



Geochemical analysis of a Glacial Lake Benson varve sequence, west-central Minnesota



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Abstract

Glacial Lake Benson formed in western Minnesota as meltwater from the retreating Des Moines Lobe filled low areas of the Minnesota River valley during the Late Wisconsin Glaciation (Rittenour et al., 1998). The lake had a maximum depth of 19 m and covered ~3900 sq. km in west-central Minnesota. Evidence for Glacial Lake Benson includes relict deltas and exposures of offshore rhythmites. In this study, we analyzed the internal geochemistry of a 15-year varve sequence to investigate how geochemistry may change in a single location during a short time interval. In addition, we compared lake sediment geochemistry to the geochemistry of the surficial till in western Minnesota (Thorleifson et al., 2007, MN Geological Survey OFR-07-01).

Fifteen samples were obtained from an outcrop of consecutive varves near the center of former Glacial Lake Benson (21 km southwest of Benson on Cty Rd 11; UTM 287,900 mE, 5,003,100 mN, Zone 15). A bulk sample of one summer and winter layer was collected for each varve. Varve couplets were 7 to 13 cm thick. Sediment was dry sieved to obtain the silt and clay fraction for major and trace element analysis by x-ray fluorescence (XRF).

Bulk geochemistry within the varved succession is relatively homogeneous, although there is a distinct geochemical partitioning between the bottom and the top of the succession. In particular, large ion lithophile (LIL) elements such as Ba, La and Rb are depleted at the base of the section. Depletion of these mobile LIL elements may indicate selective removal of elements by hydrologic scavenging associated with groundwater movement. XRF results were also compared to regional till geochemistry in the Glacial Lake Benson area, as analyzed by the Minnesota Geological Survey using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Thorleifson et al., 2007). Lake Benson sediments are significantly enriched in Cu, Zn, Nb, Zr and Y relative to the till. This geochemical enrichment, particularly in nonmobile elements such as Zr, suggests that Lake Benson sediments might have been derived from a different source than the surficial Des Moines Lobe till.

