331 wells from the North Dakota Geological Survey. The survey has also produced two maps of the Precambrian surface (Heck, 1988; Anderson, 2009). More deep wells exist (Anderson, 2007); however, not all were available. In addition, Bluemle (2003) provided a map of bedrock geology, showing small areas of subglacial Precambrian rock in eastern North Dakota, which were blanked in gridding and volumetric calculations. The Precambrian surface of North Dakota (Figure A-1) is reasonably well constrained, especially in the Williston Basin, which occupies most of the western part of the state. Precambrian rocks under North Dakota are classed into three provinces. The Superior Province of the Canadian Shield underlies the eastern part of the state. The Wyoming Province underlies only a very small portion of the southwestern corner of

North Dakota, but it occupies a salient portion of South Dakota (Figure A-2) and is notably visible in the Black Hills. Between the Superior and Wyoming Provinces is the Trans-Hudson Province, thought to be an ancient convergence zone (Bader, 2021). Each of these can be subdivided into numerous sub-provinces or tectonic zones, based primarily on geophysical data (e.g., Li and Morozov, 2006) and lithology from deep well samples.

South Dakota

In 2010, the South Dakota Geological Survey published a map of the Precambrian surface (McCormick, 2010a), supported by picks from 4,828 wells and core holes. The Sioux Quartzite, in southeastern South Dakota, forms the Sioux Ridge, elevated some hundreds of feet above the surrounding basement (Figure A-1). Perhaps the most interesting feature (thanks to dense well control) is the clarity of erosional channeling on the Sioux Ridge (Figure A-2). The Sioux Quartzite, an especially indurated metamorphic unit, extends into Minnesota and a short distance into Iowa. Where mapped in detail in those states, it shows the same erosional patterns. Its unusual hardness, formed by silica cement, is distinctive and related to diagenetic/metamorphic processes, perhaps associated with volcanism of the nearby Midcontinent Rift. South Dakota is underlain by several granitic terranes (McCormick, 2010b, 2010c), including the Yavapai Province, part of the Wyoming Province, the Trans-Hudson Province, and the Sioux block. Precambrian granite is exposed in southwestern South Dakota in the Black Hills. It is possible that the Sioux (and other Baraboo) quartzites were deposited early in the Flood, but little work has been done to map their base, and though their two-dimensional expression has been well mapped (McCormick, 2010b, 2010c), thickness

