Bob White:

CAMBRIDGE

CRUISE REPORT

SHACKLETON 1/80

GULF OF OMAN

JANUARY, 1980.

CRUISE REPORT SHACKLETON 1/80

Dates	30 December 1979 to 28 January 1980
Ports	Bombay, India to Karachi, Pakistan
Weather	Excellent. Force 1-3 with very calm seas

Scientific Personnel

Cambridge:
K E Louden, principal scientist
R S White
M Mason
M Rayner
P Barton
I Hutchison
J Duschenes

RVS
P Mason (electronics, acoustic release, shot firer)
S Smith (airgun, shot firer)
J Burnham (computer)

Other
B Rankin (Cornell University)
M Hussain (Pakistani observer)

Officers
S Mayl Master
P Coombs Mate
F Hammond CH Engineer

Crew
F Williams Bosun

Agents

Messrs Killicks Nixon Ltd
Killick House
Charanjit Rai Marg,
P O Box 109
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APPENDICES

FIGURES

Narrative

1. Preliminaries: 30 December - 3 January

On 30 December 1979 the Shackleton left Bombay and headed toward Karachi against strong winds and the only rough weather of the cruise. On 1 January 1980 explosives were loaded (see appendix VII) along with the PSO. We left Karachi at 1600 on 2 January heading for pt Of' (see fig 1). Scientific watches were begun at 2000 and the magnetometer streamed at 2100. On 3 January en route to Of' tests conducted on the explosive and fuse showed the fuse to be unreliable in water. Some slightly better results were obtained by covering it with a waterproofing compound and plastic tape, but this obviously did not bode well for the future. We also had some troubles in bench tests of the OBH release. At 1500 we arrived at pt Of' and wire tested the OBH to 1000m. We had no troubles with its release so the previous difficulties were probably caused by poor coupling between pinger and release on deck. The airgun was tested and its operating depths at various speeds determined. At 2100 the array (6 passive + 6 active sections) was streamed and we started profiling toward pt Of' along the offshore refraction line.

2. Offshore Refraction Line: 4 - 7 January

After finishing the reflection profile at pt Of' by 1600 on 4 January we deployed the OBH and S/B's according to plan (see appendix VII). S/B 4 did not transmit properly so it was retrieved; there was a basement ridge near S/B 5+6 so we placed them slightly closer to S/B 3. The shooting on the following day (5 January) was troubled by many misfires and extremely variable flight times caused by the unsuitable fuse. We tried to retard the sinking rate by placing styrofoam, which was a remnant of the packing[1], into the boxes in which the explosive was packed. Until we determined the proper amount of this, we had some floating shots. Shot No with a 96 in fuse went off in 36 sec and caused a serious shock to the ship which was the only dangerous incident of the day. We recovered the OBH which surfaced in 40 mins from its depth of 3 kms. We finished recovering the S/B's by 0400 on 7 January. The rather long time required was caused by the severe drift of the instruments (see fig 4): S/B's 1, 2 drifted far to the S while S/B's 5, 6 went NW. S/B 5 had a weak transmitted signal and S/B 6 had a bad hydrophone which we replaced. We took SVM measurements[2] after experiencing some difficulties with the connection to the end of the STD cable.

Afterwards we tested the heat flow probe which worked well except for the rather poor signals from its 12 kHz pinger. This was no doubt due to the rather sharp (high Q) response of the ship's 10 kHz PES recorder. We also retrieved a 1½ m core of green clay. Pullout of our 10 ft barrel was 3 - 4 x 10^3 kg and showed very nicely on the tensiometer. At 1500 we laid the transponder. We have only one to use as the second is not working and a third was lost during the previous cruise. We positioned this toward the S end of the detailed survey region, where the navigation will be most important in our search and experiments over a seismic "bright spot" which we hope is located just seaward of the outer fold.

3. Detailed Survey + Heat Flow: 8 - 14 January

We started the detailed survey at 1800 on 7 January using the 160 in^3 airgun, and beginning first with the N-S lines at the W end. We located a bright spot just outside of the frontal fold with a diameter of 3 nm. This is where we will concentrate our later work. We extended the N-S profiles until we reached the final shelf ledge which completely masked the buried folds. This was well outside of the transponder range of 15 - 20 nm at the best of times but we used radar sightings off the coast to help the Sat. Nav.

