Soils and Subsurface GPR Imaging of Fluvial Terraces in the Lower Chippewa River Valley, WI

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INTRODUCTION

Background

- Little detail is known about the late Quaternary geomorphic history of the Upper Mississippi River and its major tributaries. However, the Lower Chippewa River Valley (LCRV) landscape suggests a complex history of Late Quaternary fluvial aggradation and downcutting. The Chippewa River, the second largest tributary to the Mississippi River in Wisconsin, served as a major meltwater stream during the Late Wisconsin glaciation (Fig. 1).
  - o During the Late Wisconsinan the LCRV aggraded with glaciofluvial sand and gravel.
  - o At some point, as the Laurentide Ice sheet retreated, aggradation ceased and incision began.
- Seven paired terraces in the LCRV have been comprehensively mapped (Speer et al. 2007, Olson et al. 2008). The highest and most pronounced of the terraces is the Wissota Terrace (T7). The lower six terraces are inset below the Wissota Terrace.

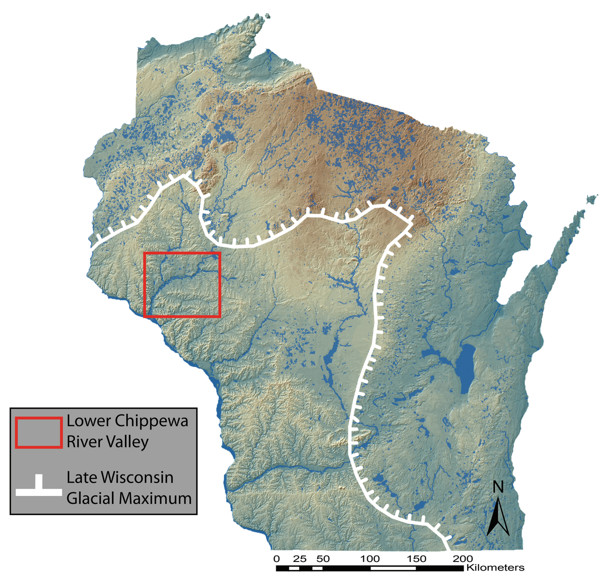

Figure 1: Location of LCRV in western Wisconsin.

Purpose of this research

- The age and genesis of the seven fluvial terraces and the chronostratigraphic relationships among them are not known.
- The primary objective of this research is to:
  Determine if ground penetrating radar (GPR), soil information, and optically stimulated luminescence (OSL) dating can be used to construct a testable chronostratigraphic model of LCRV fluvial terraces.

Location and Physical Setting

- Extending from Eau Claire, WI, about 100 km to the confluence of the Chippewa with the Mississippi River, the Chippewa River drains 24,600 km².
- The study site is located along 1000th street about 13 miles southwest of Eau Claire, WI, near Caryville.
  - o Mixed land use including agricultural fields, pasture, and residential.
  - o Terrace scarps are too steep for agricultural use.
  - o The modern Chippewa River channel is incised about 60 meters below the Wissota terrace.

METHODS

Ground Penetrating Radar (GPR)

- GPR, soils, and OSL data were collected in the summer of 2008.
- Sensors and Software pulseEKKO 100 and 1000 GPR systems were used to collect near subsurface data on 4 of 7 terraces observed in the LCRV (Fig. 2).
  - o 27 transects (2.63 km) of GPR profiles were collected using:
    - 50 MHz antennae, 2.0 m antennae separation, 0.5 m step interval.
    - 225 MHz antennae, 0.5 antennae separation, 0.1 m step interval (Fig. 3a).
    - 50 MHz antennae used 1000 V transmitter; 225 MHz antennae used 200 V transmitter.
  - o GPR transects were topographically corrected using a Topcon laser level.
  - o Common midpoint surveys (CMP) were conducted to determine near surface velocity through the sediments (to determine depth of penetration); these revealed a velocity of 0.10-0.11 m/ns (Fig. 3b).
  - o Each GPR transect was digitally processed using pulseEKKO software.

