Transactions of the Kansas Academy of Science

Vol. 125, no. 1-2
p. 41-51 (2022)

Reappraisal of the glaciation of northeastern Kansas

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The glaciation of northeastern Kansas has attracted scientific attention since the mid-19th century and has played a conspicuous role for glacial stratigraphy and chronology. Since the 1990s, many studies have been conducted in Kansas, other mid-western states, and elsewhere around the world that shed additional light on the glaciation of Kansas as well as its global role. All glacial and glacially related deposits in northeastern Kansas are designated as the Independence Formation with an age range in the interval approximately 810,000 to 640,000 years ago corresponding to MIS 20-16 (latest Matuyama - early Brunhes chrons).

The Independence Glaciation took place as two, large ice lobes - Minnesota and Dakota, which are interpreted as low-profile ice masses that were quite thin at their margins and advanced by surging over thawed or deformable beds. The Independence Glaciation corresponds in part with the Don Glaciation in Europe and to MIS 16, which is appropriately one of the greatest glacial phases in the entire Pleistocene Epoch. The Independence and Don glaciations represent the farthest southward expansions into their respective continental interiors.

Keywords: Don Glaciation, glacial dynamics, Independence Formation, ice lobe, kineto-stratigraphy, landscape symmetry, Lava Creek Tuff, magnetic polarity, marine-isotope stage (MIS), pipestone, Sioux Quartzite.

Introduction

Scientific investigation of glaciation in northeastern Kansas has a long and rich history beginning in the mid-19th century. The glacial character of this landscape was first recognized by Louis Agassiz, the father of the glacial theory, during a trip across the Great Plains in 1868. He interpreted the quartzite and granite boulders that litter the surface as erratics transported by an ice sheet from sources far to the north. He furthermore recognized that the major river valleys had originated as meltwater drainage routes away from the ice sheet.

The limits of glaciation in Kansas and related glacial and meltwater features were investigated in detail during the late 19th and early 20th centuries, most notably by Walter H. Schoewe, Bernard B. Smyth, James E. Todd, J.W. Wilson, and Lyman C. Wooster (Aber 1984). Many of their reports were published in these *Transactions of the Kansas Academy of Science*.

The terms Nebraskan and Kansan were applied respectively to the presumed oldest and second-oldest glaciations of the region by Thomas C. Chamberlin (1895), and this simple stratigraphy was generally accepted through the middle of the 20th century (Frye and Leonard 1952). The Pearlette ash, a supposed single volcanic ash fall, was utilized for regional correlation. However, much debate and uncertainty surrounded the exact definitions and meanings of these terms, as multiple glaciations and volcanic ash falls were discovered in the region (Dort 1987). The classical names Kansan and Nebraskan therefore have been discontinued (Hallberg 1986).

Aber (1991) undertook a thorough re-investigation of glaciation in northeastern Kansas including glacial limits, ice-lobe dynamics, drainage diversions, stratigraphy, and age. His main findings are summarized below (Fig. 1).

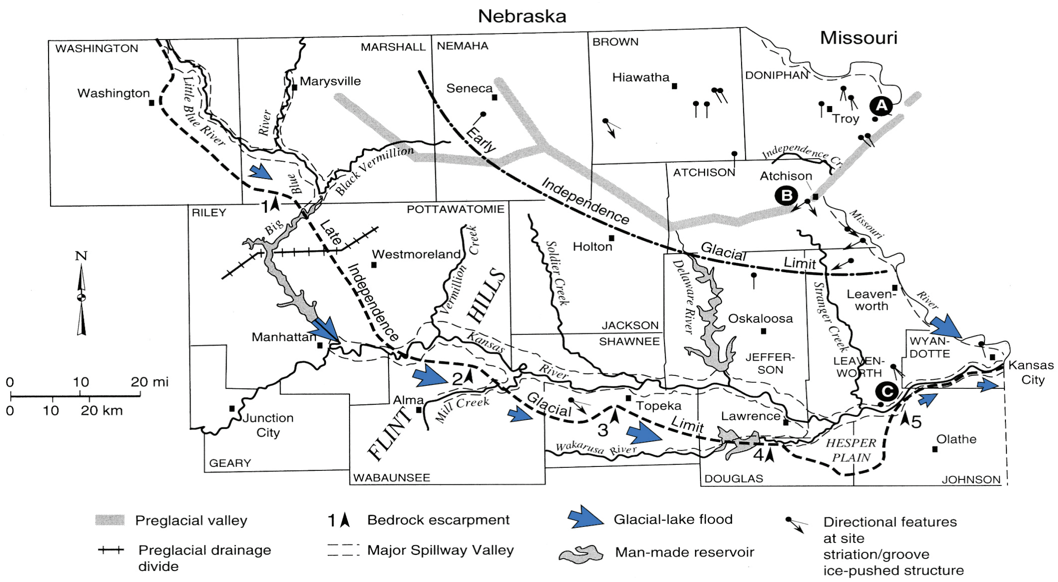

Figure 1. Glaciation of northeastern Kansas by two ice-lobe advances. Key sites for stratigraphy and dating: A: Wathena local fauna, B: Atchison stratotype, C: De Soto volcanic ash. Bedrock escarpments (1-5) held up the maximum limit of glaciation, which spread farther south in lower areas between escarpments. Based on Aber (1991); adapted from Denne et al. (1998).

