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A.R.E. seismic studies in the Norwegian Sea
Interim Report, August 1989 - August 1990

P R Miles

1990

Natural Environment Research Council

INSTITUTE OF OCEANOGRAPHIC SCIENCES
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ABSTRACT

This report describes the work undertaken during the 12 months following completion of the MV "Eastella" cruise in August 1989. Details of the cruise were published in IOSDL Cruise Report No. 208 (Whitmarsh et al, 1989).

Data transfer from the digital ocean-bottom seismograph (OBS) cartridge cassettes to the in-house IBM computer was followed by shot trace display to monitor data quality. Underway navigation files, from both LORAN and GPS fixes, were plotted for each site.

The water column velocity/depth structure was determined from XBT data and historical measurements. This enabled the airgun ranges to be calculated using a standard waterpath travel-time method. The calculation of the bottom shot ranges required some new software to be written for a technique which used the difference in travel-time between the direct waterwave and that reflected from the sea surface.

At all six sites the bottom shot traces have been displayed, the events picked and preliminary travel-time models constructed. In addition two sites have travel-time models for the airgun data and these both show the existence of low velocity zones beneath the acoustic basement.

KEYWORDS

SEISMIC WAVES; P-WAVES; RAY PATHS; EXPLOSIVES; SEISMIC REFRACTION PROFILES

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EXECUTIVE SUMMARY

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INTRODUCTION

On completion of the M.V. Eastella cruise in August 1989 (Fig. 1)(Whitmarsh et.al., 1989) it was necessary to complete three tasks in the initial processing of the data. An undergraduate vacation student (Mr. G. Milne) was employed for six weeks to assist in this data reduction.

1. Construction of navigation files for the display, editing and monitoring of data sets for each site.

2. Transfer of ocean bottom seismograph (OBS) data files for each site to a mainframe computer and their translation into a format suitable for subsequent processing.

3. Determination of the soundspeed/depth profiles for each site from the XBT stations and historical information.

The bottom shot and airgun ranges were determined subsequently and the seismic traces were then displayed in the time - distance domain as record sections. The seismic arrivals were identified and the onsets of events picked from displays of the data recorded by the horizontal (x,y) and vertical (z) geophones and the hydrophone.

NAVIGATION

Four navigational systems were used during the cruise. The acoustic system used to position the deployment of the OBSs and bottom shots at each site was required only for the operations at sea. However it was decided to return from the cruise with acoustic navigation fixes at 1 minute intervals on diskettes. These data were transcribed and transferred to the mainframe computer which enabled us to plot each site's OBS and bottom shot deployment positions at the rather large scale of 1:30,000. These plots provided independent first order checks on the bottom shot ranges.

LORAN-C was used to navigate the seismic reflection profiles (SRP) and airgun lines. A shipboard printer produced a position printout every 5 minutes. These positions were manually entered in the mainframe computer as navigation files for each site and plotted at a scale of 1:200,000. This enabled the track charts for each site to be compiled and presented in the cruise report.

Limited GPS coverage was available during the cruise. This was routinely logged on a printer and again manually composed into a navigation file of 5-minute fixes for each site. Coverage occurred during 2 - 3 hour windows only but enabled us to confirm the LORAN-C accuracy and to correct for lane-jumps.

DATA TRANSFER

Portable Digital Acquisition System (PDAS) data for each OBS, which had been transcribed to cartridge tapes during the cruise, were transferred to a PC hard disc. The data were stored as individual files for each x,y,z and h channel for each shot. PC software commands controlled file name creation and data transfer to the IBM mainframe computer.

At this stage conversion of the data to a standard 'ROSE' (Rivera Ocean Seismic Experiment) format enables it to be included in the seismic database and archived. The ROSE format has one file for each task of each OBS for every lay. Tasks are sets of airgun or bottom shots with each shot being controlled by an 'event' file. The file information includes absolute time, clock drift, static corrections and data windows.

Standard IOSDL software could now be used to display, process and organise the data.

DETERMINATION OF SOUNDSPEED/DEPTH PROFILES

An XBT was launched at each site. Strong summer heating at the survey sites produced a steep negative sound speed gradient near the surface and a shallow sound-channel axis, particularly for sites 3 to 6. The XBT data was converted to soundspeed using the approximation of Mackenzie (1981) with an estimated salinity of 34.9% (Saunders and Gould,1988). At depths greater than 2000m the profiles merged well with the historical data from Dietrich (1969). At sites 1 and 2 water depths exceeded the XBT probe depths by 2000 and 3000 m respectively. This required the deepest XBT measurement to be extrapolated using the soundspeed gradient of the historical data. The soundspeed profile for each site is shown in figure 2.

DETERMINATION OF BOTTOM SHOTS RANGES

The timer clocks which detonate the shots are accurate to only 0.5s. This is not sufficiently accurate for determining shot instants or the shot - receiver range. The acoustic navigation, although accurate to 3 metres on deployment, could not locate the OBS or shots on the sea bed. We therefore used classical techniques of direct and surface-reflected water arrivals to determine the shot-receiver ranges and hence the shot instants.

Figure 3 shows an example of the direct water-wave and surface reflection arrivals in addition to the intra-sediment events. Prior to the cruise it was uncertain that an OBS in a depth of over 1000m or so would detect the direct water-wave from a shot at about the same depth; ray theory, which is correct for infinitely high frequencies, predicts that the hydrophone should lie in an acoustic shadow. However due to the relatively low bubble pulse frequency of the bottom shots sufficient energy was detected by the sea bed hydrophone and geophones out to the maximum shot-to-OBS ranges. This precluded the necessity of deploying a buoyed hydrophone above each OBS. The waterborne arrivals could be picked from the computer display to an accuracy of 1 ms (one sample). An iterative program was developed which, given the soundspeed profile and the depth of each shot, and the OBS, matched the observed time difference (to 0.2ms) between the direct and surface-reflected arrival for each shot and OBS with that calculated for a given take-off angle from the shot (Figure 4). As two OBSs recorded each bottom shot two independent estimates of each shot instant were available from the travel-time calculation. Generally these estimates agree within 8ms (2 standard deviations). Kirk et al (in press) have computed error estimates on these measurements. They estimate the standard error in the range to be at worst 22.2m (including a systematic error of 0.5m/s throughout the soundspeed model) or 18m (assuming no errors in soundspeed). Assuming an error of 0.5m/s in the seabed soundspeed, these two estimates indicate a standard error of at worst 14 or 12ms in the shot-instant, respectively. It must be stressed that in most cases the errors in range and shot-instant will be far less than the figures quoted above.

DETERMINATION OF THE RANGES OF THE AIRGUN SHOTS

Knowing the soundspeed profile and OBS depths, hodochrons (distance - travel-time curves) were calculated for the shot - OBS direct arrival and shot - bottom - surface - OBS multiple. The depths of the intermediate reflection points were also required for the latter ray-path. These hodochrons were then used to apply the technique of Whitmarsh et al (1986) to determine range. This involves each hydrophone trace being iteratively adjusted in range so as to position the direct arrival, or its multiple, on the appropriate hodochron. In practice a number of key traces are positioned with the ranges to the others being linearly interpolated between them.

The airgun shots, which extended to some 30km range, provided an additional constraint on the accuracy of the range calculations. The mean OBS separation (range difference) calculated from the more distant bottom shots agrees within 4m with that calculated from surface airguns for two sites where bottom shots and airguns were fired along the same azimuth.

TRAVEL TIME MODELS BASED ON BOTTOM SHOT DATA

Figures 5 through 16 show the data and the fit of computed hodochrons to the observations. The bottom shot traces are displayed with a reduced travel-time versus range which enables clearer correlation of events across the record section: each trace is advanced in time by an amount equal to the range divided by the reduction velocity. The reduction velocity has been varied between sites to best display the observed arrivals.

Events on each trace were picked using interactive software and matched in travel-time by raytracing through a seafloor velocity/depth model. The preliminary calculated hodochrons are shown with event picks indicated as bars of varying height according to the estimated accuracy of the pick. Table 1 lists a preliminary interpretation for each site from the bottom shot travel-time modelling.

TRAVEL-TIME MODELS BASED ON AIRGUN SHOTS

So far sites 5 and 6 airgun data have been travel-time modelled. They are displayed in figures 17 and 19 with a reduction velocity of 5km/s, one display for each OBS at each site. The hodochron matching is shown in figures 18 and 20. The velocity depth functions used are shown in Table 2.

It is striking that both data sets from these two westernmost sites show the existence of a low velocity layer beneath the uppermost, presumably basaltic, acoustic basement. The significance of these results will be followed up during the amplitude modelling phase which will follow the travel-time modelling of each site.

SONOBUOY DATA

An undergraduate sandwich-course student (Mr. L. Ho) was employed between April and September, 1990 to digitize, display and interpret the sonobuoy data collected during the cruise. At least one sonobuoy was deployed at each site; the resulting wide-angle seismic data can provide interval velocities for the near-surface sediments. These data enable conversion from two-way travel-time to depth of the principal reflectors.

It was necessary first to digitize the data as they were recorded at sea on a Store-4 analogue tape recorder. An OBS PDAS unit was used for this purpose. As there is always a small difference in the ship AC supply compared to that in the laboratory, the Store-4 tape deck rotated at a slightly different rate on playback than during recording. Although this did not present a significant timing error over the data window of 9 seconds it did show the shot instant to drift across the display. As time zero was fundamental to the data reduction this was rectified by applying a clock drift correction to the data. An additional static correction placed the airgun trigger pulse at time zero. Once digitized the data were processed and displayed in the same way as the OBS files.

It was evident at the time of recording that the data suffered from high noise levels caused by some combination of poor radio reception and sonobuoy operation. When the traces were displayed with filtering applied only two sites, sites 2 and 3 (Fig. 21), showed both usable data quality and identifiable reflection horizons.

Interpretation of the data involved picking the reflection hyperbolae and then iterating a travel-time model to match the observed hyperbolae. Wide angle seismic reflections transmit through a layer whereas bottom shot and airgun refraction lines transmit energy along a layer. Consequently the measured interval velocities from the sonobouy data may show differences from the bottom shot velocity models because of anisotropy normal in seismic layer velocities.

CONCLUSION

The initial data reduction has been completed successfully and all data has been plotted as record sections. Datasets for each site have been archived and duplicated in a security backup. All data are also still held in their original cartridge tapes as transcribed during the cruise.

The consistent quality of the OBS data has enabled accurate event picking for subsequent travel-time modelling; at four sites the airgun data sets are outstanding. Once the travel-time modelling has been completed amplitude modelling using synthetic seismograms will be used to determine the velocity structure more accurately.

It is gratifying to notice from these preliminary results that the bottom shot and airgun data do compliment each other, as intended, by providing continuous velocity information from the sea bed to depths of several hundred metres into the crust.

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FIGURE CAPTIONS

1. MV Eastella track chart (July/Aug 1989) showing site locations. Bathymetry in metres.

2. Soundspeed/depth profiles of the water column for each site from XBT and historical data.

3. Seismogram of bottom shot number 6 at site 1.

   (a) direct water-wave (D) and first surface reflected water-wave (R_1).

   (b) expanded seismogram of sedimentary phases followed by the direct water-wave.

4. Sketch of the water-wave paths used to compute the horizontal shot-OBS range AB. Wave paths D and R_1 in Figure 3. Their time difference combined with the soundspeed structure and OBS/shot depths enable computation of the range.

5. Record section of the combined hydrophone traces recorded by the two OBS at site 1 (reduction velocity 1.9km/s). Amplitude has been scaled according to $(\text{distance})^2$.

6. Event picks from site 1 bottom shots (Figure 5) with travel-time model hodochrons (reduction velocity 1.9km/s).

7. Site 2 hydrophone traces.

8. Site 2 event picks and travel-time hodochrons.

9. & 10. Site 3

11. & 12 Site 4

13. & 14. Site 5

15. & 16. Site 6

17. Airgun record section of z geophone traces recorded by OBS 56 at site 5. Amplitude has been scaled according to distance, bandpass filter 5-30Hz.

