HIGH RESOLUTION SONAR PROFILING OF EARTHQUAKE-INDUCED FAILURES IN MARINE CLAY UNDERLYING THE OTTAWA RIVER; A CONTRIBUTION TO THE OTTAWA VALLEY LANDSLIDE PROJECT

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Abstract

The Ottawa Valley Landslide Project is, in part, a pioneering study of the capabilities of several geophysical techniques to provide regional-level reconnaissance surveys of critical geological controls related to landsliding in sensitive marine (Leda) clay near Ottawa. As part of this project, high-resolution, sub-bottom acoustic profiling was carried out in the Ottawa River in the Lefaivre area in order to examine the river bottom for evidence of continuation of "disturbed" ground mapped on land. The adjacent onshore area consists of 46 km2 of very hummocky topography and severely-deformed marine sediments that have been attributed to earthquake-induced liquefaction, lateral spreading, and differential settling.

Sonar surveys were conducted in the Ottawa River using both pulsed, and "chirp" (swept frequency/de-convolved) acoustic sources working over the effective frequency range of 2 kHz and 23 kHz. Due to superior transmission and coupling characteristics in water, marine acoustic methods can yield resolutions in the decimeter range. Excellent images of features including folding, faulting and in situ rotation of layered Champlain Sea sediments as well as sand volcanoes were obtained, and deformation could be observed to at least a depth of 30 m below river bottom.

Faults within the bedded sediments are predominately reverse faults, with dip angles ranging from 40 to 65 degrees and displacements of up to 7 metres between up and down thrown blocks. Laterally, the larger faults diminish to smaller faults, and eventually disappear altogether. The folding and reverse faulting is consistent with a compression of the sediments, such as would have occurred when the onshore lateral spreading encroached on the river channel.

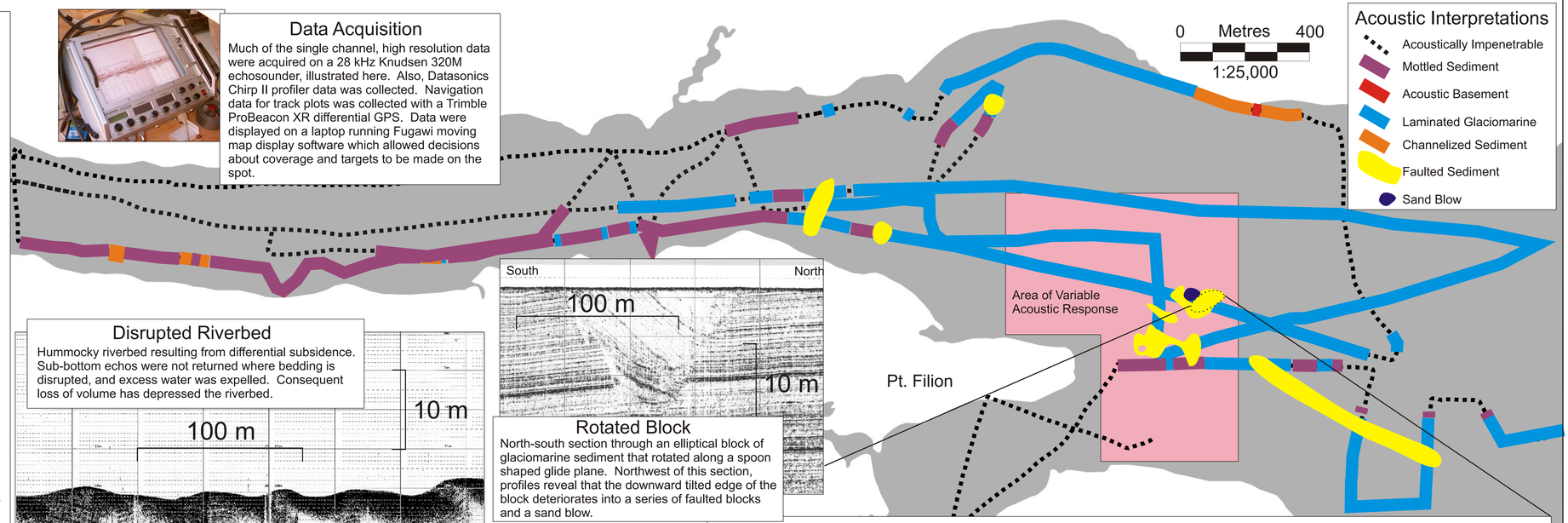
A detailed grid survey, consisting of 42 line-km of single channel sub-bottom sonar data, has mapped an in situ rotated block of layered sediment, 130 m by 200 m and about 25 m thick, with about 15 degrees of rotation. The bedded sediment has been folded, semi-symmetrically, and slightly faulted, but is otherwise coherent within the rotated block. Smaller rotated sections and areas of differential compaction occur along strike from this larger block. Seismic liquefaction of sediment through the development of excess pore pressure may have caused an initial failure along a single glide plane, which subsequently propagated upward in a curving path, through the overlying layers, to form a spoon-shaped slip plane. Portions of the rotated and extruded block of sediments may have originally projected above the riverbed, but have been subsequently eroded by the Ottawa River. Similar small independently rotated blocks also occur nearby. The scale of the offshore rotations is similar to the width of depressions onshore where inclined bedding has been observed, and coincides with the depth of severe deformation found in onshore borehole core.

