SUPPLEMENTAL MATERIALS

for

A chronology for glacial Lake Agassiz shorelines along Upham's namesake transect

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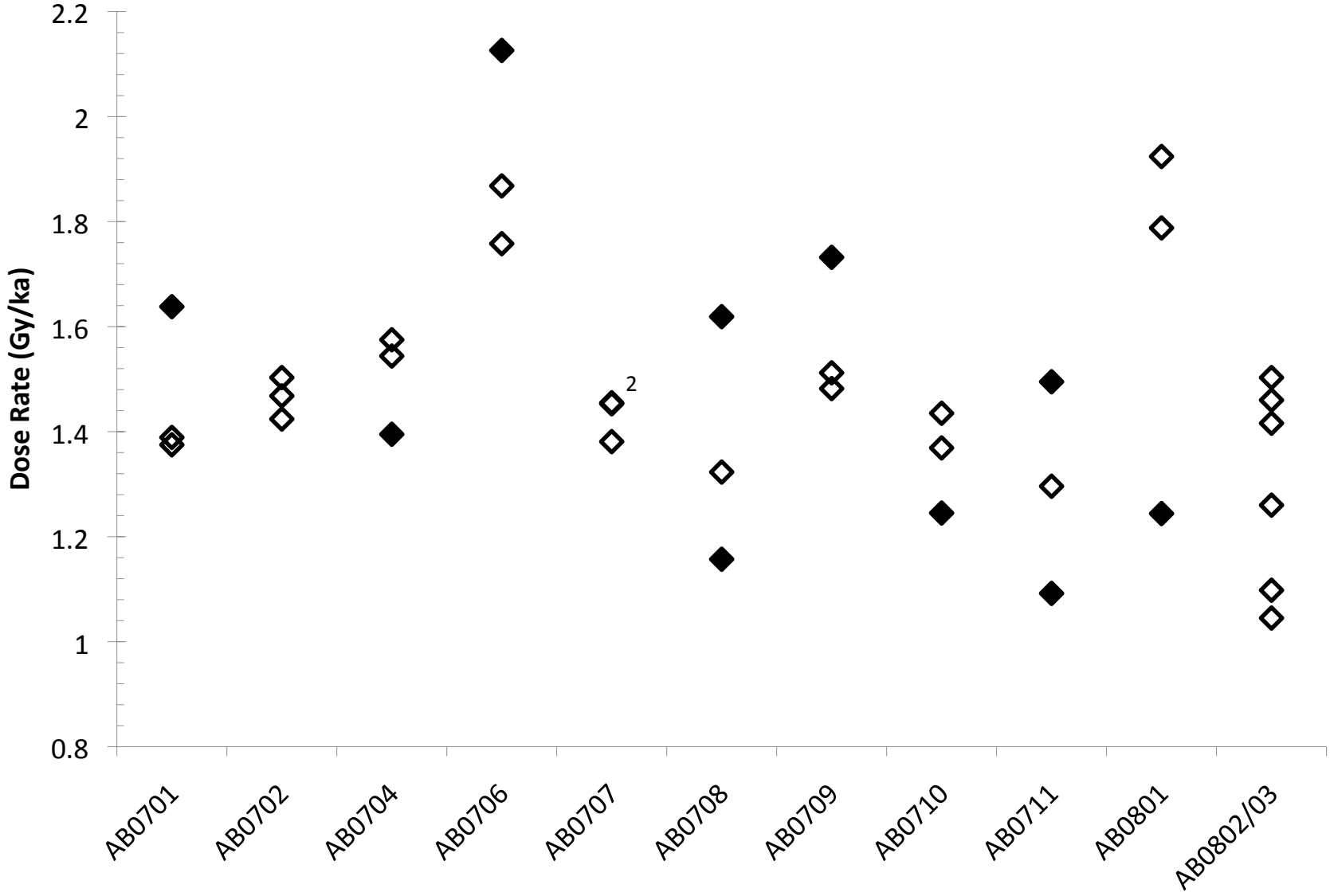
Supplemental Table S1. Dose rates, elemental concentrations of K, Rb, Th, and U determined by INAA, and other dosimetrically relevant data.

