A DESCRIPTION OF GLIMPCE, 1986, LARGE OFFSET SEISMIC EXPERIMENT FROM THE GREAT LAKES

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TABLE OF CONTENTS

List of Tables

List of Figures

ABSTRACT

In late summer of 1986, eight U.S. and Canadian academic and government groups deployed 137 seismometers and land geophone arrays at 86 locations in and around the upper Great Lakes to passively record airgun shots fired as part of a deep-penetration marine multichannel seismic reflection program of the Great Lakes International Multidisciplinary Program on Crustal Evolution (GLIMPCE). Vertical components were recorded in all locations; horizontal components were recorded in 43 locations. The primary objective of recording the refracted, wide-angle reflected, and fan arrivals was to provide information on crustal velocity structure to supplement images recorded on the eight deep-penetration marine reflection profiles (five in Lake Superior, one in Lake Michigan, and two in Lake Huron). One of the Lake Superior lines was reshot to optimize recording of the large offset data. This report gives a data summary of the field operations related to the large-offset data.

INTRODUCTION

The Great Lakes International Multidisciplinary Program on Crustal Evolution (GLIMPCE), comprises United States and Canadian government, academic and industry geoscientists interested in the evolution of the midcontinent region of North America. GLIMPCE was formed in late 1985 to direct and coordinate future research around the Great Lakes. The first major experiment (August-September, 1986) was funded by the U.S. Geological Survey (USGS) and the Geological Survey of Canada (GSC) and utilized a large marine seismic airgun source for simultaneous acquisition of nine normal-incidence multichannel reflection and wide-angle reflection/refraction profiles in Lakes Superior, Michigan, and Huron (fig. 1). Passive recording of large offset information from all lines was done by eight academic and government groups. Together, the multichannel reflection data and the wide-angle reflection/refraction data provide an impressive and unprecedented data set for studying the deep crust and velocity structure of the midcontinent region.

This report describes the details of the field operations in which the large-offset reflection/refraction data were collected. Details of the near-vertical deep-penetration multichannel reflection profiles are included where relevant to the acquisition of the wide-angle data. A summary of the acquisition and processing parameters used for the contract multichannel seismic survey is given in Lee and others (1988) and Milkereit and others (1988). No effort is made to judge data quality or present interpretations.

EXPERIMENT OVERVIEW

Objectives: This first major seismic experiment was designed to investigate the tectonic framework and regional velocity structure of the crust in the Great Lakes region. Specific targets were the midcontinental geophysical anomaly, the Keweenawan rift, the Grenville Front, the Penokean and Huronian fold belts, and the Hemlo and Michipicoten greenstone belts.

Summary: The experiment is most easily divided into two parts: a normal incidence, deep-penetration multichannel reflection survey and a large-offset refraction/wide-angle reflection survey. The vertical reflection data comprise eight lines that were shot using a state-of-the-art marine multichannel acquisition system (lines A-C, F-I, fig. 1).

The large-offset data, consisting of wide-angle reflection, refraction and fan (i.e., off-line) arrivals, were recorded by seismometers located around the lakes during shooting of the eight offshore profiles. A ninth line was shot on equally spaced firing times and recorded by seismometers located within and around Lake Superior. This refraction line, Line A-refraction, essentially overlies line A-reflection, and is not plotted as a separate line on Figure 1.

In total, 1350 km of multichannel reflection data were collected; shots for the refraction profile covered an additional 214 km. Throughout the survey, large-offset data were recorded at 137 stations in 86 locations (table 1), including five ocean-bottom seismometers within Lake Superior and three multichannel arrays positioned around the lakes. Vertical components were recorded in all locations; horizontal components were recorded in 43 locations. Recording stations for individual lines ranged from 5 (line I) to 31 (line A-Refraction).

The research groups who provided instruments for acquisition of the large-offset data included two federal surveys (USGS and GSC), two Canadian universities (U. of Western Ontario and U. of Saskatchewan), and four U.S. universities (U. of Wisconsin-Madison, U. of Wisconsin-Oshkosh, Southern Illinois U., and Northern Illinois U.). Additional personnel who participated in the field work were from U.S. Department of Energy, U.S. Coast Guard, Geological Survey of Ontario, University of Toronto, and University of Manitoba. Appendix I gives information about participants and instrumental details not covered elsewhere in the report.

MARINE SEISMIC SURVEY

All data were shot using M/V Fred J. Agnich, a seismic vessel operated by Geophoto Services, Ltd. (GSI, Calgary, Alberta). Five lines were shot in Lake Superior (lines A,B,C,F,G), one in Lake Michigan (line H) and two in Lake Huron (lines I, J). Line A in Lake Superior was also shot separately as a refraction line, utilizing the marine airgun array without the multichannel streamer array. Missing line numbers (D, E) have been reserved for speculation lines shot by GSI in Lake Superior that have not been purchased by GLIMPCE. Table 2 summarizes relevant statistical information about the marine lines. All digital navigation, shot instant, and bathymetry data as well as detailed reports from GSI are archived at GSC (Ottawa, Ont) and USGS (Denver, CO, and Woods Hole, MA).

Airgun Array: The source array (fig. 2) consisted of 76 guns, with 60 guns supplying the operating volume of 7780 in^3 (127.49L) and 16 guns providing spare volume of 2110 in^3 (34.58L). Guns were strung on six linear subarrays, each 9.9 m long, with a total array width of 80 m. Gun sizes ranged from 80 in^3 (1.31L) to 160 in^3 (2.62 L). Operating pressure was maintained at 1900-2000 psi (12.8 - 13.8 MPa). Air gun synchronization was provided by GSI TIGER II controller. Array depths were 12 ± 1 m in Lake Superior, and 6 ± 1 m in Lakes Michigan and Huron. The shallower array depth was used because of shallow water in northern Lake Michigan and in the channel between Georgian Bay and Lake Huron.

Navigation: Primary navigation for all lines was by GEONAV, which utilized doppler sonar velocities to interpolate fixes between transit-satellite updates.

LORAN C provided secondary navigation and a Global Positioning System receiver provided backup (satellite) navigation. All navigation positions refer to the position of the transit satellite antenna, which was located 74 m in front of the center of the airgun array (fig. 2). Details of the navigation system are given in Appendix II.

Shot time determination: In order to utilize a common time base between the normal incidence reflection data acquired by the contract vessel and the large-offset reflection/refraction data acquired independently during shooting, all times were synchronized to the time of the eastern Geostationary Operational Environmental Satellite (GOES). The shot instant was calculated by adding known internal system delays to the time recorded for the command to fire the guns which was always initiated on a whole second. System delays totalled .90796 s for reflection lines and 1.90796 s for line A-refraction, with additional delays of .31062 s for shots coinciding with the change of tape of the DFS V acquisition computer, 24.5 s for all of line A-reflection, and 23.1 s for SP 970-1880 for line C. Determination of these delays is given in Appendix II.

Bathymetry: Digital bathymetry was acquired by a 38-kHz fathometer assuming a water velocity of 1470 m/s. This assumed velocity is valid for Lakes Michigan and Huron, where the average water temperature during the survey was 12°C (corresponding to a theoretical fresh water velocity of 1465 m/s). Because the colder water in Lake Superior would lower the velocity (5°C corresponds to a theoretical fresh water velocity of 1432 m/s), water depths there may be slightly overestimated. The fathometer was located 33.5 m in front of the ship's antenna, or 107.5 m in front of the center of the airgun array.

The original digital bathymetry provided by the contractor contained frequent gaps and noise of 10 to 50 m compared to the fathometer strip-chart profile. Final bathymetry was obtained (fig. 3) by (1) plotting the bathymetry at the same scale as the original fathometer strip-charts, (2) adjusting line segments that were reading a constant offset, (3) redigitizing those parts of lines that were either absent or missed the character of the bottom, and (4) applying a 3-point running average to smooth the noisy signal. Because no fathometer record was kept for line A-refraction (although digital bathymetry were recorded), this line was divided into 50-shot increments and smoothed and redigitized in accordance with its agreement to the relevant portions of line A-reflection. No 3-point running average was used for these relatively widely spaced shots.

The smoothed bathymetry is considered to be accurate to within 5 m of the depth given on the fathometer strip chart, and should be more than accurate enough for topographic corrections to the large-offset data.

Brief Chronology: The experiment began in Lake Superior with shooting of line A-refraction on 31 August - 1 September 1986. After five days of down-time to resolve a navigation problem, multichannel reflection acquisition began with line B on 6 September. Maintaining the ship's speed so as to fire the guns every 50 m (about every 23 s) while recording long records (every 20 s) and keeping the streamer from sinking in the fresh water of the lake proved to be impossible. The shot spacing was therefore adjusted from 50 m (30-fold data) to 62.5 m (24-fold data). The change between 50-m and 62.5-m shots on lines F (7-8 September) and A (9-10 September) reflects unsuccessful efforts to reballast the streamer for 50-m (30-fold) data. Line G was shot on 11 September. Line C was shot in 2 parts on 12-13 September because of poor weather conditions and on-board computer problems.

After a port stop in Sault Ste. Marie to exchange personnel, replenish supplies, and reconfigure the source and streamer arrays for shallow water, the reflection shooting resumed in Lake Michigan with line H (18-19 September). Parts of the streamer damaged in the ship's propellor during retrieval were replaced in transit between Lakes Michigan and Huron. The final lines collected were lines I (21 September) and J (22-23 September) in Lake Huron.

EXPERIMENTAL DETAILS

This section provides a line-by-line description of the large offset data, including a brief summary of the stations occupied, type of data recorded, and maximum offsets. (Appendix I gives additional instrumental details, a list of participants for each group that supplied field instruments, and archive information on the field data).

During the field work, coordination between the shooting ship and land-based groups was critical to the success of the operation. A.G. Green and C. Spencer (both with GSC, Ottawa) provided this support out of Sault Ste. Marie (Lake Superior lines) and Ottawa (Lakes Michigan and Huron lines).

Line A-Refraction: Line A-Refraction in Lake Superior was shot specifically as a refraction line along the same position as line A-reflection. The primary objective of this line was to determine the velocity structure of the crust and upper mantle across the Keweenaw rift where earlier refraction studies yielded crustal thicknesses in excess of 50 km (Halls, 1982). Figure 4 shows shot and receiver locations, table 3 lists relevant information about the receiving stations.

This line was shot by time, rather than by distance, so that receiving seismographs could be synchronized to record discrete shots. The airgun array was fired every two minutes for a total of 640 shots, which averaged about 333 m apart. This shot spacing was chosen so that, at the longest ranges, arrivals from previous shots would not overlap.

A total of 31 stations recorded data along this line (fig. 4). Although no multichannel streamer array was towed from the ship, three multichannel geophone arrays were positioned on land: WISCORP south of the line, CH in the Keweenaw Peninsula, and AA north of the line. Five four-component ocean-bottom seismometers[1] (A8, A2, C4, C9, C3 of USGS) were spaced along the line within the lake. Seven vertical component seismometers were located in a linear array north of the line (SUP1, SUP3-SUP8). Five 3-component seismometers (C1, C2, C3, C4, C5, C6 of UW, Madison) and two vertical-component seismometers (2N, 5S) were located south of the lake. Three 3-component seismometers were located slightly offline on the Keweenaw Peninsula

[1] A special problem exists regarding the OBS locations. The initial locations were chosen based on LORAN C fixes of the Coast Guard vessel from which the instruments were deployed. These locations were incompatible with locations determined by arrival times of shots from the shooting ship (which used Satellite/Doppler sonar navigation). Hence, either the navigation of the deploying ship or the shooting ship or both was in error. OBS locations were calculated (as described in Appendix I) as though all of the error originated from the deploying ship. (This is reasonable because most commercial LORAN C units fail to include overland-propagation and secondary factor corrections to final latitude/longitude calculations). If, however, the error was in the navigation of the shooting ship, this implies that all ranges calculated for the onshore instruments may be biased. Relative range from shot to shot (and therefore observed apparent velocities) should not be significantly affected. This possible source of error would affect intercept times and may affect correlation of the large-offset data to the near-vertical data.

(CP1-CP3). Fan recordings were made at five locations: Michipicoten Island (A), Isle Royale (IR1, IR2), Brule River (B1), Bayfield Peninsula (BF1) and Ontanagon (ON1).

For shots along the profile, maximum ranges recorded are 256 km (SP 109 to station SUP8) and 231 km (SP 748 to station C4).

Line A-Reflection: Line A-Reflection was shot in two parts with different shot spacings (50 m and 62.5 m) because of problems in balancing ship's speed against streamer buoyancy. The overlap begins at SP 2290, with SP 2290-2326 (50 m shots) overlapping with SP 2290-2320 (62.5 m shots). As with line A-Refraction, the primary objective of this line was to image the crust and upper mantle structure at the position of the thickest crust associated with the midcontinent rift. Because this line was also shot separately as a refraction profile, collection of large-offset data was not a high priority.

Fourteen stations recorded large offset data (fig. 5; table 4). Two stations (SUP2A, SUP7A) were occupied north of the lake to record data where instruments had failed during the recording of line A-refraction. Two 3-component stations recorded data on the Keweenaw Peninsula and south of the line, respectively. Six stations recorded fan arrivals, including one 96-channel geophone array (WISCORP).

Line B: Line B, along the northeast shore of Lake Superior (fig. 6), was shot with a 50-m shot interval over a distance of 98 km. The primary objective of this line was to profile the structure of a granite-greenstone belt along the edge of the Keweenaw rift. The offline recorders also received ray paths directly through and beneath the main part of the Keweenaw rift.

A total of 13 stations (fig. 6, table 5) recorded large offset information from shots fired on line B. No station was located exactly along the axis of the profile, although BB (a 48-channel geophone array north of the lake) and A (a vertical-component seismometer on Michipicoten Island) are reasonably close to the axis. The remaining 11 stations recorded fan arrivals on 3-component instruments.

Line C: Line C in Lake Superior, 109 km long, was shot in two parts because of shipboard computer malfunction. Both parts were shot with 62.5 m shots. The objective of this line was to image the structure of the western limb of the Keweenaw rift. Its location roughly coincides with a refraction line shot in 1967 (Luetgert and Meyer, 1982).

A total of 15 stations recorded data from shots on this line (fig. 7, table 6). One 96-channel geophone array was positioned south of the line (WISCORP). The remaining fourteen stations were 3-component instruments located northwest of the line (6 stations, B1-B6), south of the line (4 stations, ON1-ON4) and offline at Isle Royal (2 stations, IR1, IR2), Keeweenaw Peninsula (1 station, CP3) and Big Bay (1 station, C6). Maximum offsets recorded were 131 km (SP 156 to station ON3 and SP 1880 to station B3).

The overlap between the two parts of line C occurs between SP 741 and SP 771. A special timing problem occurred on the start of the second part of the line. At SP 741, the GSI clock was synchronized to the satellite clock for shot instant determination. However, by SP 1057, the two clocks read 23.1 s apart. When the discrepancy occurred was not logged, and hence the exact shot instants for SP 741-1057 remains uncertain. The 23.1s correction has been applied to all shots after SP 970.

Line F: Line F, located in Lake Superior, was shot in 6 parts alternating between 50 m and 62.5 m shot intervals (see table 2). This variation reflects buoyancy problems with the streamer. A 2.2 km gap occurs between SP 455 and SP 457; and a major change in the orientation of the line occurs at SP 1579. The primary objective of this line was to image the eastern limb of the Keweenawan rift in a region of relative gravity low and two positive magnetic anomales.

Twelve stations (fig. 8, table 7) recorded data from line F. A vertical-component seismometer on Michipicoten Island (A, Fig. 8) is the closest instrument to the axis of the north-northeast segment of the line (SP 101-1579); four three-component instruments (C6, ON1-3) and a 96-channel geophone array (WISCORP) are approximately along the axis of the east-north-east segment of the line (SP 1580-1843). The remaining six stations (CP3, IR1, IR2, B1-B3) are three component seismometers that recorded fan arrivals through and beneath the rift basin.

Line G: Line G, 54 km long in Lake Superior, was shot with 62.5-m shot intervals and is the shortest of all lines. It was positioned to give a line crossing with line A in the region where continental crust was assumed to be thickest.

Eight stations, all three-component seismometers deployed by University of Wisconsin-Madison, recorded fan shots for this line (figure 9, table 8). There were no stations positioned along the axis of the line.

Line H: Line H, the only line in Lake Michigan, was shot with 62.5-m shot intervals for a total length of 283 km. A major bend in the line occurs at SP 3565. The primary objective of this line was to image the structure of the Penokean fold belt buried beneath Paleozoic sediments of the Michigan Basin.

A total of 21 stations were deployed along Line H (figure 10, table 9). Seventeen stations, containing a combination of fifteen vertical-component instruments (MC1a-MC5c) amd two 3-component instruments (MC6, MC7), were positioned north of the lake along the axis of the north-northeast trending segment of the line (SP 101-3565). The remaining four stations were vertical-component seismometers (1S, 2N, 3S, 5S) located northwest of the lake and slighly off the axis of the east-northeast trending segment of the line (SP 3565 - SP 4636). The maximum range recorded for this line was 256 km (SP 101 to station MC6).

Line I: Line I in Lake Huron, was a north-south line (108-km long) positioned so as to image the structure of Proterozic Huronian platform deposits exposed north of the lake but buried beneath the lake by Phanerozoic sediments. Shots were spaced 62.5 m apart.

Five stations were occupied during the shooting of line I (figure 11, table 10). One vertical component seismometer was positioned along the north shore of the lake (IRON). A second vertical-component instrument (MAN) was located slightly offline on the western end of Manitoulin Island. The remaining three stations, all south of the line in Michigan, comprised 2 three-component seismometers (HE1, HE2) and a 24-channel geophone array (AL). The largest offsets recorded were 116 km (SP 102 to station IRON) and 118 km (SP 1823 to station HE2). No fan arrivals were recorded for this line.

Line J: Line J, located in Georgian Bay and Lake Huron, is the longest of all lines in the GLIMPCE experiment (323 km). All shots were fired at 62.5-m spacings. Several kinks occur where the vessel adjusted course to stay within the channel separating Georgian Bay and Lake Huron (SP 1800-2300). The primary objective of this line was to profile the Grenville front and the buried igneous terrane to the west.

Eighteen stations were occupied during the acquisition of this line (figure 11, table 10). Three vertical-component seismometers were positioned east of the line on the coast of Georgian Bay (stations C, D, E). A fourth vertical-component instrument was located on the Bruce Peninsula midway down the line (station B). The rest of the stations were located just west of the end of the line and consisted of one 24-channel geophone array (SH) and thirteen three-component seismometers, ten of which were in a linear array less than 2 km long. Maximum offsets for this line are 336 km (SP 101 to station F11) and 346 km (SP 5264 to station D).

DISCUSSION AND SUMMARY

In order to insure consistency in data preparation and distribution, all participants agreed to use the same algorithm for range calculation to display and interpret the large offset data. This algorithm uses the geodetic inverse formula with geodesy by A. R. Clarke (1880) and is listed in Appendix III. Final data exchange format is a superset of SEG-Y, with header definitions for refraction data given in Appendix IV.

