U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

ACOUSTIC PROFILES OF SEDIMENT IN A MELT-WATER LAKE ADJACENT TO THE BERING GLACIER, ALASKA,

RV KARLUK CRUISE K2-91-YB
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by

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INTRODUCTION

Cruise K2-91-YB was designed to study the glacimarine sedimentary environment of Vitus Lake which is associated with the Bering Glacier, the second largest piedmont glacier in North America. Vitus Lake, an ice-marginal lake, is forming at the terminus of the retreating Bering Glacier, Alaska (Fig. 1). This study is associated with previous studies of Bering Glacier and the adjacent Gulf of Alaska (Carlson and others, 1977, 1982; Molnia and Carlson, 1978, 1980). These earlier studies, which concentrated on the Gulf of Alaska continental shelf, relied upon data from sediment sampling and high-resolution seismic-reflection profiling to define sedimentary processes and delineate sedimentary facies in this active environment. Recent work aimed more directly at the Bering Glacier environs (Molnia et al., 1991), has made use of additional powerful remote sensing tools, airborne side-looking radar (Molnia and Jones, 1989), and surface deployed ice-penetrating radar (Trabant et al., 1991), that provide other means of observing this rapidly expanding melt-water lake and the associated glacier. Cruise K2-91-BG provided about 150 km of tracklines along which Geopulse high-resolution seismic-reflection and 7 kHz bathymetric profiles were collected. We also obtained two short side-scan sonar profiles over selected features. In this report, we will briefly discuss the data collected by the seismic-reflection and side-scan systems deployed.

EQUIPMENT SYSTEMS

1. HIGH-RESOLUTION SEISMIC-REFLECTION PROFILING
The Geopulse high-resolution subbottom profiling system was operated at a power of 350 Joules at a firing rate of one-half second. Acoustic returns were recorded using a Benthos 15/30 hydrophone, filtered between 300 to 1000 Hertz, and printed on an EPC 4800 recorder at a one-half second sweep rate.

2. BATHYMETRY.
A 7 kHz Raytheon RTT 1000 hull-mounted transducer/transceiver produced profiles that provide high-resolution bathymetric data. One-half second firing and recording sweep rates also were used with this system, providing complementary simultaneous coverage with the Geopulse profiles.

3. SIDE-SCAN SONAR
A Klein 100 kHz side-scan sonar system was operated at a 100 m scan scale per side along two short lines. Use of this system in most parts of the lake was limited because of large numbers of icebergs and water too deep for the length of cable available. The hull-mounted 7 kHz bathymetric system was operated concurrently.

4. NAVIGATION
Navigation throughout Vitus Lake was controlled by the Global Positioning System (GPS). A Trimble system with an antenna mounted on the ship's mast provided navigational accuracy of about 100 m. GPS Fixes were recorded by hand.

PHYSICAL SETTING

GEOGRAPHY

Vitus Lake is forming at the southeast margin of the Bering Glacier separated from the northeastern Gulf of Alaska by a moraine and outwash plain foreland (Fig. 2). The lake, which began forming about 70 years ago, has grown by coalescesence of several ice-marginal melt-water lakes at the glacier's southeastern terminus. The lake is about 24 km long and nearly 8 km wide. (Fig. 2). Since the last surge of the Bering Glacier in 1968, retreat of the glacier has resulted in tripling of the width of the lake. The ice face of the Bering Glacier, which forms the northern border of the lake, is about 50 m-high, and over 20 km long. Elsewhere, the perimeter of the lake is composed of morainal and outwash deposits. Several small unnamed islands, composed primarily of glacial till and outwash, protrude from a few to about 10 m above the lake surface. The Seal River provides the primary outlet (minimum of 200 m wide and as much as 14 m deep) from the lake, with discharge approaching 50,000 cfs in late June 1991 and July 1992 (oral communication, Don Thomas, USGS, Juneau, 6/30/91; John Gray, USGS, Reston, 7/25/92). A pronounced sill that shoals to < 5 m depth is located at the lake outlet. This shoal acts as a barrier to prevent very large deep-draft ice bergs from leaving the lake and drifting into the Gulf of Alaska. The large collection of bergs at the entrance to the river prevented us from obtaining profiles across the entirety of the shoal, and the adjacent part of the lake. Ice also prevented profiling in several embayments of the lake. However, bathymetic coverage in Tasalich Arm at the southwestern part of the lake was obtained from an inflatable boat. These bathymetric data will be released in a separate report.

GLACIAL HISTORY

The Gulf of Alaska and the adjacent coastal area (Fig. 1) have been affected by glaciation since at least early middle Miocene time (Armentrout, 1983; Molnia, 1986; Marincovich, 1990). The presence of Bering Trough, a large glacial valley offshore of the Bering Glacier, indicates that during at least one of the Pleistocene lowstands (Carlson et al., 1982), an erosive tongue of the glacier about 25 km wide extended about 60 km to the shelf break, presently at about 200 m water depth. Bering Trough (Fig. 1) with a maximum water depth at mid-shelf of 321 m and a relief of about 100 m, is underlain by a buried trough that extends to a maximum depth of about 100 m beneath the modern trough (Carlson et al., 1982).

Vitus Lake owes its existence to twentieth century glacial retreat. The lake consists of four deep basins separated by submarine ridges or moraines. These basins contain glacial marine sediment up to 120 m thick, which suggests maximum sedimentation rates that range up to 11 m/yr. In some seismic profiles this thick glacial marine sediment section is underlain by a sequence of contorted and deformed reflections that suggest an older ice-contact sequence (Fig. 3). Grab samples collected in 1992 from shallow parts of the lake contained diamicts ranging from clay silt to silty clay with numerous dropstones (B. Molnia, unpublished data). There are no samples from the deep basin floor. Since 1920, Vitus Lake has experienced several surges of the Bering Glacier. These surges have resulted in ice re-occupying recently deglaciated parts of the basin followed by rapid down wasting and retreat of the glacier.

PRELIMINARY RESULTS

CRUISE COMMENTS

The plan for this cruise was to concentrate on obtaining high-resolution seismic-reflection profiles across the deep basins of the lake (Fig. 2). The great quantity of large icebergs that have calved off this extensive ice face limited our work to the relatively ice-free areas where the geophysical gear could be safely towed. It soon became evident that rather than being able to work from a predesigned plan, we would have to do what the ice permitted. As a result of the ice conditions, our bathymetric and seismic-reflection survey lines were modified daily, and there were parts of the lake that we were unable to reach.

BATHYMETRY

A hull-mounted 7 kHz system utilized continually on all profile lines provided bathymetric data for the areas traversed. In 1991, prior to the *RV KARLUK* work in Vitus Lake, bathymetric data were collected from an inflatable boat using a portable Lowrance fathometer and a Trimble GPS system. Additional bathymetric data were collected in 1990 from a rubber raft using a small hand-held echo sounder (Molnia, unpublished data).

The bathymetric data allowed us to delineate the deep sedimentary basins in which the pebbly mud is accumulating at a rapid rate. Four large basins are present on the floor of Vitus Lake (Fig. 2, labelled A-D; Table 1), as well as numerous small depressions on the glaciated surface (Fig. 4) that floors this rapidly expanding lake (Fig. 2). The lake has an area of about 100 sq km and the four large basins occupy an area of the lake floor totalling ~19 sq km. The basins shoal from west to east. There is a maximum of 163 m water depth in basin A and about 130 m water depth in the two middle basins. The much shallower basin D ranges in depth from 57 m at the south end to 50 m at the north end. The north end is near the mouth of the river that drains Tsivat Lake at the east side of the Bering Glacier. In July of 1991, we noted a large number of flocculating clumps of suspended particulate matter in the water of northeastern Vitus Lake. This large input of suspended sediment probably accounts for the south to north shoaling of the floor of basin D.

Slopes of the basins sides, as measured from the high-resolution seismic-reflection records, range from 9- to 33°. The steepest measured slope is in the northwest part of Vitus Lake (Fig. 5). The subaerial portion of the coast at this site includes ice-cored moraine with ice caves that were visible from the boat. At the base of the steep slope there is a small deposit formed by mass movement. At the east side of the 165 m deep depression, the hummocky slope near the present ice face (~0.5 km distance), suggests much mass movement (Fig. 5), probably from the morainal bank on which the front of the glacier is presently pinned. Although the floors of the deep basins are flat, much of the remainder of the lake floor is very irregular as befits a newly exposed glaciated surface. Along the eastern half of the northern margin of the lake a dramatic change in ice position was noted between 1990 and 1991. During this time interval of one year a large amount of the ice face had retreated up to 1.5 km (Fig. 2). A profile obtained from this newly exposed area shows very hummocky substrate with no observable subbottom reflections and, therefore, no soft-sediment accumulation (Fig. 6). The water depths of this new lake floor area ranged from ~25 to 75 m with local relief up to ~15 m.