Sample ID	Depth (cm)	H2O content (%)	INAA Set#	Vial ID	[K] (ppm)	± [K] (ppm)	[Rb] (ppm)	± [Rb] (ppm)	[Th] (ppm)	± [Th] (ppm)	[U] (ppm)	± [U] (ppm)	Dose Rates (Gy/ka)
AB0701 N	56	10 ± 3	1) -- 9/2007	VII	12089	1088	36.10	4.05	2.368	0.195	1.300	0.137	1.638 ± 0.136
AB0701 N			2) -- 7/2008	X	10372	840	32.40	4.06	2.135	0.179	0.888	0.096	1.389 ± 0.111
AB0701 N			3) -- 1/2009	I	9186	698	33.70	4.41	2.692	0.226	1.111	0.116	1.375 ± 0.103
AB0702 H	137	12 ± 3	1) -- 9/2007	VIII	11485	905	38.55	3.84	2.057	0.171	1.068	0.158	1.468 ± 0.118
AB0702 H			2) -- 7/2008	II	10665	815	34.46	4.42	2.055	0.176	1.184	0.125	1.424 ± 0.108
AB0702 H			3) -- 1/2009	II	12165	1119	32.81	5.12	2.135	0.184	0.957	0.105	1.503 ± 0.130
AB0703 H	182	15 ± 3	1) -- 9/2007	X	10523	822	36.52	3.76	3.704	0.298	1.352	0.158	1.496 ± 0.110
AB0703 H			2) -- 7/2008	III	11097	950	34.64	3.89	2.864	0.235	1.030	0.108	1.424 ± 0.113
AB0703 H			3) -- 1/2009	III	11021	1009	33.84	3.87	2.260	0.189	0.982	0.103	1.371 ± 0.116
AB0704 C	63	10 ± 3	1) -- 9/2007	XI	11916	865	45.22	6.01	3.046	0.256	0.723	0.134	1.544 ± 0.119
AB0704 C			2) -- 7/2008	IV	12161	1240	45.93	6.22	3.461	0.284	0.644	0.071	1.575 ± 0.144
AB0704 C			3) -- 1/2009	IV	10413	1156	38.68	3.98	2.209	0.183	0.873	0.094	1.395 ± 0.135
AB0706 T	85	12 ± 3	1) -- 9/2007	XIII	12426	990	42.57	3.43	3.523	0.279	2.094	0.179	1.868 ± 0.135
AB0706 T			2) -- 7/2008	V	11385	911	39.02	4.42	3.238	0.265	2.071	0.199	1.758 ± 0.129
AB0706 T			3) -- 1/2009	VI	15224	1157	52.03	7.34	3.993	0.331	2.079	0.198	2.126 ± 0.154
AB0707 H	120	8 ± 3	1) -- 9/2007	XIV	10114	879	29.31	4.95	2.638	0.219	1.063	0.129	1.453 ± 0.118
AB0707 H			2) -- 7/2008	VI	9065	676	34.45	6.13	2.588	0.224	1.148	0.119	1.381 ± 0.102
AB0707 H			3) -- 1/2009	VII	10856	955	36.53	5.19	2.105	0.181	0.930	0.102	1.455 ± 0.122
AB0708 N	44	10 ± 3	1) -- 9/2007	XV	10160	838	38.01	4.52	1.740	0.151	0.756	0.121	1.323 ± 0.112
AB0708 N			2) -- 7/2008	VII	8890	749	28.79	3.79	1.290	0.112	0.627	0.061	1.157 ± 0.099
AB0708 N			3) -- 1/2009	XVIII	11838	1006	36.55	4.09	2.141	0.163	1.360	0.141	1.619 ± 0.141
AB0709 N	81	12 ± 3	1) -- 9/2007	XVI	10165	1109	41.66	9.78	3.043	0.268	1.430	0.168	1.512 ± 0.135
AB0709 N			2) -- 7/2008	VIII	11125	1117	34.85	5.19	2.578	0.217	1.061	0.103	1.482 ± 0.131
AB0709 N			3) -- 1/2009	X	11486	953	37.40	4.08	5.753	0.466	1.154	0.122	1.732 ± 0.128
AB0710 C	72	15 ± 3	1) -- 9/2007	XVII	8673	1469	38.33	3.55	2.741	0.221	1.013	0.120	1.245 ± 0.153
AB0710 C			2) -- 7/2008	I	10528	787	45.42	5.33	2.532	0.211	0.951	0.095	1.369 ± 0.103
AB0710 C			3) -- 1/2009	XI	10478	901	37.12	3.60	2.283	0.187	1.381	0.156	1.435 ± 0.115
AB0711 C	120	10 ± 3	1) -- 9/2007	XX	9645	833	34.33	3.58	2.365	0.183	0.737	0.132	1.296 ± 0.110
AB0711 C			2) -- 7/2008	XI	7264	532	31.31	3.88	2.113	0.178	0.792	0.097	1.092 ± 0.083
AB0711 C			3) -- 1/2009	XII	10736	859	31.67	4.94	3.932	0.326	0.771	0.090	1.495 ± 0.114
AB0801 T	43	12 ± 3	1) -- 9/2007	XIII	9371	1087	27.47	4.09	2.010	0.173	0.754	0.081	1.244 ± 0.125
AB0801 T			2) -- 7/2008	XII	11132	796	48.23	5.84	4.767	0.394	1.790	0.198	1.788 ± 0.126
AB0801 T			3) -- 1/2009	XIV	13179	1028	47.05	6.02	4.881	0.400	1.608	0.156	1.924 ± 0.140
AB0802 N	150	15 ± 3	2) -- 7/2008	XX	9036	672	31.72	4.99	5.834	0.474	1.302	0.138	1.503 ± 0.104
AB0802 N			3) -- 1/2009	XV	8506	834	27.55	3.31	1.478	0.127	0.838	0.092	1.098 ± 0.099
AB0802 N			3) -- 1/2009	XVI	7746	620	24.94	3.59	1.539	0.134	0.858	0.098	1.045 ± 0.084
AB0803 N	182		2) -- 7/2008	XXI	9542	718	33.85	5.48	1.898	0.168	1.123	0.125	1.260 ± 0.095
AB0803 N			3) -- 1/2009	VIII	11646	932	39.19	4.27	2.294	0.193	1.157	0.125	1.460 ± 0.114
AB0803 N			3) -- 1/2009	XVII	11904	1059	34.97	5.94	2.117	0.178	0.903	0.088	1.416 ± 0.119
KL0902 C	66	15 ± 3	4) -- 7/2009	XII	15268	1213	47.90	3.20	2.555	0.243	0.861	0.113	1.730 ± 0.140
KL0903 C	33	10 ± 3	4) -- 7/2009	XIII	11108	950	35.62	2.42	4.257	0.383	0.533	0.088	1.518 ± 0.124



Supplemental figure S1. Dosimetric variability by sample. Individual dose rate determinations for each sample are plotted. Filled black diamonds were not included in final dose rate determinations; the strategy for which is discussed in the primary text.

