East Okoboji Lakefront
Technical Assessment

For
Iowa Department of Natural Resources
Fisheries Bureau

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Prepared by

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INTRODUCTION

At the request of Mr. Mike Hawkins, Iowa Department of Natural Resources (IDNR) fisheries biologist, a geophysical resistivity survey was performed by the IDNR Geological and Water Survey (IGWS) to evaluate the nature and extent of lake bottom sediments along a small identified area on the north shore of East Okoboji Lake. The area in question is east of the Highway 71 bridge that intersects East and West Okoboji Lakes and adjacent to Mau Marina (Figure 1). The goal of the request by Mike Hawkins, fisheries biologist, was for IGWS staff to define the age of lake bottom sediments at the site. IGWS observations are based on a geophysical survey of the area, observations of soil samples from the site and observations from cores taken from several nearby lakeshore borings on adjacent West Okoboji Lake.

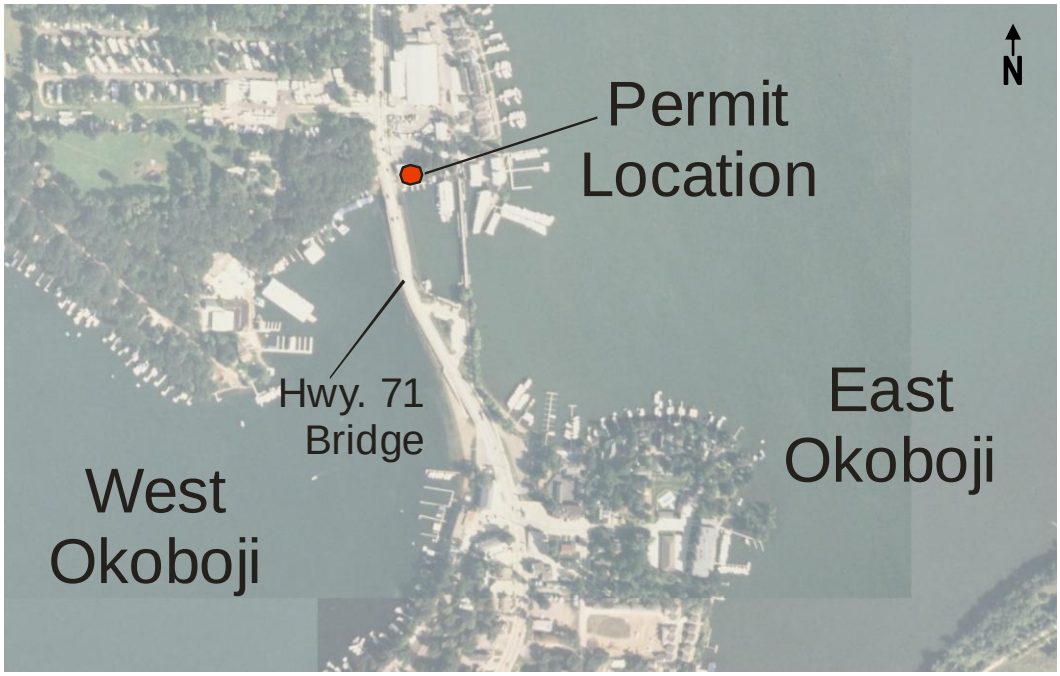

Figure 1. High altitude imagery showing the approximate location of the proposed dredging permit site on East Okoboji Lake. The figure shows the location of the lakefront marina in proximity to East and West Okoboji Lakes and the Highway 71 bridge.

GEOLOGIC SETTING

The Iowa Great Lakes Region, an area known as a premier vacation destination, is also home to some of Iowa's most spectacular glacial features that reflect the state's most recent contact with glaciers. The Iowa Great Lakes Region is located along the southwest edge of the Des Moines Lobe ice sheet which surged into Iowa about 13,500 years ago, halting at what is now the city of Des Moines (Figure 2).

