CAMBRIDGE UNIVERSITY

RRS CHALLENGER 3/81

12-25 February 1981

CRUISE REPORT

Fleetwood - Barry

12th - 25th February, 1981.

R. S. White

Introduction

This cruise report covers the work done on RRS CHALLENGER leg 3/81 (12th February - 25th February, 1981) as part of a two-ship multichannel seismic experiment in conjunction with Dr. E.J.W. Jones of University College, London on STARELLA. Dr. Jones had already arranged a cruise to the Hebridean continental shelf when in April 1980 we asked the N.E.R.C. if they could provide a second ship to make it possible to conduct some two-ship seismic experiments in the same area. At short notice, the N.E.R.C. arranged to charter a second ship (STARELLA) and to rent a digital seismic acquisition system (Texas Instruments DFS III) together with a technician to run it. The proceedings aboard STARELLA are the subject of a separate report by Dr. E.J. W.Jones.

Techniques

We conducted two main types of two-ship seismic experiments. In the expanding spread configuration the CHALLENGER towing a 12-channel hydrophone streamer sailed at the same speed (5 knots) but on a reciprocal course to the STARELLA, which fired explosives at 2 or 3 minute intervals. The profiles reached a maximum inter-ship range of 70 km. (see Appendix 2 for details of charge sizes). A schematic diagram of the expanding spread configuration is given in Figure 1. From these profiles we can find the variation of seismic velocity with depth.

The second type of experiment was the constant offset profile made by steaming the STARELLA (shooting) and the CHALLENGER (receiving) in line astern at a fixed separation. By choosing an appropriate ship separation (in our case of up to 25km) we were able to continuously profile as a first arrival the basement return, as shown schematically in Figures 2 and 3. The constant offset profiles used a sound source on STARELLA of either a 16 litre (1000 cu. inch) airgun or explosives and were run at a speed of 5 knots.

The range-keeping was monitored using a Trisponder system with the active readout on CHALLENGER's bridge. On the expanding spread profiles the two ships each travelled at 5 knots and we made no attempt to modify their speeds during the course of the experiments; subsequent analysis shows that the mid-point of all the

shot-receivers pairs remained within approximately one kilometre of the start position, which is within our error requirements. The Trisponder ranges were consistently reliable out to 35 km, but beyond that we relied on ranges calculated from the water wave travel times. On the constant offset profiles STARELLA, shooting, was the lead ship and CHALLENGER maintained a fixed distance behind her using the Trisponder readout. The separation could generally be maintained accurately to within $\pm$ 50m, even in force 5 or 6 winds.

Timing for the experiments was controlled by two Cambridge crystal clocks, one on each ship. The clocks were reset manually at a pre-arranged time and their drift rates found by separate calibrations against a 15 MHz Universal Time Signal, usually from Radio Moscow. The calibrations were repeated throughout the experiments.

Narrative

Both Starella and Challenger were in Fleetwood before sailing, which was a great help in setting up the equipment and in coordinating plans between the scientists and the ships' officers. We sailed on the afternoon of Thursday, 12th February and headed separately for the southern end of line 4 west of Barra. STARELLA picked up explosives from Ardossan en route.

We met in the early hours of Saturday, 14th February and shot a short test line, followed by explosives expanding spread line 4E, (see Figure 3 for location). The whole array became very noisy mid-way through this profile. After the line was finished, we hauled in the front part of the array, and mended a connector near the front which had leaked causing the noise. The position of the leak was successfully located using the Kalamos test box.

We waited near the northern end of the line for STARELLA to rejoin us which they did at 0200 on Sunday, 15th. We then waited until daylight, when STARELLA deployed her airgun, but was unable to get it to fire. So instead we fired an explosives constant offset profile at 23 km separation with STARELLA ahead, steaming southwards. Hydrophone streamer channel 5 was intermittently noisy and subsequently remained so throughout the cruise, despite attempts to mend it and to replace it.

At the southern end of the profile along line 4 we turned and made a third pass along the same line this time at a constant offset of, firstly 15km, then 9km, with a 1000 cu inch airgun on STARELLA. We were unable to see any reasonable arrivals, which after much experimentation with the recording parameters we found was due to the airgun being towed too shallow on STARELLA. The airgun was forced deeper by slowing the ships to 4 knots, greatly improving the quality of the arrivals.

On completion of airgunning at 0623 on Monday, 16th February we moved to the centre point of line 5E (see Figure 3) and shot an expanding spread profile using explosives. There were several mis-fires on this line, and several channels of the hydrophone streamer were noisy. Apart from these, the data were good (see Figure 4). After the

termination of the profile at 1635 we turned into the wind, which was now gusting force 8 with force 10 predicted. We pulled in the array on a very wet afterdeck in heavy seas. The rear four sections showed evidence of grounding at some time and channel 10 was leaking.

Through the remainder of Monday and Tuesday (17th February) morning we headed northwards and across the Minches, reaching shelter from the southerly winds in the lee of Cape Wrath at midday. We then removed channel 10, patched up the leaks and replaced it on the end of the array. Channel 4 was replaced by a spare section. We also calibrated the rear depth sensor by lowering it into the sea on a rope with a weight attached. Unfortuately, the depth sensor failed on the next deployment. A dry joint was found on the inboard connection to channel 12, which was mended. The Kalamos fault finder was immensely useful in locating the positions of open faulty connections.