Supplemental Materials: Discussion of figure 6 from Elson (1967)

The interpretation of water-level changes in the Lake Agassiz basin has undergone considerable revisions over the last 45 years. To illustrate, we discuss the data used in constructing the first diagram we are aware of to synthesize the various water levels into an absolute time scale (Fig. S2). It is figure 6 from Elson (1967) with a time scale in radiocarbon years (Fig. S2), whereas in Figure 6 of the present paper it is shown with a calibrated time scale. Note that Elson indicates in the original figure caption that this diagram underwent revision as it was being published.

Nevertheless this is the starting point for all subsequent water-level interpretations. The various water-level interpretations underwent, in our view, modifications for two reasons. First, early radiocarbon dates, such as those obtained by the solid carbon method, may not have been consistent even though they represented the same event. Multiple dating of stratigraphic intervals was resource intensive and any age obtained was given equal weight. For example, in Figure S2 the context of W-723 was interpreted as recording a low water level. Additional analyses from nearby sites (within several hundred meters) with very similar stratigraphic sequences were also interpreted as recording low water levels. However, the other sites had different apparent ages (e.g., W-900 and W-1005), thus the water level curve was portrayed as having two low levels although Elson (1967) may have had some doubts, as indicated by the dashed line (Fig. S2).

The second reason may have to do with the assignment of a water level from a given age. In the original data set (Table 6 in Elson, 1967) several ages (e.g. W-1360, W-1361) are reported to be organic layers below a thick gravel unit. Originally these were taken to represent the time water stood at beach elevation. An alternative view is that these ages are maximum brackets for

the strandline. That is the beach formed and accumulated after the age of material in the organic layer, thus the organics represent a time when the water level was lower than the subsequent strandline. In some cases the temporal difference may be small, but in other cases perhaps significant.

To provide context for the current work we have replicated Table 6 from Elson (1967) and added a second set of notes that discusses how each individual sample might be viewed in the context of more recent work (Table S2). This is not intended to be a review of all of the radiocarbon ages defining water levels in the Lake Agassiz basin. We note specifically that most of the ages come from one of two stratigraphic settings. The first as limiting ages for the Moorhead low water Phase, and second as lagoonal deposits associated with the Campbell strandlines during the Emerson Phase. To our knowledge there are no radiocarbon ages that constrain the Herman, Norcorss, or Tintah levels. A comparison between OSL and radiocarbon ages for the Campbell level can be found in Lepper et al. (2011).

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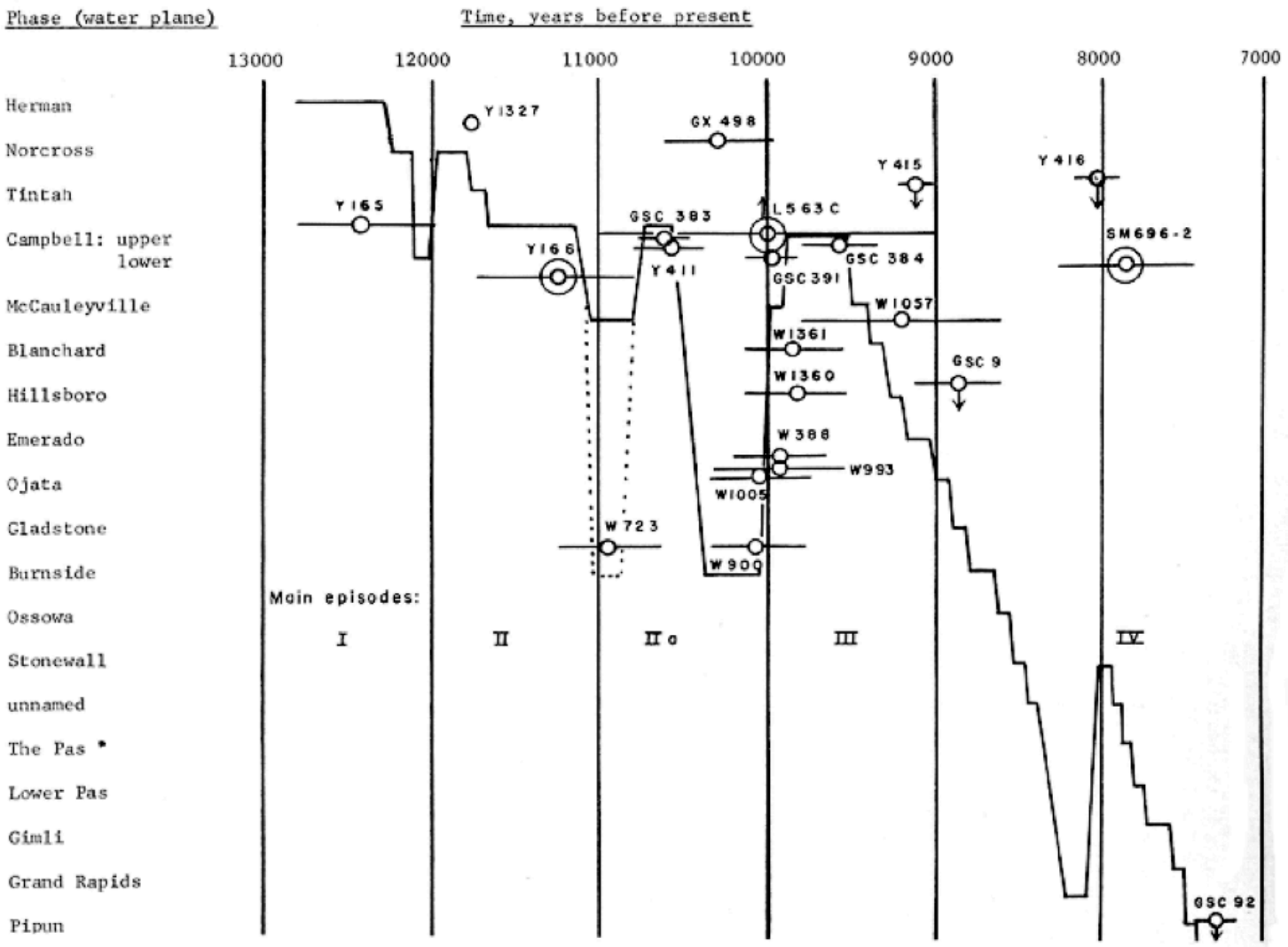


Figure 6. Hypothetical sequence of water levels of Glacial Lake Agassiz. (Note: This figure has been revised since the accompanying text was written and shows five main lake episodes rather than the four described.)