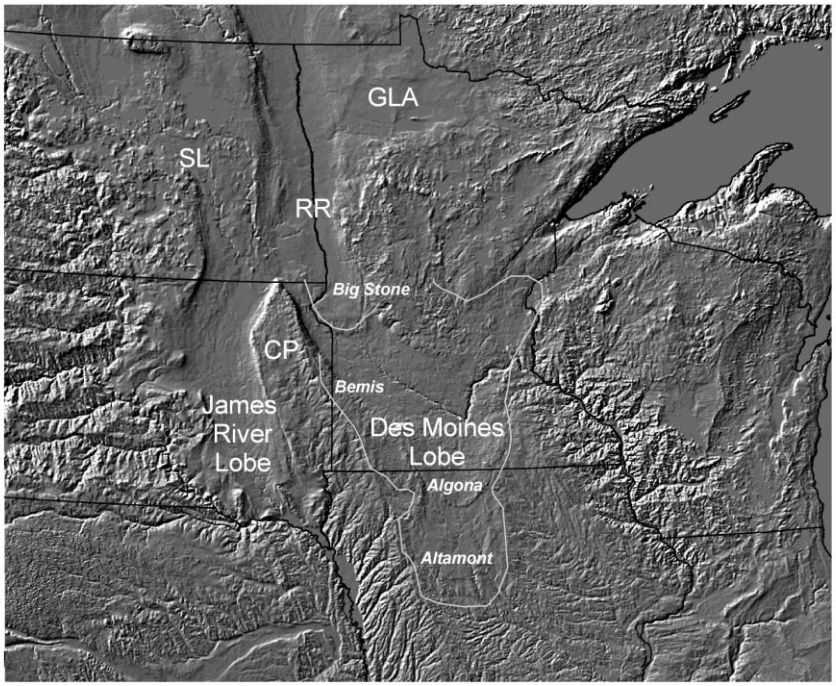

Figure 2. Location of the Des Moines Lobe in the Upper Midwest and the Coteau des Prairies (CP), Glacial Lake Souris (SL), Red River Valley (RR) and Glacial Lake Agassiz (GL).

This ice stagnated across the landscape and was followed by several readvances over the next 1,500 years. The resulting landscape in the Iowa Great Lakes Region is particularly eye-catching due to younger ice advances overlapping older ice advances and creating the "knob and kettle" terrain associated with landscapes that form in direct contact with slowly disintegrating ice. The Iowa Great Lakes Region served as an important drainage outlet for the Des Moines Lobe (DML). The Okoboji Lake Outlet was an important drainage outlet along the northwestern edge of the Lobe (Figure 3). This outlet now drains an interconnected system of lakes and sloughs, including Lower and Upper Gar, East and West Okoboji, Little Spirit, Spirit, Center, Marble, and Hottes Lakes and drains into the Little Sioux River. Extensive sand and gravel deposits provide ample evidence of the huge volumes of water and sediment discharged by melting ice during late glacial times. All of the lakes mentioned above owe their existence to the disintegration of glacial ice during Late Wisconsin time and in particular are associated with the Altamont Moraine Complex, which represents the second readvance of DML ice (see Figure 3).

The lake bottom sediments associated with these lakes are categorized into post glacial age deposits known as the West Okoboji Member of the DeForest Formation (Bettis et al., 1996). See Appendix 1 for a complete stratigraphic description of the West Okoboji Member. The West Okoboji Member represents the organic-rich silt deposits associated with lake sedimentation but do interfinger with colluvial and organic sediments associated with slough and backwater areas as well as interfingering with unnamed sandy and gravelly sediments (Triboji Member) associated with ice-push ridges (ridges resulting from the pushing action of a lake's ice sheet against the shoreline). Recent drilling along the shoreline of West Okoboji Lake has allowed a more definitive look at these gravelly sediments and it is proposed that these formerly unnamed sediments will be referred to as the "Triboji Member" in the future (Appendix 2).

