Iceberg on Lake Superior
(Tim Trombley, Great Lakes Photography)

ICEBERGS IN NORTH DAKOTA

AND THE CURIOUS ICE-DRAG MARKINGS OF GLACIAL LAKE AGASSIZ

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INTRODUCTION

How do we know that there was an extensive glacial lake in North Dakota that covered most of the Province of Manitoba along with parts of Saskatchewan and Ontario and extended as far south as eastern North Dakota and northwestern Minnesota (fig. 1)? There are hundreds of feet of glaciolacustrine sediments right beneath our feet in the shallow subsurface of the Red River Valley, and there are numerous former beaches, lakeshores, deltas, and drainage features identified by geologists over the years (Holland, 1957). There are also several microrelief geomorphic features, like ice-drag marks (fig. 2), left behind in the glacial lake sediments from the bottom (sometimes called the keel) of icebergs dragging across the shallow lake bottom (fig. 3). These features were recognized and described by North Dakota Geological Survey geologists over 50 years ago (Clayton and others, 1965).

Ice-drag marks have been mapped in North Dakota within the offshore lake sediments in five of the nine counties in the Red River Valley and include: Pembina, Walsh, Grand Forks, Traill, and Cass. No ice-drag marks have been mapped in Richland County (fig. 2), in the southeast corner of the North Dakota portion of the Red River Valley.

FIGURE 1.
Glacial Lake Agassiz at its maximum extent flooded 110,000 square miles mostly in Canada, extending to the west into Saskatchewan and south into North and South Dakota and Minnesota. Although the lake is understood to have never occupied this large expanse at any single time, its existence and great expanse can be deduced, as geologists do, from the landforms and sediments left behind.

These features are revealed in detail when coupling aerial imagery (fig. 4) and contemporary (Maike, 2016) LiDAR elevation data (fig. 5). It is conceivable that this dense scratchwork pattern records ice breakup behind the lake during the last recession of glacial ice around 9,000 years ago (Arndt, 1977).