Supplemental figure S2. Figure 6 of Elson (1967)

Table S2. Replicated *"Dates directly related to Glacial Lake Agassiz"* section from table 6 of Elson (1967) with updated analysis of radiocarbon dates.

Sample Number	^{14}C Age Yrs BP	Location Lat.	Long.	Notes (Elson, 1967)	Notes (this paper)
Y-165	12,400±420	49°47'	98°35'	Rossendale, Man., peat in alluvial fill. Science 122, 457.	This site lies in a lagoon setting behind the Campbell beach which is cut into the Assiniboine delta. Two subsequent investigations, Teller (1989) and Boyd (2006) have found younger ages in the same stratigraphic context and rejected this age. Since the lagoon could not have accumulated until after the beach formed, this is minimum age for the beach.
Y-1327	11,740	-	-	Below Herman beach in NW Minn. Wright & Frey, 1965, Quarternary of U.S.A., p. 39.	Clayton and Moran (1982) note that the age is from organic sediment and thus likely to be contaminated with older carbon.
Y-166*	[11,230±480]	49°44'	98°34'	Rossendale, Man., clam shells in alluvial fill. Science 122, 457.	See notes on Y-165.
W-723	10,960±300	47°56'	97°22'	Grand Forks, N.D., wood in sand overlying till. Radiocarbon Supplement 2, 152.	This age comes from wood on sand in a drainage ditch open in 1958. The sample is reported to be overlain by 10 ft of silt and sand and underlain by till (Meyer and Alexander, 1960). The age was replicated (10,820±190, TAM-1; Moran et al. 1973) indicating it is not contaminated. Moran et al. 1973 report three additional ages from nearby excavations but they are all younger (10,080±280, W-900; 10,050±300, W-1005; 10,340±170, I-5213; some noted below) and the set is taken as a time when water was at or below the "Ojata" level. The context of the sample indicates a exposure and then burial of the till surface. A new excavation in the same area (Fig. 1, Fisher et al. 2008) refined the earlier stratigraphy (Fig. 3) recovered another 20 radiocarbon ages. The context of the sample indicates a exposure and then burial of the till surface. One is nearly 40 ka, another is similar in age to W-723 (10,710±75, ETH-32674) but the other 18 ages range from 10,520±70 to 10,080±75 (Table 2). Taken together this suggests that W-723 is a outlier perhaps transported into this setting by a small stream that flows near by (Fisher et al. 2008).
GSC-383	10,600±150	49°46'	98°45'	Lavenham, Man., marl from valley fill. Publication pending; Radicarbon 9.	Elson (1967) notes this is from alluvial fill deposited after downcutting resulting from falling water levels. Thus is must be a minimum age on falling water levels. This is similar setting that produced ages Y-165 and Y-166 but they may be different ages.
Y-411	10,550±200	49°46'	98°45'	Lavenham, Man., wood from valley fill locality of GSC-383. Science 126, p. 912.	See notes on GSC-383.
GX-498	10,310±260	48°05'	93°30'	Koochiching Co., Minn. Peat from base of raised bog. Radiocarbon 8, p. 144.	This location information plots in the middle of a large bog. It is about 14 km NW of the Myrtle Lake site investigated by Janssen (1968). Although it is not possible to determine if this is the same site, both locations have the same significance for water levels of Glacial Lake Agassiz. The peat materials accumulated after the lake drained below the level of the peat (approximately 390 m at the location given here).

Table S2. Continued.