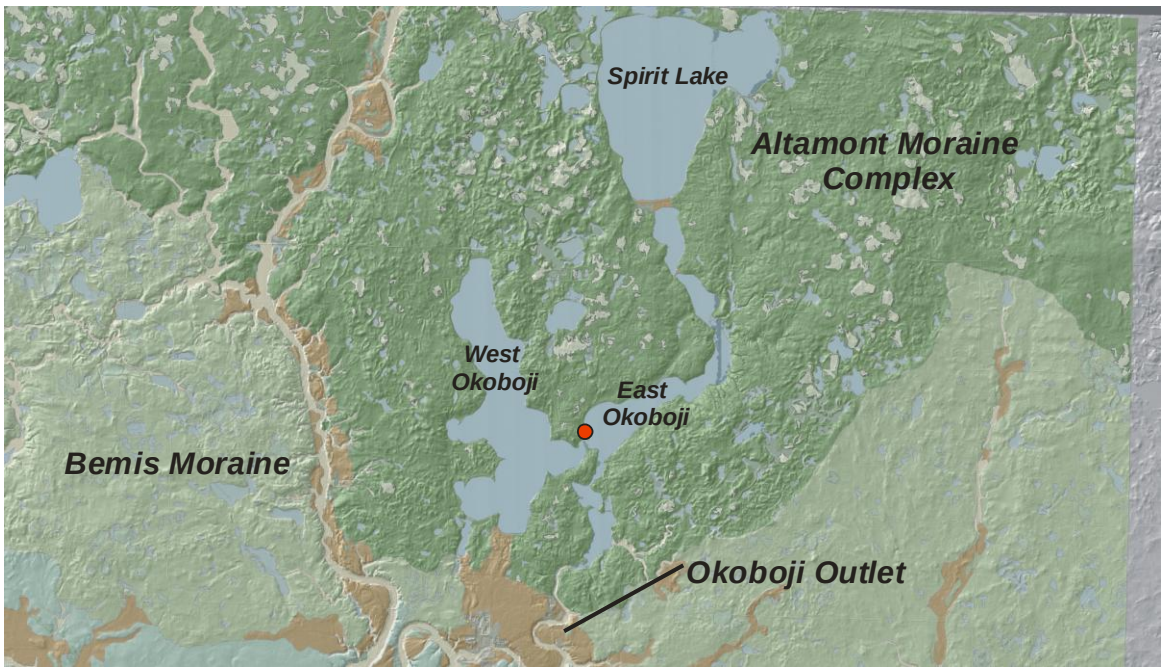

Figure 3. Map of the Great Lake Region showing former Des Moines Lobe ice positions and extent of outwash (sand and gravel) is illustrated in brown. It is concentrated along valleys and moraine margins and at the Okoboji Outlet Channel and the Little Sioux River Valley. Map is on a shaded relief base that illustrates the hummocky topography associated with the Altamont Moraine Complex (AMC). The slightly lower relief topography of the Bemis Moraine is illustrated in light green.

WORK DESCRIPTION

Prior to the geophysical investigation, IGWS was asked to visit the site on Friday November 4, 2011. IGWS geologists looked at material obtained from one of several hand auger samples taken along the shoreline (Team Services) and near the geophysical survey transect. Geologists noted that the upper 12" was an organic-rich medium to coarse sand and the second sample from 12" to 24" consisted of a loamy organic-rich medium to coarse sand with a thin bed of finer-grained deposits that appeared to be a buried soil horizon with soil structure (Figure 4). IGWS suggested to the landowner, Julie Mau, and the Team Services technician that it might be useful to collect several deeper continuous core borings and or samples along the proposed site area, preferably coring into glacial till. The reasoning for this suggestion was that continuous samples would yield a more intact view of the lake bottom sediment package. On November 10, 2011 Team Services did collect four slightly deeper borings near the geophysical transect location (Figure 5). IGWS geologists have not had an opportunity to view the boring log descriptions. Personal communication between Mike Hawkins and Team Services personnel on the day of drilling indicated that stiff blue clay (most likely glacial till) was encountered in all four borings at a range of 7-12 feet in depth (boring locations on Figures 5 and 6).

The geophysical survey was conducted the week following the first visit to the site, on November 9, 2011. The survey was conducted near the high water line area of the lakeshore (Figure 5). Interpretation of the geophysical survey is based on apparent resistivity measurements, calibration with previous observations of the bucket auger samples and personal communications with Team Services staff on the day of deeper boring sample collection.