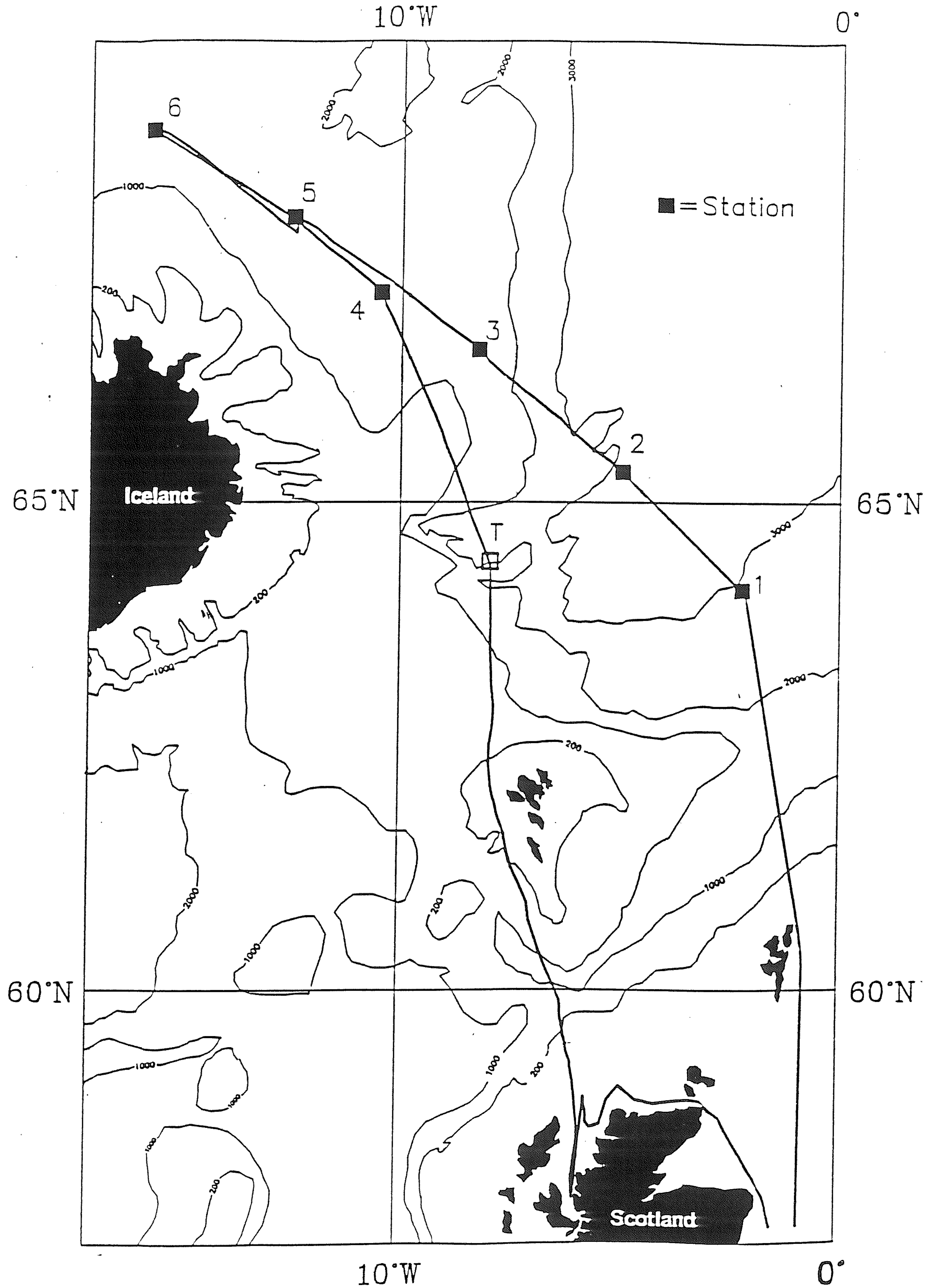
18. Site 5 event picks and travel-time model hodochrons (reduction velocity 5km/s.

19. Site 6 Airgun record section as for Fig. 17.

20. Site 6 event picks and travel-time model hodochrons (reduction velocity 5km/s).

21. Sonobuoy record sections for site 2 and 3.

Fig 1


10°W
0°
6
5
4
3
2
1
T
■ = Station
Iceland
Scotland
65°N
60°N
1000
200
2000
3000
10°W
0°

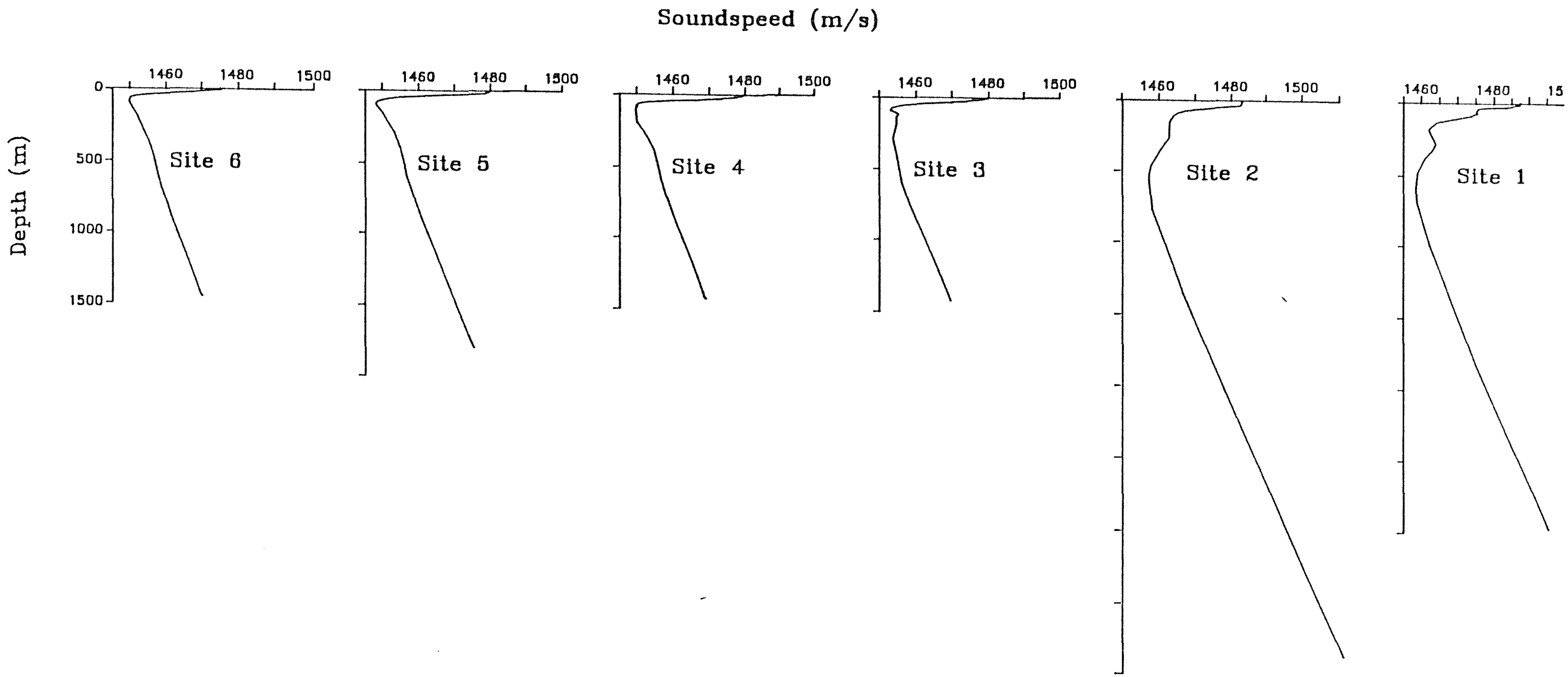

Soundspeed (m/s)
Depth (m)
1460
1480
1500
0
500
1000
1500
Site 6
Site 5
Site 4
Site 3
Site 2
Site 1

Fig 2

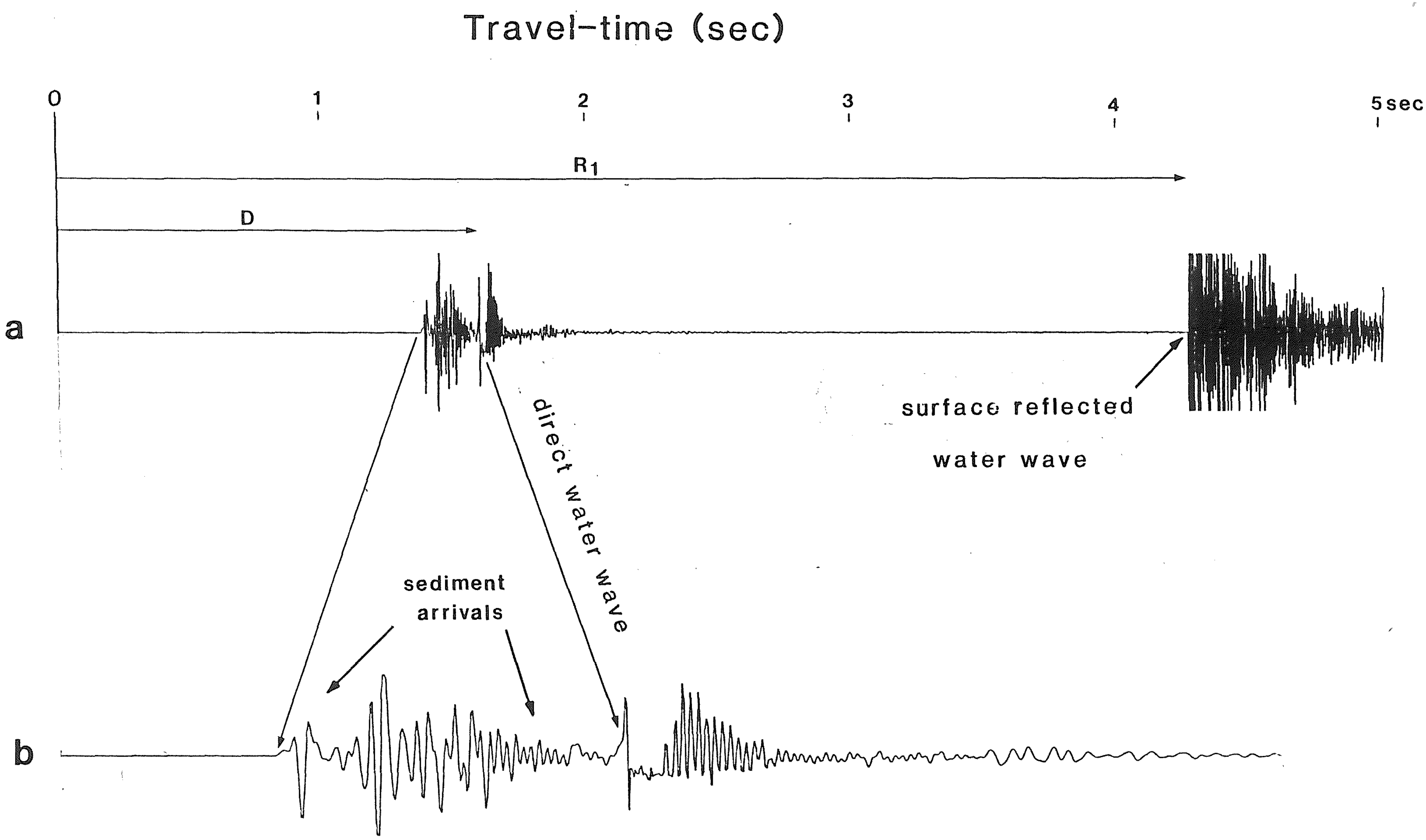

Travel-time (sec)
0
1
2
3
4
5 sec
R1
D
a
b
direct water wave
surface reflected
water wave
sediment
arrivals