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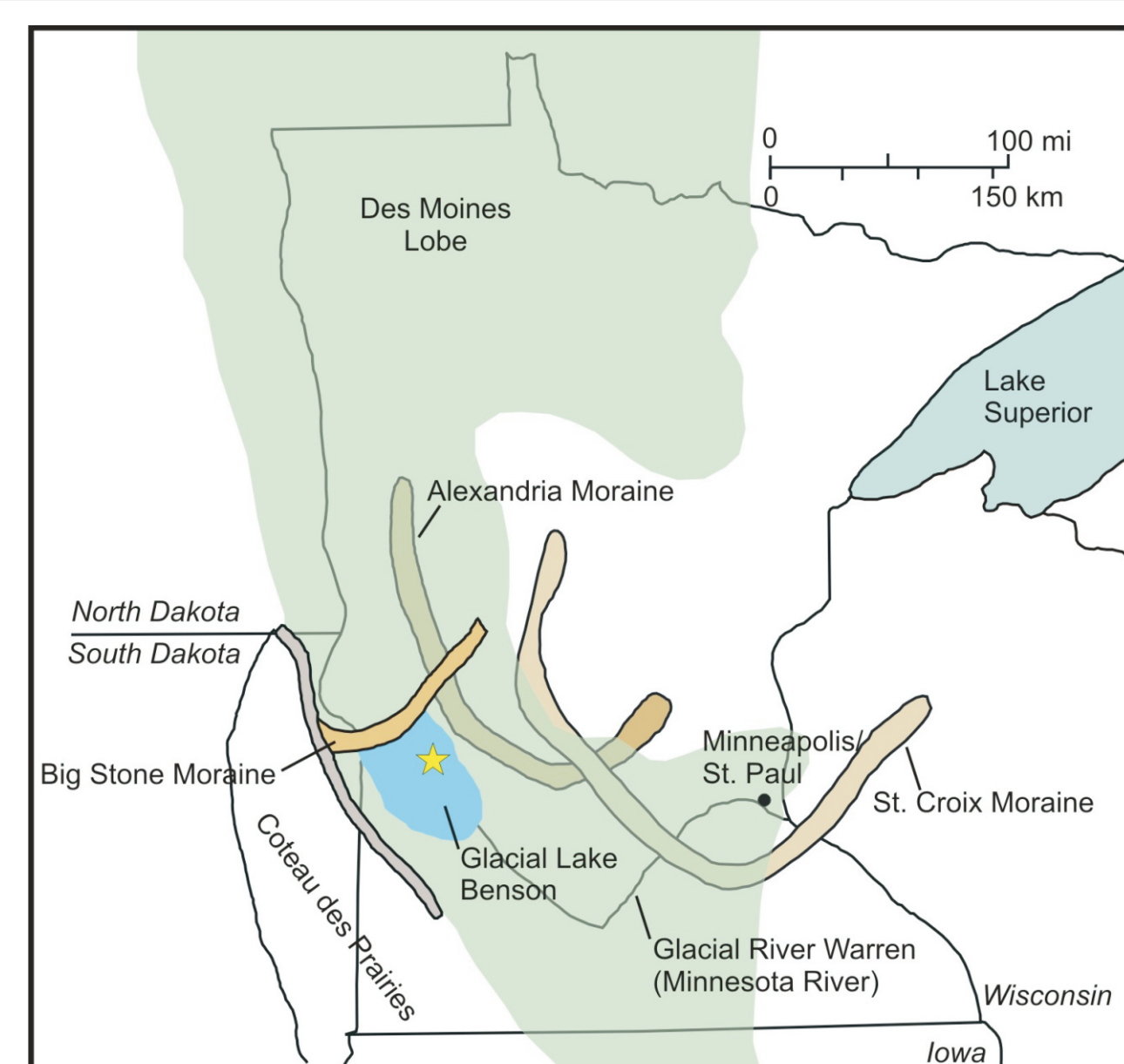
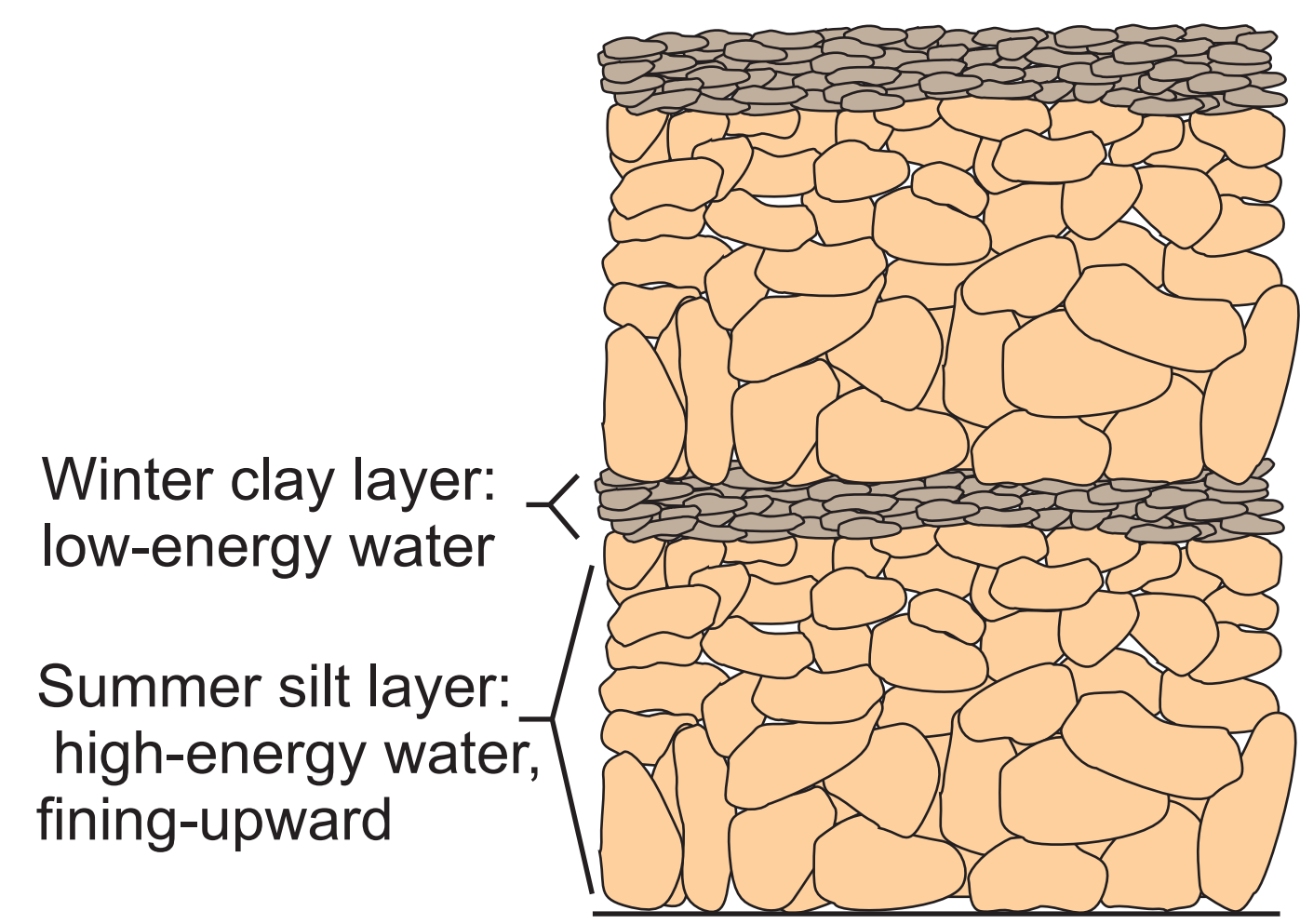