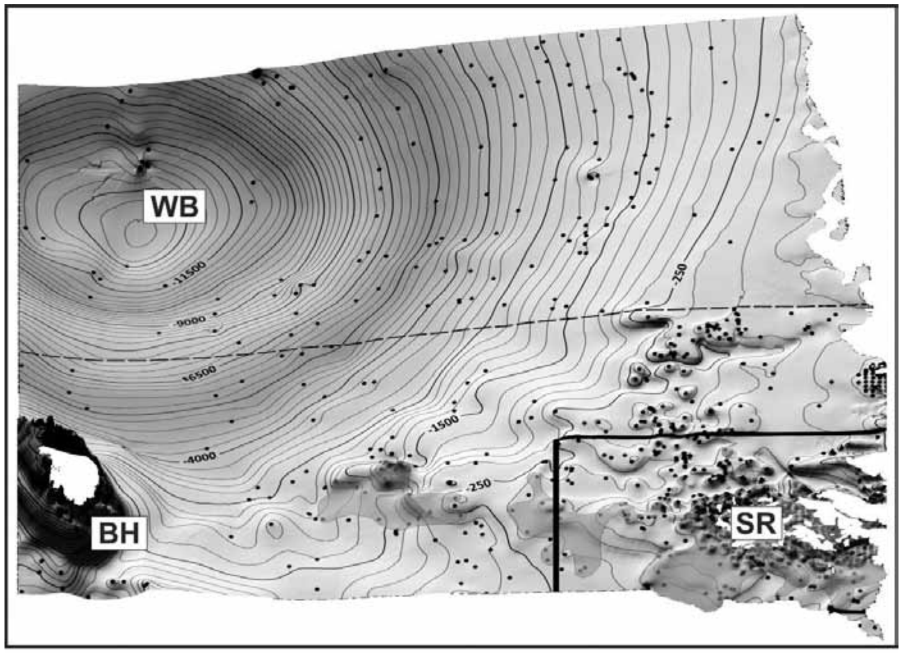

Figure A-1. Configuration of the North Dakota and South Dakota basement in feet asl. Contour interval is 250 feet. Exposed Precambrian is seen as granites in the Black Hills (BH) and far eastern North Dakota, and as subglacial and exposed Sioux Quartzite on the Sioux Ridge (SR). These areas were blanked for gridding. Dots show well control (wells in blanked areas not visible). Basement slopes into the Williston Basin (WB). Darker gray patches in southeastern South Dakota show the extent of the subcrop of the Sioux Quartzite, which extends into Minnesota, Nebraska, and Iowa (Figure A-2).

maps await new data. For this study, exposed (or subglacial) Precambrian quartzites were omitted in gridding and volumetric calculations.

Nebraska

The Nebraska basement (Figure A-3) is based on Burchett and Carlson (1986). We also obtained tops from 1,997 wells. Most were included in Burchett and Carlson's (1986) map, though some were drilled afterward. We revised their map based on that well control and rectified its contours with newer maps from South Dakota, Colorado, and Kansas. Nebraska is largely underlain by the granitic Yavapai Province (Figure 7), with the Iowa segment of the Midcontinent Rift terminating just into southeastern Nebraska. Basement topographic features include the Central Kansas Uplift, which runs as a broad ridge from the Black Hills into Kansas, dividing the Denver Basin to the west from the Salina and Central Nebraska Basins (Evenick, 2021) to the east. The Nemaha Uplift begins in southeastern Nebraska, extending south through Kansas.

Kansas

The Precambrian surface of Kansas (Figure A-3) is well constrained by data from 3,981 wells. Maps of the Precambrian surface were made by Cole (1976) and Berendsen and Blair (1996a). They also created a map of the Precambrian subcrop (1996b). Their revision was based on Cole (1976) but extrapolated fault patterns from

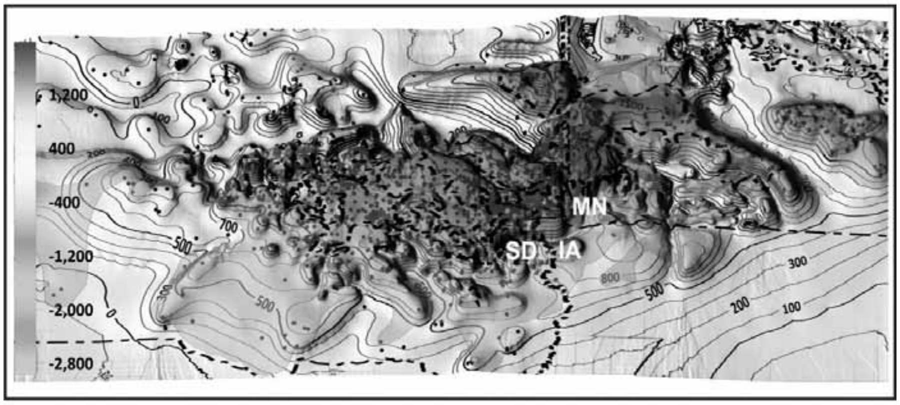

Figure A-2. Detail of the Sioux Ridge erosional patterns in feet asl. Contour Interval is 100 feet. Well control shown by black dots. Sioux subcrop from McCormick (2010b) shown in darker pattern. Dense well control allows detailed mapping of the surface. Similar erosional features and channeling occur throughout Minnesota's Precambrian surface, also visible due to significant well control. Large gullies in the Sioux Ridge exhibit up to 1,000 feet (305 m) of relief.

better studied segments of the Midcontinent Rift. However, Cole (1976) was quite detailed, using not only the Precambrian wells as control, but also many deep Cambrian wells. His work demonstrated the reality of erosional remnants scattered across the basement surface (Figure A-4), some hundreds of feet high, with control from multiple wells.