Fig 3

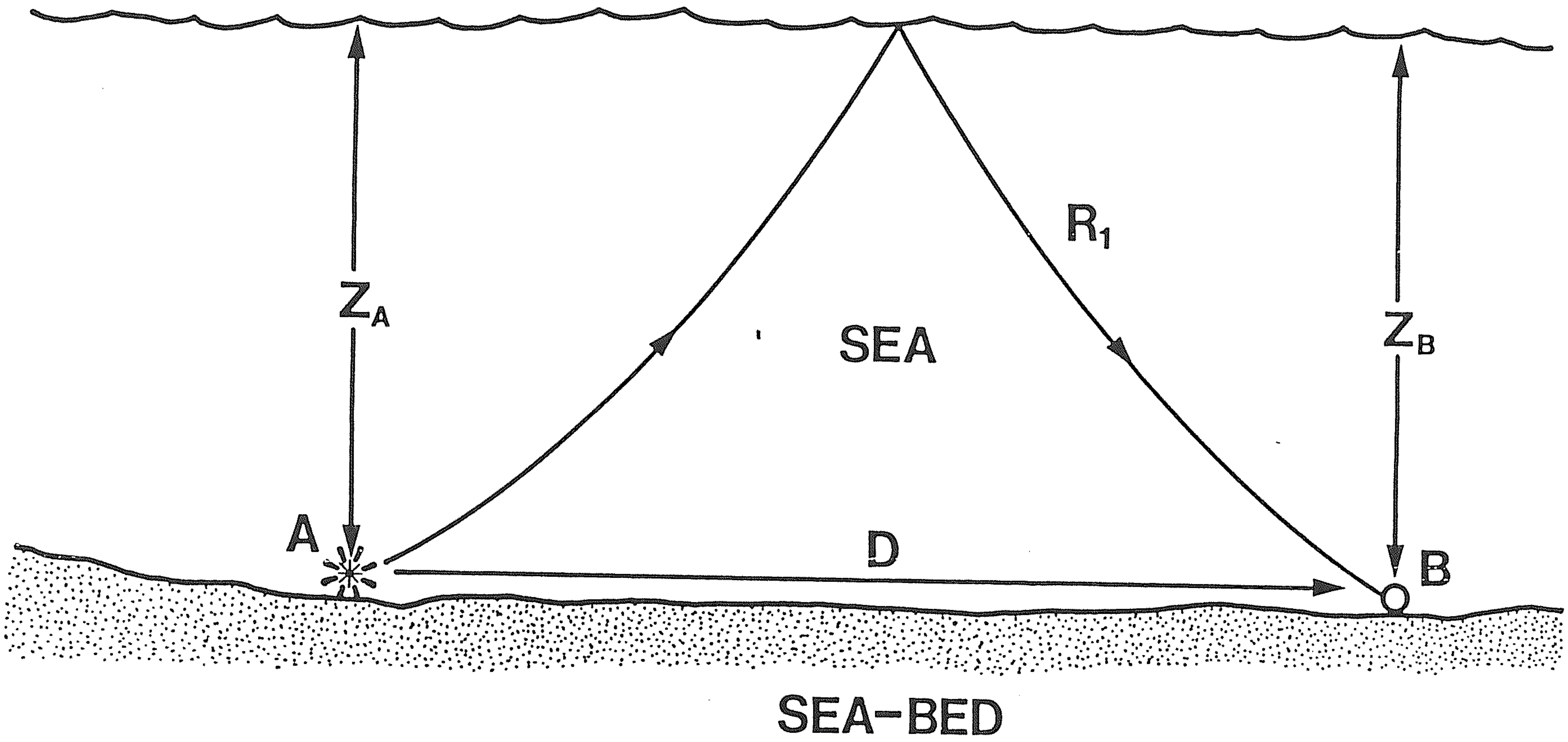


Fig 4

Site 1

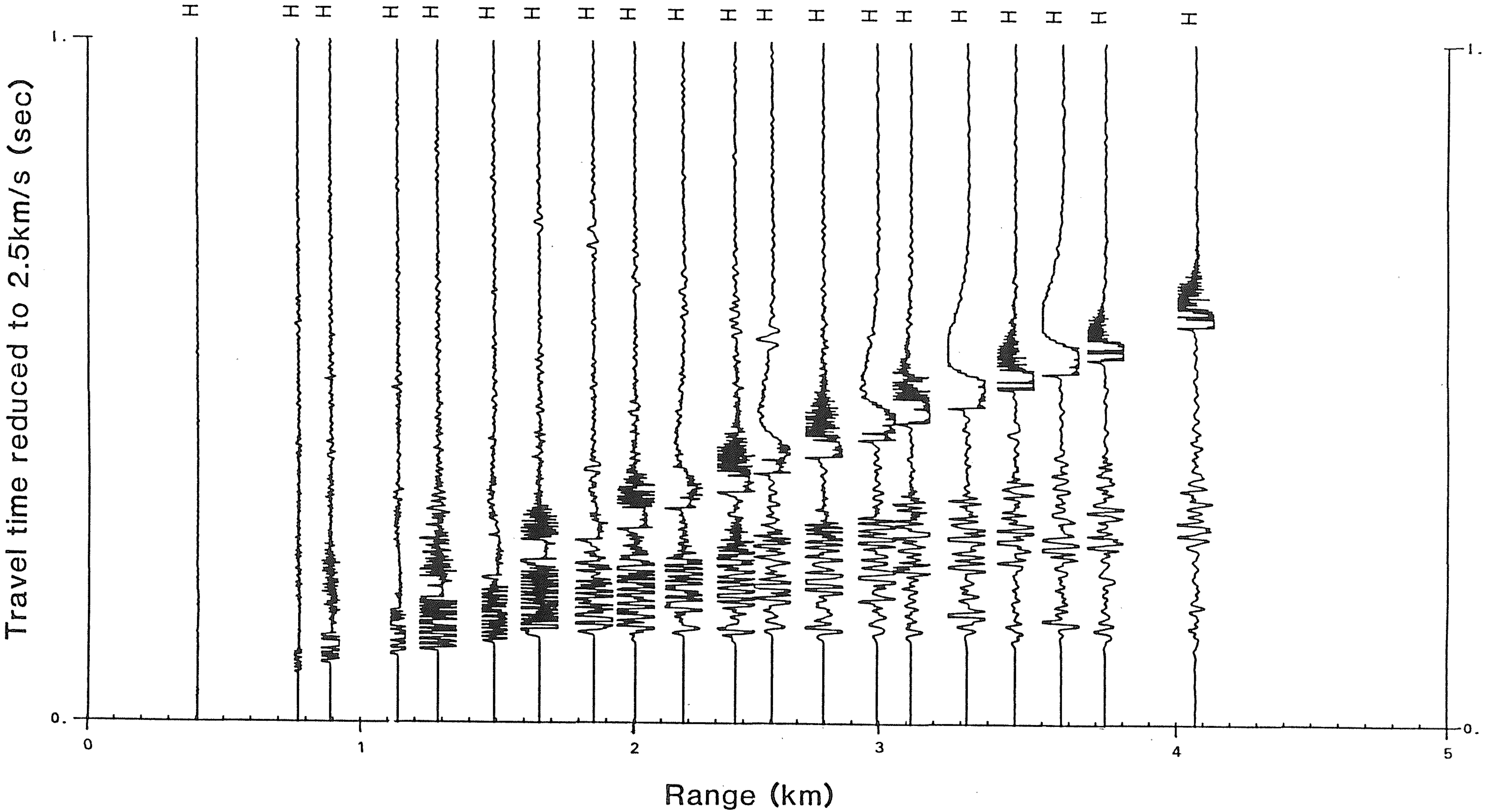


Fig 5

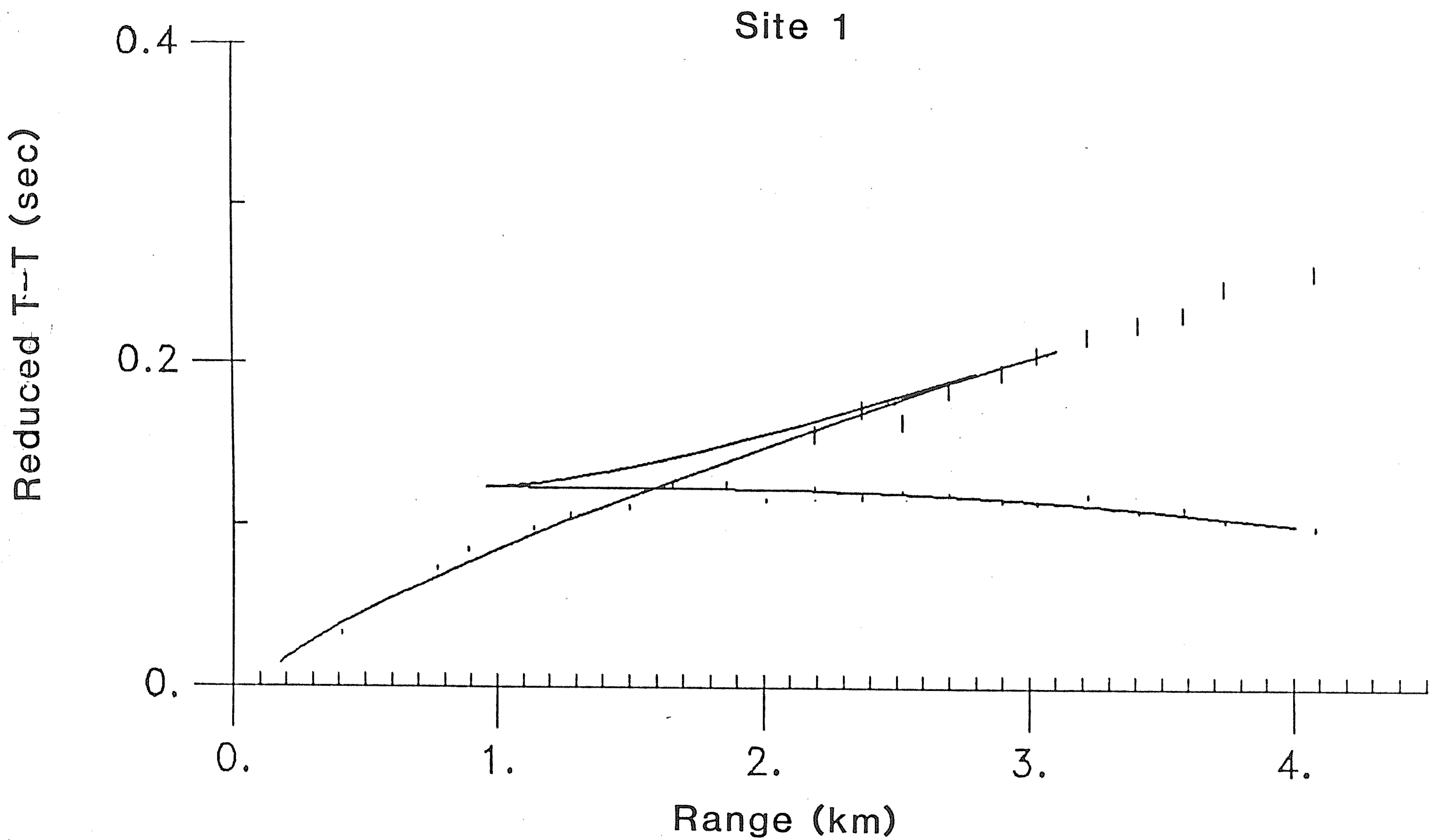


Fig 6

Site 2