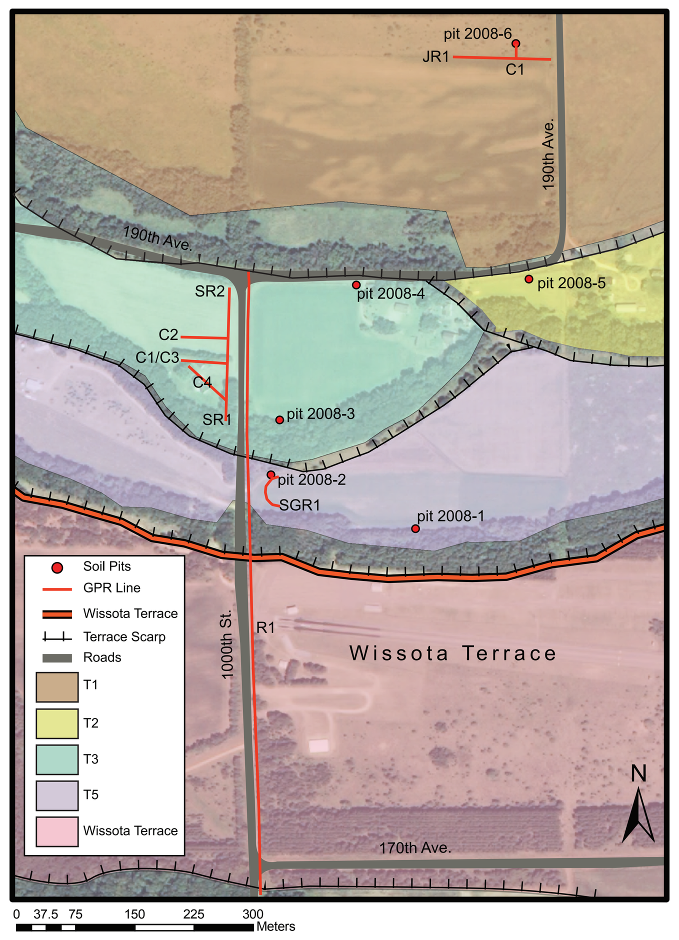

Figure 2: Study site with location of all GPR lines and soil pits investigated. Terraces shown revised from Speer et al. 2007, Olson et al. 2008.

Figure 3a: GPR data collection on Wissota Terrace along 1000th St. (R1). View to the south.

Figure 3b: Common midpoint data collection on Wissota Terrace along 1000th St. (R1). View to the southeast.

Soils

- Seven soil pits approximately 1.0 m² were excavated to a depth where parent material (C horizon) was observed (about 1.0 m), photographed, and described (Soil Survey Division Staff, 1993) (Fig. 4).
- About 250 mL of each sub horizon was collected for particle size analysis:
  - o Particle size analysis was conducted on 30-50 g sub samples using a Gilson Sonic Sifter (half phi interval).

Figure 4: Excavation of soil pit 2008-3 on T3. View to the east.

Optically Stimulated Luminescence (OSL)

- OSL samples were collected from three pits:
  - o pit 2008-2 (C horizon, 90 cm).
  - o pit 2008-3 (B1 horizon, 110 cm).
  - o pit 2008-5 (C horizon, 100 cm).
  - o one eolian cliff-top dune (not discussed).
- OSL samples were submitted to the University of Nebraska-Lincoln for analysis. OSL analysis is pending.

RESULTS

Ground Penetrating Radar

- Approximately 800 meter GPR transect line collected along 1000th Street (R1) (Fig. 5) imaged Wissota Terrace, T5, and T3.
  - o Relative elevation using a laser level found T1 ~30 m below Wissota Terrace.
- 20-30 m depth of penetration using 50 MHz (Figs. 7a, 8a-c).
- Approximately 4 m depth of penetration using 225 MHz (Figs. 6, 7b).

