

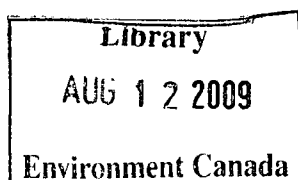
**Data on the distribution and stability of St. Lawrence River sediments  
at Cornwall, Ontario**

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## **NWRI Research Summary**

### **Plain language title**

NWRI has mapped the sediment deposits in the St. Lawrence along the Cornwall waterfront and measured their stability.

### **What is the problem and what do scientists already know about it?**

Earlier studies have shown that sediments at Cornwall are contaminated and may have to be remediated. Previous surveys by NWRI have located the fine-grained deposits with which contaminants are associated and measured their stability. Additional data about sediment distribution, thickness and stability are required at two sites where only limited data were collected previously.

### **Why did NWRI do this study?**

NWRI scientists have been conducting sediment investigations in support of the St. Lawrence River (Cornwall) Remedial Action Plan since 1993. This particular study was concerned with determining the characteristics of deposits in two zones, which have been identified as requiring additional information on sediment distribution and stability. The study also included preliminary tests on the impact of the wake from pleasure-boat traffic on exposed sediments

### **What were the results?**

Better resolution of the bathymetry and bottom-sediment type is now available as the result of detailed surveys with multi-beam sonar and a seabed-classification system. Limited data on sediment stability collected with a seabed flume and acoustic logger suggest that the deposits are stable. Further studies may be required in areas of high gas content to determine the effect of degassing of sediments on the stability of the deposits. Measurements of the erosion of sediments by boat traffic were inconclusive because of dense macrophytes and should be repeated when macrophytes are not present.

### **How will these results be used?**

The results will contribute to the development of a sediment-management framework for the St. Lawrence River (Cornwall) AOC.

### **Who were our main partners in the study?**

Canadian Hydrographic Service, DFO  
Ontario Ministry of Environment

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## **ABSTRACT**

There has been on-going research by NWRI on sediments located along the Cornwall, Ontario waterfront of the St. Lawrence since 1993. These fine-grained sediment deposits are repositories of contaminants originating from historical industrial discharges. Previous investigations focussed on the largest zone (Zone 2) of the 4 areas being investigated. This study was concerned with deposits within the areas designated as Zone 1 and Zone 3, as well as with preliminary testing of sediment resuspension in Zone 2.

Investigations were based on a combination of acoustic mapping, underwater video, deployment of acoustic dataloggers to measure changes in the position of the sediment-water interface, sediment-thickness measurements and testing of the erodibility of the sediment surface with an in-situ erosional flume. Multi-beam sonar was employed to provide high-resolution bathymetric detail of the three zones.

Acoustic and video monitoring and seabed-flume measurements all suggest that the fine-grained sediment deposits in both zones 1 and 3 are stable which is to be expected because they occur in bathymetric lows shielded from the river currents. No measurements were made, however, to determine whether sediments with high gas content might be less stable because of the disruption of the sediment surface produced by the gas.

The extensive macrophyte coverage in Zone 2 appears to provide protection from the turbulent energy produced by pleasure boats. The effect of this turbulence in the absence of macrophytes is unknown.

## **Introduction**

Persistent contaminants in the aquatic environment are often associated with fine-grained sediment deposits. Information on the spatial extent, characteristics and stability of the deposits is needed to support management decisions about their remediation.

Environment Canada's National Water Research Institute has been involved in sediment investigations in support of the St. Lawrence River (Cornwall) Remedial Action Plan since 1993. Much of the previous effort has been directed at mapping the location of fine-grained sediment deposits located between Windmill Point and Pilon Island (WPPI) (Figure 1) and determining the physical properties of those deposits (Rukavina 1993, 1994a, 1994b, 1996, 1997, 2000). These investigations were used to optimize the collection of samples for sediment chemistry investigations (Richman 1996, 1999) as well as to determine the spatial extent, thickness, volume and stability of the deposits.

This particular study focuses on the sediment distribution and stability of fine-grained sediment deposits in Zones 1 and 3. It includes additional acoustic mapping, underwater-video reconnaissance, sediment-thickness measurements, deployment of fixed-frame acoustic dataloggers and sea-bed flume measurements of the critical water velocity required for sediment erosion. Sediment stability was further investigated at 2 sites in Zone 2 by using underwater video to determine whether local boat traffic could produce resuspension of bottom sediments.

In support of this study, the Canadian Hydrographic Service of Fisheries and Oceans Canada mapped zones 1, 2 and 3, using high-resolution multi-beam sonar. This technology provides a level of bathymetric detail previously unavailable and should prove to be useful in providing a spatial context for environmental data.

## **Study Site**

The study area is located in the north channel of the St. Lawrence River adjacent to the waterfront of Cornwall, Ontario (Figure 1). The waterfront and the nearshore bathymetry have been modified over the past century as a result of shipping and regional industrial and municipal development. As a result, the riverbed along the waterfront includes the remnants of previous

excavations and dredging and shoreline infilling. Overlying this physical heterogeneity is a distribution of sediments contaminated by historical industrial discharges (Richman and Dreier, 2001). These contaminants tend to be associated with sediment deposits consisting primarily of mud and muddy sands, which have been delineated by Rukavina (2000). Zones 1, 2 and 3 in this report are the areas designated as Boat Launch, WPPI and Tank Farm respectively, in Rukavina (2000).

## **Field Procedures**

### **Sediment Mapping - RoxAnn**

Acoustic mapping of surface sediment with a RoxAnn™ seabed-classification system (Rukavina 1998, Rukavina and Cadell 1997) has been used extensively in the Cornwall reach of the St. Lawrence River since 1993 (Rukavina, 2000). The mapping conducted during this survey, which focused on Zones 1 and 3, was used to select sites for underwater-video and acoustic-tripod measurements of sediment thickness and to supplement existing information on bottom-sediment distribution.

RoxAnn acoustic labels were converted to sediment types based on the data from the 1993-1998 RoxAnn surveys and previous ground-truth including sediment grain-size data, sediment descriptions and underwater video records (Rukavina, 2000). The acoustic-sediment types were grouped into 8 classes: mud, muddy sand, sand or gassy sediment, coarse sand, gravel, boulders/hard, submerged aquatic vegetation (SAV) on soft and SAV on hard.

The RoxAnn surveys were conducted between October 10 and October 17, 2001 (Figure 2). The survey vessel, Puffin, a 9-m aluminum launch, was equipped with a dual-frequency (50kHz and 200 kHz) digital Knudsen sounder (Model 320M) with in-hull transducers. The return signal from the sounder was processed by a RoxAnn seabed-classification system. Positions were determined with a differential GPS with corrections from the Cardinal, Ontario, beacon. The RoxAnn-output signal was converted to acoustic labels by Microplot™ survey software running on a notebook computer. Microplot logged the labels and their GPS positions at 1-second intervals and displayed them in real time on a georeferenced map.

RoxAnn response to a simulated sounder signal was logged at the beginning and end of each survey day to measure equipment stability. Position data were also checked at a geodetic benchmark to provide a measure of the static accuracy of the differential GPS system. Underwater-video sites were included as part of the survey to confirm substrate types.

Previous surveys reported by Rukavina (2000) used an Atlas Deso 10™ analog sounder with frequencies of 30 kHz and 210 kHz. The RoxAnn data for 1993-1998 were used to calibrate the 2001 survey data and adjust the acoustic labels so that they fit the earlier groundtruth data.

## **Sediment Thickness**

### **Acoustic Tripod**

The thickness of modern unconsolidated sediment was measured with an acoustic tripod designed and constructed at NWRI. The apparatus consists of a sounder connected to a 210-kHz transducer which is mounted on the top plate of a weighted tripod (Figure 3). As the tripod is lowered into the deposit, the distance between the transducer and the sediment-water interface is recorded acoustically. When the tripod reaches terminal depth or maximum penetration, there is a level or stable plateau on the sounder record. Sediment thickness is then determined by subtracting the depth of this plateau from the length of the legs.

Sites for Zones 1 and 3 were selected in areas of soft sediment identified by the current and past RoxAnn and underwater-video surveys. Actual sampling sites were recorded with the DGPS antennae mounted on the davit used to lower the tripod into the sediment.

## **STING**

The STING™ or Seabed Terminal Impact Newton Gradiometer is a penetrometer which records the deceleration from free-fall descent of a probe as it contacts and penetrates sediment deposits. The deceleration profile records the thickness of the sediment for volume estimates, as well the vertical position within the deposit of strata that have different bearing strength (Figure 4).

The probe for this study was configured with a 2-m shaft terminated with a 50-mm foot. Sites were selected in Zones 1 and 3 based on information from the RoxAnn maps, underwater video and acoustic tripod. Multiple drops were made at each site and the data were downloaded

between sites. Data quality was affected by persistent harmonics produced by the probe bottoming on hard substrate or when the shaft of the probe had hard contact with the side of vessel during deployment or retrieval. At a number of sites, the soft surface layers made it difficult to select the point of contact in the data record. Jasco Research the developer of the STING was retained to reanalyse the data and determine which records were useable.

## **Sediment Erosion and Deposition**

### **Acoustic dataloggers and video logger**

Rukavina (1996, 2000) described the use of acoustic datalogger mounted on a fixed-frame to record changes in the position of the sediment-water interface (Figure 5). The system consists of a programmable echo-sounder digitizer and logger which permits continuous and unattended collection of data for extended periods of time.

Acoustic dataloggers were deployed in Zones 1 and 3 during the October 2001 field survey (Figure 6). Equipment was refurbished on November 20, 2001 and equipped with additional batteries to extend the recording period through the winter. The loggers were recovered on April 24, 2002.

During the first 2 weeks of deployment, the frame in Zone 3 was also equipped with a video logger. The video logger is integrated with the acoustic logger and records a one-minute video segment for each acoustic-sampling event. The video provides an independent record of sediment changes which can be used to explain some of the anomalies in the acoustic data.

### **In-Situ Flume Experiments**

During the October 2001 field survey, the resistance to erosion of the surface sediments in Zones 1 was measured with an in-situ erosion flume. The procedure employed was similar to that used in Zone 2 in 2000 (Krishnappan, 2001). The flume was lowered onto the test sediment and an integrated pump was used to generate a range of surface shear stresses until a current velocity was reached sufficient to produce erosion. Measurements of the velocities of bottom currents in the vicinity of the flume were also made for comparison with the shear velocities.

### **Sediment Resuspension**

Resuspension of bottom sediments by turbulence caused by pleasure boats and commercial shipping was investigated in Zone 2 which is the area most exposed to marine traffic. RoxAnn mapping and video reconnaissance were used to locate exposed fine-grained nearshore sediments which might be vulnerable to turbulence. Most of the inshore zone in water depths less than 6-7 metres had a dense cover of macrophytes, as a result testing was limited to two small patches of exposed fine-grained sediment, 3 to 5 metres across and at depths of 2.8 to 3.5 m (Figure 7).

At each site, a tripod-mounted camera was lowered to the bottom at the edge of the exposed sediment. The Gander, a twin-engine 10m x 3m landing-craft type vessel was then aggressively manoeuvred close to and over the sites. Manoeuvres included start-up with full throttle, full reverse and passing over the sites with maximum wake. Bottom response was recorded on video.

#### **Bathymetry Mapping - Multi-beam Sonar**

As part of this study, the Canadian Hydrographic Service (CHS) conducted a detailed multi-beam sonar survey of Zones 1, 2 and 3 in October 2001. The details of the equipment and operating procedures are summarized in CHS Standing Order of Survey (in preparation). The depth data were adjusted to IGLD85 and provided by CHS as point data on a 1-metre grid.

Another facet of the multi-beam data is the recorded backscatter of the signal. Maps of the RoxAnn data and the preliminary analysis of the backscatter data from the multi-beam sonar have similar boundaries of change for sediment types. Procedures are being tested to determine how well the two methods correspond. If good agreement can be achieved the multi-beam sonar data would provide complete coverage of river bottom within the survey zones and would improve area and volume estimates for sediment types.

## **Data Analysis**

### **Sediment Mapping - RoxAnn**

RoxAnn data were edited to remove depths less than 2 m and data collected at boat speeds less than 2 m/s and greater than 5 m/s. Two metres is the shallow-water limit of the high-frequency RoxAnn system, and low and high boat speeds both result in shifts of RoxAnn labels to coarser and harder sediment classes. Depth data were adjusted to International Great Lakes Datum (IGLD) 1985 based on records from the water-level gauging station located at Cornwall.

ArcView © (Environmental Systems Research Institute Inc (ESRI)) was used to map the RoxAnn sediment classification data. Areal and volume analyses of sediment types were calculated with an ArcInfo © (ESRI) procedure which creates thiessen polygon layers for both sediment type and sediment thickness. Volumes were calculated by combining the two layers and summing the volume of each polygon by fine-grained sediment type. Volume estimates were based on the acoustic tripod data and limited to the areas of fine-grained sediments as these were the only portions of the deposit tested for sediment thickness

### **Acoustic Dataloggers**

The distance between each transducer and the sediment-water interface was recorded every 20 minutes, with each sampling event consisting of 20 readings. The data were temperature-corrected to adjust for changes in sound velocity and then filtered to remove sampling events for which the standard deviation was greater than 0.25 cm. A 72-point Fast Fourier transformation (Origin Labs) was then applied to the entire record as a smoothing technique. This is similar to daily means but treats the data as a continuous function rather than as discrete daily intervals. The changes in the sediment-water interface were compared with the daily-mean water flows for the St. Lawrence River to determine if there was any response in sediment level to water discharge.

### **Multi-Beam Sonar Data**

Surface and contour maps of bathymetry were produced in Surfer 8™ (Golden Software), a commercial Windows-based software package. Default kriging procedures were used to convert the point data to grids with 1-metre nodes. Map scale, orientation and lighting were adjusted to highlight bathymetric features.

## **Results and Discussion**

### **Zone 1**

#### **Bathymetry and Sediment Mapping**

Historically, there have been a number of major construction projects in the area including the St. Lawrence Seaway and the Moses-Saunders Power Dam. The bathymetry maps (Figures 8 and 9) derived from the multi-beam sonar data, show that most of Zone 1 is a flat basin which resembles a construction excavation. The south side has a steep slope and there is a shallow shelf along the western and north-west sides of the zone (Figure 10). Towards the east, there is a transition from fine-grained sediment to the coarser and thinner deposits of recent sediment mapped by Rukavina (2000). RoxAnn mapping in this study concentrated on the area of fine-grained sediments identified in the previous surveys. There is an apparent west-to-east transition, based on the acoustic labels, from mud on the shelf, to muddy sand and then sand east of the shelf (Figure 11). However, underwater video showed that most of the surface substrate was a fine, silty material comparable to the fine-grained sediment on the shelf. Also noted on the underwater video was that the portion of the deposit labelled as sand had a very high gas content compared to other sites, making the sediment appear acoustically harder. Figure 12 shows the gas released at a video site when the surface sediments were disturbed by the tripod. Figure 13 provides a map showing the sites and the relative amount of gas bubbles observed at each site.