SUBBOTTOM PROFILES

Although more detailed, near-surface subbottom penetration is attainable with the hull-mounted 7 kHz system (Fig. 7), the lower frequency of the simultaneously operated Geopulse provided subbottom penetration through the entire thickness of the soft, fine-grained sediment and partial penetration through apparently coarser, more dense sediment at the bottom of the fill that has accumulated in the large lake basins (Fig. 3). The high-resolution Geopulse profiles provide a measure of the thicknesses of sediment accumulating in each of the four large basins. These values reach 120 m in basin A (Fig. 3) and 50 to 60 m in the other three basins (Table 1). The thicknesses listed are, however, measured at the deepest part of the sedimentary basin and thus represent the maximum thicknesses measured from the profiles collected in 1991. These measurements assume a speed of sound equivalent to that through seawater (1500 m/sec), a value that is reasonable for at least the uppermost part of the section. However, in several of the basins, a lower unit is visible that is characterized by a very disrupted, disturbed or disorganized set of reflections similar in appearance to reflections that are often attributed to some type of mass movement deposit such as a slump or a coarse grained debris flow (Fig. 8). Also, some of the irregular, disrupted lower units have an appearance that suggests an ice-contact type of deposit, such as a till (Fig. 9). These lower units have high-amplitude, stronger reflections which indicate that the lower units are most likely composed of coarser sedimentary particles. They have undergone more compaction, and are likely of greater density than the more transparent upper unit and thus would be characterized by a faster sound velocity. The thickness of these portions of the sedimentary column would be minimum if measured using the 1500 m/sec speed. However, since we do not have velocity data, our thickness measurements are conservative approximations.

High-resolution seismic-reflection profiles near the shoreline of Vitus Lake or its islands, often show parallel bedded reflections that suggest outwash deposits (Fig. 10). These reflections are similar to some of those from the relatively flat-lying bedding planes in the adjacent sandy to gravelly strata that make up the subaerial portions of the glacial sediment visible along the surrounding shoreline. In these profiles note the well-defined angular unconformity that crops out along the southeast wall of Vitus Lake and truncates some underlying gently dipping reflections. Overlying the same sharply defined angular unconformity profiled along adjacent lines we see an even more pronounced upper unit. The upper unit extends about 1.4 km toward the southeast shore of the lake before becoming masked by the lake-floor multiple (Fig. 11). In these three profiles (Figs. 9, 10, 11), the truncated reflections dip toward the lake. The unconformity probably represents an older advance and retreat cycle of the Bering Glacier. The position of the unconformity apparently cropping out on the wall of the lake just above the ponded, flat-lying sediment of the lake floor (Figs. 9 & 10), suggests that datable core samples from just above and below the unconformity might rather neatly determine the age of that erosional surface.

Profiles collected between the two largest islands in the lake, Beringa and Pointed Islands (Fig. 2), also contain well-defined high-amplitude reflections near the base of the insular slopes (Fig. 12). These reflectors apparently extended across the trough-shaped depression currently existing between the two islands, but were part of the sedimentary unit eroded during a recent advance of the Bering Glacier.

Between Pointed and Whaleback Islands, the high-resolution profiles show a small elliptical depression that has become partially filled with recent sediment (Fig. 13). A high-amplitude reflector that marks an angular unconformity underlies the fill in this depression (Fig. 13). We suggest that this small depression may be a scour that developed when an earlier advance of the Bering Glacier ice front retreated across this area. A portion of a side-scan sonar line through the middle of this depression from northwest to southeast is shown in figure 14. The irregular bottom, small area, and relatively deep water hampered our attempt, but we do include part of the sonograph that shows the relatively smooth nature of the fine-grained sediment in the scour floor and the coarser-grained sediment that makes up the surface of the sill at the southeast edge of the depression.

Areas in Vitus Lake where high-amplitude, well-defined reflections have been profiled are highlighted on the trackline map shown in figure 2. However, no samples of the sediment portrayed in these profiles have been collected. Also, we do not have a tight enough grid of track lines to allow detailed mapping of the well-defined reflectors from the various parts of the lake to permit determination of their continuity. Thus, we cannot map in detail the erosional unconformity or the other prominent reflectors throughout the lake margin. Additional high-resolution seismic-reflection profiles and selected core samples are needed to determine the character and continuity of the sediment responsible for these prominent reflections.

SUMMARY AND CONCLUSIONS

High-resolution seismic-reflection profiles collected in various parts of Vitus Lake provide useful cross-sections of the sediment that has accumulated in front of the Bering Glacier. The seismic-sedimentologic features include morainal debris underlying the fjord sedimentary basins, sediment thicknesses in the four large basins, reflections within the sediment of both the deep basins and walls of the lake and incorporated islands, and sedimentary features within the profiles. These features or structures suggest: (1) mass movement from the moraines into the deep basins; (2) stratified drift that was deposited from the meltwater discharge of Bering Glacier during one of its retreats across what is presently Vitus Lake; and, (3) a well-defined angular unconformity, especially in the eastern part of the lake, that indicates an episode of erosion that truncated earlier Bering Glacier deposits.

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Table 1. Characteristics of Vitus Lake sediment basins.

Basins	Water depth	Sed. thickness	Area(km^2)
A	163 m	120 m	5.25
B	132	50	2.5
C	130	60	3.5
D	50-57	50	7.5
		Total	18.75

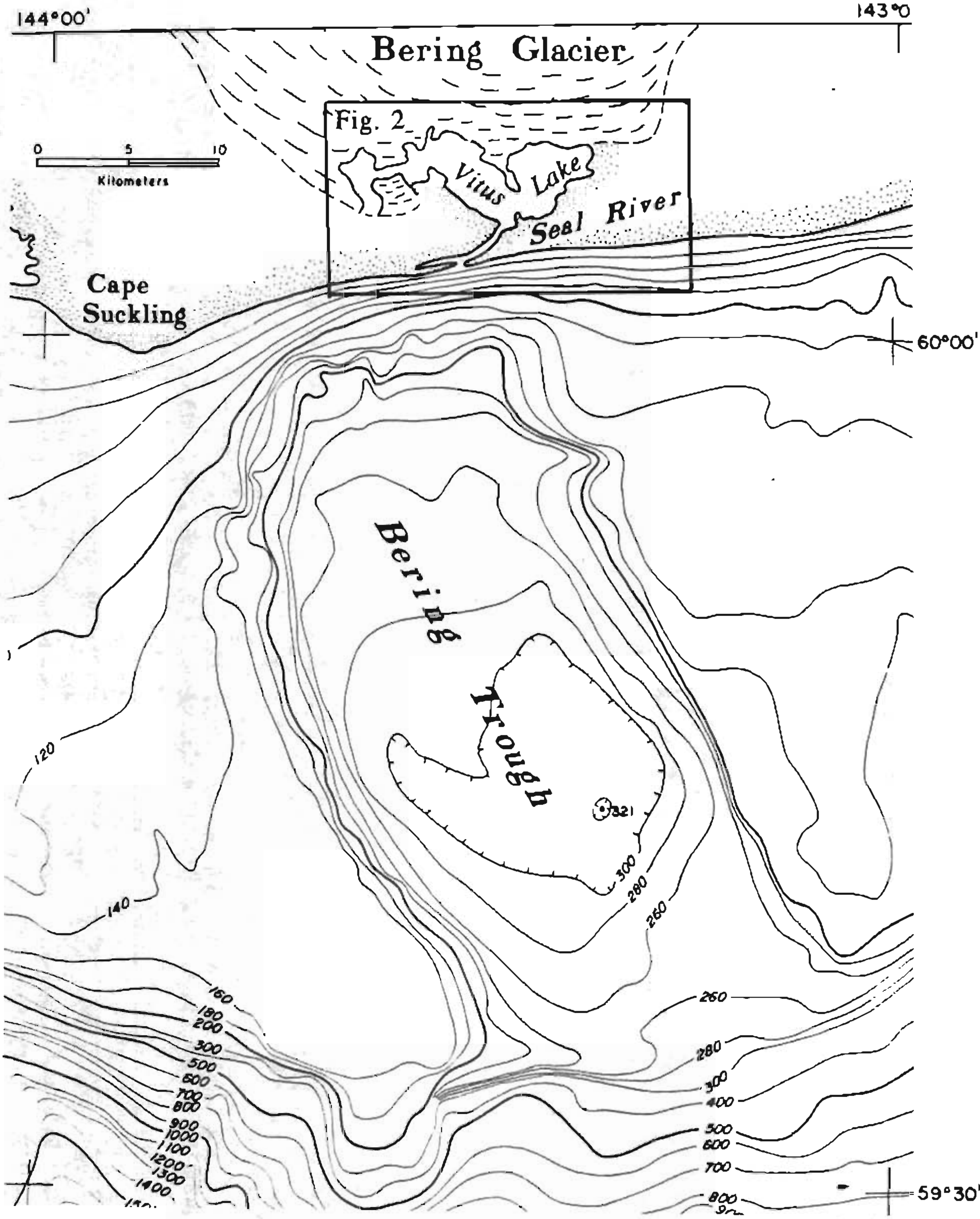


Figure 1. Bathymetric map of the northeastern Gulf of Alaska showing Bering Trough and Bering Glacier/Vitus Lake study area. Modified after Atwood et al., 1981.