- GPR reveals two reflection patterns:
  - o Reflection pattern 1: Surface to 1 - 2 m depth.
    - Continuous to semi-continuous, horizontal to sub-horizontal.
    - Depth consistent with contact between sandy surface deposit and top of gravel layer observed in soil pits 2008-4, 2008-5, 2008-6.
  - o Reflection pattern 2: Below package 1, depth ranging from 1-2 m to 20-30 m.
    - Continuous to semi-continuous to discontinuous reflection patterns that vary from sub-horizontal to undulating to inclined.
    - Apparent northward incline (5 degrees) reflection pattern from positions 10-100 m, below package 2 (green dashed line, Fig. 6), T7.
    - Channel-like form (blue line, Fig. 7b) with inset northwardly (~13 degrees apparent) inclined reflection patterns observed from position 190- 290 m, T7 (yellow lines, Fig. 7b).
    - Northeastward inclined reflection patterns (8-22 degrees apparent),10-20 m wide, 3-13 m deep (Fig. 8a-c) present below T2 and T3.

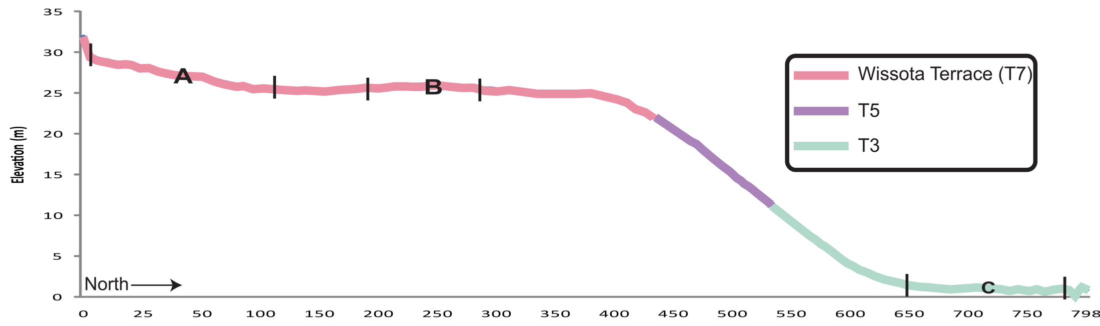

Figure 5: GPR transect (R1) shown south (left) to north (right). Elevation shown with 5x vertical exaggeration.

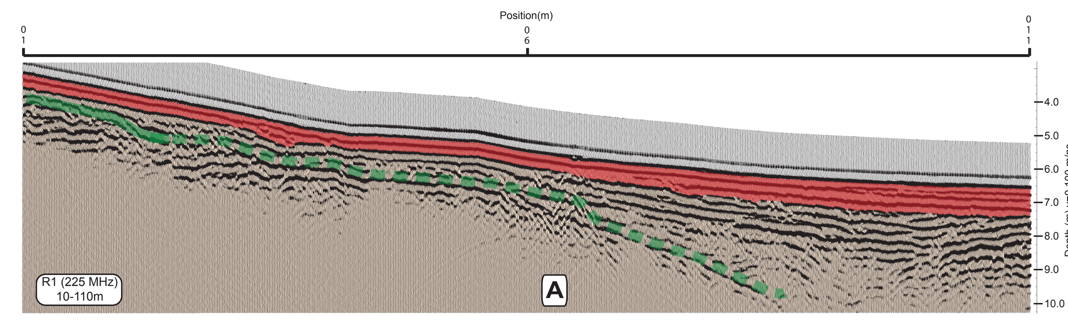

Figure 6: Northward inclined reflection pattern below radar package 2 on T7. Solid green line indicates where presence of bedrock is verified.