#### **Sediment Thickness**

Sediment thickness as measured with the acoustic tripod ranged from 0.36 m to 1.21 m and averaged 1.01 m. The few useable STING-thickness measurements were approximately twice as large as those for the acoustic tripod. The differences between the 2 methods may be attributable to the differences in sediment resistance each apparatus encounters as well as how the instruments contact the sediment. The acoustic tripod is lowered slowly into the sediment whereas the STING freefalls through the water column. Figure 14 shows the data sites and the sediment thickness measured with the acoustic tripod and STING.

## **Areas and Volumes of Sediment Types**

Fine-grained sediments are estimated to cover 24,895 m<sup>2</sup> or 83% of the 30,012 m<sup>2</sup> surveyed. This estimate includes the substrate acoustically labelled as sand, which was the predominant sediment type in Zone 1, covering 11,964 m<sup>2</sup> (39.9%) of the area mapped (Table 1). The combined volume for mud, muddy sand, sand and SAV on soft, totals 25,327 m<sup>3</sup>. The volume estimate is based on the acoustic tripod measurements. The limited STING data indicates thicker sediment layer than acoustic tripod measurements, therefore the volume estimate should be considered conservative.

Previous estimates of area and volume for fine-grained sediments including those labelled as sand for Zone 1 were 38,261 m<sup>2</sup> and 20,173 m<sup>3</sup> for a survey area of 157,206 m<sup>2</sup> (Rukavina 2000).

## **Sediment Stability**

Figure 15 shows the location of the acoustic datalogger on the western shelf of Zone 1. There are marked differences in the data records for both transducers pre- and post-refurbishment (Figure 16), which may be due in part to the initial settling of the frames in the sediment. Stability improves after refurbishment (November 20, 2001), particularly for the right transducer. The right transducer shows sediment accumulation (decrease in range) post refurbishment. Both records appear to be independent of river-discharge rates.

While the analysis of the data for the in-situ erosion-flume experiment is still in progress, the field observations suggest that the fine-grained sediment on the shelf in Zone 1 is resistant to the levels of shear stress that the sediment would be exposed to in natural conditions (Krishnappan, pers. comm.). Similar results were reported for Zone 2 by Krishnappan (2001).

East of the shelf, it was evident from the underwater video that the sediment-water interface was more disturbed or dimpled due to the collapsing of gas pockets when the gas escaped from the sediment. This disturbance may increase the roughness and reduce the cohesiveness of these surface sediments and possibly make them more susceptible to erosion than the deposit located on the shelf. Neutrally-buoyant wood litter approximately 2-3 cm in size was observed

on the areas with high gas content (Figure 13), suggesting low water velocities at the sediment-water interface.

It is important to note that the recent investigations related to Zone 1 including the 1997 sediment sampling (Richman, 1999), the deployed fixed-frame transducers and the in-situ erosion flume experiments were all located on the western shelf. As such there has been no detailed characterization of the sediments east of the shelf, which appear to have physical properties different from the sediments on the shelf.

### **Zone 3**

#### **Bathymetry and Sediment Mapping**

The high-resolution multi-beam sonar shows up the highly variable substrate bathymetry in Zone 3 (Figure 17). Surface maps and bathymetric profiles (Figures 17 and 18) show a steep inshore slope giving way to a relatively flat offshore shelf with a rectangular depression which may be from previous construction.

The map of sediment types (Figure 19) shows that mud and muddy sand deposits are perched on the central part of the shelf and bounded on the west, north and east sides by a zone of submerged aquatic vegetation (SAV) on hard and soft substrates. There is a rapid transition to the hard substrates to the south which is consistent with exposure to higher water-current velocities.

Underwater video showed that much of the substrate mapped as sand consisted mainly of finer material with a cohesive surface layer, and that gas was present at many of the sites. The presence of gas should produce a harder acoustic label which could result in the amount of soft sediment being underestimated.

#### **Sediment Thickness**

The acoustic-tripod measurements of the thickness of the soft sediments on the shelf are mapped in figure 20. The deposit is thin in the centre (0.21 – 0.46 m) and thicker towards the north and east. (0.76-1.01m) with an overall average thickness of 0.62m. It was noticed in the

underwater video that at sites where soft-sediment deposits were thin, they were overlying a hard substrate.

The 3 sites for which there were useable STING data are also mapped in figure 20. As the deposits are thinner than in Zone 3, the difference between the STING and tripod values is smaller. It was also noted that there was clay on the foot of the STING when it was recovered from the two eastern sites.

### **Areas and Volumes of Sediment Types**

Zone 3 has a total area 49,592 m<sup>2</sup> most of which (69.9%) is covered with hard substrates such as gravel and boulders. Fine-grained sediment, including the sand, accounts for an area of 13,063 m<sup>2</sup> (26.3%) and total volume 27,060 m<sup>3</sup> (Table 2). The estimate of fine-grained sediments, which includes the sediments classed as sand, may be artificially high. This is because it is unknown what fraction of sediment labelled sand/gassy sediment is fine-grained sediment acoustically hardened by the observed high gas content and cohesive surfaces and portion that is actually sand. Sand has been observed along the boundary between high-energy flow of the main channel and the slower current velocities in the embayment.

As in Zone 1, the STING measurements of sediment thickness were greater than the acoustic tripod measurements. The volume estimate for Zone 3 is estimated using the acoustic tripod data and should be considered conservative.

Previous estimates for Zone 3 are total area of 61,725 m<sup>2</sup>, fine-grained sediment including sand covering 33,448 m<sup>2</sup> with a volume of 8,276 m<sup>3</sup> (Rukavina 2000).

### **Sediment Stability**

Figure 21 shows the position of the acoustic datalogger in relation to the bathymetry of Zone 3. The spikes in the early part of the left-transducer record (Figure 22) are equivalent to erosion of up to 8 cm. Based on previous experience, these spikes are more likely to be caused by mistrigging of the sounder than large-scale sediment movement. The later data show a loss of material with a net erosion of 1 to 1.5 cm to the middle of March and then a small amount of accumulation. The accumulation coincides with an increase in the daily-mean discharge

recorded at Moses-Saunders Dam and may be caused by flow mobilizing sediment from upstream reaches and depositing it in areas such as Zone 3.

The record for the right transducer is less variable than that for the left transducer in the early data and then follows much the same pattern up until about the end of March when there appears to be rapid accumulation of about 10 cm. This is probably due to debris settling under the transducer which may have been mobilized by the higher flow rate recorded for this time. October video-logger records show occasional clumps of aquatic vegetation tumbling on the sediment surface close to the transducers.

### **Zone 2 – Sediment Resuspension**

The two test sites were patches of exposed fine-grained sediment surrounded by dense aquatic macrophytes up to 1 m high. While the macrophytes often obstructed a direct view of the sediment, it did appear that the plants dissipated the turbulence from the boat and provided protection for the sediment. Particles that had accumulated on the plants during the growing season were resuspended by the turbulence and appeared to be organic in nature.

### **Multi-beam Bathymetry**

The multi-beam sonar data provides complete coverage of the bathymetry and much better resolution than was available in the earlier data. The improved resolution is particularly useful in identifying features which may act as bathymetric traps that collect and retain sediment and associated chemical constituents. Mercury data for the top 10 cm of 1997 cores (Richman 1999) plotted on a surface-relief map shows elevated concentrations which appear to be associated with bathymetric features (Figure 23). Site 128 is on the edge of a depression, which is also downstream of a small ridge, and Site 135 is located in a bowl close to the base of the steep inshore slope. Concentrations for both of these sites are more elevated than upstream sites which are more exposed to water currents.

Artificial features are also evident. A pipeline crib is clearly visible at the western edge of Zone 2 (Figure 23). The absence of anchor drag or ship scour, which has been seen in other multi-beam sonar studies of industrial waterfronts such as Hamilton Harbour, is useful because it

suggests that local-ship traffic is likely not anchoring in this area and disturbing the bed sediments.

### **Conclusions**

The new RoxAnn, multi-beam sonar, and underwater-video surveys have been useful in improving the resolution of bottom type and bathymetry in all three Cornwall sediment zones. Detailed investigations for Zones 1 and 3 have improved the estimates of sediment distribution and volume as well highlighting how a high gas content can modify the acoustic classification and possibly physical characteristics of the sediment deposits.

The new bathymetric data show that the western shelf in Zone 1 differs from the remainder of the zone which appears to be a remnant of previous marine excavation(s). The presence of gas in the sediments adjacent to the shelf has been observed in the video records, and is responsible for the apparent increase in the acoustic hardness and roughness of the RoxAnn labels in this area rather than change in sediment type. Approximately 72% of the 25,327 m<sup>3</sup> of fine-grained sediment in Zone 1 is considered to have high-gas content. High-gas content is important because it could affect the erodibility of the sediments by reducing their cohesiveness and increasing their roughness.

The fine-grained sediments in Zone 3 are restricted to the northern boundary of the embayment. The sediments in the centre of the area are thin and overlie a hard substrate. Thicker sediments were found on the eastern side of the deposit and adjacent to or in zones of submerged aquatic macrophytes. The southern boundary of the zone shows a rapid transition to hard substrate with gravel and boulders as the flow velocity increases towards mid-channel.

Acoustic-datalogger data indicate that the deposits in Zone 1 and 3 are relatively stable with variations in the positions of the sediment-water interface of only 1 to 2 cm over a 6-month period. The gas-rich sediments in both zones were not monitored and could be less stable because of the effect of the gas release on the cohesiveness and roughness of the sediment surface. The presence of almost neutrally-buoyant wood litter (Figure 13) and floc-like material, however, suggests that the currents are too low to cause erosion in these areas. The apparent stability of sediments in Zones 1 and 3 is consistent with the datalogger data for Zone 2 which spanned several years and large variations in river flow rates (Rukavina, 2000).

Based on the limited observations of this study, it would appear that small patches of exposed fine-grained inshore sediments are protected from the turbulence of pleasure-boat traffic by the surrounding dense macrophyte coverage. While most pleasure boat activity does occur once the macrophytes are established, the effect of boat traffic earlier in the season when sediments are not protected by macrophytes has yet to be determined.

Detailed bathymetric data made possible by multi-beam sonar is useful for identifying spatial features as well as contributing to the interpretation of physical and chemical attributes of sediment deposits. The resolution is now sufficient to identify small-scale bathymetric traps which may contain contaminants at concentrations greater than those measured at adjacent or upstream sites.

### **Recommendations for further research**

The location and extent of the sediment deposits can be attributed to bathymetric features which trap and shield the sediments from water currents and ice scouring. The characteristics of the deposits appear to be modified by in-situ processes that result in the generation of high concentrations of gas in the sediment. The stability of these gas-enriched deposits could be tested using the in-situ erosional flume to determine if these deposits are more susceptible to erosion, due to the disruption and distortion of the cohesive surface layer when the gas escapes from the sediment.

The presence of a dense cover of submerged aquatic vegetation protects sediments from resuspension by the turbulence from pleasure boat traffic. A more detailed investigation in the early spring could assess the impact of boat traffic prior to submerged macrophyte coverage becoming established.

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Table 1: Areas and volumes of sediment types, Zone 1

<b>Sediment Type</b>	<b>Area (m<sup>2</sup>)</b>	<b>Percent of Area</b>	<b>Volume (m<sup>3</sup>)</b>
Mud	5432	18.1	6061
Muddy Sand	6725	22.4	6791
Sand	11964	39.9	11555
SAV on soft	774	2.6	920
Coarse Sand	24	0.1	
Hard - Gravel/Boulders	3221	10.7	
Undefined	1872	6.2	
Total Area	30012	100.0	
Volume of fine-grained sediment + sand			25327

Table 2: Areas and volumes of sediment types, Zone 3

<b>Sediment Type</b>	<b>Area (m<sup>2</sup>)</b>	<b>Percent of Area</b>	<b>Volume (m<sup>3</sup>)</b>
Mud	48	0.1	33
Muddy sand	1891	3.8	1374
Sand	8996	18.1	5510
SAV on soft	2128	4.3	1946
Coarse Sand	560	1.1	
Glacial	186	0.4	
Hard – Gravel/Boulders	34455	69.5	
Undefined	1328	2.7	
Total Area	49592	100	
Volume of fine-grained sediment + sand			27060

## Figures

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- Figure 2. RoxAnn survey lines
- Figure 3. Acoustic Tripod
- Figure 4. STING free-fall penetrometer
- Figure 5. Acoustic datalogger
- Figure 6. Acoustic datalogger locations
- Figure 7. Zone 2 Sediment-resuspension Test Sites
- Figure 8. Zone 1 Relief map of bathymetry
- Figure 9. Zone 1 Relief and contour maps of bathymetry, detail
- Figure 10. Zone 1 Bathymetric profiles
- Figure 11. RoxAnn sediment types, Zone 1
- Figure 12. Photo of gas released from Zone 1 sediment
- Figure 13. Zone 1 Video-tripod sites
- Figure 14. Zone 1 Tripod and STING Thickness Data
- Figure 15. Location of acoustic datalogger in Zone 1
- Figure 16. Zone 1 Datalogger record of changes in the level of the sediment surface
- Figure 17. Zone 3 Relief and contour maps of bathymetry
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- Figure 19. RoxAnn sediment types, Zone 3
- Figure 20. Zone 3 Tripod and STING Thickness Data
- Figure 21. Location of acoustic datalogger in Zone 3
- Figure 22. Zone 3 Datalogger record of changes in the level of the sediment surface
- Figure 23. Zone 2 Bathymetric features and mercury concentrations in top 10 cm of sediment cores.

Note: Unless, otherwise noted all maps are oriented so that the top of the map is north.

