Linking terrestrial and submarine sedimentary processes: a preliminary bathymetric and sub-bottom survey of the Stehekin Delta, Lake Chelan, WA

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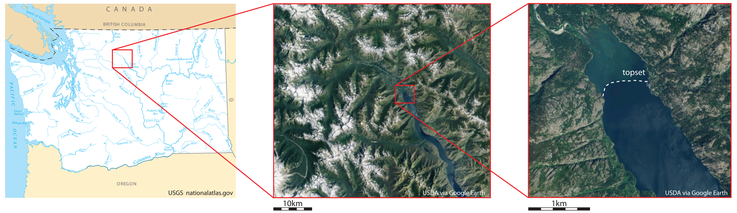
introduction

Geologists have long recognized the importance of both river deltas and deep-ocean sedimentary fans as major sinks for large quantities of land-derived sediment, and as important components in the integrated source to sink transit of terrestrial sediments. Indeed, studies too numerous to count have addressed these depositional systems individually. Relatively few studies, however, have directed their attention at the linkage between the two, despite the fact that deltaic dynamics are almost always intimately related to deep marine sediment transport systems. This linkage is key to our ability to model and understand sedimentation in both environments, as these dynamics provide an important boundary condition for terrestrial and marine models, and represent a critical interface in the source to sink system. This project is a preliminary study of the relationship between deltaic and deep- water sedimentation in Lake Chelan, WA, where the external forces acting on the system are relatively well-constrained, and the river is directly linked to deeper water. Detailed bathymetric and sub-bottom data, including lake bed grab samples, gravity cores and CHIRP, were collected in order to characterize the transport and fate of sediment. Preliminary data analysis suggests the presence of large scale bedforms on the lake floor, presumably the product of density currents produced during high river flows or as a consequence of failure on the delta front. Grainsize and isotopic analysis of the cores and grab samples should constrain the mechanisms by which deep marine flows are generated, and provide a valuable baseline from which future monitoring studies can be designed.

geographic setting

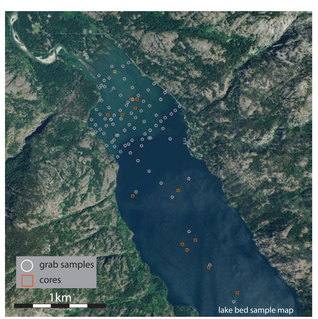


Lake Chelan sits in a fjord-like basin most recently scoured by the combination of the Chelan Glacier and Okanagan Lobe of the Cordilleran ice sheet during the LGM. The important consequence of this for the present study is that the Lake Chelan is steep-sided and relatively deep. The present day lake level fluctuates between 1090' and 1100' above sea level, though the lake is nearly 1500' deep. The northern end of the lake has been fed by the Stehekin River throughout the Holocene, prograding some 4km in the last 9000 years. The present day morphology and processes active on the Stehekin Delta are the focus of this study.

preliminary fieldwork

In June 2010 we collected a variety of data from the northernmost 5 km of Lake Chelan. The centerpiece of this data set is a new multibeam bathymetric map, collected with a Reson Seabat system mounted onboard the R/V *Lake Itasca*. The lake level during the field campaign was steady, around 1098' asl. The *Itasca* collected ADCP data continuously whenever in water depths less than 20m. Cores and grab samples in water depths exceeding 10m were taken from a modular barge, which was fitted with a 15' derrick and 300m of line.

In addition to the bathymetric data we collected:
- 25 km of 2D CHIRP data
- 90 lake bed grab samples
- 5 vibrocores on the delta top
- 7 kasten cores from the fine-grained portion of the delta bottom set



lake bed morphology

Multibeam bathymetric data was collected over the entire study area safely navigable by the *Itasca*. Using CARIS software, we have focused our processing on two phenomena to date: errors associated with vessel motion and obvious noise associated with bad returns. The processing is ongoing.