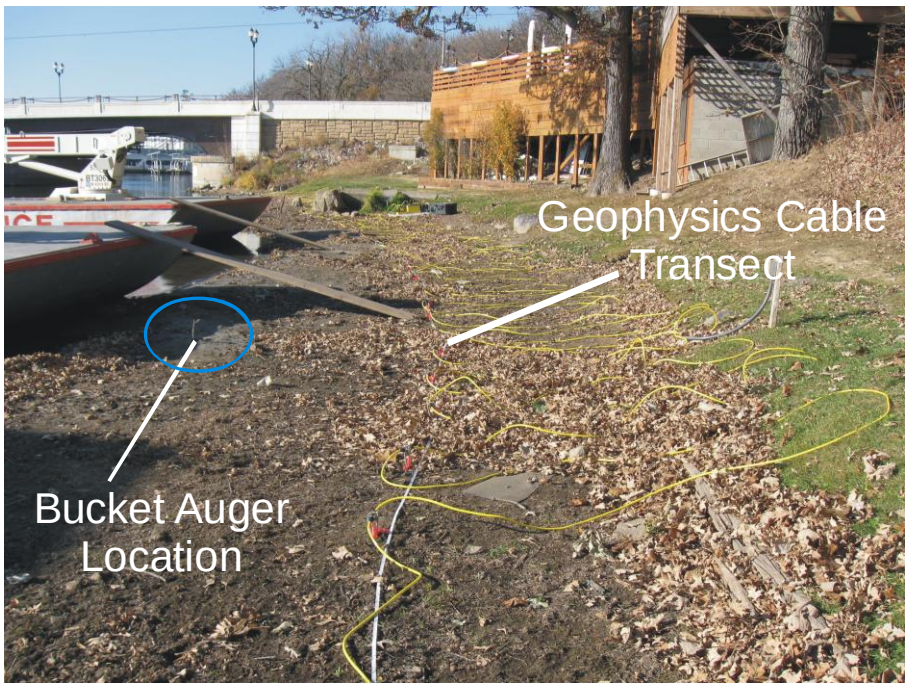

Figure 4. Location of one bucket auger site which is in close proximity to geophysical transect. Site is located at the east end of the geophysical transect which is illustrated in map view in figure 5 below.

Figure 5. High altitude imagery showing the location of geophysical survey on East Okoboji Lake. The figure shows the location of the lakefront marina in proximity to Mau Marina and the Highway 71 bridge. The survey was taken near the high water line for East Okoboji Lake and on what appeared to be exposed lake bottom materials. Team Services shallow boring locations are indicated by blue symbols.

Figure 6 displays an excellent snapshot of the underlying lake bottom package associated with the shoreline of East Okoboji and the surrounding lakes in the Iowa Great Lakes Region. IGWS has interpreted the lake bottom package as: The upper veneer (7 to 12 feet in green, primarily) of shoreline sediments at this location is primarily loamy sand in nature with some inclusions of organic-rich silty material and coarse pebbly sand (yellow and red). The underlying package (blue color) is primarily loam textured glacial till with some inclusions of silty sand.

Bucket auger samples from the upper four feet of the lake bottom (see Figure 4) were exposed to a 10% hydrochloric acid solution to test for calcium carbonates by IGWS geologists. The sandy sediments were strongly effervescent and the organic-rich finer-grained sediments were weakly effervescent and displayed moderate soil structure; indicating some period of stability (soil forming processes) on the lake bottom. Most likely soil formation may be indicative of a drought cycle.). The underlying glacial till was most likely deposited beneath glacial ice approximately 13,500 years ago (Bettis et al., 1996). Lake bottom sediments have been accumulating at varying rates since that time. Analysis of the bucket augers samples and interpretation of the resistivity data do not indicate a substantial influx of recently deposited fine-grained sediments from the nearby shoreline that might be associated with modern day human activities.. However, it would be prudent to have an opportunity to view the slightly deeper borings that were collected by Team Services staff and interpret that data for the final report.

