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The DeKalb mounds of northeastern Illinois as archives of deglacial history and postglacial environments

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ABSTRACT

The "type" DeKalb mounds of northeastern Illinois, USA (42.0°N, −88.7°W), are formed of basal sand and gravel overlain by rhythmically bedded fines, and weathered sand and gravel. Generally from 2 to 7 m thick, the fines include abundant fossils of ostracodes and uncommon leaves and stems of tundra plants. Rare chironomid head capsules, pillclam shells, and aquatic plant macrofossils also have been observed.
Radiocarbon ages on the tundra plant fossils from the "type" region range from 20,420 to 18,560 cal yr BP. Comparison of radiocarbon ages of terrestrial plants from type area ice-walled lake plains and adjacent kettle basins indicate that the topographic inversion to ice-free conditions occurred from 18,560 and 16,650 cal yr BP. Outside the "type" area, the oldest reliable age of tundra plant fossils in DeKalb mound sediment is 21,680 cal yr BP; the mound occurs on the northern arm of the Ransom Moraine (−88.5436°W, 41.5028°N). The youngest age, 16,250 cal yr BP, is associated with a mound on the Deerfield Moraine (−87.9102°W, 42.4260°N) located about 9 km east of Lake Michigan. The chronology of individual successions indicates the lakes persisted on the periglacial landscape for about 300 to 1500 yr.

Introduction

More than 2000 flat-topped hills from 30 to 10,000 m across occur in Illinois on glacial drift of the last glaciation (Fig. 1). In most cases, the hills are subtle features, rising from about 1.5 to 9 m above adjacent glacial deposits (Fig. 2). In Kane and DeKalb counties, Flemal et al. (1973) named these features the DeKalb mounds (the shaded area DKM in Fig. 1) and attributed their genesis to sediment infilling of melting open-system pingos (protrusions in areas of nearly continuous permafrost caused by freeze–thaw cycles involving upwelling groundwater). However, they did not dismiss that the mounds could be deposits of ice-walled lakes or ice-contact ridges, a hypothesis championed by Ianacelli (2003).

Some key characteristics of the DeKalb mounds include: 1) circular to semicircular appearance on aerial photographs with light-toned rims and darker interiors (evocative of the moniker "glacial doughnuts"; Fig. 2b); 2) narrow moats between mound toe-slopes and the surrounding till plain; 3) "parasitic" or "satellite" mounds; 4) rim-breaching channels; and 5) interiors of laminated silt loam and fine sand (Flemal et al., 1973). Our new contribution to understanding these landforms is the discovery of micro- and macrofossils, including ostracodes, tundra plants, pillclams, and chironomid head capsules. Radiocarbon ages of terrestrial plant fossils from the basal lacustrine sediment approximately date when the ice became stagnant. In addition, we have found that the mounds have two varieties of sediment architecture. The first kind occurs in the "type" area of the DeKalb mounds of Flemal et al. (1973) where fossiliferous lacustrine successions fill depressions on the underlying clay loam diamicton. A second variety occurs in areas underlain by finer-grained silty clay diamicton. These mounds are formed in part by diamicton that was squeezed ("pressed") into the void formed by glacial karst; any lake sediment is thin (<3 m), and fossil preservation sporadic.

Methods

DeKalb mounds were mapped digitally in a Geographic Information System (GIS) with on-line topographic and orthophotoquadrangle maps. Mapping was facilitated with shaded relief maps of high-quality LiDAR datasets for Kane (McGarry, 2000), McHenry, DuPage, and Lake counties (e.g., Fig. 2c). Color infra-red and black-and-white aerial photography was examined in the area of the "type" DeKalb mounds (Fig. 1) to assess mound distribution, shape, and size.

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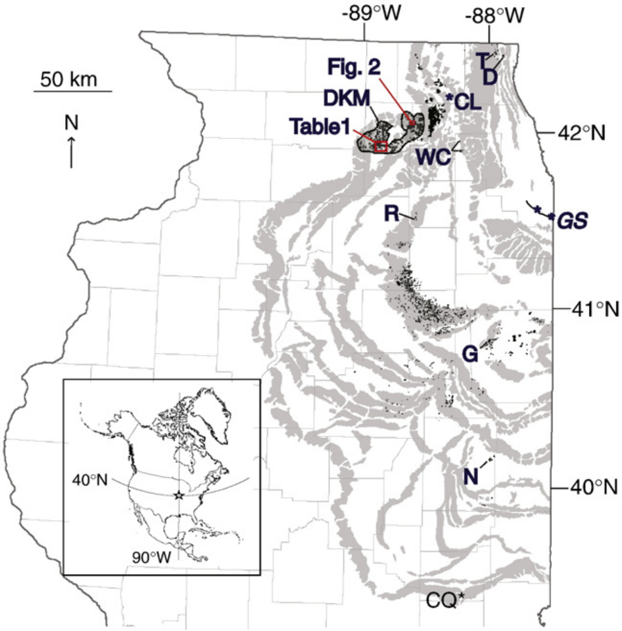

Figure 1. Distribution of DeKalb mounds in Illinois. Coring sites and associated calibrated radiocarbon ages (Table 2) include: D, Deerfield Moraine (16.6–16.3 ka), T, Tinley Moraine (17.3–16.8 ka), WC, West Chicago Moraine (18.1–16.6 ka), DKM, "type" DeKalb mounds (20.8–18.6 ka); R, Ransom Moraine (21.7–21.0 ka); G, Gilman Moraine; N, Newton Moraine; GS, Glacial Lake Chicago, Glenwood spit. Most remaining figures are based on investigations of a "type" DeKalb mound near Hampshire, Illinois. Sample cores from the Gilman and Newton moraine sites have been sieved for fossils, but no reliable ages are yet available. Site *CQ is Charleston Quarry where in-situ stumps, buried by proglacial lake sediment, have yielded ages as young 23,010 cal yr BP (Table 3). This age is considered the start of deglaciation of the Lake Michigan lobe (Hansel and Johnson, 1996). Site *CL is Crystal Lake, a modern lake.

Sediment cores were extracted with various drill rigs (PowerProbe, CME-750, and Giddings rigs). Many cores were taken from the Hampshire, Illinois, 7.5-minute Quadrangle (Curry, 2008; Fig. 2). Additional cores were taken from mounds located on or adjacent to the Newton, Gilman, Ransom, West Chicago, Tinley and Deerfield moraines (Fig. 1).

Core H-22 was selected for detailed study (Fig. 2b). Plant macrofossils, ostracodes, and other fossils were picked and identified from prepared core segments about 4 cm long. Moist samples were disaggregated by pretreating in boiling water with a pinch of baking soda, cooled to room temperature, and wet-sieved using a shower spray on a Tyler #100 sieve (0.15 mm openings). Plant macrofossils, if used for radiocarbon analysis, were kept refrigerated in vials containing tap water and a drop of 10% hydrochloric acid. Ostracode valves were picked from the dried residue and identified using Delorme (1970a,b,c, 1971) and the NANODe website (Forester et al., 2006). Four to five adult valves of *Cytherissa lacustris* were selected for chemical analyses and cleaned by soaking in household 2% hydrogen peroxide until any particulate matter detached from the valves. The valves were then immersed in methanol and then air-dried. The valves were analyzed for ^{13}C and ^{18}O using a Finnigan-MAT 252 mass spectrometer with a Kiel II device. The phosphoric acid residue from each sample was subsequently analyzed for dissolved Mg^{2+}, Ca^{2+}, and Sr^{2+} using an ICP-MS (USEPA, 1994). The mineralogy of the <2 µm fraction was determined by X-ray diffraction of ethylene glycol-solvated, oriented aggregates (Hughes et al., 1994). The clay slides were also analyzed for spectral reflectance (L^*, a^*, and b^*) defined by the Commission Internationale de l'Eclairge (CIE, 1978). The L^* parameter is a gray-scale measure; a^* values measure redness (positive values) to green (negative values), and b^* values measure yellow to blue. Particle-size analysis of core subsamples followed the modified pipette procedure (Soil Survey Staff, 1999).