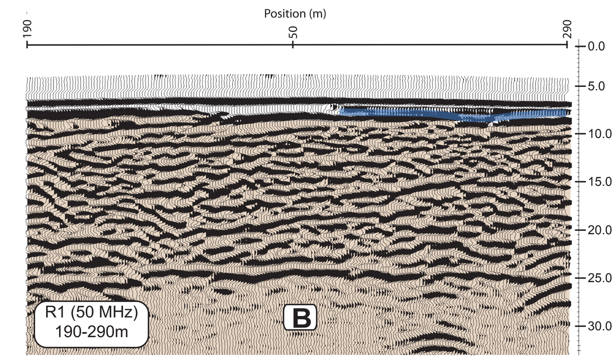

Figure 7a: Compared to high frequency antennae (225 MHz), 50 MHz antennae shows less detail but greater depth of penetration.

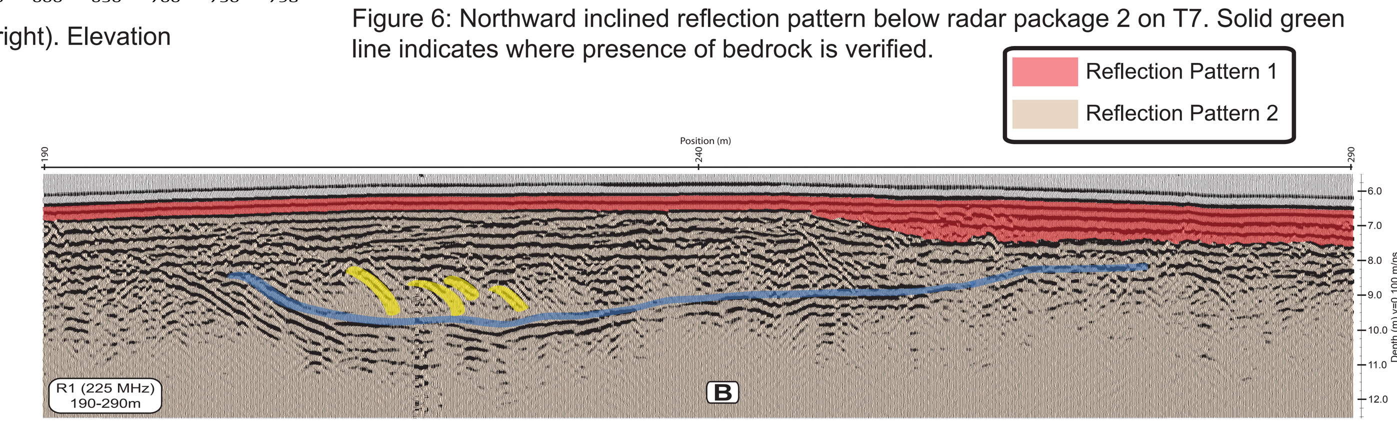

Figure 7b: Channel-like form (blue line) with inset northward inclined reflections (yellow lines) in reflection pattern 2, T7.

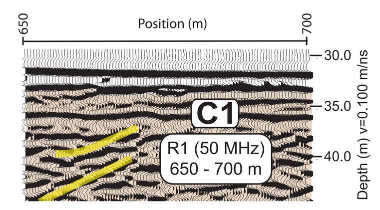

Figure 8a: Inclined reflection patterns in reflection pattern 2 (yellow lines), T3.

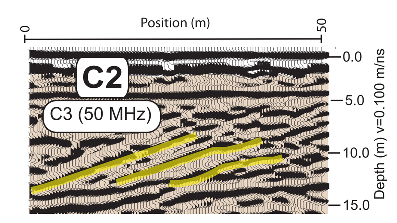

Figure 8b: Inclined reflection patterns in reflection pattern 2 (yellow lines), T3.

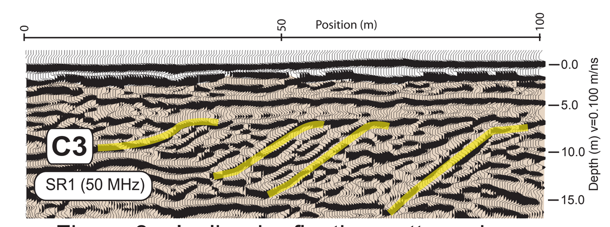

Figure 8c: Inclined reflection patterns in reflection pattern 2 (yellow lines), T3.

