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The southern shore of Lake Michigan is the type area for many of ancestral Lake Michigan's late Pleistocene lake phases, but coastal deposits and features of the Algonquin phase of northern Lake Michigan, Lake Huron, and Lake Superior are not recognized in the area. Isostatic rebound models suggest that Algonquin phase deposits should be 100 m or more below modern lake level. A relict shoreline, however, exists along the lakeward margin of the Calumet Beach that was erosional west of Deep River and depositional east of the river. For this post-Calumet shoreline, the elevation of basal foreshore deposits east of Deep River and the base of the scarp west of Deep River indicate a slightly westward dipping water plane that is centered at ~184 m above mean sea level. Basal foreshore elevations also indicate that lake level fell ~2 m during the development of the shoreline. The pooled mean of radiocarbon dates from the surface of the peat below post-Calumet shoreline foreshore deposits indicate that the lake transgressed over the peat at 10,560 ± 70 years B.P. Pollen assemblages from the peat are consistent with this age. The elevation and age of the post-Calumet shoreline are similar to the Main Algonquin phase of Lake Huron. Recent isostatic rebound models do not adequately address a high-elevation Algonquin-age shoreline along the southern shore of Lake Michigan, but the Goldthwait (1908) hinge-line model does.

Lake Michigan · Lake level · Calumet beach · Calumet phase · Algonquin phase

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Three relict shoreline complexes, consisting of mainland-attached beaches, spits, barriers, and beach ridges, occur in northwestern Indiana and northeastern Illinois, arcing subparallel to the modern shoreline of Lake Michigan (Fig. 1). From most landward to lakeward, they are formally known as the Glenwood, Calumet, and Toleston Beaches. They were defined in their current usage by Leverett (1897), who established reference lake-level elevations of ancestral Lake Michigan for each shoreline at 195, 189, and 184.5 m above mean sea level (AMSL), respectively. More recent workers (Hansel et al. 1985; Hansel and Mickelson 1988; Schneider and Hansel 1990; Thompson 1990, 1992; Thompson and Baedke 1997) added chronological control on the ages of these shorelines using radiocarbon dating, and refined lake-level elevation ch3(of)-3.6(94.5(at)-.6(t-6.4t15.u438el)-gh3(of05.6time1 scn05.eliD[(nologi)-7.Anst)-8)-3Al0 0 gonquin-

Beach at Wicker Park (Highland, Indiana) near the Illinois-Indiana state line. They suggested that the similar elevation of these two features may represent a former Algonquin water-plane in southern Lake Michigan. Colman et al. (1994a), however, dismissed this interpretation because of inconsistencies in the age control of the shoreline. Regardless of the rebound model and age control, coastal features and deposits lakeward of the Calumet Beach have been only partially addressed in reconstructions of past lake-level change for the basin (e.g., Chrzastowski and Thompson 1992, 1994). The main focus of this study is to examine the geomorphological, sedimentological, paleoecological, and radiocarbon evidence for post-Calumet phase coastal features and deposits along the Indiana shore of southern Lake Michigan and to collect additional data to support or refute their existence.

U.S. Geological Survey (USGS) 1:24,000-scale topographic maps and 1938 aerial photos along southern Lake Michigan in northwest Indiana were examined to identify geomorphic features associated with former shorelines. Landforms, including beach ridges, terraces, and erosional scarps, were traced. Particular attention was given to the Calumet Beach complex and to proximal lakeward features. Although northwestern Indiana is heavily urbanized and industrialized, relatively undisturbed sites in northwest Indiana are present. In this study, north–south-oriented (roughly onshore–offshore-oriented), transit-surveyed topographic profiles were constructed from the Calumet Beach lakeward at Wicker Park, north of the former site of Crisman Sand Company, Inc., and east of Mineral Springs Road (Fig. 1). Elevations for the profiles were established from U.S. Geological Survey and U.S. National Park Service benchmarks and are reported using the U.S. National Geodetic Vertical Datum of 1929. Fourteen vibracores were collected at strategic points along these profiles, focusing on key geomorphic changes. A ground-penetrating radar (GPR) line using a 250 MHz Sensors and Software Inc. Noggin Smart Cart was taken along the Wicker Park transect to obtain preliminary stratigraphic information on the shallow subsurface. GPR transect lines at the other two sites were unsuccessful in imaging the subsurface because of surface debris and tree roots.

Cores were transported back to the laboratory where they were split, described, sampled, and photographed. Latex peels were created from the cores to preserve them and enhance the visibi(sa)-8 -1.2462

dune and beach ridge. A broad and slightly undulating nearshore platform stretches lakeward from the crest of the Calumet Beach for ~280 m and abruptly terminates at a scarp where topographic elevations decrease 2.5 to 3 m to a second flat platform (Fig. 2A). The scarp can be traced eastward of Wicker Park for 15 km where it terminates near the western edge of Deep River (Fig. 1). At Wicker Park, eight cores were collected and a 365-m-long GPR line was run along a lakeward-oriented transect (Fig. 2A).