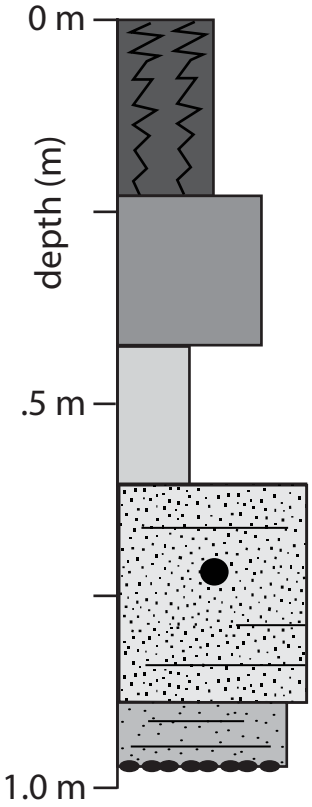
Sample Number	^{14}C Age Yrs BP	Location Lat.	Long.	Notes (Elson, 1967)	Notes (this paper)
W-900	10,080±280	47°50'	97°20'	Grand Forks, N.D., wood in sand. Radiocarbon Supplement 3, 88.	This sample was collected in a drainage ditch about 300 m south of the location of W-723 (Clayton, personal communication) but is also reported in Moran et al. (1973). It likely comes from the same buried organic unit and illustrates the difference in ages present in this unit. See notes on Y-723.
W-1005	10,050±300	47°46'	97°07'	Thompson, N.D., wood in gravel. Radiocarbon 6, 47.	Clayton and Moran (1982) report that this age comes from wood in beach that is about 40 m below the Campbell level in North Dakota. Moran et al. (1973) note the wood sample is abraded and is attributed to a low phase of Lake Agassiz. Sample may be driftwood (Ives et al., 1964). See notes on Y-723.
L-563c	10,000±1000	48°49'	91°39'	Steeprock Lake, Ont. disseminated carbonated in varved clay. Radiocarbon Supplement 3, p. 145.	Other than the report in Radiocarbon, which gives additional information besides that presented here, the ages does not appear to be discussed in the literature again. That the age is on disseminated carbonate likely means it is not closely related to water level.
GSC-391	9,990±160	49°00'	95°14'	Buffalo Point, Man., wood in gravel. Publication pending; Radiocarbon 9.	Taken as the start of the Emerson Phase when the water level rose after a low stand of the lake (Clayton and Moran, 1982). One of many similar ages. See Fisher et al. (2008) for a partial listing of similar ages.
W-388	9,930±280	-	-	Moorehead, Minn., wood in clay. Science 127, 1478.	This site lies on the Red River in the town of Moorhead and shows a “peat” layer between glaciolacustrine silts. This is known as the Mirror Pool site. Multiple occurrences of this terrestrial organic material between clays have become known as the Moorehead low. McAndrews reported the first radiocarbon ages (C-497 and W-388) from this unit. Recent studies by Yansa and Ashworth (2005) at another section nearby (Trollwood) provide additional insights to the paleoecology. However the context and dating support the interpretation of a low water phase.
C-497*	[11,283±700]	-	-	Libby, 1955, Radiocarbon Dating, p. 121.	Same site as W-388. Sample processed by the solid carbon method which is not considered reliable.
W-993	9,900±400	46°55'	96°45'	Fargo, N.D., wood below 28 ft. clay and silt. Radiocarbon 6, 45.	Wood from swamp deposits on top of a delta deposit buried by laminated clay and silt. This is the Seminary site of McAndrews (1967). Taken as near the end of the low water phase (Moran et al., 1973). See also W-388
W-1361	9,820±300	47°37'	97°10'	Blanchard beach, N.D., wood. Radiocarbon 7, p. 378.	Wood from organic rich sand and gravel taken to date the rise of water level. This is associated with the Blanchard Beach (Moran et al., 1973). See also W-1360.
W-1360	9,810±300	47°38'	97°05'	Hillsboro beach, N.D., wood. Radiocarbon 7, 378.	Wood from interval containing waterworn branches taken to date the rise of water level. This is associated with the Hillsboro Beach (Moran et al., 1973). It is near, but at a different site than W-1360.

Table S2. Continued.

Sample Number	^{14}C Age Yrs BP	Location Lat.	Long.	Notes (Elson, 1967)	Notes (this paper)
GSC-384	9,580±220	48°33'	93°29'	Roddick Tp., Ont., carbonaceous matter in marl under bench gravel. Publication pending.	Dated material described as being from foreshore/ shallow littoral deposits (Zolti, 1969). This would date shallow water above the sampling location.
W-1057	9,200±600	48°53'	95°03'	Lake of the Woods, Minn., wood from beach. Radiocarbon 6, 44.	Tamarack wood from peat below 20 ft of sand and gravel (Ives et al. 1964). Taken as beach ridge, but stratigraphy suggests it is below the beach ridge.
Y-415	9,110±110	49°40'	99°33'	Treesbank, Man., wood. Science 126, 913.	Basal wood enclosed in silty sand overlying sand and gravel over till. The sample is overlain by sand containing a soil. The wood-bearing sand is being part of the Assiniboine Delta (McNeely and Nielsen, 2000). This sets up an apparent conflict as noted in Y-165. Recent work (Teller, 1989; and Boyd, 2006) suggests the beach laying on the delta is older than this age.
GSC-9	8,860±250	51°26'	93°43'	Nungesser Lake, Ont., gyttja below alt. 1335'. Radicarbon 4, 18.	The sample underlies a peat sequence and overlies sand, but nearby the bog sediments overlay glacio-lacustrine clayey silt. The location is the northern portion of the Lake Agassiz basin. Taken as indicating a time when the water levels fell (Dyck and Fyles, 1962).
Y-416	8,020±100	49°37'	99°26'	Stockton, Man., wood and peat. Science 126, 913.	The stratigraphy and interpretation is similar to Y-415 but a different site.
SM-696-2	7,861±423	49°02'	94°18'	Morson, Ont., organic carbon from antler in wave-formed terrace. Can. Jour. Earth Sciences 2, 238.	The nature of the antler sample makes a firm age assignment problematic.

*Ages reported in [ ] are determined with the solid carbon technique and are generally not considered reliable.