Figure 1: Glacial geology of western Minnesota. Glacial Lake Benson formed in low areas of the Minnesota River Valley as the Des Moines Lobe (in green) retreated north to the Big Stone Moraine position. The star marks the location of the varve section sampled for geochemical analysis. Modified from Rittenour et al. (1998) using a Des Moines Lobe ice margin from Geobel et al. (1983).

Figure 2. Varve sedimentology. As meltwater enters a lake, coarse sediments are deposited near the shoreline. Fine sediments are carried farther into the lake and settled out in relatively still water. Water and sediment influx to the lake are high during the summer, and silt particles settle onto the lake bed. The sediment fines upward as cooler weather reduces water and sediment input to the lake. In winter, little new water and sediment are supplied to the lake, so clay particles settle slowly from the water and form thin, dark clay layers on top of the silt. This couplet of silt and clay layers form a varve (annual sedimentary layer, Ashley, 1975).



Introduction

Glacial Lake Benson formed in western Minnesota as meltwater from the retreating Des Moines Lobe filled low areas of the Minnesota River valley during the Late Wisconsin Glaciation (Fig. 1, Rittenour et al., 1998). The lake was dammed by a moraine south of the Granite Falls area and drained by an outlet to the southeast. Evidence for Glacial Lake Benson includes relict deltas and exposures of offshore rhythmites. The lake had a maximum depth of 19 m, covered ~3900 km² in west-central Minnesota, and served as the catchment for sediments and meltwater from the Des Moines Lobe and the surrounding basin (Fig. 1).

Geochemical analysis was performed on a stratigraphic section of 15 consecutive Glacial Lake Benson varves. The samples were obtained from an outcrop southwest of Benson, MN, on County Road 11 (UTM 287,900 m E, 5,003,100 m N, Zone 15). A bulk sample of one winter layer and one summer layer was collected for each varve (Fig. 2). The varves range in thickness from 7 to 13 cm and were sampled from the bottom of the soil horizon to the top of the underlying till unit. The total thickness of the varve section was 140 cm at the site (Fig. 3).

The goals of this study were to analyze the internal geochemistry of a 15-year varve sequence to investigate how the geochemistry of closely spaced varves may change in a single location during a short time interval. Changes in major or minor element signatures within the lake sediments may indicate a provenance change.