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[1] of the scientific gear

[2] To

While running the survey we tried using the sparker system simultaneously with the airgun to enhance high frequency signals in looking at the details of the shallow structure. This was not successful because the difference in the depths of the two independant systems meant that the arrivals were not coincident. This could lead to complicated interference ffects which would be difficult to interpret. Instead we used high frequency filters on the raw airgun signals and displayed this using the spare(RVS)EPC recorder. There was a surprisingly large high frequency component which allowed for a fairly clear, high resolution picture of the uppermost sediments.

The topography within the detailed survey is certainly lineated E-W except that it becomes more complex in the E sector. The gross structure is that of 3 well developed benches[1]: the frontal fold, a middle bench, and an upper bench leading up to the final shelf ledge. Toward the coastline there are deep N-S channels which cut through the E-W topography.

Eventually we completed 10 N-S and 8 E-W lines, (see fig 2) and 3 disposable S/B's - one each in the upper and mid- benches and one along the axis of the frontal fold. Two disposable S/B's over the bright spot were unsuccessful. Midway through the survey we returned to refresh the batteries in the transponder, at which time the connecting cable from the batteries to the transponder gave some initial problems. At that same time as we brought in the array, several sections had been badly damaged by shark attacks. We reduced its length to 2 active sections to reduce possible subsequent damage.

On 14 January we ended the survey and went to do a heat flow profile across the bright spot. Unfortunately the transponder quit at this time and unsuspectedly strong N-NE currents (0.5 kts) kept us from taking an even set of measurements. We bent the longer (4+m) barrel and replaced it with a shorter one (3+m). It was impossible to get much out of the pinged data as recorded on the PES even in flat calm seas. After taking heat flow stations 1 - 5 (see fig 3) and one core, we returned to pick-up the still silent transponder. I was glad to have insisted that a radar reflector be affixed.

4. Inshore Refraction Profile: 15 - 17 January

On 15 January we profiled W to E along the inshore refraction line (see fig 4) using the 300 in^3 airgun. A wide-angle disposable S/B profile over the flat sediments of the W end shows good refractors. Under these calm conditions we have increased the gain of the disposables from the reduced levels which are normally used. This has increased the range at which one still observes the sediment refractors.

At 1900 we dropped the OBH at the E end of the line (pt In') and then headed back to pt In while deploying 4 S/B's - No's 1& 2 in the middle and No's 3&5 at the W end. We did not deploy a S/B near the OBH, because of the rough topography there and the expectation of its drifting a considerable distance off line before beginning to shoot. On 16 January we shot the profile according to the schedule in appendix VII, but once again with many misfires of the larger shots. We tried to buoy the 200 kg shots using spare metal cans and disposable S/B tubes but unsuccessfully. We had to use extremely long fuse lengths because of the possibility of rapid burning as on the previous line, and thus could only single prime the charges. The only shots to go off with any regularity were the 25 kgs and these also had a very wide range of flight times.

We recovered the OBH without difficulty and then the 4 S/B's. These had drifted W along the line. No's 1&2 were difficult to find during the night because their new flashing lights had failed. The bulbs which were rather underrated in this new model had all blown, probably because of the warm weather. In this case it would help if reflector strips were affixed to the buoys to ease the visual sightings. One light on the remaining 2 buoys also failed but they were easy to recover during daylight on 17 January.

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[1] see fig 8

Some extra time allowed us to return to the bright spot to take 3 more heat flow stations, as 2 of the previous ones were unsuccessful. We also took 2 disposable S/B's over the same region to recover for the previous failures.

5. Heat Flow, Murray Ridge and Return: 18-28 Jan

On Jan 10 we took 2 heat flow runs at pt. V (stations 15-20 in fig. 3). This time we turned off the ship's engines and were finally able under these extremely quiet conditions to observe the data pings on the PES. We still have trouble breaking the bottom thermistor and occasionally dislodging the rubber connectors.