• All glacial and glacially related sedimentary deposits in Kansas were assigned to the Independence Formation with a stratotype in Atchison County (Fig. 2). This section has remained more-or-less stable since first described by Schoewe (1938) and later by Dellwig and Baldwing (1965). The stratotype and regional extent of the formation were interpreted using the principles of kineto-stratigraphy (Berthelsen 1978) and tracing of indicator erratics.

• Two main glacier advances took place and these were ascribed to large ice lobes, namely the Minnesota and Dakota (Fig. 3). The former entered the state first from the northeast and reached northern Leavenworth and Jefferson counties, and the latter then advanced from the north-northwest and extended to the maximum glacial limit south of the Kansas River valley.

• Preglacial drainage of the Grand River system was largely erased by infilling of now-buried valleys. The modern drainage network was created by meltwater erosion that reached >100 m deep below adjacent bedrock uplands. These valleys are partly infilled by outwash sediment, including the Little and Big Blue, Kansas, Wakarusa, Missouri, and others.

• Major river valleys in the modern landscape were created by meltwater erosion in three positions, namely lobe axis, lobe marginal, and interlobate (see Fig. 3).

• Age of the Independence Formation was determined by preglacial fossils at Wathena and postglacial volcanic ash at De Soto (see Fig. 1) as well as normal magnetic polarity of tills, in the range 0.7 to 0.6 million years old, which corresponded to marine-isotope stages (MIS) 18-16.

• The Independence Glaciation was recognized among the oldest Pleistocene glaciations with a regionally preserved record that is expressed in the modern landscape.

Many additional studies have been conducted since in Kansas, other mid-western states, and elsewhere around the world that shed additional light on the Independence Glaciation as well as its global role during the Pleistocene Epoch. These are reviewed in the following sections.

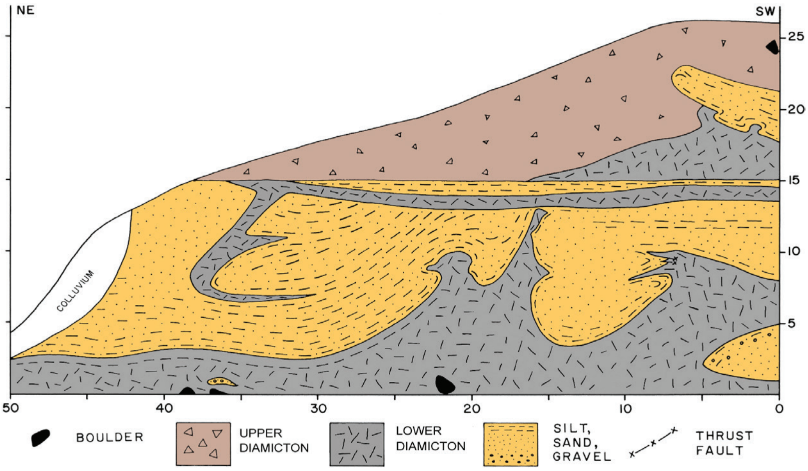

Figure 2. Measured section in the Independence Formation stratotype, West Atchison, Kansas. The lower gray diamicton (till) and middle sand are strongly deformed and overlain by the upper brown diamicton (till). Scale in meters; adapted from Aber and Ber (2007).

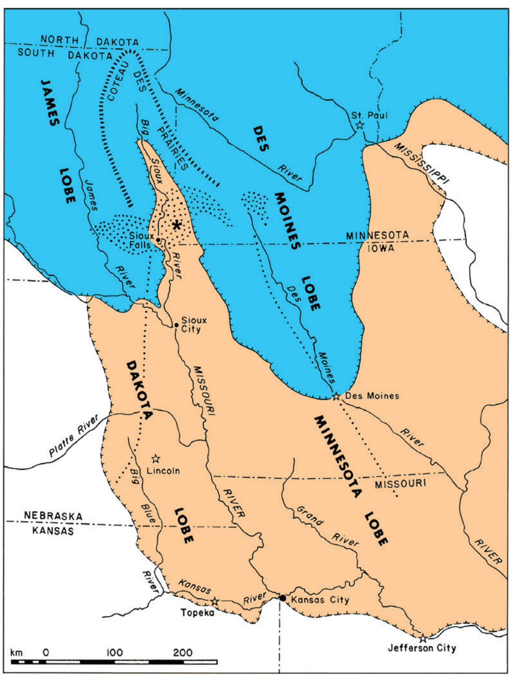

Figure 3. Late Wisconsin ice lobes (blue) and Independence ice lobes (tan) in the region west of the Mississippi River. The southern portion of the Coteau des Prairies upland is cored by a resistant ridge of Sioux Quartzite (dotted zones). Dotted lines show limits of Sioux Quartzite erratic fan to south. Asterisk (*) marks the unique source for Kansas pipestone erratics. Adapted from Aber and Ber (2007).