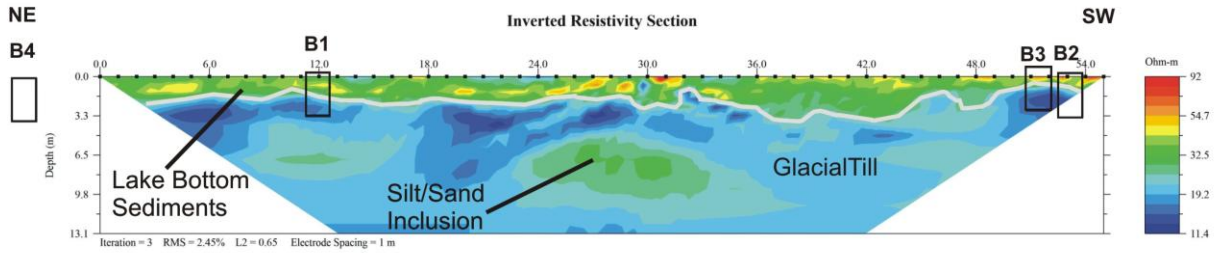

Figure 6. Shows two dimensional resistivity pseudo section in a cross section view. The upper 7 to 12 feet of the section is interpreted as coarse sand bodies (red and yellow colors) in a matrix of organic- rich loamy sand (green color). The underlying package is interpreted as primarily a loam diamicton (blue) with inclusions of what may be sandy loam sediments (green). Note the intermediate directions at the top of the figure.

GEOPHYSICS METHODS

An Advanced Geosciences Inc. (AGI) SuperSting R8 earth resistivity (ER) meter was utilized as the main method of conducting the survey. The field measurement of ER was obtained by injecting a known direct current via transmitter electrodes and measuring the voltage differences between receiver electrodes. An array of 56 stainless steel electrodes were spaced approximately one meter apart, planted on the ground surface to a depth of approximately 10 inches and connected via electrode cables to a multi-channel resistivity/IP meter. Measurements were collected and stored in a predetermined manner then processed using AGI EarthImager 2D inversion software. One line of survey was completed on site and the location and results are shown on Figures 5 and 6. The geophysical investigation of this study was calibrated with bucket auger sample data and nearby core data from West Okoboji Lake.

Figure 7. IGWS conducting geophysical survey at East Okoboji Lake shoreline. Yellow cables are attached to numerous stainless steel stakes. Electric current is directed through the cables and into the ground via metal stakes. This is a highly effective method to characterize the lateral variation and extent of sediment packages with highly varying resistivity ie. coarse-grained vs. fine-grained deposits.

PRELIMINARY CONCLUSIONS

The lake bottom sediments associated with East Okoboji Lake and nearby lakes are categorized into post glacial age deposits known as the West Okoboji Member of the DeForest Formation. See Appendix 1 for a complete stratigraphic description of the West Okoboji Member. The West Okoboji Member represents the organic-rich silt deposits associated with lake sedimentation but interfinger with colluvial and organic sediments associated with slough and backwater areas as well as interfingering with unnamed sandy and gravelly sediments associated with ice-push ridges. Recent drilling along the shoreline of West Okoboji Lake has allowed a more definitive look at these gravelly sediments and it is proposed that these formerly unnamed sediments will be referred to as the "Triboji Member" in the future (Appendix 2).

What is most important to recognize is that the age of the West Okoboji and Triboji Members date from the time of final glacial ice wastage associated with the Des Moines Lobe (~13,500 years ago); and that deposition has continued to the present, but at varied rates through time (Van Zant, 1979).

The West Okoboji and Triboji members are extensive units that are deposited on all extant lake basins associated with the Des Moines Lobe. From recent IDNR investigations, it is clear that the sediment package at the East Okoboji site, Triboji Access Beach and Emerson Bay Beach area all are quite similar (Figure 8). None of the sites exhibit sediment properties that would normally be associated with a recent influx of sediment due to post settlement human activities (layered fine grained deposits). All three sites have a relatively coarse-grained sediment package that has been deposited since the wastage of last glacial ice. The Emerson Bay site is

very similar to the East Okoboji site, in that there is a relatively shallow coarse-grained package overlying glacial till (see Appendix 2 description).