At 1130 Tuesday morning we commenced a constant offset profile along line 8 (see Figure 3) at a separation of 9 kms. North of Cape Wrath was very sheltered and we recorded a good noise-free profile of 674 shots, (illustrated in Figure 7), finishing at 0725 on Wednesday, 18th February. We then returned to the centre point of line 8 to shoot an expanding spread profile with explosives.
Expanding spread profile 8E commenced at 1252 on Wednesday, 18th February with CHALLENGER stearing northwards and STARELLA southwards, both at 5 knots. This time there were no misfires and the array was generally quiet. A single channel record section of the data is shown in Figure 5. At the northern end of the line, which finished at 1635, we deployed a 40 cubic inch airgun in order to take a normal incidence reflection profile. However, it didn't trigger properly so we pulled it in and waited for STARELLA to rejoin us which they did at about 2100.

We then made a third and final pass over line 8, this time steaming southwards at a constant offset of 15 km, with STARELLA ahead firing her airgun. The array was mostly quiet, but became very noisy for a section in the middle of the profile. Subsequently when we hauled in the array we found it was badly scratched, although otherwise undamaged over the rear six sections and we suspect that these may have grounded

in the central part of the profile. The water depth in this region was about 55m (180ft). The profile was finished at 0932 on Thursday, 19th February, and we then hauled in the array and removed channel 1, which had failed.

The rest of Thursday was spent steaming back south to the western end of line 6 (see Figure 3). Starting at 1402 on Friday, 20th February we shot a constant offset profile at a separation of 23km and a speed of 5½ knots with STARELLA firing twenty-seven 50kg exposive charges. The southerly wind was still strong, perhaps force 7 during the experiment, which made the array rather noisy. At the end of the profile (1545) we turned westward to shoot an airgun constant offset profile, but the wind was rising and the array becoming very noisy because of the heavy seas, so at 1920 we abandoned the profile and hauled the array in.

At about 2300 that night while we steamed slowly into the wind the compressor container on the upper deck of STARELLA shifted. They headed towards Ireland for shelter. We continued towards the southern end of line 5 with the intention of making a normal incidence reflection profile along it. However, during the next morning the container was secured on the deck of STARELLA and by now the seas had moderated so we waited for her to rejoin us and then shot a constant offset profile along line 5 at a separation of 9kms. STARELLA's airgun could only fire at half the previous rate due to the loss of one compressor, so we received one shot every two array spacings (one per 200m). The northern end of the profile was reached at 1000 on Sunday, 22nd February. We then continued profiling westwards to the centre point of line 9 (see Figure 3) where we shot an expanding spread profile using explosives out to 35km range, finishing at 1316. Following this, STARELLA rejoined us and at 1656 we commenced a constant offset profile along line 9. However, STARELLA's airgun arrivals started getting weaker and at 2230 it stopped firing. At this point we broke off the two ship work and CHALLENGER returned to the northern end of line 5 to take a noraml incidence reflection profile. Our 40 cubic inch airgun was deployed at 2230, but it stopped firing after about a dozen triggers. We

hauled it in, stripped and rebuilt it and finally got the gun firing reliably at 0600 on Monday, 23rd February. We continued along line 5 until 0930 when the compressor failed with a fan belt failure. We then pulled in the gun and the hydrophone array and at 1130 headed back to RVS Barry. The ship berthed at 1130 on Wednesday, 25th February. Whilst on passage we re-digitised from the continuously running analogue tape recording the shots that had not been digitally recorded, either because of mis-triggering or because of failure of the digital tape drive.

Digital Recording

The digital recording equipment (Texas Instruments DFS III) was run at a 4 msec sampling rate with a 62 Hz anti-alias filter. Airgun records on the constant offset profiles were run for 12 secs from the detonation instant, and explosives records for 30 secs. It had been intended to use a V.H.F. radio tone break transmitted from STARELLA to CHALLENGER to trigger the digitisation, but this was found to be unreliable with only a short range, so for the explosives lines a manual trigger was used instead using the pre-planned firing schedule. The shot instant was usually within $\pm$ 5 secs of the expected time and this manual triggering with careful time-keeping proved to be adequate. The few shots that were missed because of a late detonation of the explosives or because of tape failure on the digital acquisition system, were subsequently re-digitised from a 14 channel analogue tape recorder which was run continuously as a back-up.

The digitisation for the airgun shots was triggered using a timer on the clock on CHALLENGER synchronised with the clock on STARELLA. The start-up time of the digital system following the clock trigger varied by up to 100 msecs. but we were able subsequently to correct for this using the 1 second clock signal recorded on an auxilliary channel of the DFS III.

Results

Two examples of expanding spread profiles using explosives are shown in Figure 4 (ESP 5E west of Barra), and Figure 5 (ESP 8E north of Cape Wrath). These profiles show only one mid-streamer channel for each shot, and the maximum amplitudes of each trace have been normalised. Note the good signal to noise ratio and the facility with which second arrivals can be correlated, most notably from converted shear waves and from the super-critical Moho reflection.

An example of part of a 9 km constant offset profile from west of Barra is shown in Figure 6 (COP 5E). Note the great lateral variations in the amplitude of the converted shear wave caused by lateral variability in the seismic structure of the basement. In Figure 7 we show the constant offset profile coincident with line 8E north of Cape Wrath.

Results from this cruise have been reported at several meetings and in publications[1,2]: more is presently being prepared for publication.

1. White, R.S., Jones, E.J.W., Hughes, V.J. & Matthews, D.H., 1982. Crustal structure from two-ship multichannel profiles on the continental shelf off north-west Scotland. Tectonphys. 90, 167-178.

2. Hughes, V.J., White, R.S., Jones, F.J.W., Matthews, D.H., Brewer, J.A. & Smythe, D.K., 1983. A wife angle seismic profile in Seismic Structure Atlas, (ed. A.W. Bally), Amer. Ass. Petr. Geol.

