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High-resolution sonar profiling of glacial and postglacial sediments in the Ottawa River near L'Orignal, Ontario

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Douma, M. and Aylsworth, J.M., 2001: High-resolution sonar profiling of glacial and postglacial sediments in the Ottawa River near L'Orignal, Ontario; Geological Survey of Canada, Current Research 2001-D4, 9 p.

Abstract

In 1999, a high-resolution sub-bottom sonar survey in the Ottawa River, 5 km west of L'Orignal, Ontario, indicated faulted Champlain Sea sediments. In 2000, detailed grid surveys consisting of 42 line kilometres of single-channel sub-bottom sonar data were conducted to outline the extent of the faulted areas. A rotated block of sediment, 130 m by 200 m and up to 25 m thick, was discovered to have rotated about 15°. Smaller rotated sections, and areas of differential compaction occur along strike from the large rotated block. Small independently rotated blocks also occur nearby.

Faulting and rotation of sediments is attributed to earthquake shaking. Seismic liquefaction of sediment leading to 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.

Résumé

En 1999, un levé sonar haute résolution réalisé près du fond de la rivière des Outaouais, à 5 km à l'ouest de L'Orignal (Ontario), a révélé la présence de sédiments faillés de la Mer de Champlain. En 2000, on a effectué un maillage détaillé sur des lignes de quadrillage totalisant 42 km en recueillant des données sonar monovoie près du fond de la rivière en vue de délimiter l'étendue des zones faillées. On a découvert un bloc de sédiment de 130 m sur 200 m atteignant jusqu'à 25 m d'épaisseur qui a subi une rotation d'environ 15°. De plus petites sections ayant également subi une rotation, de même que des zones de compaction différentielle, ont été observées parallèlement à la direction à partir du grand bloc de sédiment. De petits blocs ayant subi une rotation distincte se trouvent à proximité.

INTRODUCTION

North of Alfred, Ontario (approximately midway between Ottawa and Montreal), in a generally flat erosional plain adjacent to the Ottawa River, lies a unique area (46.3 km^2) of very disturbed terrain consisting of hummocky ground surface and severely deformed bedding. Recently, Aylsworth et al. (2000) postulated that this disruption is the result of liquefaction, differential settling, and lateral spreading in response to earthquake shaking of sensitive marine sediments ca. 7060 BP. It is known that anomalous ground-surface motions can be created by earthquakes in soft soils. Using shallow seismic reflection techniques, Hunter et al. (2000) outlined a local, buried bedrock basin that may have caused ground-motion amplification leading to surface-sediment disturbance. The disturbed ground and the interpreted bedrock low have been mapped on both sides of the Ottawa River (Richard, 1984; Hunter et al., 2000), but to date there have been no attempts to document any evidence of disturbance in the sediments underlying the adjacent channel of the river.

In the summer of 1999, geophysicists with the Terrain Sciences Division conducted a reconnaissance side-scan sonar and sub-bottom profiling survey in the Ottawa River between Chaudière Falls in Ottawa and de L'Orignal Bay, 80 km downstream. The objective of the reconnaissance survey was to characterize the sediment type underlying the river channel and also to determine whether the severely disturbed terrain, observed onshore and tentatively attributed to liquefaction of sensitive sediments during earthquake shaking, continued offshore.

Profiling revealed that the main channel of the Ottawa River has a U-shaped cross-section and is floored by an acoustically impenetrable bottom. The channel is flanked by shallow, 2–3 m deep shelves extending to the shoreline. Profiles between the channel edge and the shore revealed a succession of well defined, near-horizontally laminated sediments, up to 50 m thick, below which sub-bottom returns faded out. Although the sediments are as yet unsampled, they are probably glaciomarine sediments, informally known as Leda clay, deposited in the Champlain Sea. Contrary to this general pattern of near-horizontal laminations, a south-to-north profile off the eastern tip of Point Filion, in the 1999 reconnaissance, showed a clear record of folding and faulting within the glaciomarine sediments. Consequently, follow-up surveys were conducted in this area in the summer of 2000 to establish the extent and character of the deformed sediments.