High-resolution electric-earth resistivity (HREER) profiling was used to determine the geometry of sedimentary units with contrasting particle-size characteristics (Fig. 2b). The data were acquired with a multi-electrode resistivity system using a dipole–dipole array and 2-m electrode separation. Approximate depth of penetration for this array was 10 m with a resolution of about 1 m laterally and vertically. Raw data were processed into two-dimensional models using a least-squares inversion technique (Loke and Barker, 1996).

Results

More than 2200 mounds were identified and mapped throughout northeastern and central Illinois (Fig. 1). Most mounds occur on proximal morainal slopes and on gently sloping till plains beyond the mapped moraines. On aerial photography, mound shapes are round, multilobate (Fig. 2c), elliptical, and irregular. A remarkably high density of DeKalb mounds are found on the southern half of the DeKalb, Illinois, 7.5-minute Quadrangle; 311 mounds of all shapes have been identified (Table 1). Geologic mapping and identification of subtle terraces in mound complexes are facilitated by using shaded relief maps of LiDAR data (Curry, 2006). In many cases, the relief of rim ridges is too subtle to be interpreted from contour lines on USGS topographic maps (contour interval = 10 ft). Away from the type area of the DeKalb mounds, the mounds are typically simple, circular features. Most have rim ridges.

Sediment forming the "type" DeKalb mounds overlie and are set within diamicton of the last glaciation classified as the Tiskilwa Formation (Curry, 2008). In the type area, the mounds are composed of four layers, including (1) basal sand and gravel, (2) fossiliferous, rhythmically bedded, laminated silt loam and very fine sand, (3) weathered sandy loam diamicton or sand and gravel, and (4) weathered silt loam (Figs. 3 and 4). A notable characteristic of layer 2 is the lack of sediment coarser than coarse sand, and yet the units above and below are composed of sand and gravel with little silt. This four-layer succession is mapped as unit e (x) in Figure 2d.

The sand and gravel lag (layer 1), fossiliferous fines (layer 2), and the silty soil mantle (layer 4) were observed in all nine borings sampled across the DeKalb mound near Burlington (Figs. 2b, 3 and 4). The sediment cores indicate that the sand and gravel lag (layer 1) is continuous and from about 5 to 7 m below ground surface. The HREER transect data reveal that the fine-grained sediment extends to the eastern edge of the mound (Fig. 4). The HREER data are unable to resolve layer 1 (the basal sand and gravel), and the mantle of loess.

Laminated layer 2 contains abundant ostracode valves, rare head capsules of chironomids, achenes of white water-buttercup (*Ranunculus* cf. *aquatilis*), resting cocoons of flatworms (Tuberellia), shells of *Pisidium conventus* (pillclams), and beetle elytra. The stems and leaves of tundra plants are common in some intervals, especially at the base (Fig. 5). The older mounds (e.g., ones located in the "type" area, and on the Woodstock and Ransom moraines; Fig. 1) contain tundra plant fossils of Arctic bilberry (*Vaccinium uliginosum* ssp. *alpinum*) and snowbed willow (*Salix herbacea*), whereas plant fossils from mounds on the younger Tinley and Deerfield moraines are dominated by stems and leaves of Arctic dryad (*Dryas integrifolia*). The basal ages of three successions on the Hampshire Quadrangle are 20,820, 20,420, and 20,370 cal yr BP (Table 2).

In some cases, the base of layer 2 is uniform and contains common fossil wood fragments. The fine cellular structure and presence of resin are indicative of boreal tree wood fragments. A radiocarbon age of 29,930 cal yr BP (24,950 ± 150 C-14 yr BP) indicates that most, if not all, of the wood fragments are reworked from the Robein Member of the Roxana Silt (Table 2); this unit comprises a mid-Wisconsin episode paleosol buried locally by drift of the last glaciation (Curry, 1989). Wood fragments also occur in