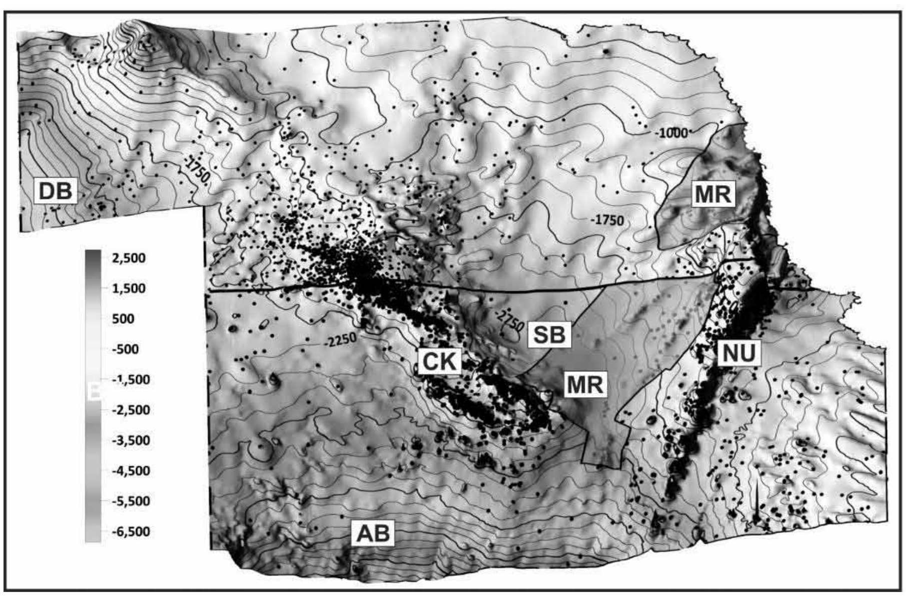

Figure A-3. Configuration of Kansas and Nebraska Basin in feet asl. Contour interval is 250 feet. Black dots show well control. Features include the eastern edge of the Denver Basin (DB), Central Kansas Uplift (CK), Salina Basin (SB), Nemaha Uplift (NU), and the northern part of the Anadarko Basin (AB). The Midcontinent Rift (solid and dashed lines and darker gray) underlies the Salina Basin.

The basement in Kansas is formed by granite of the Mazatzal and Southern Granite-Rhyolite provinces (Figure 7). It is elevated at the Central Kansas and Nemaha uplifts. Between them is the Salina Basin, overlying the southern segment of the Midcontinent Rift. The western Kansas basement dips south into the Anadarko Basin. Reed (2003, 2004b) described the Kansas basement in more detail. Precambrian lithologies were plotted in Berendsen and Blair (1996b) and Bickford et al. (1979).

Missouri

The Precambrian surface in Missouri (Figure A-5) was mapped by Kisvarsaynyi (1984) using well control from 898 wells for the top of the Precambrian and several hundred other wells that reached total depth in the Precambrian but with no specific pick. The basement is exposed in the southeast corner of the state in the St. Francois Mountains, which exhibit granite, rhyolite, felsite, ignimbrite, and volcanics. The area is well known for its iron and lead mines. Overall, the Missouri basement is granitic, with parts of the Mazatzal, Yavapai, Southern Granite-Rhyolite and Eastern Granite-Rhyolite provinces underlying the state (Figure 7). At the southeastern tip of Missouri, the basement dives southeast from the surface exposure of the St. Francois Mountains into the Reelfoot Rift (also called the Mississippi Valley Graben), which reaches depths exceeding 38,000 ft. (11,582 m) below sea level in Kentucky (Hickman, 2011, 2013).

Iowa

Iowa's basement surface (Figure A-5) dips from the Sioux Quartzite in the far northwestern corner down to the south and east. In addition to the Sioux, the northwestern part of the state is underlain by Archean rocks of the Superior Province. Moving southeast, the Yavapai Province is cut by the Midcontinent Rift (Figure 7). Granitic rocks of the Eastern Granite-Rhyolite Province underlie the southeastern part of Iowa (Anderson, 2006). The Midcontinent Rift is, by far, the most dramatic feature of Iowa's basement. Reverse faults form a central volcanic horst (visible in Figure 1) bounded on both sides by sedimentary basins (Anderson, 1990). Anderson (1995, 2006) mapped the Precambrian surface, and we obtained depths from 46 wells, including one deep test, the Amoco M.G. Eischeid #1, on the flank of the Midcontinent Rift (Anderson, 1990). Anderson and McKay (1989) also described the sediments in the flanking basins of the Midcontinent Rift in some detail, summarized in Reed (2000).