GEOLOGICAL SETTING

Figure 1 shows the general location of the survey area, about 80 km southeast of Ottawa. Except for portions of the survey that extended into the main channel of the Ottawa River, and the des Atocas Bay, water depths in the area are in the range of 2–3 m. The main channel of the Ottawa River can reach 30 m in depth, and the narrow channel that forms the eastward extension of des Atocas Bay can reach as much as 13 m in depth. Nearshore areas are deep enough that small boats can approach within a few metres of the shore. In summer, development of beds of aquatic plants can obscure the sediment-water interface, but do not otherwise interfere with the acoustic records.

The study area lies next to, and is probably within, a large zone of disturbed terrain and deformed marine sediments. A complete description of the adjacent, onshore, disturbed area can be found in Aylsworth et al. (2000). Onshore topography is similar in appearance to that of some massive earthflows, although no landslide scarp exists. The ground surface is gently rolling to hummocky with small shallow ponds or wet areas lying in the low areas. Local relief is of the order of 3–8 m. The elevations of the tops of hummocks are relatively uniform and coincide with the surrounding level plains and the boundaries of the disturbed areas are gradational. Within the disturbed area, two drainage ditches expose steeply inclined beds of alternating red and grey clay beds, occasionally offset by small horizontal faults. In some parts of the ditch wall, mixing of clay beds has obscured their boundaries, and sand lenses and flame structures are locally present. A sand boil was found near one ditch, and large patches of sand occur randomly about the area. Until further investigated, the possibility exists that some, or most, of the sand patches are not sand blows, but rather the remnants of fluvially deposited sand laid down when the Ottawa River flowed over a much wider area than it does today. A tree encased in the deformed sediments was dated as 7060 ± 80 BP (GSC-6470) (Aylsworth et al., 2000).

Seismic work has established that the deformed areas lie in a steep-sided bedrock basin that reaches 170 m depth. (Hunter et al, 2000). Further shallow seismic suggests that the upper 30 m of sediments are disturbed (J.A. Hunter, pers. comm., 1999).

Overall, it appears that a large earthquake ca. 7060 BP induced ground motion, likely amplified by the deep basin, that caused liquefaction of sensitive clays and sands in the unconsolidated Champlain Sea sediments (Aylsworth et al., 2000).

METHODS

The surveys in July 1999 and June 2000 were conducted using a Knudsen 320M™ high-resolution sub-bottom profiler, operating a 28 kHz transducer, on a supply voltage of 24 VDC. The sounder output consists of a 32-tone greyscale printout on thermally sensitive plastic medium. A detailed survey in September 2000, focusing on the rotated blocks, was conducted with a Datasonics Chirp II™ acoustic profiling system. The two transducers in this system sweep frequencies from 2 kHz to 23 kHz, and returns are digitally processed to enhance low-frequency echoes, for improved penetration, and high-frequency echos, for improved resolution of acoustic boundaries.

A Trimble ProBeacon XR™ global positioning system and a TDC-1™ data logging computer were used for real-time differential navigation. The Canadian Coast Guard beacon at Cardinal, Ontario, was used as the reference base station. Navigation fixes were stored at 5 second intervals, for production of track plots, and simultaneously transmitted to a laptop computer running Fugawi™ moving map display software. The combination of a sub-bottom profile and simultaneous updates of position, heading and speed on a moving map allowed the design of the survey grid to be altered even while underway.

Although the original survey in 1999 was conducted from the *M.V. J. Ross Mackay*, a 12 m aluminum work boat, subsequent operations were conducted from a 5 m aluminum open boat, powered by a 20 horsepower outboard motor. Survey speeds were approximately 6 km/h in calm conditions, although in windier weather, survey speed varied somewhat, depending on wind direction. The effect of river current in the survey area was negligible.