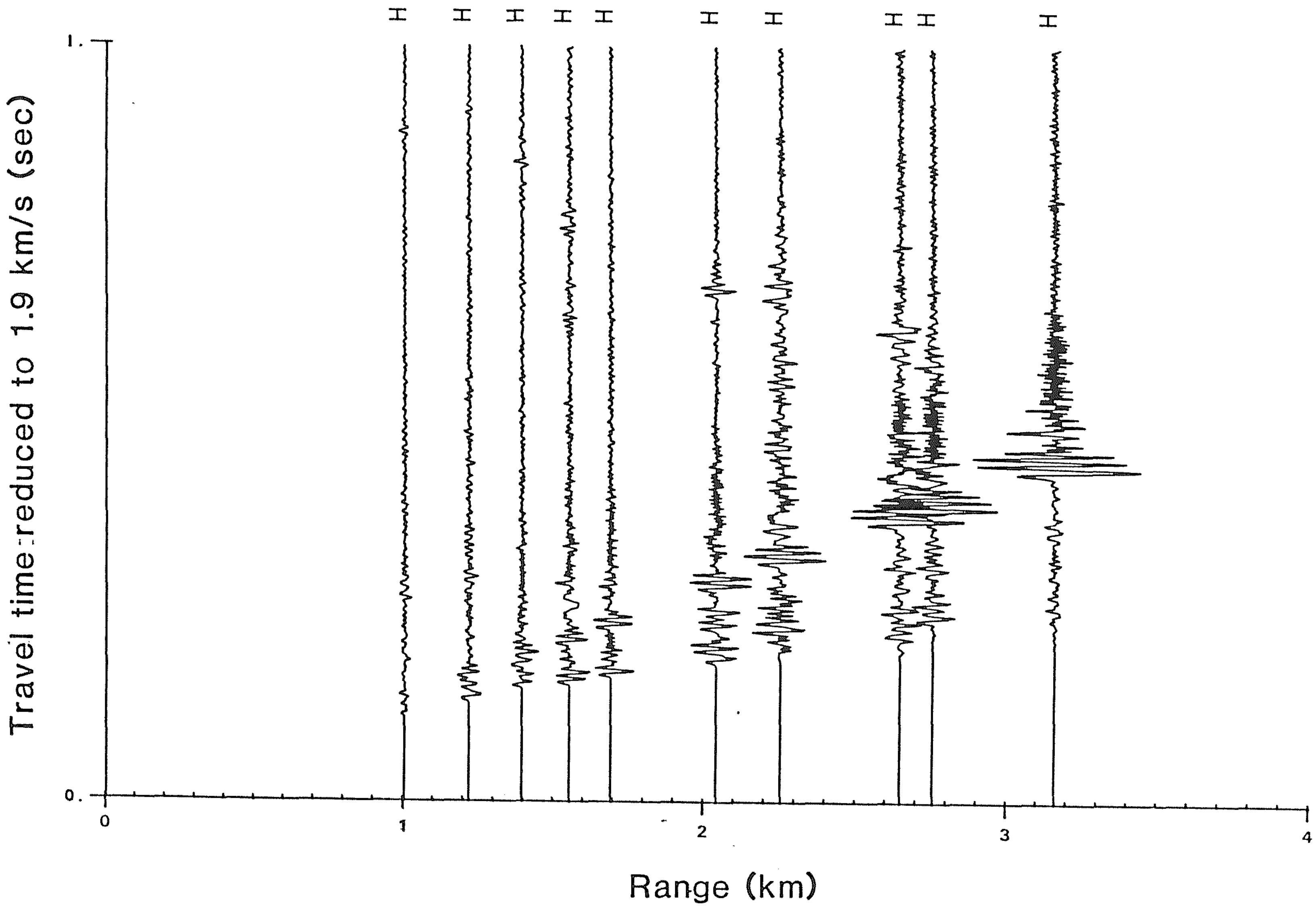


Fig 7

Site 2

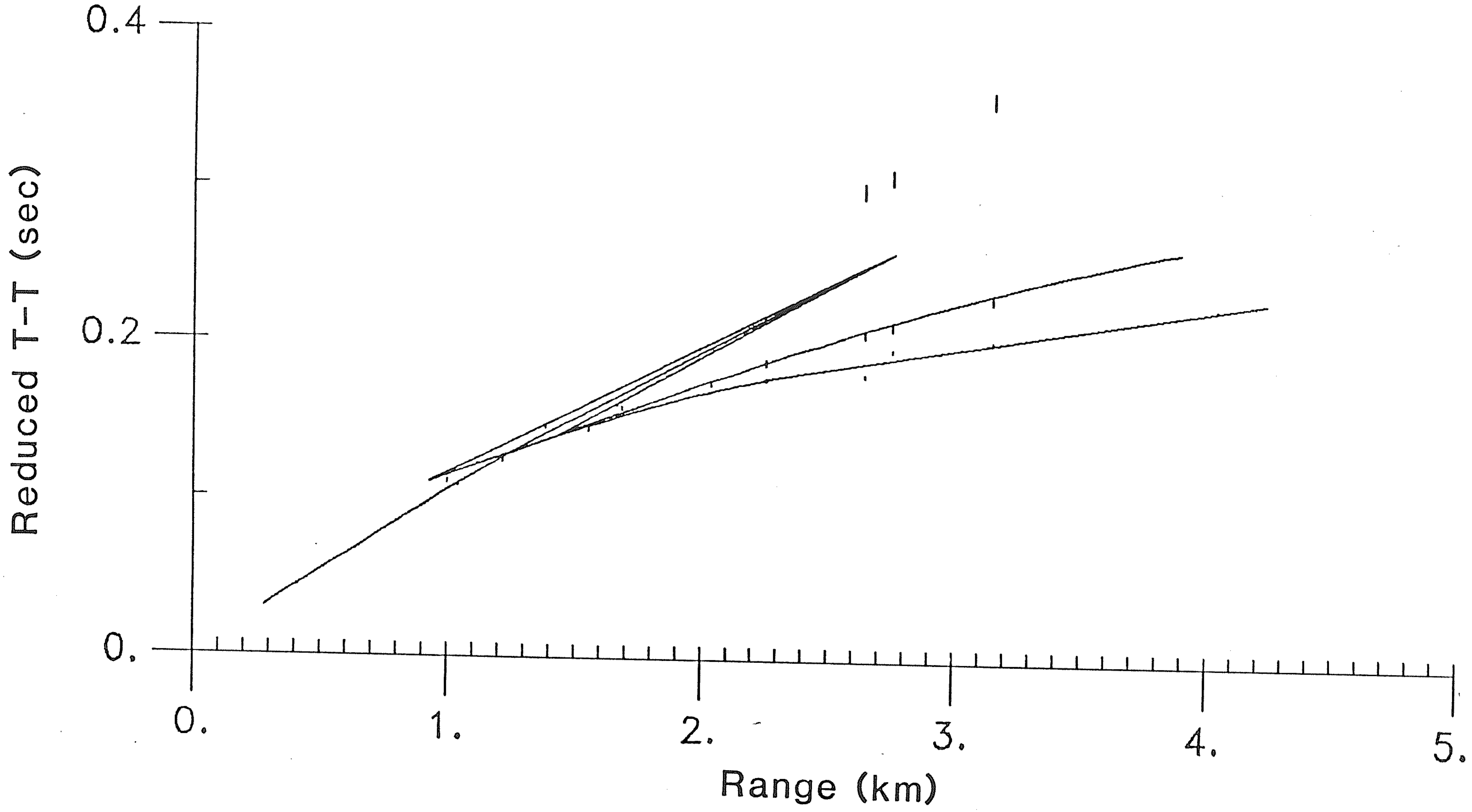


Fig 8

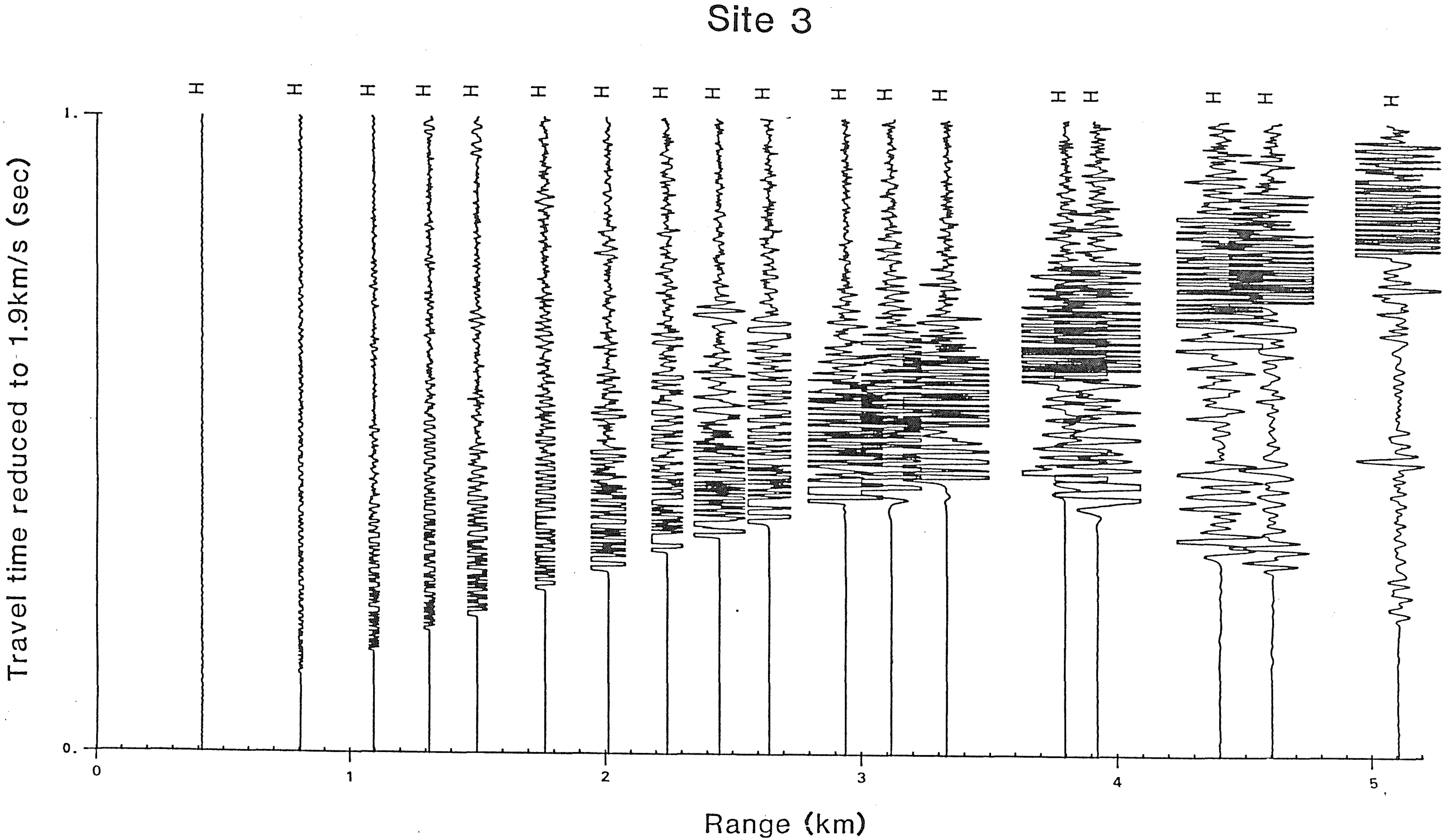


Fig 9

