ABSTRACT

Many distinct glacial episodes in the past ~1 million years in the Central Lowlands of North America left behind a patchwork of glaciated landscapes of different ages and formed through different glacial, paraglacial, and proglacial processes. Herein, we synthesize and reconcile diverse data sources across nine states in the Central Lowlands to create a generalized landform regions map, incorporating information from surficial geology, age-constrained glacial boundaries, soil properties and parent material, and topography. The resulting map presents regions of till plains, moraines, outwash plains, and glacial lakes with ages ranging from 10.2 cal ka BP to greater than 500 cal ka BP. This new map improves on regional perspectives of the glaciated Central Lowlands by modifying and reconciling boundaries to agree with a variety of spatial data sources with finer detail. This refined map enables a more accurate spatial analysis of the landform regions by reducing noise from imprecise boundaries.

1. Introduction

Maps characterizing the materials and landforms of Earth’s surface have long been created and used in numerous ways (e.g. Raisz, 1931; Smith, 1815). Diverse aims and evolving geospatial technologies have led to a variety of methods and data formats for creating these maps (Miller & Schaetzl, 2014; Schaetzl et al., 2013). Two types of commonly referenced physical geography maps for the glaciated Central Lowlands (CL), surficial geology maps and glacial boundary maps, have delineated units based on geologic material, age, and topographic patterns. Similarly, soil maps have inventoried the spatial distribution of surface characteristics in the physical landscape that include consideration of geologic material, age, and topography (Dokuchaev, 1883/1967; Miller & Schaetzl, 2016). However, under past paradigms for mapping, soil maps in the USA were too detailed to be produced and displayed for extents larger than a county (~2,000 km²). All of these map types, including physiographic maps in general, often reference each other resulting in a recursive process whereby generations of maps improve by synthesizing previous maps and incorporating new information (Miller & Burras, 2015).

Maps of geologic materials within approximately 10 m of the land surface are typically referred to as surficial geology maps. These maps are useful for identifying mineral resources (e.g. gravel deposits), shallow aquifer properties and extents, and significant...
landforms. Surficial geology maps are typically produced at a cartographic scale that can facilitate resource planning (Rickels et al., 2017). In addition, identification of significant landforms such as moraines, drumlins, and glacial lakes aids the interpretation of glacier extents and flow trajectories, thus informing glacial boundary maps. Many surficial geology maps are created at the quadrangle scale (1:24,000–1:100,000) and then generalized to produce state-scale maps (1:600,000–1:5,000,000).

Glacial boundary maps depict changes in geologic materials and the absolute or relative age of glacial deposits. They delineate the extent of glacial advances from moraine landforms or date-constrained deposits, while focusing less on the discrete landforms and materials within the boundaries of individual advances. The maps are used to provide geochronological context for the extent of glacial lobe advances and provide constraints for key glacial events like global ice volume changes, glacial lake drainage, and migration corridors (Dyke & Prest, 1987; Pedersen et al., 2016; Stokes et al., 2015).

Soil maps tend to focus on the characteristics of the uppermost 2 m of surficial materials and describe the modification of geologic material by physical, chemical, and biological processes. Traditionally, soil maps have been produced at cartographic scales as large as possible (e.g. > 1:25,000) to better serve cadastral and agricultural management needs. Soil maps produced at medium cartographic scales (1:1,000,000–1:25,000) tend to parallel surficial geology maps and at small cartographic scales (< 1:1,000,000) largely reflect bio-climate zones (Miller & Schaetzl, 2016). Detailed, large cartographic scale soil maps have been produced county by county in the USA by a coordinated effort between county-level governments, state universities, and the United States Department of Agriculture (USDA), known as the National Cooperative Soil Survey (NCSS). The mapping strategy employed by the NCSS commonly subdivides areas of similar geological material by geomorphic position and associated drainage conditions. In recent decades, the USDA Natural Resources Conservation Service – as stewards of these Soil Survey maps – have digitized the county maps and worked to reconcile discrepancies between adjoining county maps.

