Cosmogenic ^{36}Cl Dating of Late Pleistocene Glacial Deposits in Southwestern North Dakota

By Lorraine A. Manz

Scattered boulders and a veneer of glacial deposits indicate that areas southwest of the Missouri River in North Dakota were glaciated prior to, or during, the Wisconsinan Stage (90,000 – 10,000 years ago). At least three distinct presumed pre- or Early Wisconsinan advances have been identified (fig. 1). The oldest of these, referred to as the Dunn Glaciation, marks the apparent limit of glaciation in southwestern North Dakota. A second glacial margin to the northeast defines the maximum extent of the Verone Glaciation. An absence of glacial landforms and the patchiness of glacial sediment within this zone suggest that both events may be pre-Wisconsinan in age. The third event, or Napoleon Glaciation, is characterized by a thin cover of glacial sediment draped over, but not significantly modifying the pre-glacial topography. A fairly well-integrated drainage pattern and limited evidence of constructional topography indicate that Napoleon sediments are significantly older than those of known Late Wisconsinan age to the north and east, but not as old as Dunn or Verone deposits. The Napoleon Glaciation is therefore considered to be Early Wisconsinan.

No reliable dates are available for these glaciations. Boundaries between successive episodes have been allocated primarily on the basis of boulder distribution and surface morphology (Clayton, 1969, Bickley, 1972). Such age estimates are tentative at best, and a need still exists to accurately place these early glacial events within an absolute temporal framework. The results of such a study would be useful in improving the understanding of the Quaternary climatic cycles of the central and northern Great Plains, and would also provide a means of correlating these early glacial advances with others of known age in North America.

The cosmogenic ^{36}Cl dating method (Gosse and Phillips, 2001; Manz, 2002) was used to determine the exposure ages of glacial erratics between the Dunn and Verone ice margins, and thus the timing of the maximum extent of glaciation in North Dakota. ^{36}Cl dating is one of several methods that rely upon the accumulation of cosmogenic nuclides in geologic materials at or near the earth's surface (Gosse and Phillips, 2001). The method is based on the understanding that most cosmic rays do not penetrate more than 1-2 meters into the subsurface. Thus, under conditions of deep burial (> 1-2 m) followed by rapid surface emplacement through glacial excavation and deposition, for example, (i.e. assuming an initial concentration of zero) the buildup of cosmogenic nuclides in surface rocks is a function of exposure time, and hence the age of the landform or geomorphic feature on which they reside.

The selected study area lies in southeastern Grant County, approximately 50 miles (80 km) southwest of the