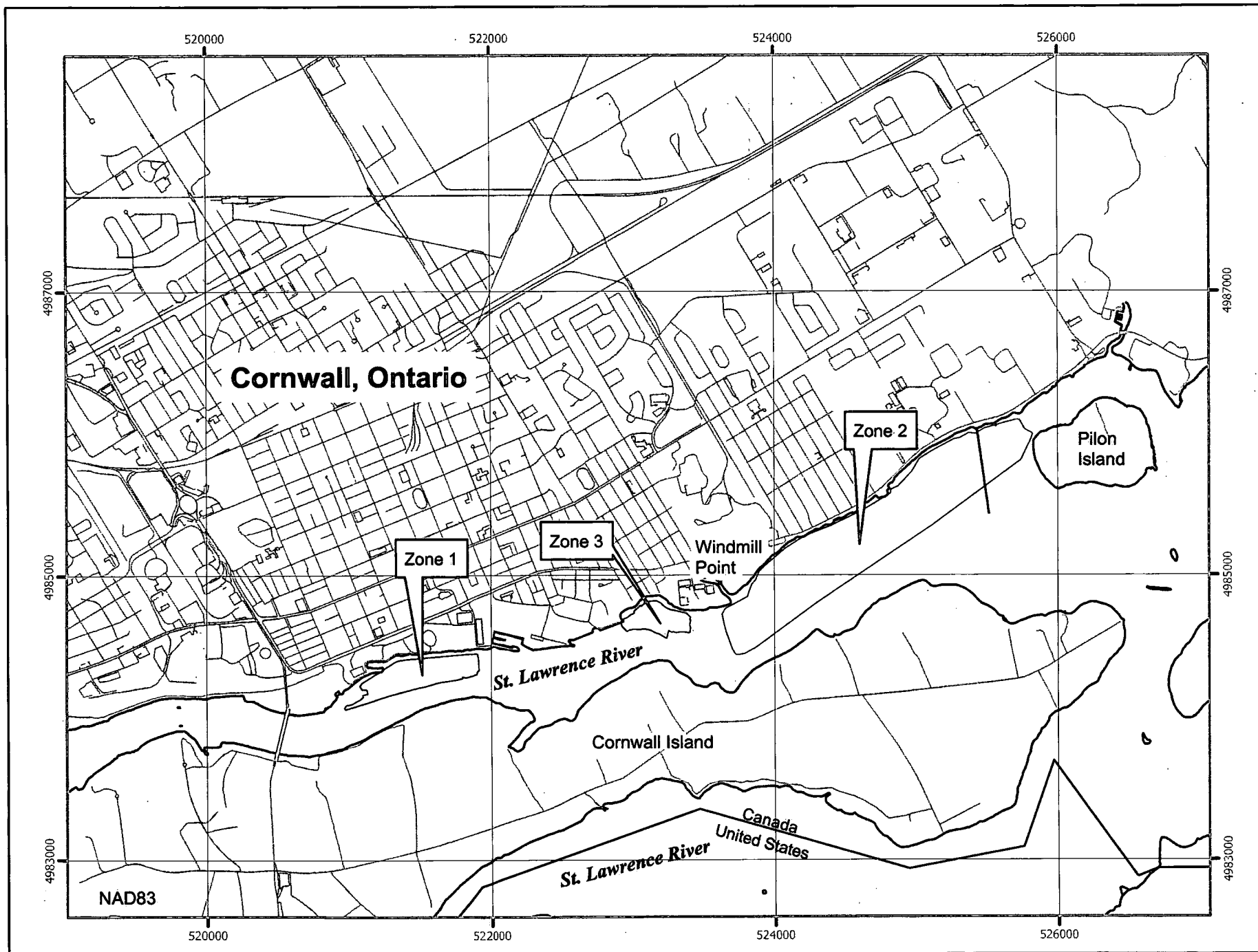


Figure 1: Study Area

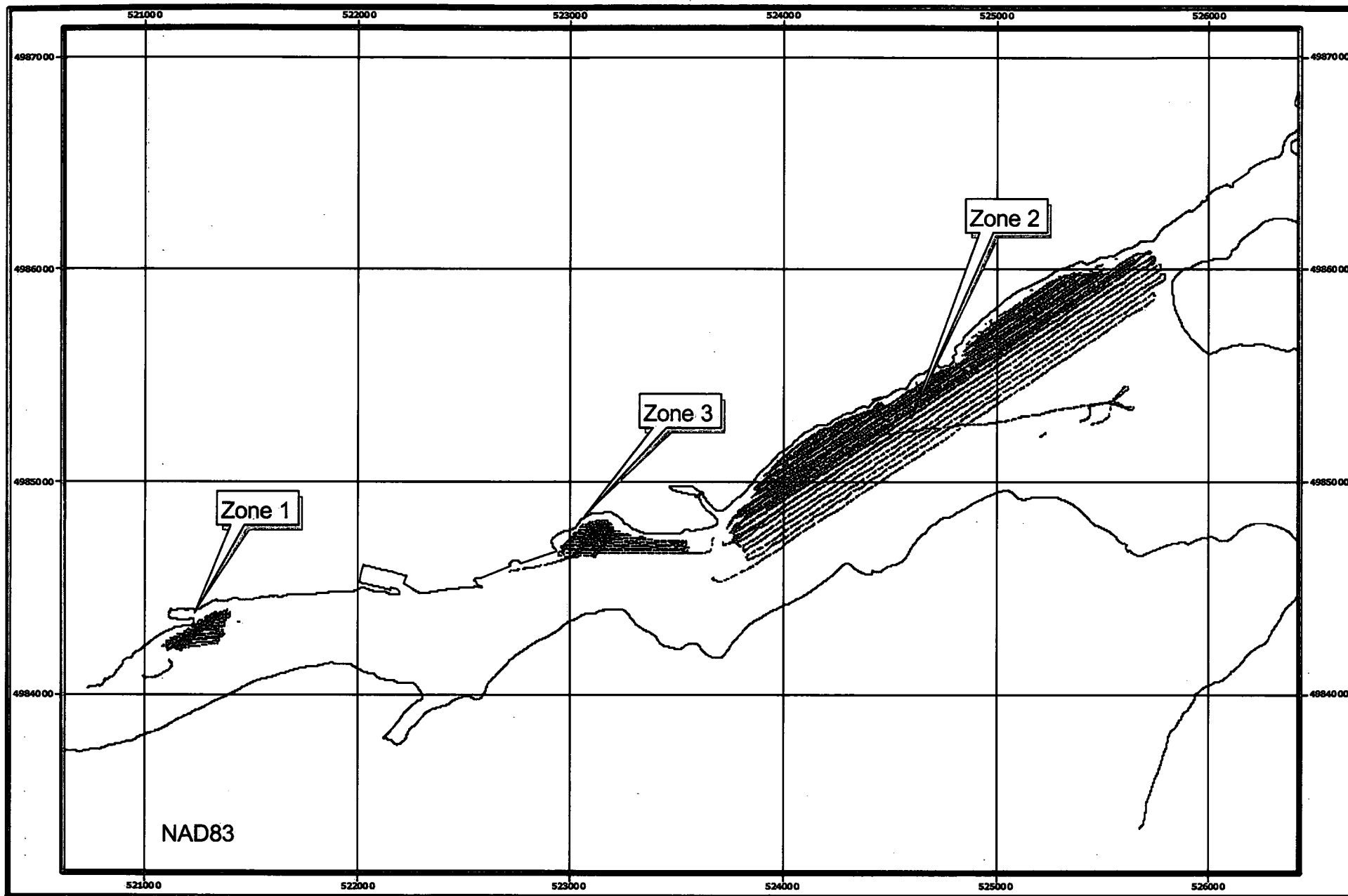


Figure 2: RoxAnn Sounding Lines (2001)

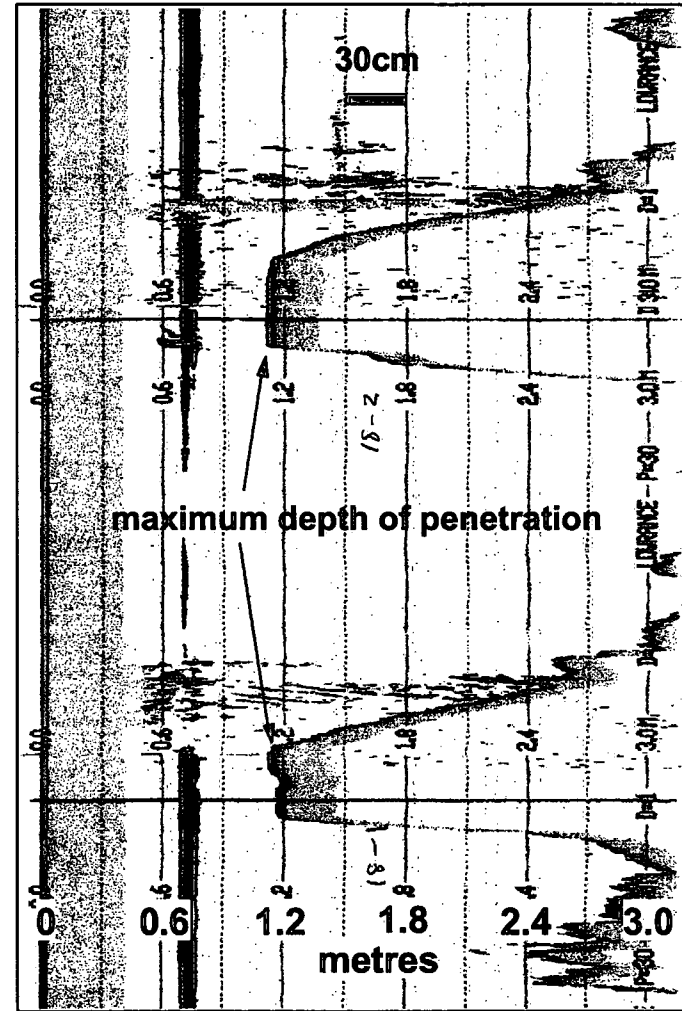
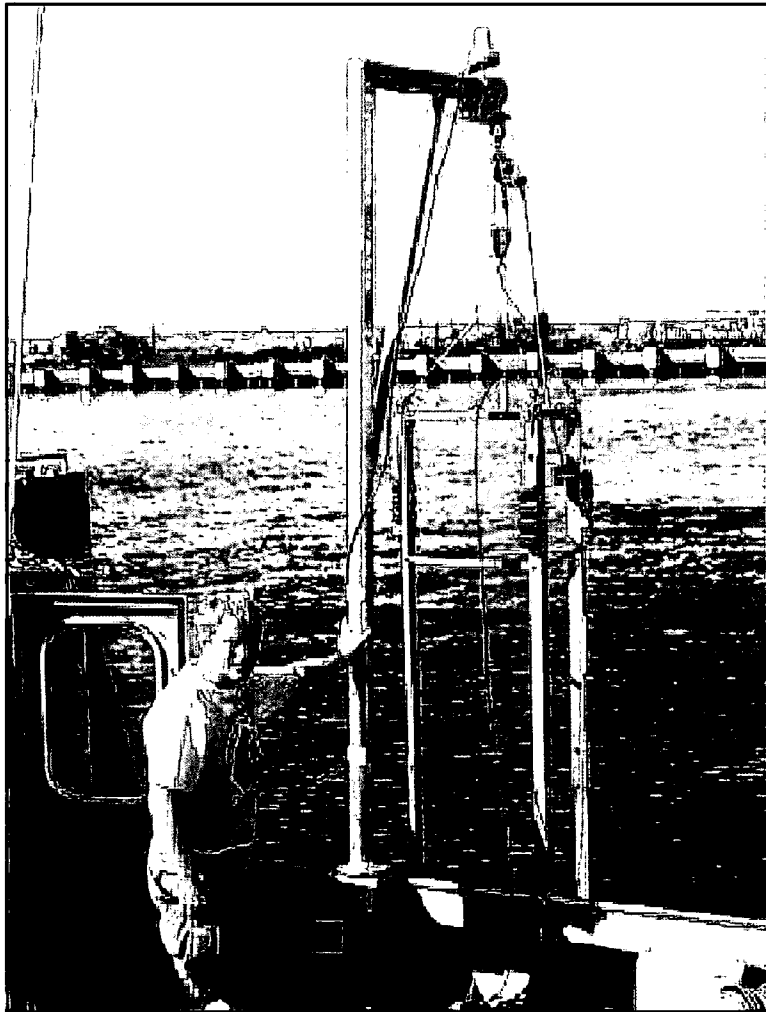