We then profiled V to Z and took a disposable S/B over the Indus Cone sediments, parallel and to the E of the Murray Ridge. On 22 Jan while recovering the array, the array winch failed and could only be partially mended. We then took heat flow stations 21-27 (fig. 3). We next profiled pts M to P. On 25 Jan with a few hours to spare we took a final core from the upper trench and tested S/B 4 which had not been working. We had intended to take more heat flow but the precision resistor[1] did not have a large enough range for the warmer, shallower water on the bench. On 26-28 Jan we finished the remaining reflection profiles (pts P to S) and arrived in Karachi at 1020.

In the end we had successfully taken:

a) 28 heat flow stations
b) 3 cores
c) 2 refraction lines using a total of 9 S/B's and 2 OBH's over 190 nm.
d) 9 disposable S/B's.
e) 400 hrs of reflection profiles (2400 nm).

We had occasional problems with most of the instruments, but the explosive misfires probably caused by the inappropriate fuse which was supplied, was the only failure that seriously detracted from our results. Even so we were able to satisfy all of our scientific objectives.

[1] In the Woods Hole Optical Heat Flow instrument, all the sediment thermistors are compared to a water thermistor located at the top of the core barrel.

Scientific Results

We achieved all the scientific objectives of the cruise, which were:

a. Find the crustal structure and the depth to the Moho beneath the Gulf of Oman abyssal plain and the Makran accretionary wedge, to test whether the crust is oceanic or continental and whether it dips northward beneath the Makran.

b. Investigate three dimensional structure of the ridges and intervening basins on the Makran continental margin using a closely spaced grid of continuous seismic reflection profiles.

c. Take heat flow measurements to constrain the age of the crust, which is otherwise unknown, and to assist in interpretation of the prominent gas hydrate - free gas reflectors found in the area.

d. Make a detailed seismic survey across a localized accumulation of gas to test whether it is trapped by a phase change to gas hydrate as has been previously postulated.

e. Continue the reconnaissance survey of the Makran margin eastwards to the plate triple junction near Karachi to see whether subduction deformation persists along the entire coast.

f. Survey the Murray Ridge, a prominent feature of unknown origin, using seismic reflection profiles, and underway gravity, magnetic and bathymetric measurements.