RESULTS

A generalized track plot of the area that was surveyed in detail in 2000 is shown in **Figure 2**. Line 63 traces the original Knudsen sub-bottom profile recorded in July 1999 and is depicted in **Figure 3**. This profile reveals a 25 m thick section of southeasterly dipping, uniformly laminated, glaciomarine sediments that has been disrupted by faulting and folding. The glaciomarine sequence of sediments probably outcrops at the river bed, or is covered by a thin veneer of modern sediments that cannot be resolved by the sub-bottom profiles. The texture of the river bed shown on side-scan sonar records suggests bioturbation, and beds of aquatic vegetation are evident on sub-bottom and side-scan records.

Deformation in the sediments are predominately reverse faults, with dip angles ranging from 40° to 65° and throws of up to 7 m between up- and down-thrown blocks. Most of the fault planes between the larger blocks are obscured, either by distortions in the shear zones, possibly by gas, or because the sounder passed over the zone at an oblique angle, which would also distort returns. Multiple passes over the area show that this particular zone covers an area of several hectares. Laterally, the larger faults transform into smaller faults, and eventually disappear altogether.

Further evidence of disruption of sediments is shown in **Figures 4** and **5**. Chirp sonar records of a series of parallel passes reveal a package of glaciomarine sediments that has been rotated in place along a curved failure surface. The vertical exaggeration of the records suggests that the beds have been virtually upended, although the most extreme dips are only about 15° to the north. The series of sections, both in a south-to-north orientation, and in a west-to-east direction, makes it possible to visualize the feature.

Line 15 lies just to the east of the margin of the rotated block in question. The small faults in the centre of the panel disappear farther west, and may represent the edge of another disturbed zone east of line 15.

Line 17, 50 m west of line 15 shows the eastern edge of a slump. Although the slump extends to only 10 m depth, the beds have rotated 11° from horizontal. This profile also shows that the area 75 m south of the rotated block is dissected by small reverse faults extending from the surface down to about 12 m.

Line 20, 100 m west of line 15, shows the rotated block at its maximum vertical dimension, about 23 m. Subsequent profiles not illustrated here, but plotted on the trackplot (**Fig. 2**), reveal that the rotated block increases in width, both at the surface and at the bottom of the glide plane. The small faults visible on profile 17 have disappeared, and the laminations are undisturbed. The white area at the southern margin of the profile is caused by biogenic gas which has been trapped by a near-surface layer. The effect of gas bubbles is to impede the propagation of acoustic energy, thus masking the underlying features.

All of the south-to-north profiles west of line 20 show an extensive area of gas masking, with occasional 'windows' that reveal laminations. The extent to which the laminated portions are distorted increases to the west, and eventually develop into the disturbed section shown in **Figure 3**, 400 m west of line 15.

West-to-east profiles (**Fig. 5**) across the rotated block reveal curving reflectors that are roughly bilaterally symmetrical about a vertical plane that trends southwest to northeast. Line 14, in the south, shows a small rotated block of sediment, similar to the eastern sections of the feature depicted in lines 17 and 20. This feature develops into the curved block shown in line 12, over a distance of only 100 m. Line 7, about 25 m north of line 12, shows the block becoming wider, and increasingly disrupted by small faults.

A layer of shallow gas masks the centre of the feature in line 8. Sediments are further disrupted within the curved block, and there is the development of some faulting, steeper than the glide plane of the rotated block, at the east edge of the feature. The gas and remnants of the feature persist for another 50 m northeast (line 11), but only 50 m further, along line K1, there is no evidence of disturbed sediments.

The step-wise progression of profiles, only some of which are shown here, allow the deformed beds to be visualized in a conical shape, since the sub-bottom profiles across the dip (**Fig. 4**) show flat, inclined beds, like a short section of a hyperbola or parabola, while longer profiles at right angles to the dip develop into the curved surfaces shown in Figure 5. **Figure 6** illustrates the geometry of the feature in a schematic manner. No west-to-east profiles were recorded over the critical zone between line 11 and line K1, and thus the nature of the transition between the rotated block and the undisturbed sediments in the northeast remains in question. Two possible alternatives are that the glide plane that confines the disturbed block arches back to the surface, as it does at the southwest end of the block, or that there was no rotational translation at the northeast end of the block and that the sediments there were disrupted, but not transported.