Soils

- Weakly expressed, sandy Inceptisols ~100 cm thick (Fig. 9 and Tables I-II).
  - o Thickness consistent with depth to contact with reflection pattern 2. Often underlain by a distinct bounding layer of clast-supported gravel (Fig. 9 and Table II).
  - o Gravel more continuous on lower terraces (T2-T1).
- Bw horizon (thickness) development decreases systematically from high (T5 & T3) to low terraces (T2 & T1).

Table I: Particle size analysis, profile exposed in pit 2008-6 (yellow highlights indicates modal sand fraction).

	Particle Size Analysis, Fine Earth Fraction (percent)											
	Sieve Size (mm)											
	1.4	1	0.71	0.5	0.355	0.25	0.18	0.125	0.09	0.063	<0.063	Starting
	Sand Subfraction*										silt &	Sample
Horizon	vCu	vcL	cU	cL	mU	mL	fU	fL	vfU	vfL	clay	Weight
AB1 up	1%	1%	2%	7%	15%	24%	14%	9%	5%	5%	14%	47.92
AB1 mid	1%	1%	2%	6%	12%	22%	16%	10%	5%	7%	16%	47.67
AB1 low	0%	0%	2%	6%	12%	22%	17%	9%	6%	6%	19%	49.03
AB2	1%	2%	3%	6%	11%	21%	18%	9%	6%	5%	8%	49.2
BC	1%	1%	2%	8%	19%	32%	16%	7%	4%	3%	7%	49.27

*Subdivisions within sand fraction: vcU = very coarse upper (2.0-1.41 mm), vcL = very coarse lower (1.41-1.0 mm),cU = coarse upper (1.0-0.71 mm), cL = coarse lower (0.71-0.5 mm), mU = medium upper (0.5-0.35 mm), mL = medium lower (0.35-0.25 mm), fU = fine upper (0.25-0.177 mm), fL = fine lower (0.17-0.125 mm), vfU = very fine upper (0.0125-0.088 mm), vfL = very fine lower (0.088-0.0625 mm).