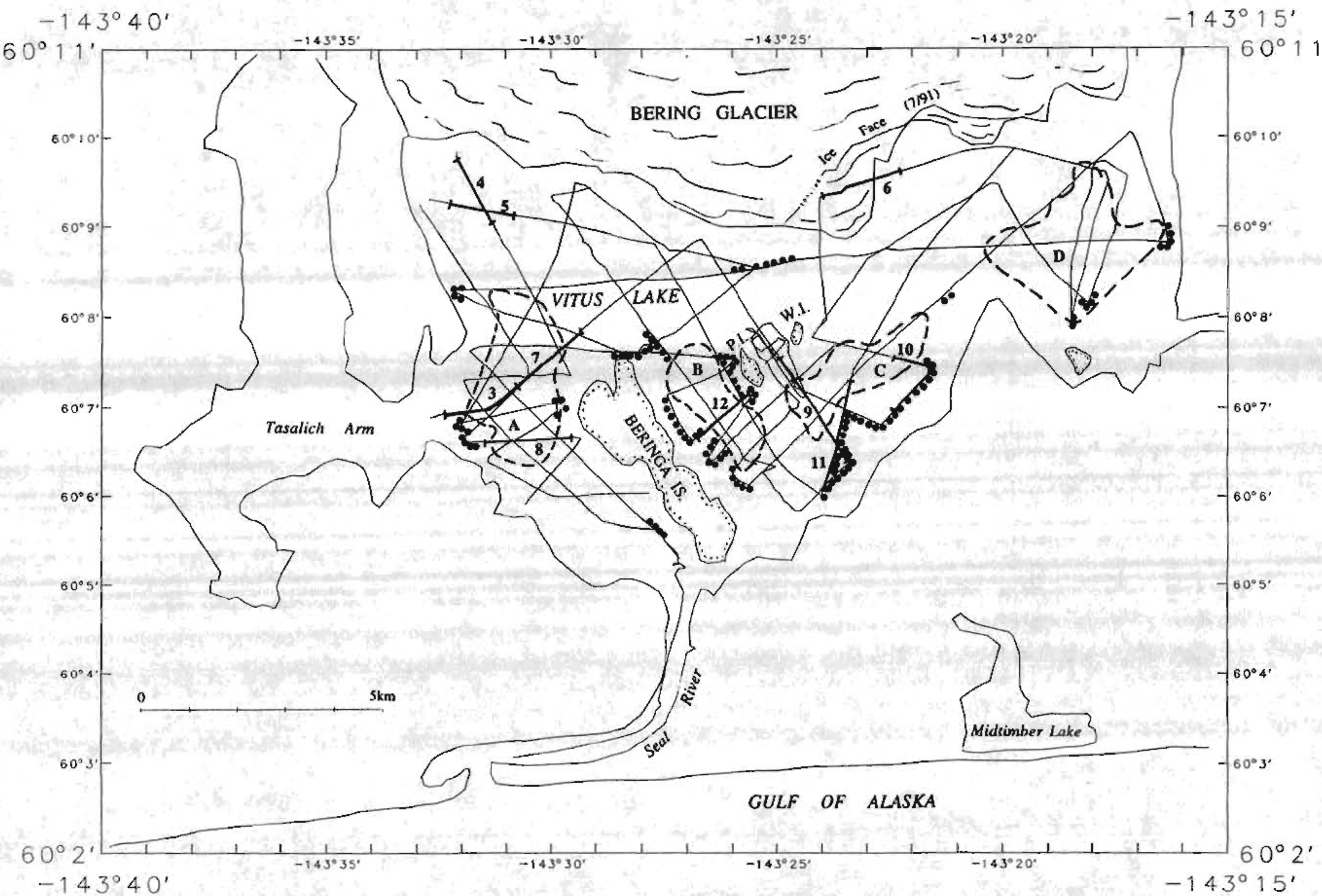


Figure 2. Map of Vitus Lake and adjacent Bering Glacier ice front as drawn by Austin Post (U.S.G.S., retired) from 1990 aerial photos. Acoustic profile track lines were run in July 1991--note position of ice-face at that time. Letters A-D indicate sediment basins (dashed outlines) as delimited by the acoustic profiles. Numbered heavy lines indicate illustrated segments of profiles (Figs. 3-12). Track lines highlighted by large dots show areas of high-amplitude reflections. P.I.= Pointed Island, W.I.= Whaleback Island.

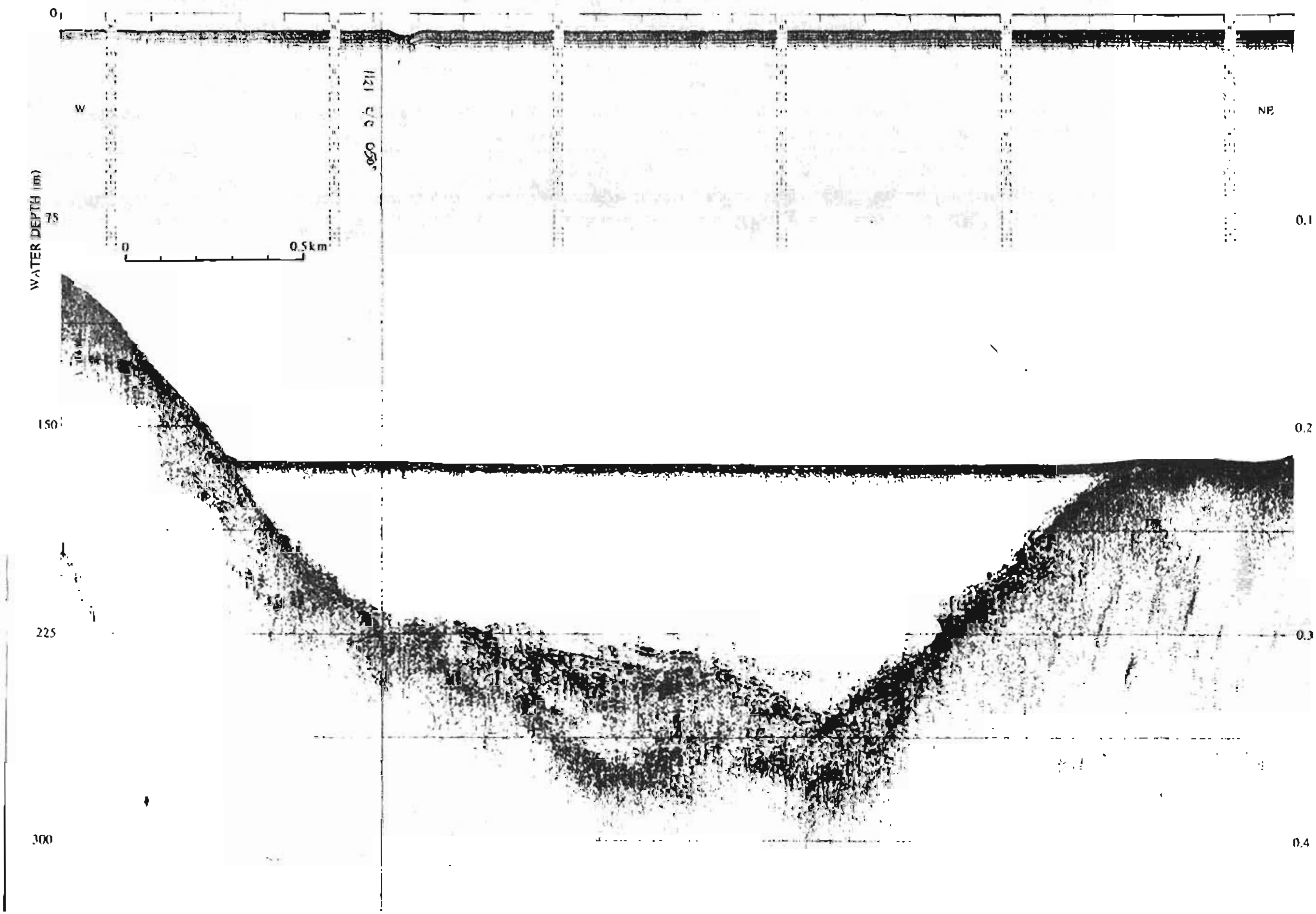


Figure 3. Geopulse profile showing cross section of basin A, the deepest basin with the thickest accumulation of sediment (see Table 1). See figure 2 for location. Vertical exaggeration, V.E.~7.6x.