Figure 3: Acoustic Tripod

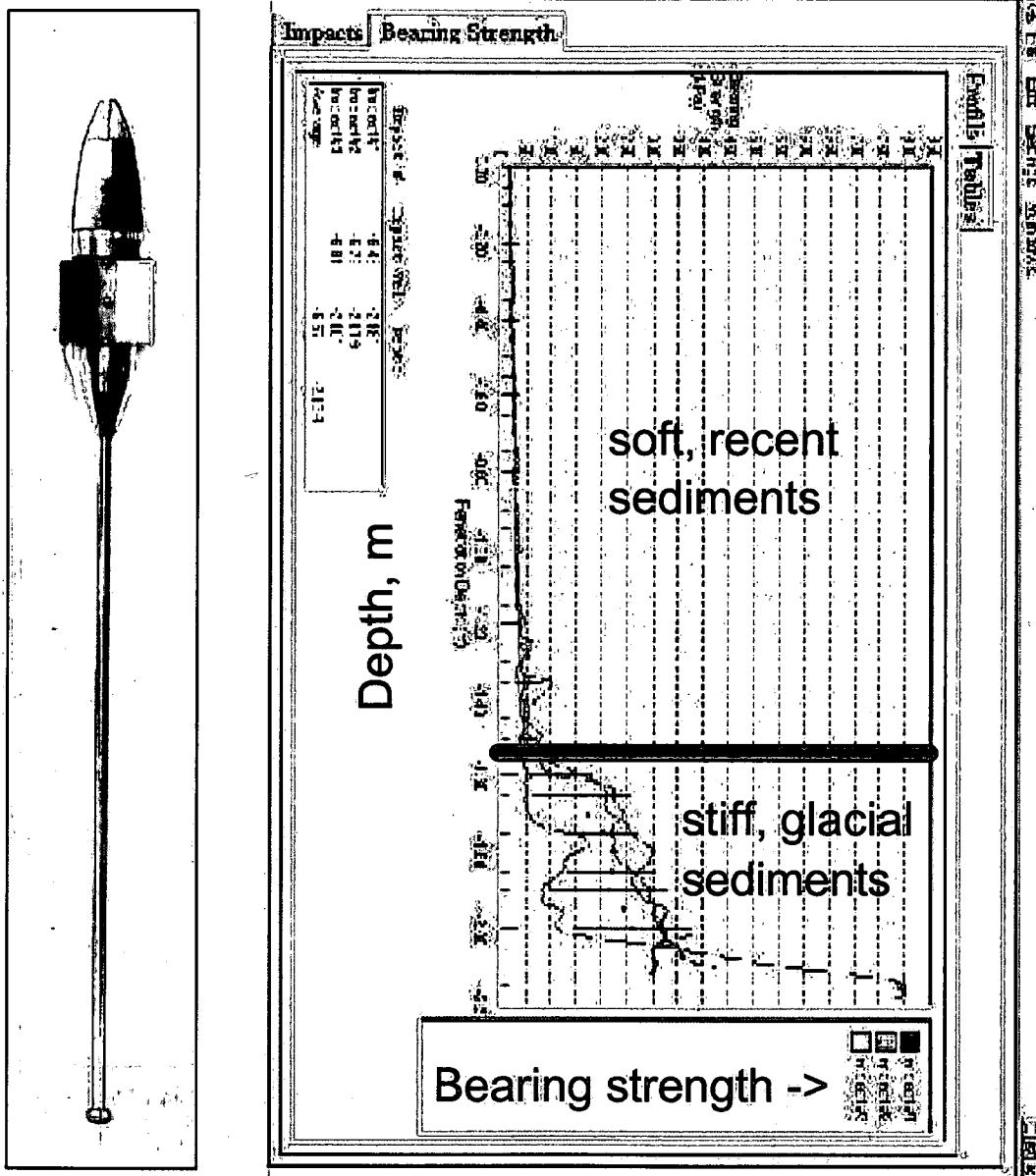


Figure 4: STING free-fall penetrometer

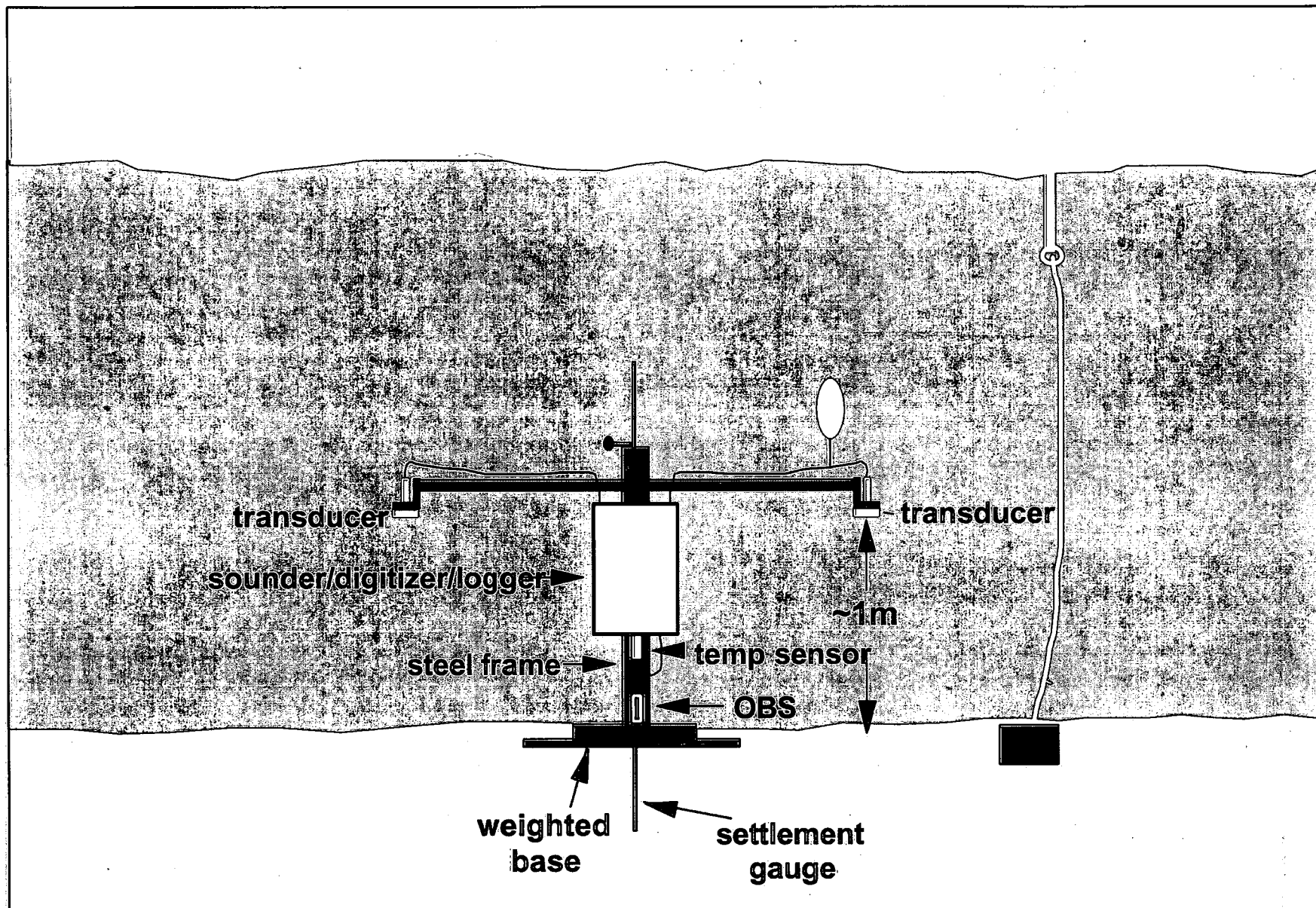


Figure 5: Acoustic datalogger

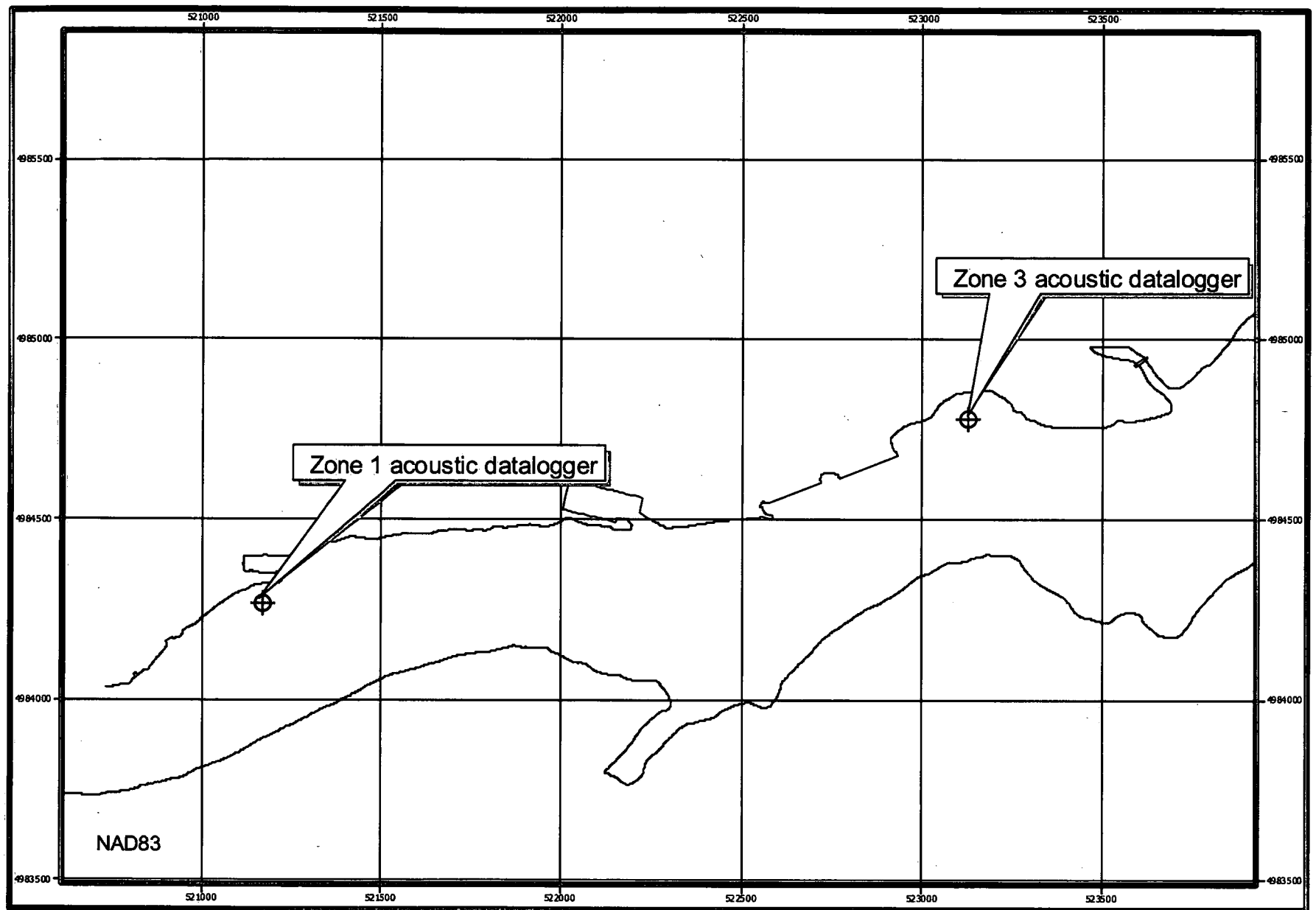


Figure 6: Acoustic Data-logger locations.