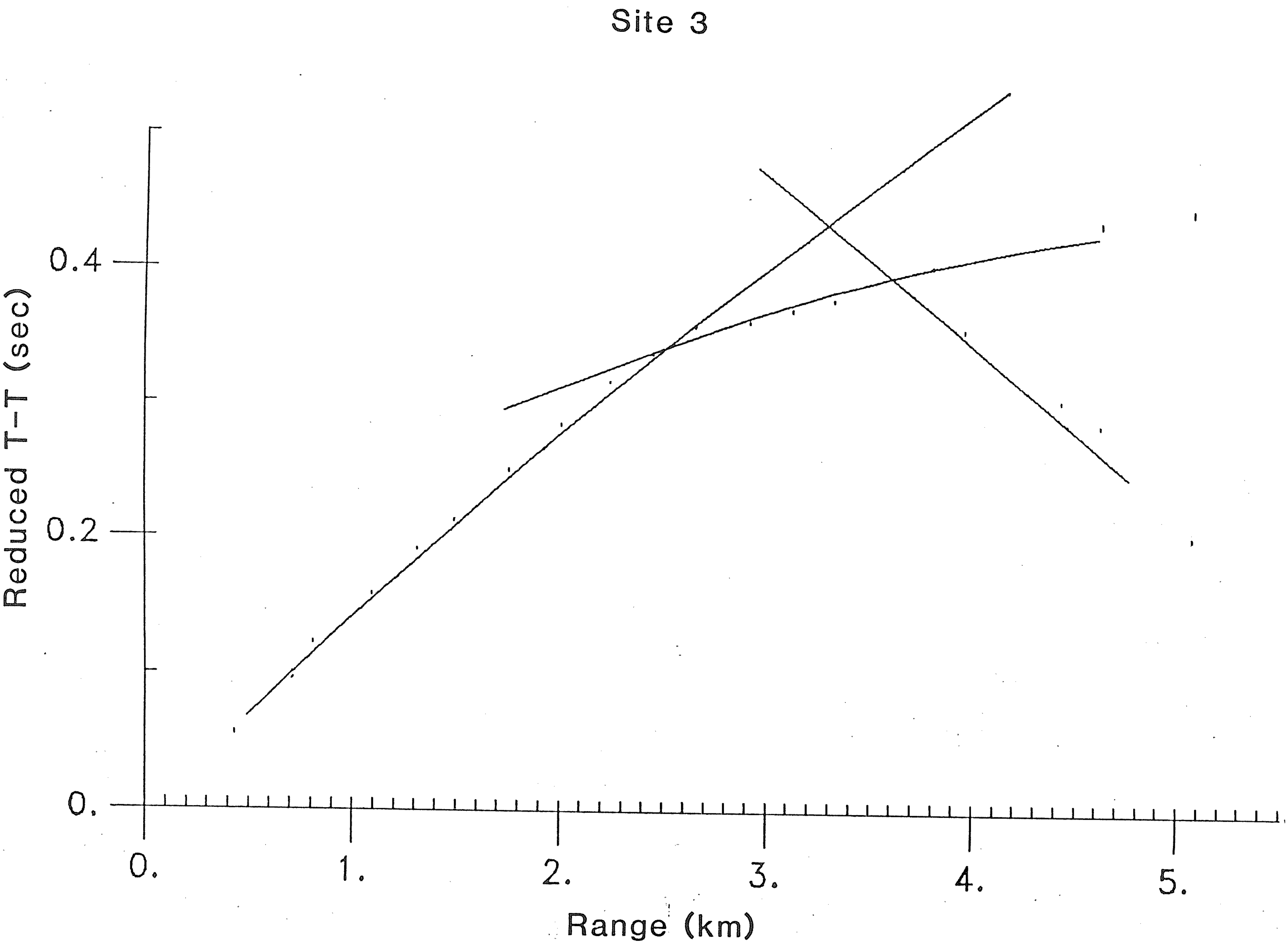


Fig 1(

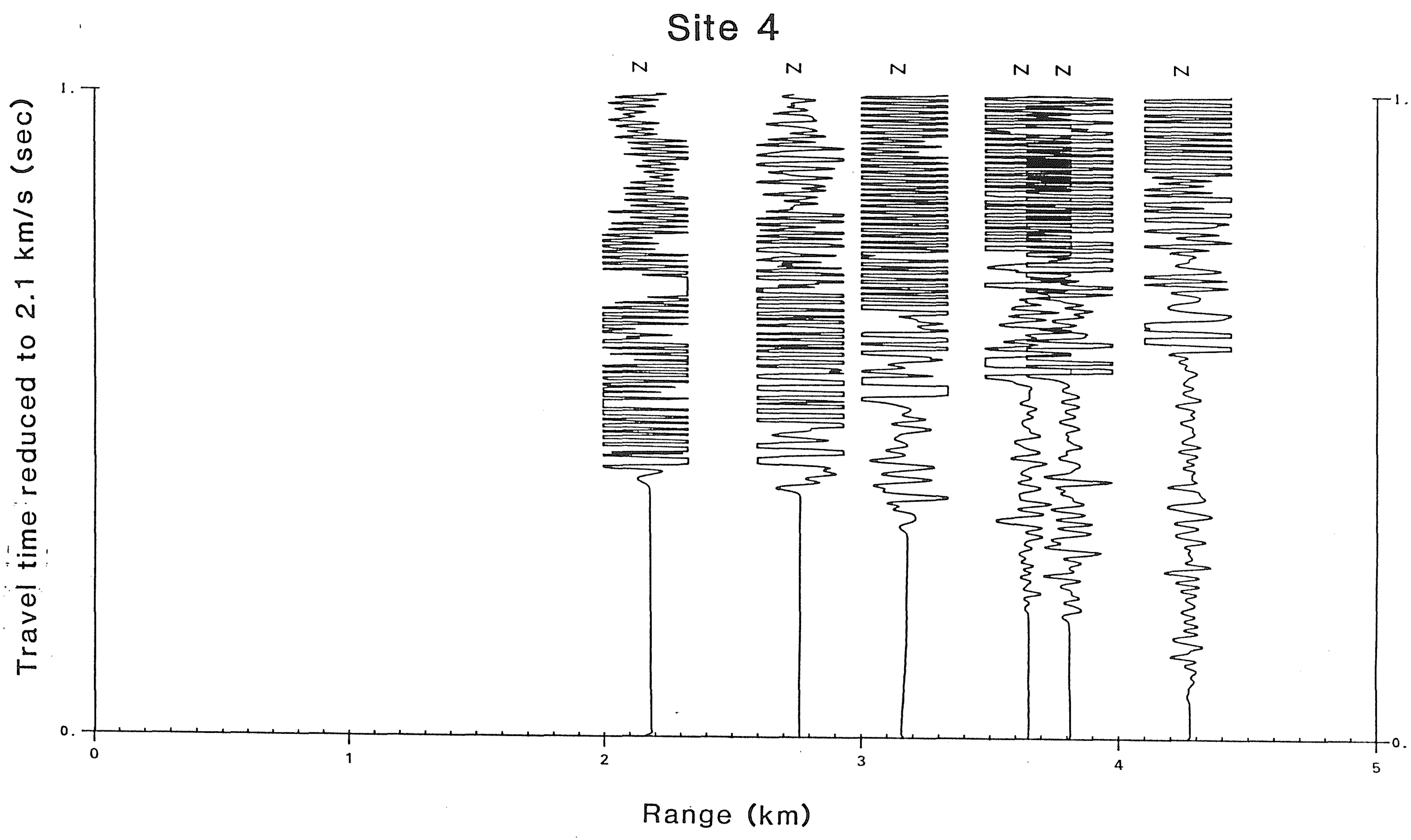

Site 4
Z
Z
Z
Z
Z
Z
Travel time reduced to 2.1 km/s (sec)
1.
0.
0
1
2
3
4
5
Range (km)