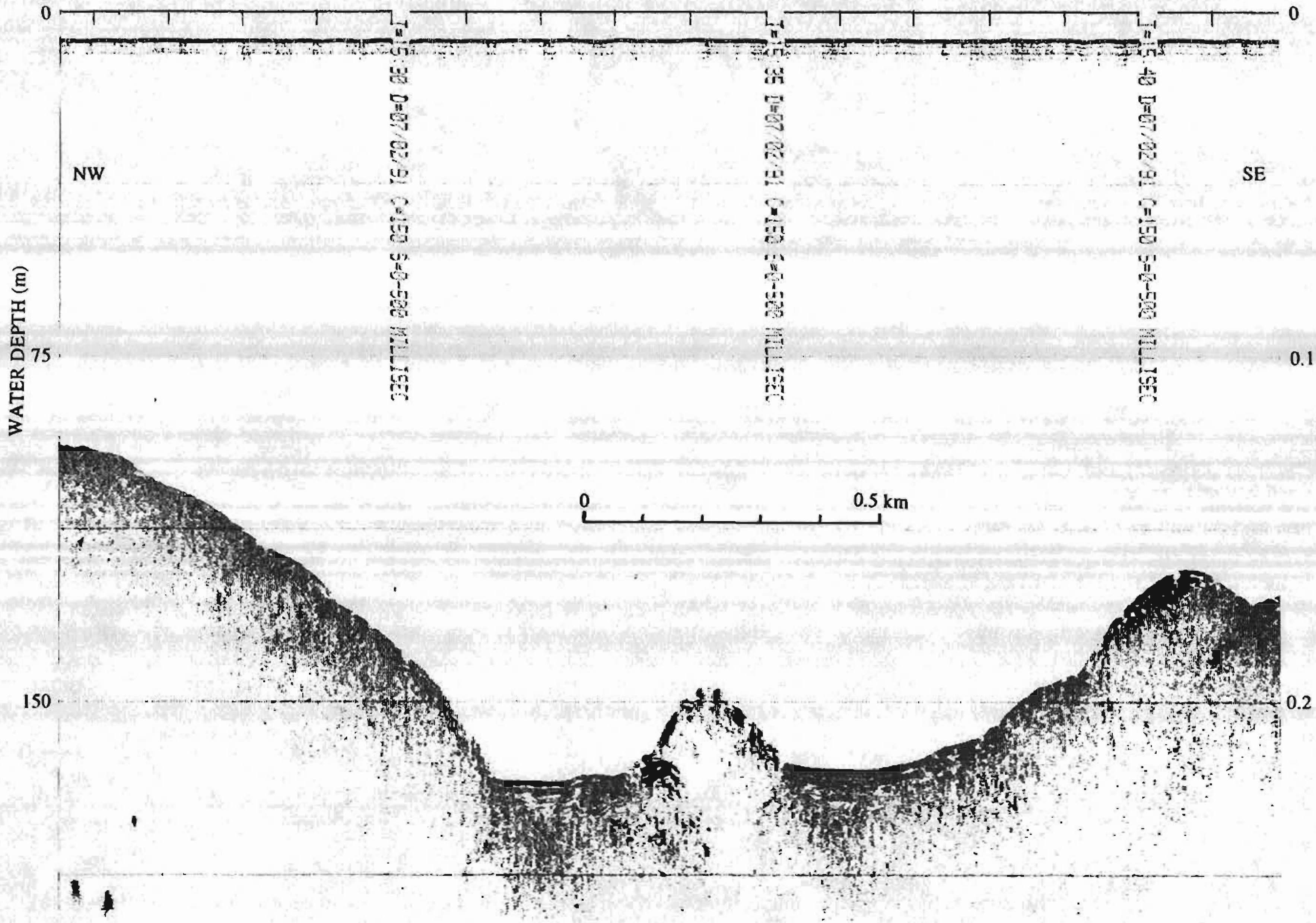


Figure 4. Geopulse profile of northwest part of Vitus Lake showing small depressions on the recently deglaciated floor and partial filling of these holes by modern sediment. See figure 2 for location. V.E.~7.6x.

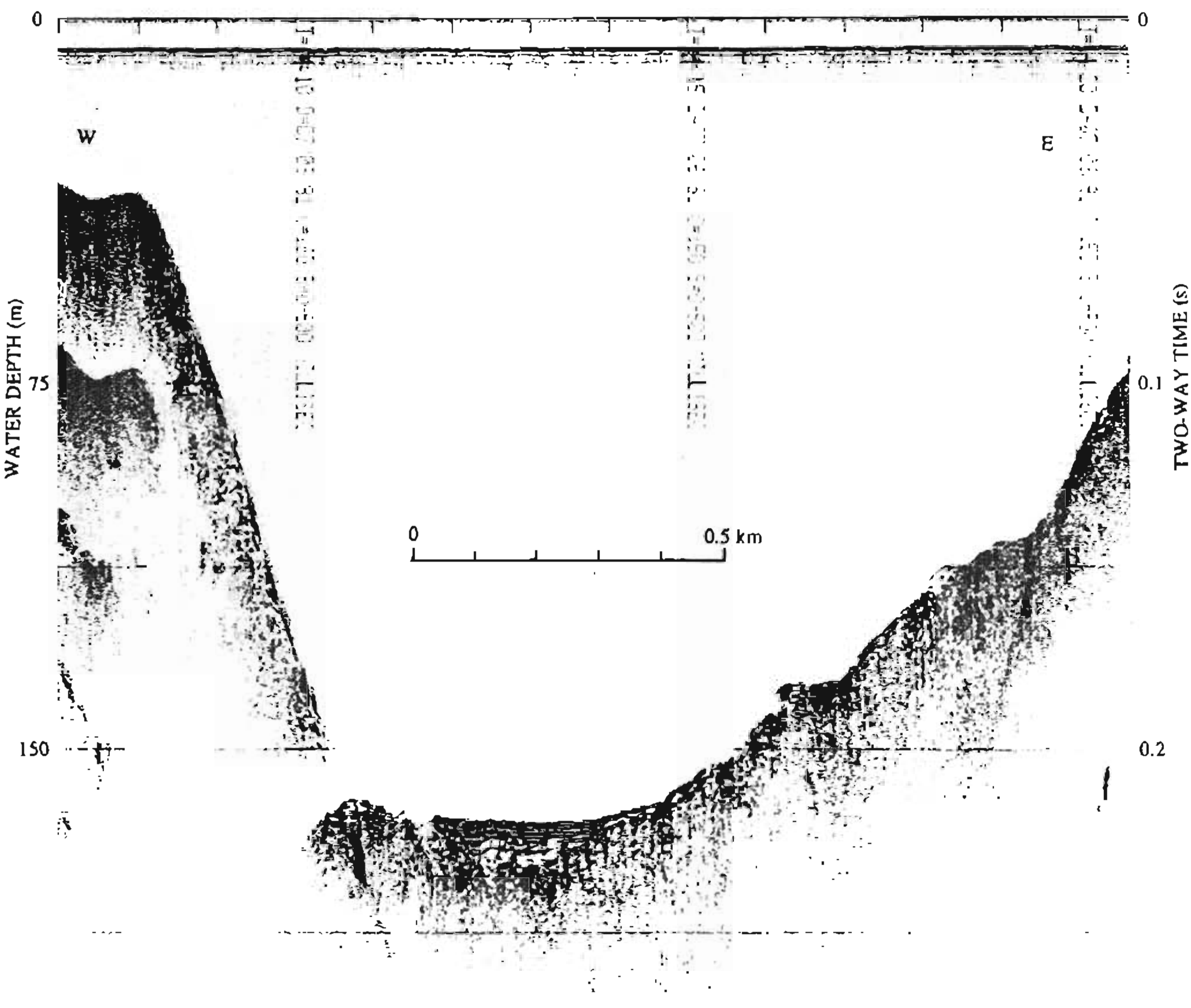


Figure 5. Geopulse profile of steepest wall found in Vitus Lake. See figure 2 for location. V.E.~7.6x.