In practice, the extent of these maps is constrained by political units (e.g. quadrangle, county, state), which commonly results in adjacent and sometimes overlapping maps that are not in agreement. This lack of agreement can result from different mappers interpreting the evidence differently, but also results from differences in cartographic style such as level of generalization and valuing features differently. In addition, these maps can be created many years apart and thus reflect the tools available or prevalent conceptual models of the landscape from the time they were made. Recognizing this issue, the USDA Natural Resources Conservation Service (NRCS) has been working on a Soil Data Join Recorrelation Initiative for the past decade to harmonize county extent soil maps and enable their composite use at regional scales (USDA-NRCS, 2013). Similar attempts to reconcile surficial geology and glacial boundary maps of the CL over the years reflect the improvements made in detail of sediment dating and the understanding of glacial events (Chamberlin, 1883; Clayton & Moran, 1982; Dalton et al., 2020; Dyke & Prest, 1987; Flint et al., 1959; Hallberg & Kemmis, 1986).

1.1. Research problem

Quantitative analysis comparing characteristics of landform regions is hindered by low-spatial accuracy typical of generalized regional maps. For example, a comparison of postglacial stream networks by landscape age and physical characteristics requires regional scale delineations. However, the border placement of these delineations must be accurate at the local level (e.g. 1:12,000) to minimize noise in such analyses. To achieve the optimal map for this or other similar applications, information from multiple relevant sources needs to be synthesized. While different cartographic scales were a limitation for integrating maps in the past, the ability of geographic information systems (GIS) to freely move between cartographic scales allows the best qualities of maps from different cartographic scales to be brought together.

Although many supporting maps are available for the glaciated regions of the CL (e.g. glacial boundary, surficial geology, and detailed soil survey maps), there are inconsistencies in the way landforms and ages are treated across political boundaries. The existing glacial boundary maps also have inconsistencies when overlaying them on a fine resolution (<10 m) digital elevation model (DEM). These inconsistencies highlight uncertainty in the maps and present a source of error in regional analysis, allowing the characteristics of one region to be included in the analysis results of another.

While large extent generalizations are still needed for regional analysis, the same map can also have the boundary placement accuracy of a local scale map due to the ability to adjust cartographic scale in a GIS (i.e. zoom functionality). A map that is more reliable for geomorphic analyses of patterns between regions would (1) reconcile inconsistencies between maps that are synthesized in the new map’s production, and (2) refine line placement to the level of detail contained in available fine resolution maps. Therefore, our goal was to develop such a map with detailed physical boundaries delineating what we term ‘landform regions’ based on a harmonization of data sources across cartographic scales and extents.
The regions of this map were then associated with an attribute table providing a synthesis of distinct ages since glaciation or transitions from glacial to postglacial process domains. In addition, the resulting map includes summary statistics for some physical characteristics of each region (i.e. median slope gradient and mean sand content).

2. Methods

The scope of the map produced in this work is the recently glaciated portion of the CL (Figure 1). Glaciers and ice-marginal glacial lakes deposited sediment in this area as recently as 10 ka BP and as long ago as 2.45 Ma BP (Balco & Rovey, 2010; Clayton & Moran, 1982). Note that portions of eastern Nebraska, northeast Kansas, and northern Missouri were also glaciated repeatedly prior to the Illinoian stage (prior to 300 ka). These portions of the midcontinent are omitted from this map because no moraines or constructional glacial landforms remain to demarcate distinct advances and large uncertainties remain in the extent and ages of pre-Illinoian tills (Rovey & McLouth, 2015).

Landscapes in the study area express a variety of topographies corresponding to their glacial legacy, surficial materials, depositional processes, and the accumulated time that postglacial processes have been modifying them. Spatial transitions in geomorphic surfaces and geological materials are thus represented to different degrees in different source datasets. These data sources also provide varying degrees of detail, necessitating both generalization and harmonization.

2.1. Data sources

Initial glacial landform region boundaries were assembled from a combination of state surficial geology maps and parent material classifications derived from soil survey maps (Miller et al., 2008). Identification of glacial landform types was based on state surficial geology maps and associated parallel information in the soil survey maps. In states without statewide surficial geology maps, interpretation of parent material from NCSS Soil Survey maps was relied upon more heavily. Where incongruities between surficial geology maps arose at state borders, other data sources were used to aid in resolution, including soil parent material, glacial boundary maps, and topography interpreted with a fine-resolution elevation hillshade.