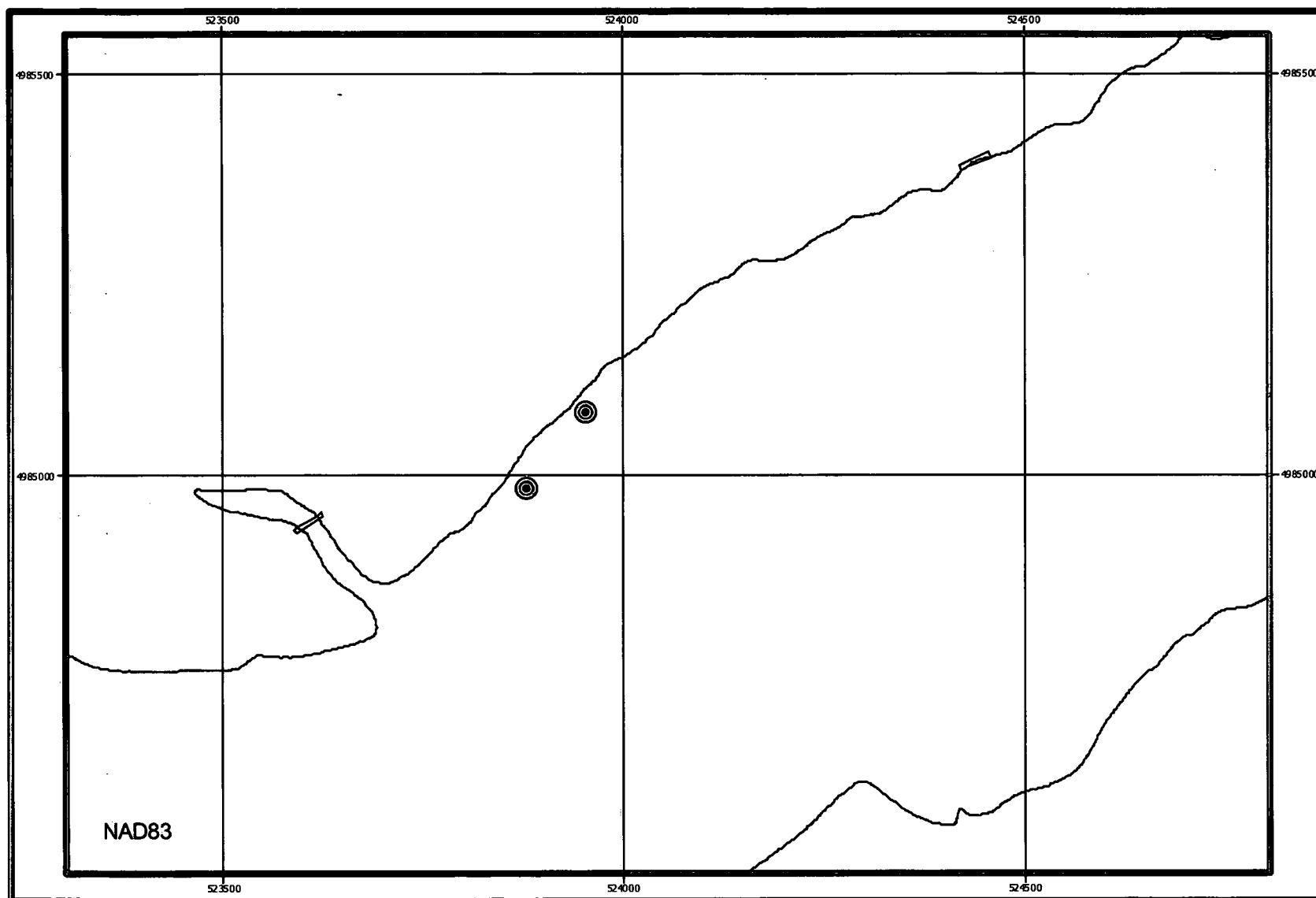


Figure 7: Zone 2 Sediment-resuspension Test Sites

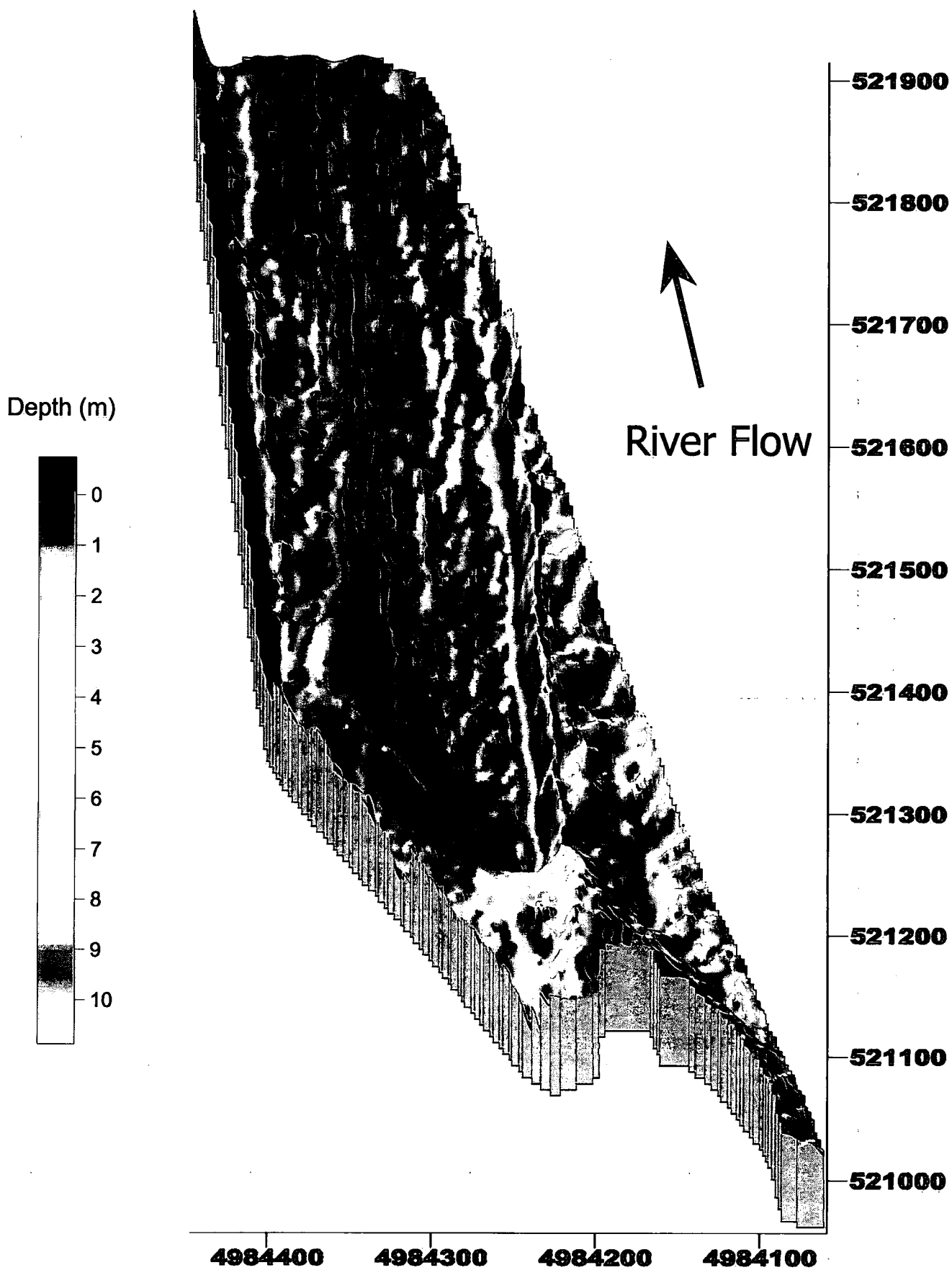
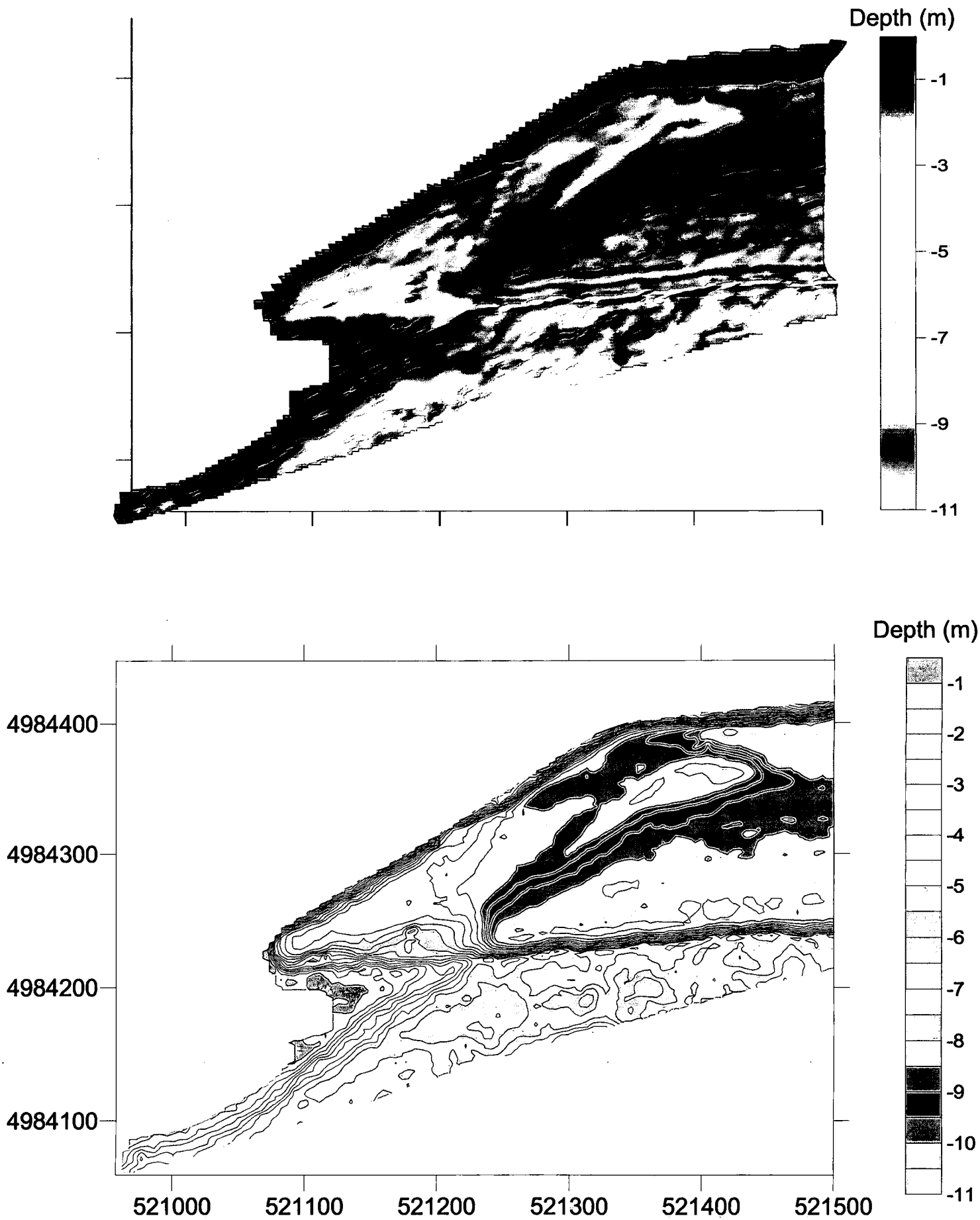