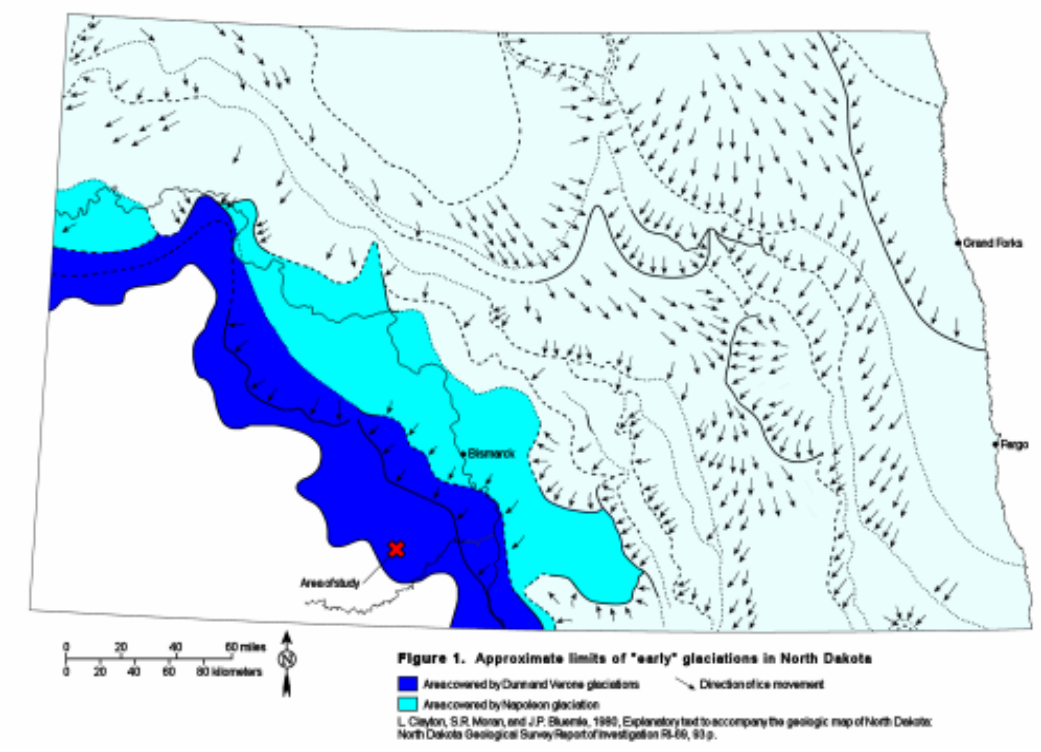

Figure 1. Approximate limits of "early" glaciations in North Dakota

Area covered by Dunn and Verone glaciations

Direction of ice movement

Area covered by Napoleon glaciation

L. Clayton, S.R. Moran, and J.P. Bluemle, 1980, Explanatory text to accompany the geologic map of North Dakota: North Dakota Geological Survey Report of Investigation RI-69, 93 p.

city of Bismarck and the Missouri River, and a few miles east of the maximum limit of glaciation (fig. 1). This places the site within the boundaries of the oldest of the three undated glaciations (Dunn Glaciation). The site consists of a line of well-defined, grassy ridges, or buttes, that rise to a height of about 160 feet (50 m) above the surrounding countryside, or about 2,450 feet (1,530 m) above sea level. The southern portion trends roughly NE/SW, then makes an abrupt 90° turn to the northwest. The ridges are cored by the Paleocene Cannonball Formation (Carlson, 1982), which comprises a series of interbedded, marine shoreline and offshore yellowish-brown sand and gray to brownish-gray silt and shale. However, the crests and slopes are littered with glacial erratics (fig. 2).

Figure 2: Boulder-strewn hillside within the study area.

Approximately 90% of the larger erratics are of Canadian Shield (igneous and metamorphic) provenance, the remainder being made up of carbonates and local bedrock. Several erratics displayed clear evidence of subglacial transport in the form of planed surfaces and striae. Two disused gravel pits a short distance below the ridge crests revealed a thin mantling of yellow-brown oxidized till that extended to a depth of several feet (the actual thickness was not determined).

Seven erratics, all located at the northwestern end of the ridge line, were selected for sampling according to established protocols (Zreda and Phillips, 1994). Samples (approx. 500g) were collected from the upper 2 inches (5 cm) of the top surfaces of the erratics by hammer and chisel. All the erratics sampled were extremely hard and required considerable effort on the part of the collectors. The dimensions of each erratic were noted, and its location and elevation obtained using a portable GPS unit and local 1:24,000-scale topographic maps. The angle to the horizon (è) and bearing (ö) were measured to determine the topographic shielding correction factor. The degree of weathering was noted. In all cases this consisted of a thin oxidation rind not more than a few millimeters thick.

The chlorine in the samples was extracted and analyzed as isotopically diluted silver chloride with ^{35}Cl as the internal standard. Chlorine isotope ratios were measured by accelerator mass spectrometry at the Lawrence Livermore National Laboratory, University of California. Ages were calculated as a function of erosion rate over a range from 0 mm/kyr to 5 mm/kyr. The results are summarized in Table 1 and in Figure 3.

Uncertainties (in parentheses) are one sigma, and are based only on the analytical uncertainties in the AMS measurements.