Digital formats of surficial or Quaternary geology maps for North Dakota (Clayton, 1980), South Dakota (Martin, 2004), Minnesota (Minnesota Geological Survey, 2019), Illinois (Hansel & Johnson, 1996; Lineback, 1979), Indiana (Gray, 1989), Michigan (Farrand & Bell, 1982), and Ohio (Ohio Division of Geologic Survey, 2005) were downloaded from respective state
GIS repositories. A comparable surficial geology map of Wisconsin was not publicly available in a digital format, so preliminary region boundaries were derived from a surficial deposits spatial dataset (Wisconsin Department of Natural Resources, 2019) and paper maps (e.g. Attig et al., 2011). The surficial deposits map only included attributes of deposit type (e.g. sand, loam, and clay), but boundaries between those deposit types could be associated with landform regions described in sources that were not available in a GIS format. Iowa also lacks a statewide surficial geology map in digital format, so we began with a generalized landform region map based on Prior (1991) and added moraines and glacial boundaries based on Ruhe (1969) and Hallberg et al. (1994). Attention was also given to any existing physiographic region maps that might provide information about the extent of landform regions (e.g. Brockman, 1998; Gray, 2001; Schaetzl et al., 2013).

The NCSS Soil Survey maps were integrated in GIS from the USDA-NRCS gridded Soil Survey Geographic (gSSURGO) database (Soil Survey Staff, 2021a). NCSS Soil Survey maps do not describe soil parent material to the same level of attribute detail as surficial geology maps, especially with respect to landform age. To compensate for this lack of geologic focus in the soils maps, a custom table was generated linking soil map units with landforms identified in the surficial geology maps as described in Miller et al. (2008). The process of constructing this custom attribute table for the Soil Survey maps included referencing the Official Soil Series Descriptions for geographic setting information such as parent material and landform (Soil Survey Staff, 2021b). For verification and to deduce missing information, the spatial extent of soil series was evaluated for correspondence to boundaries in the surficial geology maps. The result from this processing of the gSSURGO soil map was a classification of the study area by seven sediment and two non-sediment map units (Figure 2).

Landforms inherited from glaciation are often expressed in topographic patterns, particularly in the more recently glaciated areas where postglacial erosion has not yet subdued constructional landforms. Thus, as additional supporting evidence, major topographic features were used to guide the discretization of landform regions. Hillshade and digital hillslope position models (Miller & Schaetzl, 2015) were generated from the U.S. National Elevation Dataset with a 10-meter resolution (USGS, 2020) for the entire area of interest. The elevation data provided a valuable reference at the regional scale due to its continuity across political boundaries. The hillshade provided an indicator of relief, while the digital hillslope position model classified the landscape into geomorphic hillslope components for a visualization of slope arrangement patterns.

2.2. Map generalization & boundary adjustment

Map generalization requires striking a balance between detail and simplicity in the context of known heterogeneity. For the purpose of our map, the priorities were to differentiate landscapes formed at different times and by different glacial lobes or depositional processes. To allow for analysis of regional patterns like drainage network morphometry, regions must be sufficiently large to encompass many drainage basins. At the same time, natural breaks in landscape age or dominant processes require differentiating between surfaces exposed by distinct retreats of ice lobes or the presence of ice-marginal lakes and large outwash plains. Thus, our landform regions generally cross-cut smaller Pleistocene outwash valley trains and Holocene alluvial deposits unless these units coincide with major ice margin indicators preserved on the landscape. In practice, no region less than 100 km² was preserved in our delineations, and most were much larger. When justifiable within our delineation framework, smaller fragments were incorporated within the adjoining region they most resembled.

Regions more recently glaciated typically retain more information about the glacial deposits and can therefore be subdivided in more detail than surfaces from older glaciations. Past work has indicated that much of the large-scale postglacial geomorphic change happens relatively quickly following deglaciation (e.g. Knighton, 2014), therefore older surfaces are less likely to be distinguishable in the same ways as younger surfaces. The gradual destruction of high-relief glacial landforms with time since deglaciation also contributes to boundaries between and within these older surfaces being less distinctive.