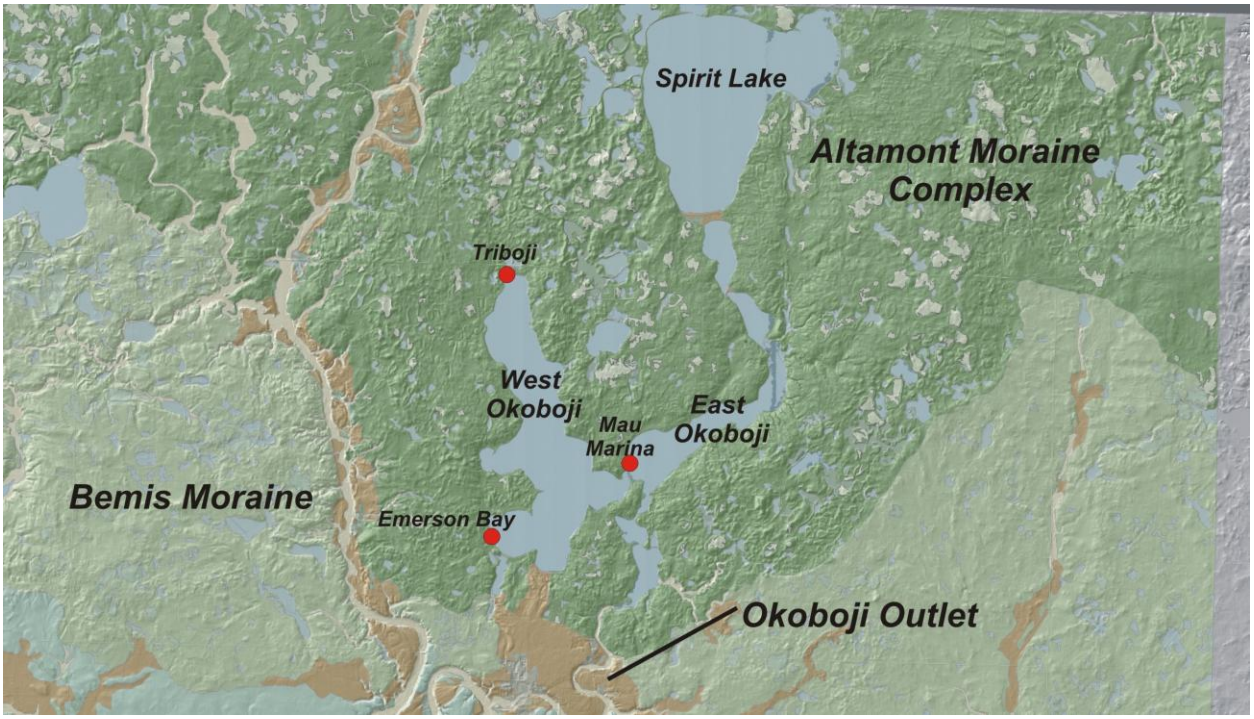

Figure 8. Map of the Great Lake Region on a shaded relief base that illustrates the hummocky topography associated with the Altamont Moraine Complex (AMC). The Triboji, Emerson Bay and Mau Marina locations are located with red symbols. Complete descriptions of Triboji and Emerson Bay are included in Appendix 3. The sediment package is remarkably similar at all three sites and shows no appreciable evidence of recent sediment influx due to human activities.

In conclusion, it is the interfingering of these two lake sediment packages coupled with drought cycles throughout post glacial time that make it extremely difficult to assess a definitive age of the entire lake sediment package. It is recognized that in part, the West Okoboji and Triboji Members are late glacial in age. Potential dredging of a portion of the lake bottom sediment package could disturb late glacial and post glacial age Triboji and West Okoboji Member sediments.

REFERENCES

Bettis, E.A. III, Quade, D.J. and Kemmis, T.J., 1996, *in* Hogs, Bogs, and Logs: Quaternary Deposits and Environmental Geology of the Des Moines Lobe. Edited by: E.A. Bettis, III, D.J Quade, and T.J Kemmis. Iowa Department of Natural Resources-Geological Survey Bureau, Guidebook Series No. 18, 170 p.

Van Zant, K., 1979, Late glacial and postglacial pollen and plant macrofossils from West Lake Okoboji, northwestern Iowa: Quaternary Research, v. 12, p. 358-380.

APPENDIX 1- West Okoboji Member Formal Description

West Okoboji Member

Source of Name: Lake West Okoboji, Dickinson County, the location of the Type section.
Type Section: Little Millers Bay core, collected in two meters of water in the northernmost portion of Millers Bay, a western projection of Lake West Okoboji, SW 1/4 SW 1/4, NE 1/4 of section 23, T. 99 N., R. 37 W., Dickinson County, Iowa (Van Zant, 1979; Figure 15). This is within the Bemis/Altamont ice margin complex.