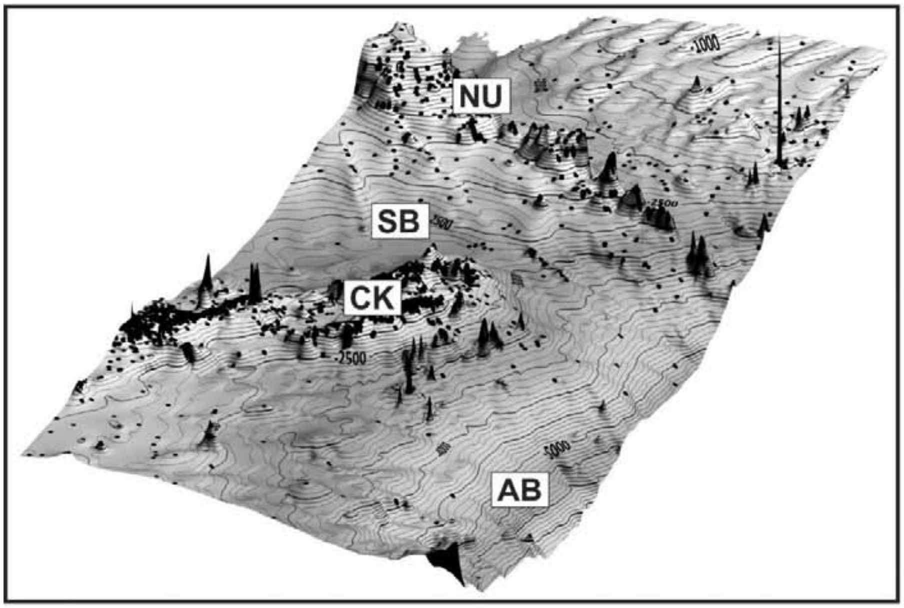

Figure A-4. Erosional remnants on Kansas basement surface, as mapped by Cole (1976), and with significant vertical exaggeration, looking east from Colorado. Most are controlled by multiple wells (black dots). Labels as in Figure A-3.

Minnesota

The Precambrian surface of Minnesota (Figure A-6) is well constrained by data from 40,369 wells with top Precambrian picks, 3,223 additional wells that reach total depth in the Precambrian with no stratigraphic pick, and 2,807 wells that reached total depth in the overlying Mt. Simon Sandstone. This is by far the best constrained Precambrian surface in the study area, made possible in large part by the large areas of shallow Precambrian crystalline rock immediately underlying glacial deposits. In addition, more detailed maps of the Precambrian surface exist in the Minnesota Geological Survey County Atlases (45 out of 87 counties as of this paper). These are not cited individually but can be found at the home page of the survey (https://cse.umn.edu/mgs). Almost all of these Atlas maps were used to help constrain Figure A-6. This surface was a combination of County Atlas Maps, well data points, and control from surrounding states. The well control and careful mapping by Minnesota survey geologists has produced a picture of a deeply eroded basement surface as shown in Figure A-7, which does not blank out areas of exposed or subglacial Precambrian basement. Minnesota occupies part