SUMMARY

Records of a sub-bottom profiler survey of a portion of the Ottawa River near L'Orignal were examined, and the locations of two areas of extensive disruption to the glaciomarine sediments were identified and described. One area shows folding and reverse faulting consistent with a compression of the sediments. Similar, although less graphic folds and faults occur throughout the survey area. A second disturbed area, covering several hectares, and extending to over 20 m in depth, is a spoon-shaped glide plane, where sediments have been folded semi-symmetrically and slightly faulted, but are otherwise coherent within a rotated block. Portions of the rotated and extruded block of sediments probably originally projected above the river bed, but have been subsequently eroded by the Ottawa River.

Distortion of the Champlain Sea sediments in the adjacent onshore areas is attributed to earthquake activity ca. 7060 BP (Alysworth et al., 2000). The same event may have caused the disruption of the sediments in the survey area but corroborative evidence must be acquired. The sub-bottom profile records for much of the area remain to be examined and a few more kilometres of data must be collected in critical areas so that a clearer picture of deformation features and their genesis may be compiled.

ACKNOWLEDGMENTS

Our thanks to R.A. Burns, R.L. Good, and A. Buttle, all of the Terrain Sciences Division, who ably and cheerfully contributed to the marine component of the survey, despite the tribulations of brilliant sunshine and calm weather. We thank Greg Brooks for critically reviewing the manuscript.

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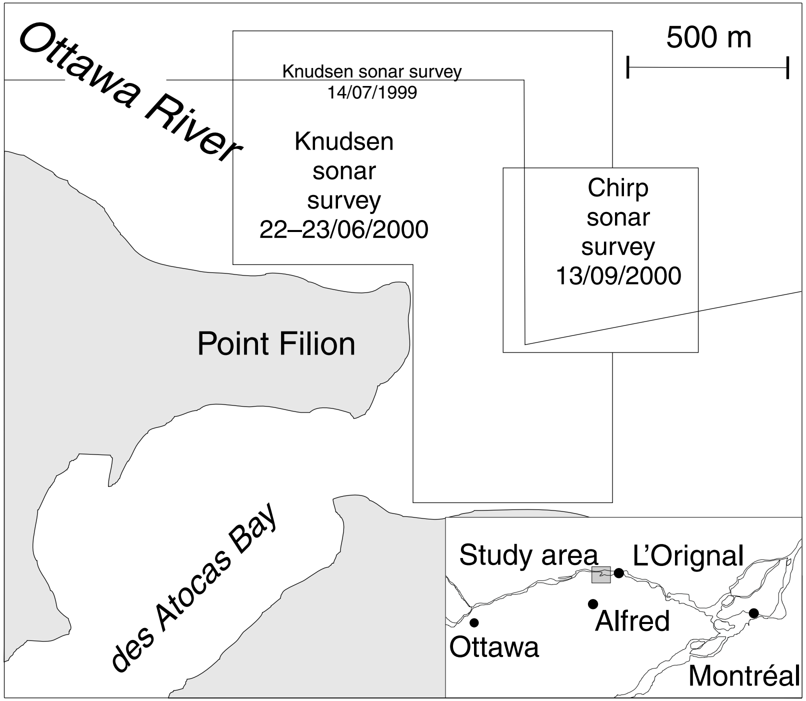

Figure 1. Location diagram showing the general survey area.