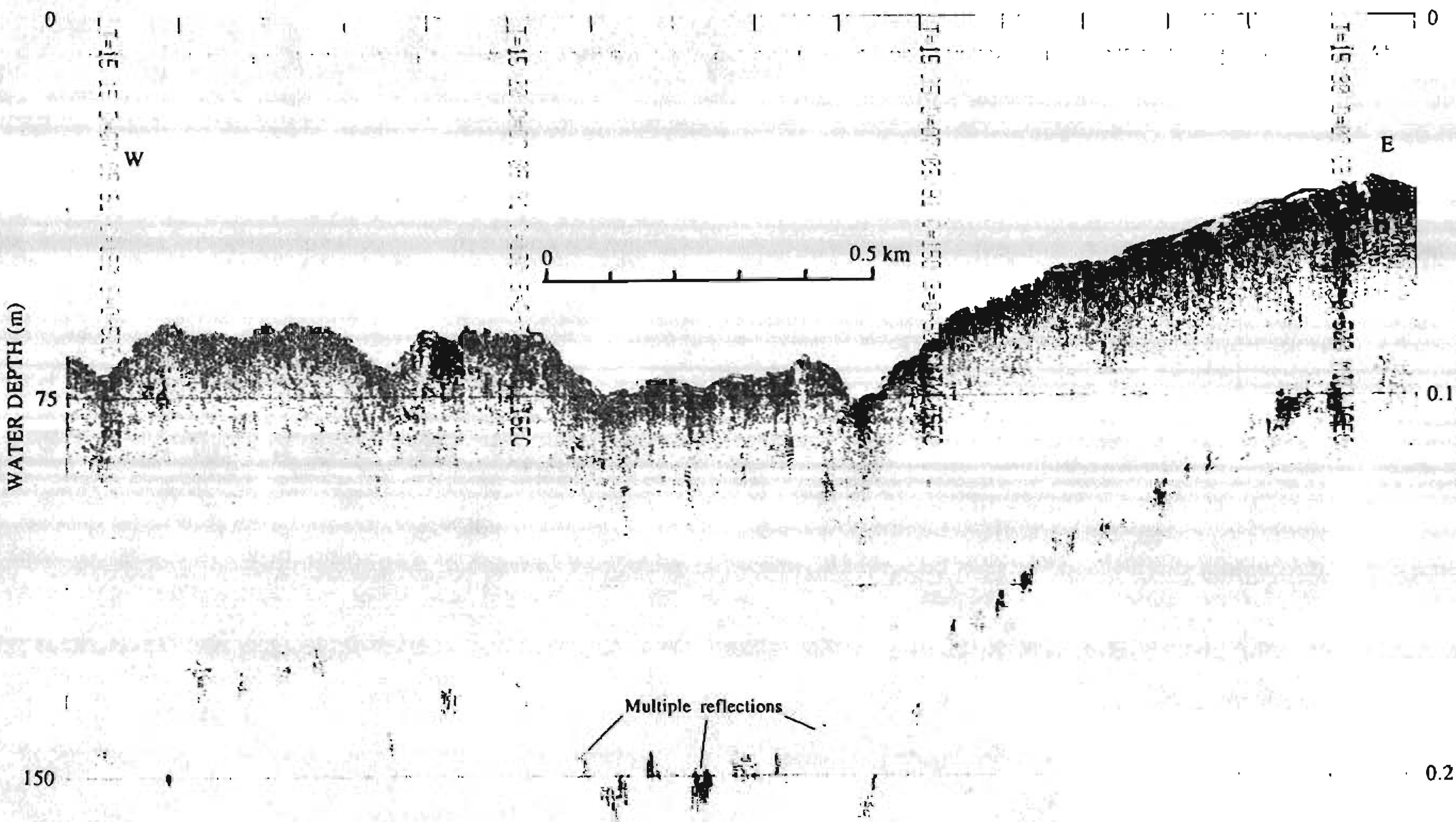


Figure 6. Geopulse profile of a portion of the lake floor that was covered by the glacier as recently as 1990. See figure 2 for location. V.E.~7.6x.

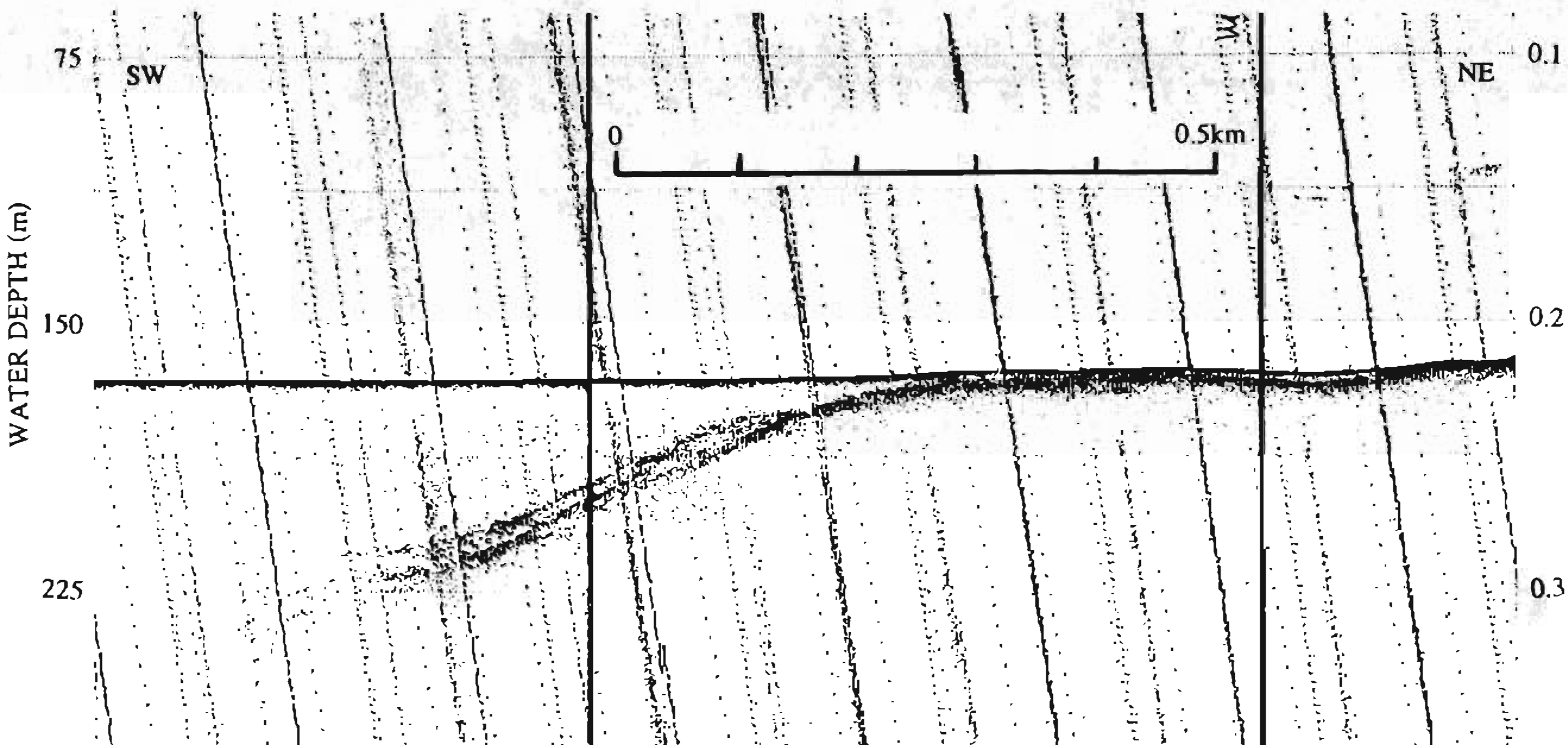


Figure 7. ,The high resolution of 7 kHz records illustrates the greater detail attainable on the 7 kHz system where only a thin layer of surficial sediment has been deposited. Note greater subbottom penetration obtained with the Geopulse system over the same area (Fig. 3). See figure 2 for location. V.E.~3x.