The tight clustering of ages within the 0-1 mm/kyr erosion rate range suggests that these values are the most accurate, and that none of the erratics have been subjected to prior burial. The former statement is supported by the apparent freshness of the erratics' surfaces (presence of glacial markings and an overall lack of significant weathering). Thus, with one exception, the samples yielded ages that fall within a remarkably narrow range between 25,000 and 28,000 years before present (b.p.) Such consistency also indicates that these ages are also probably very close to the time of emplacement of the erratics, that is, the actual (calendar) age of the moraine.

Sample GRT6 is an outlier. Since the AMS results show that its anomalous age (40.0 ± 1.40 kyr) is not the result of ^{36}S interference the most likely explanation is that GRT6 was exposed to cosmic radiation at some time prior to emplacement.

The ^{36}Cl ages show that the three undated glacial advances in southwestern North Dakota are considerably younger than was previously thought, falling within an early phase of the Late Wisconsinan substage. They also indicate

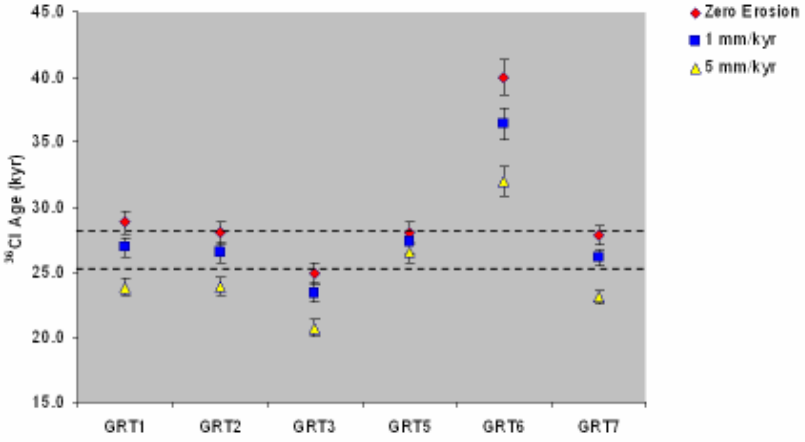

Figure 3: ^{36}Cl ages of glacial erratics on the Grant County moraine.

Sample I.D.	Rock Type	ε_1 (mm/k.a.)*				Minimum Age (k.a)
		0	1	2.5	5	
GRT1	Granite	28.8 (0.87)	26.9 (0.77)	25.2 (0.70)	23.8 (0.66)	23.8 (0.66)
GRT2	Granite	28.0 (0.85)	26.5 (0.77)	25.1(0.71)	23.9 (0.68)	23.9 (0.68)
GRT3	Granite	24.9 (0.85)	23.4 (0.75)	22.0 (0.69)	20.7 (0.64)	20.7 (0.64)
GRT5	Granite	28.0 (0.88)	27.3 (0.84)	26.8 (0.82)	26.5 (0.83)	26.5 (0.83)
GRT6	Granodiorite	40.0 (1.40)	36.4 (1.20)	33.8 (1.10)	32.0 (1.10)	32.0 (1.10)
GRT7	Granite	27.8 (0.69)	26.1 (0.61)	24.5 (0.56)	23.1 (0.52)	23.1 (0.52)

* $\varepsilon_1 = \frac{1000\varepsilon}{\rho}$

where ρ = rock density; ε = erosion rate in g/cm^2 yr.

Table 1. Cosmogenic ^{36}Cl ages for Grant County samples as a function of rock erosion rate. All ages are expressed in kyr.

a very rapid and much more extensive expansion of Late Wisconsinan ice across the state. In other words, the ice margin that marks the limit of the Dunn Glaciation appears to coincide with the maximum extent of Late Wisconsinan ice.

A glacial maximum so early in the last major southward expansion of ice is surprising, but not implausible, and there is evidence to support its timing. The ^{18}O record from foraminifera in the Sulu Sea in the western North Pacific (Linsley, 1996) shows initiation of an increase in ä^{18}O, marking the beginning of marine isotope stage 2 (MIS2) at about 30,000 ^{14}C years ago[q]. This is followed by a plateau, then a major rise at about 27,000 ^{14}C years ago that goes right into the last glacial maximum.