Description of Unit: The West Okoboji Member comprises lake sediment associated with extant lakes on the Des Moines Lobe. The lower part of the member usually consists of organic-rich silt, and the remainder of the unit is dominantly *gyttja*, sometimes with lenses of silt, sand, and pebbles. Shells and plant macrofossils are common.

Nature of Contacts: The West Okoboji Member abruptly and unconformably overlies glacial diamicton of the Dows Formation. Laterally the Okoboji Member may interfinger with sediments of the Woden Member, or unnamed sandy and gravely sediments of ice-push ridges. In most cases the member is overlain by lake water.

Differentiation From Other Members: The West Okoboji Member differs from other members of the formation, except the Woden Member, in geomorphic position and nature of the stratigraphic sequence. The West Okoboji Member differs from the Woden Member in that it does not contain peat or muck, generally lacks root traces, and is covered by more than one meter of standing water.

Regional Extent and Thickness: The West Okoboji Member is restricted to extant lake basins on the Des Moines Lobe. Thicknesses vary depending on the size of the lake and the topography of the pre-West Okoboji surface in the lake basin. The thickest sections occur in depressions in the lake basin and near the location of surface drainage inlets. At the type section the member is 11.7 m thick.

Origin: Sediment in the West Okoboji Member is primarily mineral and organic sediment that was deposited from suspension. Minor amounts of fine-grained mineral sediment and sand and pebbles in the member were deposited by *turbidity currents*, ice rafting, and by ice-pushing during periods of low lake levels.

Age: The West Okoboji Member dates from the time of the final wastage of glacial ice from the Des Moines Lobe. Deposition has continued to the present, but depositional rates have varied (Van Zant, 1979).

APPENDIX 2- Triboji Member Formal Description

Triboji Member

Source of Name: Lake West Okoboji, Dickinson County, the location of the Type section.
Type Section: Triboji Beach core, collected adjacent to the water on the northernmost portion of Lake West Okoboji, SW 1/4 NE 1/4, NE 1/4 of section 2, T. 100 N., R. 37 W., Dickinson County, Iowa (unpublished, Quade 2011). This is within Altamont Moraine Complex ice margin.

Description of Unit: The Triboji Member comprises lake sediment associated with extant lakes on the Des Moines Lobe. The member usually consists primarily of sandy and gravely sediments related to late glacial deposition and later ice-push ridge activity. Inclusions of organic-rich silt are possible. Shells and plant macrofossils are uncommon.

Nature of Contacts: The Triboji Member abruptly and unconformably overlies glacial diamicton of the Dows Formation. Laterally, the Triboji Member may interfinger with sediments of the West Okoboji Member. In some cases the member is overlain by lake water dependent on climatic conditions.

Differentiation From Other Members: The Triboji Member differs from the other members of the formation, in geomorphic position and nature of the stratigraphic sequence. The Triboji Member differs from the West Okoboji Member in that it is primarily coarse-grained sand and gravels and generally lacks thick deposits of organic-rich sediments as well as shells and plant macrofossils.

Regional Extent and Thickness: The Triboji Member is restricted to extant lake basins on the Des Moines Lobe. Thicknesses vary depending on the size of the lake and the topography of the pre-West Okoboji surface in the lake basin. The thickest sections may occur in areas subject to heavy ice push ridge activity. At the type section the member is at least 3 m thick.

Origin: Sediment in the Triboji Member is primarily mineral sediment that was deposited during the evolution of extant lakes on the Des Moines Lobe. Inclusions of fine-grained organic-rich silt may be related to climate variability and changing lake level conditions.

Age: The Triboji Member dates from the time of the final wastage of glacial ice from the Des Moines Lobe. Deposition has continued to the present, but depositional rates have varied over time (Van Zant, 1979).

APPENDIX 3- Triboji Member Soil Descriptions (Triboji and Emerson Bay)

Included in this appendix are two descriptions for the newly named Triboji Member. The first soil description is from the Triboji Beach Access at West Okoboji Lake. The second description on the following page is from Emerson Bay Beach Area. A formal stratigraphic description is attached in this report. This information was collected for an unrelated project IGWS was working on along West Okoboji Lake. The deposits characterized below formed under similar conditions to the shoreline at the East Okoboji site.