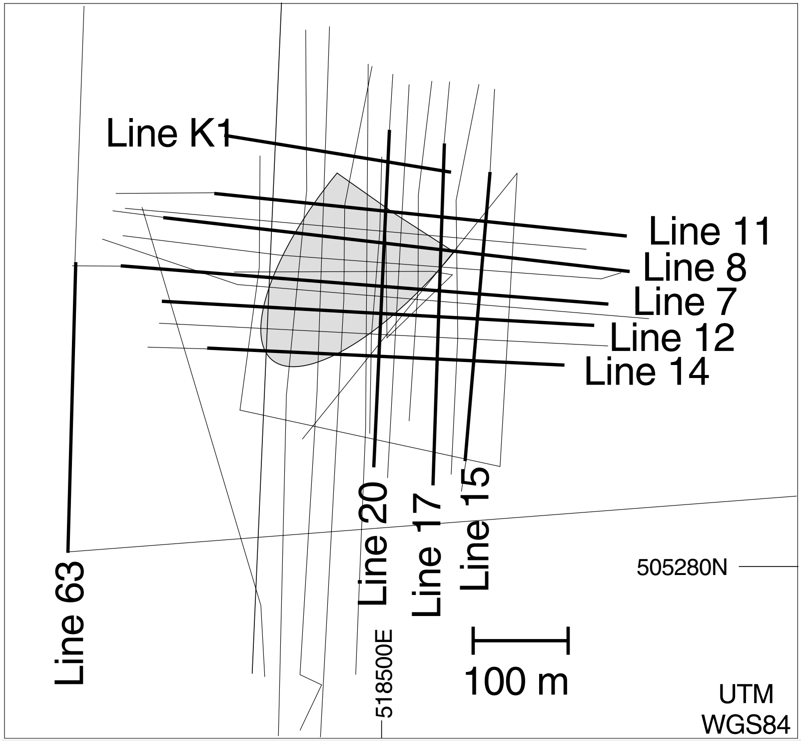

Figure 2. Track plot of the Chirp sonar survey area. Labelled, dark traces represent the profiles discussed in this paper. The thin traces show the extent of the coverage, but are not specifically discussed. The shaded area is the location of the rotated, disturbed zone.