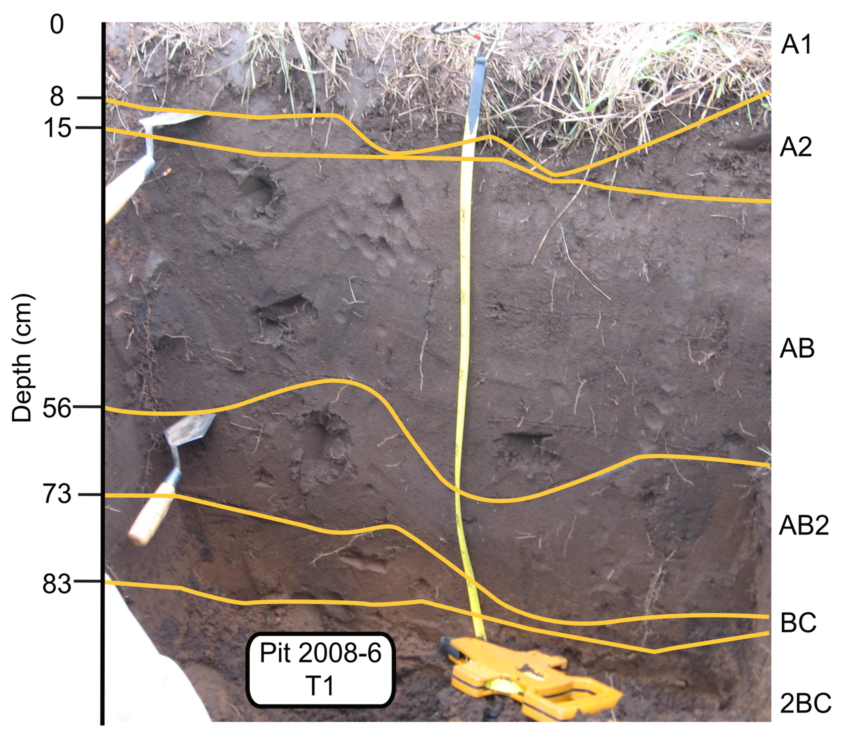

Figure 9: Soil profile exposed in the west wall of pit 2008-6,T1 (yellow lines indicate the approximate horizon boundaries. Tape measure, resting on clast-supported gravel, shows bottom of pit.

Table II: Detailed description of the soil profile in soil pit 2008-6, T1.

Depth (cm)	Horizon	Description
0-15	A1	10YR3/2 (very dark grayish brown); medium loamy sand; weak, fine, granular; friable, slightly sticky, non plastic; roots- very fine-medium, many; smooth, abrupt.
8-15	A2	10YR2/2 (very dark brown); medium loamy sand; weak, fine, granular-weak, subangular blocky; friable, slightly sticky, non plastic; roots-very fine-fine, common; broken, abrupt.
15-30	AB Upper	10YR2/2 (very dark brown); medium loamy sand; weak, subangular blocks; roots- fine - medium, few.
30-45	AB Middle	10YR2/2 (very dark brown); medium sandy loam; weak subangular blocks; roots- fine-medium, few.
45-56	AB Lower	10YR3/2 (very dark grayish brown); medium loamy sand; weak subangular blocks; roots-fine-medium, few; abrupt, wavy.
56-73	AB2	Darkest: 10 YR2/2 (very dark brown) Reddest: 10YR 3/3 (dark brown); medium sandy loam; weak subangular blocks. Slightly sticky, non plastic; roots-fine-medium, few; abrupt,wavy.
73-83	BC	7.5YR3/3 (dark brown): medium sand; massive, subrounded gravel; roots- very fine-fine, few; sharp, straight.
83+	2BC	Gravel (not sampled)

INTERPRETATIONS & DISCUSSIONS

Interpretations

- Reflection pattern 1: A single layer of sand underlain by gravel lag, deposited during incision phase.
- Reflection pattern 2: Horizontal layers of sand and gravel deposited during aggradation phase.
  - o Northward inclined reflection pattern from 10-100 m interpreted as bedrock contact (Fig. 6).
  - o Channel-like form (Fig. 7b) interpreted as a paleochannel, infilled with bedforms during lateral migration of the braided glacial Chippewa River.
  - o Thick northeastward inclined reflections (Fig. 8a-c) are large bedforms.

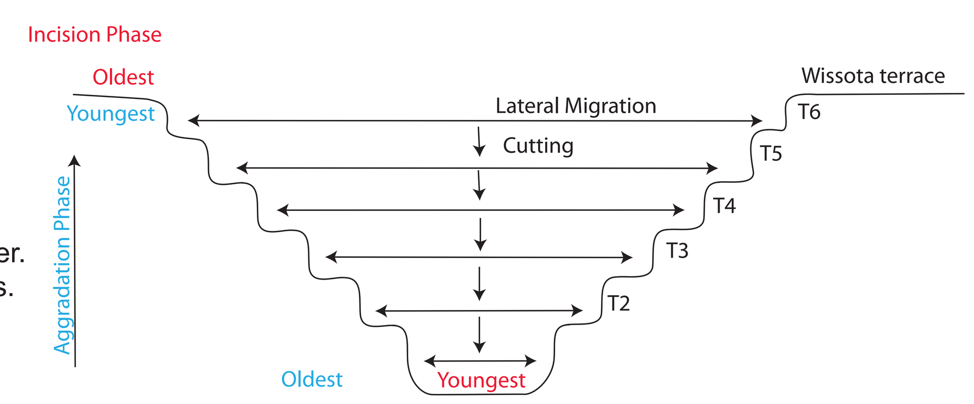

Figure 10: Aggradation phase glaciofluvial sand and gravel deposits, reflection pattern 2, should be oldest at the bottom and be progressively younger upward. Episodic phase sand and gravel lag deposits, reflection pattern 1 (reworked reflection pattern 2 deposits) should be oldest on the Wissota Terrace and be progressively younger on lower terraces.