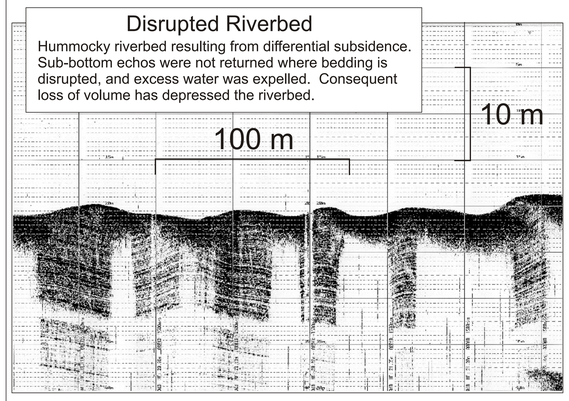
Several sonar profiles have intersected what seems to be the remains of sand or mud blows or volcanoes. Laminated bedding has been ejected, producing a depression that was subsequently infilled, either with the ejected sediments themselves, or with later fluvial sediments. The shallow water in this reach probably allowed river ice to truncate the sand mounds.

These sonar surveys have confirmed that deformed sediments are present beneath the riverbed and are associated only with the zones of "disturbed" ground on land. The offshore deformation features are probably the result of the same catastrophic earthquake. These acoustic profiling results, with such excellent horizontal and vertical definition of disturbed features, are a significant contribution towards developing models for the process of surface disturbance onshore.

Data Acquisition

Much of the single channel, high resolution data were acquired on a 28 kHz Knudsen 320M echosounder, illustrated here. Also, Datasonics Chirp II profiler data was collected. Navigation data for track plots was collected with a Trimble ProBeacon XR differential GPS. Data were displayed on a laptop running Fugawi moving map display software which allowed decisions about coverage and targets to be made on the spot.



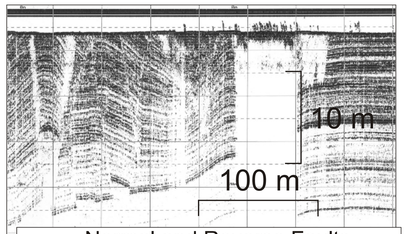


Disrupted Riverbed

Hummocky riverbed resulting from differential subsidence. Sub-bottom echos were not returned where bedding is disrupted, and excess water was expelled. Consequent loss of volume has depressed the riverbed.

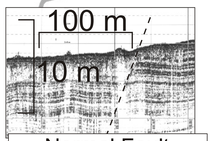
Rotated Block

North-south section through an elliptical block of glaciomarine sediment that rotated along a spoon shaped glide plane. Northwest of this section, profiles reveal that the downward tilted edge of the block deteriorates into a series of faulted blocks and a sand blow.



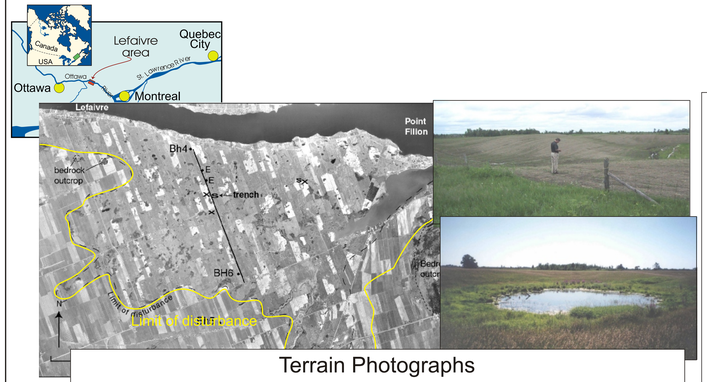
Normal and Reverse Faults

Faults have distorted the fine silts and clays. Underlying sand has been expelled as a sand blow with the characteristic downturned edges of the laminated strata.