The draft bathymetry shown here highlights several interesting phenomena on the floor of Lake Chelan:

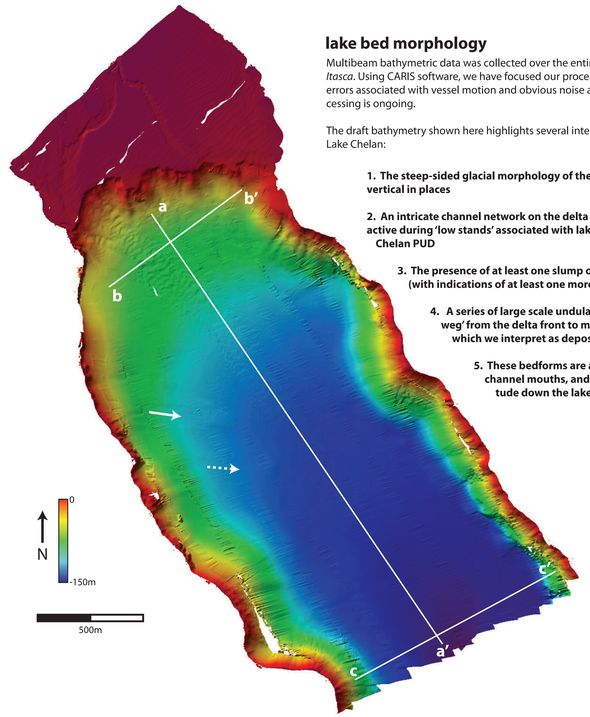
1. The steep-sided glacial morphology of the lake--side walls are nearly vertical in places

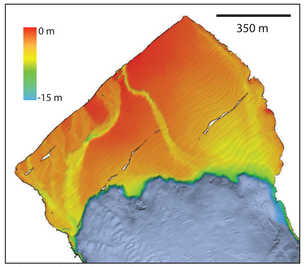
2. An intricate channel network on the delta top, which is presumed to be active during 'low stands' associated with lake level management by the Chelan PUD

3. The presence of at least one slump on the west side of the lake (with indications of at least one more)

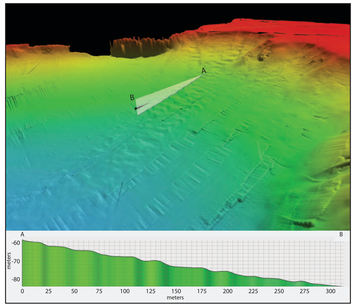
4. A series of large scale undulatory features along a 'thalweg' from the delta front to more than 100m water depth, which we interpret as depositional bedforms

5. These bedforms are aligned with the lowstand channel mouths, and appear to decrease in amplitude down the lake





delta top channel network: note the direct connection between bedforms and western channel mouth



perspective view (looking west) of bedforms: note the average wavelength ~25m and average amplitude ~1m in this area

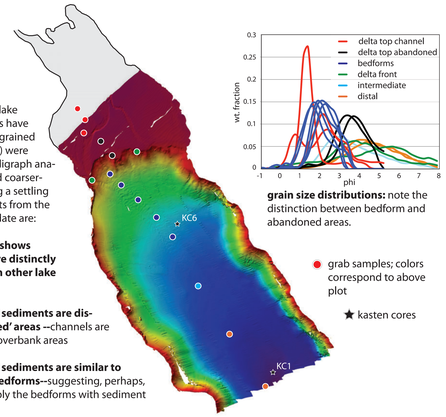
grain size

Only a fraction of the lake bed sediment samples have been analyzed. Fine-grained samples (silt and finer) were processed using a Sedigraph analytical instrument, and coarser-grained samples using a settling column. The key results from the sediment analysis to date are:

1. grainsize analysis shows that the bedforms are distinctly coarser-grained than other lake floor sediments

2. delta top channel sediments are distinct from 'abandoned' areas --channels are notably coarser than overbank areas

3. delta top channel sediments are similar to those found in the bedforms--suggesting, perhaps, that channels do supply the bedforms with sediment



grain size distributions: note the distinction between bedform and abandoned areas.