In summary, this first GLIMPCE experiment has provided an impressive amount of seismic information for studying crustal structure and tectonics of the mid-continent. Eight academic and government groups "piggybacked" on a major marine multichannel reflection survey and were able to record vertical and three-component data for all seismic lines shot in the Great Lakes. The success of this effort rests with the careful coordination between the shooting ship and the land-based groups. The experiment demonstrates that large offset information can be acquired simultaneously with deep crustal reflection profiling at a fairly modest expenditure of dollars, time and effort.

ACKNOWLEDGEMENTS

An experiment of this size and cost would not have been possible without the dedication and cooperation of numerous individuals. Bill Cannon of USGS and Alan Green of GSC provided the driving force behind the organization of GLIMPCE and the 1986 seismic experiment and were instrumental in securing the USGS and GSC funding that made the experiment possible. Alan Green, with help from Carl Spencer, also impressively coordinated efficient communications between the shooting ship and the often remotly located field parties deploying seismometers and geophone arrays. J.C. Behrendt (USGS) and L.D. McGinnis (U.S.-DOE) were GLIMPCE representatives aboard M/V Fred J. Agnich during the Lake Superior lines; A.G. Green (GSC) and D.R. Hutchinson (USGS) were on-board representatives during the Lake Michigan and Lake Huron lines. We thank John Clink (GSI) and the captain and crew of the Fred J. Agnich for their cooperation during the contracting and shooting. We thank the Captain and crew of the U.S. Coast Guard vessel Katmai Bay for their cooperation during deployment and recovery of the OBS's in Lake Superior, and the Geological Survey of Ontario for helicopter logistics into Michipicoten Island. Much of the field logistics would not have been possible without the dedicaton of the many researchers, technicians, and students who operated the field instrumentation, most who are listed in Appendix I. Finally, we thank K. Ruffin, M.C. Mons-Wengler, E. Winget, P. Forrestel, J. Zwinakis and D. Blackwood for technical assistance in preparing the manuscript and J. Luetgert and W. Agena for critical reviews.

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TABLE 1: Summary of Stations Occupied in GLIMPCE '86 Experiment

Research Group[1]	Instrument Type	Instrument Components[2]	Lake Superior A (refraction)	Lake Superior A (reflection)	Lake Superior B	Lake Superior C	Lake Superior F	Lake Superior G	Lake Michigan H	Lake Huron I	Lake Huron J	TOTAL STATIONS OCCUPIED	TOTAL LOCATIONS OCCUPIED
GSC	PRS 1	z	7	2						2		11	11
USGS	Ocean Bottom Seismometer	x,y,z, p	5									5	5
UW-Madison	UW Digital Seismographs	x,y,z	13	11	11	14	10	8	17[3]	2	13	99	53
UW-Oshkosh	96-channel geophone array	z	1	1		1	1					4	2
SIU	24-channel geophone array	z	1							1	1	3	3
NIU	1) S-6000 2) MEQ-800	z	2						4			6	5
UWO	UWO/MP	z	1		1		1				4	7	5
USask	48-channel geophone array	z	1		1							2	2
TOTAL			31	14	13	15	12	8	21	5	18	137	86

[1] Abbreviations: GSC-Geological Survey of Canada; USGS-U.S. Geological Survey; UW-Univ. of Wisconsin; SIU-Southern Illinois Univ.; NIU-Northern Illinois Univ.; UWO-Univ. of Western Ontario; USask-Univ. of Saskatchewan.

[2] Components: x,y-horizontal; z-vertical; p-hydrophone

[3] On Line H, 15 of the 17 stations were collecting Z-component data only

TABLE 2: Start and End Information for Marine Seismic Lines

Glimpce Line ID	GSI ID[1]	Length (KM)	Shot Int (m)	Fold	Start Time[2] JD/GMT	End Time[2] JD/GMT	Start SP	End SP
A-refraction	AA-	214	2 min		243/1600	244/1318	109	748
A-reflection	A'A	111	50	30	252/0950	253/0012	101	2326
	A"A	103	62.5	24	253/0327	253/1428	2290	3944
B	BB'	98	50	30	249/1345	250/0216	111	2063
C	CC'	38	62.5	24	255/1320	255/1715	156	771
	CC'A	71	62.5	24	255/2250	256/0609	741	1880
F	BFLINK	18	50	30	250/1732	250/1946	101	455
	FF'	26	62.5	24	250/1959	250/2246	457	866
		2	50	30	250/2246	250/2300	867	902
		42	62.5	24	250/2300	251/0330	903	1579
	F'F"	26	50	30	251/0656	251/1016	1580	2095
		47	62.5	24	251/1016	251/1541	2096	2843
G	G'G	54	62.5	24	254/0312	254/0849	101	969
H	3	283	62.5	24	261/1306	262/1840	101	4636
I	1	108	62.5	24	263/1943	264/0701	102	1823
J	2A	323	62.5	24	265/0649	266/1631	101	5264

TOTAL 9 lines 1564 km

1 Line ID used by the contractor in collecting the multichannel data and processing the navigation data.

2 JD-Julian Day; GMT-Greenwich Mean Time. All times rounded to whole minutes.

TABLE 3: Summary of Stations Occupied for Line A - refraction

Research Group	Station ID	LAT	LON	Elev[1] (masl)	Components[2]	Record Time (JD/GMT) start	Record Time (JD/GMT) end
U.S.G.S.	A8	48.54810	-87.16109	38	z,p	243/1600	243/2154
	A2	48.26583	-87.27365	-47	x,y,z,p	243/1600	244/1628
	C3	47.14079	-87.59501	62	x,y,z,p	243/1600	244/1618
	C4	47.95688	-87.36752	-24	x,y,z	243/1600	244/1512
	C9	47.71128	-87.43908	23	x,y,z	243/1600	244/1450
G.S.C	SUP1	48.77233	-87.11450	190	z	243/1600	244/1520
	SUP3	48.90250	-87.06650	305	z	"	"
	SUP4	48.94567	-87.07983	320	z	"	"
	SUP5	48.99717	-87.10017	335	z	"	"
	SUP6	49.04100	-87.07417	302	z	"	"
	SUP7	49.09283	-87.06217	338	z	"	"
	SUP8	49.14400	-87.05467	325	z	"	"
U. Wisconsin (Madison)	B1	47.90127	-90.06084	451	x,y,z	243/1523	244/1816
	BF1	46.80583	-91.03833	347	x,y,z	242/1302	244/1600
	C1	46.80610	-87.64292	198	x,y,z	243/1518	244/1444
	C2	46.78452	-87.64140	201	x,y,z	242/2036	244/1411
	C3	46.76120	-87.64594	201	x,y,z	243/1521	244/0903
	C4	46.71639	-87.63824	259	x,y,z	242/2343	244/1640
	C6	46.78597	-87.72867	305	x,y,z	243/1517	244/1516
	CP1	47.45694	-87.79222	305	x,y,z	243/1316	244/1500
	CP2	47.41778	-87.75833	247	x,y,z	243/1506	244/1600
	CP3	47.41194	-87.79722	222	x,y,z	243/1415	244/1546
	IR1	48.09617	-88.59450	207	x,y,z	243/1518	244/1536
	IR2	48.09250	-88.60083	207	x,y,z	243/1553	244/1612
	ON1	46.82167	-89.35833	221	x,y,z	243/1508	244/1540
U. Western Ontario	A	47.720045	-85.798667	230	z	243/1550	244/1314
Northern Illinois U.	5S	45.73383	-88.18883	387	z	243/1555	243/2230
	2N	45.92033	-88.15667	384	z		
U. Saskatchewan	AA	48.85033	-87.09867	317	48 * z	243/1600	244/0812
U. Wisconsin (Oshkosh)	WISCORP	46.80167	-87.64333	204	96 * z	243/1600	244/1319
Southern Illinois U.	CH	47.42639	-87.76278	242	24 * z	243/1600	244/1422

1 All OBS elevations corrected for lake level (183 masl).
2 x,y-horizontal; z-vertical; p-pressure (hydrophone)

TABLE 4: Summary of Stations Occupied for Line A - reflection

Research Group	Station ID	LAT	LON	Elev (masl)	Components	Record Time (JD/GMT) start	end
G.S.C.	SUP2A	48.84033	-87.10017	314	z	253/0400	253/1430
	SUP7A	49.09250	-87.06233	332	z	253/0400	253/1430
U. Wisconsin (Madison)	B1	47.90127	-90.06084	451	x,y,z	252/0115	253/1939
	B2	47.84592	-90.04132	338	x,y,z	252/0200	254/1400
	B3	47.95893	-90.12148	552	x,y,z	253/0037	253/0119
	B4	47.91972	-90.09130	527	x,y,z	251/2130	252/2100
	B5	47.93963	-90.09724	546	x,y,z	251/2345	252/2330
	C6	46.78597	-87.72867	305	x,y,z	252/0252	253/0505
	CP3	47.41194	-87.79722	222	x,y,z	251/0146	253/0849
	IR1	48.09617	-88.59450	207	x,y,z	251/2339	253/2259
	IR2	48.09250	-88.60083	207	x,y,z	252/0040	253/2345
	ON2	46.71833	-89.38250	347	x,y,z	251/1900	256/1235
	ON3	46.67917	-89.35417	348	x,y,z	251/1941	254/1700
U. Wisconsin (Oshkosh)	WISCORP	46.68667	-89.38750	337	96 * z	252/1010	253/0009

TABLE 5: Summary of Stations Occupied for Line B

Research Group	Station ID	LAT	LON	Elev (masl)	Components	Record Time (JD/GMT) start	Record Time (JD/GMT) end
U. Wisconsin (Madison)	B1	47.90127	-90.06084	451	x,y,z	249/0000	250/1919
	B2	47.84592	-90.04132	338	x,y,z	249/0000	251/0145
	B3	47.95893	-90.12148	552	x,y,z	249/2137	250/2319
	IR1	48.09617	-88.59450	207	x,y,z	249/0000	250/2325
	IR2	48.09250	-88.60083	207	x,y,z	249/0000	251/0005
	ON1	46.82167	-89.35833	221	x,y,z	249/1300	250/1201
	ON2	46.71833	-89.38250	347	x,y,z	247/0830	250/1330
	ON3	46.67917	-89.35417	348	x,y,z	248/2120	251/1926
	ON4	46.69833	-89.37167	366	x,y,z	249/2145	250/1400
	C6	46.78597	-87.72867	305	x,y,z	249/1200	250/0452
	CP3	47.41194	-87.79722	222	x,y,z	248/2134	250/1211
U. Western (Ontario)	B	47.720045	-85.798667	230	z	249/1220	250/0337
U. Saskatchewan	BB	49.029167	-87.211167	445	48 * z	249/1345	250/0223

TABLE 6: Summary of Stations Occupied for Line C

Research Group	Station ID	LAT	LON	Elev (masl)	Components	Record Time (JD/GMT) start	Record Time (JD/GMT) end
U. Wisconsin (Madison)	B1	47.90127	-90.06084	451	x,y,z	255/1051	255/2351
	B2	47.84592	-90.04132	338	x,y,z	255/0945	256/0047
	B3	47.95893	-90.12148	552	x,y,z	255/1200	255/2302
	B4	47.91972	-90.09130	527	x,y,z	255/1122	255/2332
	B5	47.93963	-90.09724	546	x,y,z	255/1137	255/2314
	B6	47.85279	-90.05097	402	x,y,z	255/1550	256/0022
	IR1	48.09617	-88.59450	207	x,y,z	255/1202	255/2320
	IR2	48.09250	-88.60083	207	x,y,z	255/1230	255/2352
	ON1	46.82167	-89.35833	221	x,y,z	255/1138	256/0323
	ON2	46.71833	-89.38250	347	x,y,z	255/1213	256/0016
	ON3	46.67917	-89.35417	348	x,y,z	255/1312	256/0106
	ON4	46.69883	-89.37167	366	x,y,z	255/1229	256/0036
	C6	46.78597	-87.72867	305	x,y,z	255/1259	255/1309
	CP3	47.41194	-87.79722	222	x,y,z	255/1235	255/1909
U. Wisconsin (Oshkosh)	WISCORP	46.68667	-89.38750	337	z	255/1335	256/0641

TABLE 7: Summary of Stations Occupied for Line F

Research Group	Station ID	LAT	LON	Elev (masl)	Components	Record Time (JD/GMT) start	Record Time (JD/GMT) end
U. Wisconsin (Madison)	B1	47.90127	-90.06084	451	x,y,z	249/2320	252/0108
	B2	47.84592	-90.04132	338	x,y,z	250/0020	252/0200
	B3	47.95893	-90.12148	552	x,y,z	249/2137	251/2359
	IR1	48.09617	-88.59450	207	x,y,z	249/2318	251/2321
	IR2	48.09250	-88.60083	207	x,y,z	250/0000	252/0040
	ON1	46.82167	-89.35833	221	x,y,z	250/1252	250/1900
	ON2	46.71833	-89.38250	347	x,y,z	250/1330	251/1830
	ON3	46.67917	-89.35417	348	x,y,z	249/2330	251/1926
	C6	46.78597	-87.72867	305	x,y,z	250/0520	250/2359
	CP3	47.41194	-87.79722	222	x,y,z	250/1227	252/0239
U. Wisconsin (Oshkosh)	WISCORP	46.68667	-89.38750	337	96 * z	251/0717	251/1440
U. Western (Ontario)	A	47.720045	-85.798667	230	z	250/1000	251/0400

TABLE 8: Summary of Stations Occupied for Line G

Research Group	Station ID	LAT	LON	Elev (masl)	Components	Record Time (JD/GMT) start	Record Time (JD/GMT) end
U. Wisconsin (Madison)	B1	47.90127	-90.06084	451	x,y,z	254/0230	255/0200
	B2	47.84592	-90.04132	338	x,y,z	254/0230	254/0845
	IR1	48.09617	-88.59450	207	x,y,z	253/2339	254/2219
	IR2	48.09250	-88.60083	207	x,y,z	254/0000	255/0005
	ON2	46.71833	-89.38250	347	x,y,z	253/2150	254/1700
	ON3	46.67917	-89.35417	348	x,y,z	253/2230	254/1700
	C6	46.78597	-87.72867	305	x,y,z	254/0220	254/1034
	CP3	47.41194	-87.79722	222	x,y,z	253/2210	254/0924

TABLE 9: Summary of Stations Occupied for Line H

Research Group	Station ID	LAT	LON	Elev (masl)	Components	Record Time (JD/GMT) start	Record Time (JD/GMT) end
U. Wisconsin (Madison)	MC1a	46.05033	-86.07704	221	z	261/0800	262/2015
	MC1b	46.04953	-86.07764	221	z	"	"
	MC1c	46.04793	-86.07884	219	z	"	"
	MC2a	46.04873	-86.07824	219	z	261/0800	262/2020
	MC2b	46.04712	-86.07945	218	z	"	"
	MC2c	46.04553	-86.08065	215	z	"	"
	MC3a	46.04632	-86.08004	216	z	261/0840	262/1424
	MC3b	46.04472	-86.08124	213	z	"	"
	MC3c	46.04311	-86.08245	210	z	"	"
	MC4a	46.04391	-86.08185	213	z	261/0830	262/2030
	MC4b	46.04231	-86.08305	209	z	"	"
	MC4c	46.04150	-86.08365	207	z	"	"
	MC5a	46.04070	-86.08425	207	z	261/0900	262/1917
	MC5b	46.03990	-86.08485	207	z	"	"
	MC5c	46.03910	-86.08545	207	z	"	"
	MC6	46.09363	-86.07319	197	x,y,z	261/1600	262/1957
	MC7	46.01237	-86.11105	207	x,y,z	261/1700	262/2045
Northern Illinois U.	1N	45.90917	-88.09217	380	x,y,z	262/0253	262/1230
	1S	45.69683	-87.90033	290	z	261/2222	262/0920
	3S	45.72133	-88.03533	329	x,y,z	262/0300	262/0700
	5S	45.73383	-88.18883	387	z	262/0300	262/0739

TABLE 10: Summary of Stations Occupied for Line I

Research Group	Station ID	LAT	LON	Elev (masl)	Components	Record Time (JD/GMT) start	end
G.S.C.	IRON	46.24067	-83.23833	204	z	263/1400	264/1100
	MAN	45.91350	-83.17917		z	263/1400	264/1000
U. Wisconsin (Madison)	HE1	45.15621	-83.39214	207	x,y,z	263/1244	264/1200
	HE2	45.10619	-83.39413	201		263/1500	264/1120
Southern Illinois U.	AL	45.07917	-83.39583	158	24 * z	263/1930	264/0736

TABLE 11: Summary of Stations Occupied for Line J

Research Group	Station ID	LAT	LON	Elev (masl)	Components	Record Time (JD/GMT) start	Record Time (JD/GMT) end
U. Wisconsin (Madison)	F1	45.59559	-84.35345	220	x,y,z	265/0600	266/1733
	F10	45.59939	-84.37473	220	x,y,z	265/1200	266/1755
	F11	45.61227	-84.38957	220	x,y,z	265/1655	266/1801
	F12	45.57724	-84.33746	220	x,y,z	265/1700	266/1730
	F13	45.58297	-84.38998	215	x,y,z	265/2300	266/1054
	F2	45.59612	-84.35585	220	x,y,z	265/0600	266/1744
	F3	45.59621	-84.35826	220	x,y,z	265/0600	266/1654
	F4	45.59628	-84.36082	220	x,y,z	265/0600	266/1204
	F5	45.59643	-84.36338	220	x,y,z	265/0600	266/1745
	F6	45.59679	-84.36577	220	x,y,z	265/0600	266/1750
	F7	45.59689	-84.36833	220	x,y,z	265/0600	266/1750
	F8	45.59746	-84.37056	220	x,y,z	265/0600	266/1750
	F9	45.59818	-84.37284	220	x,y,z	265/0600	266/1755
U. Western Ontario	B	45.200548	-81.555128	207	z	265/0651	266/1800
	C	45.086081	-80.029875	197	z	"	"
	D	45.070883	-79.851781	230	z	"	"
	E	45.165681	-79.880952	230	z	"	"
Southern Illinois U.	SH	45.62638	-84.21250	188	24 * z	265/1451	266/1755

Figure 1: Location of GLIMPCE multichannel seismic reflection lines and stations used to record wide-angle and large-offset data. Line A-refraction overlies line A-reflection and is not plotted. Individual station names associated with each line are shown in figures 4 to 12.