Glacial dynamics, limits, and drainage diversions

The two-ice-lobe model for glaciation of Kansas was accepted by Merriam (2003; 2008), who reviewed all striations and ice-pushed structures as directional indicators for glacier movement in northeastern Kansas. He mapped the southernmost extent of glaciation to 38.83° N latitude in the Hesper Plain east of Lawrence (see Fig. 1). He furthermore determined the glacier snout must have been no more than a few 100 m thick. This is compatible with the younger and equivalent Des Moines lobe in Iowa and James lobe in South Dakota of Late Wisconin age (20,000 to 14,000 years ago).

Clark (1992) reconstructed and interpreted the Des Moines and James lobes as low-profile glacier masses that were no more than 100-200 m thick near their margins, and Mickelson and Colgan (2004) elaborated this concept. These lobes advanced rapidly over thawed ground by surging on water-lubricated or deforming beds. Repeated advances alternated with ice stagnation. The Minnesota and Dakota lobes may have behaved in a similar manner, particularly near the southern extents of their advances where permafrost was scarce.

Among the most unusual erratics in northeastern Kansas is pipestone, a soft, blood-red rock that was widely used by

Figure 4. Pipestone erratic collected from ice-contact meltwater deposits near Marysville. Comb is about 5 inches (~13 cm) long.

Native Americans (Fig. 4). Pipestone is found in glacial deposits of the Dakota lobe to the maximum limit of late Independence glaciation. Pipestone was derived from the same source formation as Sioux Quartzite erratics (see Fig. 3). For many years, it was assumed this distinctive stone was the variety catlinite from Pipestone National Monument (PNM), but this is not the case for a couple of reasons. First, far more pipestone erratics are found in Kansas than could be explained by the thin catlinite seam at PNM. Second, Kansas pipestone is compositionally different from catlinite. The unique source for Kansas pipestone was discovered by Gundersen at Jasper in southwestern Minnesota near the South Dakota boundary (Gundersen and Tiffany 1986; Hadley 2018).

Denne et al. (1998) conducted detailed subsurface exploration for buried valleys in northeastern Kansas. Aber (1999) and Aber and Apolzer (2004) undertook digital mapping of glacial features across the pre-Illinoian region of the central United States west of the Mississippi. These efforts revealed many more meltwater drainage routes in northeastern Kansas, including the Black Vermillion, Vermillion, Soldier, Delaware, and Stranger valleys (see Fig. 1), as well as channels that were infilled with glacial sediment and have no surface expression in the modern landscape

Figure 5. Buried valley filled with ice-contact stratified drift has been excavated as a source for sand and gravel for many years. South of Marysville and parallel to the Big Blue River valley.

(Fig. 5). These valleys were created during the early Independence ice advance and extend southward from its maximum position. Once formed these valleys were reused for meltwater drainage during advancing and retreating phases of the late Independence glaciation.

At the maximum of the late Independence Glaciation, the Blue/Kansas drainage route was blocked in the vicinity of the cities of Manhattan and Wamego, which impounded glacial Kaw Lake (Todd 1918; Dort 1987). This proglacial lake must have filled quite rapidly as it received meltwater from the western margin of the Dakota ice lobe as well as runoff from the northern Great Plains and glaciers in the northern Rocky Mountains (Fig. 6). Catastropic flooding overflowed local divides and eroded spillways into Mill Creek and farther downstream into Wakarusa, Kansas, and Missouri valleys (Fig. 7).

Stratigraphy and age

Glacial stratigraphy in northeastern Kansas was reviewed thoroughly by Denne et al. (1998), who accepted the Independence Formation, and this designation was adopted by many authors (Colgan 1998; Jennings et al. 2007; Ehlers and Gibbard 2008). Advances in various radiometric dating techniques have led to refinements in the probable age range for the Independence Formation. Minimum age is given by the De Soto volcanic ash in post-glacial alluvium of the Kansas River