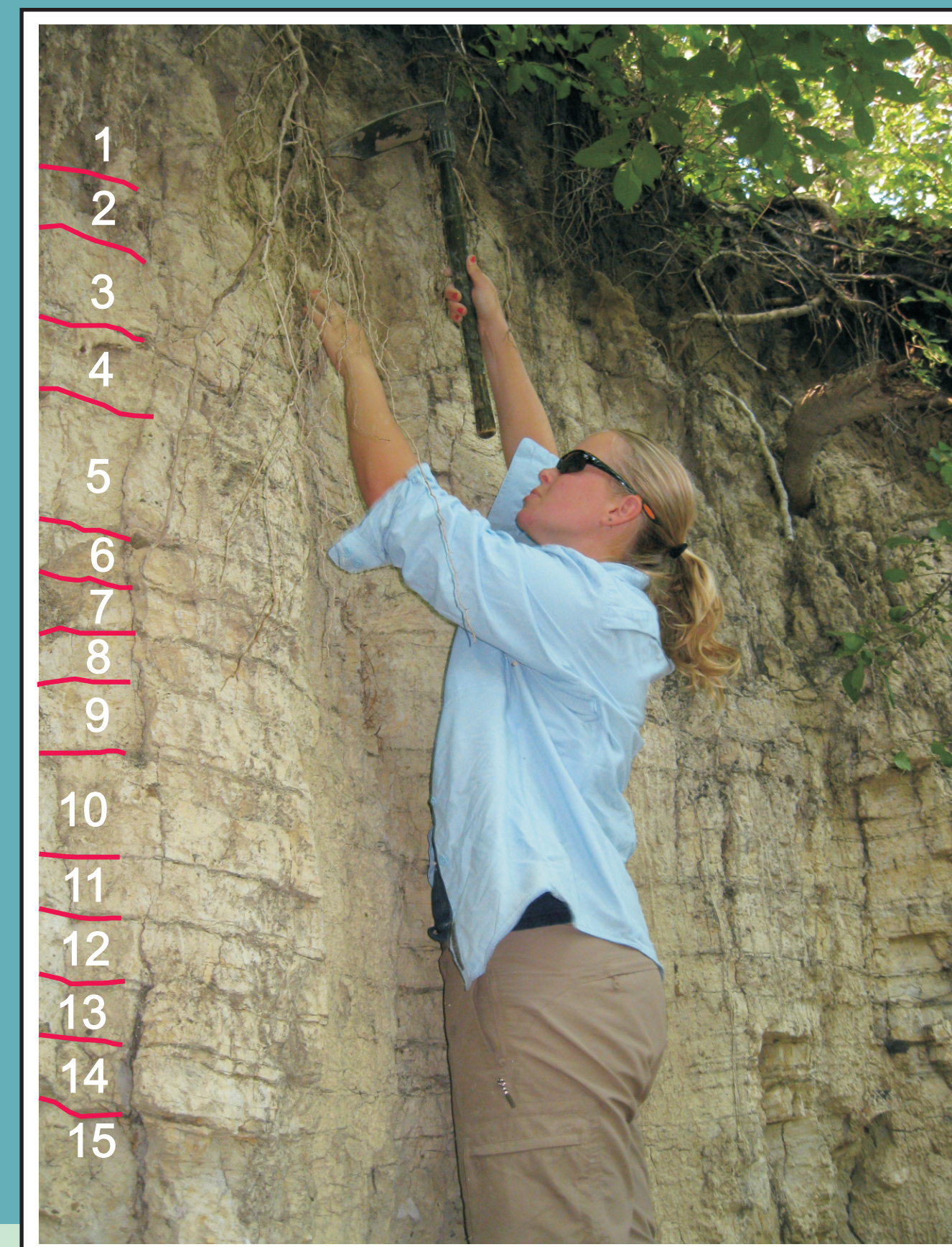


Figure 3: Glacial Lake Benson varve section sampled for geochemical analysis. Red lines indicate darker winter clay layers. The section was 140 cm thick and exposed by a downcutting river. Fifteen bulk samples of one winter layer and one summer layer were collected.

Results

- The rare earth element signatures for each sample are quite uniform. This indicates that sediment provenance did not change during the fifteen-year interval when the varves were deposited (Fig. 5).
- Calcium oxide and magnesium oxide are enriched in the lower 60 cm (Fig. 6).
- Large ion lithophile elements (i.e. barium, rubidium and lanthanum) are depleted in the lower 60 cm of the section relative to the upper 80 cm (Fig. 6).
- Loss-on-ignition values (and carbonate values) are 3 to 4 percent greater in the lower 60 cm of the section than in the upper 80 cm of the section.