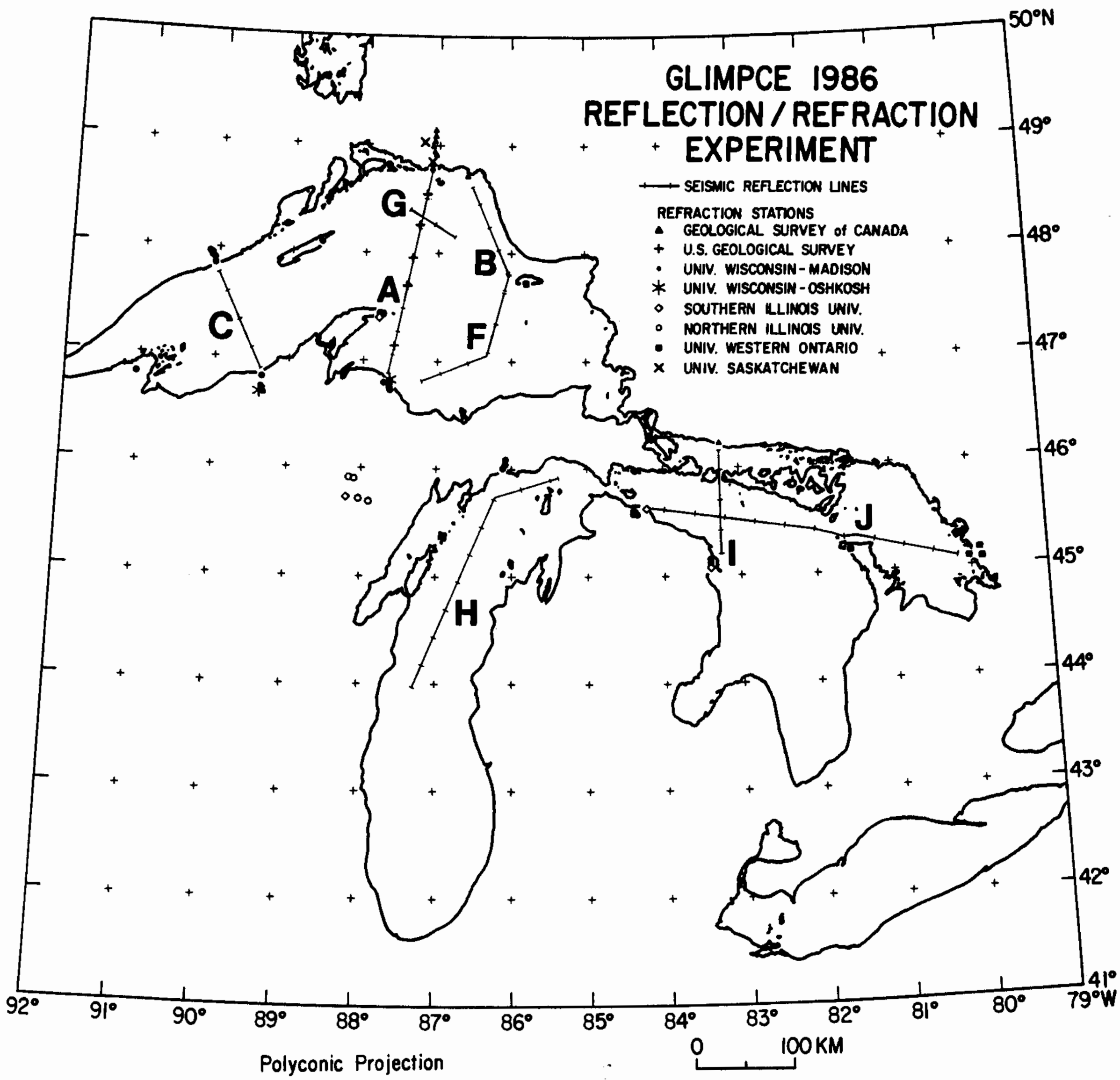
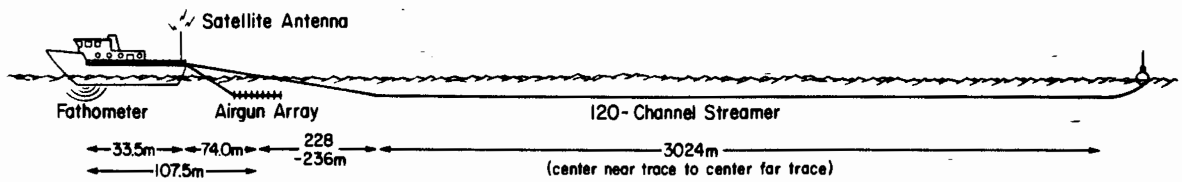

GLIMPCE 1986
REFLECTION / REFRACTION
EXPERIMENT
SEISMIC REFLECTION LINES
REFRACTION STATIONS
GEOLOGICAL SURVEY of CANADA
U.S. GEOLOGICAL SURVEY
UNIV. WISCONSIN - MADISON
UNIV. WISCONSIN - OSHKOSH
SOUTHERN ILLINOIS UNIV.
NORTHERN ILLINOIS UNIV.
UNIV. WESTERN ONTARIO
UNIV. SASKATCHEWAN
A
B
C
F
G
H
I
J
50°N
49°
48°
47°
46°
45°
44°
43°
42°
41°
92°
91°
90°
89°
88°
87°
86°
85°
84°
83°
82°
81°
80°
79°W
0
100 KM
Polyconic Projection

Figure 2: Source and streamer configuration for GLIMPCE marine multichannel profiles. A) Streamer geometry and relative positions of fathometer, satellite antenna, airgun array and streamer. B) Geometry and size of the airgun array. Whereas the total array contained 76 guns, only 60 guns were operational at any one time.

A. GLIMPCE 1986 CONTRACT VESSEL



B. AIRGUN ARRAY

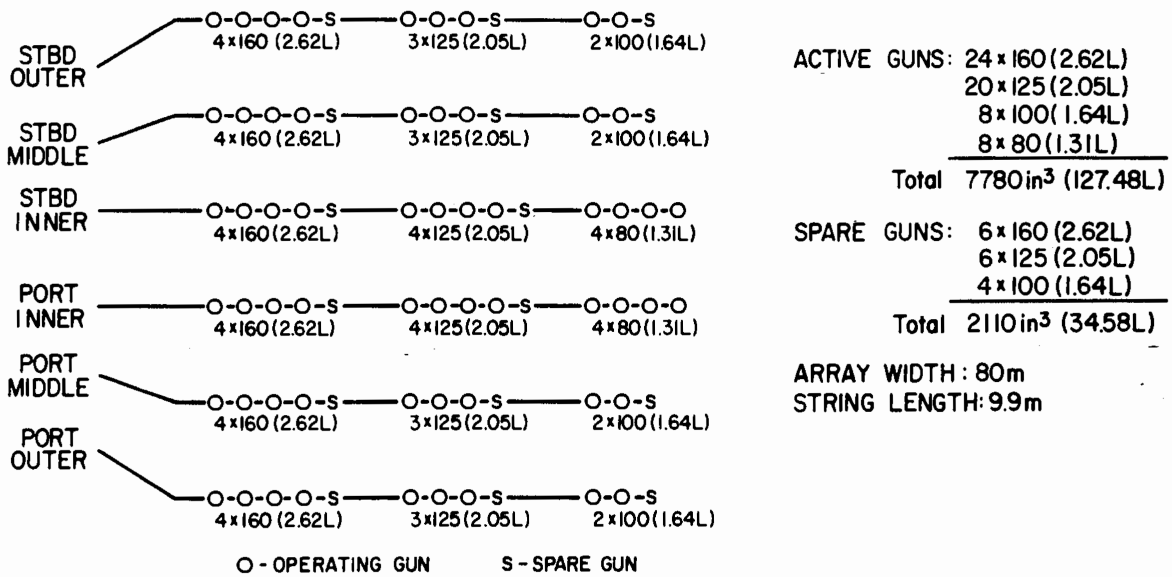


Figure 3: Bathymetric profiles associated with each GLIMPCE shot line. See text for a description of processing and smoothing of the digital data.

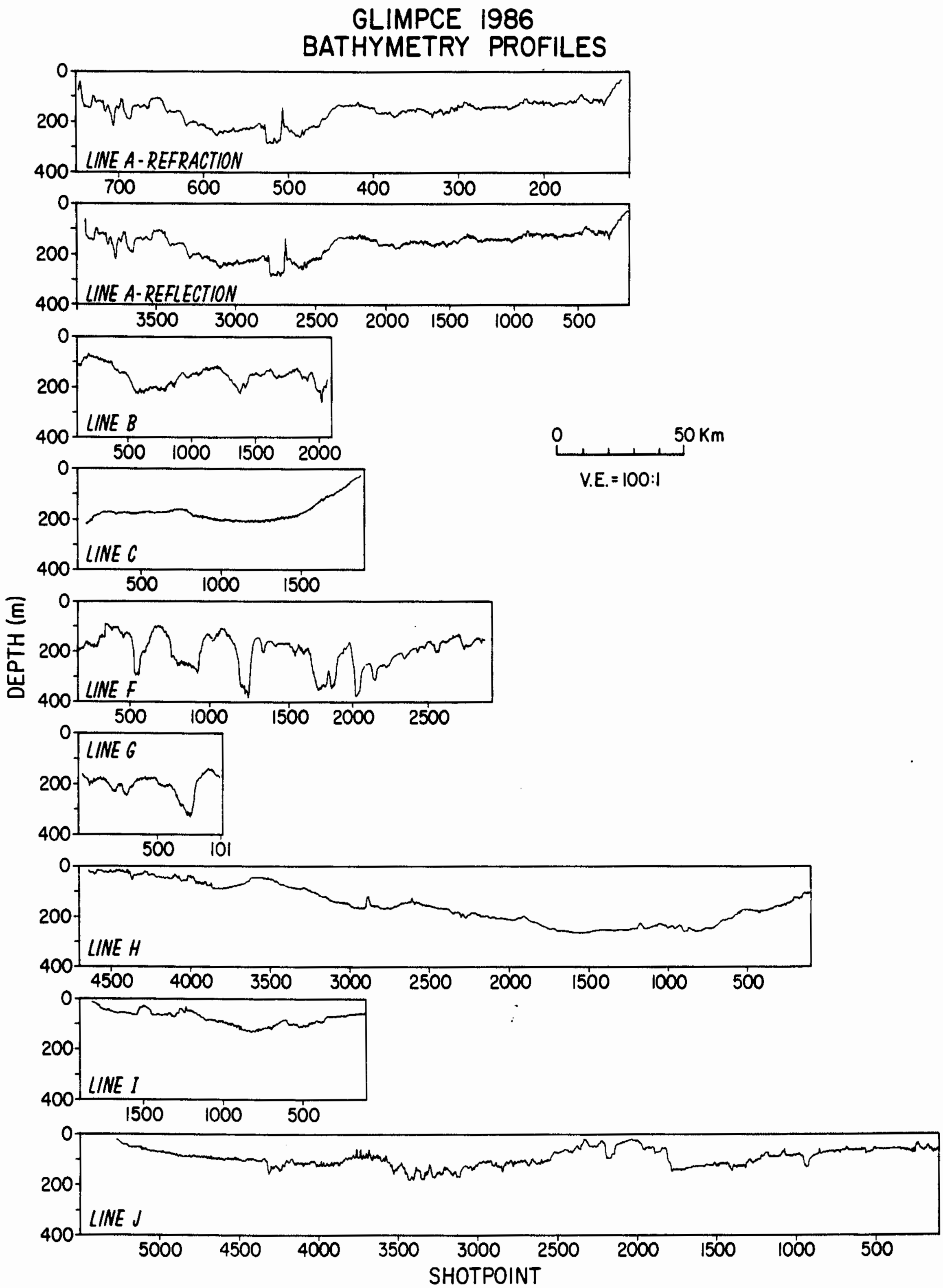

GLIMPCE 1986
BATHYMETRY PROFILES
LINE A - REFRACTION
700 600 500 400 300 200
LINE A - REFLECTION
3500 3000 2500 2000 1500 1000 500
LINE B
500 1000 1500 2000
0 50 Km
V.E. = 100:1
LINE C
500 1000 1500
DEPTH (m)
LINE F
500 1000 1500 2000 2500
LINE G
500 101
LINE H
4500 4000 3500 3000 2500 2000 1500 1000 500
LINE I
1500 1000 500
LINE J
5000 4500 4000 3500 3000 2500 2000 1500 1000 500
0 200 400
SHOTPOINT

Figure 4: Shot and station locations for line A-refraction. Symbols are the same as those used in Figure 1. Additional information is listed in Table 3.

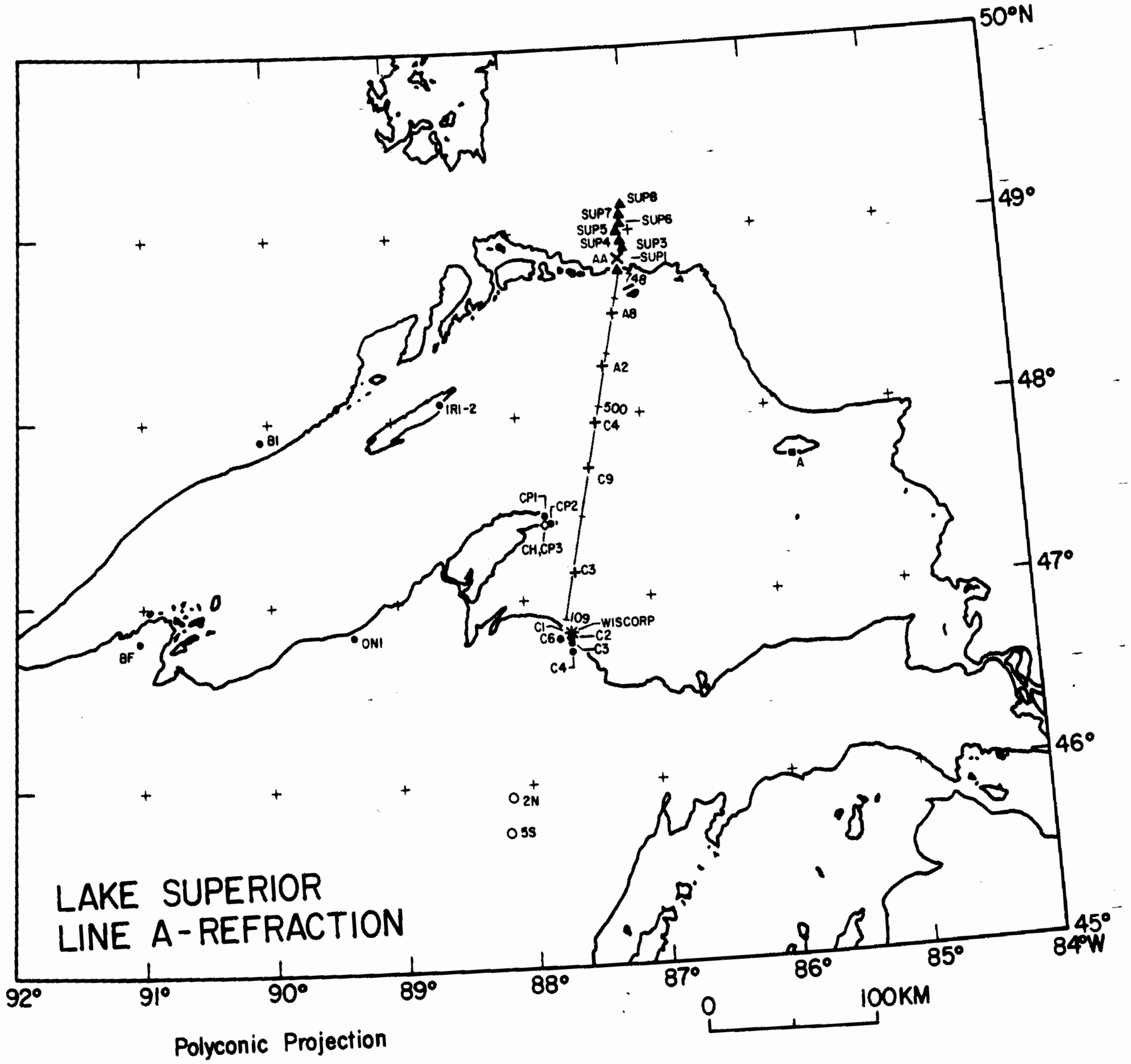
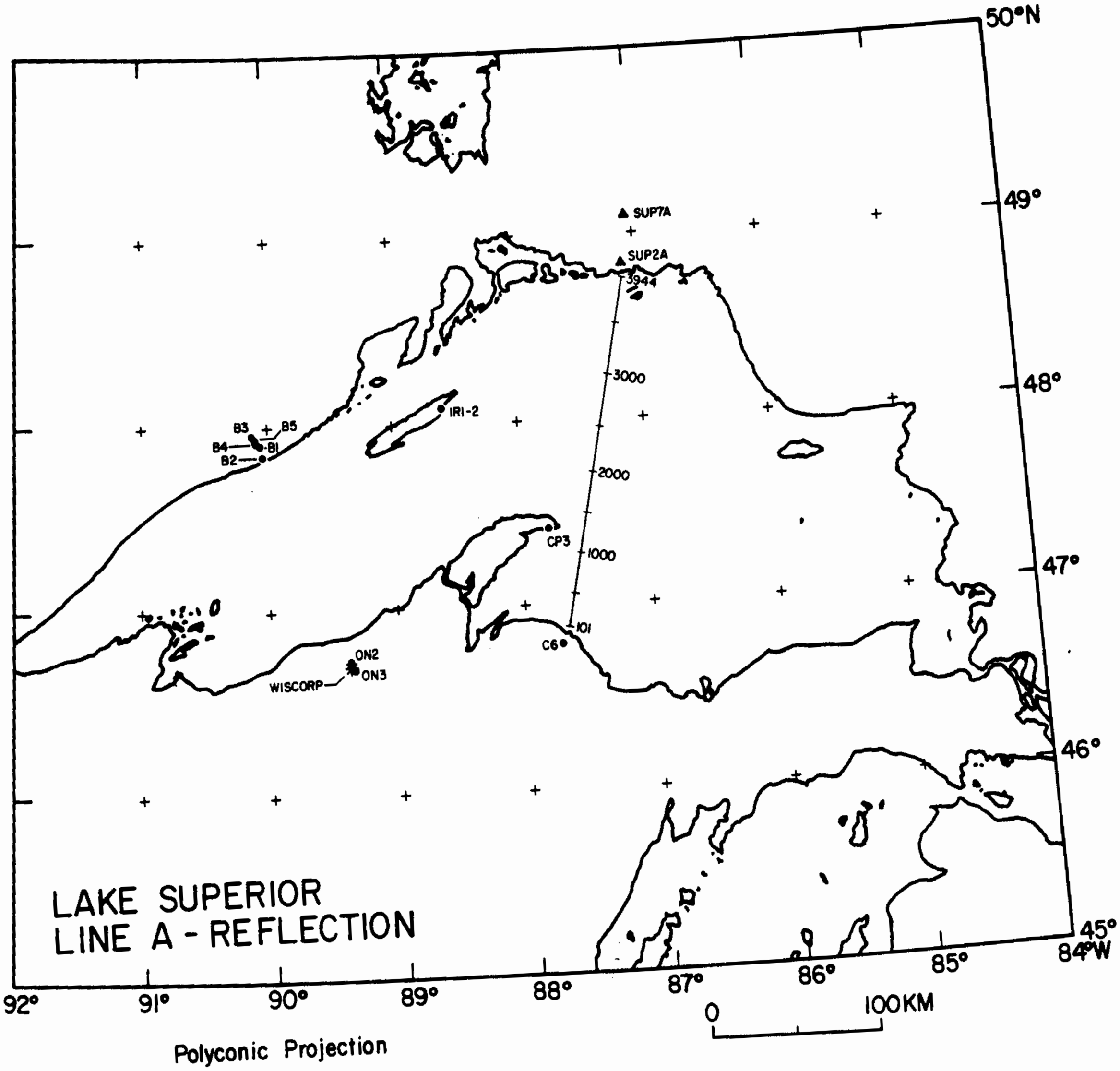

LAKE SUPERIOR
LINE A-REFRACTION
Polyconic Projection
50°N
49°
48°
47°
46°
45°
84°W
85°
86°
87°
88°
89°
90°
91°
92°
0
100KM
SUP8
SUP7
SUP6
SUP5
SUP4
SUP3
AA
SUP1
748
A8
A2
500
C4
C9
CP1
CP2
CH,CP3
C3
109
WISCORP
C1
C6
C2
C3
C4
IRI-2
B1
A
BF
ON1
2N
5S

Figure 5: Shot and station locations for line A-reflection. Symbols are the same as those used in Figure 1. Additional information is listed in Table 4.