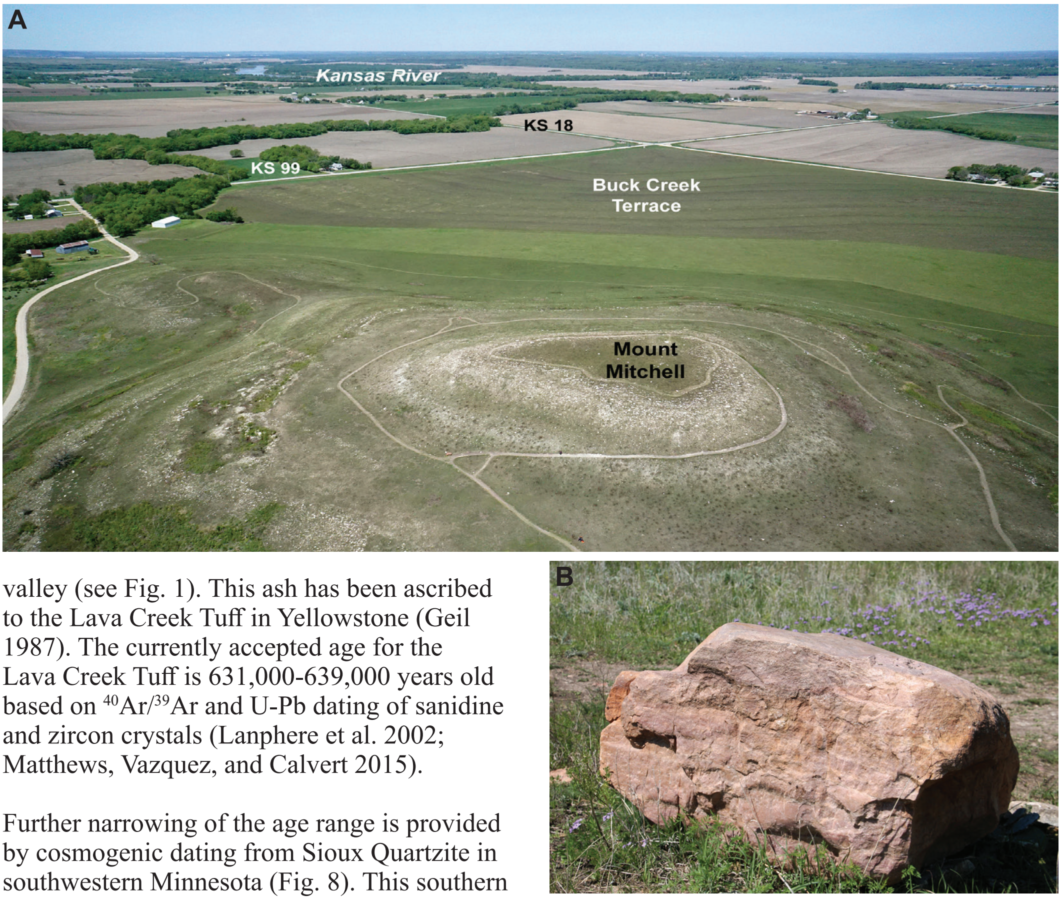

Figure 6. Mount Mitchell (39.145°, -96.298°) is a bedrock knob with numerous erratic boulders on the southern side of the Kansas River valley, north of Alma. (A) Kite aerial overview looking to the northwest. Mount Mitchell rises some 55-60 m above the Buck Creek Terrace of Middle Pleistocene age, which stands in turn more than 10 m above the Kansas River valley bottomland. The area visible beyond Mount Mitchell was inundated by proglacial Kaw Lake during the maximum late Independence Glaciation. (B) Erratic boulder of Sioux Quartzite is about 1 m long.

valley (see Fig. 1). This ash has been ascribed to the Lava Creek Tuff in Yellowstone (Geil 1987). The currently accepted age for the Lava Creek Tuff is 631,000-639,000 years old based on $^{40}Ar/^{39}Ar$ and U-Pb dating of sanidine and zircon crystals (Lanphere et al. 2002; Matthews, Vazquez, and Calvert 2015).

Further narrowing of the age range is provided by cosmogenic dating from Sioux Quartzite in southwestern Minnesota (Fig. 8). This southern portion of the Coteau des Prairies upland was an interlobate zone between the Des Moines and James lobes during the Late Wisconsin glaciation (see Fig. 3). Bierman et al. (1999) determined that exposed surfaces on the Sioux Quartzite were last overrun by glacier ice some 740,000 to 640,000 years ago and have not been glaciated since. Thus, no younger ice sheet could have reached southward as far as Kansas after 640,000 years ago, but earlier glaciations were certainly possible.

Early results indicated that tills within the Independence Formation have primary normal magnetic polarity (Aber 1991). Colgan (1998) confirmed the normal magnetic polarity of tills in the Kansas City vicinity (Missouri and Kansas), which he considered time equivalent to the Independence Formation in Kansas and the McCredie Formation in Missouri. This would restrict the maximum age to the current Brunhes Chron. On this basis, Colgan (1999) estimated the age range as 780,000 to 620,000 years old. Subsequent investigations by Roy et al. (2004) revealed the presence of tills with reversed polarity in northeastern Kansas. This raises the possibility that some older glacial deposits in Kansas date from the late Matuyama Chron (Fig. 9). A maximum age of about one million years is provided by the Wathena local fauna

Figure 7. Kaw Point at the junction of the Kansas and Missouri rivers. These valleys were the principal ice-marginal meltwater drainage routes along the late Independence maximum advance. Panoramic view looking eastward assembled from two helium-blimp airphotos. Skyline of downtown Kansas City, Missouri in the right background.

preserved in preglacial alluvium (Martin and Schultz 1985; see Fig. 1). The verified age for the Independence Formation must be adjusted, therefore, to the range ~1.0 million to 640,000 years old.