Appendix One: Scientific Complement

Bob White	Cambridge University
Viv Hughes	" "
Penny Barton	" "
Martyn Rayner	" "
Adrian Bowen	" "
Trevar Smith	Horizon Technician
Ed. Cooper	R.V.S.
Chris Jackson	"
Robin Powell	"
Martin Beney	"
(Drum Matthews	Cambridge University on STARELLA)

Appendix Two: Expanding Spread Shot-Firing Schedule

The hydrophone array was only relatively short (1.1 km), so it was necessary to fire charges once every 2 mins. to obtain two-fold coverage on the expanding spread profiles. Larger charges were deployed once per 3 mins., which gave sufficient overlap to check for relative timing errors between adjacent shots. Charges were chemically fused with ICI type LIA1 green oceanographic capped fuses, with sufficiently long fuses to ensure that the majority of the charges detonated on the sea bed (the sea was approximately 100m deep over most of the profiles). Sea bed detonation not only facilitated accurate determination of the shot instant, since the depth is accurately known but also generated strong shear waves. The shear waves propogated within the crust, and were detected at the hydrophone array after conversion from shear to compressional waves.

The tone break system for the shot instant transmission from the shooting to the receiving ship did not work reliably at more than a few kilometres range. We found, however, that if both the shooting and the receiving ship kept to the pre-planned schedule, the charges could be deployed to within a few seconds of the planned time. On the shooting ship the shot firing was accomplished by having one person in charge solely of the timing, one pair of people unpacking the geophex and one pair actually firing the shots. For long runs of large shots the geophex can be pre-banded into pairs of 12.5kg sticks.

The shot sizes we used were sufficient out to about 50 km range, but rather too small beyond this: 50 kg charges would have been better at the larger ranges. We commenced firing 8 mins. before we expected the two ships to pass at their point of closest approach.

Shot numbers	Shot size	Firing interval
1 - 20	2.1 kg	2 mins
21 - 26	4.2 kg	3 mins
27 - 40	12.5 kg	3 mins
41 - 80	25.0 kg	3 mins

Total explosives:	32 x 2.1 kg	=	67.2 kg
plus	94 x 12.5 kg	=	1175.0 kg
			1242.2 kg

Appendix Three: Table of Day Numbers

Thursday	12th	February	1982	=	Julian Day 043
Friday	13th	"		=	" 044
Saturday	14th	"		=	" 045
Sunday	15th	"		=	" 046
Monday	16th	"		=	" 047
Tuesday	17th	"		=	" 048
Wednesday	18th	"		=	" 049
Thursday	19th	"		=	" 050
Friday	20th	"		=	" 051
Saturday	21st	"		=	" 052
Sunday	22nd	"		=	" 053
Monday	23rd	"		=	" 054
Tuesday	24th	"		=	" 055
Wednesday	25th	"		=	" 056

Circulation

Dr. L. M. Skinner, Research Vessel Base, Barry.

Dr. J. Cleverly, N.E.R.C., Swindon.

Dr. E.J.W. Jones, University College, London.

Dr. D. H. Matthews, Cambridge University.

Cambridge participants (5).

Cambridge cruise file.

M.I.A.S. I.O.S. Wormley.

Admiral D. Haslam, Hydrographer of the Navy.

The Master, RRS CHALLENGER (Geof Long).

Dr. T. Huntingdon, N.E.R.C., Swindon.

3 Spare Copies.

Figure Captions

Figure 1 Schematic diagram showing expanding spread profile configuration.

Figure 2 Schematic diagram showing constant offset profile configuration.

Figure 3 Locations of two-ship seismic profiles (solid lines), and passage tracks (broken lines).

Figure 4 Record section from a single mid-streamer group of the expanding spread profile 5E west of the Outer Hebrides. Explosive sources varied in size from 2.1 kg at short ranges to 25 kg beyond 30 km range. Trace amplitudes have been normalised. The centre of profile 5E is at 57°06' N 8°18' W, and the shooting azimuth was 000°. The arrow marks the range at which the constant offset profile 5C09 was shot (see Fig. 6).

Figure 5 Record section from a single mid-streamer group of the expanding spread profile 8E north-east of Cape Wrath. Explosive sources varied in size from 2.1 kg at short ranges to 25 kg beyong 30 km range. No travel time corrections have been applied for the effects of varying sediment thickness, and trace amplitudes have been normalised. Least squares fit lines to the first arrivals and major second arrivals derived from all twelve streamer groups are superimposed on the record section. The centre point of profile 8E is at 58°54' N 4°18' W, and the shooting azimuth was 224°. The arrow marks the range at which the constant offset profile 8C09 was shot (see Fig. 7).

Figure 6 Monitor records from a single mid-streamer group of portion of constant offset profile 5C09. The source is a 1.6 litre (1000 cu. in.) airgun fired once every 100 m along the track, with a constant separation between ships of 9 km. No processing has been applied to the signals. Note the marked changes in amplitude of the shear wave basement arrival ("Sb") which has been doubly mode converted at the top of the basement, whilst the compressional wave basement return ("Pb"), varies little in amplitude over the same portion of crust.

Figure 7 Constant offset profile 8C09 made at a shooting to receiving ship separation of 9 km using a 1.6 litre (1000 cu. in.) airgun fired once every 100 m along track. The refraction profile at the left-hand end was generated as the ships separated. Elsewhere travel time corrections have been made for small variations in ships' spacing about the mean of 9 km and for clock drift on the shooting and receiving ships. The section has been stacked over channels and band-pass filtered from 0 to 16 Hz before display.