The process of harmonization across political boundaries reconciled discontinuities in both soil and surficial geology maps. In some cases, boundaries between topographically expressed landforms such as terminal moraines appeared offset at political boundaries. In other cases, boundaries coincided but the ages assigned to regions or landform interpretations were at odds across state or county lines. Many of these discontinuities could be addressed by consulting existing harmonized maps, such as the USGS’s Quaternary Geologic Atlas of the United States, I-1420 (e.g. Hallberg et al., 1994; Lineback et al., 1983). Where existing harmonized maps did not exist, larger-scale surficial geology and soil maps were compared in regions of conflict to identify opportunities for adjustment of boundaries. When this approach did not resolve a conflict, glacial boundary studies were referenced (e.g. Dalton et al., 2020). Finally, if all those steps failed to provide a clear resolution, topography was used to guide boundary delineations since the 10-meter
elevation data is continuous across political boundaries.

2.3. Region attributes

A vast body of surficial mapping and geochronological research on glacial deposits allowed us to apply landform types consistent with the literature and age attributes to our mapped regions. One of four landform types was assigned to each region according to the dominant composition and morphology characteristics described in primary sources. The four landform types are: (1) till plain; (2) moraine; (3) glacial lake; and (4) outwash. The moraine landform type was distinguished from till plain type by an abundance of constructional glacial landforms and/or sediments and morphologies associated with supraglacial sedimentation, such as ice-walled plains and high-relief hummocky moraine (e.g. Johnson & Clayton, 2005). This landform type included relatively diverse surficial materials in end moraine belts as well as regions described as ‘stagnation moraine’ or ‘interlobate.’ In contrast, till plains were predominantly low-relief surfaces without constructional glacial landforms or with landforms associated with subglacial processes such as drumlins and washboard moraines. Glacial lakes and outwash plains were identified based on the dominant surficial materials or soil parent materials.

Each landform region presented in the map produced by this work has been associated with an age that reflects the length of time a region has been exposed to nonglacial physical and biological processes at the surface. Many landform regions have experienced multiple ice advances. The ages presented here only reflect the most recent episode documented in surficial geology or glacial boundary studies. Similarly, regions that were glacial lakes use reported surface exposure ages that reflect time since the lake drained.

Ages are primarily determined from the MOCA (Meltwater routing and Ocean-Cryosphere-Atmosphere response project) compilation by Dalton et al. (2020), hereafter referred to as the ‘MOCA’ dataset. This dataset has been refined to meet our criteria of age since exposure to postglacial processes. Specifically, dates reflecting materials that were stratigraphically below till or below sediments associated with subsequent ice advances have been excluded. A total of 449 samples from the MOCA dataset were used to approximate an age of surface exposure. These dates were supplemented in Illinois by data from the Illinois State Geological Survey. Landform regions contain as few as zero and as many as 48 dated sample locations from these two data sources. Surface exposure ages for regions with multiple sample locations were estimated by taking the mean of the available calibrated ages. For regions without near-surface sample locations within their boundaries, ages were inferred from relevant literature (Bettis et al., 1996; Balco & Rovey, 2010; Clayton & Attig, 1989; Curry et al., 2018; Fisher et al., 2015; Mickelson & Attig, 2017) and, when necessary, calibrated using IntCal20 (Reimer et al., 2020). Specific
sample locations and references can be accessed in the digital data download (supplementary information). Only calibrated radiocarbon ages are reported here.

In addition to age and landform type, physical landscape attributes were associated with each landform region in the attribute table as a resource for future regional analysis. Specifically, we included mean sand percentage from a depth of 100–150 cm and median slope gradient. These attributes represent objective measures for differences between regions stemming from sedimentology and topography. Mean sand percentage was calculated for the area-weighted components of each soil map unit from gSSURGO. Slope gradient was calculated at a 30 m analysis scale in percent slope from the USGS DEM (USGS, 2020) using ArcGIS Pro v2.8. We then used the zonal statistics tool in ArcGIS Pro to determine a spatially weighted mean sand percentage and median slope gradient for each region.