Regional relationships

Glacial deposits of similar characteristics and ages to the Independence Formation are known in Missouri, specifically the Fulton Member of the McCredie Formation (Balco and Rovey 2010). Even older tills with reversed polarity are present in eastern Nebraska, northeastern Missouri, and southern Iowa. These represent two glaciations about 1.3 and 2.4 million years ago (Roy et al. 2004; Balco and Rovey 2010).

The oldest known till in the Canadian Prairie comes from the Mennon Formation in southern Saskatchewan. This till has reversed polarity, rests on preglacial sediments of the Empress Group that contain the Wellsch Valley Tephra, dated 780,000 years old, and is overlain by normal-polarity sediments that include the Wascana Creek Tephra (Lava Creek Tuff). The Mennon Formation is assigned to the late Matuyama Chron and specifically to MIS 20 (Barendregt, Enkin, and Tessler 2012).

Figure 8. Natural outcrop of Sioux Quartzite showing a conglomerate layer in southwestern Minnesota. Surface exposures of this type are suitable for cosmogenic dating. Brunton compass for scale.

The ultimate source of the Minnesota and Dakota lobes of the Independence Glaciation was previously considered to be an ice dome in central Canada, namely the Hudson Bay dome and possibly the Keewatin dome west of Hudson Bay. Barendregt and Duk-Rodkin (2011) reconstructed North American ice-sheet coverage for the Matuyama and early Brunhes chrons. Early Matuyama glaciations that reached eastern Nebraska are associated with an ice sheet derived from eastern Hudson Bay and Labrador sources.

Late Matuyama glaciations, on the other hand, were centered in the Hudson Bay region with a modest Keewatin Ice Center to the west, as indicated by the Mennon till in southern Saskatchewan and the Minnesota ice-lobe advance into northeastern Kansas. The Keewatin Ice Center was even more prominent during early Brunhes glaciations, as shown by the Dakota ice-lobe advance to the maximum glacial limit in northeastern Kansas.

Another long-term factor that must be considered is the changing nature of the substrate over which successive ice sheets advanced (Balco and Rovey 2010). In general, crystalline bedrock of the Canadian Shield is considered rigid; whereas, sedimentary bedrock is more susceptible to deformation and potential ice-lobe surging. During the Independence and earlier glaciations, sedimentary bedrock cover may well have extended much farther north than the present limit of the Canadian Shield in southern Minnesota. This would have allowed relatively thin, low-profile ice lobes to expand southward. Progressive glacial erosion and removal of sedimentary bedrock, thus exposing larger areas of the Canadian Shield, may have limited the southward expansion of later glaciations.

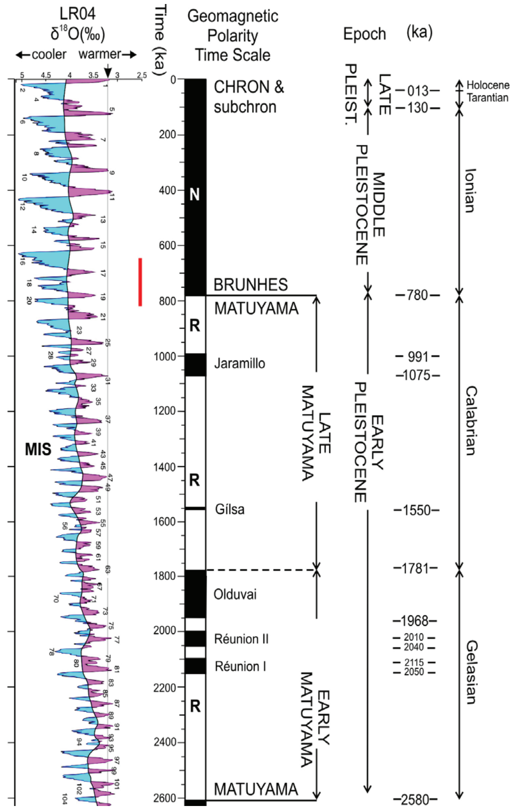

Figure 9. Global stratigraphic relations for the Pleistocene Epoch. Numbered marine-isotope stages (MIS) are given on the left side; even are glacial, odd are interglacial. Red bar denotes the likely age range for the Independence Formation, ~810,000 to 640,000 years ago, corresponding to MIS 20-16. Age in thousands of years (ka). Adapted from Barendregt and Duk-Rodkin (2011; fig. 32.1); color image courtesy of R.W. Barendregt.

Global connections

It is now generally accepted that Middle and Late Pleistocene glaciations took place in a regular, repetitive manner, in which each glacial cycle lasted approximately 100,000 years driven by Earth-Sun orbital eccentricity (Hughes and Gibbard 2018). This cyclic pattern of large glaciations began approximately 900,000 years ago with MIS 22 (see Fig. 9). The marine-isotope record provides a means to refine the likely age range for glaciation in Kansas. In combination with regional relationships, the best estimate for age of the Independence Formation is MIS 20-16 (latest Matuyama – early Brunhes chrons), approximately 810,000 to 640,000 years ago.