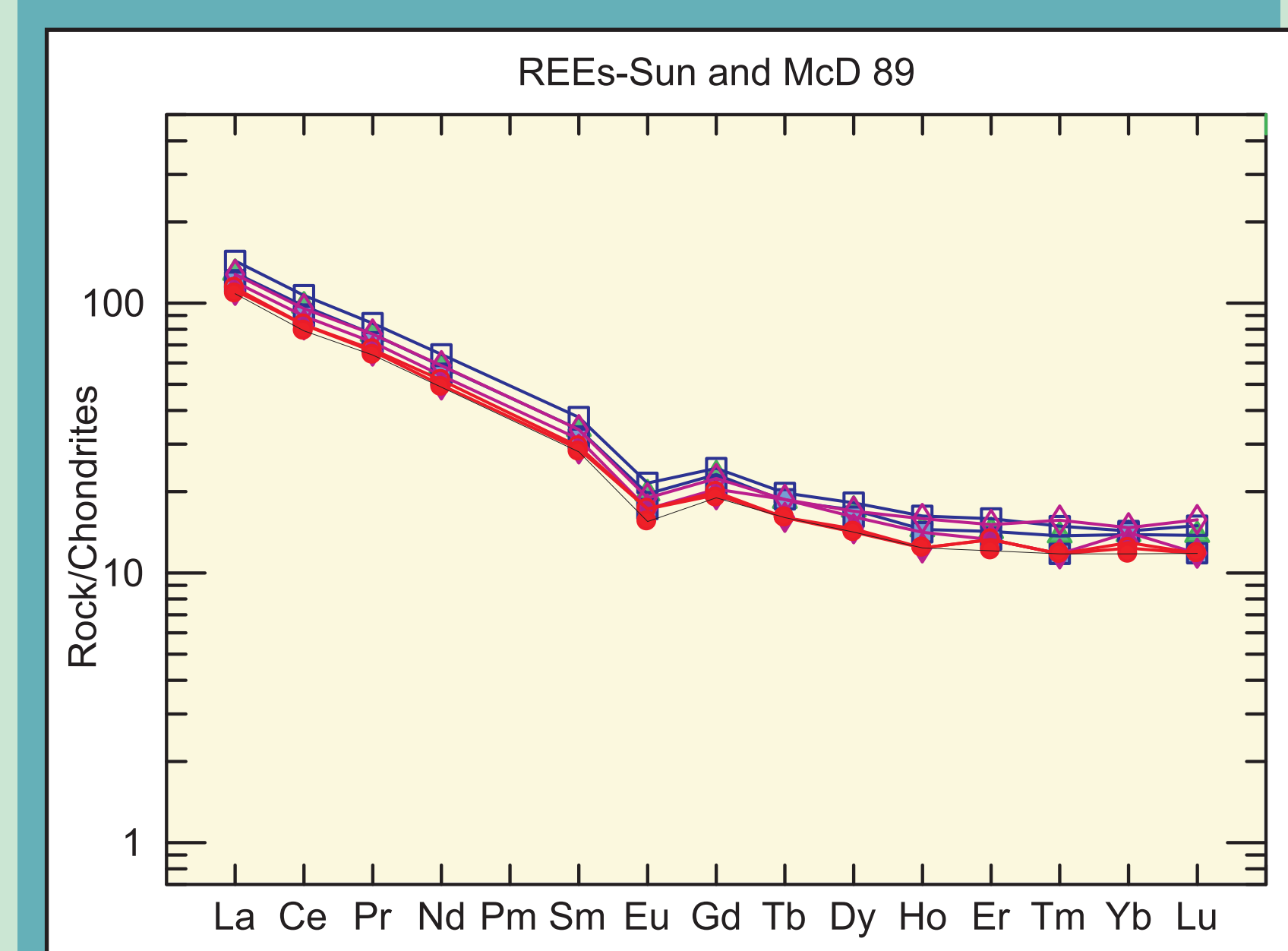


Figure 5: Rare earth element signature is uniform. Over the 140 cm section, there is no change in rare earth element geochemistry, suggesting there is no shift in provenance during varve deposition.

Methods

- Completed a field analysis of glacial and lacustrine sediment in the Minnesota River valley and Big Stone Moraine area during summer 2009.
- Collected fifteen bulk samples (one winter and one summer layer) of Glacial Lake Benson varves in stratigraphic sequence (Fig. 1, 3).
- Prepared samples for x-ray fluorescence spectroscopy using a Bruker SRS 3000 WD-XRF. Samples were dry sieved to obtain the silt and clay fraction (< #230 U.S. Standard Sieve) used to create fused beads and pressed pellets (Fig. 4).
- Performed rare earth element analysis on 8 samples with inductively-coupled plasma mass spectrometer (ThermoFinnigan Element 2 ICP-MS) to determine any geochemical partitioning in the varve sequence.
- Conducted loss-on-ignition analysis to determine the amount of volatiles (specifically CO₂) as an indicator of the amount of carbonate present.
- Analyzed IgPet plots of varve sediment geochemistry to determine geochemical changes within varve section.