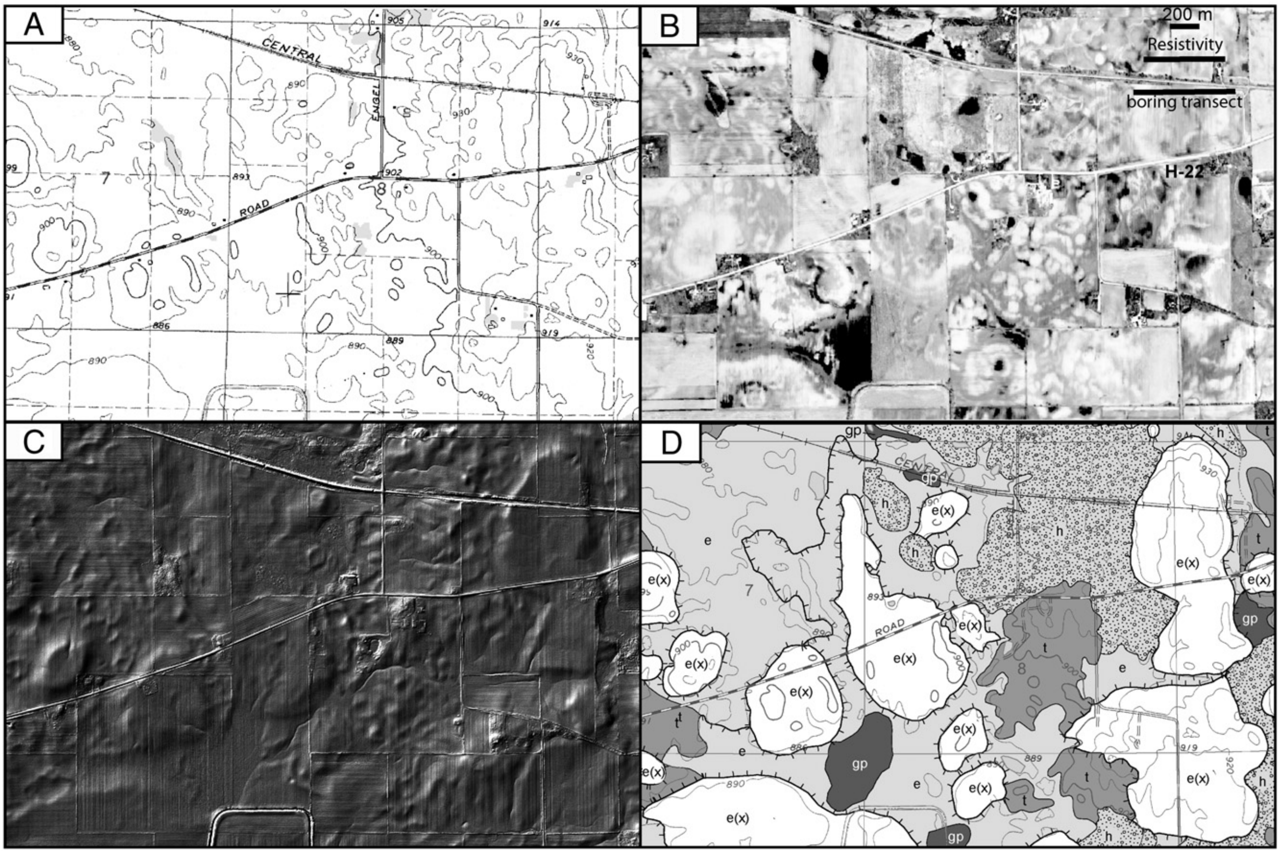

Figure 2. Located on the Hampshire, Illinois, 7.5-minute Quadrangle, these four maps are of the same area along Plank Road, immediately west of Burlington, Illinois (Fig. 1; Curry, 2008). Sediments forming the DeKalb mounds are mapped as unit e(x) on map d. The maps show (A) topography with 10-foot (3-m) contour intervals, (B) USGS digital orthophoto quadrangle (DOQ) imagery with the lines of section for the cross section and HREER transect (Fig. 4), and location of boring H-22 (Fig. 5), (C) shaded relief made from a DEM of 2-foot (0.6-m) contours, and (D) the surficial geology map. On the latter map, gp is Grayslake Peat; e, Equality Formation; e(x) Equality Formation complex; h, Henry Formation sand and gravel; and t is clay loam diamicton of the Tiskilwa Formation.

the laminated portion of layer 2, but they are less common than the leaves and stems of tundra plants.

The sediment core and HREER transects indicate that the resistivity contour value separating diamicton from water-washed sediment is about 45 Ω m. The wavy contours in the upper 3 to 4 m of the mounds are due to interference with field tiles (Fig. 4). Unit architecture is speculative on the west end of the profile, especially where there is additional interference with a barbed-wire fence with metal posts. Boring B-9, sampled at the crest of the rim, revealed fining-upwards rhythmically bedded sediment, with thin beds of medium to fine sand at the base. The coarser sand and gravel, suggested by the high resistivity values on both rims, occurs below the slopes of the landform, and not below the rim ridge.

On the easternmost part of the HREER profile in Figure 4, the diamicton of the Tiskilwa Formation shows characteristics similar to the sorted sediments forming the mounds. The contrast in resistivity, about 45 to 30 Ω m in the upper 4 m, and 80 to 45 Ω m in the lower 6 m, occurs at about the same depth as the contact

Table 1
DeKalb mound sizes classified by shape. (W = short axis; L = long axis; meters) The southern half of the DeKalb, Illinois, 7.5-minute Quadrangle was examined.

	Round		Elliptical		Irregular	
	W	L	W	L/W	W	L
Average	84	122	74	1.7	138	276
Median	66	104	66	1.6	114	208
Maximum	312	824	578	7	1003	1354
Minimum	38	38	28	1.1	47	66
Number	54		170		87	

between the lacustrine succession and diamicton forming the till plain. Continuous cores B-1 and 35692 reveal that the low resistivity layer of the Tiskilwa is likely caused by subvertical joints with organo-sesquioxide stains. The physical character of the diamicton is otherwise monotonous. Thirteen core subsamples of borings B-1 and 35692 yielded mean values and standard deviations for moisture content, moist bulk density, and particle-size analyses of 11.8 ± 1.4% and 2.1 ± 0.1 gm/cm^3, and 37 ± 2, 43 ± 2, and 20 ± 2% sand, silt, and clay (<0.004 mm), respectively. The sample spacing along the cores was about 3 m. The values are consistent with regional textural data of Tiskilwa diamicton (Wickham et al., 1988; Graese et al., 1988).

The ostracode assemblage from "type" mound sediments on the Hampshire Quadrangle includes *C. lacustris*, *Limnocythere friabilis*, and less common *Heterocypris* sp. In core H-22, valve concentration is as great as 1.0 valves per gram moist sediment, with abundant *L. friabilis* at the base, and near-constant abundance of *C. lacustris* (Fig. 5). Additional species have been identified from other mounds including abundant *Fabaeformiscandona rawsoni*, *F. caudata*, and occasional *L. varia* (Table 3).

In core H-22, XRD clay mineral analyses of unweathered laminated silt yielded values of 13 ± 2% expandable clay minerals, 61 ± 2% illite, 9 ± 1% kaolinite, and 17 ± 1% chlorite (n = 31), statistically identical to the mineralogy of the subjacent glacial diamicton (14% expandable clay minerals, 61% illite, 8% kaolinite, and 17% chlorite; n = 1; see also data in Wickham et al., 1988). These values contrast with the mantle of smectite-rich loess (73 ± 6% expandable clay minerals, 17 ± 6% illite, 6 ± 1% kaolinite, and 4 ± 2% chlorite; n = 3; Fig. 5). High illite/chlorite ratios and sediment redness values (a^*) with relatively little chlorite and carbonate mineral content indicate weathering in the