3. Results and discussion

3.1. Examples of reconciling attributes

Inconsistencies in source surficial geology maps appear frequently at state boundaries and arise from one of two main causes: (1) differences in mapping detail; or (2) differences in geological or geomorphic interpretation. For example, the borders between Iowa and each surrounding state show many discontinuous boundaries due to a comparatively lower degree of detail in the Iowa source maps (Figure 1). In most cases, these inconsistencies were resolved by eliminating smaller regional subdivisions in the surficial geology maps during the generalization process.

Conflicts in surface interpretation and age assignment are evident in places such as the crest of the Prairie Coteau in southeastern South Dakota and neighboring Minnesota and Iowa (the northwestern extent of region 8 and 12 in Figure 3, enlarged in Figure 4). While the sur-

150 cm

3.2. Adjustment of boundaries

Landform region boundaries are based primarily upon boundaries retained following generalization of the surficial geology maps, adjusted as necessary according to topographic patterns and soil data. When unclear signals in soil or topographic data arose, decisions about boundary line placement were made based on reassessment of past glacial boundary literature and more detailed surficial geology maps (e.g. quadrangle maps). Below are two examples of different types of boundary adjustments made during the preparation of our map.

Glacial Lakes Minnesota (22) and Benson (14) are thought to have been short-lived (a few decades), shallow lakes formed at the margin of the retreating Des Moines Lobe in southern Minnesota (e.g. Rittenour et al., 1998). The lake plains they left behind exhibit substantial variation in sediment texture but little topographic relief (Figure 5). Each lake plain has discontinuous lacustrine deposits separated by areas of till or alluvium, possibly reflecting islands or penin-

5a). At this point, general-

and underlain by age-constrained (610 cal ka BP) Pearlette ash layers (Hallberg, 1986). There is no strong evidence of a distinct Illinoian glacial advance in this region. However, most recent interpretations have assigned a pre-Illinoian age to the correlated tills nearest to the surface (Johnson & McCormick, 2005; Patterson, 1997). East of region 8 but west of the Late Wisconsinan Bemis Moraine (region 13) of the Des Moines Lobe is a belt of landscape formed in a glacial advance that pre-dates the Bemis Moraine and is draped in Late Wisconsinan loess (Figure 4b). In South Dakota, this was referred to as the Toronto till plain, and the surficial till there is inferred to correlate with the Verdi member of the New Ulm Formation in Minnesota (Johnson et al., 2016). The same surface extends into northwestern Iowa where it has sometimes been called the ‘Tazewell’ till plain (e.g. Clayton & Moran, 1982). Recent stratigraphic work in this region of Iowa (Kerr et al., 2021) identifies this as a distinct surface reflecting at least two Middle Wisconsinan advances.

Glacial Lake Benson’s boundary, however, was extended well beyond the mapped extent in either data source. The increased area was guided by an understanding of methods used to make the original source maps and additional information available in the literature. The soil survey maps in this area were made county by county, which perpetuates the landscape model of the different mappers to the county boundaries. This situation can lead to a binary recognition (i.e. either present or not present) of sediment type presence in the respective mapping areas. Geology and soil mappers build from each

Figure 3. Landform regions of the glaciated Central Lowlands delineated using the methods described in text. Regions are shown draped over a hillshade derived from a 10-meter DEM (USGS, 2020). Refer to Table 1 for region names based on numbering. Lettered zones are areas shown as examples in (A) Figure 4, (B) Figure 5, and (C) Figure 6.

Figure 4. Enlarged view of the Prairie Coteau (region 8), showing age inconsistency between South Dakota and Minnesota (4a), and the soil parent material map derived from soil survey maps in the same region (4b). Colors in the surficial geology map (4a) correspond to the legend shown in Figure 1; colors in the soil parent material map (4b) correspond to the legend shown in Figure 2. Maps draped over a hillshade derived from a 10-m DEM (USGS, 2020). Refer to Table 1 for region names based on numbering. Location shown by zone A in Figure 3.
other’s work in a way that generally advances science but can sometimes perpetuate oversights (Miller et al., 2008). In this case, the sharp truncation of mapped lake deposits coinciding with a county line indicates a potential artifact from the mapping process. Reconstruction of Glacial Lake Benson based on strandlines and elevation contours suggests that it extended considerably further east.