EXPANDING SPREAD

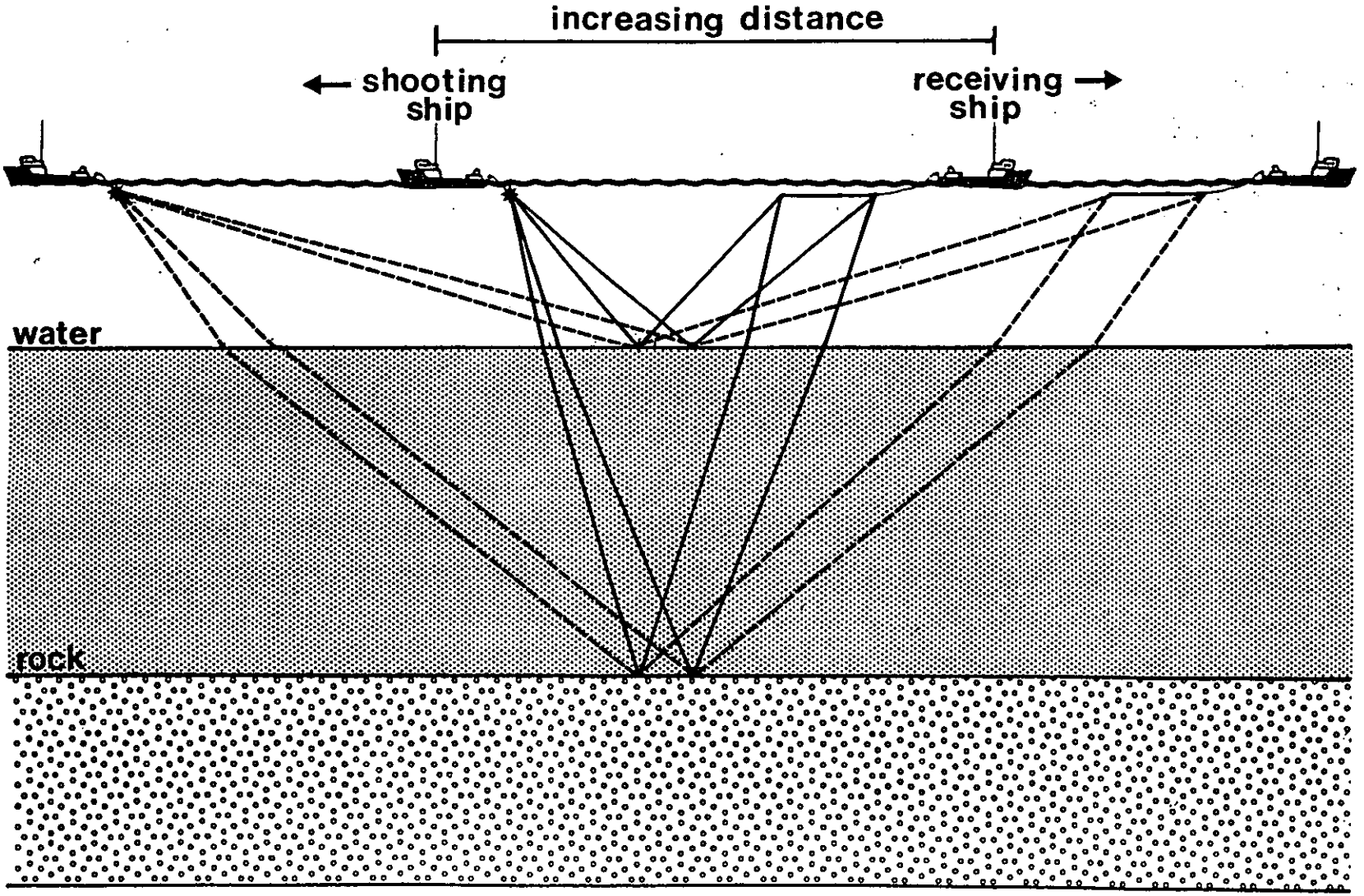

Figure 1

CONSTANT OFFSET

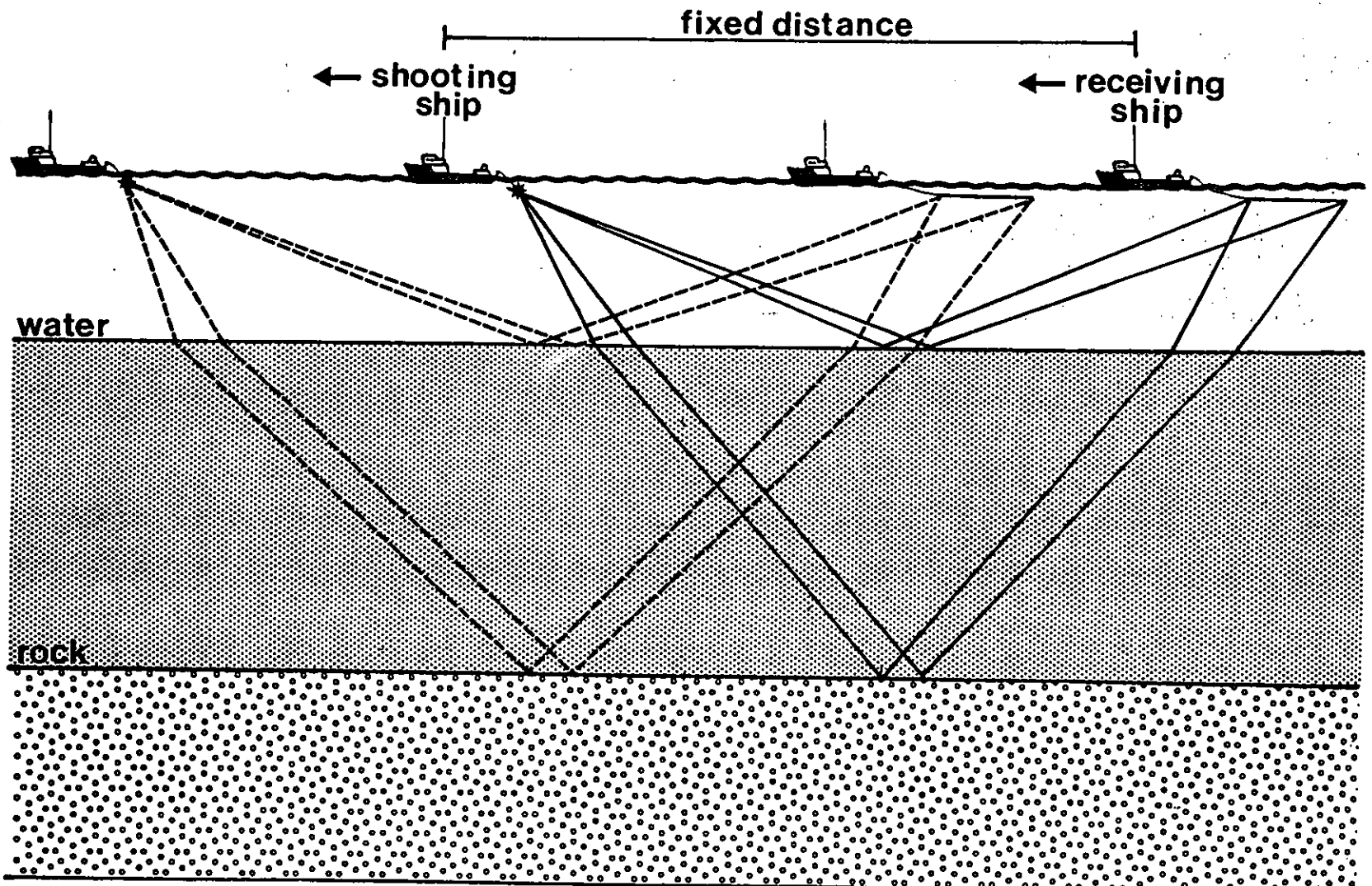