Figure 8: Zone 1 Relief map of bathymetry

Figure 9: Zone 1 Relief and contour maps of bathymetry, detail



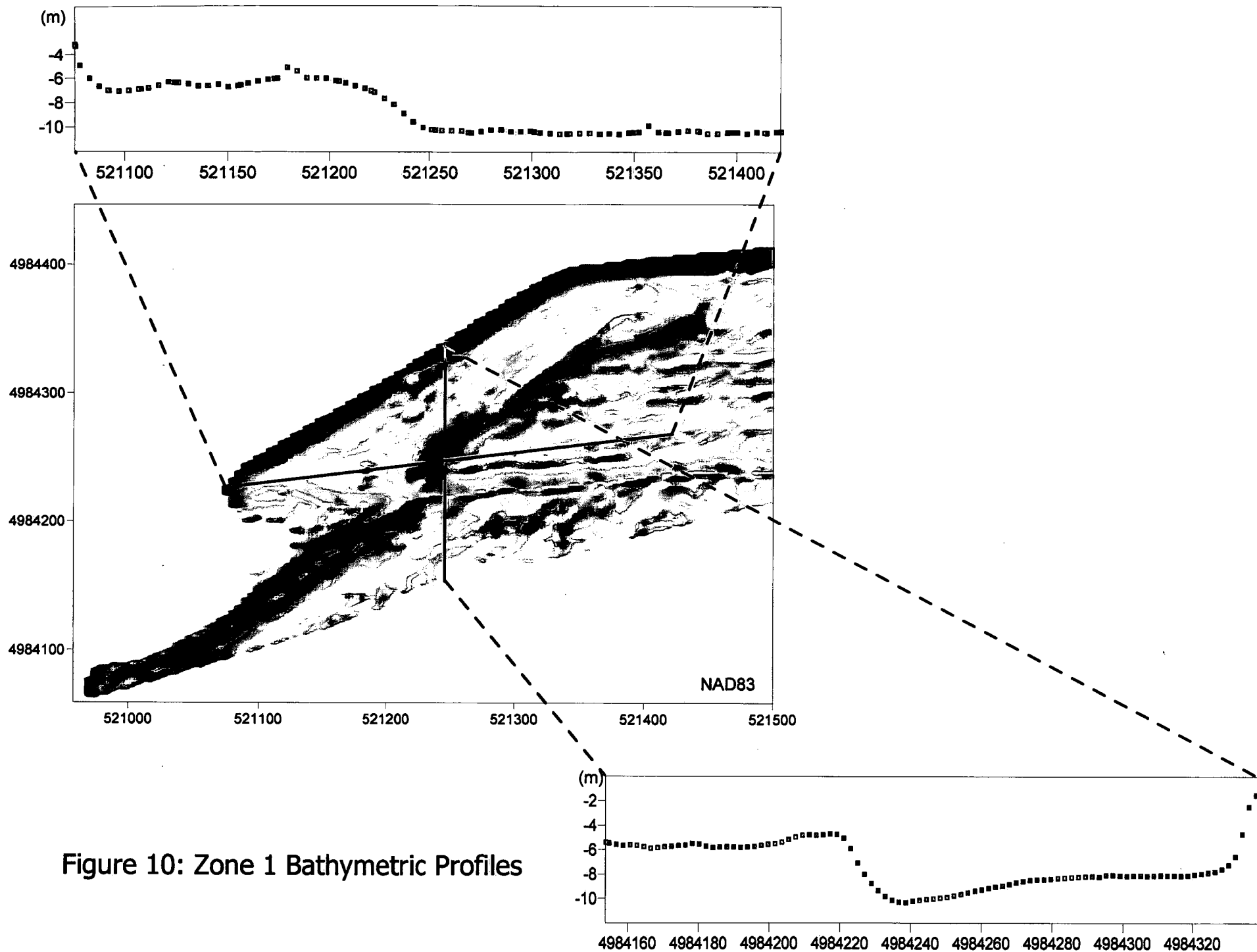


Figure 10: Zone 1 Bathymetric Profiles

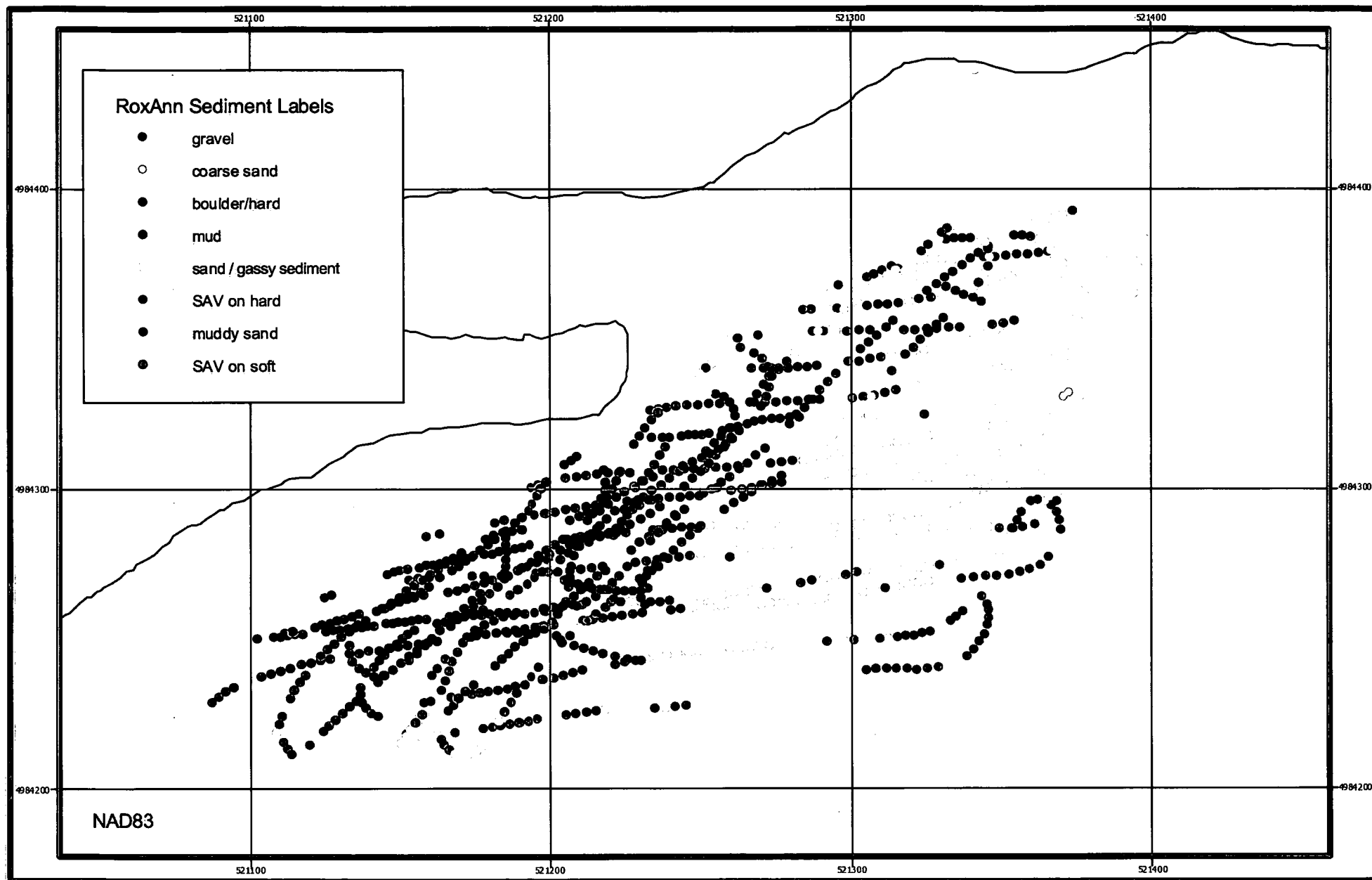


Figure 11: RoxAnn sediment types, Zone 1

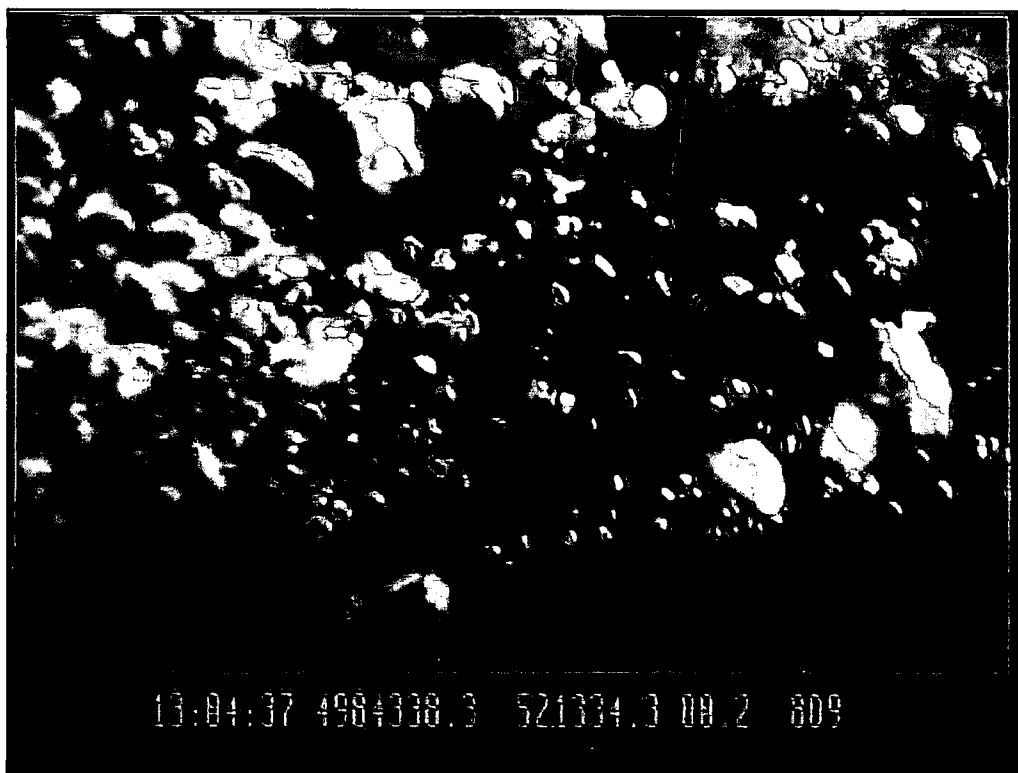


Figure12: Photo of Gas Released from Zone 1 Sediment

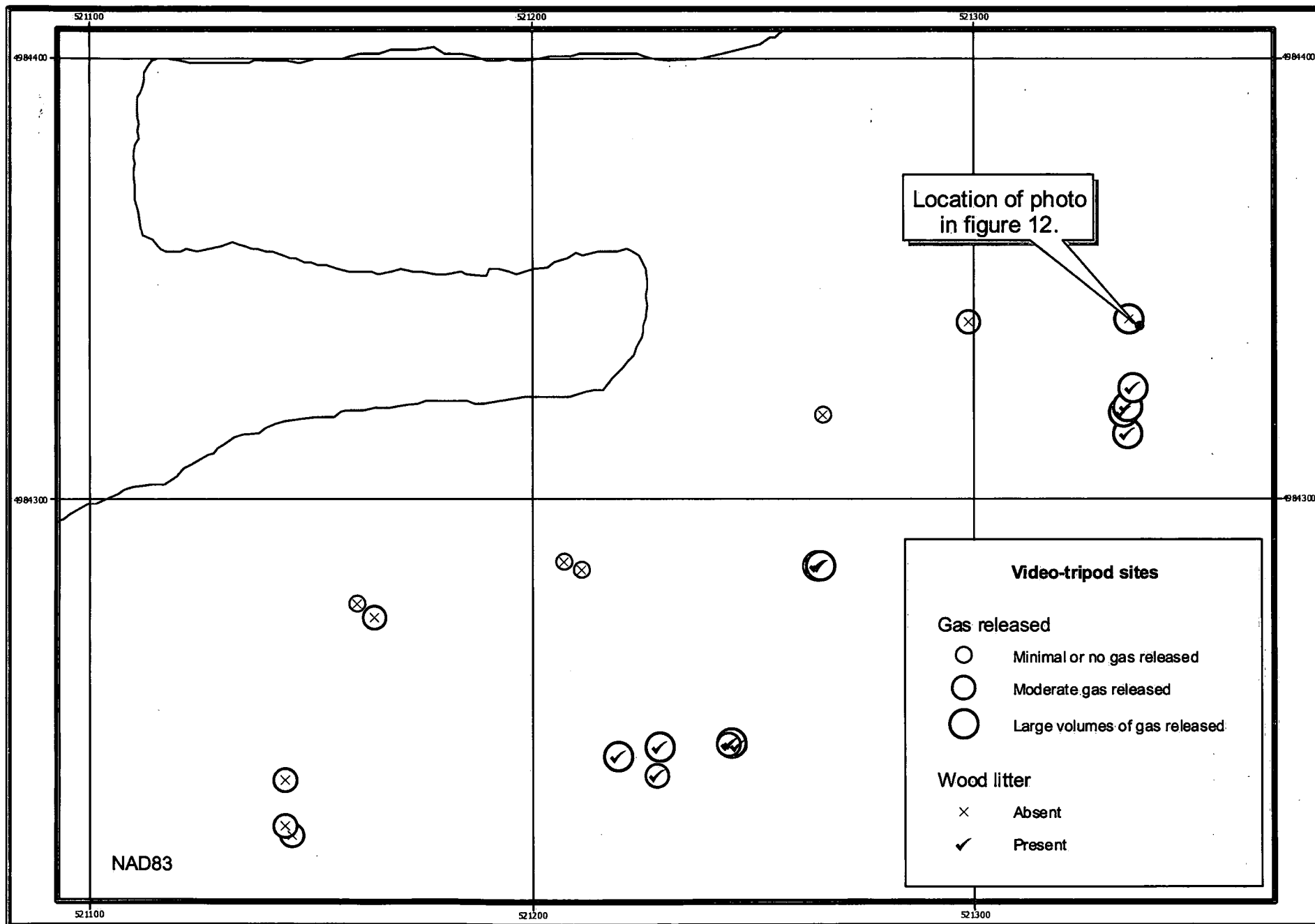


Figure 13: Zone 1 video-tripod Sites

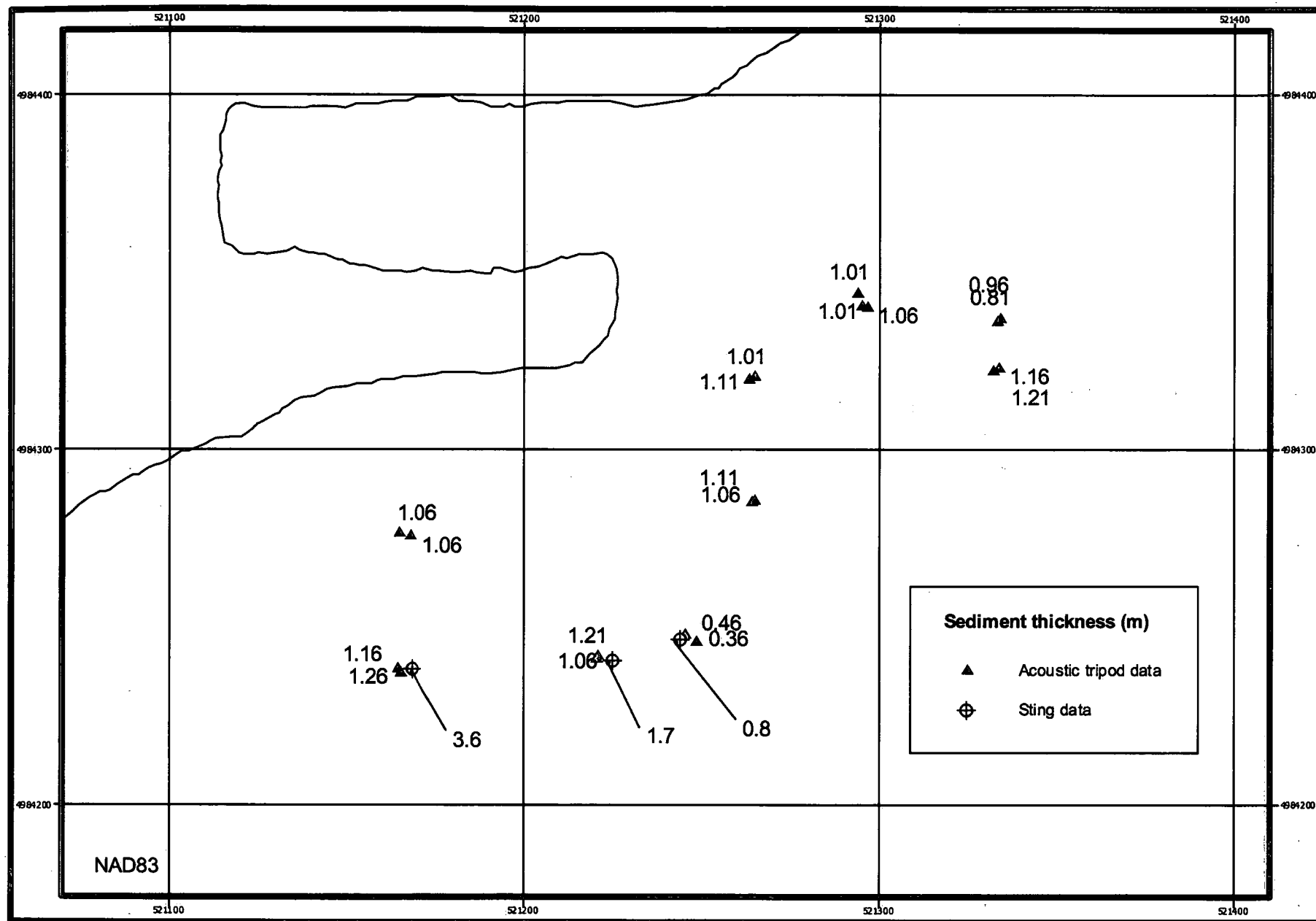


Figure 14: Zone 1 Tripod and STING thickness data

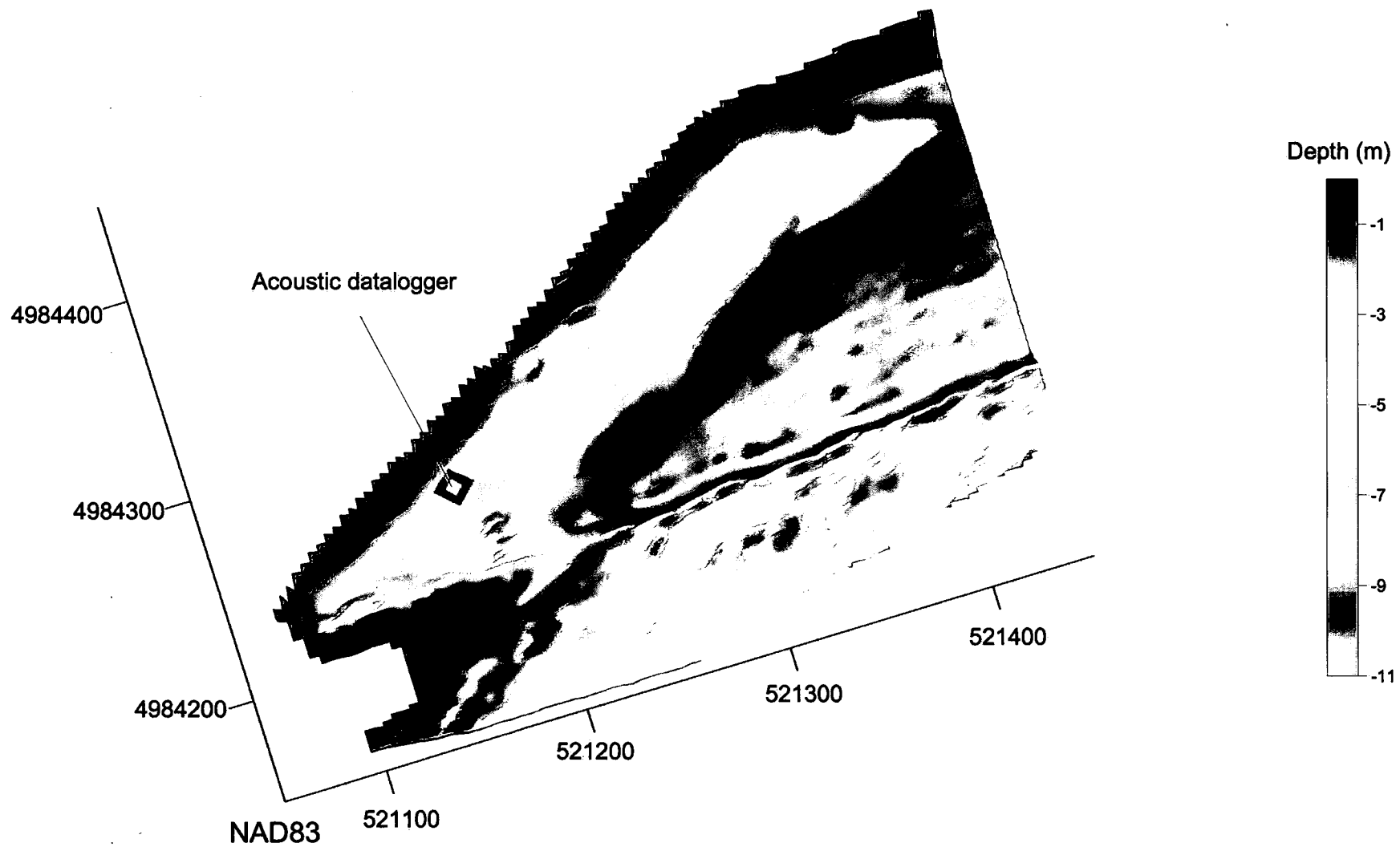


Figure 15: Location of Acoustic datalogger in Zone 1.