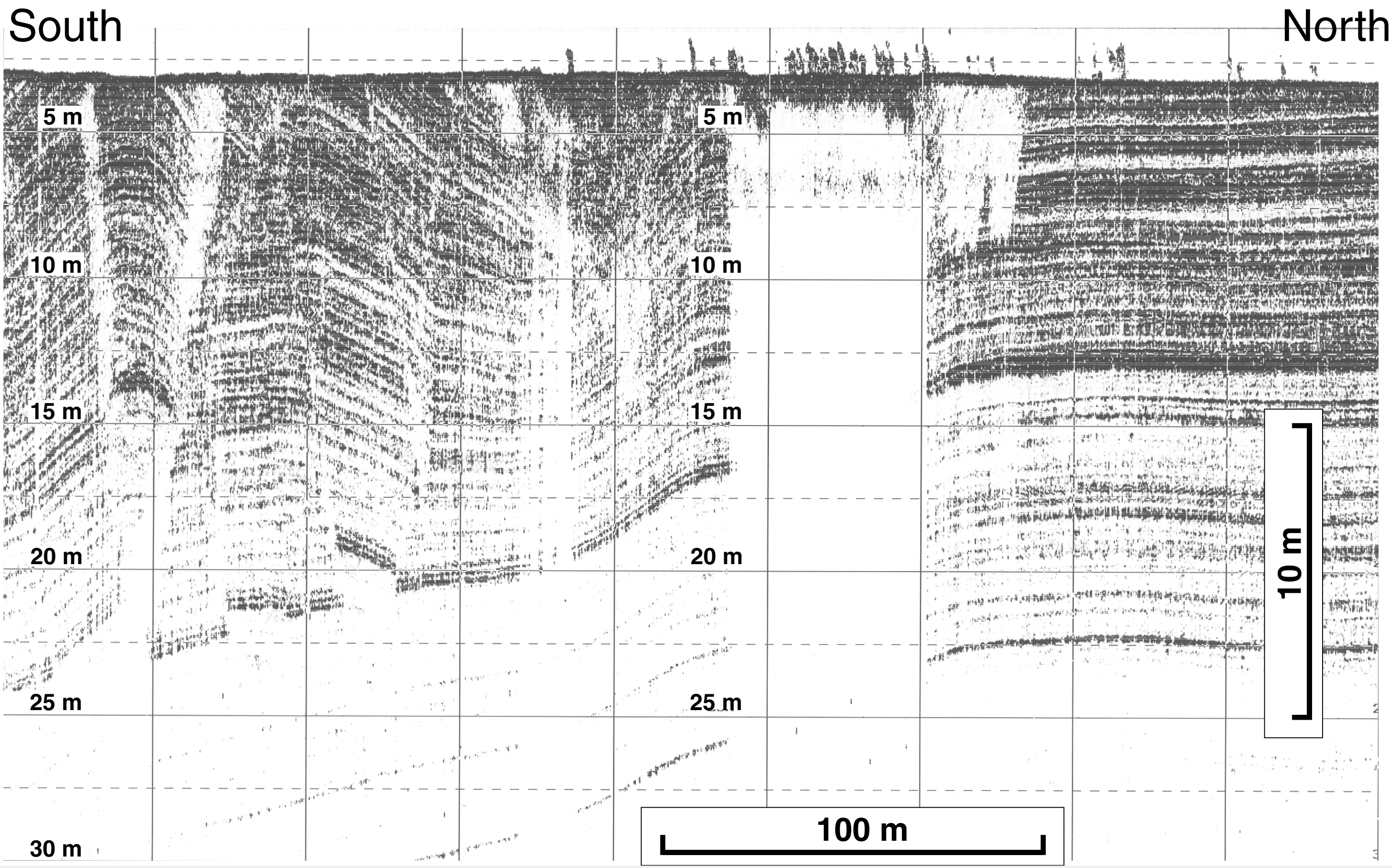

Figure 3. Sub-bottom profile of line 63, showing the folded and faulted nature of the glaciomarine sediments underlying the Ottawa River. Vertical exaggeration is 7.7x.