50°N
49°
48°
47°
46°
45°
84°W
92°
91°
90°
89°
88°
87°
86°
85°
SUP7A
SUP2A
3944
3000
2000
1000
101
IRI-2
B3
B5
B4
B1
B2
CP3
C6
ON2
ON3
WISCORP
0
100KM
LAKE SUPERIOR
LINE A - REFLECTION
Polyconic Projection

Figure 6: Shot and station locations for line B. Symbols are the same as those used in Figure 1. Additional information is listed in Table 5.

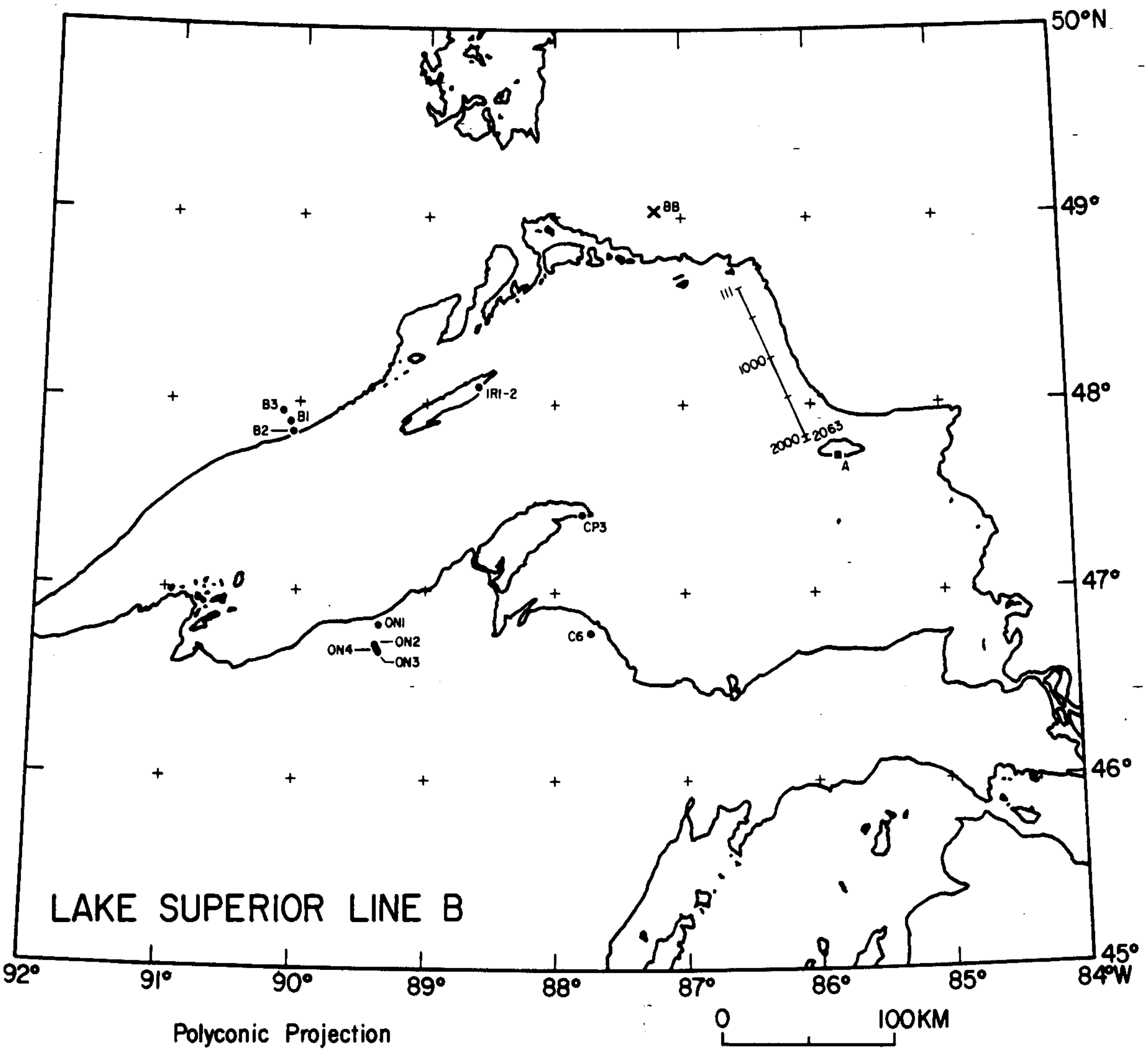

50°N
49°
48°
47°
46°
45°
92°
91°
90°
89°
88°
87°
86°
85°
84°W
88
B3
B1
B2
IRI-2
1000
2000
2063
A
CP3
ON1
ON2
ON3
ON4
C6
LAKE SUPERIOR LINE B
Polyconic Projection
0
100KM

Figure 7: Shot and station locations for line C. Symbols are the same as those used in Figure 1. Additional information is listed in Table 6.

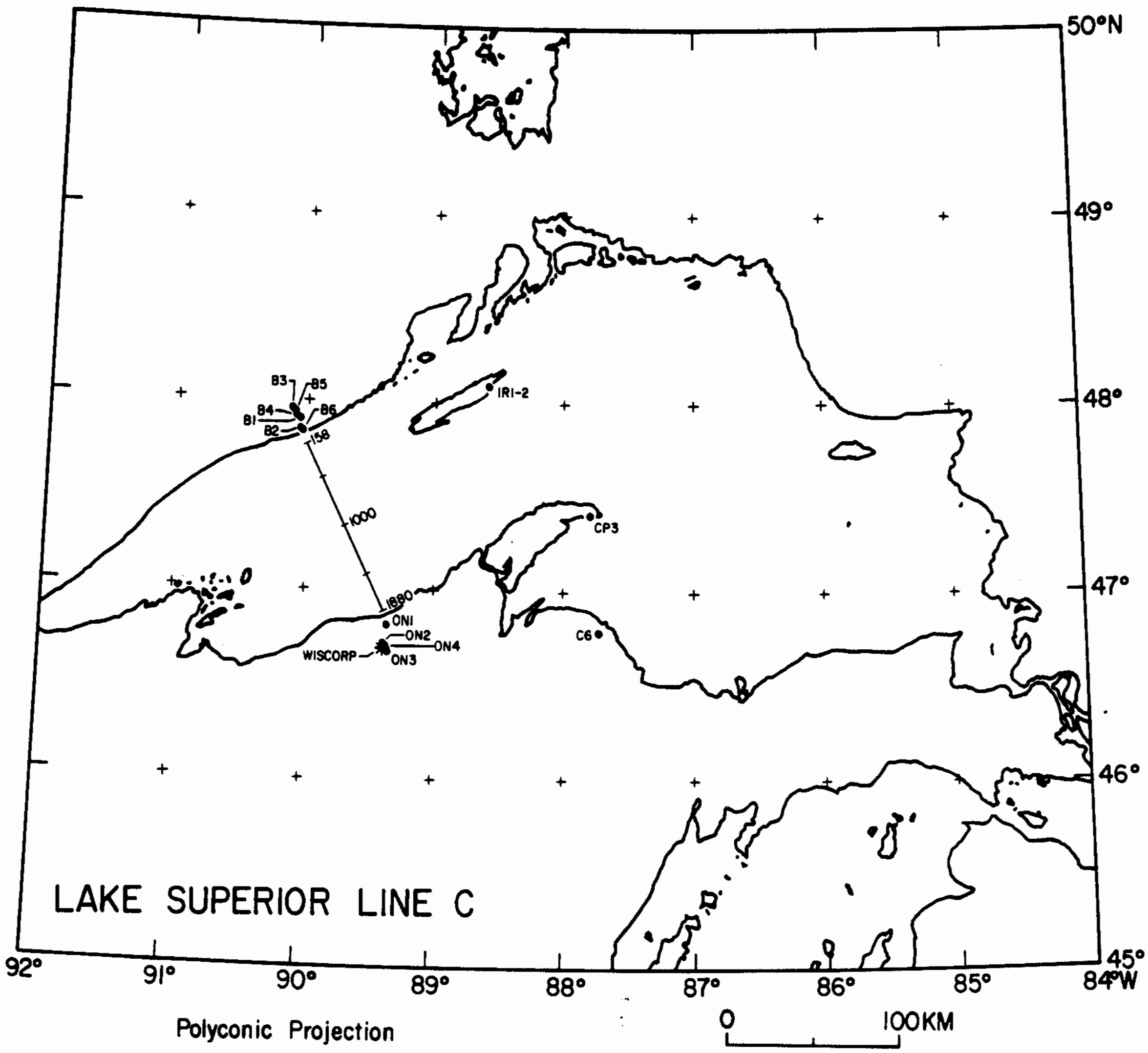
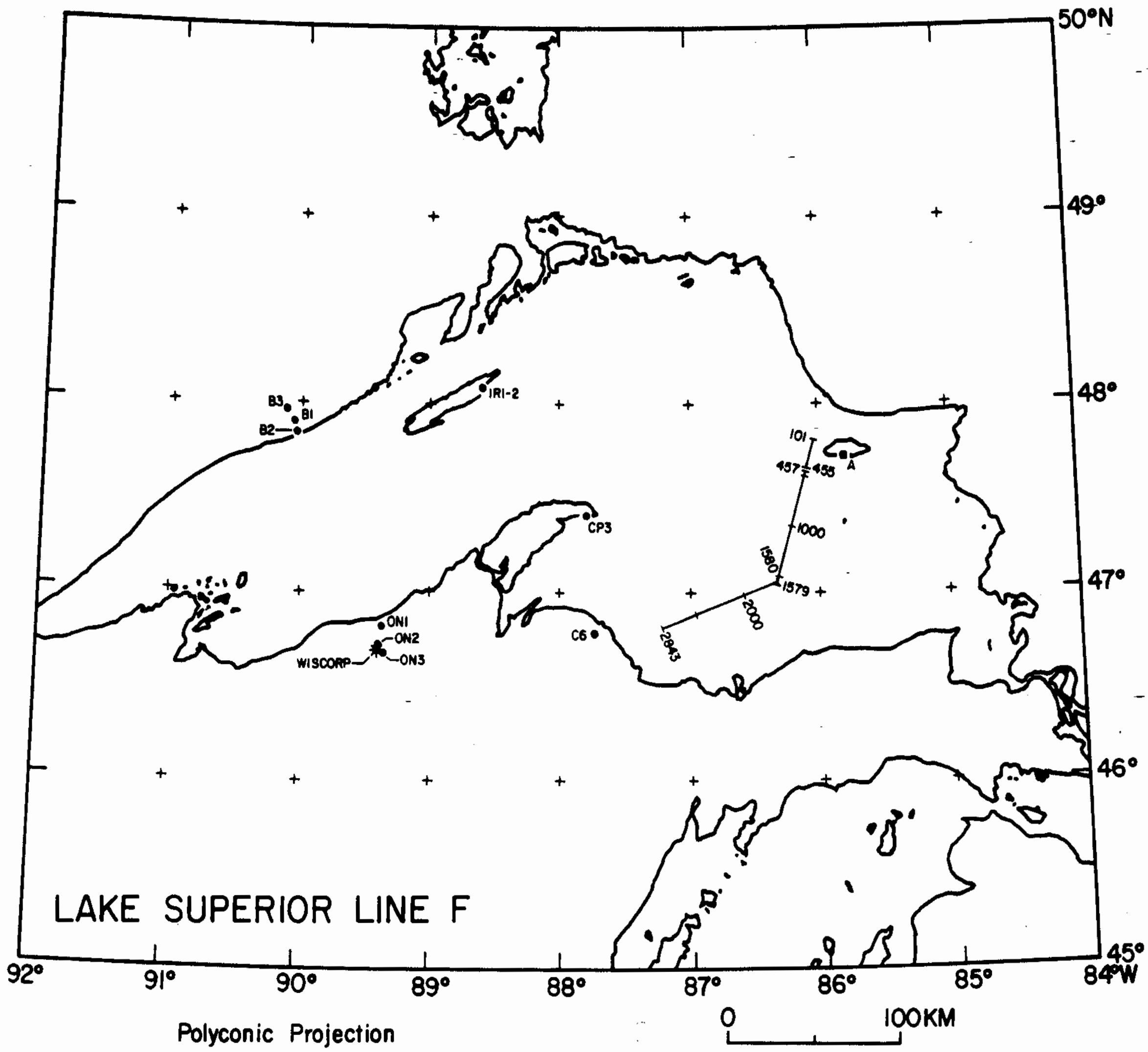
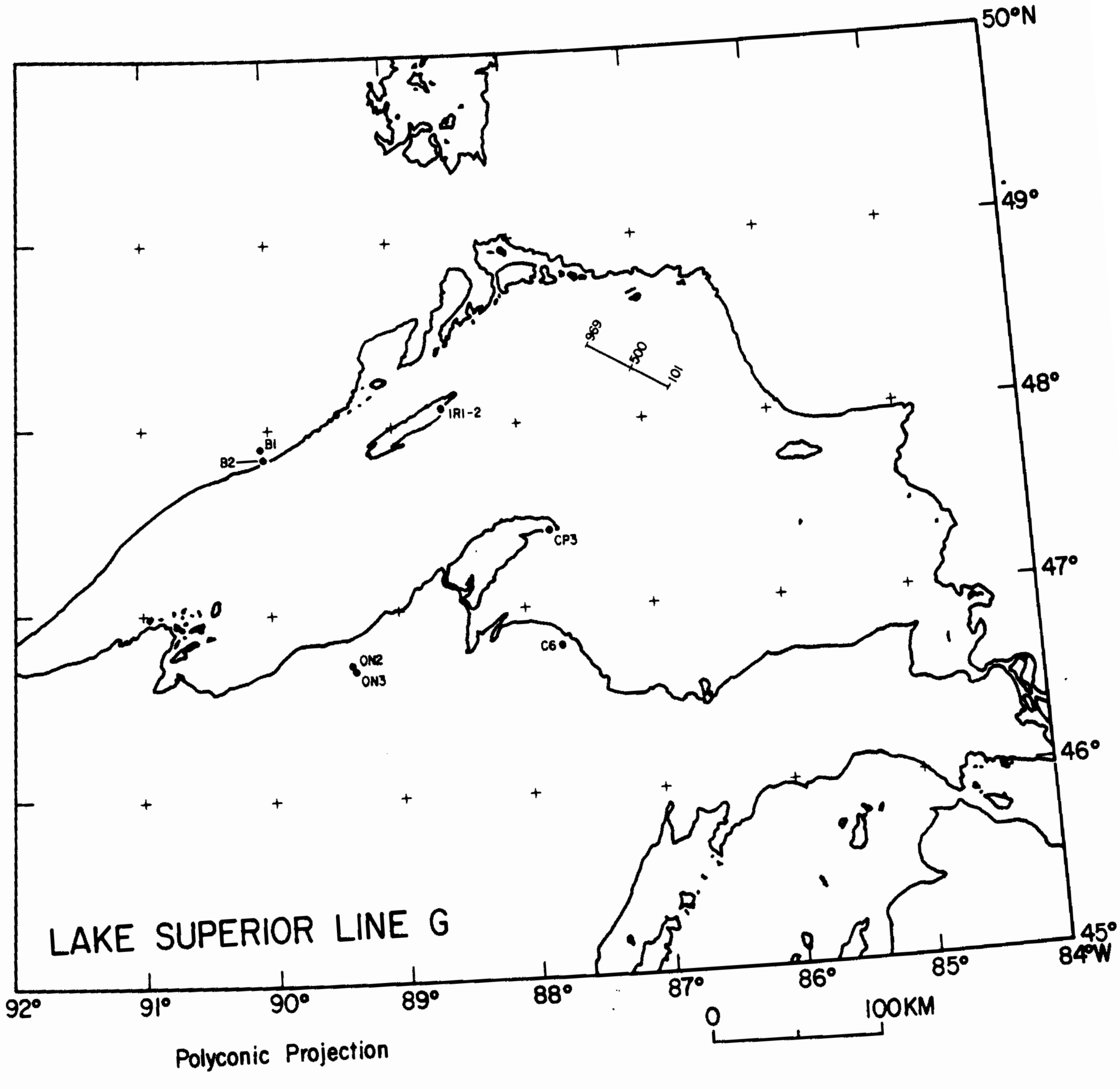

LAKE SUPERIOR LINE C
50°N
49°
48°
47°
46°
45°
92°
91°
90°
89°
88°
87°
86°
85°
84°W
B3
B5
B4
B6
B1
B2
158
1000
1880
IRI-2
CP3
C6
ON1
ON2
ON4
ON3
WISCORP
Polyconic Projection
0
100KM

Figure 8: Shot and station locations for line F. Symbols are the same as those used in Figure 1. Additional information is listed in Table 7.