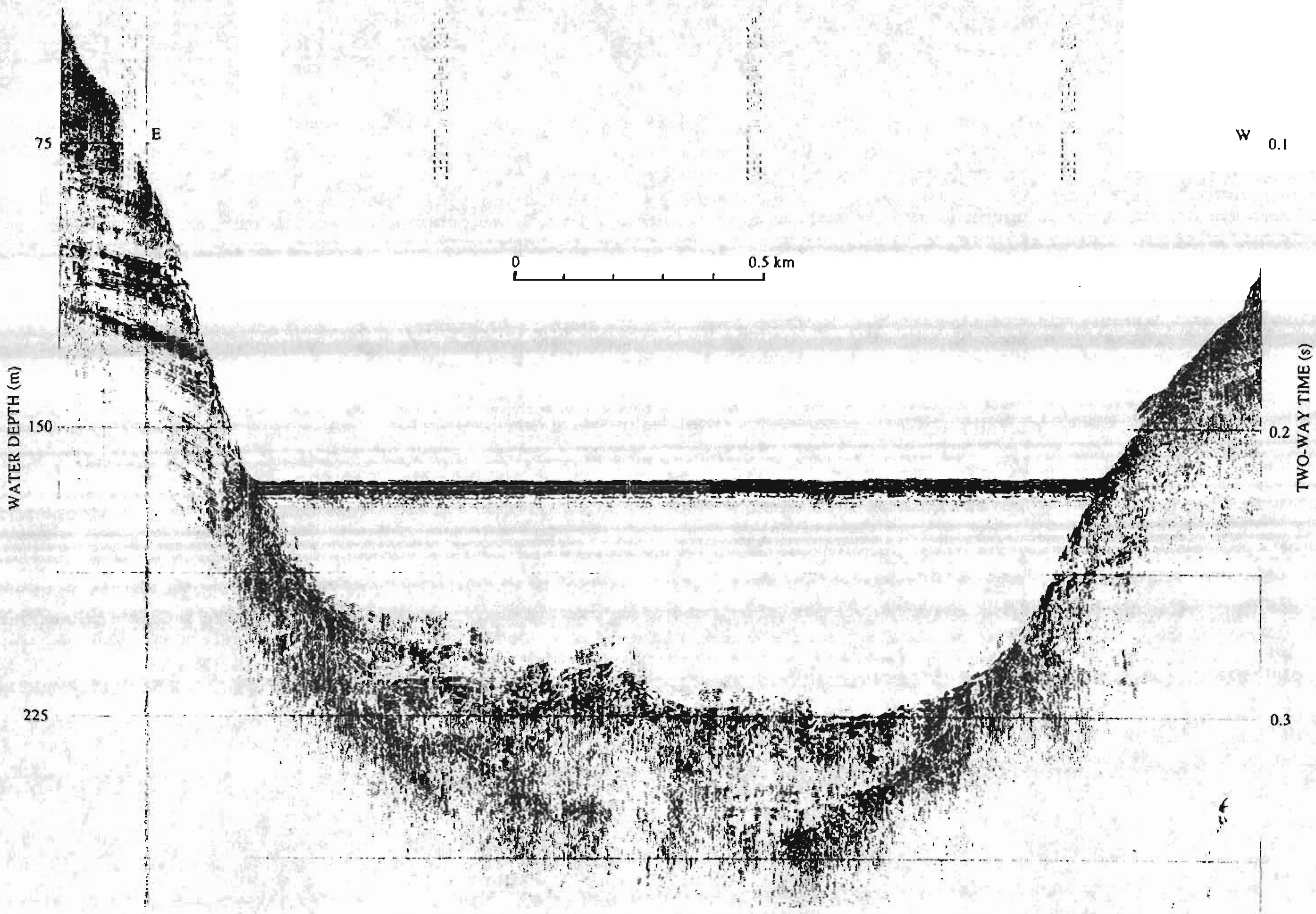


Figure 8. Geopulse profile of mass movement deposit in basin A. See figure 2 for location. V.E.~7.6.x.

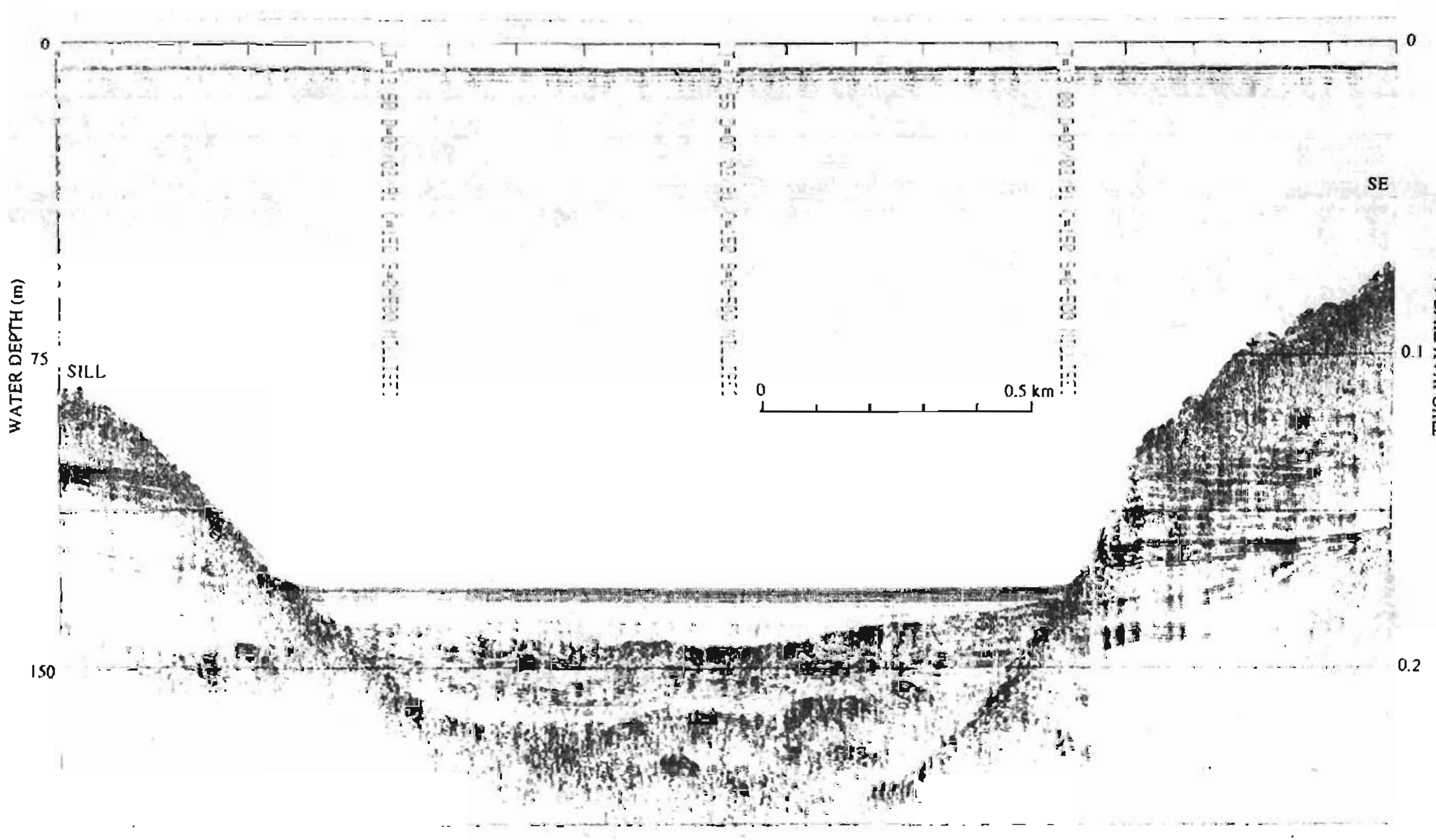


Figure 9. Geopulse profile of basin C showing subbottom reflections that may be the result of ice-contact or outwash deposition. Note angular unconformity on east bank of the lake, indicating at least two glacial advances and retreats across this area. See figure 2 for location. V.E.~7.6x.