Figure 2

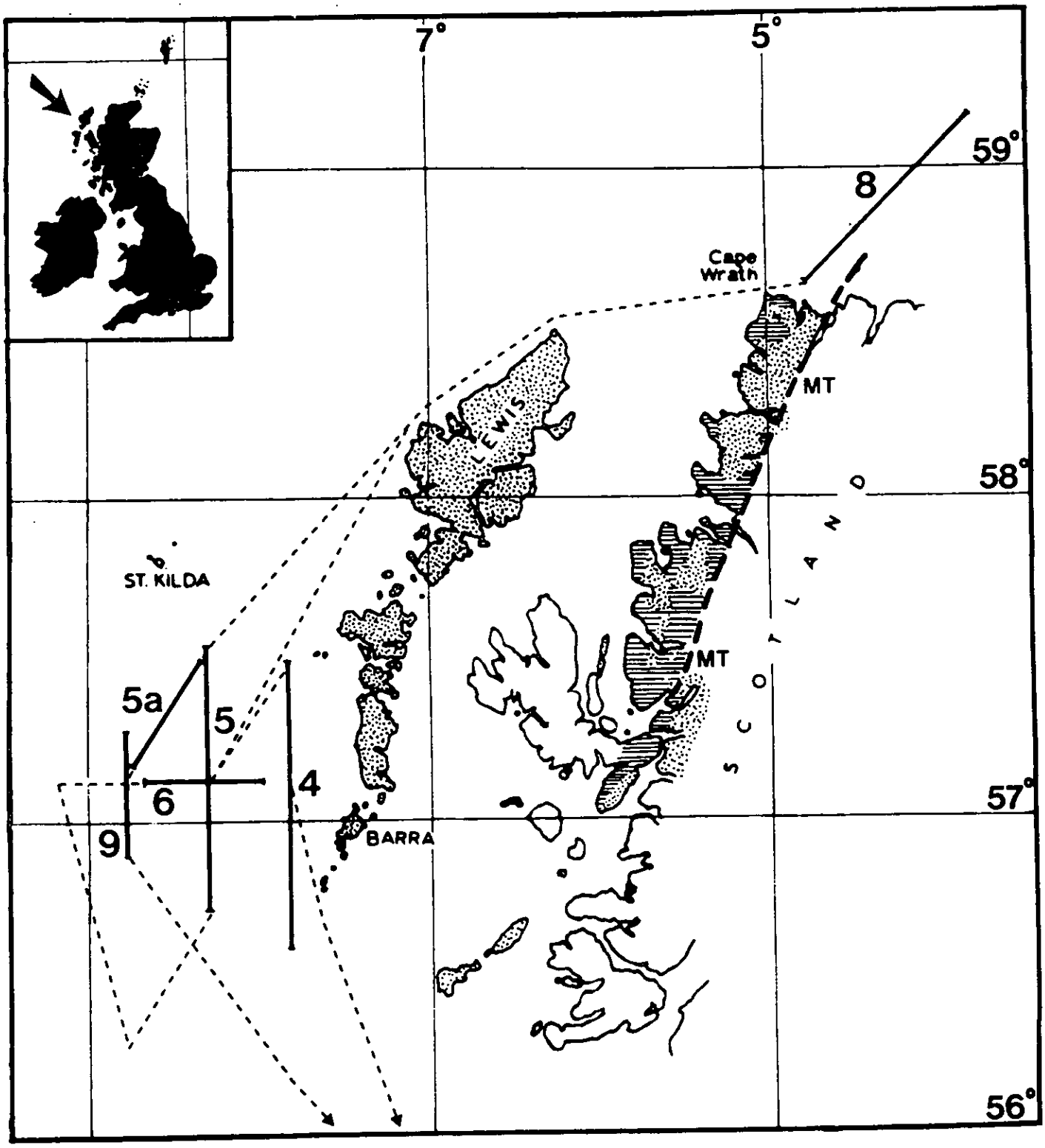
7°
5°
59°
58°
57°
56°
8
Cape Wrath
MT
LEWIS
MT
SCOTLAND
ST. KILDA
5a
5
4
6
9
BARRA