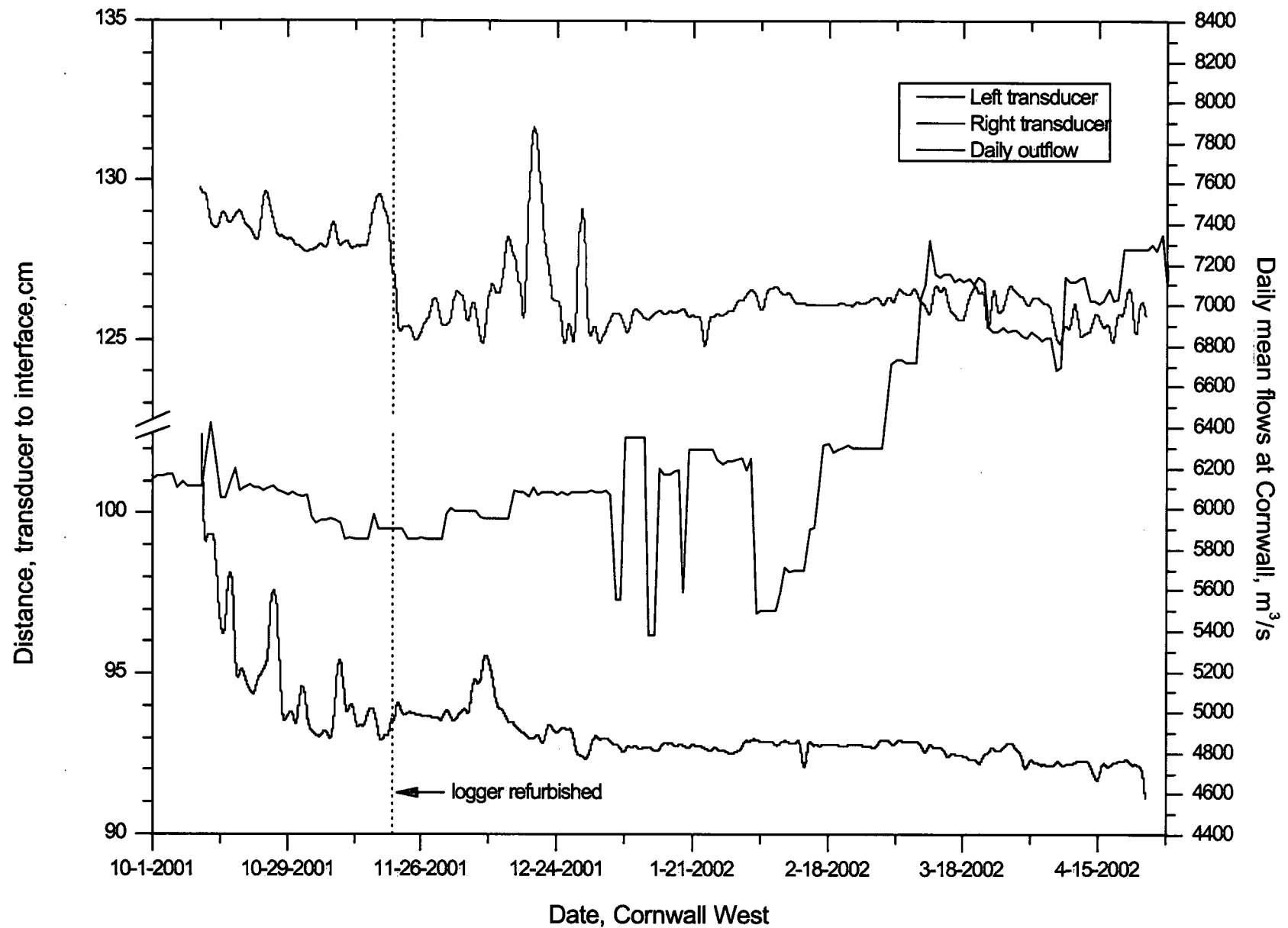


Figure 16: Zone 1 Datalogger record of changes in the level of the sediment surface