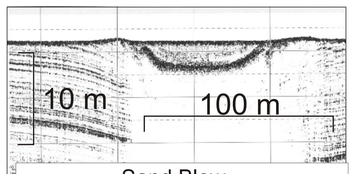
Normal Fault

A rare instance of an isolated, normal fault, with a throw of about 4 m. Sedimentation subsequent to the event has created the massive looking deposit over the downthrown block.



Terrain Photographs

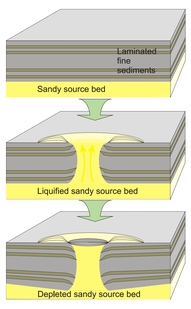
An area of about 46 sq. Km, southeast of Lefaivre, Ontario, consists of hummocky terrain and numerous small ponds which have been interpreted to be the result of a large earthquake ca. 7060 BP. Extensive high resolution single channel profiling in the river has revealed similar features.



Sand Blow

Example of a sand blow near the rotated block. Profile shows the downward turned edges of laminated fine grained sediments. The bottom of the depression in the riverbed has been refilled with coarser sediment which does not transmit acoustic energy, hence the lack of reflections. A low berm of expelled sediment still surrounds this blow.

Development of a Sand Blow



Sand blows are one of the most recognizable features visible after ground shaking. Initially, water saturated sediments are stable (top).

Strong ground motion causes excess pore pressure to develop, followed by upward flow of pore water. If water velocities are sufficient, sediments are carried to the surface (middle). A cone may be developed.

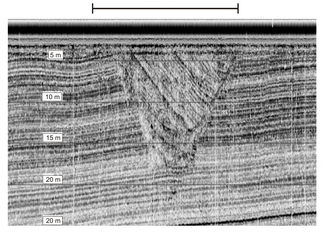
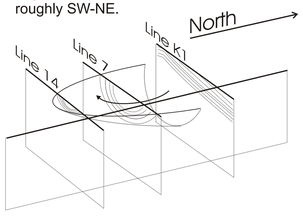
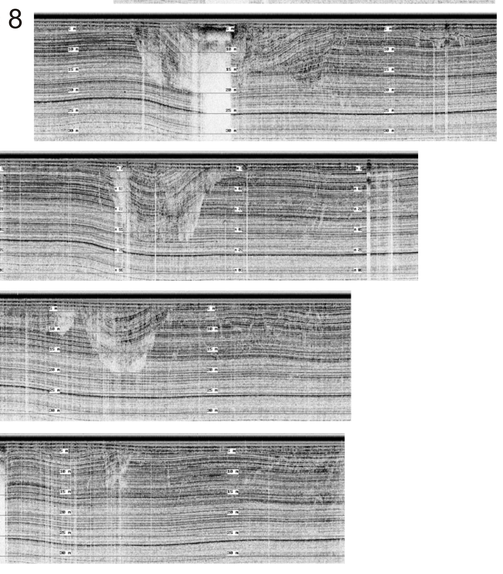
Depletion of the underlying sand layer causes the overlying sediments to collapse into the cavity. The depression may fill with water, on land, or may have sediment deposited in it, in a depositional environment (bottom).

The Rotated Block

One of the finest examples of disturbance and deformation came with the discovery of a block of glaciomarine sediments that had rotated, in situ, leaving a large proportion of its laminated sediments intact. The sonar profiles, on the right, are east-west slices through the block, and illustrate how the sediments have conformed to the curved surface of the glide plane.

Line K1 shows the undisturbed bedding immediately north of the block. The transition between the undeformed sediments and the rotated block was not traversed A sand blow obscure much of the detail in Lines 11 and 8. Lines 11 to 14 intersect the block.

A south to north line, reproduced below at twice the scale of the east-west lines, shows flat, inclined beds, unbroken by classical faults.



The schematic below offers an interpretation of the rotated block. It is slightly misleading in that it represents the N-S and E-W surve lines crossing the block along the axes of an elliptical feature. In fact, the block is oriented roughly SW-NE.