Geochemical Transition Zone

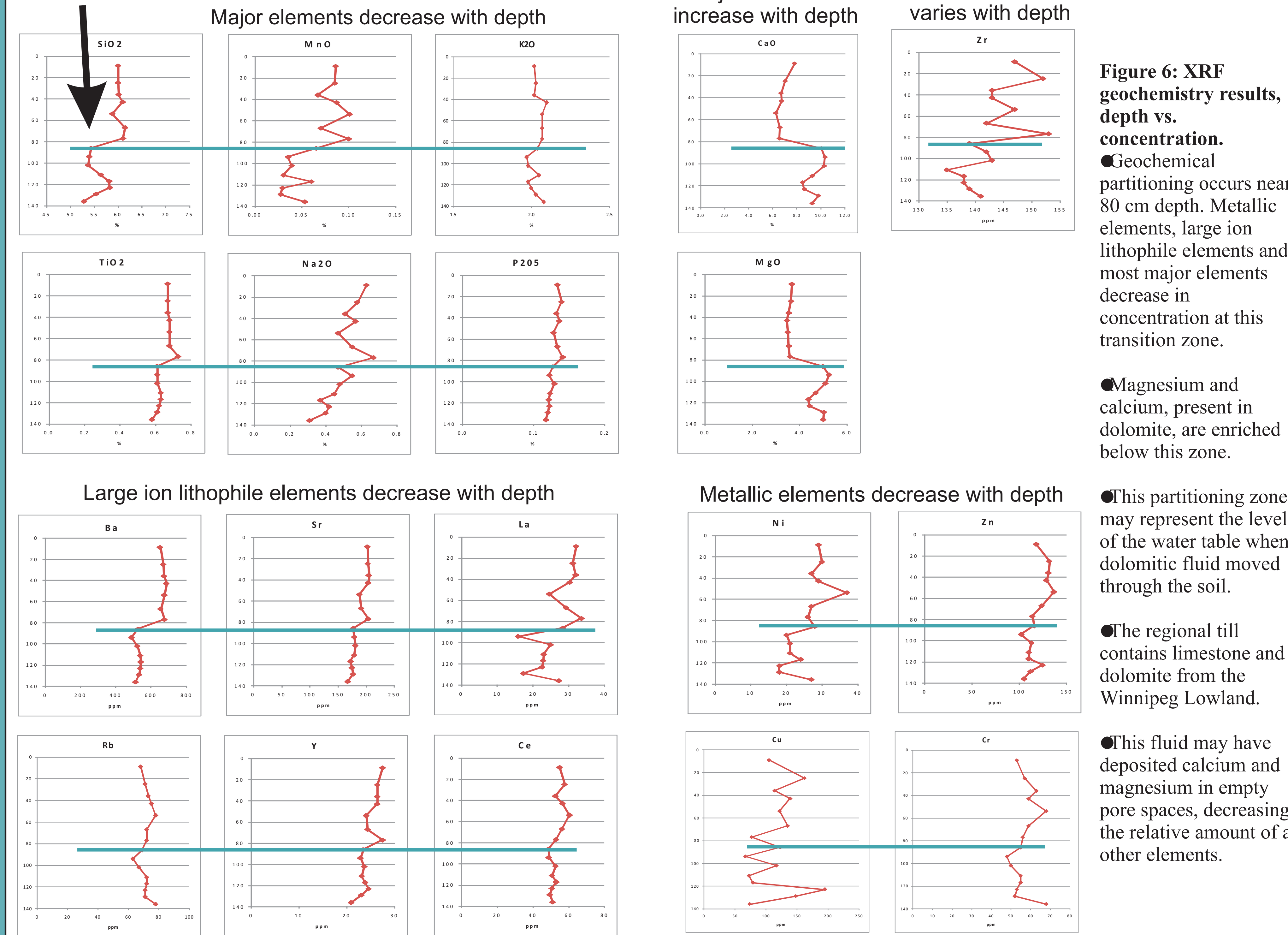


Figure 6: XRF geochemistry results, depth vs. concentration. Geochemical partitioning occurs near 80 cm depth. Metallic elements, large ion lithophile elements and most major elements decrease in concentration at this transition zone. Magnesium and calcium, present in dolomite, are enriched below this zone. This partitioning zone may represent the level of the water table when a dolomitic fluid moved through the soil. The regional till contains limestone and dolomite from the Winnipeg Lowland. This fluid may have deposited calcium and magnesium in empty pore spaces, decreasing the relative amount of all other elements.