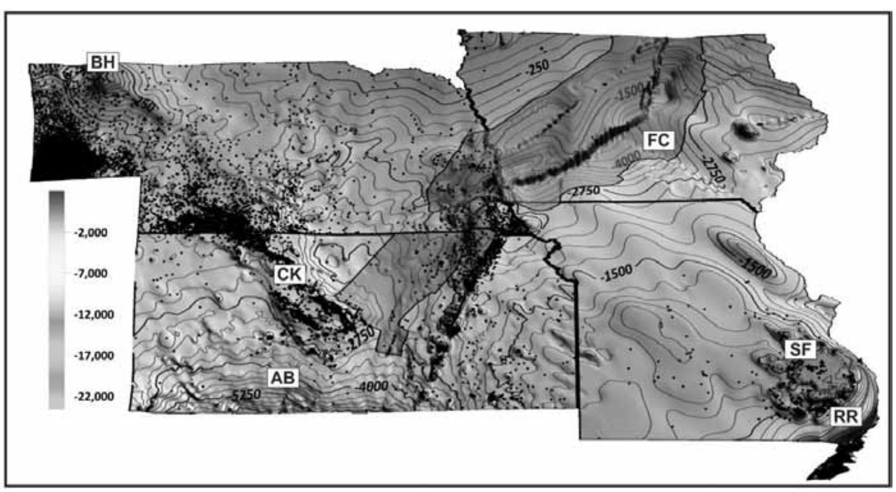

Figure A-5. Configuration of the basement of Nebraska, Kansas, Missouri, and Iowa in feet asl. Contour Interval is 250 feet. Dots show well control. Outline of the Midcontinent Rift shown in darker gray inside dashed line. Features include the Reelfoot Rift (RR), St. Francois Mountains (SF), Nemaha Uplift (NU), Salina Basin (SB), Anadarko Basin, (AB), Forest City Basin (FC), Central Kansas Uplift (CK), and Black Hills (BH). See Figure 7 for Precambrian provinces.

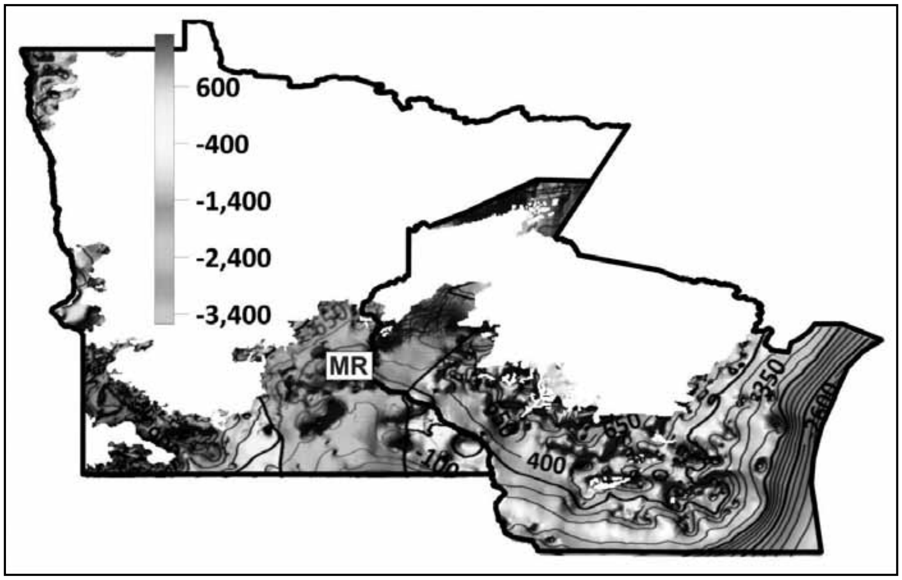

Figure A-6. Configuration of the basement of Minnesota and Wisconsin in feet asl. Contour interval is 200 feet. Blanked areas show subglacial exposed Precambrian crystalline rock. The size of these areas, combined with the thin Phanerozoic sediments results in very low volumes of sediments and with a much higher ratio of Ice Age to marine diluvial strata, though the ratios change significantly when the fill of the Midcontinent Rift is added.