The glaciation of northeastern Kansas necessarily represents an ice sheet with greater geographic extent than later glaciations in the Great Plains. This may be explained in part by substrate conditions, as noted above, but may also reflect global climate. Not surprisingly, MIS 16 (early Brunhes Chron) displays one of the strongest glacial signals in the Pleistocene record with an exceptionally high $^{18}O/^{16}O$ ratio, low sea level (-120 m), and the lowest atmospheric greenhouse gases (CO_2 and CH_4) of the last 800,000 years (Past Interglacials 2015). MIS 16 is designated as "pre-Illinoian D" in North America and ranks as one of the two greatest glacial phases (along with MIS 12) during the entire Pleistocene Epoch (Hughes, Gibbard, and Ehlers 2019).

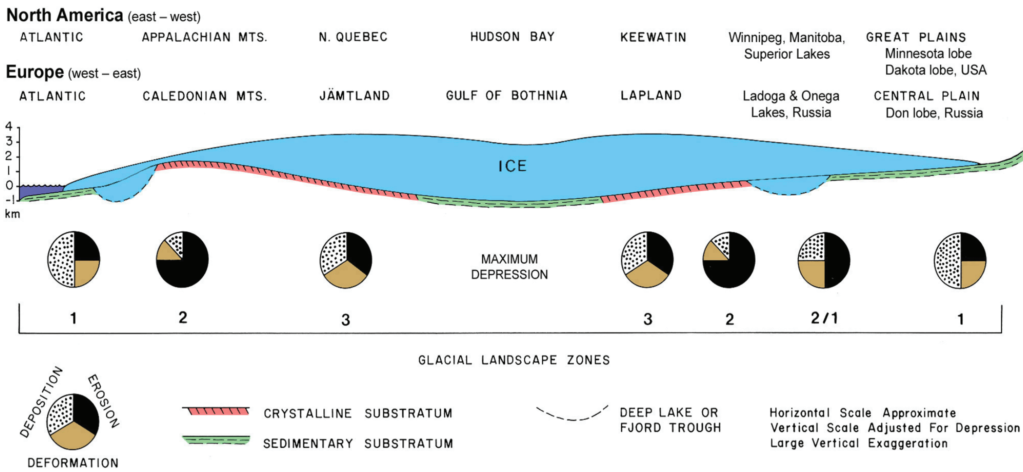

Figure 10. Model of glacial landscape symmetry for North America (east-west) and Europe (west-east) with schematic ice-sheet profile, substratum bedrock, and crustal depression. Pie diagrams represent local, relative contributions of glacial erosion, deformation, and deposition for modifying the three landscape zones (1-3); overall magnitude of glacial landscape modification increases outward to the east and west. Positions for the Minnesota, Dakota, and Don ice lobes are marked in the outer landscape zone (1) to upper right. Adapted from Aber and Ber (2007).

In Europe, the Don (Donian) Glaciation took place during MIS 16 and reached its peak in the eastern European Plain about 650,000 years ago. At its maximum extent, it expanded into central Poland, and a large ice lobe flowed to the southeast, across Moscow, to the Don River (~49.6° N latitude) near Volgograd, Russia (Turner 1996). The Don advance into Russia was the most extensive of all Pleistocene glaciations in eastern Europe (Hughes, Gibbard, and Ehlers 2019).

The Independence and Don glaciations took place at approximately the same, or overlapping, times. Both represent the farthest southward expansion of ice lobes into the continental interiors (southwest in the U.S. and southeast in Russia). The Don Glaciation was fed from a central ice dome in Fennoscandinavia, particularly Finland and northwestern Russia, as shown by erratic indicators (Alekseev 1996).

Aber (1992) called attention to the symmetrical arrangement of continental glacial landscape zones in Europe and North America (Fig. 10). These zones represent mature, end-product landscapes produced by multiple ice-sheet glaciations (Aber and Ber 2007). The Don and Independence glaciations occupy similar settings as the farthest southern advances by ice lobes into their respective continental interiors.

The questions remain of why the Independence and Don glaciations were larger overall than Late Pleistocene glaciations and, in particular, why these glaciations achieved their greatest expansions into the continental interiors far from central ice domes and far from moisture sources. The answers to these questions are connected to continental tectonics, paleoceanography, and global climate, which remain uncertain and are beyond the scope of this brief reappraisal.

Conclusions

All glacial and glacially related deposits in northeastern Kansas are designated as the Independence Formation with a stratotype in Atchison County. The glaciation of Kansas took place as two large ice lobes - Minnesota and Dakota - advanced respectively from the northeast and north-northwest. The Minnesota lobe was first to enter the state and reached a maximum position in northern Leavenworth and Jefferson counties. The Dakota lobe was next and advanced to a maximum position south of the Kansas River valley. These advances blocked and infilled the preglacial Grand River drainage system. Meltwater impounded in proglacial lakes overflowed and eroded spillways that led to development of the modern drainage system including all larger river valleys and most smaller stream valleys.