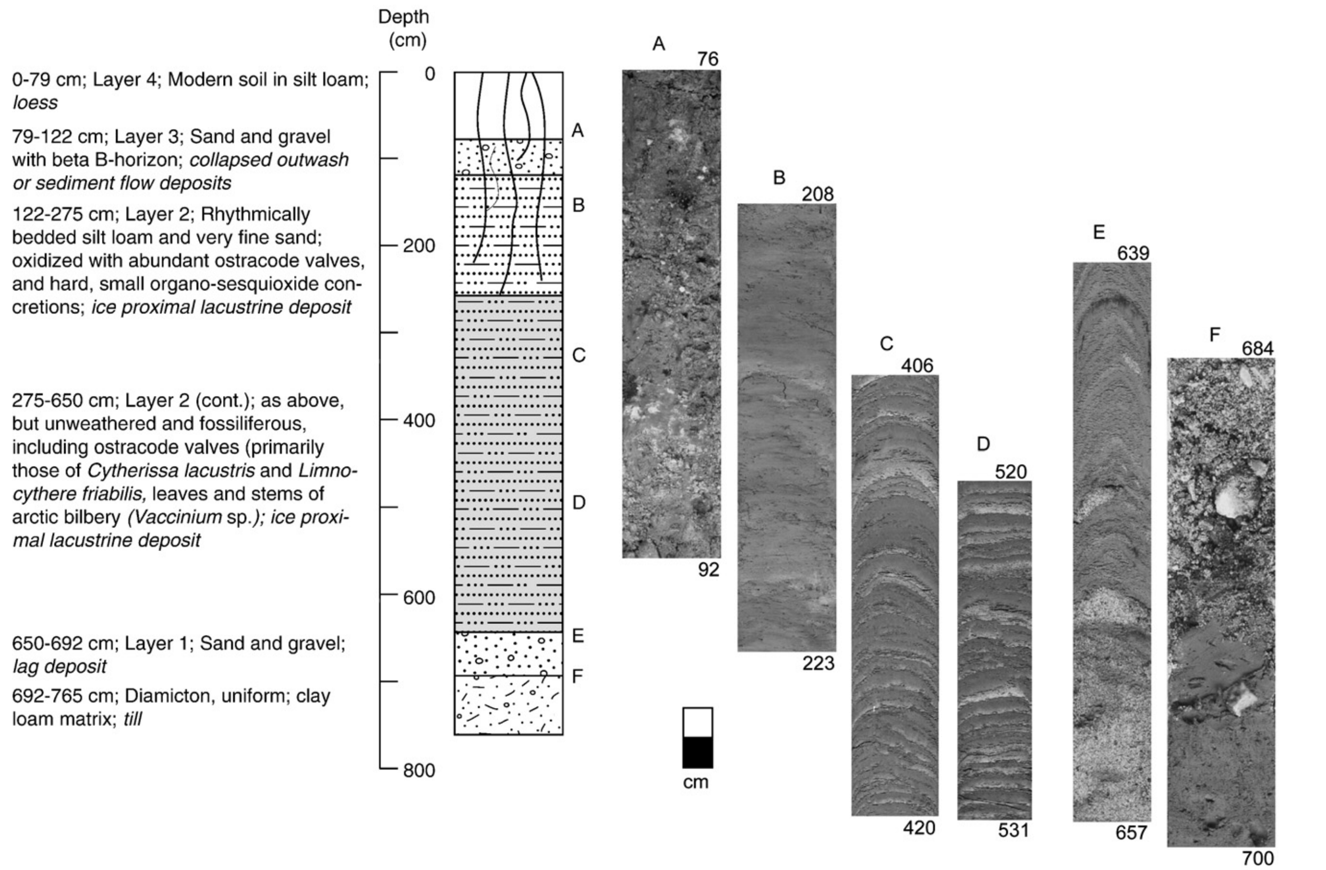

Figure 3. Representative core segments from site H-22. Segment A (76–92 cm depth) shows the gradational contact between the basal loess (layer 4) and weathered sandy loam diamicton (layer 3); Segment B (208–223 cm) shows calcareous, oxidized sediment with abundant ostracode valves, common sesquioxide concretions, but no plant fossils; Segment C (406–420 cm) shows rhythmically bedded silt with light-toned, thin beds of very fine sand; many sand layers are stained with oxidized iron oxides; Segment D (520–531 cm) shows unweathered, fossiliferous rhythmites; Segment E (639–657 cm) shows the contact between the fossiliferous rhythmites and underlying lag of sand and gravel; and Segment F (684–700 cm) shows the contact between the sand and gravel lag and diamicton of the Tiskilwa Formation. The downward-turned edges of some core segments is from deformation caused by sediment friction against the core tube during coring.

uppermost 1.5 m of the laminated fines. These sediments contain abundant sesquioxide concretions and do not contain fossils.

On the till plain, the mantle of low resistivity values (20–10 Ω m) is of loess and a thin mantle of laminated silt and clay that forms extensive, low-level terraces throughout the area (Curry, 2008). Mapped as unit e on Figure 2d, the laminated sediment is smectite-rich, similar to the overlying loess. In places, the sediment is fossiliferous, containing plant fragments and ostracodes, including *F. rawsoni*.

The biogeochemical profiles of ostracode calcite (*C. lacustris*) from boring H-22 are variable upsection. The values range from −5.9 to −1.7‰ for δ^{13}C; −2.3‰ to +1.5‰ for δ^{18}O; 0.0071 to 0.012 for $Sr^{2+}/Ca^{2+}{}_m$; and 0.013 to 0.073 for $Mg^{2+}/Ca^{2+}{}_m$. The isotopic profiles trend upwards to "heavier" values (especially δ^{13}C), whereas the molar trace element ratios reveal no significant trends (Fig. 5).

Discussion

The altitude of fossiliferous, rhythmically bedded lake sediment with respect to the adjacent till plain indicates the DeKalb mounds are ice-walled lake deposits. Cross sections across the largest mounds suggest the ice walls were at least 8 m high. The lack of sediment deformation in the cores, and the flat, featureless mound surfaces indicate deposition on firm subglacial till (Johnson and Clayton, 2003).

Two ideas on the genesis of the "type" DeKalb mounds include degradation of open-system pingos (Flemal et al., 1973) or dead-ice ridges (Gravenor and Kupsch, 1959; Clayton, 1967; Flemal et al., 1973; Ianacelli, 2003). We suggest that the difference between the two ideas is not significant and reflects nuances in terminology. The nomenclature associated with melting dead ice and its associated landforms is complicated because once it is buried by about 1 m of supraglacial debris, the ice is permafrost; the moisture in the debris is, in effect, the active layer (Evans, 2009). In the case of the DeKalb mounds, the permafrost envisioned by Flemal et al. (1973) ostensibly was stagnant glacier ice. However, the modern analogs they drew upon to argue for the pingo origin formed in frozen alluvium or in relatively thin regolith over bedrock (Müller, 1963; De Gans, 1988). We follow the conventional terminology of ice-walled lakes (e.g., Clayton et al., 2008), recognizing that the "ice" was likely dead-ice permafrost.

C. lacustris and *L. friabilis* dominate the ostracode assemblages. *C. lacustris* is common in modern Canadian lakes with low total dissolved solids (TDS; 25–700 mg/L; Delorme, 1989). Importantly, DeKalb mounds from outside the "type" area have yielded other species including *F. rawsoni*, *F. caudata*, and *L. varia* (Table 3). This five species assemblage is known from Lake Michigan at water depths greater than 15 m (Buckley, 1975). Parallels between the paleohydrology of the ice-walled lakes and conditions in the profundal zone of modern Lake Michigan likely include low salinity (~150 mg/L), sub-thermocline temperatures (ca. 4 °C), and low seasonal variability of these parameters.

The isotope data indicate that the source water of the ice-walled lakes was dominated by precipitation rather than meltwater. Today, water evaporated from the Gulf of Mexico accounts for about 75% of the precipitation received in the Upper Midwest (Simpkins, 1995). The δ^{18}O values of lakes in northeastern Illinois typically range from