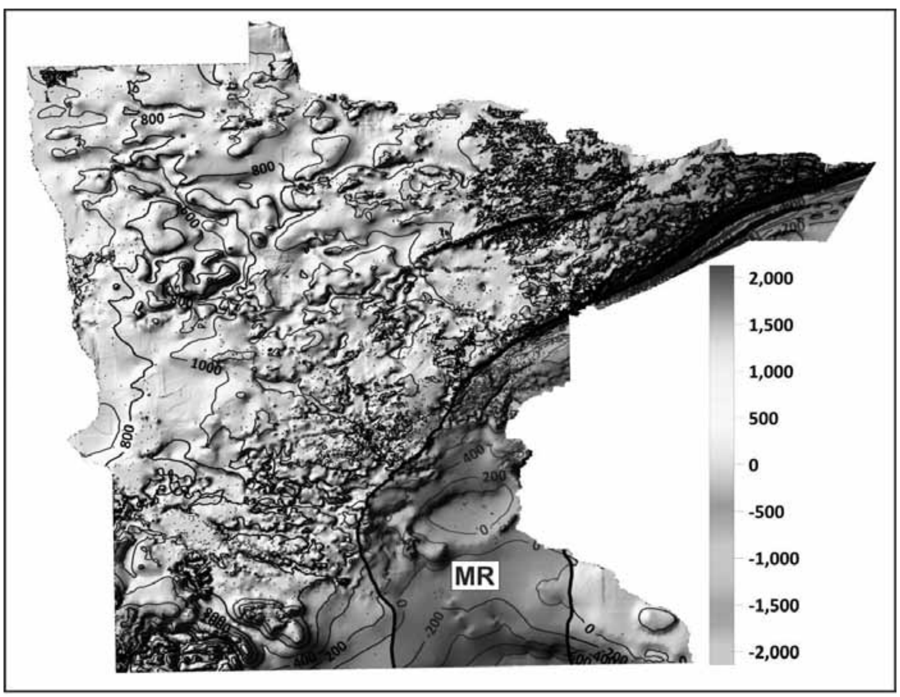

Figure A-7. Precambrian surface of Minnesota with no blanking. Contour Interval is 200 feet. Black dots show well control and abundant well control allows more detailed mapping of the erosion surface. Erosion could date from Early Flood or Late Flood, but it is likely Ice Age. Fewer wells over the Midcontinent Rift surface (MR) smooths contouring there, unlike the detailed picture on the Sioux Ridge (SR) in the southwest corner of the state.

of the southern edge of the Canadian Shield (Boerboom, 2020). Rocks classified as Archean belong to the Superior Province, with several sub-provinces defined and described. These are usually grouped by purported age, with the gneisses of the Minnesota River valley thought to be the oldest, followed by Greenstone-Granite Terrane, followed by metamorphic rocks of the Penokean Orogen in east-central Minnesota (Figure 7). Proterozoic rocks include a Paleoproterozoic terrane of metamorphosed sedimentary and volcanic rocks, including slate, graywacke, quartzite, iron formation, and patches of the Sioux Quartzite. The youngest Precambrian rocks are the Mesoproterozoic volcanic and sedimentary rocks of the Midcontinent Rift. There is abundant copper mined from these rocks, as well as copper, nickel, gold, platinum, and palladium from the Duluth Complex, an intrusive unit associated with the rift on the northwest shore of Lake Superior.

Wisconsin

The Precambrian surface of Wisconsin (Figure A-6) is well constrained by data from 3,190 wells. The only available map of the Precambrian surface was an old USGS map of the upper midcontinent. So we contoured the well data following the general lines of the USGS map and clipped in a recent detailed map of south-central Wisconsin (Stewart et al., 2022). Contours were also constrained by maps from surrounding states, though not at the expense of clear well control. The basement surface, like Kansas and South Dakota, shows evidence of erosion in the form of erosional remnants and channels. That pattern is clearest in the Baraboo Hills (Stewart et al., 2022). A Precambrian geologic map (Mudrey et al., 1982) provides a general picture of the Wisconsin Precambrian. The eastern area is occupied by the Midcontinent Rift, cutting Archean and Proterozoic terranes of the southern Lake Superior Province (Geiger and Guidotti, 1989). These are interpreted to have a long history of igneous and metamorphic activity, particularly the Penokean orogeny. Of some interest are the patches of Baraboo quartzites, which are considered to be of the same middle Proterozoic stratigraphic interval but thought to vary widely in their time and temperature of metamorphism (Geiger and Guidotti, 1989).

Michigan

Michigan lies at the junction of several prominent Precambrian provinces. The Yavapai and Mazatzal Provinces (Figure 7) underlie western and southwestern Michigan, and the Grenville Province underlies the southeastern part of the state. Sims et al. (2008) show boundaries in the central U.S. for the Penokean orogen. However, the Midcontinent Rift forms the most dramatic Precambrian feature of Michigan, extending from the eastern end of Lake Superior through the middle of the state beneath the Michigan Basin (Figure A-8). Though there are limited available seismic data showing details of the rift, COCORP lines (Sleep and Sloss, 1978; Brown et al., 1982) reveal a structure similar to that in the rest of the rift, as expected from the continuity of the linear gravity anomaly from Lake Superior to the Grenville Front (Hinze, 1975; Kucks, 1999) or beyond (Stein et al., 2018).

Aside from the Midcontinent Rift, the most dramatic feature of the Michigan basement is the Michigan Basin. Its subsidence has been stretched by uniformitarian geologists over more than 100 million years, and ultimately tied to episodic crustal weakness linked to the Appalachian Basin development and thermal trends in the crust (Howell and van der Pluijm, 1990, 1999).