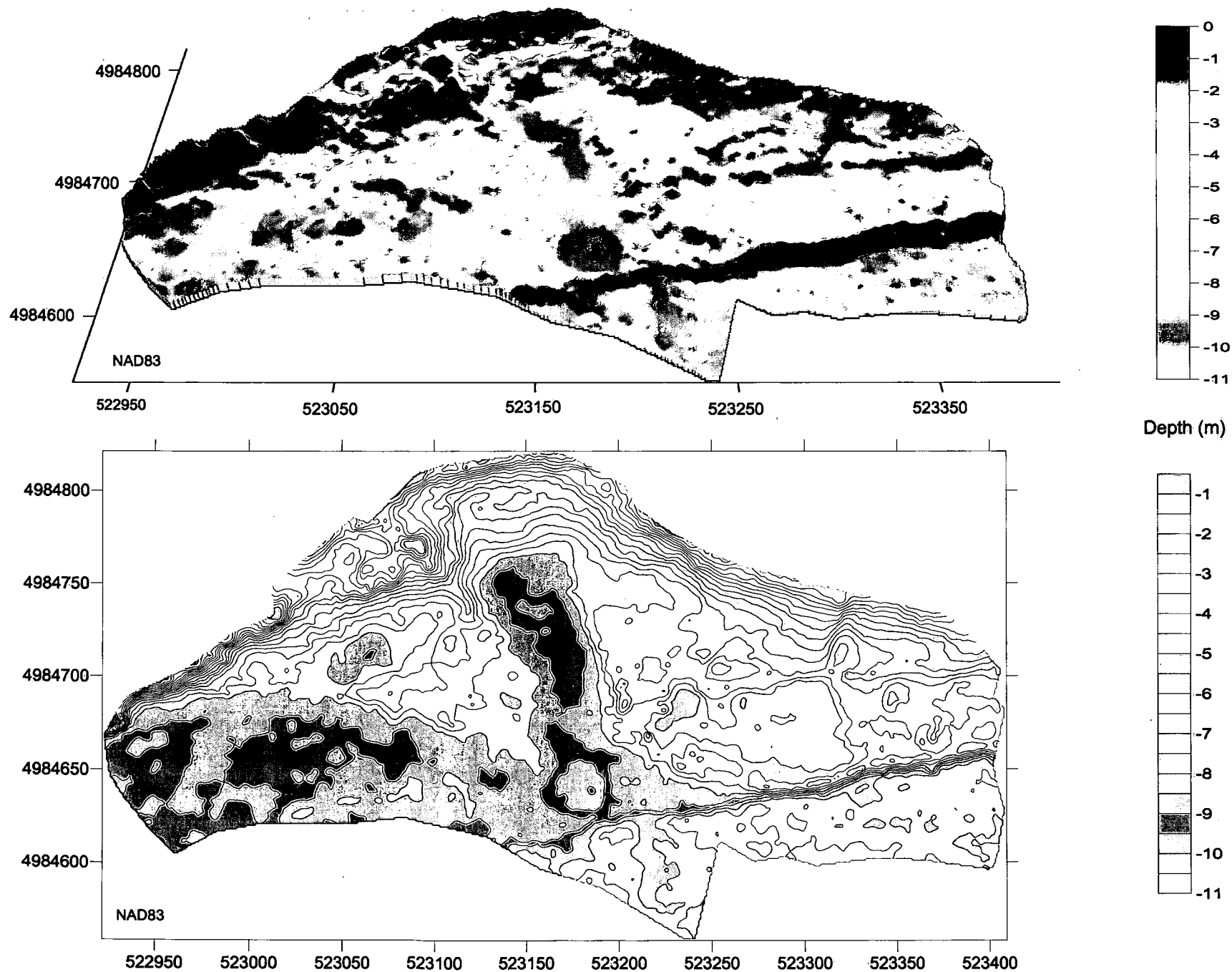


Figure 17: Zone 3 Relief and contour maps of bathymetry

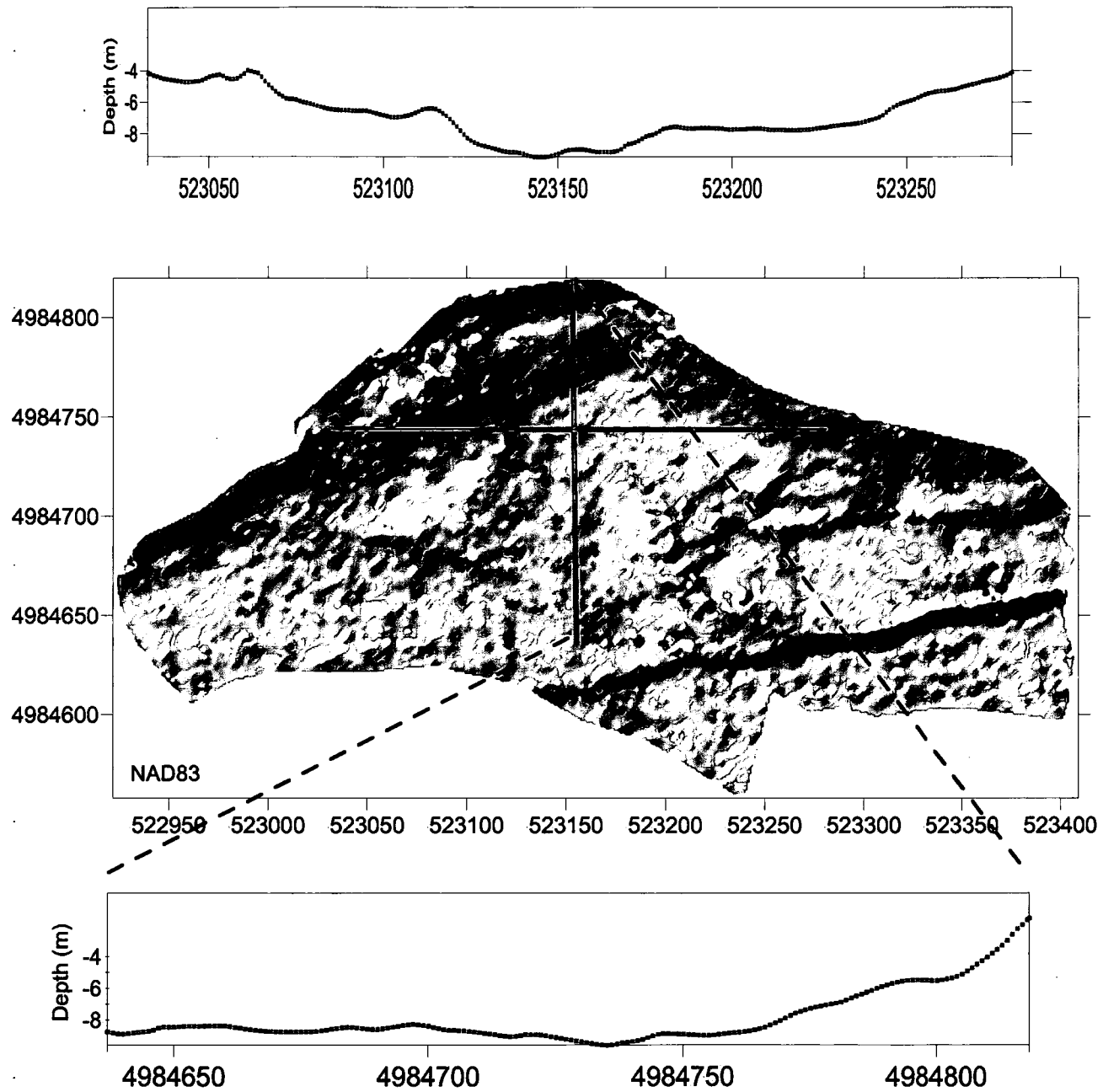


Figure 18: Zone 3 Bathymetric Profiles

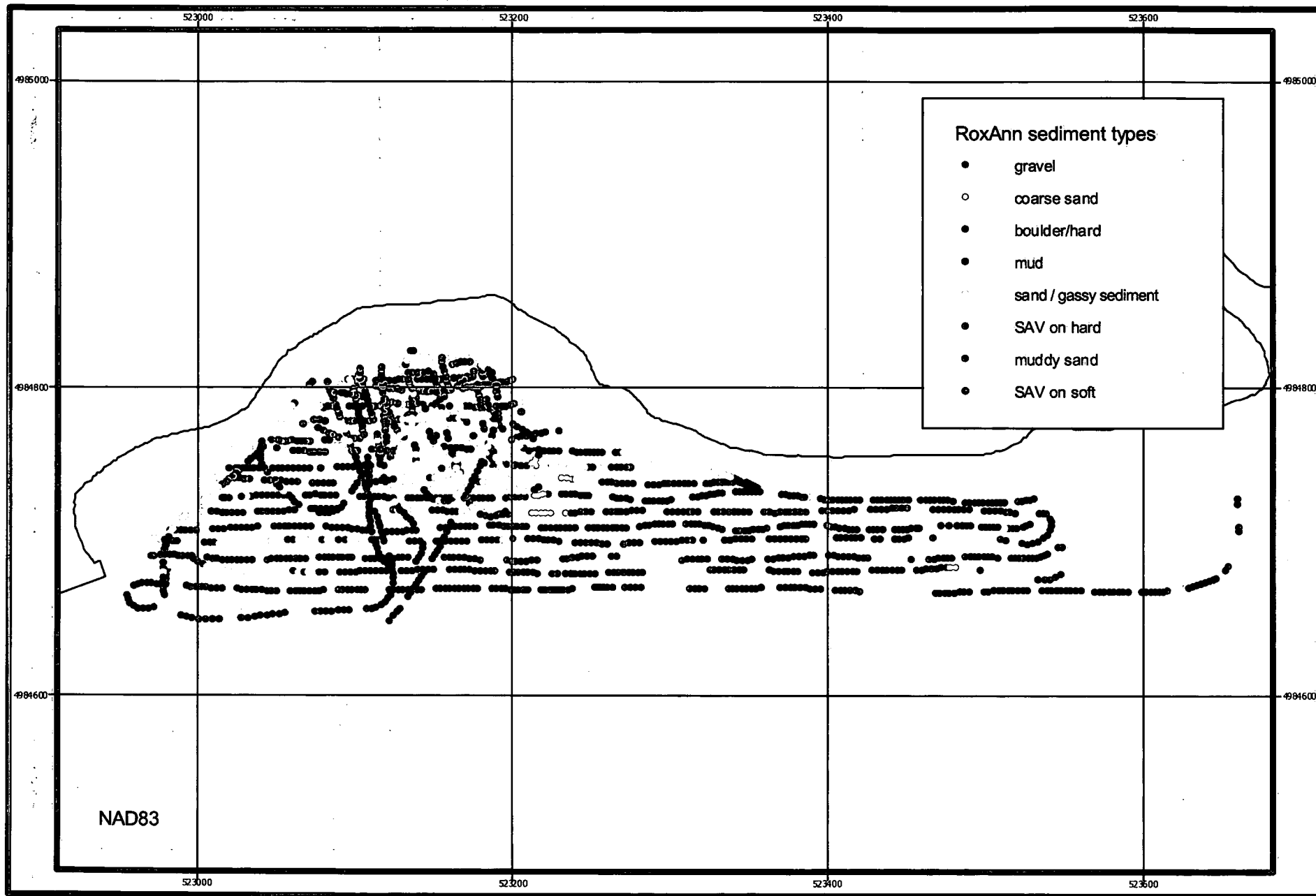


Figure 19: RoxAnn sediment types, Zone 3

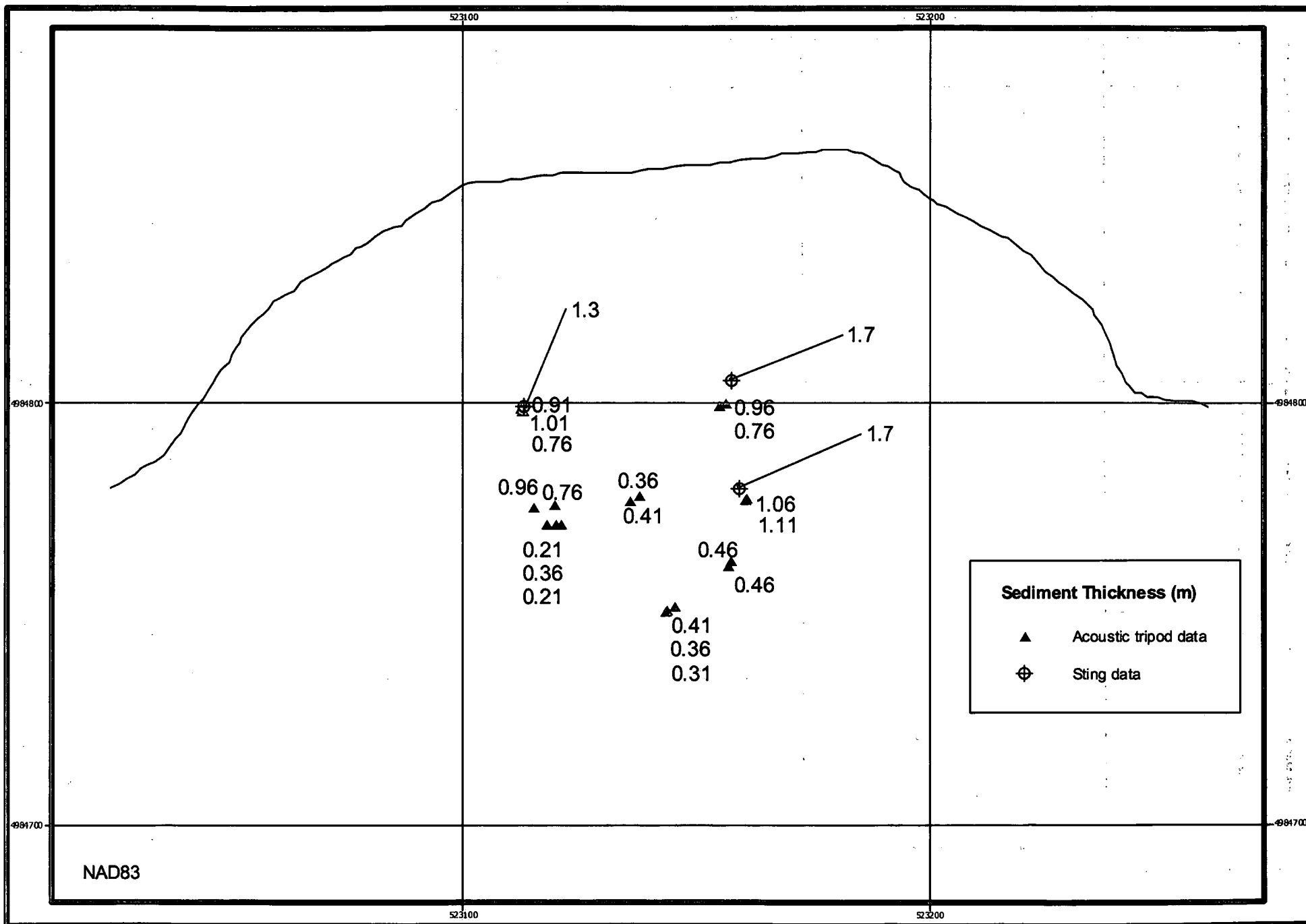


Figure 20: Zone 3 Tripod and STING thickness data

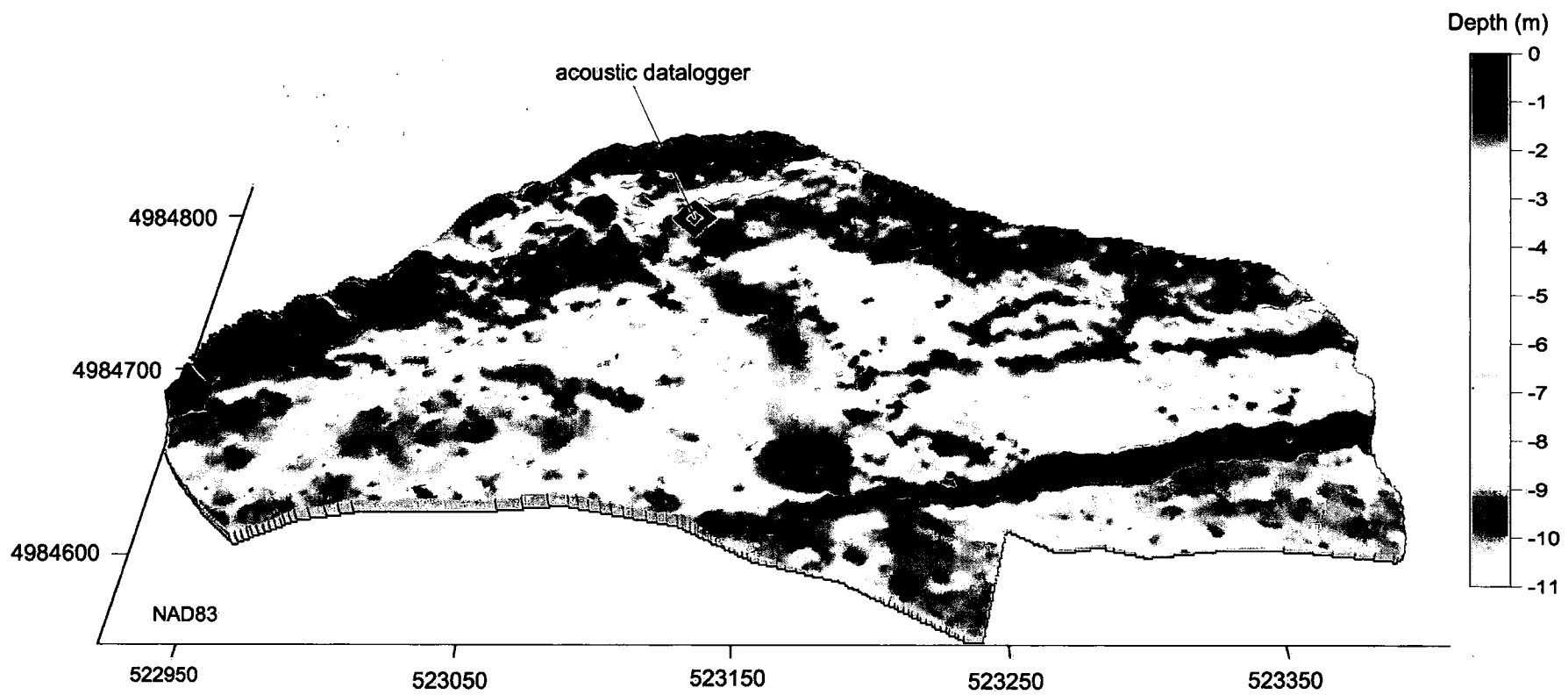


Figure 21: Location of Acoustic datalogger in Zone 3

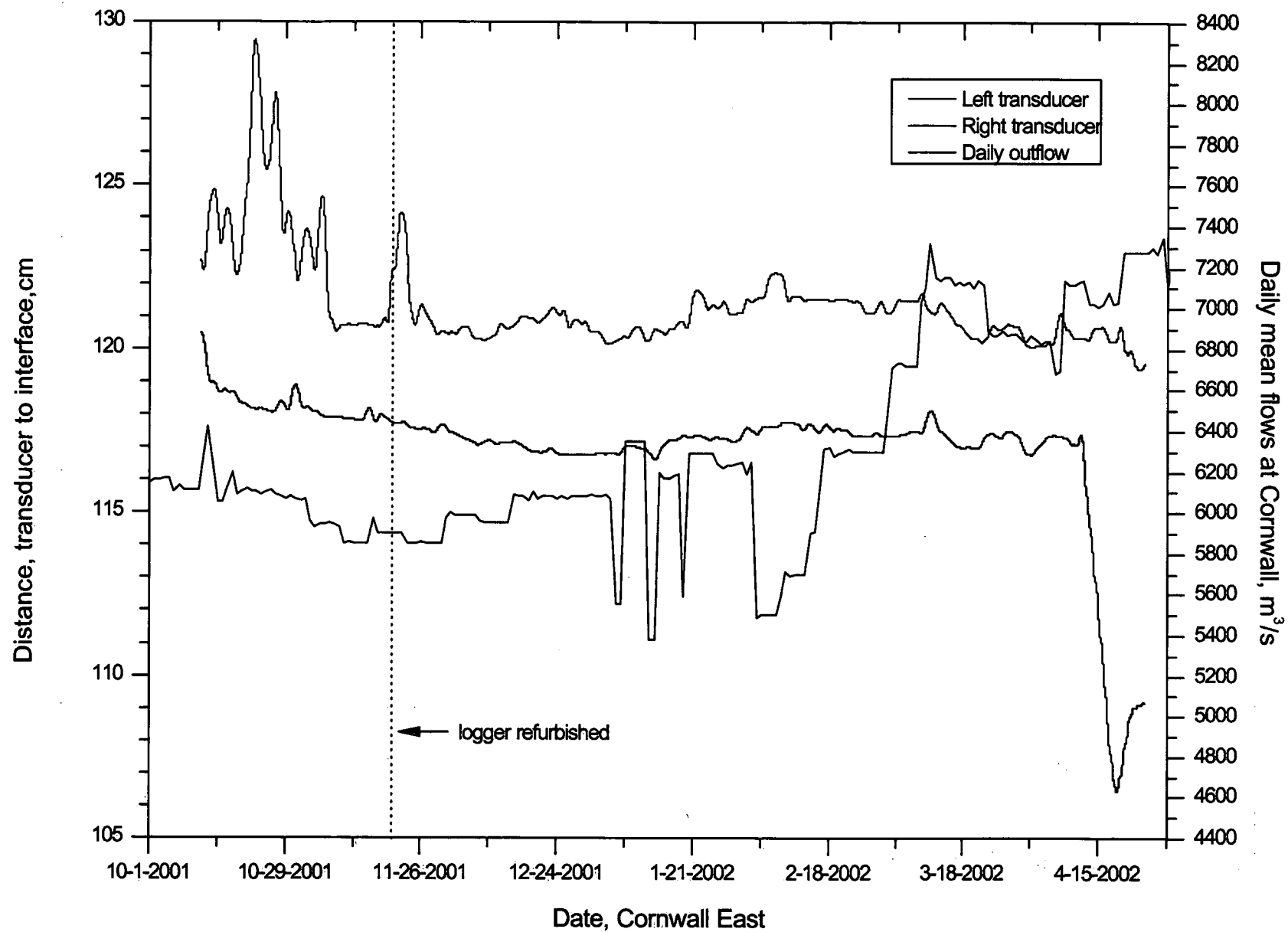


Figure 22: Zone 3 Datalogger record of changes in level of the sediment surface

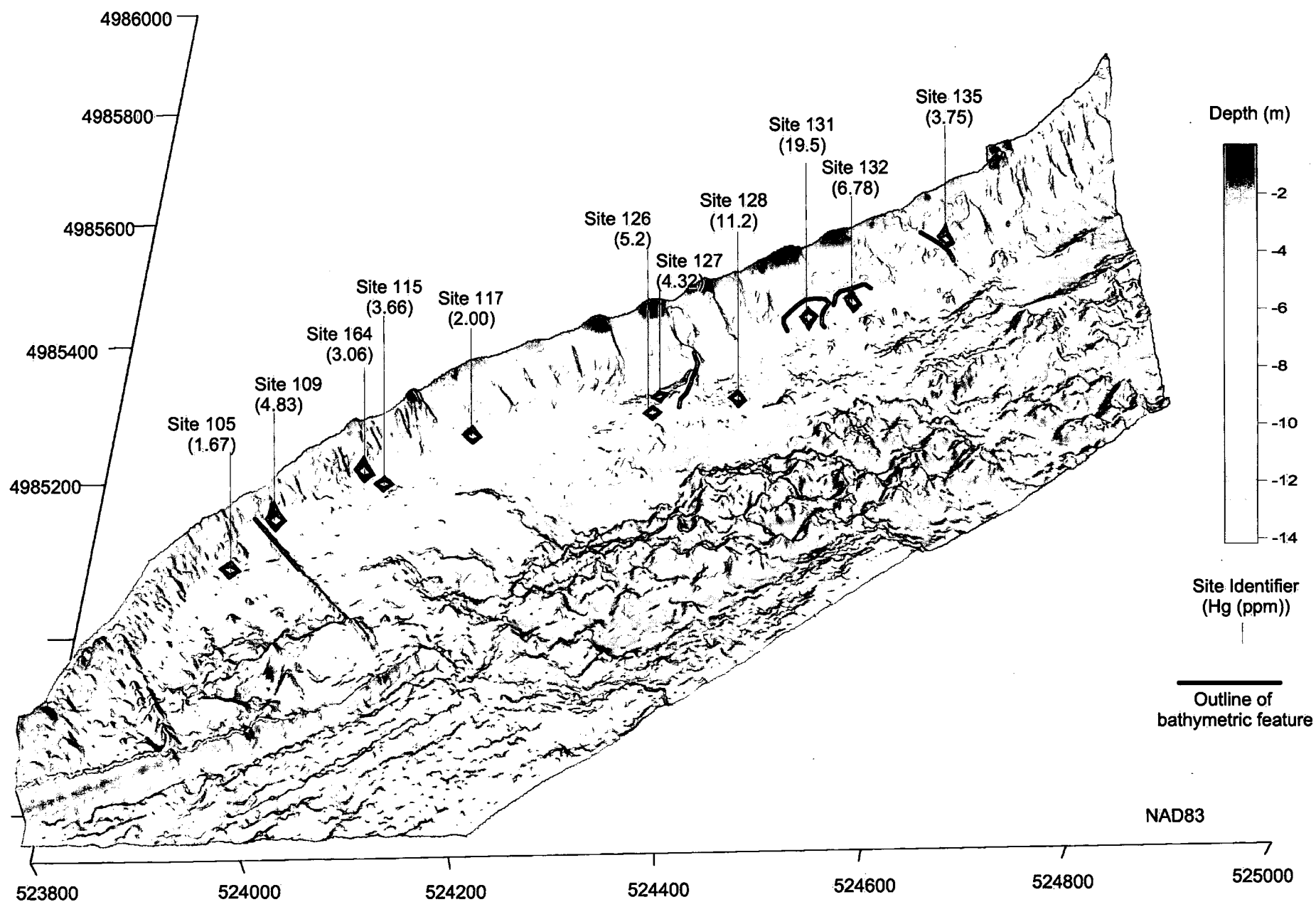


Figure 23: Bathymetric features and mercury concentrations in top 10 cm of sediment cores.



3 9055 1017 8144 0

*Due*

**AUG 12 2011**