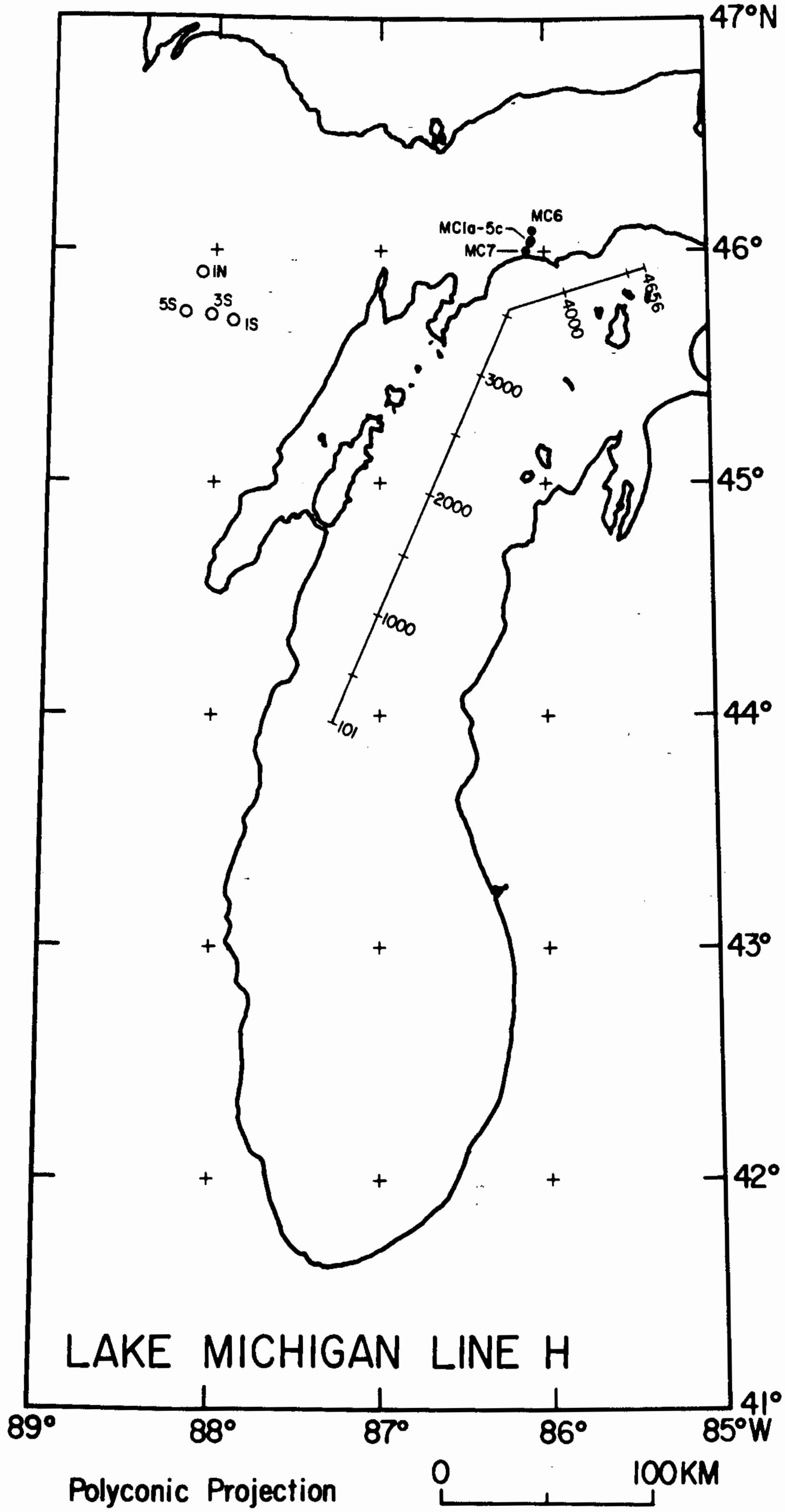
50°N
49°
48°
47°
46°
45°
92°
91°
90°
89°
88°
87°
86°
85°
84°W
B3
B1
B2
IRI-2
CP3
ON1
ON2
ON3
WISCORP
C6
A
101
457
455
1000
1580
1579
2000
2843
LAKE SUPERIOR LINE F
Polyconic Projection
0
100KM

Figure 9: Shot and station locations for line G. Symbols are the same as those used in Figure 1. Additional information is listed in Table 8.



50°N
49°
48°
47°
46°
45°
84°W
85°
86°
87°
88°
89°
90°
91°
92°
969
500
101
IRI-2
B1
B2
CP3
C6
ON2
ON3
LAKE SUPERIOR LINE G
0
100KM
Polyconic Projection

Figure 10: Shot and station locations for line H. Symbols are the same as those used in Figure 1. Additional information is listed in Table 9.



47°N
46°
45°
44°
43°
42°
41°
89°
88°
87°
86°
85°W
MC6
MC1a-5c
MC7
OIN
5S
3S
IS
4656
4000
3000
2000
1000
101
LAKE MICHIGAN LINE H
Polyconic Projection
0
100KM

Figure 11: Shot and station locations for line I. Symbols are the same as those used in Figure 1. Additional information is listed in Table 10.

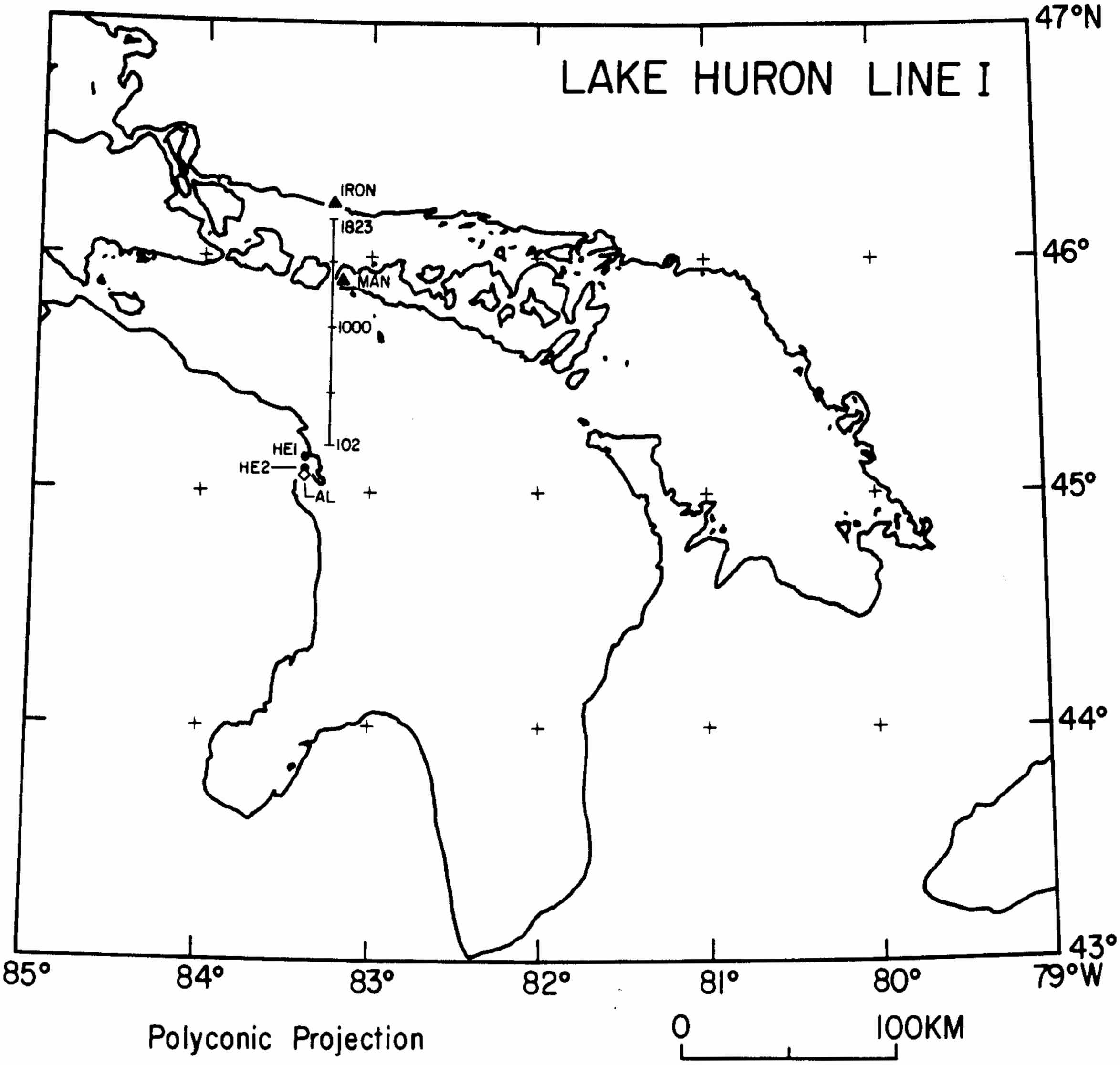
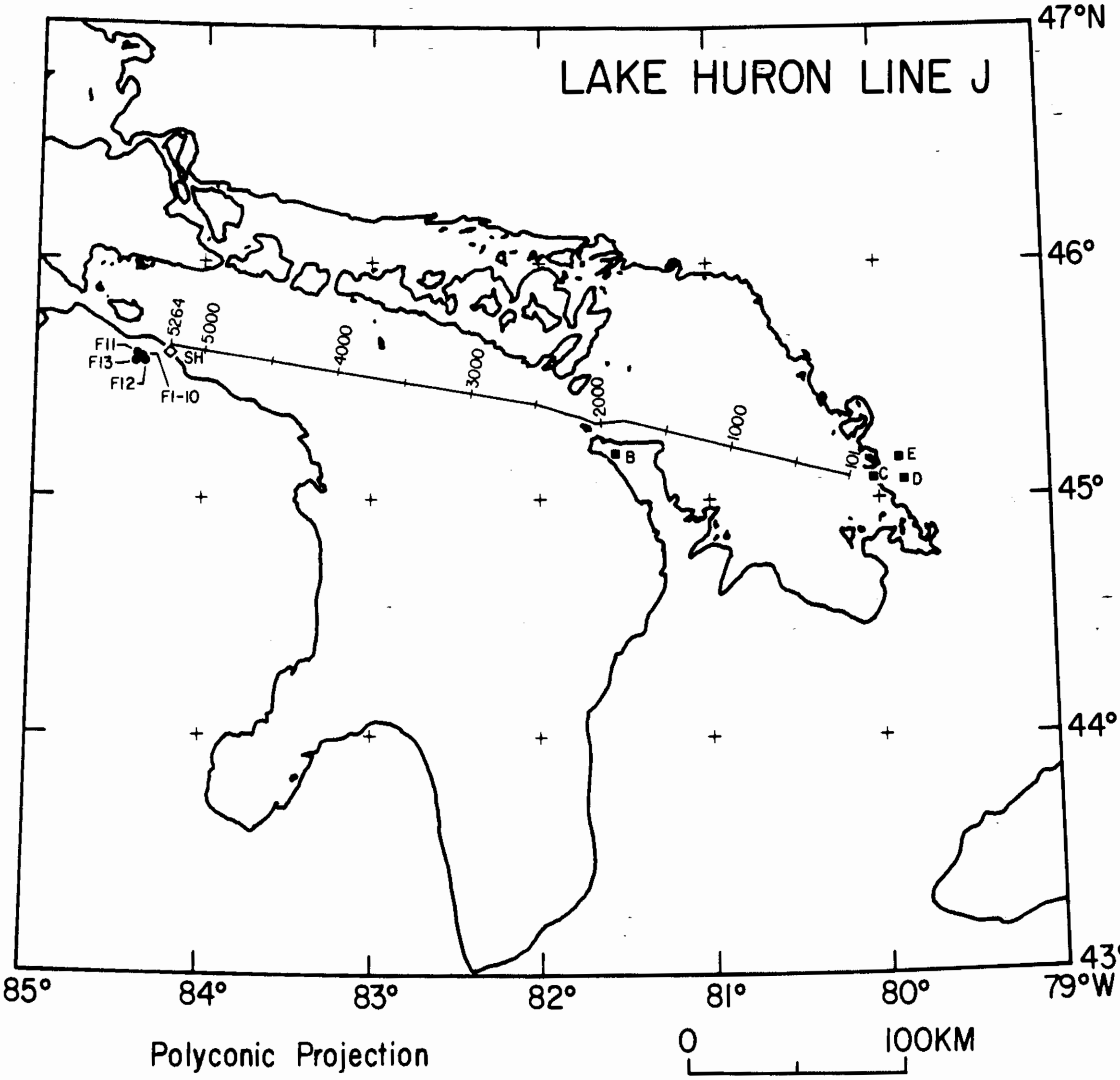

LAKE HURON LINE I
IRON
1823
MAN
1000
102
HE1
HE2
AL
47°N
46°
45°
44°
43°
85°
84°
83°
82°
81°
80°
79°W
Polyconic Projection
0
100KM

Figure 12: Shot and station locations for line J. Symbols are the same as those used in Figure 1. Additional information is listed in Table 11.


LAKE HURON LINE J
47°N
46°
45°
44°
43°
85°
84°
83°
82°
81°
80°
79°W
5264
5000
4000
3000
2000
1000
101
SH
F11
F13
F12
F1-10
B
C
D
E
Polyconic Projection
0
100KM

APPENDIX I

INSTRUMENT DETAILS AND PERSONNEL

This Appendix lists the people participating in the field effort and appropriate instrumental details and archive information not covered elsewhere in the report.

I. U.S. GEOLOGICAL SURVEY (USGS)

Anne M. Trehu: USGS, Principal Investigator
G. Miller: USGS
J.F. Boyd: U.S. Coast Guard, Captain
Crew of vessel U.S.C.G. Katmai Bay

Instrument: USGS Ocean Bottom Seismometer
Sample rate: 7.813 ms, reformatted to 8 ms.
Record length: 32 s
Frequency of recording: 2 min
Filters: 0-30 Hz
Field tape ID: GL86-A2,-A8,-C9,-C4,-C3
Field tape format: TIP (USGS/OBS internal format)
Archived at: U.S. Geological Survey
Data Library
Branch of Atlantic Marine Geology
Woods Hole, MA 02543

Comment:
- Instruments C3, C4, C9: no hydrophone data.
- Instrument A8: recorded only far ranges.
- Locations for A2, C3, C4, C9 calculated by water wave inversion technique, as described below.
- Location for A8 taken as the LORAN C position calculated by ranging to the instruments from USCG Katmai Bay.
- Horizontal components recorded for only a portion of the line because of data storage limitations.

Note on Instrument locatons:

Instrument locations in field were determined by acoustically ranging to the OBS on the lake floor from 4-6 surface locatons and inverting the travel-times thus obtained (Creager and Dorman, 1982). Ranges calculated from these locations were not consistent with the positions of the closest shots plotted on the record sections, indicating that the navigation of the Coast Guard Ship (LORAN C) was incompatible with that of the shooting ship (Satellite and Doppler Sonar).

Instrument locatons for A2, C3, C4, and C9 were recalculated based on the locations of the shots provided by the shooting ship using water-wave inversion solutions, which invert the travel times of the water waves from the closest shots. Because the cross-over distance between the direct water-wave arrival and first refracted arrival occurred within 2-3 shots of the closest approach, locating the instruments with this technique required information on the near-surface sediment velocity in the vicinity of the instrument. This velocity was not well known; however, varying the assumed velocity should yield a solution for both instrument position and velocity that gives minimum travel-time variance. This was not done because of program limitations and the probable poor resolution of the final result. The simplified water-wave inversion solutions were in good agreement with the plotted intersections of allowable range circle drawn for the three closest shots based on direct water wave arrival times and an assumed velocity of 1.45 km/s. The water-wave inversion technique also calculates water depths (given in Table 3) which were essentially identical to those recorded on the ship's fathometer during OBS deployment.

Because the water-wave inversion technique utilizes the closest shots, none of which were recorded for instrument A-8, its location is based on inversion of travel-time ranging obtained on the Coast Guard ship

II. GEOLOGICAL SURVEY OF CANADA (GSC)

Patrick Morel-a-l'Huissier: GSC, Principal Investigator
C.P. Spencer: GSC
I. Asudeh: GSC
W. Moon: University of Manitoba
P. Burchat: GSC
J. Craven: GSC
F. Larue: GSC
H. Lau: GSC
P. Shyre: GSC
R. Stevens: GSC
C. Samson: University of Toronto
D. Epili: University of Western Ontario
T. Shortt: University of Western Ontario

Instrument: PRS 1 digital recorder
Sample rate: 120 Hz (8 ms)
Record length: 30, 40, 50 s, 3 min
Frequency of recording: 2 min and continuous
Filters: 0.5 - 60 Hz
Field tapes: floppies and/or cassettes (transcribed to 9T)
Field tape format: SEGY (9T)
Archived at: P. Morel-a-l' Huissier

Lithosphere and Canadian Shield Division
Geological Survey of Canada
1 Observatory Crescent
Ottawa, Ontario KIAOY3

Comment:
- SUP1, SUP7: data sets incomplete because of instrument malfunction
- SUP8: hole in middle of section because of instrument malfunction
- SUP2A: completes data that were not recorded by Univ. of Saskatchewan because of poor weather
- SUP7A: completes data not recorded for SUP7.
- Locations and elevations from TOPO sheets

III. UNIVERSITY OF WISCONSIN - MADISON (UWM)

Robert P. Meyer: UWM, Principal Investigator
H. Meyer: UWM
R. Meyer: UWM
V. Green: UWM
S. Shih: UWM
B. Unger: UWM

Instrument: UW Digital Seismographs
Sample rate: 10 ms
Record length: variable
Frequency of recording: variable
Filters: 0.27 - 24 Hz
Field tape 10: 275 field tapes
Field tape format: UW Digital Seismograph Standard
Archived at: Dept. of Geology and Geophysics
University of Wisconsin
1215 W. Dayton St.
Madison, Wisconsin 53706

Comment: - Stations MC1, MC2, MC3, MC4, MC5 are 3 vertical geophones in a linear array: all others are 1 vertical, 2 horizontals (north and east).
- Locations and elevations from TOPO sheets

IV. UNIVERSITY OF WESTERN ONTARIO (UWO)

Robert F. Mereu: UWO, Principal Investigator
T. Cox: UWO
J. Wu: UWO
T. Shortt: UWO
C. Faust: UWO
D. Epili: UWO
R. Secco: UWO
B. Lenson: UWO
C. Spindler: UWO
J. Brunet: UWO
B. Dunn: UWO
B. Price: UWO

Instrument: U. Western Ontario Portable FM recorders
Sample rate: 8 ms (125 Hz)
Record length: 45 min
Frequency of recording: continuous
Filters: 0.1 - 35 Hz
Field tapes: analog transcribed to digital
Field tape format: SEGY (digital tapes)
Archived at: R.F. Mereu
Department of Geophysics
University of Western Ontario
London, Ontario N6A 5B7

Comment: - Locations and elevations from TOPO sheets

V. NORTHERN ILLINOIS UNIVERSITY (NIU)

Patrick Ervin: NIU, Principal Investigator
P. Carpenter: NIU
G. Frantti: Michigan Tech.
B. Morrow: NIU
T. Salihoglu: NIU
M. Thompson: NIU
C.L. Ervin: NIU
Students from Michigan Tech University

Instrument: PDR-2 and MEQ-800
Sample rate: 10 ms
Record length: 6258 bytes
Frequency of recording: continuous
Filters: 0-50 Hz
Field tapes: 20 tapes and paper records
Field tape format: Kinemetrics hi-density, Terra-Tec internal format
Archived at: Department of Geology
Northern Illinois University
Dekalb, Illinois 60115

Comment:
- Instrumental problems and large noise made data recovery on all instruments minimal
- Locations and elevations from TOPO sheets

VI. UNIVERSITY OF SASKATCHEWAN (U SASK.)

Zoltan Hajnal: U. Sask, Principal Investigator
W. Chan: U. Sask.
D. Wilkinson: U. Sask.
M. Johnson: U. Sask.
G. Wood: U. Sask.