Christianson Site (AB0710)



"A" Granular, black clay loam

"B" Dark gray, sandy loam

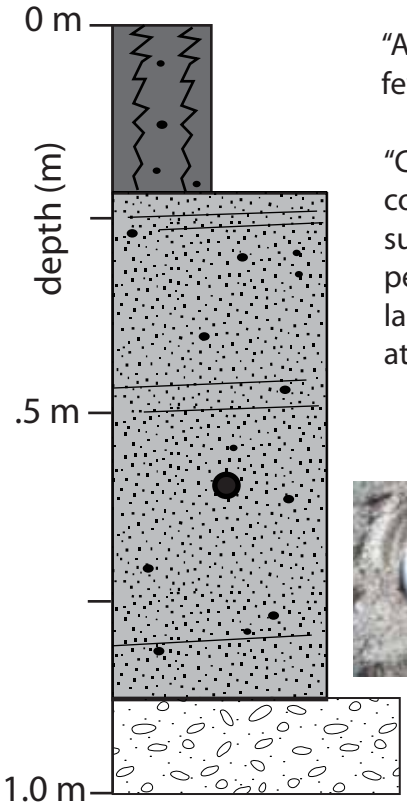
"C1" Light gray, pebbly clay

"C2" Yellowish brown, medium sand with pebbles; weak planar bedding

"C3" Light gray, very fine sand; weak planar bedding, cobble lag at base of pit

OSL sample

Bertelsen Site (AB0704)

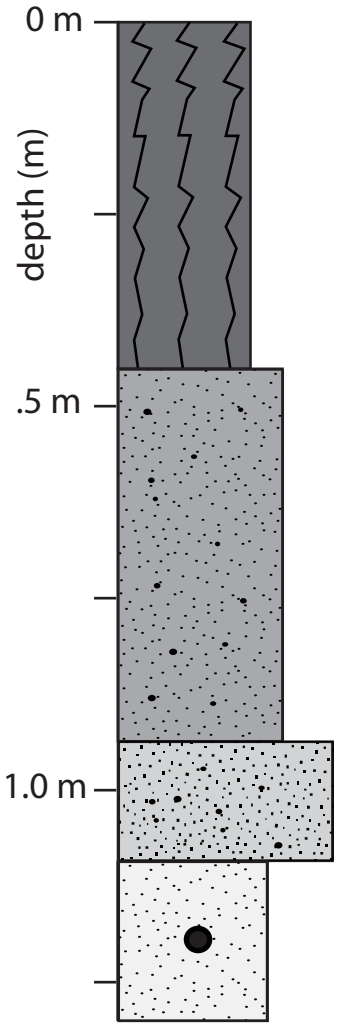


"A" Black loam with few pebbles

"C1" Poorly sorted coarse sand, with subangular/subrounded pebbles; planar laminations dip SSE at low angle

"C2" Pebble & cobble gravel

Pleasant Hill Cemetery (AB0711)



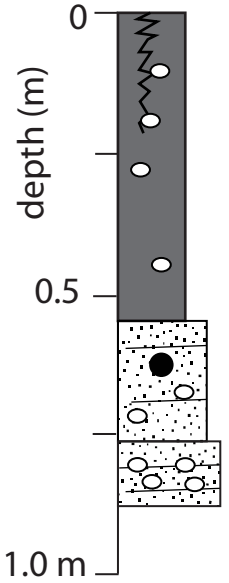
"A" Dark brown, sandy loam

"B" Sandy loam, with medium pebbles

"C1" Yellow gravelly sand; poorly sorted

"C2" Light brown, fine sand

Harris Twin Ridge (KL0902)

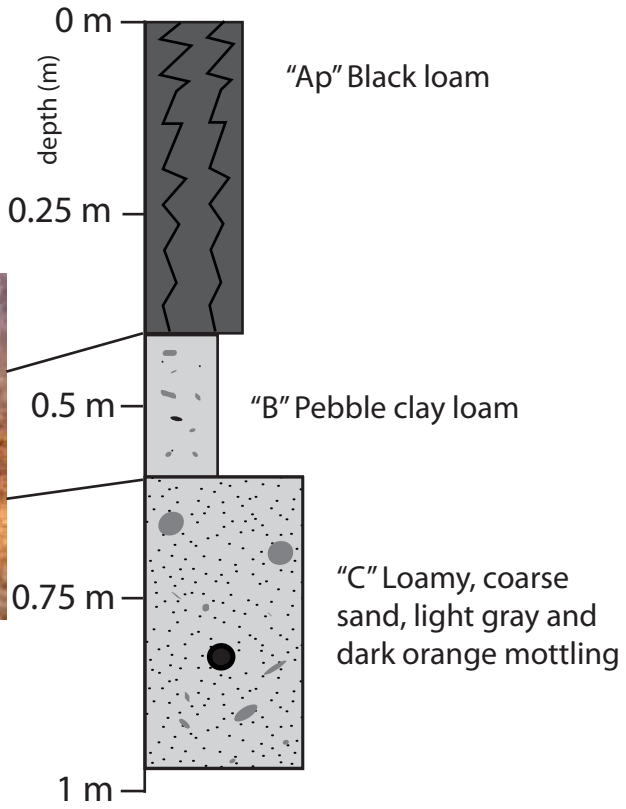


"A" Black, sandy loam; small pebbles and dark brown sand lenses

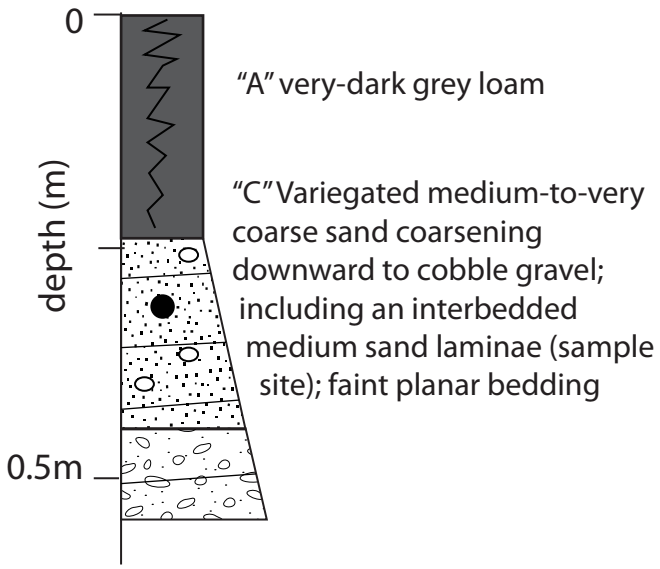
"B" medium sand; pebbles and faint planar bedding