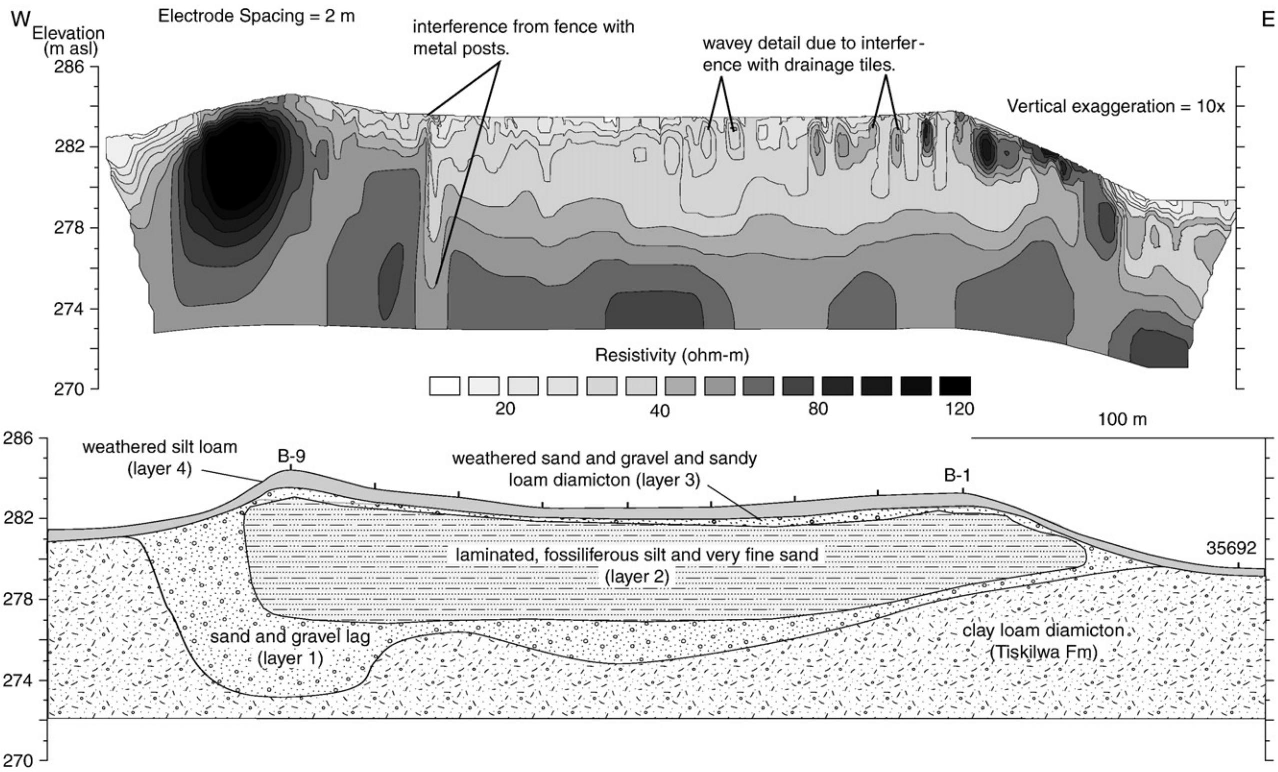

Figure 4. High-resolution electric-earth resistivity profile (top) and geologic cross section (bottom) across a DeKalb mound (Fig. 2b). In the resistivity profile, the darkest colors are interpreted to be sand and gravel. Most domains shaded light gray are interpreted to be clay loam diamicton of the Tiskilwa Formation. Near-white domains are deposits of silt loam, silty clay loam, and silty clay.

about −5 to +2‰; shallow groundwaters typically range from −9 to −5‰. The other likely water source, meltwater from dead-ice permafrost, had δ^{18}O values estimated to be from −24‰ to −17‰ (Remenda et al., 1994; Dettman et al., 1995). The δ^{18}O values of adult *C. lacustris* in core H-22 range from −2.3 to +1.5‰ (Fig. 5); given this species vital effect of about +1.5‰ (von Grafenstein et al., 1999), the values of the host water ranged from about −3.8 to 0.0‰ consistent with a precipitation source from the Gulf. Supporting this hypothesis is a comparison of the range of ostracodal δ^{18}O values from boring H-22 with those from a long sediment core from Crystal Lake, Illinois, a 13-m deep hard-water kettle lake about 30 km NE of boring H-22 (Fig. 1). In sediment dating 14,670 cal yr BP to the present, and accounting for the vital effects of *Candona ohioensis* (+2.2‰; von Grafenstein et al., 1999 and unpublished data of Curry), Crystal Lake's lake water δ^{18}O values varied from −5.2 to −0.2‰ similar to the values determined from boring H-22 (Fig. 5).

The combined evidence, especially the sediment architecture and texture, suggests the following set of processes during the ontogeny of a DeKalb mound. Although this scenario is consistent with the formation of "stable environment" ice-walled lake deposits as envisioned by Clayton and Cherry (1967) and others (e.g., Syverson, 2007), several questions remain.

One such conundrum is the formation of the ca. 10 m deep depressions on the glacier bed surface (Fig. 4). The collective data support erosion by plunge pools associated with moulins. Drainage from stagnating ice, and later, dead-ice permafrost, explains the coincidence on the basin's western side of the deepest depression with the highest point of the rim, accounting for both the greatest initial erosion, and as the basin matured, a sediment source. The continuity of the basal lag (layer 1 in Fig. 4) indicates that outward expansion was rapid, and may have been facilitated by other processes such as calving. At some point, the basin reached an equilibrium in which expansion slowed or ceased with subsequent infilling of the basin with laminated fines. The existing suite of radiocarbon ages (Table 2) indicate that this period of quiescence occurred over a period of 200 yr or longer.

One of the more enigmatic characteristics of the ice-walled lake successions is the absence of coarse fragments in layer 2, the fossiliferous, rhythmically bedded very fine sand and silty loam (Fig. 4). The lack of cross-bedding or other evidence of deposition by traction suggests that the sediment source was not from debris melting from the ice walls of the lake, but rather from suspended sediment. We envision the rhythmic delivery of sediment via seasonal discharge from the active layer. Lake ice, observed to cover present-day ice-walled lakes during the summer, may have prevented the development of wind-driven currents. The provenance of the suspended sediment was likely debris-rich ice in the lake's drainage basin. The sediment was thermally and mechanically eroded by water in karstic englacial conduits such as inactive crevasses that intersected the lake. The water was largely derived from melting snow and permafrost from the active layer. This accounts for the similar clay mineralogy of the lake sediment and underlying diamicton, as well as the isotopically "heavy" δ^{18}O values of the lake water indicated by analyses of ostracode valves. The longevity of the lacustrine successions forming the DeKalb mounds (from 200 to 1400 yr) is consistent with "stable environment" ice-walled lakes (Clayton and Cherry, 1967; Syverson, 2007). "Unstable environment" ice-walled lakes are short-lived, and fill with coarse sediment.

The final step in the ontogeny of the DeKalb mounds was ice-wall disintegration. Conditions allowing the ice-walled lakes to slowly fill with fine-grained, fossiliferous lake sediment changed abruptly once ice-wall degradation ensued. Saturated, coarse debris eventually spread across the shallow frozen lake or saturated lake sediment. During this final stage, and probably prior to the arrival of far-traveled smectite-rich loess, active permafrost may have formed in the upper 1–2 m of the lake sediment which may account for some of the remarkable features, such as the parasitic doughnuts and the narrow curvilinear ridges observed on aerial photography (Fig. 2; Flemal et al., 1973).