Instrument: multichannel geophone array
Total groups: 48
Group Interval: 67 m
Array geometry: linear (N45°W-BB), (N30°E-AA)
Recording Instrument: DFS V
Sample rate: 2 ms
Record length: 20 s, 30 s
Frequency of recording: 40 s, 2 min.
Filters: 0-128 Hz
Field tapes: 2 - 102 (9T, 1600 BPI)
Field tape format: SEG B
Archived at: Department of Geological Sciences
University of Saskatehewan
Saskatoon, Saskatchewan S7N OWO

Comment:
- Instrument failure 31 Aug: 1756 - 1916 and no recording because of storm after 1 Sept 0759
- Locations and elevations from TOPO sheets
- Locations are given for the center of the array. Locations written in to the SEG-Y tape header are for the best trace of the array and are slightly different.

VII. SOUTHERN ILLINOIS UNIVERSITY (SIU)

John L. Sexton: SIU, Principal Investigator
S. Wendling: SIU
J. Bowden: SIU
H. Henson: SIU

Instrument: multichannel geophone array
Total Groups: 24
Group Interval: 25 ft.
Array Geometry: linear (E/W)
Recording Instrument: DFS V
Sample Rate: 2 ms
Record Length: 60 s, 44 s
Frequency of recording: continuous
Filters: 0 - 64 Hz
Field tapes: 186 (9T, 1600 BPI) tapes
Field tape format: SEG B
Archived at: Department of Geology
Southern Illinois University
Carbondale, Illinois 62901

Comment:
- Some 60 Hz problems on lines I, J
- Locations and elevations from TOPO sheets

VIII. UNIVERSITY OF WISCONSIN - OSHKOSH (UWOSH)

John H. Karl: UWOSH, Principal Investigator
T. Jefferson: UWOSH
S. Bouc: UWOSH
J. Colletta: UWOSH
D. Kowalkowski: UWOSH
P. Meyer: UWOSH

Instrument: multichannel geophone array
Total Groups: 96
Group Interval: 100 m, 50 m
Array Geometry: L-shape, X-shape
Recording Instrument: DFS - IV
Sample Rate: 8 ms
Record length: 295 s, 80s
Frequency of recording: continuous, 2 min
Filters: 0-31 Hz
Field tapes: 87 (9T, 1600 BPI) tapes
Field tape format: SEGB
Archived at: Department of Physics and Astronomy
University of Wisconsin, Oshkosh
Oshkosh, Wisconsin 54901
414-424-4432/4431

Comment:
- Locations and elevations from TOPO sheets
- Reel changes cause 10-minute gaps in recording, approximately every hour
- Instrument failure on Line A-reflection caused loss of E-W arm of x-shaped array on 7 September, 0420-1400 GMT.

APPENDIX II:

NAVIGATION AND TIMING DETAILS FOR SHOT POINTS

This appendix consists of the final report submitted by the contractor on the navigation and shot instants. Note that the navigation for each shot point is taken to be the position of the satellite antenna, which was located 74 m in front of the center of the airgun array. These data are archived at USGS (Denver, CO, and Woods Hole, MA) and are available from National Geophysical Data Center, NOAA, Code E64, 325 Broadway, Boulder, CO, 80303 (telephone: 303-497-6338)

NAVIGATION REPORT

ON

SATELLITE AND TIMING CORRECTIONS
FOR THE 1986 GREAT LAKES REFRACTION
AND REFLECTION SEISMIC SURVEY

FOR

THE GEODETIC SURVEY OF CANADA (SIC)
AND
THE UNITED STATES GEOLOGICAL SURVEY

by

GEOPHOTO SERVICES, LTD.
CALGARY, ALBERTA

1987 12 07

CONTENTS | PAGE

INTRODUCTION

A marine geophysical survey was conducted for the Geodetic Survey of Canada in conjunction with the United States Geological Survey between 1986 08 29 and 1986 09 23 in the Great Lakes. The M/V Fred J. Agnich shot two lines of refraction data and 1343 km of reflection data in Lake Superior, Lake Huron and Lake Michigan.

Geonav was used as the navigation system to shoot the entire Great Lakes prospect. The integrated navigation was a configuration of a Magnavox 1107 TRANSIT satellite receiver, doppler sonar and a gyrocompass. An Internav 400 LORAN C receiver was available with additional velocity and position information and a TI4100 GPS receiver was on board for most of the survey as backup and an additional QC system and for updates to the LORAN C.

For the purposes of the GLIMPCE experiment some special modifications were made to the M/V Agnich's control/navigation system (CMS). These include interfacing to a GOES satellite receiver/chronometer, interfacing to a modified CMS chronometer and modifying the system coordinator to allow predetermined delays to be set into the recording sequence.

The CMS was synchronized to WWV time through the GOES satellite receiver and the CMS chronometer. After the initial passing of time to the CMS chronometer and simultaneous CMS start and WWV synchronization, the chronometer supplied the CMS with a 100 ms interrupt by which the CMS kept time. If the CMS chronometer missed its interrupt from the WWV chronometer the two would be out of synchronization and a LED indicated the error unless the CMS was stopped and restarted.

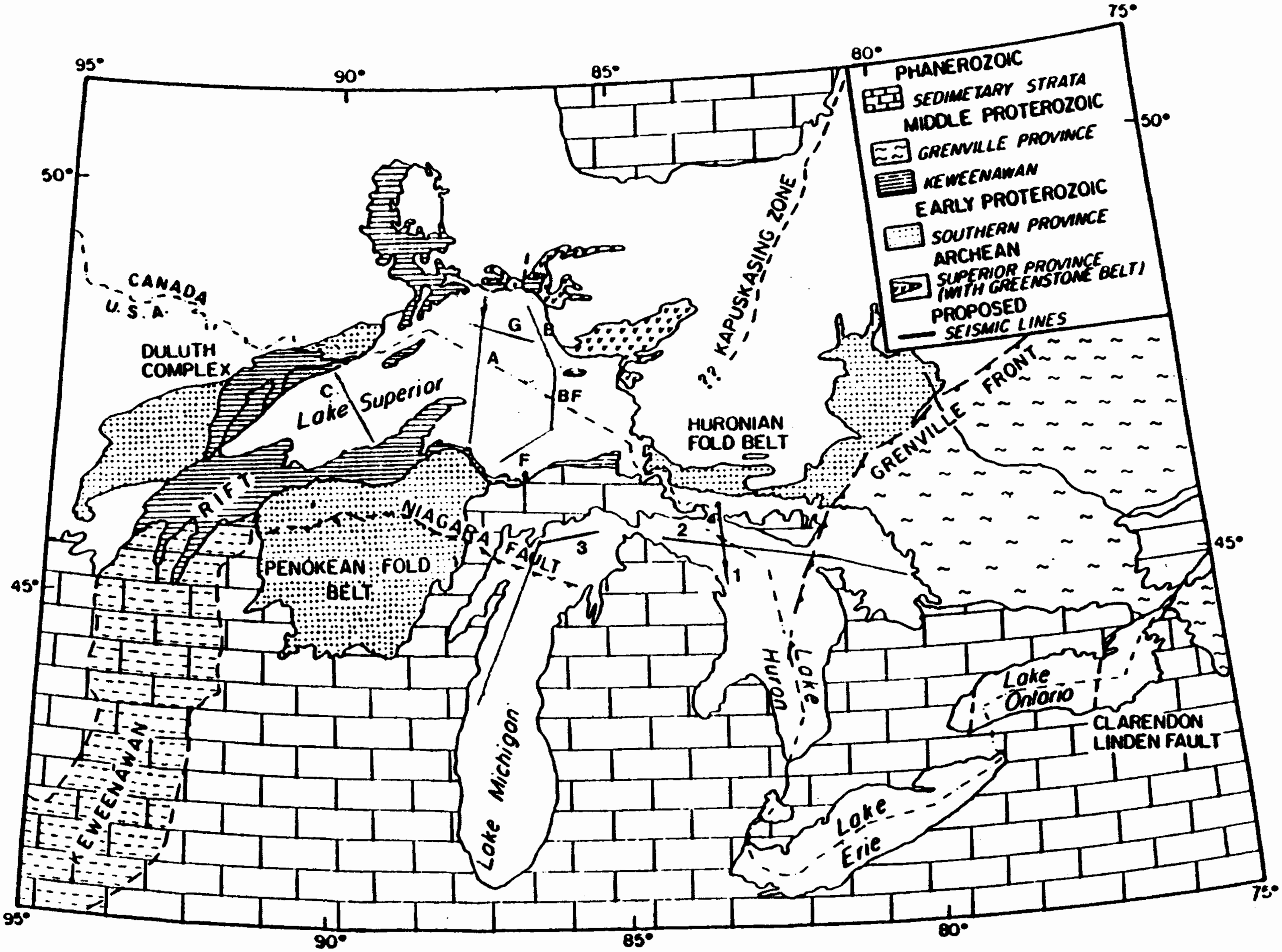
During the course of the project several problems affected the data collection. One serious problem was unexplained large satellite updates occurring with otherwise good navigation data. After completion of the first line on 09 01 several days were spent investigating all aspects of the satellite system and on 09 05 it was discovered that the update problems were a result of loading an erroneous antenna height into the

CMS (neglecting to account for 183 metre difference of Lake Superior to sea level). Another problem affecting the data was the time as recorded on tape was not in synchronization with the WWV satellite time. This was due to some delays not being accounted for and interruptions in the system.

The errors introduced by the above incidents were corrected. This report gives an explanation of the corrections and how they were applied.

LIST OF SEISMIC LINES

Line	Julian Day	FSP	Julian Day	LSP
AA-	243	109	244	748
BB'	249	111	250	2063
BFLINK	250	101	250	455
FF'	250	457	251	1579
F'F"	251	1580	251	2843
A'A	252	101	253	2326
A"A	253	2290	253	3944
G'G	254	101	254	969
CC'	255	156	255	771
CC'A	255	741	256	1880
3	261	101	262	4636
1	263	102	264	1823
2A	265	101	266	5264



AREA OF SURVEY

FIGURE 1

3

SUMMARY OF EVENTS DURING SURVEY

LAKE SUPERIOR

Line AA- was shot in time mode with an external chronometer synchronized to WWV satellite time for control. An external fire command was issued on every even two minute mark. Various stations were set along the shore to collect refraction data in a continuous mode as well as several buoys being placed the U.S.G.S. by the U.S. Coast Guard for collection of reflection data. Problems with large satellite updates began during the shooting of the line but as it was a one time effort (batteries in the buoys were good for about 24 hours) the production was continued. Line AA- was completed on 09 01. After several days of investigating all aspects of the satellite system, on 09 05 it was discovered that the update problems were a result of loading an erroneous antenna height into the system This incident is detailed later in this report.

The first chargeable shotpoint on line BB′ was 111 and the line proceeded normally to the end with a 50 m shot spacing.

The end coordinates for BFLINK were the southerly coordinates off line BB′ and the the northerly coordinates of FF′ and the line was shot as a tie between the two. The shot interval was 50 m but the cable became uncontrollable and sank due to a change in water temperature. The line was terminated at shotpoint 456. The client representative on board the vessel approved a decision to increase the shotpoint interval to 62.5 m to allow an increase in vessel speed.

Line FF′ was started with the 62.5 m shot interval and a speed of 4.3 kn until shotpoint 865 where the interval was reduced to 50 m and then increased to 62.5 m at shot 902 for the remainder of the line. A dogleg was executed at shotpoint 592.

F′F′′ was started at a 50 m interval and remained that way until shot 2096 where it was increased to 62.5 m for the remainder of the survey. Velocity information was from sonar and at times LORAN C due to loss of tracking in deep water (+365 m).

The 980B NAV computer was halted temporarily to replace a circuit board before the beginning of Line A'A. The system was restarted before the first chargeable shotpoint. The synchronization between the CMS and WWV time were lost because of this and the CMS time had a 24.5 s offset (slow) that remained until the end of A"A.

On line A"A the sonar velocities gave some problems due to a rising and falling water bottom.

Before commencing Line G'G the CMS/GOES timing system was resynchronized.

On Line CC' the compasses in the streamer began spiking and were unusable due to a very strong magnetic anomaly in the area. By shotpoint 356 the anomaly was sufficiently far enough away for the Streamer Tracking System (STS) to accept the compass data and they remained settled for the remainder of the line. There were time loss problems at the end of this line due to a loose connector for the 100 KHz signal thus affecting the count-up for the CMS 0.1 s clock interrupt and causing it to lose time. It was terminated for this reason and restarted at the last known good time.

Line CC'A was started with the CMS synchronized to WWV but a 23.1 s shift occurred was discovered to have occurred sometime after shotpoint 970.

LAKE MICHIGAN

The CMS was reinitialized with the new antenna height to include the elevation of Lake Michigan (176.5 m above sea level). Line 3 had a dogleg initiated at shotpoint 3556.

LAKE HURON

The elevation of Lake Huron (& Georgian Bay) is the same as Lake Michigan so the antenna heights remained unchanged. Line 1 was shot South to North through Mississagi Strait in Lake Huron. The beginning of the line was shot at a slower speed to avoid a barge. It was no longer obstructing the path by shot 166. The line was terminated 3.8 km from the preplotted E.O.L. due to impending shallow water endangering the streamer.

Line 2A was shot from East to West from Georgian Bay into Lake Huron through the Main Channel via a series of dogleg segments. Deviations of up to 485 m to the north of the intended line had to be initiated through the channel to avoid rocks, ferry boats and shallow water. The doglegs were executed at shotpoints 1841, 2033 and 2487. At the second dogleg the vessel was steered off line to starboard to avoid a shallow water area. They were back on line at shot 2281 and performed another dogleg at shot 2487. The line terminated normally.

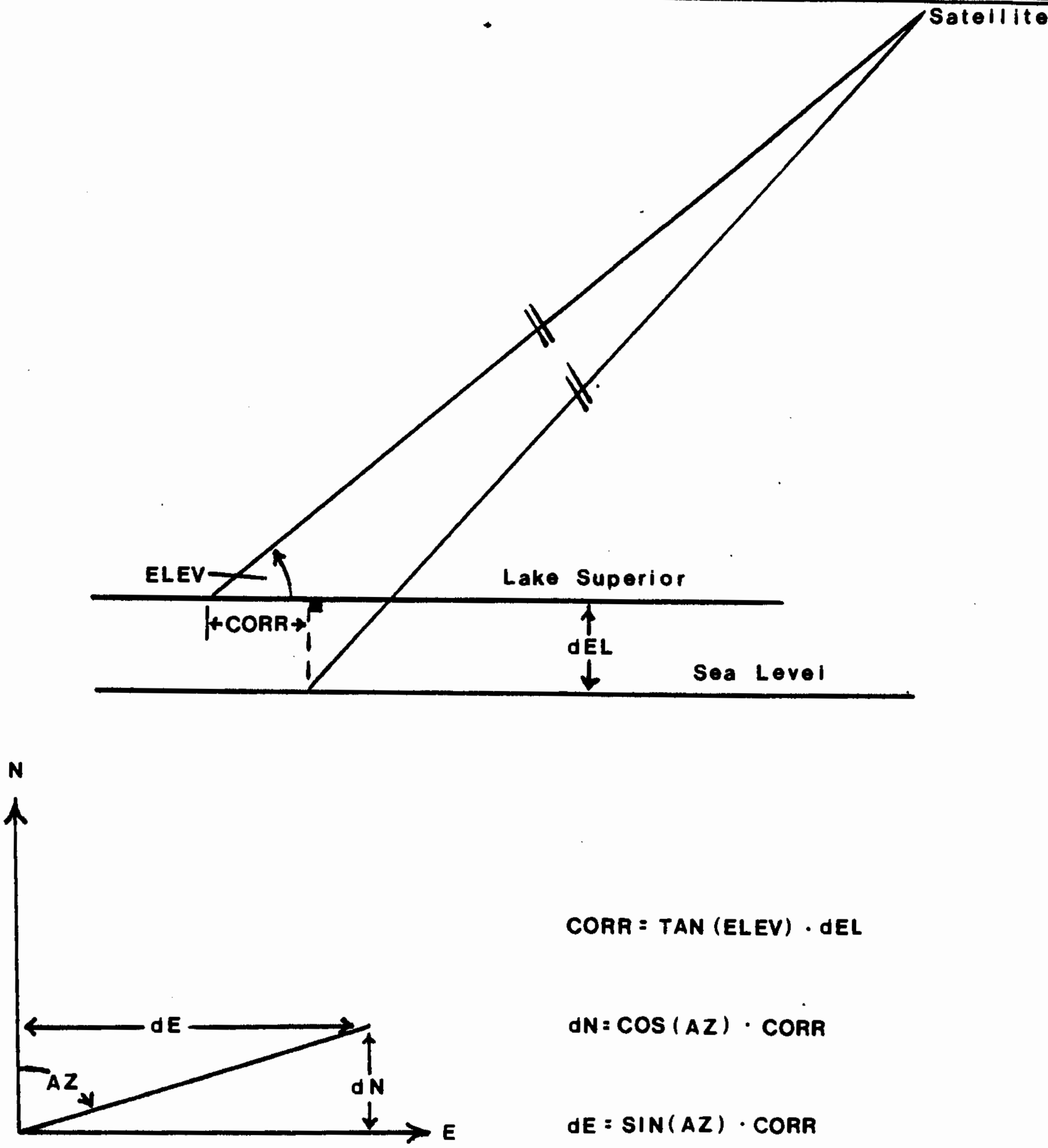
SATELLITE ANTENNA HEIGHT ERROR

It was discovered after completion of line AA- that the update problems were due to the wrong satellite antenna elevation being input into the CMS. Lake Superior is 183 m above mean sea level which was not originally accounted for during system initialization. The errors introduced by this omission are predictable and were corrected in post processing. The magnitude of shift introduced by the error in height initialization ranged from 42 to 392 m with the greatest movement in a longitudinal direction. The table below summarizes the corrections computed. Figure 2 gives a graphical representation of the situation and Figure 3 shows the magnitudes of the displacement (corrections) versus the satellite elevation angles.

The following is a list of the corrections applied to the individual satellite fixes on line AA- in the post processing:

FIX#	Elev.	Az.	CORR(M)	dN(M)	dE(M)
15	25	85.2	85.3	85.0	6.7
16	65	272.6	392.5	-392.1	17.8
17	13	95.7	42.2	42.0	- 4.2
18	54	285.6	251.9	-242.4	67.7
19	11	89.7	33.0	35.6	0.2
20	41	259.9	158.2	-156.6	- 27.9
21	13	101.4	42.2	41.4	- 8.3
22	55	91.7	261.4	261.2	- 7.8
23	27	265.7	93.2	- 93.0	- 7.0
24	26	75.4	89.2	86.4	22.5
25	26	75.4	89.2	86.4	22.5
26	57	238.4	281.7	-240.0	-147.7
27	54	87.5	251.9	251.7	11.0
28	56	281.2	271.3	-266.1	52.7
29	20	73.5	66.6	63.8	18.9

Subsequent lines were shot with the proper antenna height applied.



The elevation (ELEV) of the satellite is the vertical angle from the horizon to the satellite and should be between 12 and 75 degrees to be acceptable.