Fig 1

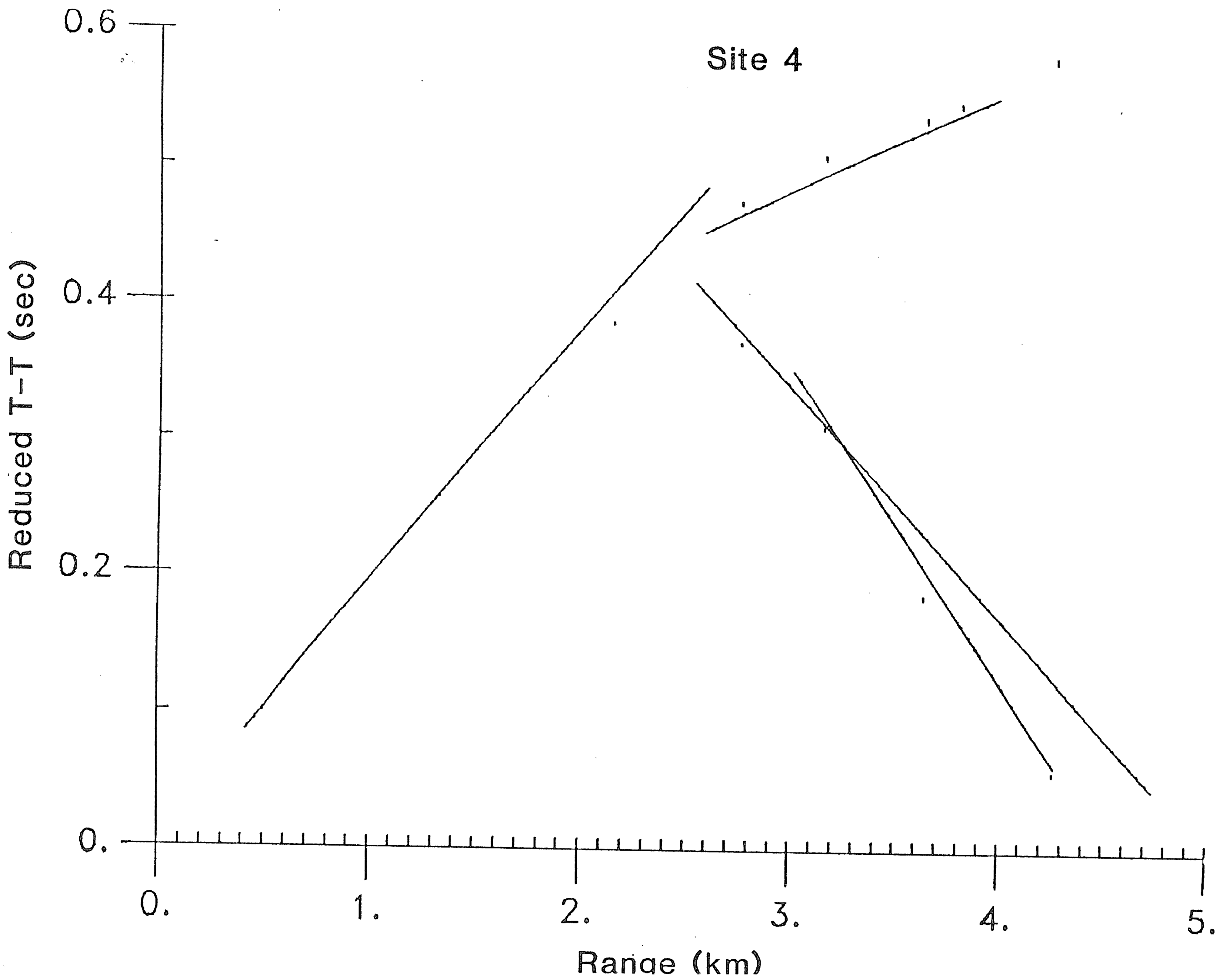


Fig 1

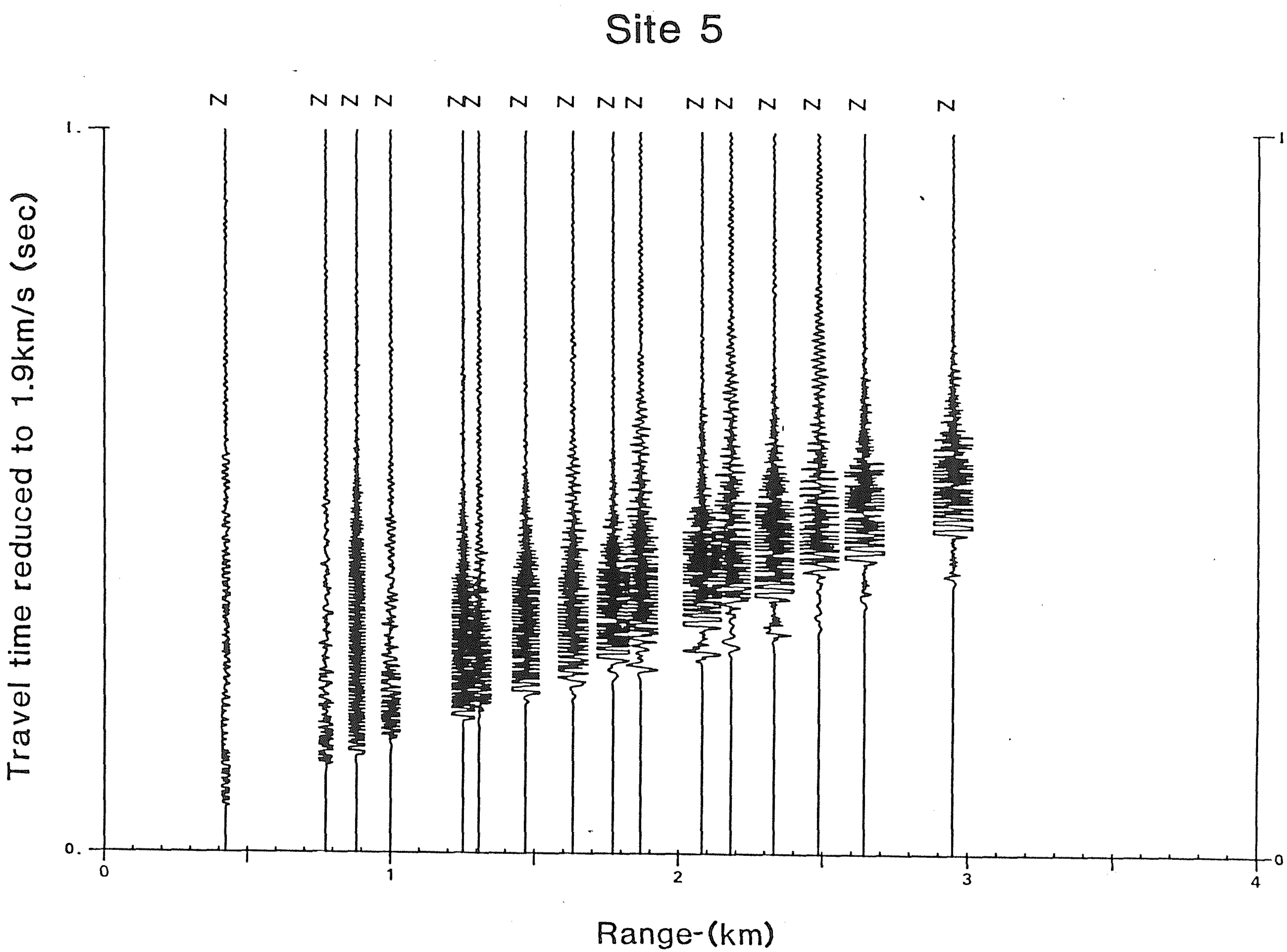


Fig 1

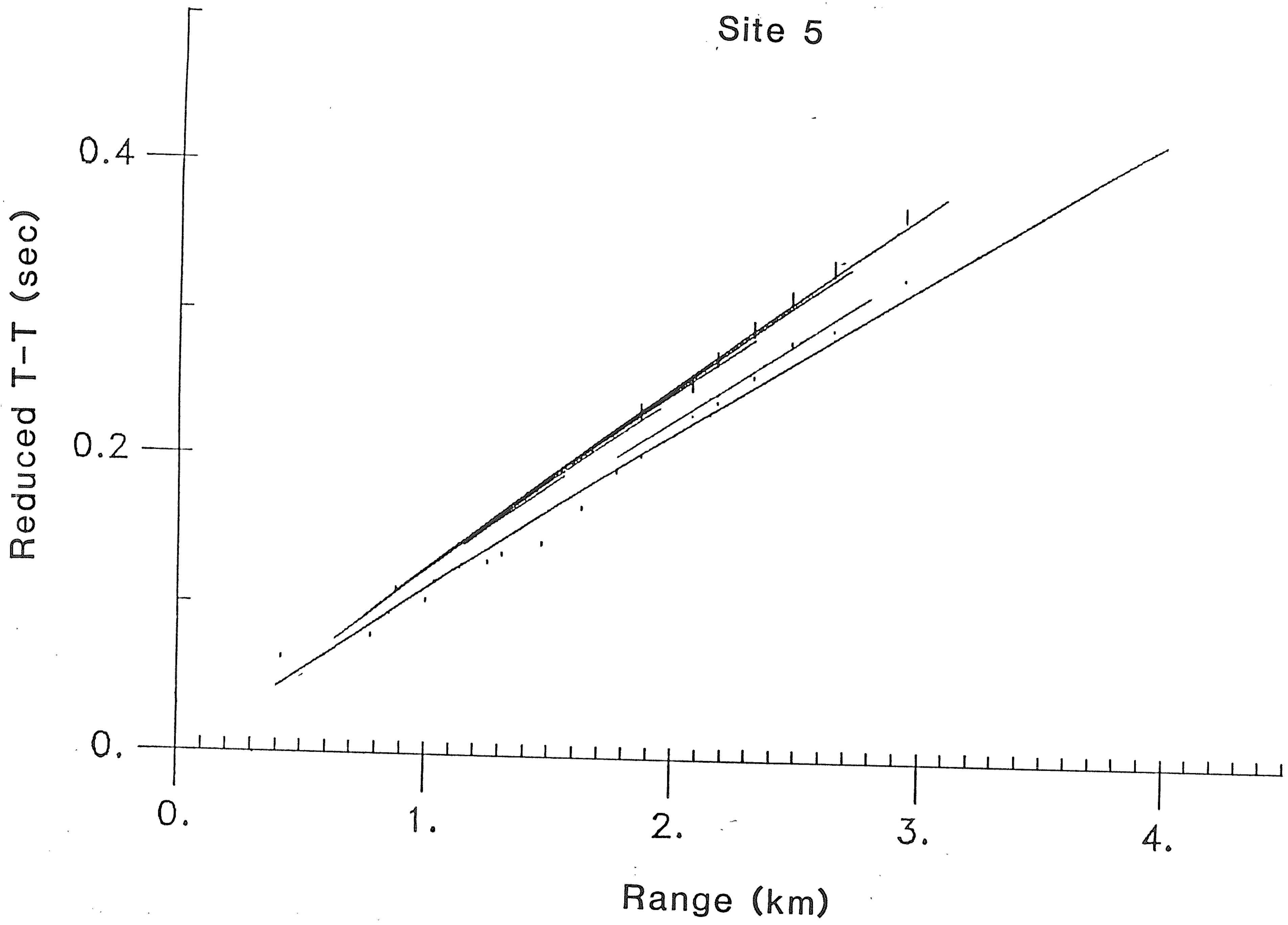


Fig 14

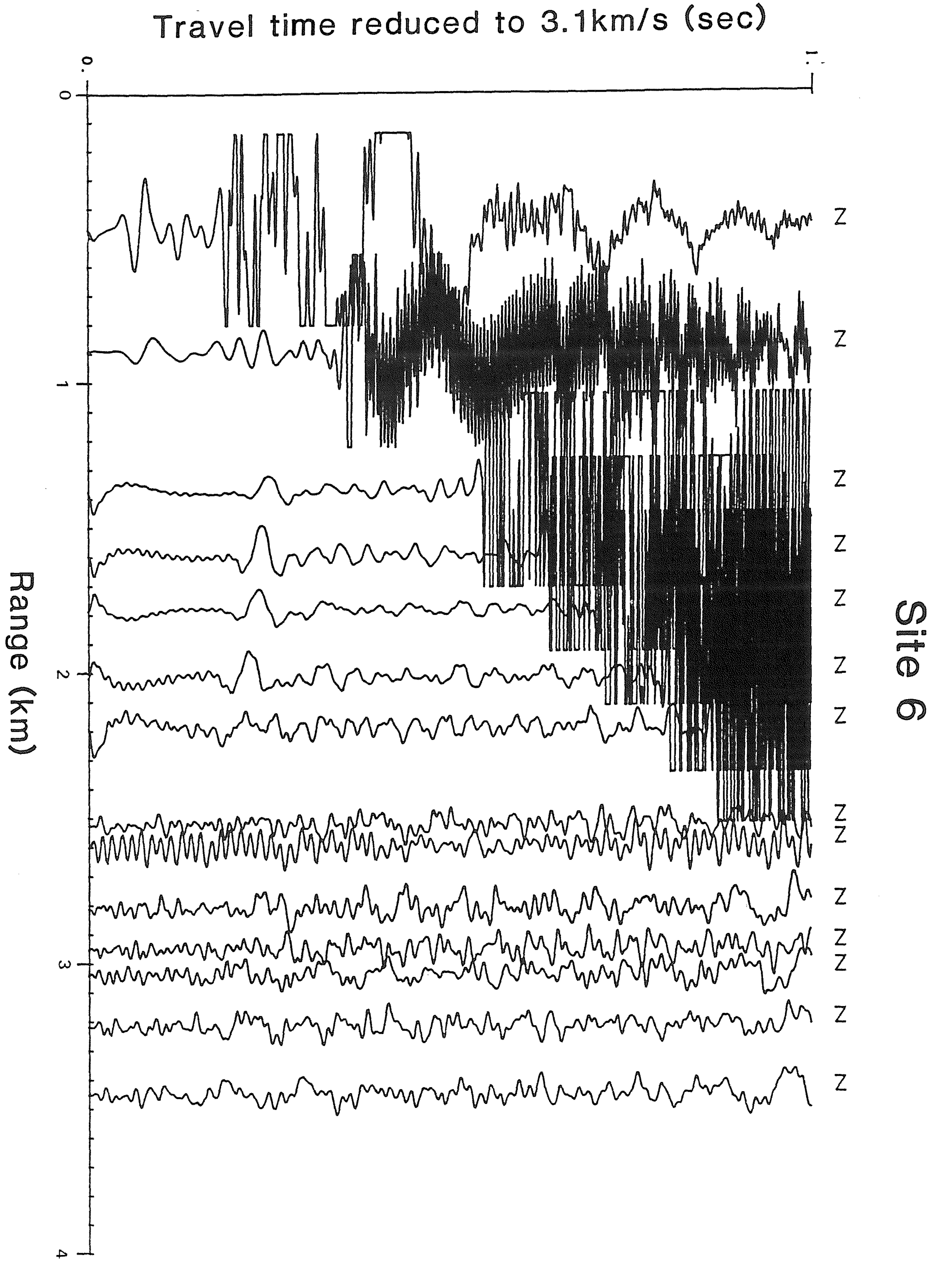


Fig 1

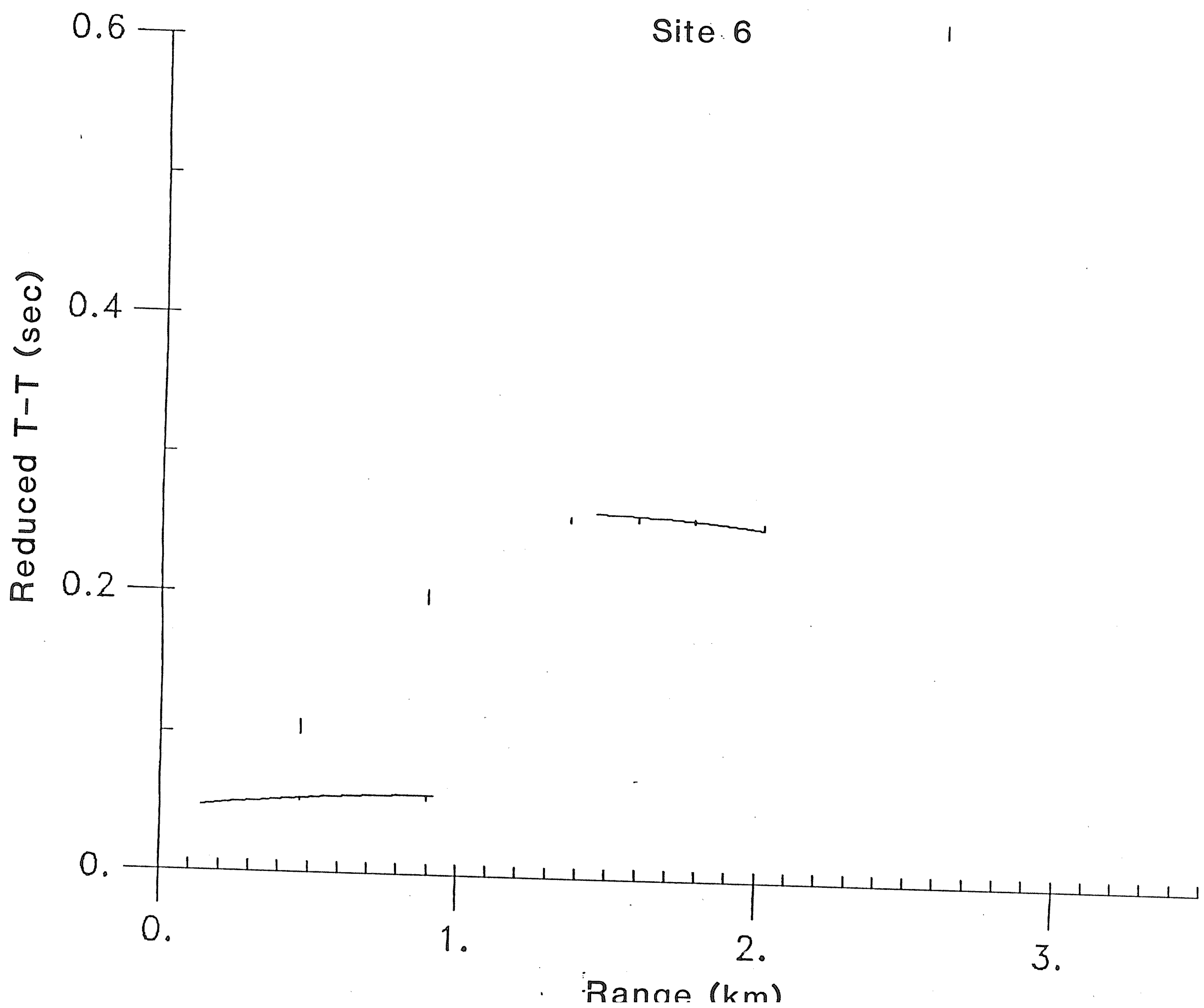


Fig 1