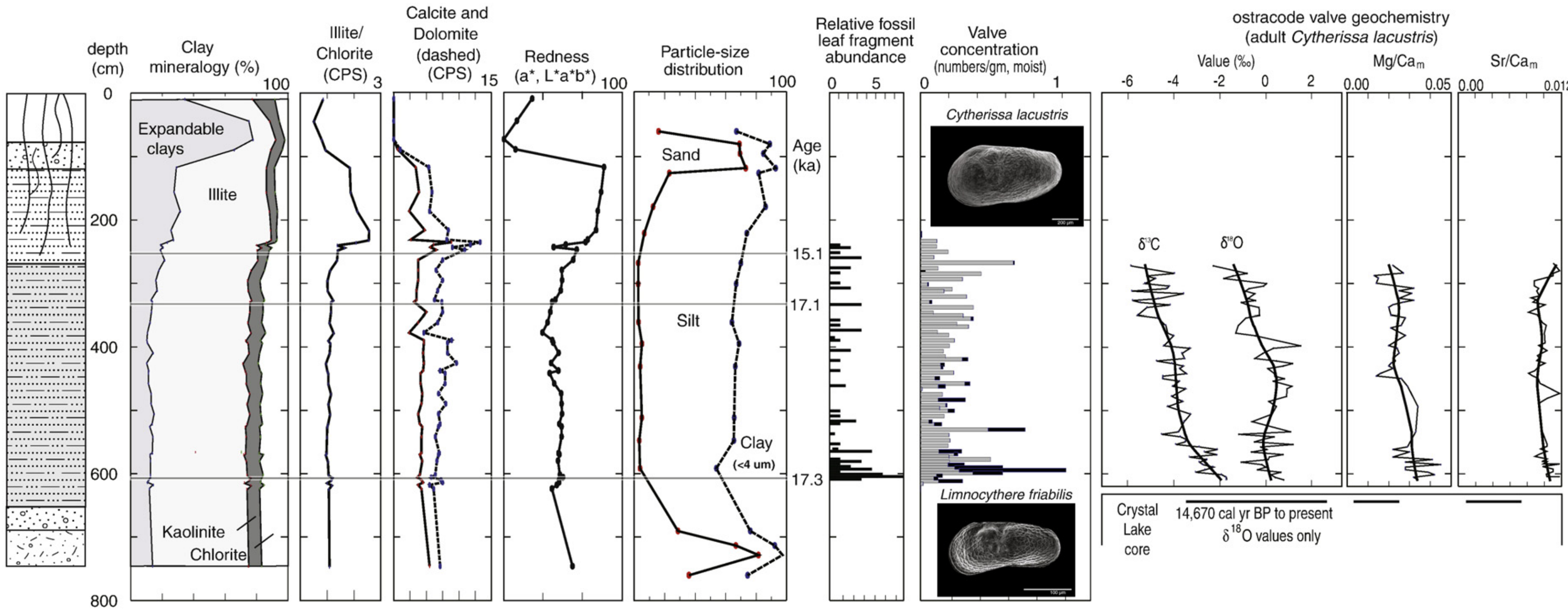

Figure 5. Profiles of data from core H-22, including XRD analyses, redness (a^*) ($L^*a^*b^*$), particle-size distribution, plant fossil and ostracode valve abundance, and ostracode valve geochemistry ($\delta^{18}O$, $\delta^{13}C$, $Mg^{2+}/Ca^{2+}{}_m$, and $Sr^{2+}/Ca^{2+}{}_m$). The XRD profiles include semi-quantitative clay mineralogy, illite/chlorite, and calcite and dolomite abundance (in CPS, counts per second). The fossil abundance data are from continuous 4-cm long subsamples (core diameter = ~2 cm). The bars in the SEM images of the ostracodes (left valves) are 0.2 mm long. The range of values from valves of *Candona ohioensis* picked from a sediment core from Crystal Lake (McHenry County), Illinois, is shown except for $\delta^{13}C$. The $\delta^{18}O$ values of *C. ohioensis* have been adjusted +0.65‰ to account for the greater vital effect compared to *Cytherissa lacustris* (von Grafenstein et al., 1999).

Table 2
Radiocarbon ages. Calib 5.02 was used to calibrate the ages (Reimer et al., 2004). Site locations are shown in Figure 1.

Site or boring			Material dated	^{14}C age ^{14}C yr BP	±	Calibrated age (cal yr BP)		
Site lab number(depth, cm)						Sigma-1	Mean	Sigma+1
D	Deerfield Moraine (Lake Border Moraine)							
	UCIAMS-46829	WAD 08-12 (580–590)	Stems, leaves	13,650	40	16,050	16,250	16,430
	UCIAMS-63075	WAD 08-13 (497–507)	Stems, leaves	13,695	45	16,110	16,310	16,490
	UCIAMS-63076	WAD 08-13 (650–660)	Stems, leaves	13,910	35	16,380	16,570	16,770
GS	Glacial Lake Chicago, Glenwood spit, (Hansel and Johnson, 1996)							
	ISGS-1549	Lynwood Reservoir	Wood	13,870	170	16,240	16,530	16,810
	ISGS-1649	Tinley Park	Wood	13,890	120	16,310	16,550	16,790
T	Tinley Moraine							
	UCIAMS-26262	WAD 05-02 342–366	Stems, leaves	14,070	40	16,580	16,770	16,970
	UCIAMS-26263	WAD 05-02 384–392	Stems, leaves	14,110	35	16,640	16,820	17,020
	UCIAMS-26264	WAD 05-02 692–695	Stems, leaves	14,420	40	17,100	17,290	17,510
WC	Cranberry Lake (West Chicago Moraine)							
	UCIAMS-46831	STR 05-01 439–451	Leaves	14,780	50	17,830	17,950	18,050
	UCIAMS-26265	STR 05-01 698–716	Stems, leaves	14,860	40	17,960	18,080	18,150
W	Nancy Drive kettle (Woodstock Moraine)							
	ISGS-A-0143	37144; 738	Stems	14,860	110	17,450	17,640	17,950
	ISGS-A-0165	37144; 841	Stems	14,610	110	17,940	18,140	18,240
DKM	DeKalb mounds (Curry, 2008)							
	UCIAMS-23773	23513; 428	Stems, leaves	15,150	45	18,170	18,590	18,340
	UCIAMS-23772	35696; 415	Stems, leaves	15,740	150	18,750	18,970	19,280
	UCIAMS-23765	35155; 497	Stems, leaves	17,290	140	20,070	20,420	20,850
	UCIAMS-23768	35696; 268	Stems, leaves	15,125	45	18,130	18,560	18,360
	UCIAMS-23770	35696; 335	Stems, leaves	17,090	190	19,850	20,220	20,690
	UCIAMS-23769	35696; 579	Stems, leaves	17,250	60	20,130	20,370	20,620
	OxA-W917-11	35527; 610	Stems, leaves	16,700	90	19,560	19,850	20,060
	OxA-W917-9	35527; 759	Stems, leaves	17,610	270	20,120	20,820	21,610
R	Ranson Moraine (Marseilles Morainic Complex)							
	UCIAMS-26260	KC5 524–579	Stems, leaves	17,760	60	20,780	20,970	21,150
	UCIAMS-26261	KC5 782–792	Stems, leaves	18,210	60	21,510	21,680	21,910
CQ	Shelbyville Morainic Complex; proglacial lake, wood; silt, (Hansel and Johnson 1996)							
	ISGS-2918	Charleston Quarry	Wood	19,340	180	22,660	23,010	23,290
	ISGS-2842	Charleston Quarry	Wood	19,980	150	23,740	23,930	24,140
	ISGS-2593	Charleston Quarry	Wood	20,050	170	23,800	24,010	24,230

Our interpretations are tempered with new data from the southernmost ice-walled lake plains in Illinois. Here, the formation of the mounds requires diapiric movement of diamicton into a hole in the ice. The resulting form results in diamicton within the present-day mounds that is as much as 6 m higher in elevation than diamicton forming the adjacent till plain. The "squeeze" mechanism was suggested by Gravenor and Kupsch (1959) and later modeled by Boone and Eyles (2001). The diamicton in these areas (classified as Yorkville Member, Lemont Formation) is on average about 16% clayier and has a 6% higher moisture content than the Tiskilwa diamicton associated with the DeKalb mounds (Graese et al., 1988). These differences in physical properties likely account for the diapiric behavior of Yorkville diamicton.

Possible modern analogs for the DeKalb mounds are the ice-walled lakes of the Siberian Taymyr Peninsula formed in slowly melting remnants of the Kara ice sheet (Fig. 6; 75°N, 100°E; Alexanderson et al., 2002). Here, the soil is thin (<2 m), covered with tundra plants, and susceptible to slumping. Some lakes are flat-bottomed, and have steep slopes reaching depths of more than 14 m. Other more-often photographed modern ice-walled lakes are located on stagnant arms of active piedmont or mountain glaciers with supraglacial debris tens of meters thick, such as the Bering Glacier, Alaska. Although thick supraglacial drift was not present during formation of the DeKalb mounds, such conditions have been interpreted in areas peppered with high-relief ice-walled lake plains on the North American prairies (i.e., Parizek, 1969; Ham and Attig, 1996; Clayton et al., 2008).

Ice-walled lake plains in North America have been classified with respect to relief, from those of low relief (<20 m) to those of high relief (20–50 m; e.g. Clayton et al., 2008). The greatest relief of the DeKalb mounds is about 9 m, averaging no more than about 4 m. The DeKalb mounds are thus end members of low-relief ice-walled lake plains. The sediments comprising the DeKalb mounds are, in general, finer-grained than their higher-relief counterparts, which is a

Table 3
Location of ice-walled lake plains located in Illinois with relative ostracode valve and plant macrofossil abundance.