Discussion

We have developed a model that explains the chronostratigraphic relationships among fluvial terraces within LCRV:

- o GPR reflection pattern 2 suggests one period of aggradation.
  - Aggradation phase - During the late Wisconsinan, the Chippewa River valley infilled with glaciofluvial sand and gravel as braided channels migrated laterally across the valley floor during a single episode of aggradation.
- o GPR reflection pattern 1 suggests lateral migration following each episode of incision.
  - Incision phase - sand over gravel lag, reflection pattern 1 deposits, formed from reworked reflection pattern 2 deposits during lateral migration between episodes of incision.
- o Although we have developed a testable chronostratigraphic model, chronology of the aggradation phase and episodes of incision during the incision phase must be determined. If our model is correct, we expect:
  - Sandy deposits, reflection pattern 1, will be oldest on Wissota Terrace and be progressively younger to T1 (Fig. 10).
  - Sand and gravel deposits, reflection pattern 2, will be youngest directly below gravel lag on the Wissota Terrace and be progressively older in that stratigraphic position to T1 (Fig. 10).
- o OSL samples submitted to UNL were obtained from reflection pattern 1. In the future, multiple OSL sample pairs (composed of samples from reflection pattern 1 deposits and samples from reflection pattern 2 deposits directly below the gravel lag) must be collected to test our model (Fig. 11).

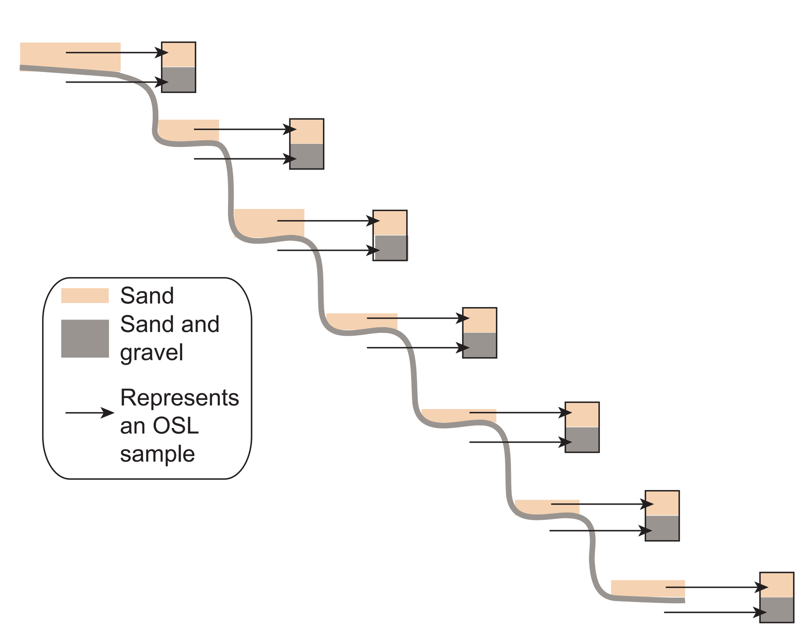

Figure 11: Schematic representation of OSL sample pairs needed to confirm our model.

CONCLUSIONS

- Ground Penetrating Radar and soils data can be used to determine chronostratigraphic relationships among fluvial terraces in the LCRV.
- Future study needed to test the chronostratigraphic model we present here.
  - o Multiple OSL sample pairs from all terraces will be needed to test our model, determine the age of aggradation phase deposits and the ages of incision phase deposits.

REFERENCES CITED

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