Figure 3

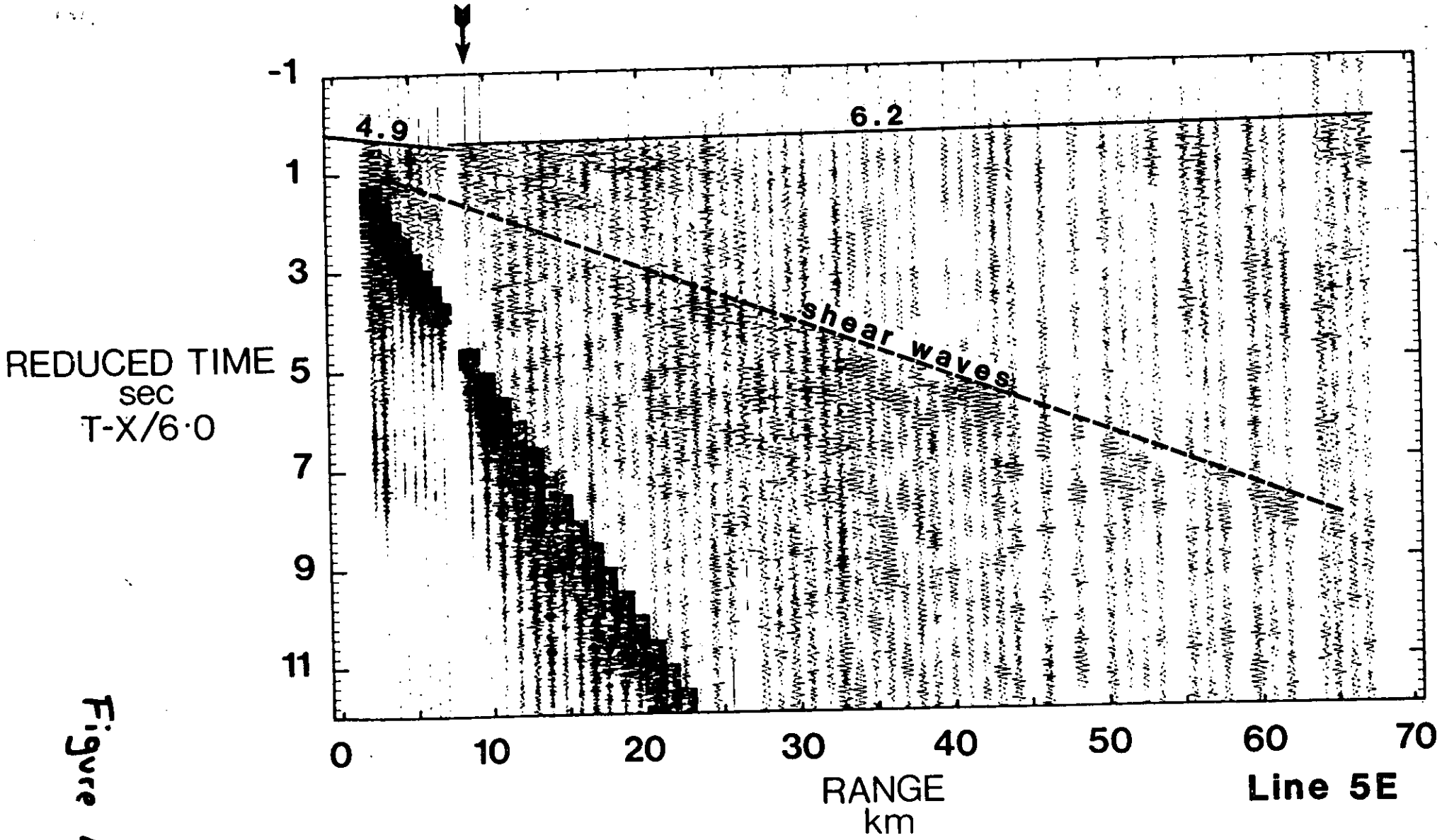
-1
1
3
5
7
9
11
REDUCED TIME
sec
T-X/6·0
4.9
6.2
shear waves
0
10
20
30
40
50
60
70
RANGE
km
Line 5E