Moraine	7.5-minute Quadrangle	N Lat	W Long	CYTH	LFRI	HET	FRAW	FCAU	LVAR	CYCA	VACC	SALIX	DRYAS	RAN	SIL
Deerfield	Wadsworth	42.43	−87.90	C	A	NP	NP	C	NP	NP	C	R	R	R	R
Tinley	Wadsworth	42.44	−87.97	A	NP	NP	C	NP	NP	NP	C	R	R	R	R
West Chicago	Streamwood	42.02	−88.20	A	A	R	NP	C	R	R	NP	C	C	NP	NP
Burlington	Hampshire	42.05	−88.57	A	A	R	NP	NP	R	NP	NP	R	NP	NP	NP
Ransom (N)	Newark	41.50	−88.54	A	A	NP	C	C	R	NP	NP	A	NP	NP	R
Ransom (S)	Dwight	41.08	−88.49	NP	A	NP	A	NP	NP	NP	NP	NP	NP	NP	NP
Gilman	Gilman	40.82	−87.99	C	C	NP	A	NP	NP	NP	NP	NP	NP	NP	NP
Newton	Royal	40.17	−87.98	NP	A	R	C	NP	NP	C	NP	NP	NP	R	NP

CYTH, *Cytherissa lacustris*; LFRI, *Limnocythere friabilis*; HETI, *Heterocypris incongruens*(?); FRAW, *Fabaeformiscandona rawsoni*; FCAU, *F. caudata*; LVAR, *L. varia*; CYCA, *Cyclocypris ampla*; VACC, *Vaccinium ugilonosum* spp. *alpinium*; SALIX, *Salix herbacea*; DRYAS, *Dryas integrifolia*; RAN, *Ranunculus* cf. *R. aquitilis*; SIL, *Silene* cf. *S. acaulis*.

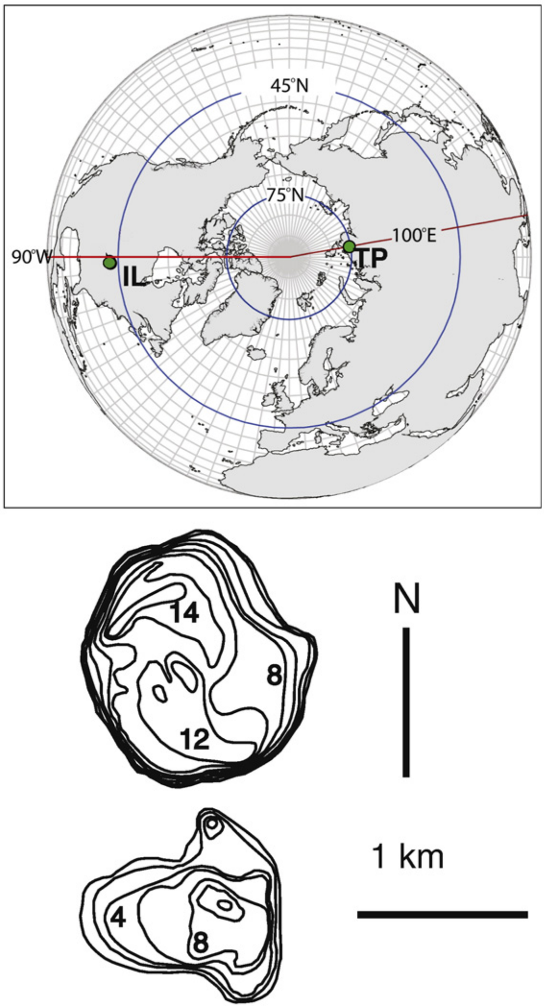

Figure 6. Bathymetry maps of two ice-walled lakes from the Taymyr Peninsula, Siberia. Contour interval = 2 m. On the inset map, TP = Taymyr Peninsula and IL = Illinois. The steep sides, size, and plan-view shape of these features are consistent with the low-relief ice-walled lake plain deposits in Illinois.

reflection of the fine-textured glacial diamicton of the Lake Michigan lobe. In addition to containing abundant carbonate, the low-relief and fine-grained texture of the DeKalb mounds promote fossil preservation. Following the cautionary rule of equifinality, the subtle ice-walled lake plains in Illinois may not have formed in the same manner as high-relief ones in sandier drift.

Low-relief ice-walled lake plains of the kind found in Illinois are likely present wherever silty and clayey, matrix-supported diamicton was deposited under stagnating conditions (e.g., Bleuer, 1974). In the midcontinental United States, such features have been identified from shaded relief maps of LiDAR, notably in Indiana, Wisconsin, Minnesota, Iowa, Ohio, and the Dakotas. Many of these features have yet to be mapped, and in some cases, occur with large high-relief ice-walled lake plains (Clayton et al., 2008).

Radiocarbon ages associated with low-relief ice-walled lakes allow a more robust assessment of deglacial history than previously possible. Bottom ages from the laminated, fossiliferous silt loam facies indicate when glacial conditions shifted from active to stagnating. Top ages help to provide minimum age estimates of the period of stagnation. The span of time between the latter ages and those ages from the base of kettle sediment successions encompass the period of final melting. In the "type" area, this period was between about 18,550 and 16,500 cal yr BP (Curry, 2008). This span of time represents an important topographic reversal during deglaciation. At the onset, ice-walled lakes and their sediment fill were the lowest parts of the periglacial landscape; as melting approached completion, kettles formed in low spots of the deglaciated landscape. In many places, the modern deglacial landscape is likely the result of both processes. For example, Crystal Lake, which occupies a kettle, is today surrounded by subaerial patches of lacustrine deposits that had accumulated in ice-walled lakes.

Summary

The ecology and age of terrestrial and aquatic fossils of the DeKalb mounds indicate that they formed in the karstified, stagnating Lake Michigan lobe during the last deglaciation. High-resolution resistivity profiling and cores reveal that "type" mound sediment successions are nestled within depressions in the surface of the underlying glacial diamicton; roughly two-thirds to three-quarters of the lacustrine succession is located below the level of the adjacent till plain. The collective evidence indicates that the depressions were eroded by subglacial plunge pools that originated as moulins. Endogenic fossils of DeKalb mounds in Illinois include *C. lacustris*, *L. friabilis*, *L. varia*, *F. rawsoni*, and *F. caudata*. This assemblage has a modern analog with profundal Lake Michigan suggesting dilute, stenotopic conditions. Radiocarbon ages of tundra plant macrofossils preserved in mound successions provide temporal control on the onset and duration of glacier stagnation.

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References

Alexanderson, H., Adrielsson, L., Hjort, C., Möller, P., Antonov, O., Eriksson, S., Pavlov, M., 2002. Depositional history of the North Tamyr ice-marginal zone, Siberia—a landsystem approach. Journal of Quaternary Science 17, 361–382.

Bleuer, N.K., 1974. Distribution and significance of some ice-disintegration features in west-central Indiana. Indiana Geological Survey Occasional Paper 8, 11p.

Boone, S.J., Eyles, N., 2001. Geotechnical model for great plains hummocky moraine formed by till deformation below stagnant ice. Geomorphology 38, 109–124.

Buckley, S.B., 1975. Study of post-Pleistocene ostracode distribution in the soft sediments of southern Lake Michigan . Unpublished Ph.D. dissertation, University of Illinois , Urbana-Champaign, 293 p.