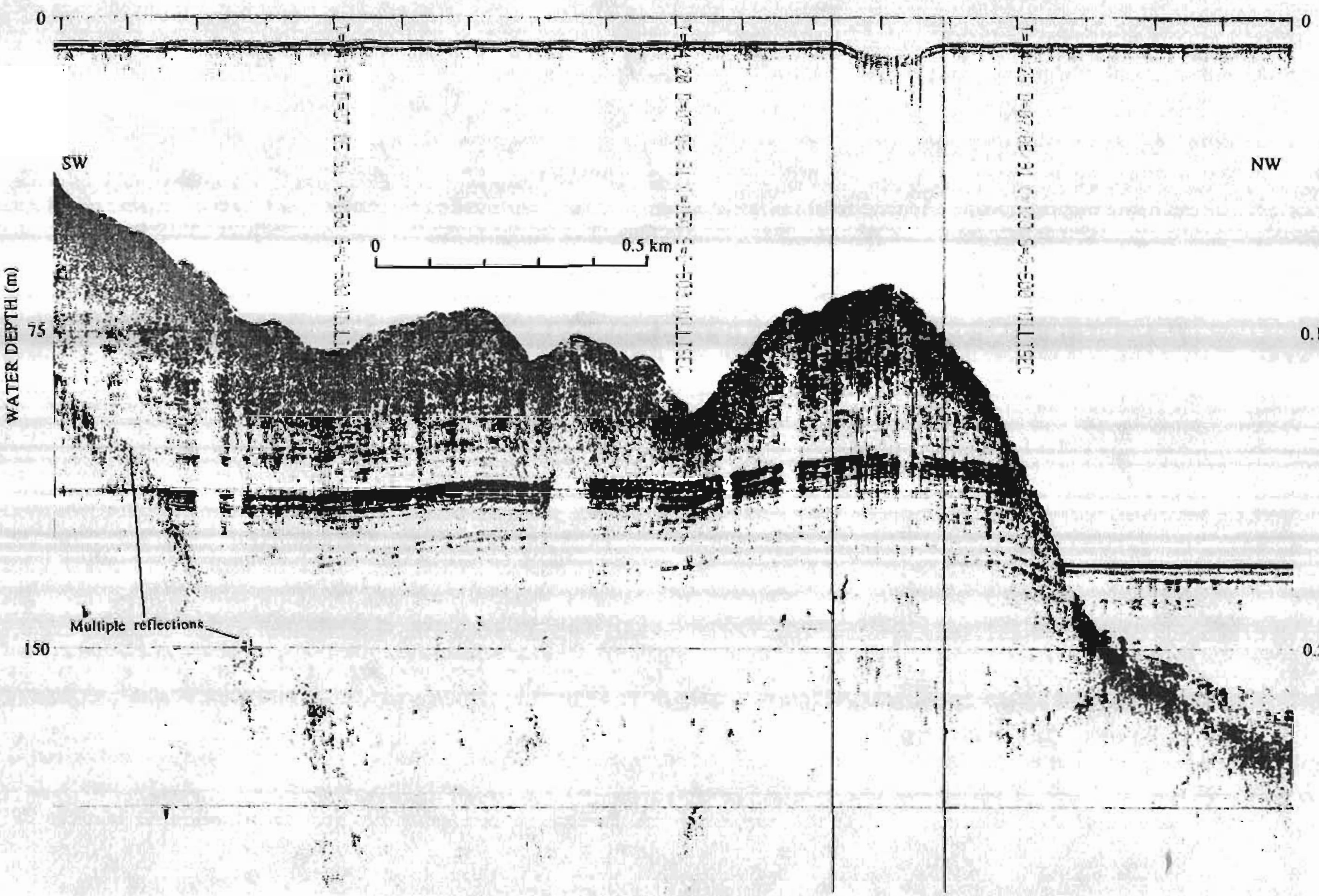


Figure 10. Geopulse profile along southeast wall of Vitus Lake with possible outwash deposits above and below a well-defined angular unconformity. See figure 2 for location. V.E.~7.6x.

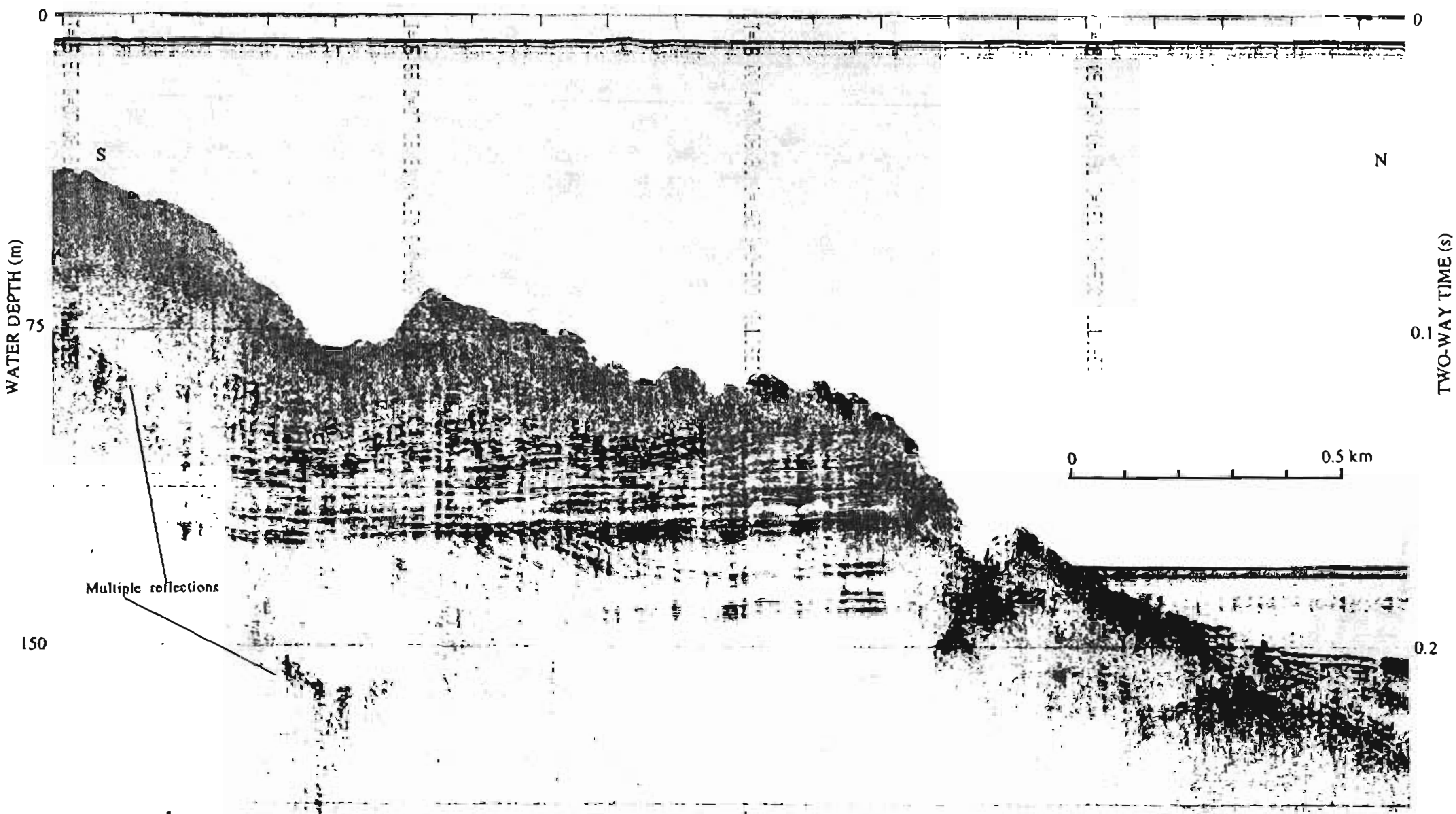


Figure 11. Geopulse profile showing extensive segment of angular unconformity that extends along the southeast wall Vitus Lake. See figure 2 for location. V.E.~7.6x.