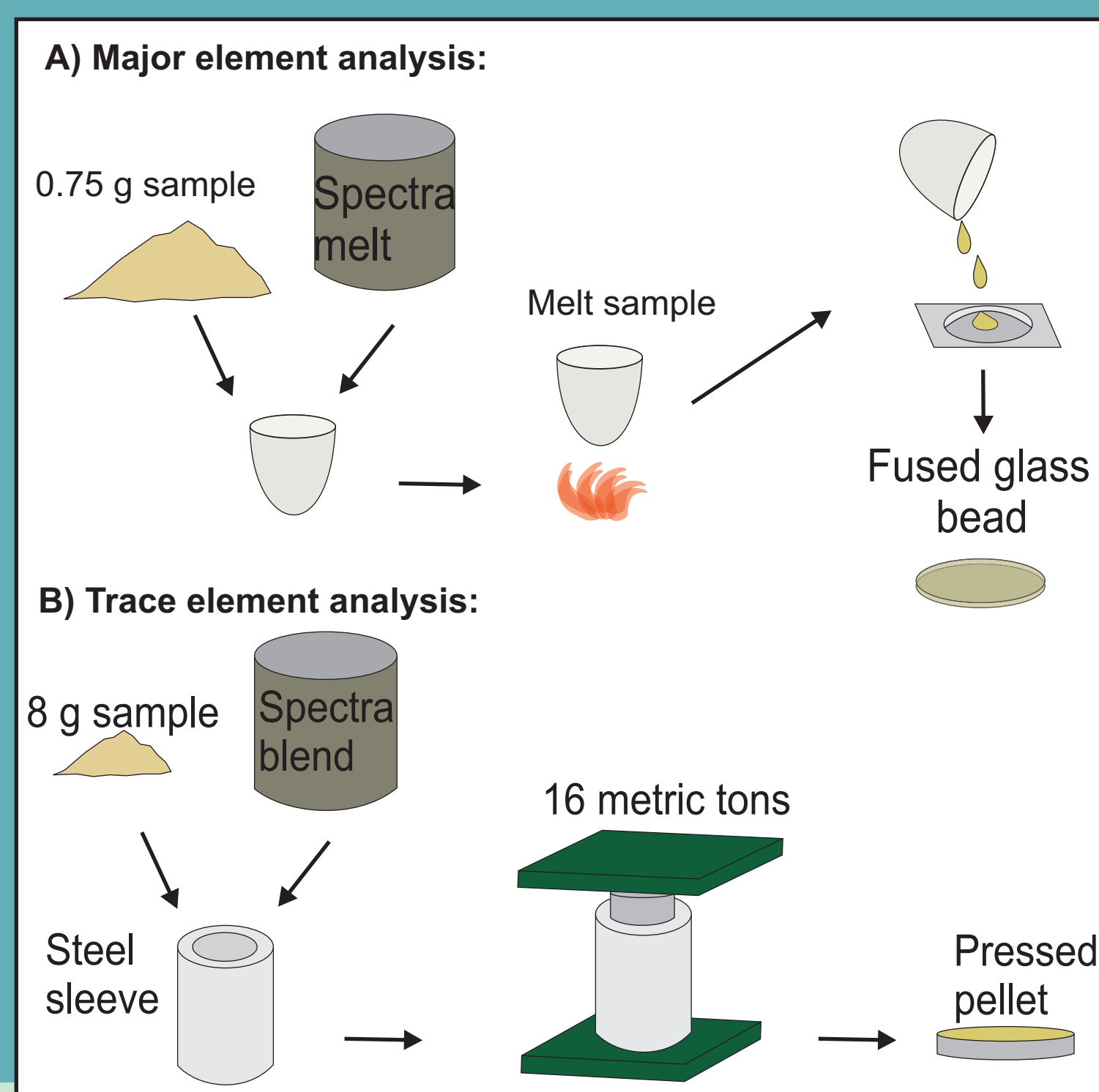


Figure 4: XRF sample preparation. A. In major element analysis, Spectra Melt (lithium tetraborate), ammonium iodide, and 0.75g sample powder are combined in a platinum crucible. Crucibles are heated and the melted sample is poured into disc-shaped molds. The liquid cools to form fused glass beads. B. For trace element analysis, 8.0 g sample powder is combined with Spectra Blend. The mixture is poured into a mold and placed inside a press. Roughly 16 metric tons of pressure is applied for 3 minutes which compresses the samples into disc-shaped pellets. Fused glass beads and pellets are then placed in the XRF for analysis.