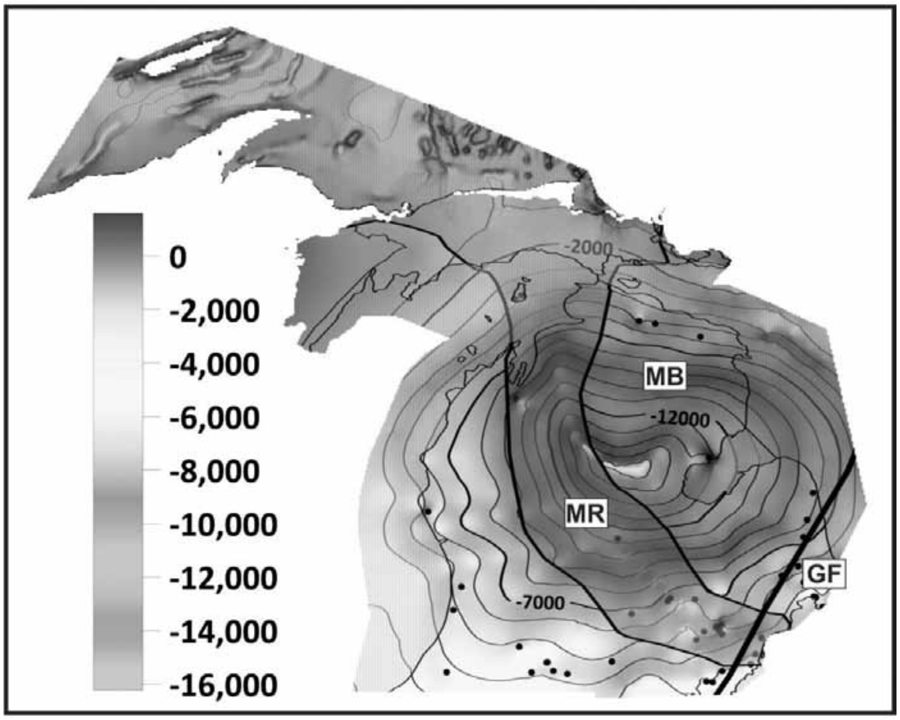

Figure A-8. Configuration of the basement of Michigan in feet asl. Contour interval is 1,000 feet. The Michigan Basin (MB) is underlain by the Midcontinent Rift (MR), shown by the darker gray outline. Parts of the Northern Peninsula are blanked where exposed Precambrian crystalline rock directly underlies glacial sediments, although the bedrock surface beneath Lake Superior is shown.

Illinois

The Precambrian surface of Illinois (Figure A-9) was taken from maps (Collinson et al., 1988; Albert et al., 2016) and constrained by 46 deep wells and seismic data. COCORP lines are publicly available, and private lines are published in some articles (e.g., McBride et al., 2016). The Illinois Basin is a heavily drilled basin, and features are well known in the subsurface, though less so at the Precambrian surface. The state is underlain by the Eastern Granite-Rhyolite Province, although McBride et al. (2016) suggest that small dish structures, a few km across, seen on more detailed seismic data, were created by mafic sills. The deepest part of the Illinois Basin is found in Kentucky, in the Rough Creek Graben (Hickman, 2011, 2013). Freiburg et al. (2022) proposed a Proterozoic Illinois Graben in the eastern part of the state (Figure 7) but evidence is limited. The Rough Creek Graben is bounded by normal faults and largely infilled with Paleozoic sediments, especially thick, Early Cambrian to early Ordovician (Knox Group) sandstones, siltstones, and carbonates. Rifting is interrupted by a basement high just west of the Grenville Front (Figure 7).