Sitename: OK-9A (Triboji Beach Access)

Location: T-99 N R-37 W section 2 NE1/4
Landscape position: Altamont Moraine Complex-ice push ridge West Okoboji Lake
Parent Material: gravelly lacustrine sediments
Soil Series: Cylinder Date Drilled: 11/4/2011
Vegetation: none Slope: 0 %
Quadrangle: Okoboji Elevation: 1400 ft.
Described by: Deborah Quade and Kathy Woida. Jason Vogelgesang well installation.
Landowner: IDNR

Remarks: NRCS drill rig-4.5 inch solid stem auger cuttings. 1.5 ' PVC well installed w/ 5 ft screen. Casing height 20". Gravel pack=2.5 ft to land surface. Bentonite plug to land surface.

GPS Location: Garmin Etrex Receiver (<3 meters); gps locations in ArcGis shapefile. Updated location in accompanying GEOSAM header record.

Depth (ft)	Horizon /W. Zone	Description
		DeForest Formation-- Triboji Mbr.
0-1	RU	dark gray (2.5Y 4/1) and gray (2.5Y 5/1) coarse pebbly sand; massive loose; strongly effervescent
1-2	RU	dark grayish brown (2.5Y 4/2) and grayish brown (2.5Y 5/2) gray (2.5Y 5/1) coarse pebbly sand; loose; strongly effervescent
2-3	RU	grayish brown (2.5Y 5/2) and gray (2.5Y 5/1) coarse pebbly sand; loose; strongly effervescent
3-5	RU	gray (2.5Y 5/1) medium to coarse pebbly sand; loose; strongly effervescent
5-10	RU	gray (2.5Y 5/1) matrix-supported pebble gravel (coarse sand matrix); loose; strongly effervescent

Sitename: OK-15 (Emerson Bay State Park)

Location: T-99 N R-37 W section:35 NE1/4NW1/4NE1/4
Landscape position: Altamont Moraine Complex-ice push ridge West Okoboji Lake
Parent Material: gravelly lacustrine sediments
Soil Series: Webster Date Drilled: 11/8/2011
Vegetation: grass Slope: 0%
Quadrangle: Milford Elevation: 1400 ft.
Described by: Deborah Quade and Kathy Woida. Jason Vogelgesang well installation.
Landowner: IDNR
Remarks: NRCS drill rig-4.5 inch solid stem auger cuttings. 1.5" PVC well installed w/ 10 ft screen-15 ft of pipe. Casing height 20". Gravel pack=2.0 ft to land surface. Bentonite plug to surface.

GPS Location: Garmin Etrex Receiver (<3 meters); gps locations in ArcGis shapefile. Updated location in accompanying GEOSAM header record.

Depth (ft)	Horizon /W. Zone	Description
		DeForest Formation-- Triboji Mbr.
0-2	OL	very dark gray (2.5Y 3/1) loam to sandy loam; weak subangular blocky structure; friable; noneffervescent
2-3	RU	dark gray (5Y 4/1) gravelly sandy loam; friable; moderately effervescent
3-5	MRU	dark gray (5Y 4/1) to very dark gray (5Y 3/1) gravelly sandy loam to coarse pebbly sand in lower foot of interval; common medium yellowish brown (10YR 5/6) mottles; loose; strongly effervescent
5-7	MRU	very dark gray (5Y 3/1) coarse pebbly sand; few medium strong brown (7.5YR 5/6) mottles; loose; strongly effervescent
7-8	MRU	gray (5Y 5/1) and olive gray (5Y 5/2) gravelly sandy loam with few gray (5Y 5/1) silt inclusions; common fine strong brown (7.5YR 4/6) and strong brown (7.5YR 5/6) mottles; loose; strongly effervescent abrupt boundary
		Dows Formation-- Morgan Mbr.
8-10	UU	dark yellowish brown (10YR 4/4) to yellowish brown (10YR 5/4) resedimented loam diamicton with inclusions of fine sand; few medium strong brown (7.5YR 5/6) mottles; slightly firm; few Mn concentrations; strongly effervescent End of boring