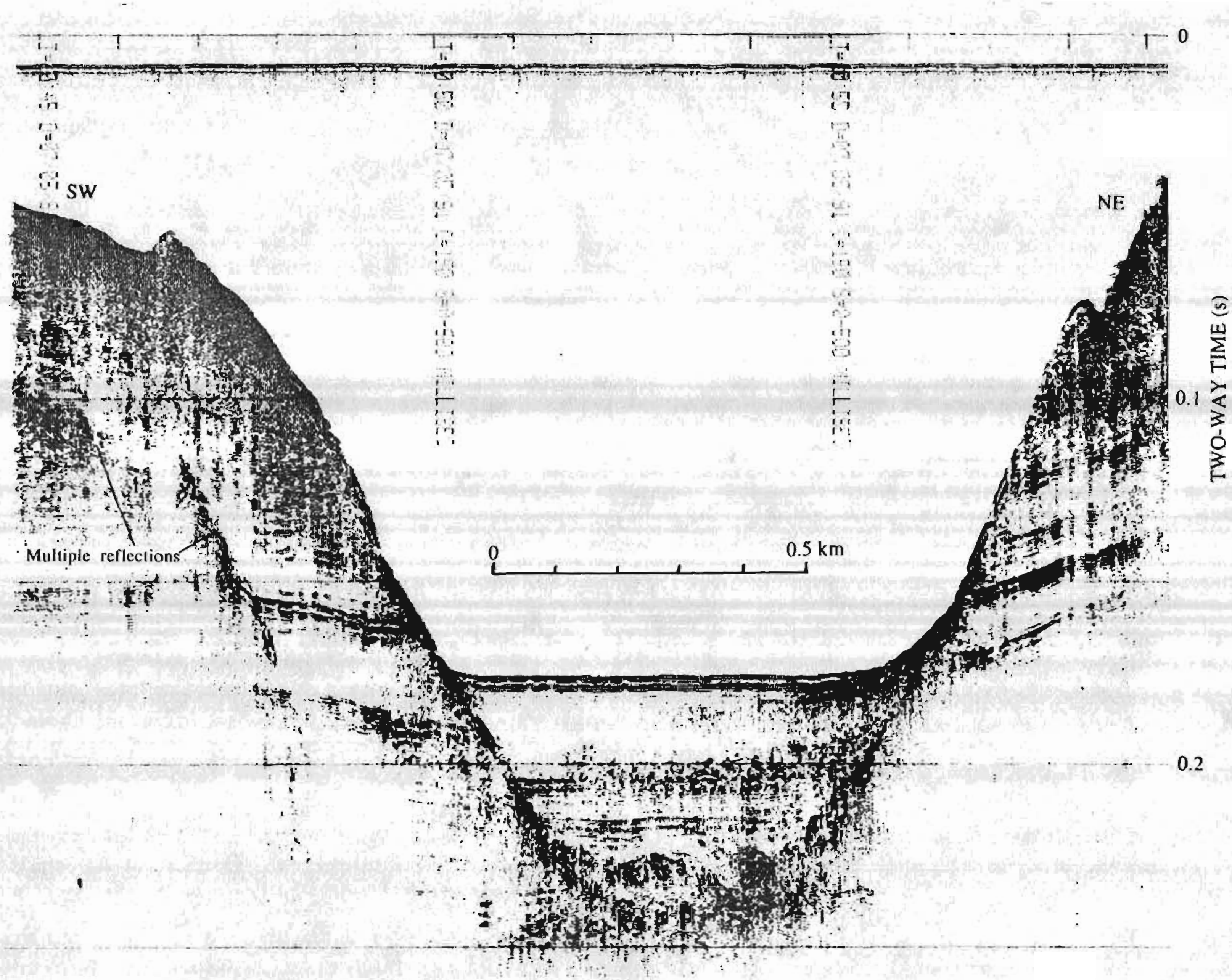
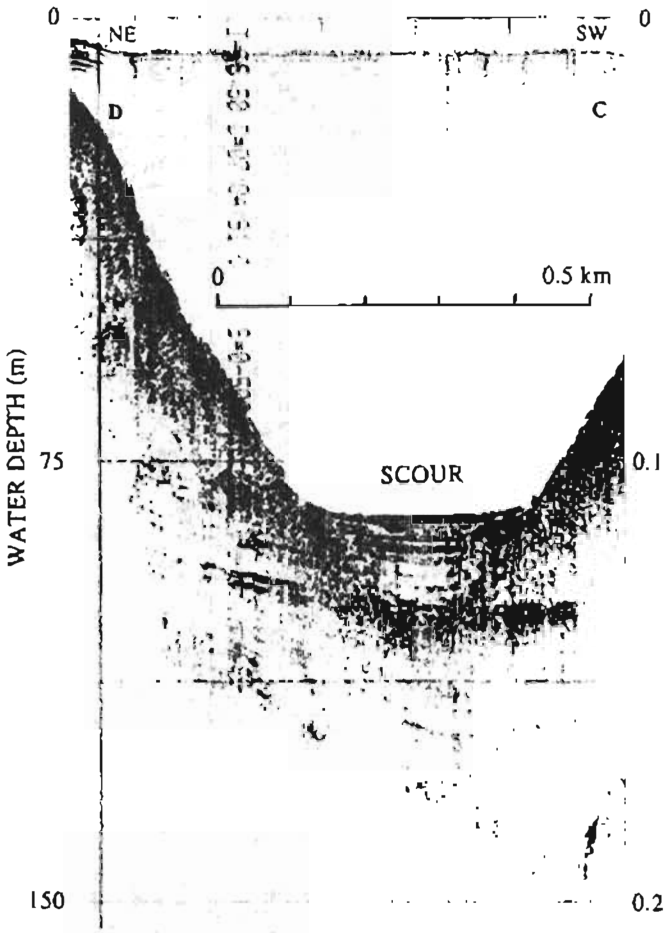
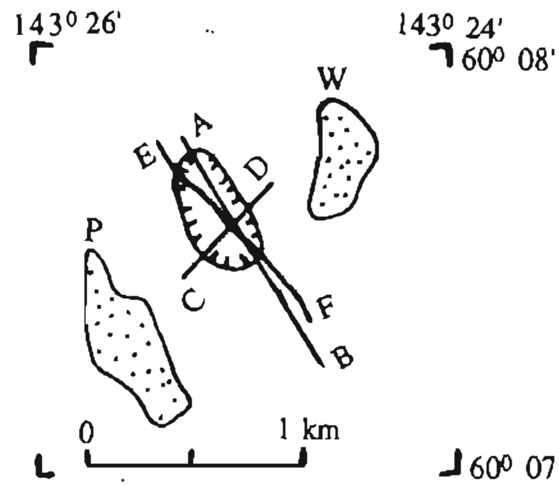


Figure 12. Geopulse profile across partially filled depression (basin B) between Beringa and Pointed Islands. See figure 2 for location. V.E.~7.6x.





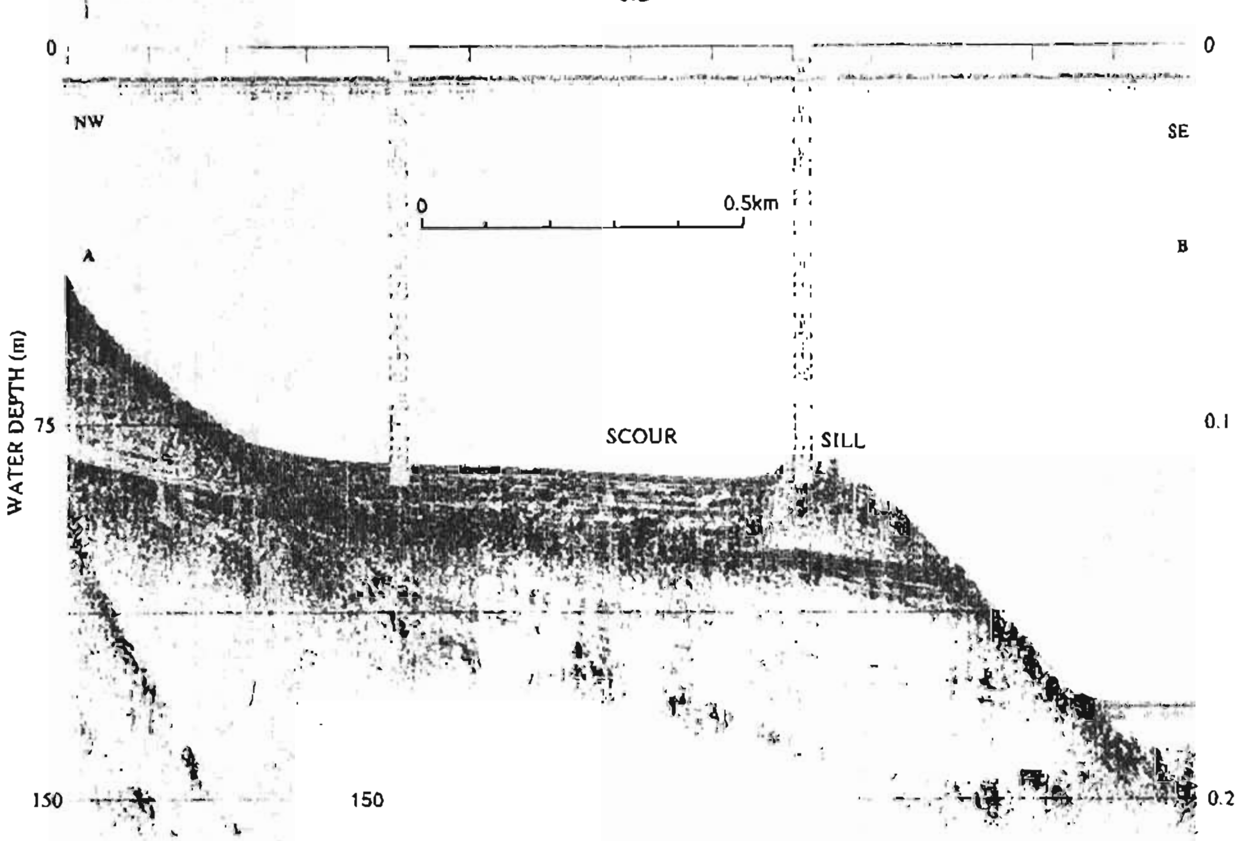


Figure 13. Geopulse profiles (V.E.~7.6x) and map of possible scour (hachured) between Pointed (P) and Whaleback (W) Islands. Line E-F locates side-scan sonograph of figure 14.

Figure 14. Side-scan sonograph of part of scour profiled in figure 13.