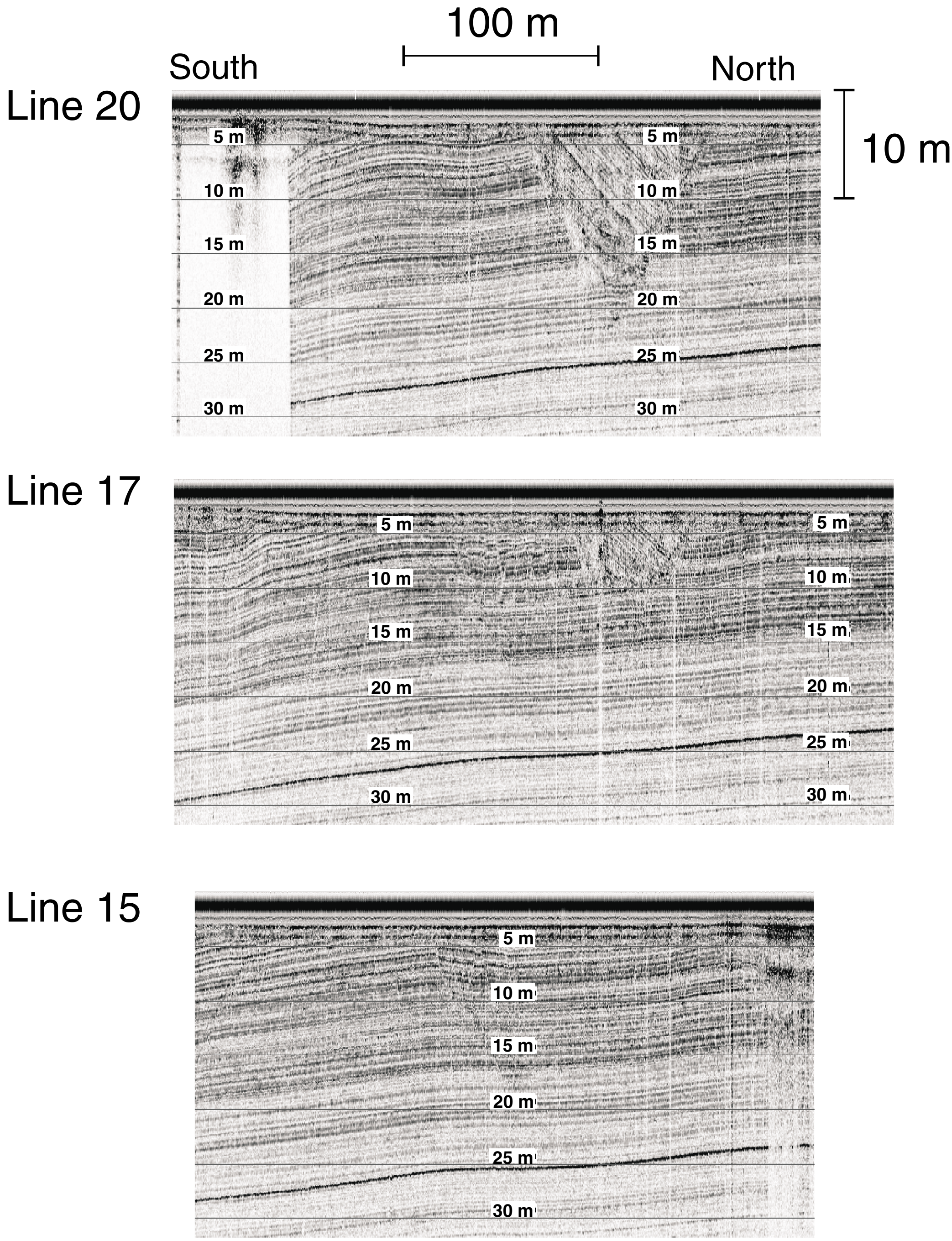

Figure 4. South-to-north profiles showing the rotated block of glaciomarine sediments. Vertical exaggeration is 5.5x.