grab samples; colors correspond to above plot

★ kasten cores

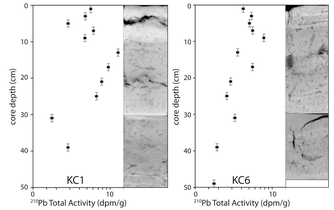
core data

Preliminary analysis of kasten cores collected from relatively proximal (KC6) and distal (KC1) locations suggests the presence of a recent 'event' layer in the upper 10cm the lake bed. We cannot determine the origin of this bed conclusively, but note that:

1. ^{210}Pb activities are relatively low and uniform in this layer

2. x-ray images of the cores seem to indicate that this layer is coarser than underlying sediments

3. below this layer, ^{210}Pb activities generally decrease logarithmically, though analysis is ongoing

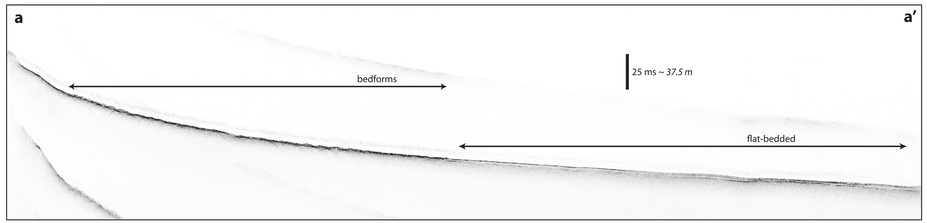


Lead 210 activity and x-radiographs: note the light-colored, low-activity layer in the upper 10cm of both cores

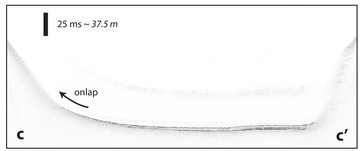
sub-bottom profiling

Chirp seismic data were collected on a reconnaissance grid comprising approximately 25 km of 2D lines. Unfortunately, the presence of biogenic gas in the sediments significantly attenuated the signal. This was particularly pronounced on the delta top, rendering the data unusable. Despite this, the chirp data provide insight into several aspects of the sedimentary system.

1. Longitudinal depositional trends: The bedforms progressively decrease in amplitude and seem to increase in wavelength with distance down the lake. Low on the delta front the bedforms transition into flat-lying, layered sediments (see line a-a'). This relatively abrupt transition could be associated with a change in available sediment grainsize.



2. The bedforms: due to the poor acoustic penetration, the internal structure of the bedforms is not well imaged. The data do indicate, however, that the bedforms are associated with a bathymetric high (see line b-b'). Whether this high is due to aggradation of the bedforms, or thickening associated with mass failure is unclear.



3. Lateral depositional trends: The chirp data indicate that distal flat-lying sediments thin and onlap onto the steep sides of the lake, in a manner consistent with deposition by relatively thick (10s of m) turbidity currents (see line c-c').

preliminary conclusions & future directions

We would emphasize that this project is ongoing. The conclusions, to date, reflect only minimal processing and analysis of the data collected during the first field season. However, we feel confident that we can draw the following conclusions:

1. Submarine processes (such as hyperpycnal flows and/or turbidity currents) have been active in recent Lake Chelan history. The presence of what we believe to be bedforms indicates that bottom-hugging flows have been active in the last decade. Coarser-grained layers with low ^{210}Pb activities in the uppermost portions of cores KC1 and KC6 may be the products of such flows.

2. Whatever the nature of the currents, they have modified the lake bed in a manner that we interpret as depositional bedforms. The wavelength and amplitude of these features appear too regular to be associated with *en echelon* failure. That they are relatively well-sorted sand suggests depositional winnowing. Future work will include morphodynamic analysis of flow character, and ideally *in situ* monitoring of flow character.

3. The data suggest that the submarine depositional system is most active during lake level 'lowstands.' The apparent link between bedforms and delta top channels suggests that it is flow across the delta top during lake level lowstands that produces the observed morphology.

acknowledgements

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