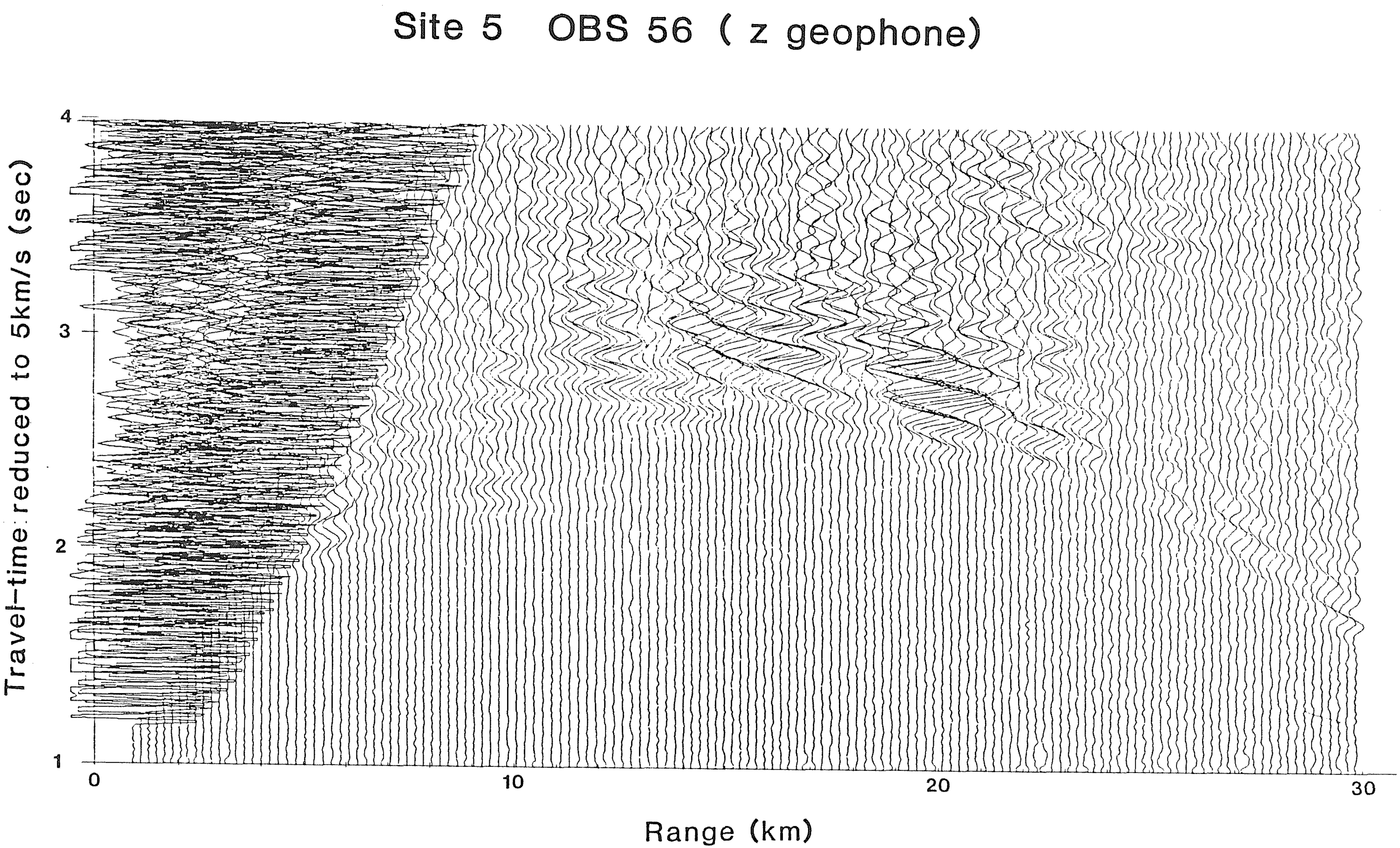
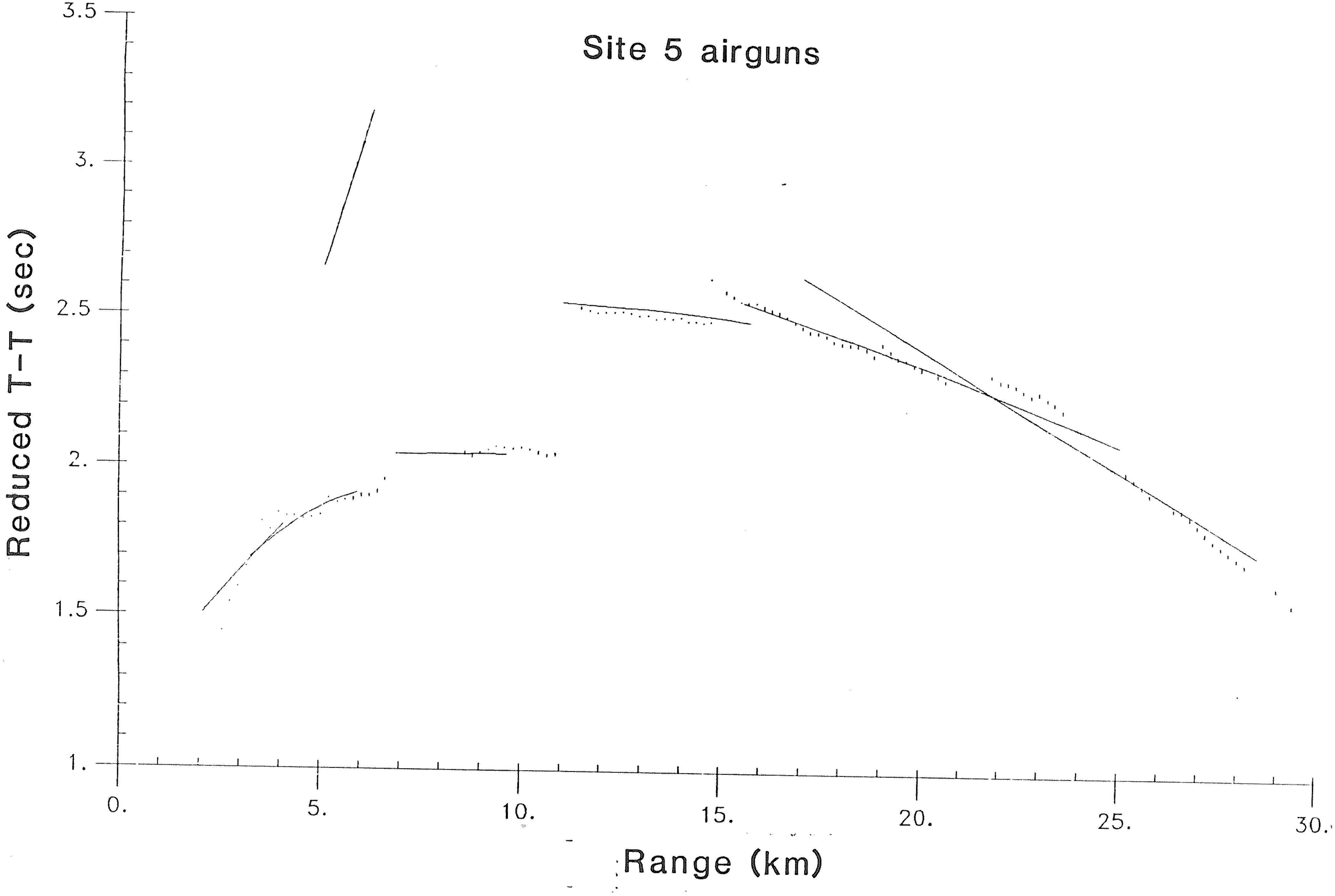

Site 5 OBS 56 (z geophone)
Travel-time reduced to 5km/s (sec)
4
3
2
1
0
10
20
30
Range (km)

Fig 17



Site 5 airguns
3.5
3.
2.5
2.
1.5
1.
Reduced T-T (sec)
0.
5.
10.
15.
20.
25.
30.
Range (km)