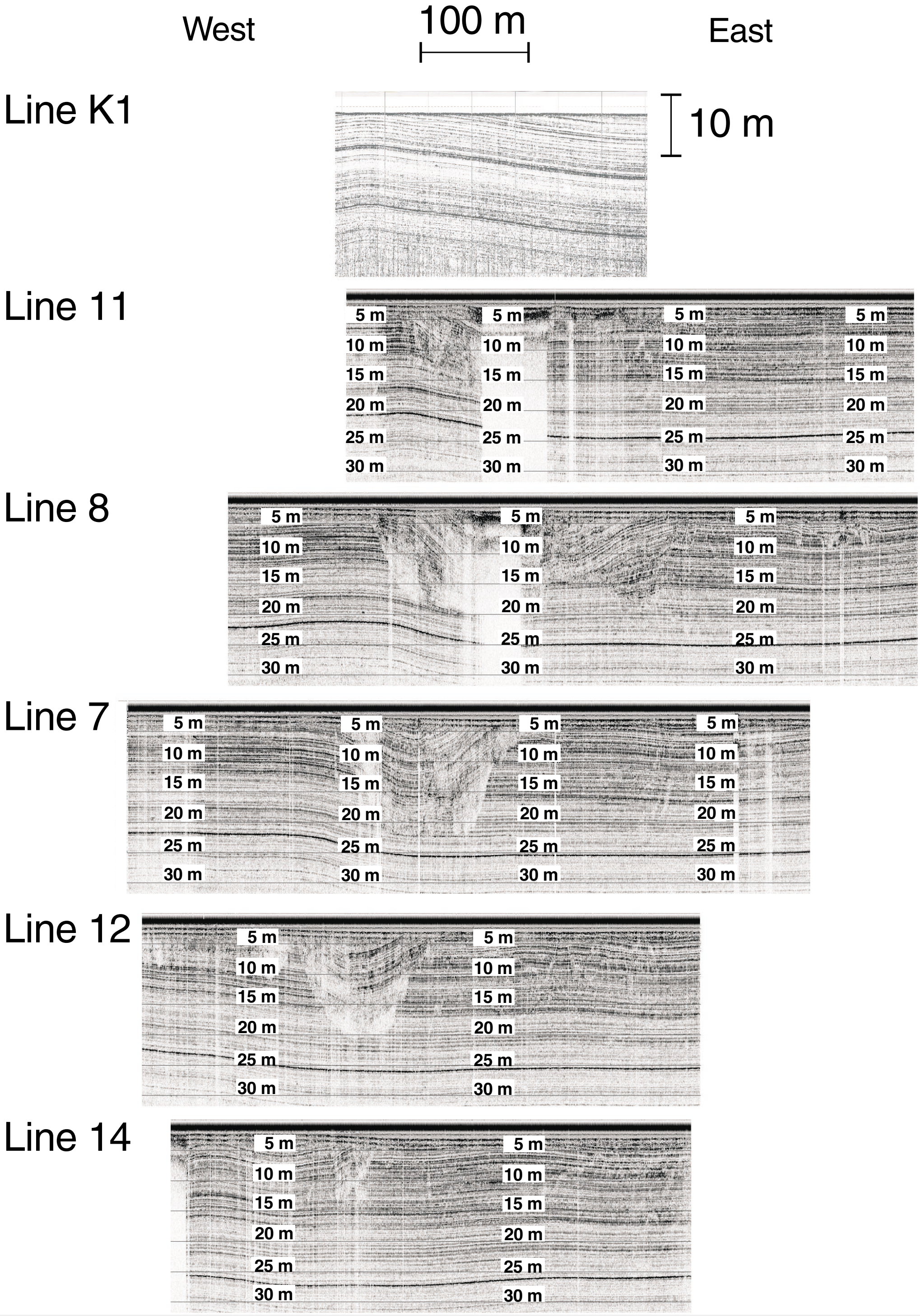

Figure 5. West-to-east profiles showing the gradual northward deepening of the disrupted sediments, and the abrupt transition back to undisturbed bedding. Vertical exaggeration is 5.5x.

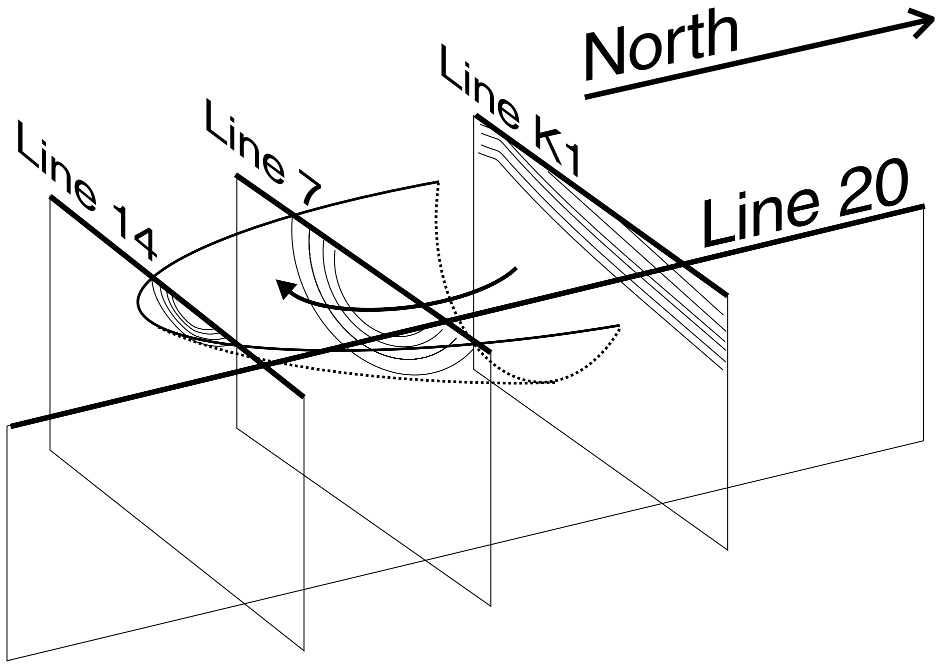

Figure 6. Conceptual drawing of the rotated block of glaciomarine sediments. Sediments at the south end of the block appear to have been squeezed or rotated upward, and subsequently planed by river erosion.