The revised age range for the Independence Formation is about 810,000 to 640,000 years old. This corresponds to MIS 20-16, which appropriately represents one of the greatest glacial phases during the Pleistocene Epoch. In Europe, the Don Glaciation took place during MIS 16, reached its peak about 650,000 years ago, and was the most extensive of all Pleistocene glaciations in eastern Europe. Both the Don and Independence glaciations represent the farthest southern penetrations by ice lobes into their respective continental interiors, which reflect the general landscape symmetry and synchronism of glacial maxima in North America and Europe.

Acknowledgments

My interest in the glaciation of Kansas was inspired by Wakefield Dort, Jr. and Louis F. Dellwig and further renewed by Daniel F. Merriam. Recent field observations in northeastern Kansas were conducted with Paul Johnston, Alan and Tom Peterson, Randy Rose, and students from Emporia State University. Kite and helium-blimp aerial photographs were acquired with Susan E.W. Aber. René Barendregt and Carrie Jennings provided constructive reviews that helped to focus the manuscript.

Literature Cited

Aber, J.S. 1984. History of Kansas glacial geology. Earth Sciences History 3, p. 134-142.

Aber, J.S. 1991. The glaciation of northeastern Kansas. Boreas 20, p. 297-314.

Aber, J.S. 1992. Glaciotectonic structures and landforms. Encyclopedia of Earth System Science, vol. 2, p. 361-378. Academic Press, San Diego.

Aber, J.S. 1999. Pre-Illinoian glacial geomorphology and dynamics in the central United States, west of the Mississippi. In Mickelson, D.M. and Attig, J.W. (eds.), Glacial processes past and present. Geological Society of America, Special Paper 337, p. 113-119.

Aber, J.S. and Apolzer, K. 2004. Pre-Wisconsinan glacial database and ice limits in the central United States. In, Ehlers, J. and Gibbard, P. (eds.), Quaternary Glaciations – Extent and Chronology, Part II: North America. Developments in Quaternary Science, Vol. 2b, p. 83-88. Elsevier, Amsterdam.

Aber, J.S. and Ber, A. 2007. Glaciotectonism. Developments in Quaternary Geology 6, Elsevier, Amsterdam, 246 p.

Alekseev, M.N. 1996. Possible 'Cromerian Complex' equivalent sequences in the Russian Plain. In, Turner, C. (ed.), The early Middle Pleistocene in Europe, p. 273-277. Balkema, Rotterdam. Accessed online <https://www.qpg.geog.cam.ac.uk/research/projects/nweurorivers/donglaciation.html> 2 February 2022.

Balco, G. and Rovey, C.W. II 2010. Absolute chronology for major Pleistocene advances of the Laurentide Ice Sheet. Geology 38, p. 795-798.

Barendregt, R.W. and Duk-Rodkin, A. 2011. Chronology and extent of Late Cenozoic ice sheets in North America: A magnetostratigraphic approach. In, Ehlers, J. Gibbard, P.L. and Hughes, P.D. (eds.), Quaternary glaciations – Extent and chronology: A closer look, p. 419-426. Elsevier, Amsterdam, Netherlands.

Barendregt, R.W., Enkin, R.J., and Tessler, D.L. 2012. Magnetostratigraphy of Late Neogene Glacial, Interglacial, and Preglacial sediments in the Saskatoon and Regina areas, Saskatchewan, Canada. Studia Geophysica et Geodaetica 56, p. 705-724.

Berthelsen, A. 1978. The methodology of kineto-stratigraphy as applied to glacial geology. Geological Society of Denmark, Bulletin 27, Special issue, p. 25-38.

Bierman, P.R., Marsella, K.A., Patterson, C., Davis, P.T., and Caffee, M. 1999. Mid-Pleistocene cosmogenic minimum-age limits for pre-Wisconsin glacial surfaces in southwestern Minnesota and southern Baffin Island: A multiple nuclide approach. Geomorphology 27, p. 25-39.

Chamberlin, T.C. 1895. The classification of American glacial deposits. Journal Geology 3, p. 270-277.

Clark, P.U. 1992. Surface form of the southern Laurentide ice sheet and its implications to ice-sheet dynamics. Geological Society America, Bulletin 104, p. 595-605.

Colgan, P.M. 1998. Paleomagnetism of pre-Illinoian till near Kansas City, Kansas. Transactions of the Kansas Academy of Science 101, p. 25-34.

Colgan, P.M. 1999. Early middle Pleistocene glacial sediments (780000-620000 BP) near Kansas City, northeastern Kansas and northwestern Missouri, USA. Boreas 28, p. 477-489.

Dellwig, L.F. and Baldwin, A.D. 1965. Ice-push deformation in northeastern Kansas. Kansas Geological Survey, Bulletin 175, part 2, 16 p.