The azimuth (AZ) of the satellite is its direction from the vessel with respect to north.

The correction (CORR) is the absolute distance in metres that the particular fix must be adjusted by.

The correction in Northing (dN) and Easting (dE) is the computed value in metres to be added to the coordinates to compensate for the error in antenna height.

FIGURE 2

DOPPLER SATELLITE HEIGHT CORRECTIONS

FOR LAKE SUPERIOR (183 M ABOVE MSL)

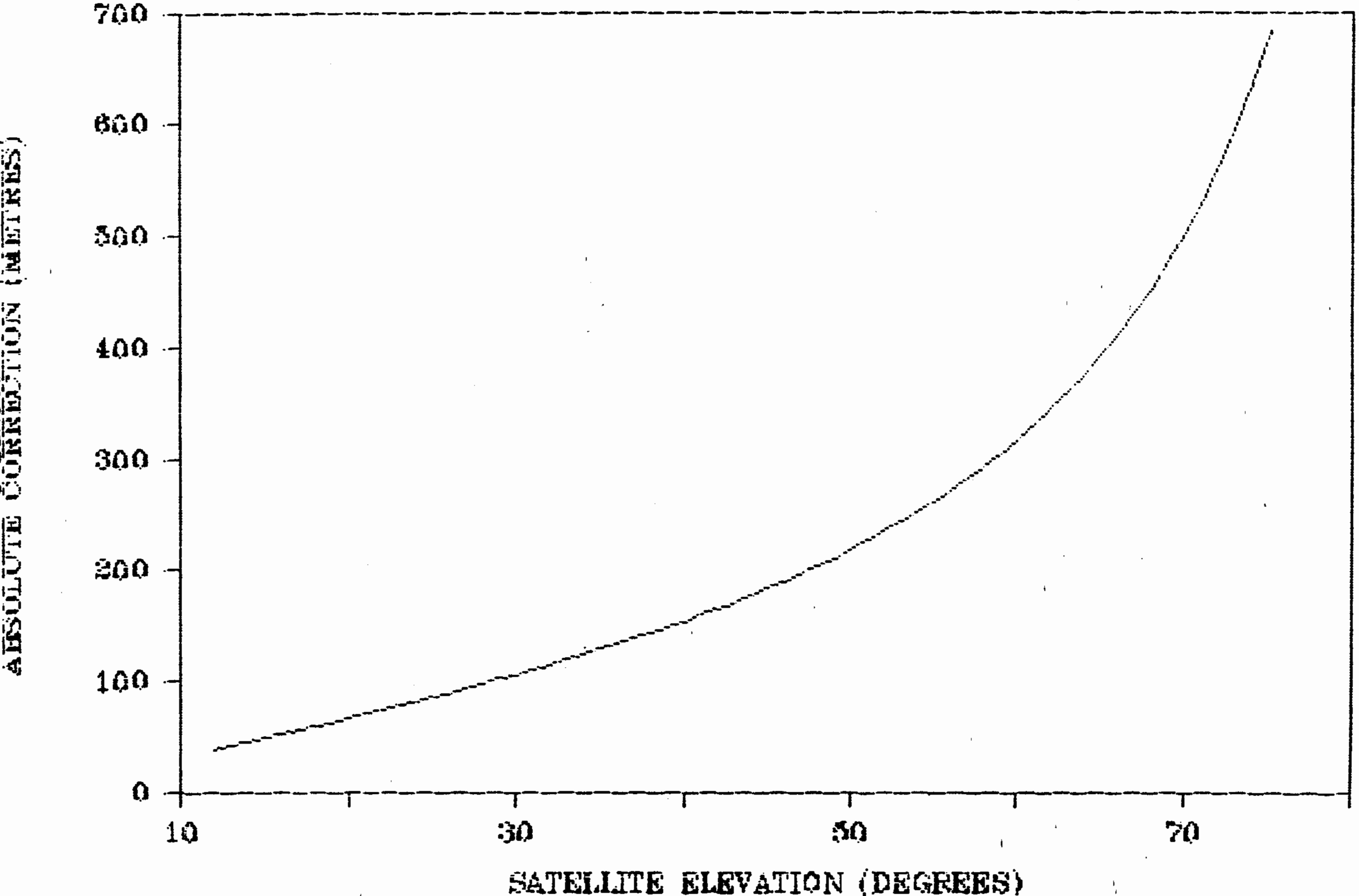


FIGURE 3

ERRORS IN THE TIMING SYSTEM

A variety of different timing delays affected the the data collected for the prospect.

The firing sequence for all lines except the first (AA-) was accomplished with the DFS V in distance mode. The CMS issued the firing command to start the sequence. Additional circuitry to delay the start by 200 ms was added to avoid CMS shot-to-shot jitter of the start pulse (1 - 20 ms). A delay off 0.65536 swas present to allow the DFS tape transports to ramp up to speed and write the header data. A wire blast was issued to the TIGER II which issued a time break (1.4 ms delay). There was a 51.2 ms delay from the issue of the field time break to the firing of the guns. There was a further 1.31072 second delay at the first shot after each DFS tape change due to the DFS taking longer writing its ID burst to tape and detection of the wire blast missing the first normal "window" latch and catching the next rising clock cycle.

Line AA- was shot for refraction data in a time fired mode. The DFS V was fired on a two minute interval controlled by the time from the WWV satellite. To accomplish this additional circuitry was installed in the chronometer to synchronize it with the WWV clock to within 1 ms. The interval was set to fire on even two minute marks with the external start issued from this clock circuitry to the system coordinator which passed it to the CMS and immediately issued a start. All of the above mentioned delays were also present during this mode of shooting except that an additional 1 s delay was introduced into the time as recorded on the CMS (ex: 5 m 59 s would be recorded on tape for a shot at 6 m 00 s) since it used presently latched time to store on tape (gets updated 50 - 150 ms later).

The navigation data were processed without due regard for the original field time and in cases of missed shotpoints and deletions of data anomalies the time was interpolated. Under reflection seismic processing circumstances this would not cause any problems but in the case of the refraction lines it is not acceptable. The time as recorded in the field was stripped from the CMS data and used for the final data.

The final navigation data with original CMS times were corrected to remove the effects of the delays and time offsets.

The following is a summary of the various system delay corrections (all are positive values) used for the final post processed Navigation Tape:

Distance & External Mode ....

delay from fire issue to DFS receiving start	0.20000 s
start issue to wire blast to TIGER ----------	0.65536 s
wire blast at TIGER to field time break -----	0.00140 s
internal gun delay -------------------------	0.05120 s
TOTAL	0.90796 s

Total Delay in Distance Mode:

Total of the above delays --	0.90796 s
First shot at every BOT ----	2.21868 s

Total delay in External Mode:

Total of the above delays --	0.90796 s
External Mode delay --------	1.00000 s
	1.90796 s

RECOMMENDATIONS

On any future jobs of this nature it is recommended that the time from the reference source (WWV satellite receiver in this project) be input from a parallel output into a display with an accuracy of milliseconds. In addition to this a similar output from the CMS clock should be sent to the same display and the time difference computed and displayed as well. These times should be recorded for every shotpoint (to 5 significant digits) in a spare or unused position on the CMS tape. An alarm associated with the display should be in place so that a defined limit could be set and any differences outside the chosen range would be flagged and the alarm tripped. A hardcopy of all times and differences should be recorded in the ADL printer output.

In addition to displaying both CMS start time and WWV clock time we should also log the true firing time of the airguns by using the sum shuttle pulse to load the clock time. This could be output to the line printer and stored to tape at the next (SP +1) shotpoint. We would always have to shoot 1 extra shot at the end of the line but this would be easy to do with existing CMS software. Every shot would have a three-way check (time) with all delays being known. This would also show any wire-blast to time break jitter which exists in the present TIGER II software if the TIGER II is not synchronized to a 1 millisecond interrupt.

As well as the proper recording and QC display of the timing there should be the opportunity to make corrections to the CMS recorded time for the known delays including those due to BOT headers at DFS tape changes so that the WWV and CMS time difference is zero. The proper time to be recorded on tape is the correct one (no changes or corrections in post processing). If an offset does occur due to a system idle or a loose connection and can't be corrected immediately, then the corrections will have to be made during the post processing.

Respectfully submitted by Geophoto Services, Ltd.

Andrew Brebner, P.Eng
Navigation Dept. Manager

Distribution:

Dr. Alan Green	8 Copies	G.S.C.	Ottawa, Ont.
John Clink		Geophoto	Calgary, Alta.
Matt Kimball		Geophoto	Calgary, Alta.
Dave Ridyard		G.S.I.	Houston, Tex.
John Rollans		G.S.I.	Dallas, Tex.
Jim Spackman		G.S.I.	Dallas, Tex.

APPENDIX III:

RANGE ALGORITHM

The attached listing gives the FORTRAN code for the algorithm used by all participants in calculating ranges from the shots to the instruments.

```
C
      SUBROUTINE GEODIST (SLAT,SLON,ELAT,ELON,D,AZ1,AZ2)
C
      IMPLICIT REAL*8 (a-h,o-z)
C
C     uses geodetic inverse formula (geodesy by A.R. Clarke)
C     SLAT, SLON - station latitude and longitude in radians
C     ELAT, ELON - shot latitude and longitude in radians
C     D - distance in kilometers
C     AZ1 - azimuth of station from the shot in radians
C     AZ2 - azimuth of the shot from the station in radians
C
      DIMENSION C(4)
      ABLE = 6378.2064d0
      BAKE = 6356.5838d0
      EASY = 0.006768658d0
      RAT = BAKE*BAKE/(ABLE*ABLE)
      CSLAT = COS(SLAT)
      SSLAT = SIN (SLAT)
      CELAT = COS (ELAT)
      SELAT = SIN (ELAT)
      CD = COS (SLON - ELON)
      SD = SIN (SLON - ELON)
      ENS = ABLE/SQRT (1.d0-EASY*SSLAT*SSLAT)
      ENE = ABLE/SQRT (1.d0-EASY*SELAT*SELAT)
      ENE = ENE/ENS
      A = -CSLAT*SD
      B = RAT*CELAT*SSLAT-CSLAT*SELAT*CD+EASY*CELAT*SELAT*ENE
      AZ1 = ATANG(A,B)
      A = CELAT*SD
      B = RAT*CSLAT*SELAT-CELAT*SSLAT*CD+EASY*CSLAT*SSLAT/ENE
      AZ2 = ATANG (A,B)
      FKON = CELAT*CD*ENE-CSLAT
      A = CELAT*SD*ENE
      B = SELAT*ENE-SSLAT
      B = B*RAT
      FKON = FKON*FKON+A*A+B*B
      FKON = SQRT (FKON)
      B = SQRT (EASY/(1.-EASY))
      A = B*SSLAT
      B = B*CSLAT*COS (AZ2)
      BEFF = 1.d0+B*B
      FKOR = FKON*BEFF
      BEFF = 1.d0/BEFF
      BACH = (A*A-B*B)*BEFF
      BEFF = A*B*BEFF
      C(1) = -0.1875d0*BEFF*BACH-0.3333333333d0*BEFF*BEFF*BEFF
      C(2) = 0.0046875d0+.0375d0*BACH+0.25d0*BEFF*BEFF
      C(3) = -0.125d0*BEFF
      C(4) = 0.04166666667d0
      D = C(1)
      DO 1 K = 2,4
       D = D*FKOR+C(K)
 1    CONTINUE
      D = D*FKOR*FKOR+1
      D = FKON*ENS*D
      RETURN
      END
C***********************************************************************
      FUNCTION ATANG(A,B)
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C     Computes ATAN(A/B) for all values of A and B from 0 to 2*PI
C
      IF (B) 1,3,5
```

```
1       ATANG = ATAN (A/B) + 3.14159265d0
        RETURN
3       IF (A) 7,9,11
7       ATANG=4.71238897d0
        RETURN
9       ATANG = 0.
        RETURN
11      ATANG = +1.57079632d0
        RETURN
5       IF (A) 13,15,15
13      ATANG = ATAN (A/B) + 6.2831853d0
        RETURN
15      ATANG = ATAN (A/B)
        RETURN
        END
```

APPENDIX IV:

SEG-Y(LDS) EXCHANGE FORMAT

This appendix lists the FORTRAN code used for the exchange of all refraction and wide-angle data. This code is a series of FORTRAN EQUIVALENCE statements which define file and trace header information for programs used to read the data. This code was developed by C. Spencer and I. Asudeh at GSC for use with Lithoprobe refraction data.

The exchange format, called SEG-Y(LDS) (SEG: Society of Exploration Geophysicists; LDS: Lithoprobe data storage), is a superset of SEG-Y format. Whereas SEG-Y provides an industry standard for the exchange of seismic-reflection data (Barry et al., 1975), SEG-Y(LDS) provides a suitable format for the storage and exchange of seismic refraction data. Any existing SEG-Y program is capable of reading the data. However, SEG-Y(LDS) goes beyond SEG-Y in three ways: (1) it utilizes unused portions of SEG-Y headers for informaton unique to refraction data; (2) it extends the definition to organization within a disk file; and (3) it allows (but does not require) that data be stored with word formats other than the IBM real and integer formats defined in the industry standard.

Header definition: SEG-Y(LDS) maintains the two part file organization of standard SEG-Y in which a file header (3600 bytes long) is followed by seismic trace data blocks, each containing a 240-byte trace header. The last 340 bytes of the file header and the last 60 bytes of the trace header, which were undefined in original SEG-Y standard, are used in SEG-Y(LDS) for information relative to refraction data, such as shot times. The main additions are allowing storage of (1) flexible shot, receiver and line names, (2) more shot and receiver information, (3) more data word formats, and (4) different seismic sttributes. Comments within the code clearly indicate which items are unique to SEG-Y(LDS).

Disk storage: SEG-Y(LDS) has been adapted to disk storage primarily by GSC. The SEG-Y file contains a number of traces, each trace containing a number of data samples. File organizaton, as on tapes, consists of a single line header followed by data blocks containing trace headers. The file is a series of bytes with no logical record structure, and the bytes are defined as for tapes. A file structure without logical record structure allows easy access by most machines (all files must have a machine dependent physical record length, but on most machines this can be transparent to the user). For instance, on the PC, the bytes may easily be read in the C-language. Using the IBM PROFORT compiler the file must be opened for direct access with a chosen record length, then data must be read into a buffer in chunks with that record length. Because most sophisticated processing needs direct access to a particular trace, it is convenient to pad out all traces to the same length (and a minimum of 3600 bytes). When this is done easy direct access to bytes from FORTRAN is possible. Other institutions and users of other languages may ignore this restriction.