Table 1. Select attributes for all delineated regions.

| Region Number | Name                      | Deposit Type | Major Lobe | Area (km²) | Median Slope (%) | Mean Sand (%) | Calibrated Age (ka) |
|---------------|---------------------------|--------------|------------|------------|------------------|---------------|---------------------|
| 1             | Missouri Couteau          | James        | James      | 46,200     | 2.6              | 38            | 13.50               |
| 2             | James Lobe                | Till Plain   | James      | 89,164     | 1.4              | 40            | 12.49               |
| 3             | SD Pre-Illinoian Moraine  | Moraine      | Pre-Illinoian | 30,581   | 3.0              | 38            | 210.00              |
| 4             | Lake Souris               | Glacial Lake | James      | 8,242      | 0.7              | 58            | 11.70               |
| 5             | SD Bemis West             | Moraine      | James      | 8,579      | 2.0              | 29            | 22.00               |
| 6             | Lake Dakota               | Glacial Lake | James      | 5,967      | 0.6              | 30            | 11.70               |
| 7             | Lake Agassiz              | Glacial Lake | Des Moines | 63,114     | 0.5              | 40            | 11.77               |
| 8             | Pre-Illinoian Glaciation  | Till Plain   | Pre-Illinoian | 129,885 | 4.1              | 24            | 210.00              |
| 9             | SD Bemis                  | Till Plain   | James      | 15,260     | 2.0              | 27            | 13.55               |
| 10            | Algona Moraine            | Till Plain   | Des Moines | 26,809     | 1.8              | 40            | 13.89               |
| 11            | Big Stone Moraine         | Till Plain   | Des Moines | 6,296      | 1.5              | 33            | 12.27               |
| 12            | Sheldon Creek Formation   | Till Plain   | Middle Wisconsinan | 8,516 | 2.1              | 33            | 34.36               |

JOURNAL OF MAPS 455
than mapped in either surficial geology or soil survey maps (Rittenour et al., 1998). We therefore followed Rittenour et al. (1998) in extending the lake boundary eastward along their inferred shoreline, encompassing additional lacustrine deposits to the south and east in adjacent counties.

Figure 5. Detailed view of central and southern Minnesota glacial lake plains Benson (region 14) and Minnesota (region 22). 5a. Sediment textural zones within glaciolacustrine deposits in Lusardi and others’ surficial geology map of Minnesota (Minnesota Geological Survey, 2019) shown with the landform region boundaries from this study. 5b. Classified soil parent materials shown with the landform region boundaries from this study. Colors correspond to the legend shown in Figure 2. Maps draped over a hillshade derived from a 10-m DEM (USGS, 2020). Refer to Table 1 for region names based on numbering. Dashed lines are county borders. Note that the northeastern portion of Glacial Lake Benson included in this study’s delineation and not in the surficial geology or soil parent material maps, correspond to the political boundaries of a single county. This reevaluation of the likely extent of Glacial Lake Benson illustrates the importance of considering a regional context beyond work that may have been constrained by political borders. Location shown by zone B in Figure 3.