Denne, J.E., Miller, R.E., Hathaway, L.R., O'Conner, H.G., and Johnson, W.C. 1998. Hydrology and geochemistry of glacial deposits. Kansas Geological Survey, Bulletin 229, 127 p.

Dort, W. Jr. 1987. Salient aspects of the terminal zone of continental glaciation in Kansas. In, Johnson, W.C. (ed.), Quaternary environments of Kansas. Kansas Geological Survey, Guidebook Series 5, p. 55-66.

Ehlers, J. and Gibbard, P. 2008. Extent and chronology of Quaternary glaciation. Episodes 31, p. 211-218.

Fyre, J.C. and Leonard, A.B. 1952. Pleistocene geology of Kansas. Kansas Geological Survey, Bulletin 99.

Geil, S.A. 1987. Significance and dating of a volcanic ash located within terrace fill north of De Soto, Kansas. Kansas Geological Survey, Guidebook Series 5, p. 33-37.

Gundersen, J.N. and Tiffany, J.A. 1986. Nature and provenance of red pipestone from the Wittrock Site (130B4), northwest Iowa. North American Archaeologist 7, p. 45-67.

Hadley, A.M. 2018. Continuity and change in pipestone sources at Great Bend aspect and Wichita sites. Plains Anthropologist 64, p. 93-114. Accessed online <https://www.tandfonline.com/doi/abs/10.1080/00320447.2018.1465801> 9 March 2022.

Hallberg, G.R. 1986. Pre-Wisconsin glacial stratigraphy of the Central Plains region in Iowa, Nebraska, Kansas, and Missouri. Quaternary Science Reviews 5, p. 11-15.

Hughes, P.D. and Gibbard, P.L. 2018. Global glacier dynamics during 100 ka Pleistocene glacial cycles. Quaternary Research 90, p. 222-243.

Hughes, P.D.,Gibbard, P.L., and Ehlers, J. 2019. The "missing glaciations" of the Middle Pleistocene. Quaternary Research 1–23 <https://doi.org/10.1017/qua.2019.76>.

Jennings, C.E., Aber, J.S., Balco, G., Barendregt, R., Bierman, P.R., Rovey II, C.W., Roy, M., and Mason, J.A. 2007. Mid-Quaternary in North America. In Elias, S. A. (ed.), Encyclopedia of Quaternary Science, v. 2, p. 1044–1051. Elsevier, Amsterdam.

Lanphere, M.A., Champion, D.E., Christiansen, R.L., Izett, G.A., and Obradovich, J.D. 2002. Revised ages for tuffs of the Yellowstone Plateau volcanic field: Assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event. Geological Society of America, Bulletin 114, p. 559-568.

Martin, L.D. and Schultz, C.B. 1985. Small mammals of the Seneca and Sappa local faunas (post-Ogallala of Nebraska). Ter-Qua Symposium Series 1, p. 163-179.

Matthews, N.E., Vazquez, J.A., and Calvert, A.T. 2015. Age of the Lava Creek supereruption and magma chamber assembly at Yellowstone based on $^{40}Ar/^{39}Ar$ and U-Pb dating of sanidine and zircon crystals. Geochemistry, Geophysics, Geosystems 16, p. 2508-2528.

Merriam, D.F. 2003. Southern extent of the Kansan Glaciation (Pleistocene) in Douglas County, Kansas. Transactions of the Kansas Academy of Science 106, p. 17-28.

Merriam, D.F. 2008. Glacial striae and ice-push deformation as indicators of glacial directional movement in northeastern Kansas. Transactions of the Kansas Academy of Science 111, p. 45-48.

Mickelson, D.M. and Colgan, P.M. 2004. The southern Laurentide Ice Sheet. In, Gillespie, A.R., Porter, S.C. and Atwater, B.F. (eds.), The Quaternary Period in the United States, p. 1-16. Developments in Quaternary Science 1, Elsevier, Amsterdam.

Past Interglacials Working Group of PAGES. 2015. Interglacials of the last 800,000 years. Reviews of Geophysics 54, p. 162-219.

Roy, M., Clark, P.U., Barendregt, R.W. Glasmann, J.R., and Enkin, R.J. 2004. Glacial stratigraphy and paleomagnetism of late Cenozoic deposits of the north-central United States. Geological Society of America, Bulletin 116, p. 30-41.

Schoewe, W.H. 1938. The west Atchison glacial section. Transactions of the Kansas Academy of Science 41, p. 227.

Todd, J.E. 1918. History of Kaw Lake. Transactions of the Kansas Academy of Science 28, p. 187-203.

Turner, C. 1996. A brief survey of the early Middle Pleistocene in Europe. In, Turner, C. (ed.), The early Middle Pleistocene in Europe, p. 295-317. Balkema, Rotterdam. Accessed online <https://www.qpg.geog.cam.ac.uk/research/projects/nweurorivers/donglaciation.html> 1 February 2022.