Data word formats: SEG-Y defines four data word formats. The actual format used is indicated by the contents of bytes 25-26 in the line header. For SEG-Y(LDS) we have chosen a fifth format to be the gain-ranged LUNCHBOX format utilized by GSC, and a sixth format to be VAX FORTRAN R*4. Note that SEG-Y defines the byte organization within a 2-byte integer on a tape. This is opposite to that on the VAX and the P.C. Yet to be decided is which would be the most sensible ordering on disk. Currently, GSC is using the natural way for the VAX and PC, i.e., least significant byte is the first in a two byte integer.

```
c
c                   LDS INCLUDE FILE VERSION 1.0
c
c this file is an implicit definition of SEGY format with additions
c for refraction work. It is the SEGY standard of Barry et al
c Geophysics (1975) with extensions labelled LDS USE for refraction
c work. When used as an INCLUDE file for a FORTRAN programme, all
c vaiables will be set after reading arrays SEGY1A, SEGY1B, and SEGYDB.
c
c Character code is EBCDIC unless using IEEE (see variable 'icode')
c
c------ modifications -----------------------------------------
c Carl Spencer  and Isa Asudeh   4/2/86 original specification
c
c Isa Asudeh , may 31, 1986
c Carl Spencer  3/9/86
c       update:  july 15, 1986
c                july 26, 1986
c                oct  16, 1986
c Isa Asudeh     nov  16, 1986
c Claire Smith:  feb  16, 1987
c Carl Spencer   nov  19  1987 FINAL VERSION marked with CPSNOV87
                          *****

c------- Parameter definitions --------------------------------

 integer*4 maxlen,maxsam
c
c       maxlen   maximum data file size in bytes
c                (including a 240 bytes header)
c
 parameter (maxlen = 131068)
c       maxsam   maximum number of samples
 parameter (maxsam = 32767)

c SEGY REEL IDENTIFICATION HEADER PART 1
      character*1  segy1a(3200)
c SEGY REEL IDENTIFICATION HEADER PART 2
      character*1  segy1b(400)
 c SEGY TRACE DATA BLOCK  - System dependent maximum record size
      character*1  segydb
      dimension segydb(MAXLEN)
c
       equivalence(segydb(1),thead(1))
c
c
c DATA WORDS
          integer*2    idata(maxsam)
          real*4       rdata(maxsam)
          equivalence(segydb(241),idata(1),rdata(1))
```

```
c
c SEGY VARIABLES
c
c-----------------------------------------------------------------------
-
c Binary area of file (or Reel) Identification Header Starts here
|
c-----------------------------------------------------------------------
-
c
c Job Identification number                                SEGY STANDARD
      integer*4    jobid
      equivalence  (segy1b(1),jobid)
c Line Number                                              SEGY STANDARD
      integer*4    lineno
      equivalence  (segy1b(5),lineno)
c reel Number                                              SEGY STANDARD
      integer*4    reelno
      equivalence  (segy1b(9),reelno)
c
c Number of data traces per record                         SEGY STANDARD
      integer*2    ntrace
      equivalence  (segy1b(13),ntrace)
c
c Number of auxilliary traces per record                   SEGY STANDARD
c
      integer*2    nauxt
      equivalence  (segy1b(15),nauxt)
c
c Sample interval in microseconds - this data              SEGY STANDARD
      integer*2    sint
      equivalence  (segy1b(17),sint)
c
c Sample interval in microseconds (in field)               SEGY STANDARD
c
      integer*2    sint2
      equivalence  (segy1b(19),sint2)
c
c No of samples per trace this data                        SEGY STANDARD
      integer*2    nsam
      equivalence  (segy1b(21),nsam)
c
      integer*2 nsamf
      equivalence  (segy1b(23),nsamf)
c NO of samples per trace in the field

c Data sample format code                                  SEGY STANDARD
c the ordering of bytes within this field indicates whether data
c is stored in SEGY standard  or IEEE standard. SEGY has most
significant
c byte first, IEEE (as on PC, or VAX) has least significant byte first
```

```
c       icode=0001    FLOATING POINT                     SEGY STANDARD
c       icode=0002    FIXED POINT (4 bytes)              SEGY STANDARD
c       icode=0003    FIXED POINT (2 bytes)              SEGY STANDARD
c       icode=0004    FIXED POINT WITH GAIN              SEGY STANDARD

c       icode=0100    FLOATING POINT - IEEE              VERITAS
STANDARD
c       icode=0200    FIXED POINT (4 bytes) - IEEE
c       icode=0300    FIXED POINT (2 bytes) - IEEE

c       icode=0500    LUNCHBOX FORMAT                    LDS USE ***
c       icode=0600    VAX R*4 FORMAT                     LDS USE ***
c Note that the swapped bytes of codes 0100 - 0600 will indicate
c       that all other header and data words also have their bytes
c       swapped. In this case, character information is ASCII.
c
c
      integer*2     icode
      equivalence   (segylb(25),icode)
c
c No of traces per  CDP ensemble                         SEGY STANDARD
c
      integer*2     ncdp
      equivalence   (segylb(27),ncdp)
c Trace sorting code                                     SEGY STANDARD
c     itsort=1      as recorded                          SEGY STANDARD
c     itsort=2      CDP ensemble                         SEGY STANDARD
c     itsort=3      Single fold continuous               SEGY STANDARD
c     itsort=4      Horizontal stack                     SEGY STANDARD
c                                                        NO  LDS USE
      integer*2     itsort
      equivalence   (segylb(29),itsort)
c
c  Vertical sum code                                     SEGY STANDARD
c     vcode=n sum on n traces                            SEGY STANDARD
c
      integer*2     vcode
      equivalence   (segylb(31),vcode)
c Start sweep frequency (HZ)                             SEGY STANDARD
c
      integer*2     ssweep
      equivalence   (segylb(33),ssweep)
c
c End sweep frequency (HZ)                               SEGY STANDARD
c
      integer*2     esweep
      equivalence   (segylb(35),esweep)
c Sweep Length in milliseconds                           SEGY STANDARD
c
c CPSNOV87
      integer*2     sleng
```

```
      equivalence  (segylb(37),sleng)
c
c SWEEP TYPE                                                    SEGY STANDARD
c     stype=1  LINEAR                                           SEGY STANDARD
c     stype=2  PARABOLIC                                        SEGY STANDARD
c     stype=3  EXPONENTIAL                                      SEGY STANDARD
c     stype=4  OTHER                                            SEGY STANDARD
c     stype=5  BOREHOLE SOURCE                                  LDS USE
c     stype=6  WATER EXPLOSIVE SOURCE                           LDS USE
c     stype=7  AIRGUN SOURCE                                    LDS USE
      integer*2    stype
      equivalence  (segylb(39),stype)
c
c Trace no of sweep channel                                     SEGY STANDARD
c
      integer*2    nts
      equivalence  (segylb(41),nts)
c
c Sweep trace taper in milliseconds at start                    SEGY STANDARD
c
      integer*2    stts
      equivalence  (segylb(43),stts)
c
c Sweep trace taper length in milliseconds at end               SEGY STANDARD
c
      integer*2    stte
      equivalence  (segylb(45),stte)
c
c Taper type                                                    SEGY STANDARD
c     ttype=1 LINEAR                                            SEGY STANDARD
c     ttype=2 COS**2                                            SEGY STANDARD
c     ttype=3 OTHER                                             SEGY STANDARD
c
      integer*2    ttype
      equivalence  (segylb(47),ttype)
c
c Correlated data traces                                        SEGY STANDARD
c     cort=1 no 2 yes
c
      integer*2    cort
      equivalence  (segylb(49),cort)
c Binary Gain recovered                                         SEGY STANDARD
c     arm=1 yes 2 no
c
      integer*2    bgr
      equivalence  (segylb(51),bgr)
c Amplitude recovery methods                                    SEGY STANDARD
c     arm=1 none 2 spherical 3 AGC 4 OTHER
c
      integer*2    arm
      equivalence  (segylb(53),arm)
```

```
c
c Measurement system                                          SEGY STANDARD
c     1=meters 2=feet                                          SEGY STANDARD
      integer*2    isys
      equivalence  (segylb(55),isys)
c
c Polarity                                                     SEGY STANDARD
c     ipol=1 upward case movement gives negative number SEGY STANDARD
c     ipol=2 upward case movement gives positive number SEGY STANDARD
      integer*2    ipol
      equivalence  (segylb(57),ipol)
c
c Vibrator polarity code                                       SEGY STANDARD
c
      integer*2    vpc
      equivalence  (segylb(59),vpc)
c
c     number of traces in the file                             SEGY UNASSIGNED
c     used for disk files                                      LDS USE ****
      integer*2 notif
      equivalence (segylb(61),notif)
cCPSNOV87
c      attribute information
c        attri=0    velocity/displacement data
c        attri=1    instantaneous amplitude
c        attri=2    instantaneous frequency
c        attri=3    instantaneous phase
c        attri=4    slowness (m/ms)
c        attri=5    semblance (0-1000)
       integer*2 attri
       equivalence (segylb(63),attri)
c                                                              LDS USE ***
c
c     mean amplitude of all samples in all traces in the file.
c     used for disk files.
cCPSNOV87
c                                                              SEGY UNASSIGNED
      real*4 meanas
      equivalence (segylb(65),meanas)
c domain of data                                               LDS USE
c       domain=0 time/distance
c              =1 fk
c              =2 tau-p
       integer*2 domain
       equivalence (segylb(69),domain)
c
c 71,72 unused to allign four byte boundaries.
c        reduction velocity meters/second if data is reduced
cCPSNOV87
 integer*4   vred
 equivalence (segylb(73),vred)
```

```
cCPSNOV87
c       minimum of all samples in the file.
        real*4    minass
        equivalence (minass,segylb(77))
cCPSNOV87
c       maximum of all traces in the file
        real*4     maxass
        equivalence (maxass,segylb(81))
c
c
c n.b. bytes 85-400 of File Id. Header are not used.
c
c-----------------------------------------------------------------------
-
c Binary area of file (or Reel) Identification Header Ends here
|
c-----------------------------------------------------------------------
-
c
c
c
c-----------------------------------------------------------------------
-
c Trace Identification Header (total of 240 bytes) starts here
|
c-----------------------------------------------------------------------
--
c
c Trace sequence number within line                     SEGY STANDARD
      integer*4 tsnl
      equivalence (thead(1),tsnl)
c
c Trace sequence number within tape                     SEGY STANDARD
c
      integer*4 tsnt
      equivalence (thead(5),tsnt)
c
c Original field record number                          SEGY STANDARD
c for LDS this will be sequential shot number           LDS USE
c
      integer*4 ofrn
      equivalence (thead(9),ofrn)
c
c Trace number withint original field record            SEGY STANDARD
      integer*4 tnofr
      equivalence (thead(13),tnofr)
c
c ENERGY source point number                            SEGY STANDARD
c
      integer*4 espn
      equivalence (thead(17),espn)
```

```
c CDP number                                                  SEGY STANDARD
c
      integer*4 cdp
      equivalence (thead(21),cdp)
c
c Trace number within cdp                                     SEGY STANDARD
c
      integer*4 tncdp
      equivalence (thead(25),tncdp)
c

c
c TRACE IDENTIFICATIONS CODE                                  SEGY STANDARD
c     tic=1 seismic data                                      SEGY STANDARD
C     TIC=2 DEAD                                              SEGY STANDARD
c     tic=3 dummy                                             SEGY STANDARD
c     tic=4 time break =5 uphole =6 sweep                     SEGY STANDARD
c     tic=7 timing =8 water break                             SEGY STANDARD
c
      integer*2 tic
      equivalence (thead(29),tic)
c
c Number of vertically summed traces yeilding this trace SEGY STANDARD
      integer*2 nvs
      equivalence (thead(31),nvs)
c
c Number of horizontally stacked traces yeilding this trace SEGY
STANDARD
      integer*2 nhs
      equivalence (thead(33),nhs)
c
c Data use   (1=productions 2=test)                           SEGY STANDARD
      integer*2 duse
      equivalence (thead(35),duse)
c
c Distance from source to receiver                            SEGY STANDARD
      integer*4 idist
      equivalence (thead(37),idist)
c
c Receiver group elevation                                    SEGY STANDARD
      integer*4 irel
      equivalence (thead(41),irel)
c
c Surface elevation of source                                 SEGY STANDARD
      integer*4 ishe
      equivalence (thead(45),ishe)
c c
c Shot depth                                                  SEGY STANDARD
      integer*4 ishd
      equivalence (thead(49),ishd)
c
```

```
c
c Datum elevation at receiver                          SEGY STANDARD
c
      integer*4 delr
      equivalence (thead(53),delr)
c
c Datum elevation at source                            SEGY STANDARD
c
      integer*4 dels
      equivalence (thead(57),dels)
c
c
c water depth at source                                SEGY STANDARD
      integer*4 wds
      equivalence (thead(61),wds)
c
c water depth at receiver                              SEGY STANDARD
      integer*4 wdr
      equivalence (thead(65),wdr)
c
c Scalar multiplier/divisor (+/-)for bytes 41-68        SEGY STANDARD
      integer*2 smul1
      equivalence (thead(69),smul1)
c
c
c Scalar multiplier/divisor (+/-)for bytes 73-88       SEGY STANDARD
c
      integer*2 smul2
      equivalence (thead(71),smul2)
c
c Source coordinate X or Longitude (East positive)     SEGY STANDARD
      integer*4 ishlo
      equivalence (thead(73),ishlo)
c
c Source coordinate Y or Latitude  (North positive)     SEGY STANDARD
      integer*4 ishla
      equivalence (thead(77),ishla)

c
c Group   coordinate X or Longitude (East positive)     SEGY STANDARD
      integer*4 irlo
      equivalence (thead(81),irlo)
c
c Group coordinate Y or Latitude  (North positive)     SEGY STANDARD
      integer*4 irla
      equivalence (thead(85),irla)
c
c coordinate units (      1 : meters/feet,                 SEGY STANDARSD
c                          2 : seconds of arc (smul2 holds multiplier)
c                        -N : mod 100 = TX zone
c                             div 100 = RX zone              )
```

```
      integer*2 cunits
      equivalence (thead(89),cunits)
c
c Weathering velocity (m/s?)                                    SEGY
STANDARD
      integer*2 wvel
      equivalence (thead(91),wvel)
c
c
c SUBWeathering velocity (m/s?)                                  SEGY
STANDARD
      integer*2 swvel
      equivalence (thead(93),swvel)
c
c Uphole time at source                                          SEGY
STANDARD
      integer*2 utimes
      equivalence (thead(95),utimes)
c Uphole time at group                                           SEGY
STANDARD
      integer*2 utimeg
      equivalence (thead(97),utimeg)
c Source static correction  (ms?)                                SEGY
STANDARD
      integer*2 sstati
      equivalence (thead(99),sstati)
c Group static                                                   SEGY
STANDARD
      integer*2 gstati
      equivalence (thead(101),gstati)
c
c Total static                                                   SEGY
STANDARD
      integer*2 tstati
      equivalence (thead(103),tstati)
c
c Lag time A                                                     SEGY
STANDARD
c
c LDS USE  definition:
c Time in millisec between end of 240 byte trace Identification Header
and
c time bread (time zero). Positive if time break occurs after end of
header,
c negative if time break occurs before end of header.
c This value is the negative of the start time of the trace,
c i.e. if the trace ranges from -50 to + 75 millisec then this entry
will
c be  +50.
c
      integer*2 istime
```

```
      equivalence (thead(105),istime)
c
c
c Lag time B                                                    SEGY
STANDARD
c
      integer*2 ibtime
      equivalence (thead(107),ibtime)
c
c Delay recording time                                          SEGY
STANDARD
      integer*2 ictime
      equivalence (thead(109),ictime)
c
c Mute time start                                               SEGY
STANDARD
c
      integer*2 mtimes
      equivalence (thead(111),mtimes)
c
c Mute time end                                                 SEGY
STANDARD
c
      integer*2 mtimee
      equivalence (thead(113),mtimee)
c
c
c No of samples in this trace                                   SEGY
STANDARD
c                                                               VISTA
USE ***
      integer*2 length
      equivalence (thead(115),length)
c
c Sample interval in microseconds                               SEGY
STANDARD
c
      integer*2 isi
      equivalence (thead(117),isi)
c
c Gain type  (1=fixed 2=binary 3 floating)                      SEGY
STANDARD
c
      integer*2 gaint
      equivalence (thead(119),gaint)
c
c Gain constant                                                 SEGY
STANDARD
c
      integer*2 gc
      equivalence (thead(121),gc)
```

```
c
c Instrument or initial gain in dB                                 SEGY
STANDARD
c
      integer*2 gidb
      equivalence (thead(123),gidb)
c
c Correlated 1=no 2=yes                                             SEGY
STANDARD
c
      integer*2 tcorr
      equivalence (thead(125),tcorr)
c
c Start sweep frequency (HZ)                              SEGY STANDARD
c
      integer*2    tsswee
      equivalence  (thead(127),tsswee)
c
c End sweep frequency (HZ)                                SEGY STANDARD
c
      integer*2    teswee
      equivalence  (thead(129),teswee)
c Sweep Length in milliseconds                            SEGY STANDARD
c
      integer*2    tsleng
      equivalence  (thead(131),tsleng)
c
c SWEEP TYPE                                              SEGY STANDARD
c     stype=1  LINEAR                                     SEGY STANDARD
c     stype=2  PARABOLIC                                  SEGY STANDARD
c     stype=3  EXPONENTIAL                                SEGY STANDARD
c     stype=4  OTHER                                      SEGY STANDARD
c     stype=5  BOREHOLE SOURCE                            LDS USE
c     stype=6  WATER EXPLOSIVE SOURCE                     LDS USE
c     stype=7  AIRGUN SOURCE                              LDS USE
      integer*2    tstype
      equivalence  (thead(133),tstype)
c
c
c Sweep trace taper in milliseconds at start              SEGY STANDARD
c
      integer*2    tstts
      equivalence  (thead(135),tstts)
c
c Sweep trace taper length in milliseconds at end         SEGY STANDARD
c
      integer*2    tstte
      equivalence  (thead(137),tstte)
c
c Taper type                                               SEGY STANDARD
c     ttype=1 LINEAR                                      SEGY STANDARD
```

```
c     ttype=2 COS**2
c     ttype=3 OTHER                                     SEGY STANDARD
c
      integer*2    tttype
      equivalence  (thead(139),tttype)
c Anti alias filter frequency                           SEGY STANDARD
      integer*2    aif
      equivalence  (thead(141),aif)
c
c Alias filter slope                                    SEGY STANDARD
      integer*2    ais
      equivalence  (thead(143),ais)
c Notch filter frequency                                SEGY STANDARD
      integer*2  nif
      equivalence (thead(145),nif)
c
c Notch filter slope                                    SEGY STANDARD
      integer*2    nis
      equivalence  (thead(147),nis)
c
c Low cut frequncy                                       SEGY STANDARD
      integer*2    flc
      equivalence  (thead(149),flc)
c
c High cut frequncy                                        SEGY
STANDARD
      integer*2    fhc
      equivalence  (thead(151),fhc)
c
c
c Low cut slope                                            SEGY
STANDARD
      integer*2    slc
      equivalence  (thead(153),slc)
c
c High cut slope                                           SEGY
STANDARD
      integer*2    shc
      equivalence  (thead(155),shc)
c
c Year of start of trace                                   SEGY
STANDARD
      integer*2    tyear
      equivalence  (thead(157),tyear)
c
c day of start of trace                                  SEGY STANDARD
      integer*2    tday
      equivalence  (thead(159),tday)
c
c Hour of start of trace                                   SEGY
STANDARD
```

```
      integer*2    thour
      equivalence  (thead(161),thour)
c
c Minute of start of trace                                          SEGY
STANDARD
      integer*2    tmin
      equivalence  (thead(163),tmin)
c
c
c second of start of trace                                          SEGY
STANDARD
      integer*2    tsec
      equivalence  (thead(165),tsec)
c Time basis code  1=local 2=gmt                                    SEGY
STANDARD
      integer*2    tbcode
      equivalence  (thead(167),tbcode)
c
c Trace weighting factor                                            SEGY
STANDARD
c
      integer*2    twf
      equivalence  (thead(169),twf)
c
c Geophone group no on roll switch first position                   SEGY
STANDARD
c
      integer*2    ggrp1
      equivalence  (thead(171),ggrp1)
c
c Geophone group no trace position 1 on field rec                   SEGY
STANDARD
c
      integer*2    ggtp
      equivalence  (thead(173),ggtp)
c
c Geophone group no on last trace of filed rec                      SEGY
STANDARD
c
      integer*2    gglp
      equivalence  (thead(175),gglp)
c
c Gap size                                                          SEGY
STANDARD
c
      integer*2    gapsz
      equivalence  (thead(177),gapsz)
c
c Overtravel 1=down 2=behind                                        SEGY
STANDARD
c
```

```
      integer*2    overt
      equivalence  (thead(179),overt)
c
c
c microseconds of trace start time                              LDS USE
      integer*4   mst
      equivalence (thead(181),mst)
c
c millisecond of timing correction                              LDS USE
c to be added to reported times to get local or gmt times
      integer*2   cor
      equivalence (thead(185),cor)
c
c charge size in kg                                             LDS USE
      integer*2   charge
      equivalence (thead (187),charge)
c
c shot time - year
      integer*2 syear
      equivalence (thead(189),syear)
c                                                               LDS USE
c
c shot time - day
      integer*2 sday
      equivalence (thead(191),sday)
c                                                               LDS USE
c
c shot time - hour                                              LDS USE
      integer*2 shour
      equivalence (thead(193),shour)
c shot time - minute                                            LDS USE
      integer*2 smin
      equivalence (thead(195),smin)
c shot time - second                                            LDS USE
      integer*2 sseco
      equivalence (thead(197),sseco)
c
c shot time - microsecond                                       LDS USE
      integer*4 ssmic
      equivalence (thead(199),ssmic)
c
c azimuth of receiver from shot-units are minutes               LDS USE
      integer*2 azimut
      equivalence (thead(203),azimut)
CPSNOV87
c azimuth of geophone orientation axis with respect to true north
c in minutes of arc
      integer*2 geoazi
      equivalence (thead(205),geoazi)
CPSNOV87
c angle between geophone orientation axis and vertical.
```

```
c in minutes of arc
       integer*2 geover
       equivalence (thead(207),geover)
CPSNOV87
c time to be added to recorded trace time to get actual trace start
c time. To be used when data has been reduced but trace start time is
not
c updated so that the actual time can be recovered even if distance and
shot
c time have changed (microseconds).
c                                                              LDS USE
      integer*4   ttrace
      equivalence (thead (209),ttrace)
c
c
CPSNOV87
c recording instrument number                                 LDS USE
      character*4   scrs
      equivalence (thead (213),scrs)
c
c deployment name                                             LDS USE
      character*4 deploy
      equivalence (thead(217),deploy)
c
c Shotpoint Name                                              LDS USE
      character*4 spname
      equivalence (thead(221),spname)
c
c Receiver site Name                                          LDS USE
      character*4 rstnam
      equivalence (thead(225),rstnam)
c
c SHOTID                                                      LDS USE
      character*4 shotid
      equivalence (thead(229),shotid)
c
c LINEID                                                      LDS USE
      character*4 lineid
      equivalence (thead (233),lineid)
c
c GEOPHONE ORIENTATION EG R40,Z                               LDS USE
      character*4 geoor
      equivalence (thead (237),geoor)
c
c
c--------- END SEGY.INC -----------------------------------------------
$LIST
```