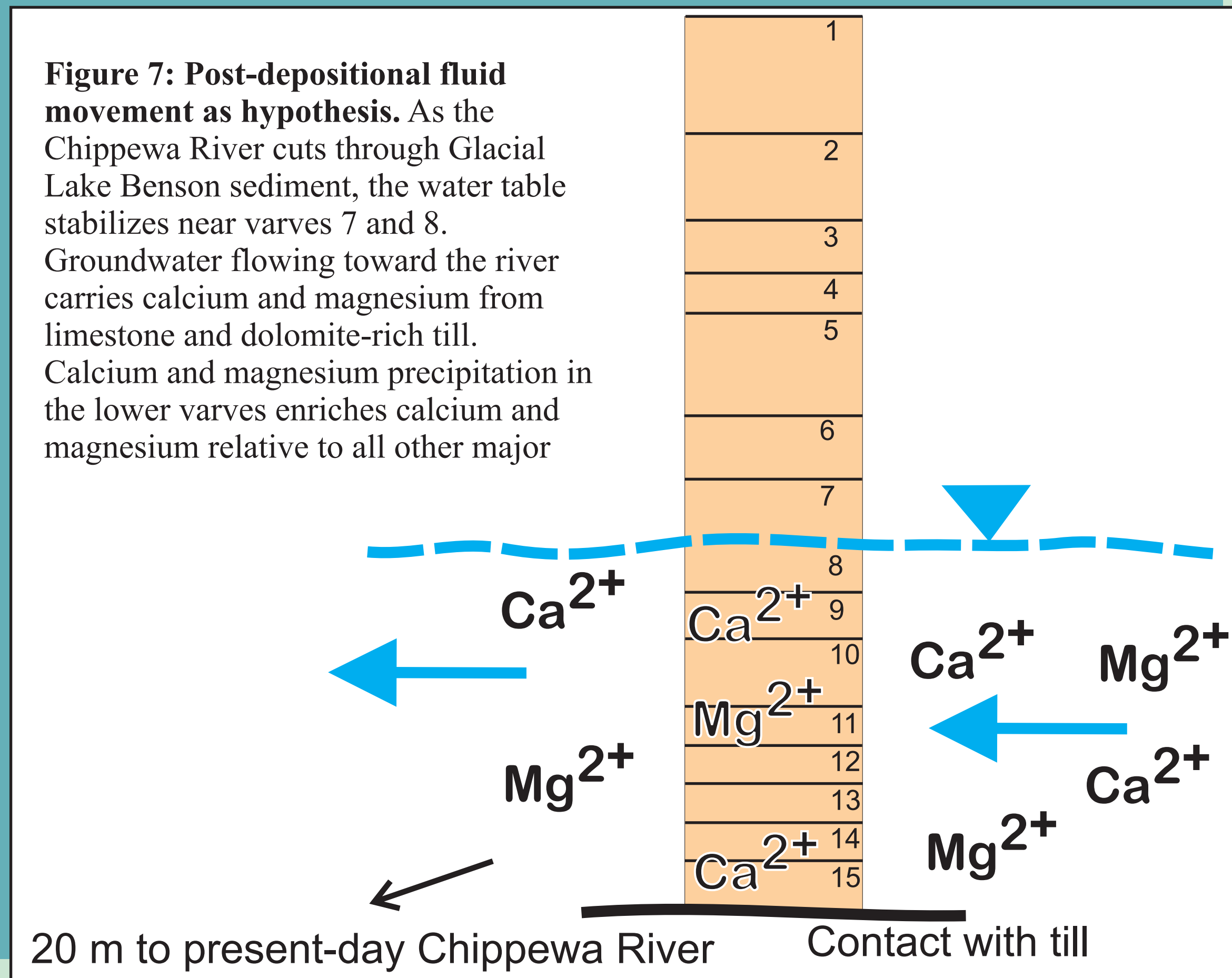


Figure 7: Post-depositional fluid movement as hypothesis. As the Chippewa River cuts through Glacial Lake Benson sediment, the water table stabilizes near varves 7 and 8. Groundwater flowing toward the river carries calcium and magnesium from limestone and dolomite-rich till. Calcium and magnesium precipitation in the lower varves enriches calcium and magnesium relative to all other major

Possible Interpretation

- **Post-depositional groundwater movement.** The geochemical transition zone represents a former boundary between the vadose zone and phreatic zone. Groundwater moving through carbonate-rich Des Moines Lobe and Wadena Lobe till flowed through the lower 60 cm of the section (Chernicoff, 1983; Douglas, 1970; Wright, 1962). The water stripped calcium and magnesium from the till and deposited it in the varve sediments, thereby increasing the relative amounts of these two elements. This decreased the relative amounts of the remaining major, large ion lithophile, metallic elements and zirconium (Fig. 7)

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