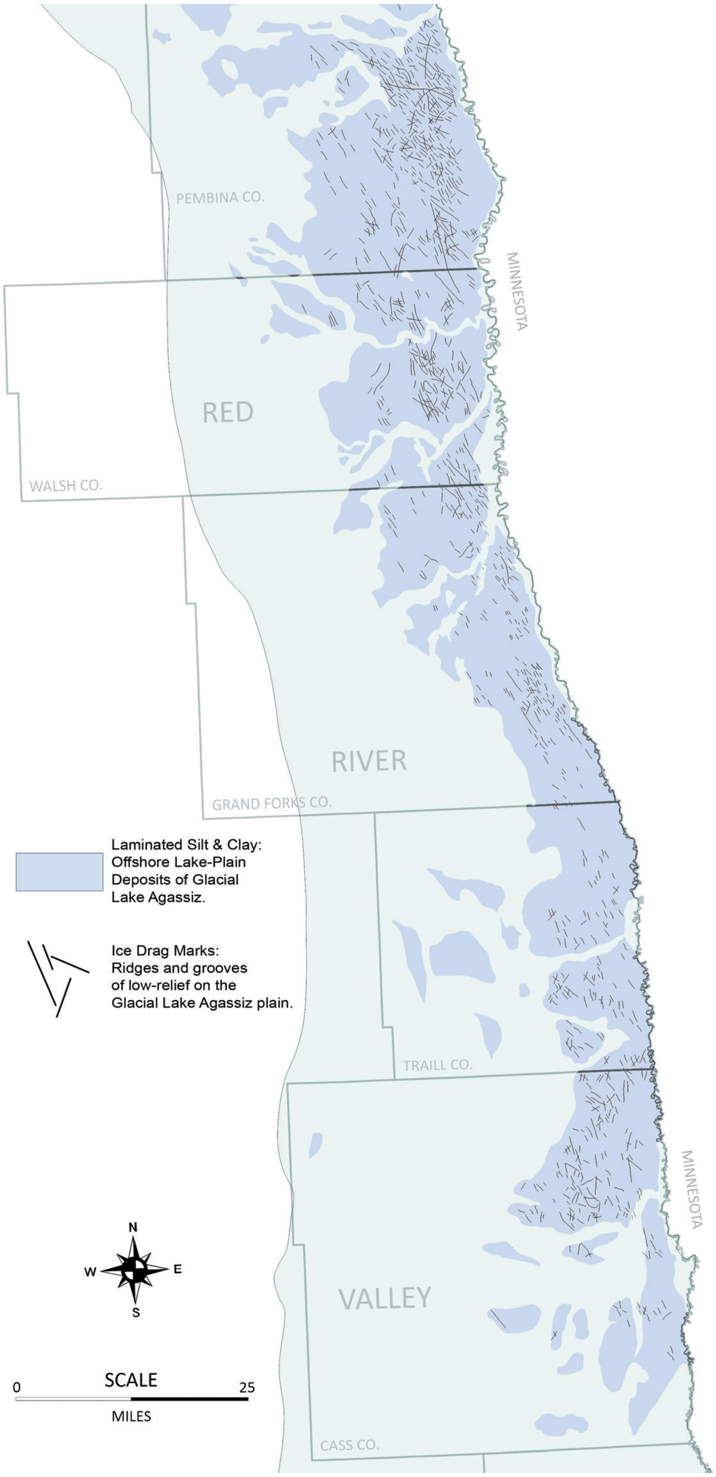

FIGURE 2.
Ice-drag markings mapped in North Dakota (from Clayton and others, 1980). There are no ice-drag marks mapped in Richland County, presumably due to the relatively small amount of soft glacial lake offshore sediments present which are required to preserve these types of features. Southeastern and northeastern directional trends are observed consistently in these features.

A fundamental concept in geology is the principle of Uniformitarionism, or in more simple terms "the present is the key to the past." With this concept in mind, geologists look for modern comparisons or analogs to help explain physical features and landforms that we find throughout the geological record. An example that compares quite well to our Lake Agassiz ice markings is revealed in recently published seafloor mapping studies from offshore

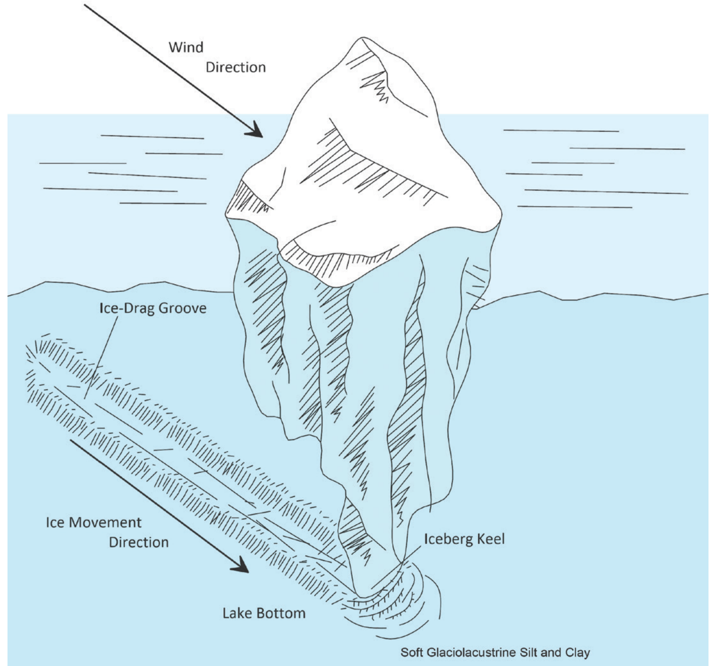

FIGURE 3.
Suggested mechanism of ice-drag mark formation on the bottom of Glacial Lake Agassiz. As the wind pushes the iceberg along in the water the keel of the submerged portion of the iceberg in contact with the soft lake bottom sediments cuts its own groove along a path that reveals past wind directions on the lake.

FIGURE 4.
Ice-drag marks shown in digital aerial imagery from northeastern Pembina County in northeastern North Dakota are a striking feature as seen by air. On the ground these features are virtually indistinguishable to the casual observer.

Svalbard, a Norwegian island archipelago in the Arctic Ocean (Dowdeswell and others, 2016) where similar looking iceberg-drag marks are found on the modern seafloor (fig. 6).