Fig 18

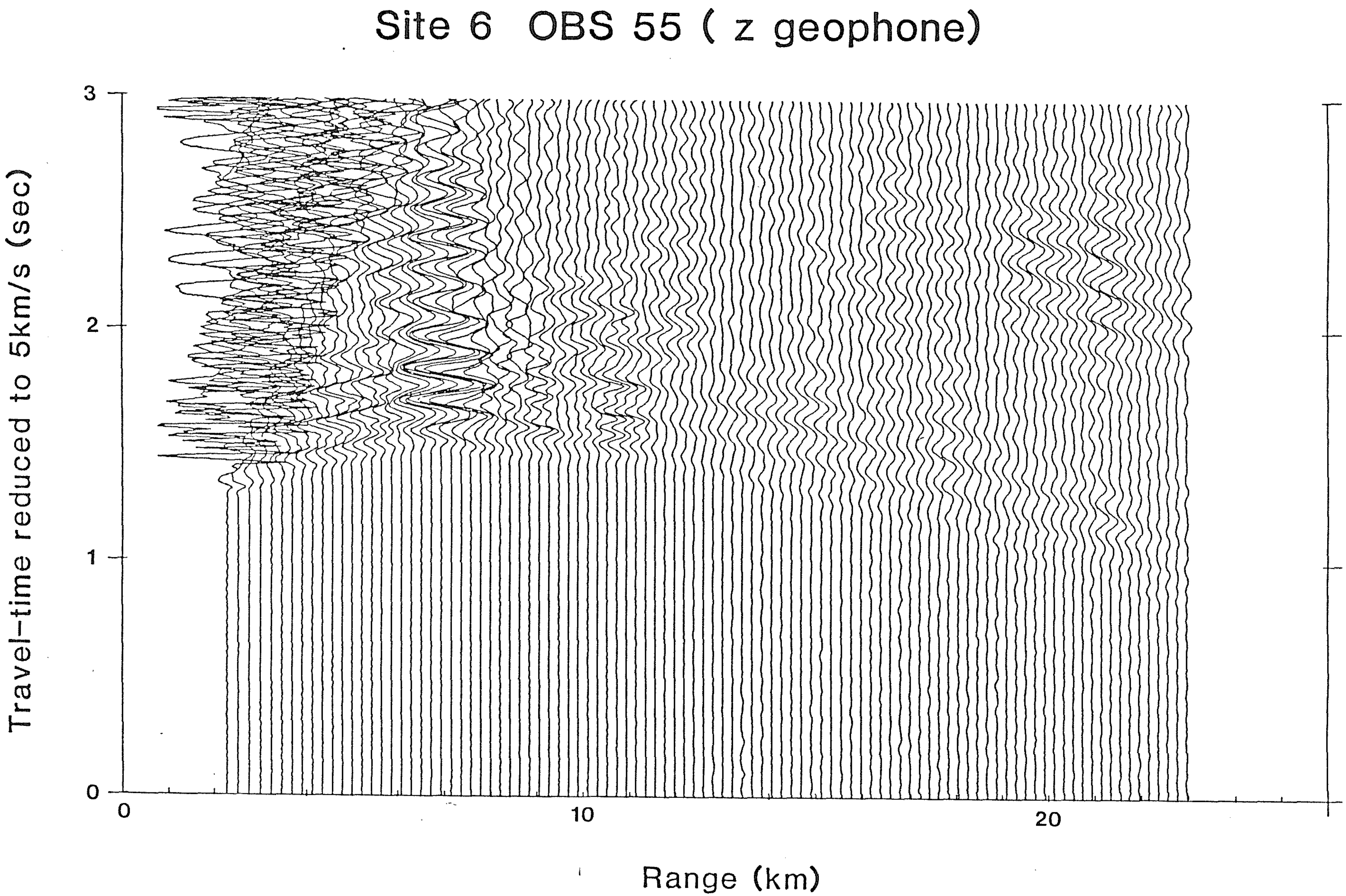

Site 6 OBS 55 (z geophone)
Travel-time reduced to 5km/s (sec)
3
2
1
0
0
10
20
Range (km)

Fig 1

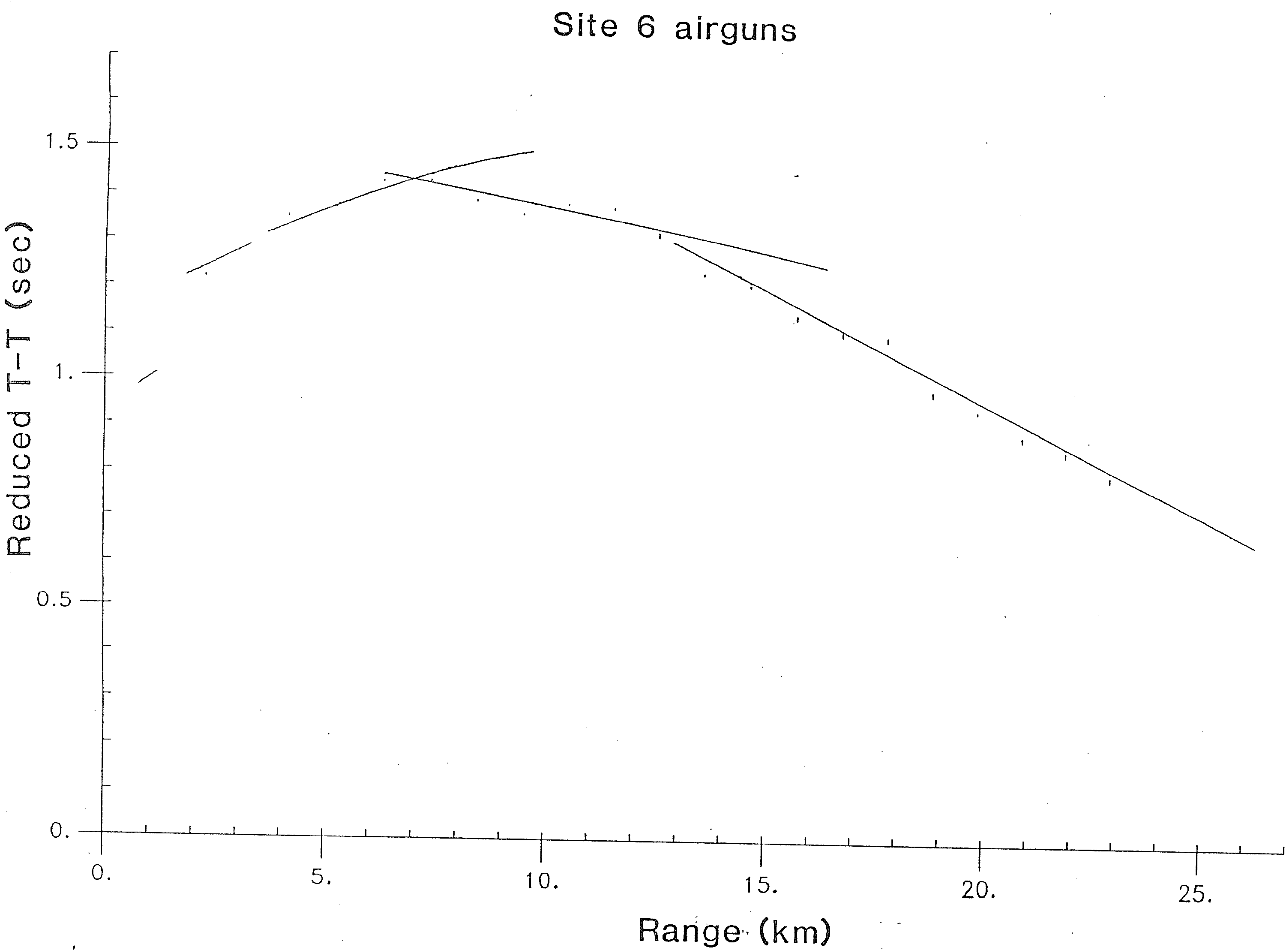


Fig 20

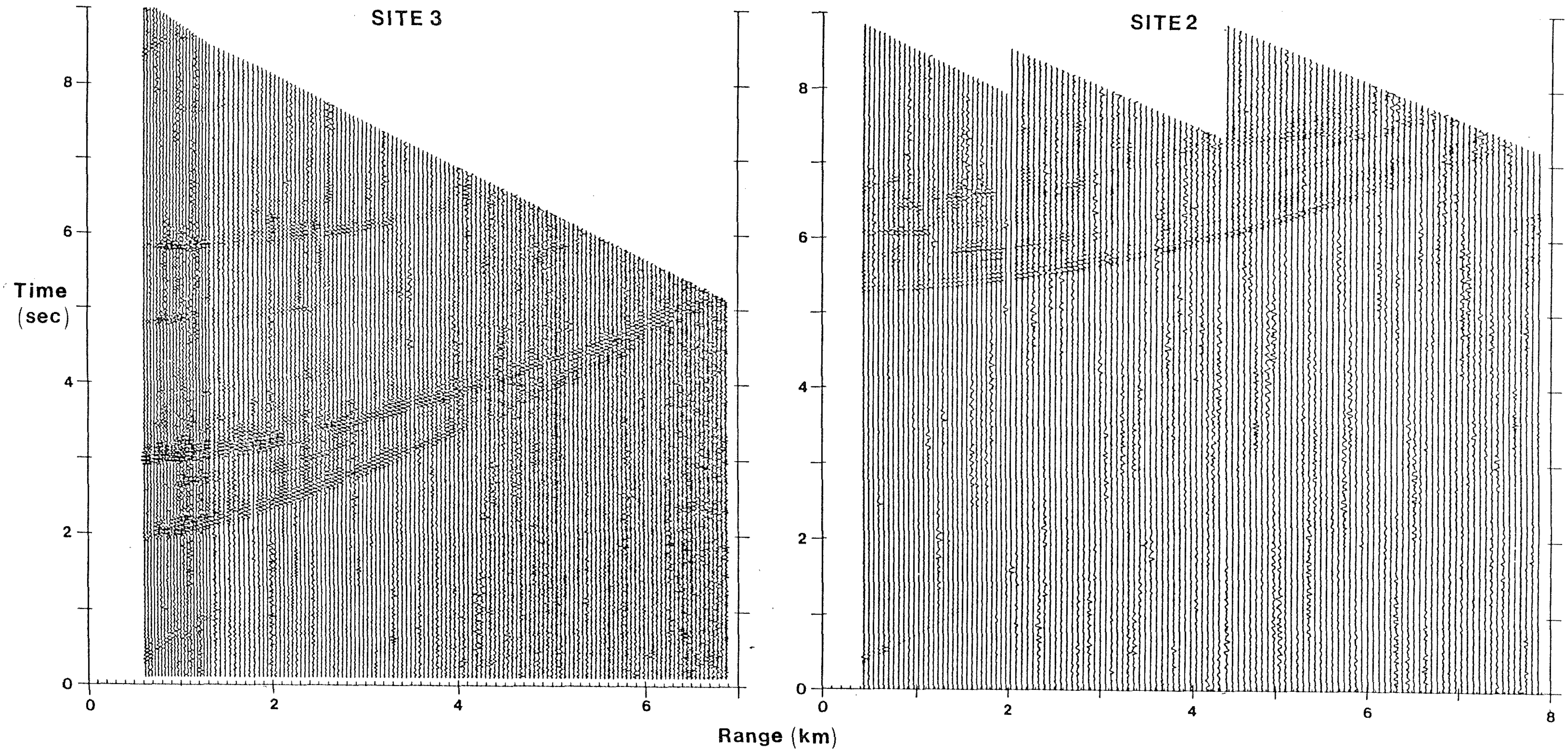


Fig 21

TABLE 1

Bottom Shot Preliminary Travel-Time Model Velocities

Site	OBS Water Depths (m)		Sub-Bottom Depth (m)	Velocity (kms^{-1})	Site	OBS Water Depths (m)		Sub-Bottom Depth (m)	Velocity (kms^{-1})
	OBS 55	OBS 56				OBS 55	OBS 56		
1	2907	2907	0	1.55	4	1368	1384	0	1.47
			40	1.65				50	1.51
			110	1.70				200	1.55
			235	1.735				370	1.57
			235	1.900				370	1.80
			401	1.96				510	1.84
			1000	2.09				770	1.87
								770	2.65
2	3883	3884	0	1.47				980	2.69
			50	1.51				980	3.45
			200	1.55				1350	3.55
			350	1.57				1350	4.25
			350	1.70					
			450	1.74	5	1750	1754	0	1.52
			500	1.76				25	1.565
			500	2.50				90	1.585
			2000	2.78				265	1.610
								490	1.635
3	1422	1427	0	1.47				1000	1.655
			50	1.505					
			200	1.55	6	1402	1402	0	1.6
			350	1.575				40	1.61
			350	1.70				40	3.70
			560	1.785				130	4.00
			750	1.85				150	4.00
			1000	1.875				160	2.70
			1000	2.48				490	2.70
			2000	2.78				490	3.90
								525	4.15
								675	4.40
								1900	4.80

TABLE 2

Airgun Preliminary Travel-Time Model Velocities

Site 5 OBS Depth 1750m		Site 6 OBS Depth 1402m	
Sub-bottom depth (m)	Velocity (kms^{-1})	Sub-bottom depth (m)	Velocity (kms^{-1})
0	1.52	0	1.60
25	1.565	40	1.61
90	1.585	40	3.70
150	1.635	118	4.0
150	2.80	148	4.0
450	3.01	198	2.7
450	3.10	488	2.7
1400	4.25	488	3.9
2260	4.45	678	4.18
2260	4.92	1608	4.68
2500	5.08	1608	5.10
2500	3.00	1848	5.50
3450	3.00	2498	5.64
3450	5.15	3098	5.64
4400	5.60	3098	6.60
5500	5.80	3898	6.66
5500	6.38		
6250	6.65		
7250	7.00		
8000	7.10		
8000	8.25		

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