Figure 6. Detailed view of the interface between the Saginaw interlobe and Huron-Erie Lobe regions. 6a. Deposition types in Gray’s Quaternary geology map of Indiana (1989) shown with the landform region boundaries from this study. 6b. Classified soil parent materials shown with the landform region boundaries from this study. Colors correspond to the legend shown in Figure 2. Maps draped over a hillshade derived from a 10-m DEM (USGS, 2020). Refer to Table 1 for region names based on numbering. Note that the boundary between the Union City moraine (region 58) and Outer Saginaw Plains (region 56) follows a break between loess cover to the east and the start of outwash bodies to the west. Regions 58, 59, 61, 62, and 64 are similar in composition and relief, but are differentiated by moraines that indicate a time transgressive sequence of landscape exposure. Location shown by zone C in Figure 3.
The northern margin of the Late Wisconsinan Huron-Erie Lobe in northeastern Indiana and southern Michigan was a challenging area to delineate due to the complex relationship with the adjacent Saginaw lobe and associated interlobate landforms and deposits (Fisher et al., 2020; Sodeman et al., 2021) (Figure 6). Surficial geology maps describe a complicated, fragmented boundary at the interface between these regions marked by the Union City Moraine (region 58). The complex boundary undoubtedly reflects the dynamic glacial, glaciofluvial, and aeolian processes acting on the landscape at the time (Figure 6a) but did not lend itself easily to generalization. However, inspection of the soil survey map (Figure 6b) suggests that loess cover can be used in part to distinguish Huron-Erie lobe moraines and till plains from adjacent surfaces. This loess cover becomes diffuse in the northeast corner of Figure 6b, though. In this area, many outwash bodies originate with northwest-trending paleocurrents, suggesting a former ice margin there (Zumberge, 1960). Thus, our generalized boundary separating the Union City Moraine from the Outer Saginaw Plains (region 56) follows the upstream end of many of these drainages (Figure 7).

4. Conclusions

The harmonization of multiple datasets of varying scale, detail, and focus has resulted in a map that is appropriate for quantitative analyses of landform regions in the glaciated CL. The map reduced inconsistencies between existing maps that cover only portions of the study area. Inconsistencies between attributes across political boundaries were reconciled based on the latest understanding of geologic history. Inconsistencies in existing boundaries due to different levels of generalization across political boundaries were resolved by applying a consistent criterion for delineating or grouping areas (i.e. soil parent material). Line placement was refined by tracing contrasts found in complementary datasets with finer resolution while zoomed in at the local scale. Specifically, line adjustments were guided by changes in relief observed in a 10-m resolution DEM and differences in soil parent material interpreted from soil survey maps originally created at cartographic scales between 1:12,000 and 1:24,000. The resulting regions were then associated with unique ages of exposure to postglacial processes. For these reasons, we anticipate this map will facilitate spatial analysis of the glaciated CL.

Geolocation information: centroid (−91.850674, 44.005068), extent (−104.041936, 37.595493, −80.518697, 49.384366).

Software

The production of the landform regions map started with a compilation of state-level surficial geology maps in ArcGIS Pro 2.8. Additional information was integrated from the processing of soil maps from the USA’s National Cooperative Soil Survey and a digital elevation model (DEM) from the United States Geological Survey, which were also performed in ArcGIS Pro 2.8.
**Data availability statement**

The spatial dataset used for the main map and supporting information for assigning ages to landform regions are available at Iowa State University’s DataShare open data repository (https://doi.org/10.25380/iastate.19386011.v1). Supporting data from the following resources are available in the public domain:

- National Elevation Dataset (https://viewer.nationalmap.gov/basic/)
- Soil Survey Geographic (SSURGO) Database (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053628#download)
- State Surficial/Quaternary Geology Maps
  - Illinois (https://data.ilsol.illinois.edu/arcgis/rest/services/Geology/Quaternary_Deposits_1979/MapServer)
  - Indiana (https://maps.indiana.edu/metadata/Geology/Geological_Map_North_Dakota.html#Distribution_Information)
  - Iowa (https://geodata.iowa.gov/documents/iowadnr::landforms-of-iowa/about)
  - Michigan (https://gis.michigan.opendata.arcgis.com/datasets/egle:quaternary-geology-map-about)
  - Minnesota (https://mngs-umn.opendata.arcgis.com)
  - North Dakota (https://mrddata.usgs.gov/geology/state/state.php?state=ND)
  - Ohio (https://apps.ohiodnr.gov/gims/report.asp)
  - South Dakota (https://mrddata.usgs.gov/geology/state/state.php?state=SD)
  - Wisconsin – Surficial Deposits (https://data-wi.dnr.opendata.arcgis.com/datasets/gcsm-surficial-deposits/explore?location=44.766028%2C-89.815361%2C7.24)

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