Indiana

The Precambrian surface of Indiana is largely underlain by the Illinois Basin (Figure A-9), contoured by Albert et al. (2016) and constrained by 28 wells. It is underlain by the Eastern Granite-Rhyolite Province and cut by the Fort Wayne Rift in the northeastern part

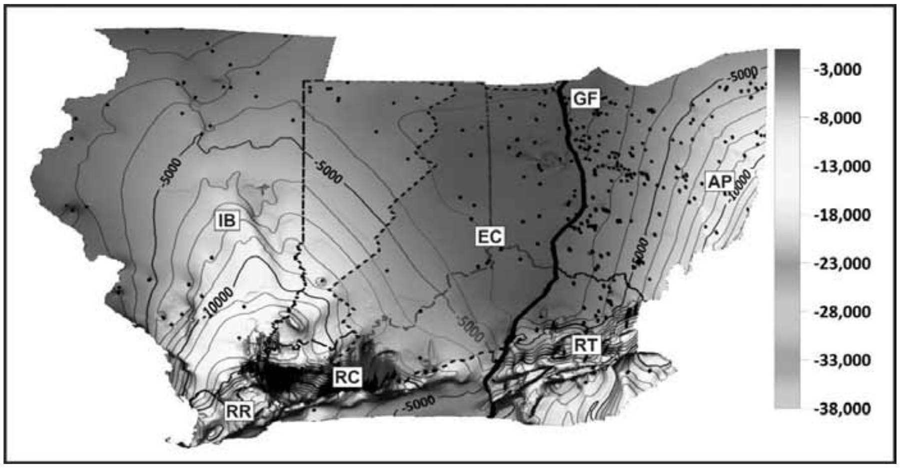

Figure A-9. Configuration of the basement of Kentucky, Ohio, Indiana, and Illinois in feet asl. Contour interval is 1,000 feet. The East Continent Basin (EC, dashed and shaded) is bounded on the east by westward thrusting along the Grenville Front (GF). The Reelfoot Rift (RR), Rough Creek Graben (RC), and Rome Trough (RT) show deep Cambrian rifting, and the trend bends north into the Appalachian Basin (AP) out of the figure.

of the state. The East Continent Basin continues from western Ohio into eastern Indiana and is infilled by volcanics and unfossiliferous red and gray clastic sediments of the Middle Run Formation (Moecher et al., 2018).

Ohio

The Precambrian surface of Ohio (Figure A-9) was mapped by the Ohio Geological Survey (Baranowski, 2013). It is divided north to south by the Grenville Front (Figure 7), separating the Grenville Province from the Eastern Granite-Rhyolite Province. The Precambrian surface in the western part of the state is underlain by sedimentary rocks of the East Continent Basin (Figure 1), and the eastern Ohio basement dips into the Appalachian Basin, with the Cincinnati Arch forming a high in early marine diluvial deposition between the Illinois, Michigan, and Appalachian Basins (Figures 6 and 7).

We obtained data from 205 wells from the Ohio Geological Survey, although Baranowski's (2013) map shows significant additional well control. He also used seismic lines, not publicly available, that provide detailed coverage in some areas (see his map insets). Baranowski contoured the top of the Precambrian surface, which included the Middle Run Formation of the East Continent Basin. The Grenville Front is considered the southward extension of the Canadian Grenville Province (e.g., Bickford et al., 1986), although Stein et al. (2018) used gravity data to propose that it is a southern extension of the Midcontinent Rift. However, seismic data (Baranowski, 2009) show the Grenville Front as an extensive thrust-faulted terrane pushing west over the East Continent Basin, making that debate unclear at present.

Kentucky

The basement surface in Kentucky (Figure A-9) is constrained by 55 wells to the Precambrian, by a number of local seismic lines, and by maps and cross sections published by the Kentucky Geological Survey. Its most dramatic features are the Reelfoot Rift/Rough Creek Graben (Dart and Swolfs, 1998; Csontos et al., 2008; Hickman, 2011, 2013) in the western part of the state and the Rome Trough in eastern Kentucky (Drahovzal and Noger, 1995). These features form deep basement grabens in two distinct segments but do not exhibit the vast basalt flows or dominant terrestrial sedimentation of the Midcontinent Rift. There are thick accumulations of Cambrian sandstones, siltstones, and carbonates (Hickman, 2011, 2013) indicating very rapid sedimentation coinciding with rifting. The Grenville Front runs through central Kentucky and forms the eastern edge of the East Continent Basin, which Drahovzal et al. (1992) extended into Tennessee, although Moecher et al. (2018) terminate it at the edge of the Rough Creek and Rome grabens. Abutting the Grenville Front in Ohio and Kentucky, this basin reaches over 24,000 ft. (7,500 m) (Drahovzal, 1992).