According to a calibration of the ^{14}C timescale prior to 20,000 years ago by Hughen and others (2004) 30,000 ^{14}C years corresponds to about 35,000 calendar years, and 27,000 ^{14}C years to about 32,000 years. Thus in terms of calendar years, MIS2 started between 35,000 and 32,000 years ago. Since the ^{36}Cl ages appear to be close to the calendar scale, this would have allowed about 8,000 years for ice to advance from wherever it was during MIS3 to the Grant County moraine.

Recent compilations of ^{14}C dates for Illinois and Wisconsin (Clayton and others, 2001) show that ice was actively advancing into the Lake Michigan Lowland 27,000 years ago. In addition, wood in buried tills at two locations in North Dakota (one in Ramsey County, and the other in Ward County) were ^{14}C dated by the US Geological Survey at 28 kyr (Moran and others, 1973). Both wood samples were collected from till that was overlain by at least two younger tills. In Minnesota and other parts of the Midwest a number of tills previously mapped as Early Wisconsinan are now being reinterpreted as Late Wisconsinan (Hobbs, 2005).

The erratics are direct ice deposits. There is no evidence to indicate they were emplaced by ice rafting or a catastrophic flooding event associated with an ice margin further to the northeast.

The main factors that argue against a maximal advance at 28,000 years are the patchiness of the glacial deposits in this part of North Dakota and the general absence of glacial landforms. In addition, as Clayton (1969) points out, there is no evidence that a glacial diversion channel ever existed west of the Dunn ice margin to carry water from the upper Missouri drainage. The topography in Grant County, like most of that in southwestern North Dakota is dominated by bedrock topography, typically consisting of rolling to hilly plains, buttes, and a fairly well-integrated drainage pattern.

In conclusion, it is my belief that the ^{36}Cl ages of the Grant County erratics are accurate, and are close to the true age of the event that emplaced them. The position of the erratics suggests a glacial event rather than ice-rafting or catastrophic flooding. A Late Wisconsinan glacial maximum at 28,000 years is plausible within the constraints of recently revised ^{14}C and ^{18}O records, and regional radiocarbon data. However, geomorphological observations tend to support the hypothesis that the Dunn erratics are remnants of a much earlier glacial episode. Reconciling such conflicting evidence will clearly require further study.

[q]Approximately 99.8% of naturally-occurring oxygen consists of the stable (nonradioactive) isotope ^{16}O. Most of the remaining 0.2% is ^{18}O, which is also isotopically stable. In the hydrologic cycle water containing lighter, ^{16}O preferentially evaporates from the oceans. When this ^{18}O-depleted water vapor falls on land in the earth's Polar Regions it is locked up as ice and thus prevented from returning to the ocean. Thus, during a glacial stage, oceanic oxygen becomes progressively richer in ^{18}O as more and more ^{16}O-enriched moisture is incorporated into the expanding ice sheets.

Marine organisms that incorporate oxygen into their calcium carbonate shells use whatever oxygen is available at the time (although some are capable of being quite selective). Consequently, changes in the $^{18}O/^{16}O$ ratio in biogenic carbonates of a given fossil organism over time reflect changes in the volume of ice on land and prevailing climatic conditions. Deviation of this ratio from an arbitrary standard is referred to as $\ddot{a}^{18}O$. Oxygen isotope studies of marine sediment cores spanning the last few million years or so have revealed a number of $\ddot{a}^{18}O$ maxima and minima, each one designated, in sequence with 1 as the most recent, a marine oxygen isotope stage (MIS) number. Cold (glacial) periods correspond to even-numbered stages, (high $\ddot{a}^{18}O$). Thus, MIS2 refers to the last major glaciation, or Late Wisconsinan Stage.

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What more can we require? Nothing but time.

James Hutton, defining uniformitarianism