"C" Pinkish-gray, planar bedded, pebbly medium-to-very coarse sand

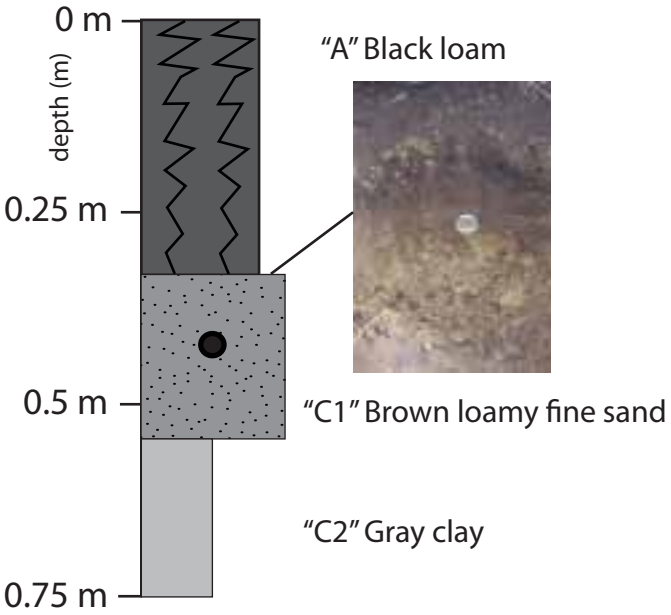
Hawes Silo (AB0706)



Badger Hill (KL0903)

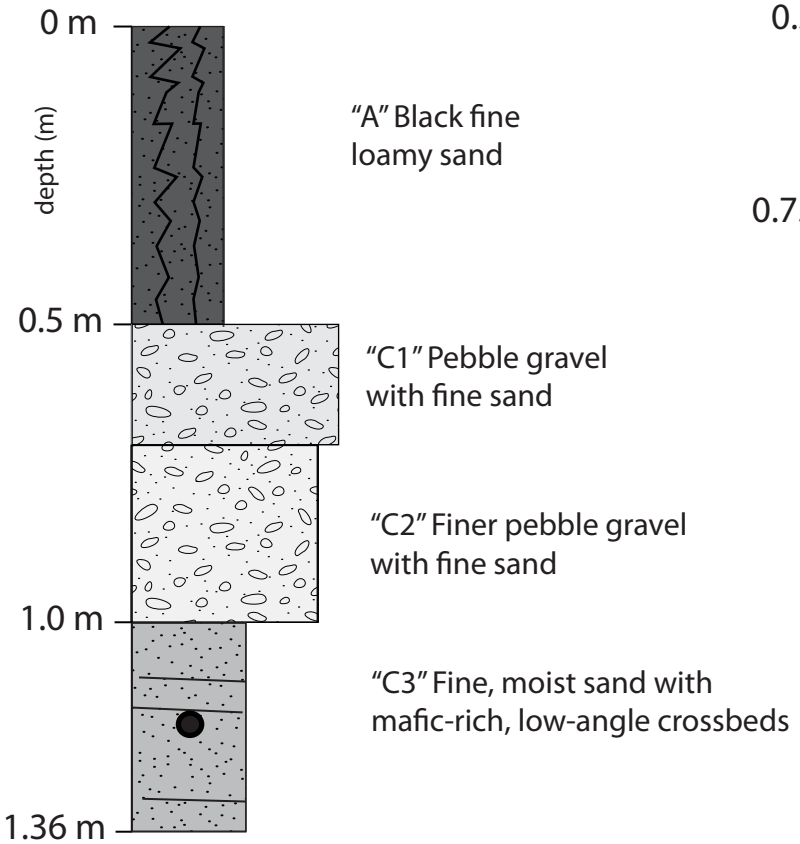


Kath Roadside (AB0801)