Clayton, L., 1967. Stagnant-glacier features of the Missouri Coteau in North Dakota. North Dakota Geological Miscellaneous Series 30, 25–46.

Clayton, L., Cherry, J.A., 1967. Pleistocene superglacial and ice-walled lakes of west-central North America. North Dakota Geological Survey, Miscellaneous Series 30, 47–52.

Clayton, L., Attig, J.W., Ham, N.R., Johnson, M.D., Jennings, C.E., Syverson, K.M., 2008. Ice-walled-lake plains: implications for the origin of hummocky glacial topography in middle North America. Geomorphology 97, 237–248.

Commission Internationale de l'Eclairge (CIE), 1978. Recommendations on uniform color spaces, color difference, and psychometric color terms. Paris, CIE, Coloimetry, Publications, 15. supplement 2, 21 pp.

Curry, B.B., 1989. Absence of Altonian glaciation in Illinois. Quaternary Research 31, 1–13.

Curry, B.B., 2006. Subtle ice-walled lake terraces identified and mapped with shaded relief maps of 2-ft DEMS from aerial photography or LIDAR. Geological Society of America Abstracts With Programs 38 (7), 164.

Curry, B.B., 2008. Surficial Geology of Hampshire Quadrangle, Kane and DeKalb Counties, Illinois. Illinois State Geological Survey, Illinois Geological Quadrangle Map, IGQ—Hampshire SG. 1:24,000.

De Gans, W., 1988. Pingo scars and their identification. In: Clark, M.J. (Ed.), Advances in Periglacial Geomorphology. John Wiley and Sons Ltd., pp. 299–322.
Delorme, L.D., 1989. Methods in Quaternary ecology. No 7a: freshwater Ostracoda. Geoscience Canada 16, 85–90.
Delorme, L.D., 1970a. Freshwater ostracodes of Canada. Part II. Subfamily Cypridopsinae and Herpetocypridinae, and family Cyclocyprididae. Canadian Journal of Zoology 48, 253–266.
Delorme, L.D., 1970b. Freshwater ostracodes of Canada. Part III. Subfamily Candonidae. Canadian Journal of Zoology 48, 1099–1127.
Delorme, L.D., 1970c. Freshwater ostracodes of Canada. Part IV. Families Ilyocyprididae, Notodromadidae, Darwinulidae, Cytherideidae, and Entocytheridae. Canadian Journal of Zoology 48, 1251–1259.
Delorme, L.D., 1971. Freshwater ostracodes of Canada. Part V. Families Limnocytherdae, Loxoconchidae. Canadian Journal of Zoology 49, 43–64.
Dettman, D.L., Smith, A.J., Rea, D.K., Moore, T.C., Lohmann, K.C., 1995. Glacial meltwater in Lake Huron during early postglacial time as inferred from single-valve analysis of oxygen isotopes in ostracodes. Quaternary Research 43, 297–310.
Evans, D.J.A., 2009. Controlled moraines: origins, characteristics and palaeoglaciological implications. Quaternary Science Reviews 28, 183–208.
Flemal, R.C., Hinkley, K.C., Hesler, J.L., 1973. De Kalb mounds: a possible Pleistocene (Woodfordian) pingo field in north-central Illinois. In: Black, R.F., Goldthwait, R.P., Willman, H.B. (Eds.), The Wisconsin Stage: Geological Society of America Memoir, 136, pp. 229–250.
Forester, R.M., Smith, A.J., Palmer, D.F., Curry, B.B., 2006. North American Non-Marine Ostracode Database NANODe, Version 1. Kent State University, Kent , Ohio , U.S.A. http://www.kent.edu/nanode.
Graese, A.M., Bauer, R.A., Curry, B.B., Vaiden, R.C., Dixon, W.G., Kempton, J.P., 1988. Geological–geotechnical studies for siting the Superconducting Super Collider in Illinois: regional summary. Illinois State Geological Survey Environmental Geology Notes, 123, 100 pp.
Gravenor, C.P., Kupsch, W.O., 1959. Ice-disintegration features in western Canada. Journal of Geology 67, 48–64.
Ham, N.R., Attig, J.W., 1996. Ice wastage and landscape evolution along the southern margin of the Laurentide Ice Sheet, north-central Wisconsin. Boreas 25, 171–186.
Hansel, A.K., Johnson, W.H., 1996. The Wedron and Mason Groups, a lithostratigraphic reclassification of deposits of the Wisconsin Episode, Lake Michigan Lobe area. Illinois State Geological Survey Bulletin, 104, 116 pp.
Hughes, R.E., Moore, D.M., Glass, H.D., 1994. Qualitative and quantitative analysis of clay minerals in soils. In: Amonette, J.E., Zelazny, L.W. (Eds.), Quantitative Methods in Soil Mineralogy. Soil Science Society of America, Madison, WI, pp. 330–359.
Ianacelli, M., 2003. Reinterpretation of the original De Kalb mounds in Illinois: physical geography 24, 170–182.
Johnson, M.D., Clayton, L., 2003. Supraglacial landsystems in lowland terrain. In: Evans, D.J.A. (Ed.), Glacial Landsystems. Arnold, London, pp. 228–258.
Loke, M.H., Barker, R.D., 1996. Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method. Geophysical Prospecting 44, 131–152.
McGarry, C.S., 2000. Shaded relief of Kane County, Illinois. Illinois State Geological Survey, OFS 2000–6, 1:62, 500 map.
Müller, F., 1963. Observations on pingos (D.A. Sinclair, translator): Canada National Research Council Technical Transactions 1073, 177 p.
Parizek, R.R., 1969. Glacial ice-contact ridges and rings. Geological Society of America Special Paper 123, 49–102.
Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hogg, A.G., Hughen, K.A., Kromer, B., McCormac, G., Manning, S., Ramsey, C.B., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F. W., van der Plicht, J., Weyhenmeyer, C.E., 2004. INTCAL04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. Radiocarbon 46, 1029–1058.
Remenda, V.H., Cherry, J.A., Edwards, T.W.D., 1994. Isotopic composition of old ground water from Lake Agassiz: implications for late Pleistocene climate. Science 266, 1975–1978.
Simpkins, W.W., 1995. Isotopic composition of precipitation in central Iowa. Journal of Hydrology 172, 185–207.
Soil Survey Staff, 1999. Soil Taxonomy, A Basic System of Soil Classification for Making and Interpreting Soil Surveys, 2nd Edition. : United States Department of Agriculture, Natural Resources Conservation Service, Agriculture Handbook No. 436. 871 pp.
Syverson, K.M., 2007. Pleistocene geology of Chippewa County, Wisconsin. Wisconsin Geological and Natural History Survey Bulletin 103, 53 pp.
United State Environmental Protection Agency, 1994. SEPA Method 6020A, determination of trace elements in waters and wastes by inductively coupled plasma–mass spectrometry, Rev. 5.4, In Methods for the Determination of Metals in Environmental Samples, PA-600/R-94/111, May 1994, USEPA, Environmental Monitoring Systems Laboratory, Office of Research and Development, Cincinnati, OH.
von Grafenstein, U., Erlernkeuser, H., Trimborn, P., 1999. Oxygen and carbon isotopes in modern fresh-water ostracod valves: assessing vital offsets and autecological effects of interest for palaeoclimate studies. Palaeogeography, Palaeoclimatology, Palaeoecology 148, 133–152.
Wickham, S.S., Johnson, W.H., Glass, H.D., 1988. Regional geology of the Tiskilwa Till Member, Wedron Formation, northeastern Illinois. Illinois State Geological Survey Circular 543, 35 pp.