CHARACTERISTICS OF LAKE AGASSIZ ICE-DRAG MARKINGS

In the Red River Valley, our interesting ice-drag markings can stretch for tens of miles and tend to trend in northwest to southeast orientations along with intersecting marks in southwest to northeast orientations. There are also a few curvilinear features which trend from the south and then loop back to the north suggesting changing weather patterns and wind directions on the lake (Clayton and others, 1965). Using the principle of cross-cutting relationships, several of these marks show relative age differences between the ice-drag markings. However, the cross cutting does not appear to follow any specific directional relationships as many of the southwest trending ridges and grooves are crosscut or appear contemporaneous with southeast trending features, and vice-versa (fig. 7).

Most of the ice-drag markings appear to surround some of the areas that show wave-modified bedforms, suggesting that these ice-drag markings occurred later, presumably as the lake ice was entering the open water during glacial recession along the ice-margin. Some of the ice-drag features cross-cut one another which provide clues as to relative ages between different features although some appear to have occurred at roughly the same time.

These subtle microrelief features are on the order of just a few feet in local relief (fig. 8) and are nearly indistinguishable from a ground-based observer's perspective.

A statistical analysis of the lengths of 976 mapped ice-drag features indicates that these features range from 0.36 to 16.04 miles in length with a mean of 1.55 miles.

FIGURE 5.
National Agricultural Imagery Program (NAIP) aerial imagery overlain on LiDAR surface model displays linear ice-drag marks in the left section of land with the sinuous wave-modified bedforms in the adjacent section. The northwest to southeast orientation of the ice-drag markings suggests similar wind directions. The wave-modified bedforms in the section of land at right suggest offshore wave activity perpendicular to the emplacement of Lake Agassiz beaches-oriented northwest to southeast.

Over 82% or 804 of these marks are less than two miles in length (fig. 9). The distribution of the measurements of these trends is log-normal which is a numerical characteristic of the measurement of natural geologic features (Koch and Link, 1980), which further supports that these are indeed natural and not artificially interpreted features. A directional

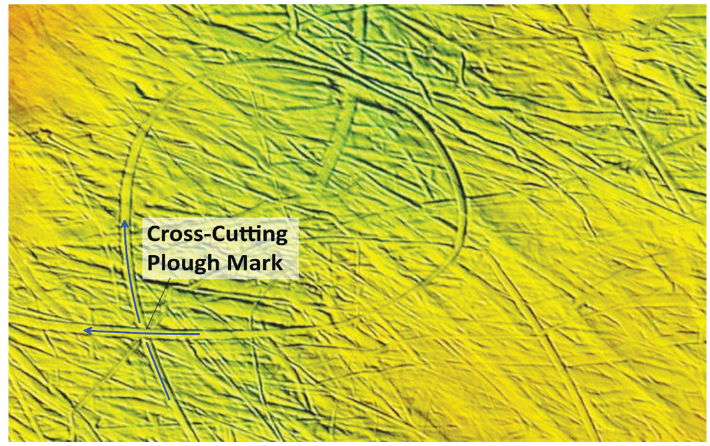

FIGURE 6.
Markings on the seafloor of the Arctic Ocean near Svalbard, Norway. These features, called iceberg plough marks, exhibit remarkably similar groove and ridge patterns to Lake Agassiz ice-drag markings. Using the geologic principle of cross-cutting relationships, we can see that one of these icebergs had traveled in one direction (towards the top of the image) first, and then turned around in a big circle reversing its path and finally moved off in another direction (towards the left of the image) cutting across its previous track.

FIGURE 7.
LiDAR elevation map with draped NAIP imagery from 2016 showing intersecting ice-drag marks in Pembina County, North Dakota. Several older north-south trending ice grooves at this location are cut through by a younger east-west trending singular groove suggesting a possible change in lake ice conditions.

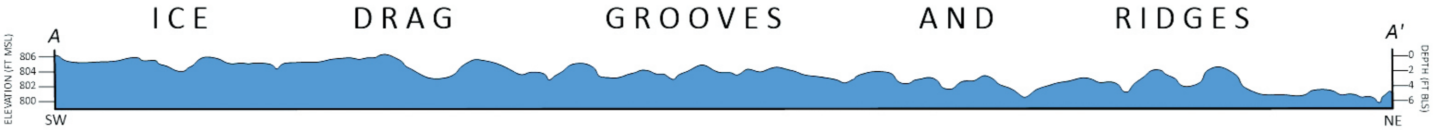

FIGURE 8. Topographic section A to A' from LiDAR surface model of the ice-drag features noted in Figure 5. Local relief on these grooves and ridges is only a few feet. This profile has been considerably stretched or exaggerated in the vertical scale to visualize these micro-relief features as the horizontal distance depicted here is over a mile.

analysis of 976 ice-drag markings as mapped by Clayton and others (1980) reveals two dominant trends (fig. 10). A large primary (1°) trend-oriented northwest to southeast (S 44° E) and a much smaller secondary (2°) trend-oriented southwest to northeast (N 36° E).