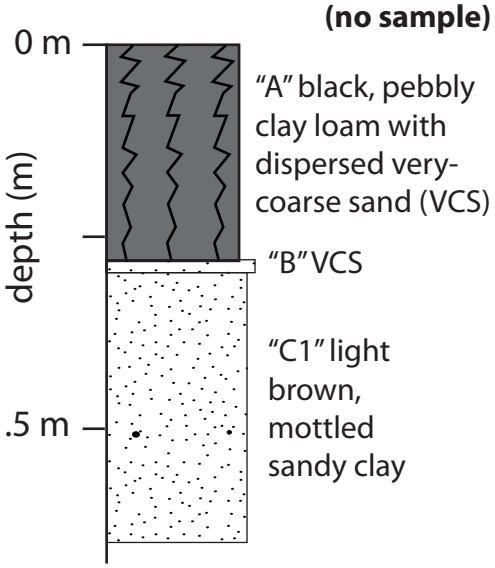


OSL sample

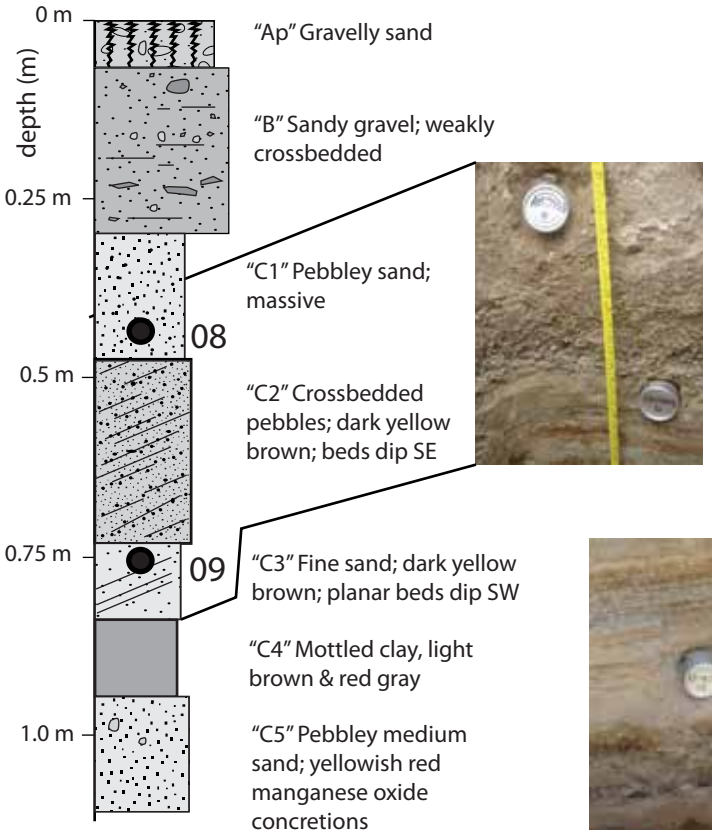
Busenga Farm (AB0707)



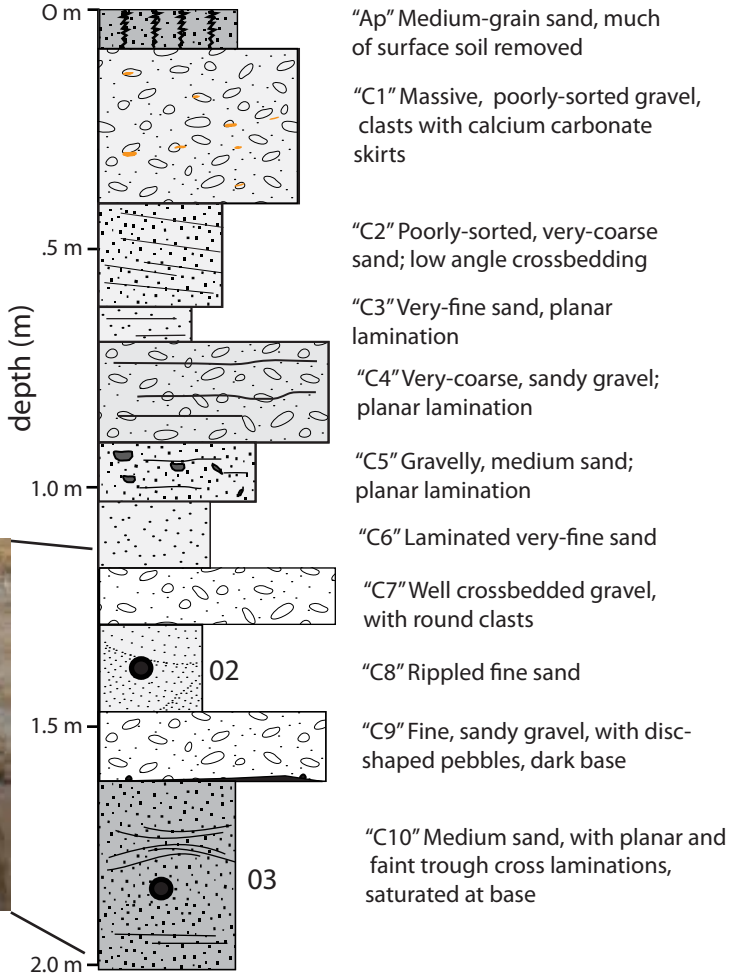
BNSF Communications Tower site (no sample)



Larson Farm (AB0708, 09)

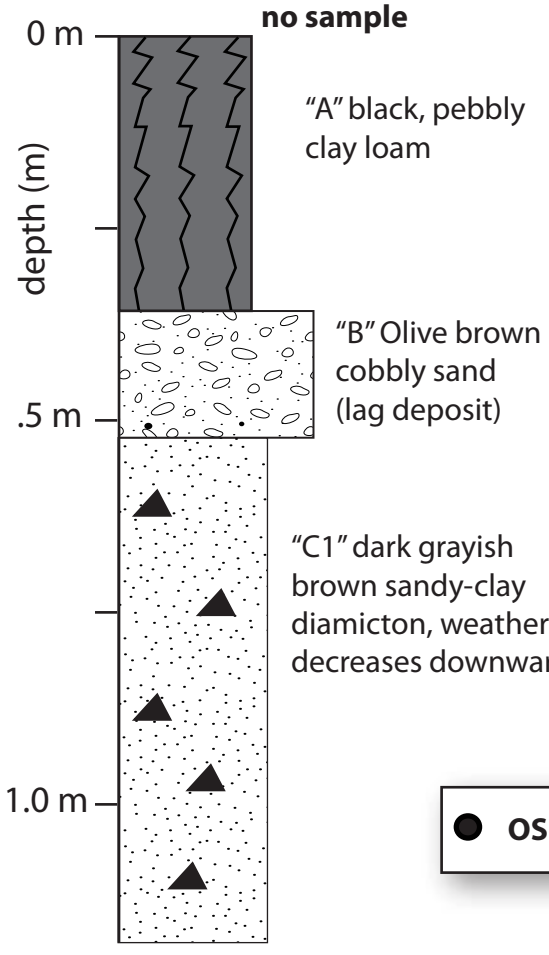


Tolifson Site (AB0702, 03)



Raguse Home Site (Tintah)

no sample



OSL sample

Ogg Site (Norcross)