Cores along the transect at Wicker Park penetrated to a light gray clayey diamicton with quartzite and siltstone pebbles and granules that is interpreted as subglacial till of the Lake Border sequence (Brown and Thompson 1995). The diamicton is clearly identified on the GPR profile where the GPR signal is rapidly dissipated and reflected by the clay-rich nature of the deposit. Landward of the scarp (Cores 325 to 327), the diamicton is overlain by upper shoreface deposits of lakeward-dipping subhorizontal and micro-trough cross-stratified, lower fine- to upper fine-grained sand, sandy gravel, and granular sand. The position of these deposits lakeward of the crest of the Calumet Beach suggests that they are nearshore deposits associated with the Calumet phase of ancestral Lake Michigan. Lakeward of the scarp (Cores 329 to 332) is a mix of poorly sorted and organic-rich muddy sand and sandy gravel. Many of the clasts are locally derived from the diamicton. No recognizable coastal facies occur in these deposits, and they are interpreted to be colluvial. The elevation of the surface of the diamicton (Core 329) beneath the colluvium is 182.8 m AMSL.

The GPR profile shows a bowl-shaped scour at an elevation of ~186 m AMSL beneath the toeslope of the Calumet Beach. The bowl-shaped scour likely represents the location of the Calumet phase foreshore deposits. These probable foreshore deposits were not cored because Ridge Road follows the northern margin of the Calumet Beach; consequently, the Calumet foreshore deposits are inaccessible and probably disturbed at this location. However, we estimate an elevation of 186 m for basal Calumet foreshore deposits at Wicker Park based on the elevation of the base of the scour in the GPR profile.

Crisman Sand

The Crisman Sand site is 0.5 km northeast of the intersection of State Route 249 and Interstate 94 in northwestern Porter County, Indiana (Fig. 1). In this area, a shore-parallel, 2- to 5-m-high, topographic rise occurs 80 to 100 m lakeward of the crest of the 10- to 15-m-high Calumet Beach. Vibracores were collected on the crest and lakeward and landward toeslopes of this post-Calumet beach ridge (Fig. 2B).

The two landward cores (Cores 333 and 334) are capped by dune sediments, consisting of structureless lower to upper fine-grained sand with scattered rootlets throughout. The dune sediments overlie ~1-m-thick foreshore deposits of horizontally to subhorizontally stratified, upper fine- to upper coarse-grained sand. Laminae are defined by alternations in grain size, and the foreshore sequence slightly coarsens downward. Basal foreshore elevations for the Calumet Beach in the two cores range from 186.4 m to 187 m AMSL. Upper shoreface sediments below the foreshore deposits consist primarily of upper fine-grained sand alternating with more coarse-grained sand to granular horizons. Sedimentary structures in the upper shoreface sequence vary from horizontal and subhorizontal parallel laminae to ripple and micro-trough cross-stratification.

Facies within the core-collected lakeward of the post-Calumet ridge (Core 335) are similar to the two landward cores, but the elevation of the basal foreshore deposits is much lower and the dune deposits are overlain by ~2 m of lower to upper fine-grained sand and marly granular sand. The fine-grained sand and marly sand are interpreted as Nipissing-phase lagoonal (back-barrier lacustrine) deposits because of their texture and composition, and occurrence upsection, and therefore, lakeward of the post-Calumet shoreline but landward of the Nipissing-aged Toleston Beach. Thompson (1990) recognized similar deposits in the eastern part of the Indiana Dunes. The elevation of the post-Calumet basal foreshore sediments is 183.2 m. This elevation is 3 m to 4 m below the elevation of the basal Calumet Beach foreshore deposits in the two landward cores.

Mineral Springs Road

The Mineral Springs Road study site is 200 m northeast of the intersection of U.S. Route 12 and Mineral Springs Road in north-centratiatower fTCountforeshore elevations increase landward and range from 185.2 m to 185.9 m AMSL. The foreshore deposits overlie fibrous peat in the landward cores, but in the more lakeward core the foreshore deposits overlie 0.3 m of horizontally stratified, upper fine- to upper medium-grained

Crisman Sand study areas. At the Liverpool West site, Calumet and post-Calumet deposits were exposed in a currently flooded borrow pit. A stratigraphic section for the Liverpool West site (Schneider and Hansel, 1990, their fig. 7) shows a basal till (diamicton) of the Lake Border se-of strong ground-water influence (Andrus 1986; Crum 1988), therefore, the AMS radiocarbon date on [illegible] remains should not be influenced by any radiocarbon-dead carbonates present in the ground water. Testate amoebae, amoeboid protozoans that produce a decay-resistant shell, provide additional support for only limited ground-water influence at the surface of the peatland. The distribution of testate amoebae in [illegible]-dominated peatlands is primarily controlled by moisture conditions, and secondarily by pH, trophic status, and other aspects of water chemistry (Woodland et al. 1998; Mitchell et al. 2000; Booth 2001, 2002; Charman 2001). The species of testate amoebae recovered from the peat all have optimum abundance today in relatively dry and low pH habitats (Booth 2001, 2002). Together, the macrofossil and testate amoeba data suggest that the peatland lakeward of the Calumet Beach at Minerals Springs Road was a [illegible]-dominated poor fen or bog, with little standing water except for upper portions of Core 336. Upper portions of Core 336 were probably deposited under fluctuating hydrologic conditions that may possibly have been caused by the landward-translating post-Calumet shoreline.