Figure 4

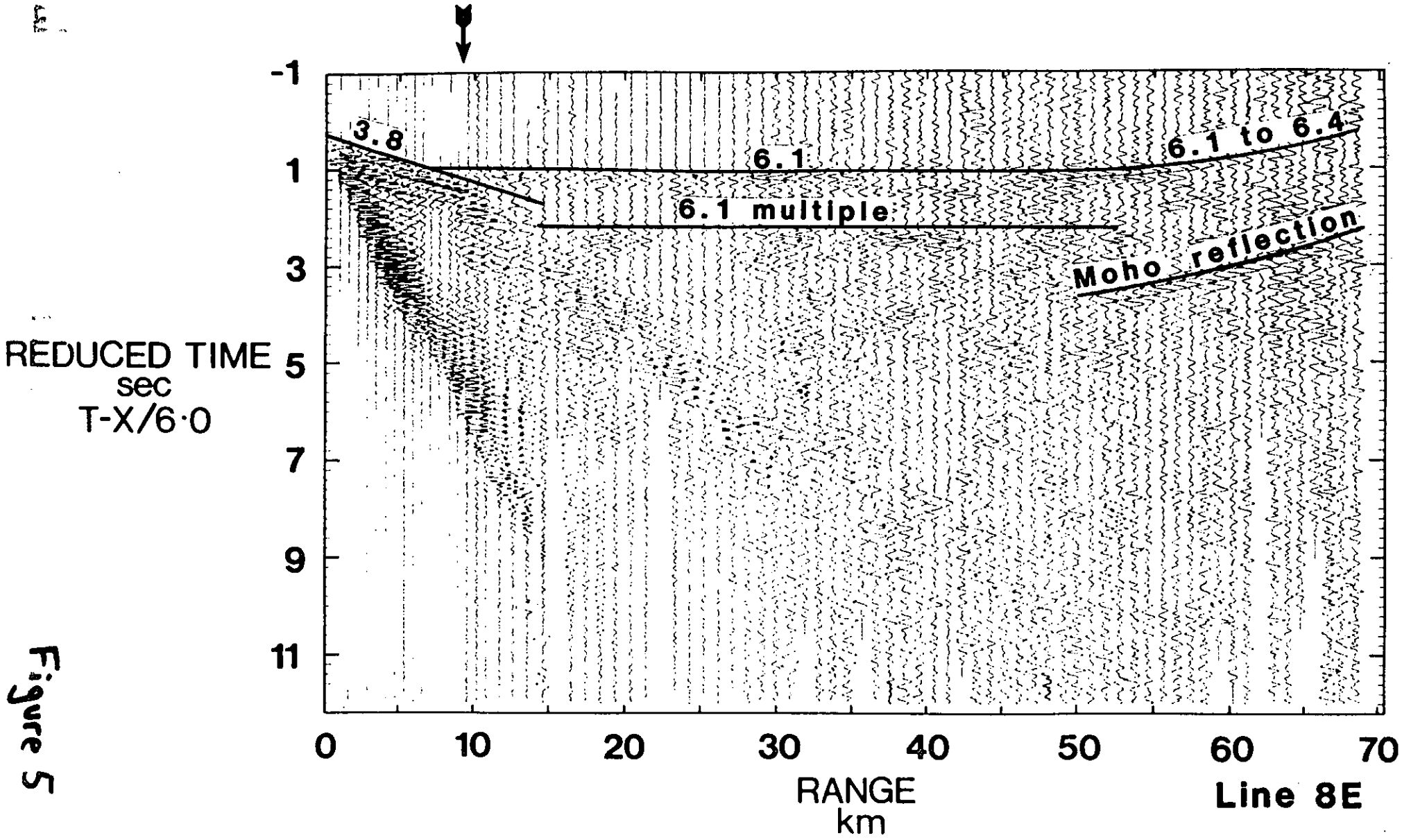
-1
1
3
5
7
9
11
REDUCED TIME
sec
T-X/6·0
3.8
6.1
6.1 to 6.4
6.1 multiple
Moho reflection
0
10
20
30
40
50
60
70
RANGE
km
Line 8E