DISCUSSION

Using a southward notation for the primary directional trend assumes that ice-movement directions would have been towards the south-southeast, away from the main ice body to the north in the direction of prevailing winds, which are assumed to be from the northwest to the southeast. The smaller secondary directional trend towards the northeast may be the result of changing wind patterns from a more southward direction. The relationship of these two groups suggests two or more dominant ice breakup events occuring on the lake just prior to the final lake recession.

More in-depth studies of these fascinating micro-relief structures are now possible with the increased availability of LiDAR maps and data products, and may help to reveal several new insights into the history of this expansive glacial landscape.

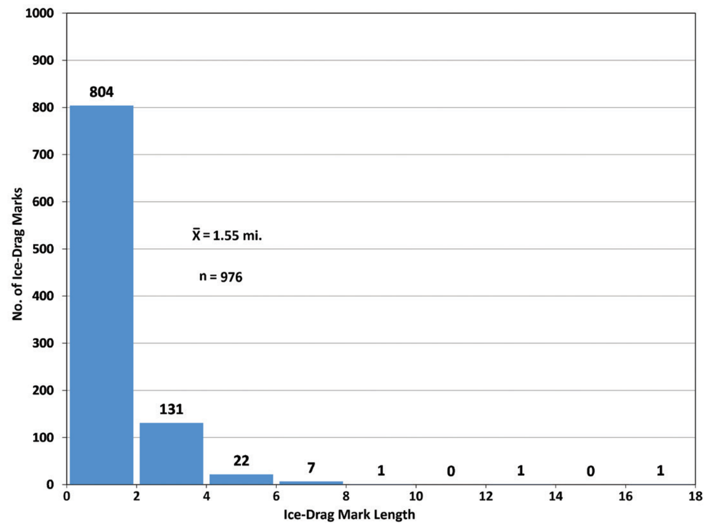

FIGURE 9.
Distribution of ice-drag mark lengths mapped in offshore sediments of the former Glacial Lake Agassiz in North Dakota. Most of these linear features are less than two miles in length and follow a lognormal distribution which is a numerical characteristic of the measurement of natural features.

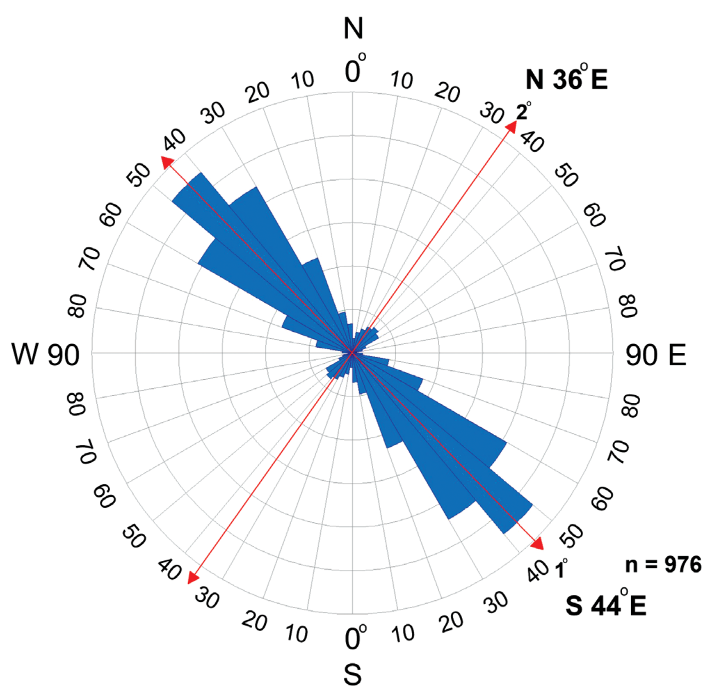

FIGURE 10.
Frequency rose diagram of the orientations of 976 mapped ice-drag features on the Glacial Lake Agassiz plain. A dominant southeastern trend and smaller northeasterly trend are revealed in this data.

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