Pollen data collected from the peat in Cores 338 and 336 are consistent with the ^{14}C age determinations. Pollen assemblages prior to ~11,500 to 10,000 year B.P. in northern Indiana and southern Michigan are characterized by high [illegible], [illegible], and [illegible] percentages (e.g., Williams 1974; Futyma 1988; Singer et al. 1996), probably reflecting the dominance of open [illegible] woodlands at this time (Webb et al. 1983). Between 11,000 year and 10,000 year B.P., a mixed forest dominated by [illegible], [illegible], [illegible], and [illegible] developed, and by 10,000 year B.P. forests dominated by [illegible] and [illegible] became established (Webb et al. 1983; Singer ([[(11ar)-285(b2stab-)]Uppewith7(Th 0 0 9.9629(Calume)-7.5(t)-48.1(co5scn2 sites and Mineral Springs Road are most likely time-equivalent.

Radiocarbon dates collected from the surface of the peat at Mineral Springs Road from this study and Thompson (1990

Scenario 2

The retreat of the Lake Michigan ice lobe joined Lake Michigan and Lake Huron at the Main Algonquin level or one of the post-Algonquin phase levels. Combined with Lake Huron, Lake Michigan underwent similar stair-step lowerings of lake level throughout the post-Algonquin as glacial ice margin retreated from northern Lake Huron (cf. Eshman and Karrow 1985). The post-Calumet shoreline is time-equivalent to one of the post-Algonquin phase levels.

Scenario 3

The post-Calumet shoreline formed during the Moorhead phase influx from glacial Lake Agassiz littoral sediment would not be available landward of the Toleston Beach to build the post-Calumet beach ridge. Scenarios 1 and 3 both involve rising water-levels in the basin at the appropriate time that could scarp the Calumet nearshore and transgress palustrine sediments. It is not possible at this time to distinguish between the two possible scenarios, but we favor Scenario 1 because Scenario 3 may have been too short-lived to have significant impact on shoreline behavior along the southern shore of Lake Michigan.

Rebound

A high-elevation Algonquin-aged shoreline along the southern shore of Lake Michigan is inconsistent with the rebound model of Larsen (1987) and favors the longstanding model of Goldthwait (1908

Michigan. Rates of rebound increase northward and slightly southward from this area. In effect, the modern gage data illustrate vertical ground movement that is somewhat similar to the Goldthwait (1908) hinge model (Fig. 5). This new interpretation of historical gage data is based on longer data sets and additional gaging sites that were not available to Larsen (1987) or Clark et al. (1994) who used Coordinating Committee (1977) data.

The post-Calumet shoreline of southern Lake Michigan is elevation-and time-equivalent to the Main Algonquin of southern Lake Huron. The gage data of the Coordinating Committee (2001) show that the southern shore of Lake Huron is relatively rising 9 to 12 cm/century more rapidly than the southern tip of Lake Michigan (Fig. 5). Following the Coordinating Committee (2001) data and projecting modern rates into the past, the post-Calumet shoreline of southern Lake Michigan should be 9.5 m to 13 m lower than coastal features and deposits of similar age along southern Lake Huron. Baedke and Thompson (2000), however, have shown that during the late Holocene the southern shore of Lake Michigan was rising more rapidly (19 cm/century) than the Port Huron outlet before 1,400 cal year B.P. and less rapidly (–7 cm/century) than the Port Huron outlet after 1,400 cal year B.P. The pattern observed by the Coordinating Committee (2001), therefore, may hold for only the past 14 centuries, yielding an elevation difference between southern Lake Michigan and southern Lake Huron of no more than –1.2 m to –1.7 m. Such a slight difference in the elevation of coastal features and deposits between locales that are 450 km apart is probably not recognizable.

[illegible]

Geomorphological, sedimentological, paleoecological, and radiocarbon data indicate that deposits and features of a relict shoreline are present along the lakeward margin of the Calumet Beach in northwestern Indiana. This post-Calumet shoreline was primarily erosional west of Deep River but primarily depositional east of the river. The elevations of basal foreshore deposits east of Deep River and the base of the scarp west of Deep River indicate a slightly westward-dipping water plane for the shoreline that is centered at ~184 m AMSL. Basal foreshore elevations also indicate that lake level fell ~2 m during the development of the shoreline. Post-Calumet foreshore deposits overlie peat at Mineral Springs Road, and the pooled mean of radiocarbon dates from the surface of the peat indicates that the lake transgressed over the peat at 10,560 ± 70 year B.P. Pollen assemblages from the peat are consistent with this age. The elevation and age of the post-Calumet shoreline is similar to the Main Algonquin phase of Lake Huron. Recent isostatic rebound models do not adequately address a high-elevation Algonquin-age shoreline along the southern shore of Lake Michigan. The long-standing hinge-line model of Goldthwait (1908) is consistent with a high-elevation shoreline, and at8Sedl onr-440.6(a)-538.4(aodel)-

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