Figure 5

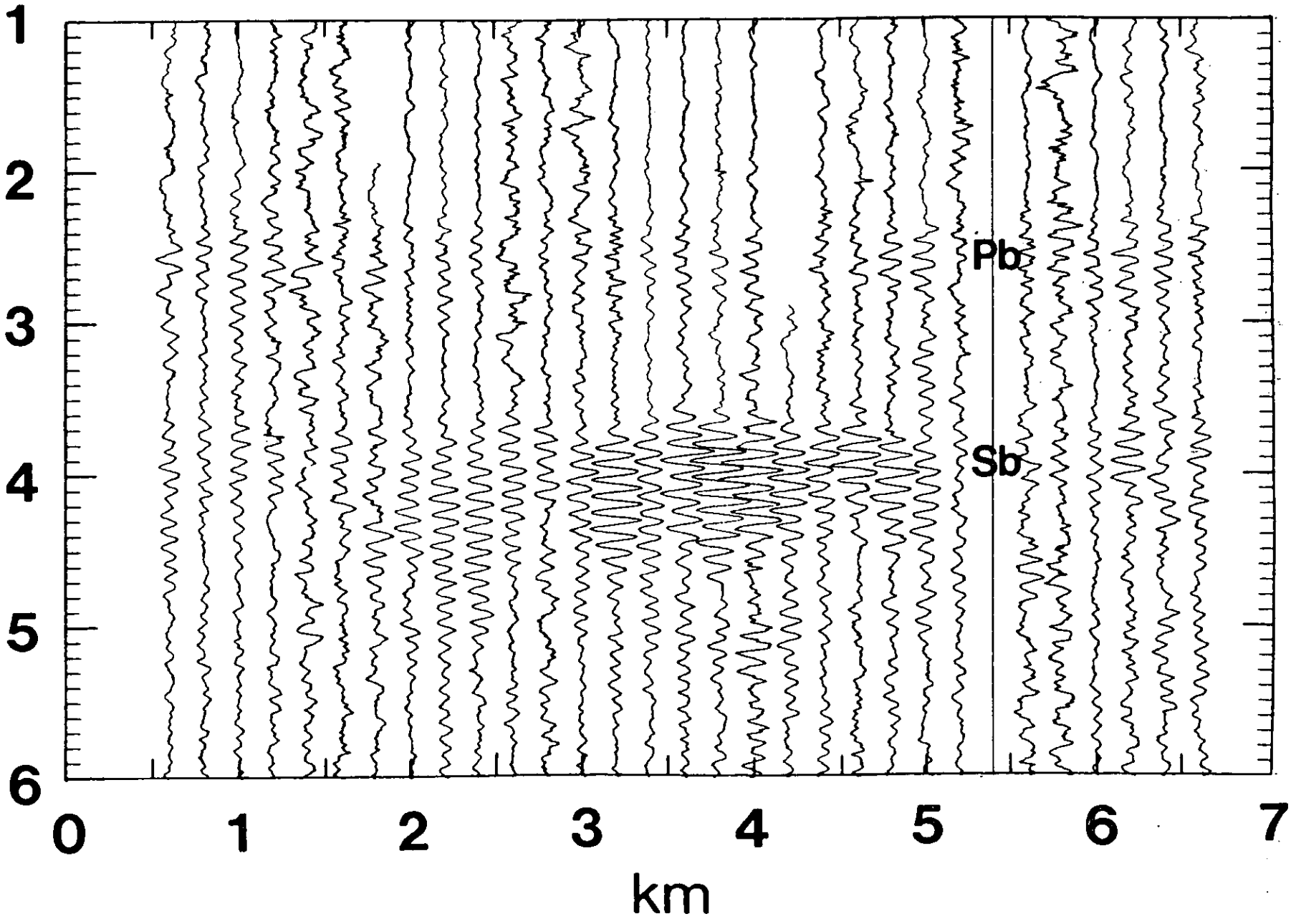

Figure 6

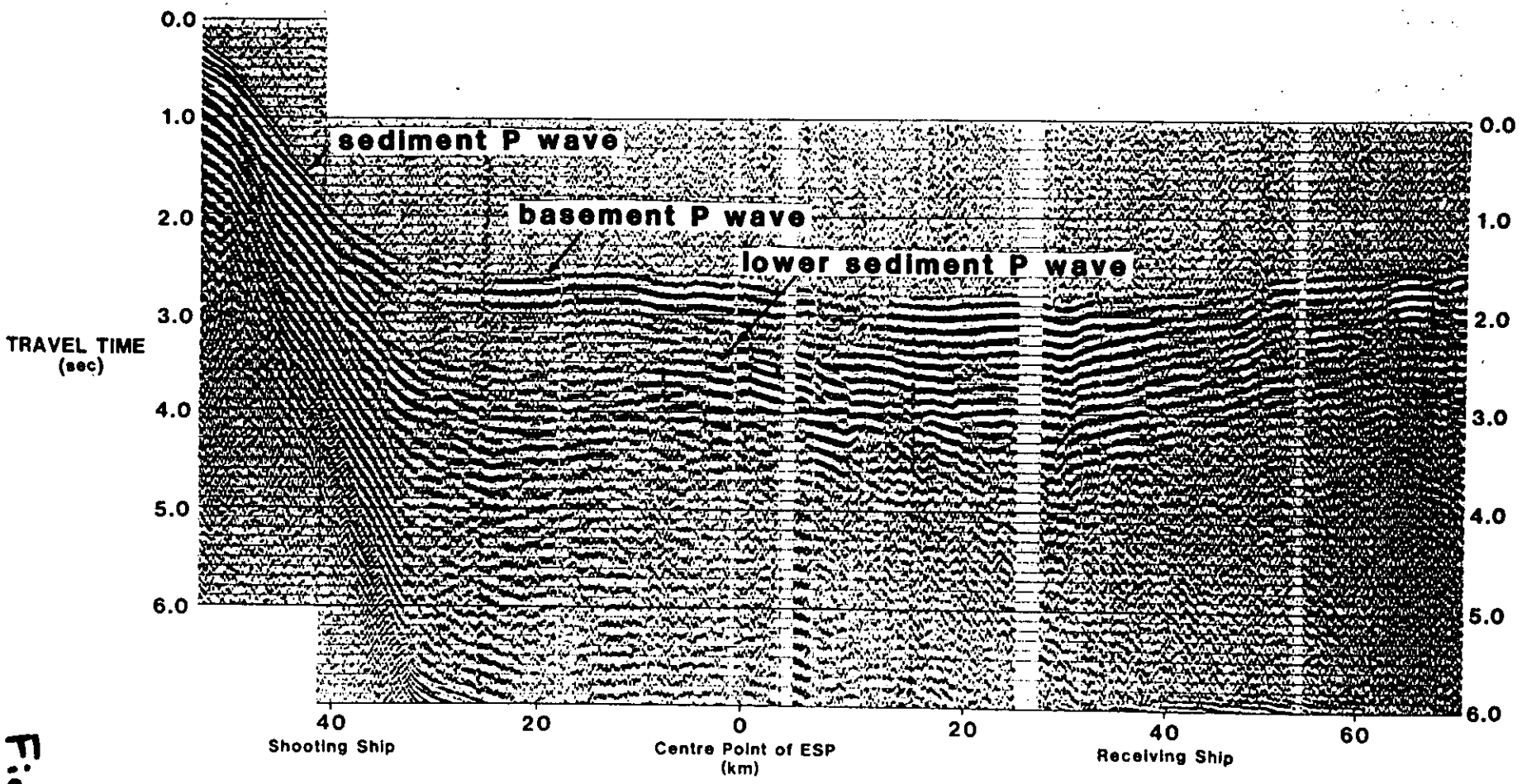
0.0
1.0
2.0
3.0
4.0
5.0
6.0
TRAVEL TIME
(sec)
sediment P wave
basement P wave
lower sediment P wave
40
20
0
20
40
60
Shooting Ship
Centre Point of ESP
(km)
Receiving Ship

Figure 7