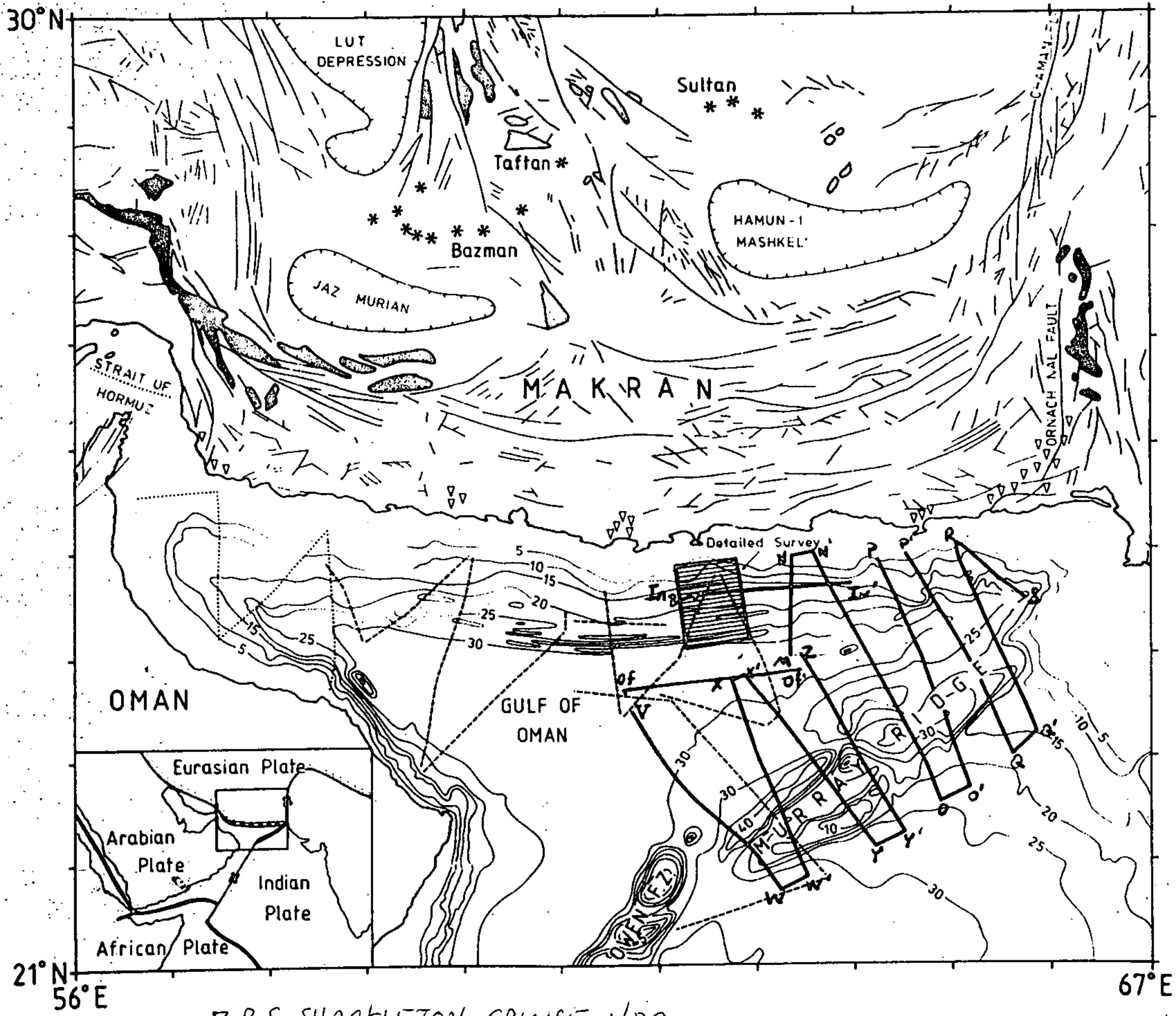
Despite the difficulties caused by the unreliability of the explosives, discussed in the narrative, the two seismic refraction lines yielded good Moho arrivals on most of the receivers, giving good control on the mantle velocity and depth. Locations of the lines are shown in Fig 1 and the detailed receiver configurations in Fig 4. Record sections from a number of the sonobuoys are illustrated in Fig 5, together with preliminary least squares fit straight lines to the first arrivals. In Fig 6 the travel times from the offshore and inshore lines are plotted and show that we only see arrivals from two main horizons: the consolidated sediments (velocity 3.9 to 4.5 km/sec), and the Moho (velocity 7.9 km/sec). Deeper crustal layers are masked by the thick sediment layer. These velocities and intercepts are translated into depth profiles in Fig 7, with a two layer crustal model on the left and a three layer model assuming a 'hidden' layer of velocity 6.8 km/sec on the right. Both models show the Moho dipping northwards at about 1½° as expected from our model of plate subduction under the Makran. The sediment pile becomes thicker on the inshore line due to accretion above the subducting plate. These results have been presented at the Hedberg conference in Galveston, USA in January 1981 and a written version is currently in press for an American Association of Petroleum Geologists Memoir.

The seismic reflection profiling system gave good results, thanks partly to the calm seas. An example of a profile across the margin is given in Fig 8. The detailed grid survey showed the accretionary margin to be well lineated, with a series of cross-cutting channels near the coast. The deformed sediment prism was traced eastwards, and was found to become more chaotic as the triple junction near Karachi was approached. Initial results from the reflection surveys have been presented at a conference organized by the Geological Society of London on Trench and Fore-Arc sedimentation in London in June 1980 and will shortly appear in a published volume of the proceedings.

The heat flow results (see appendix IX and fig 9) constrain the age of the crust beneath the Gulf of Oman to between 65 and 120 my, and confirm the temperature at the hydrate-free gas phase transition assumed in previous calculations. Implications of the heat flow measurements will be discussed at the UK Geophysical Assembly in April 1981 and in a paper in Earth and Planetary Science Letters. The bathymetry measurements made in January 1980 were incorporated into a new Admiralty chart of the Arabian sea published in April 1980; the previous new edition of this sheet was in 1874.

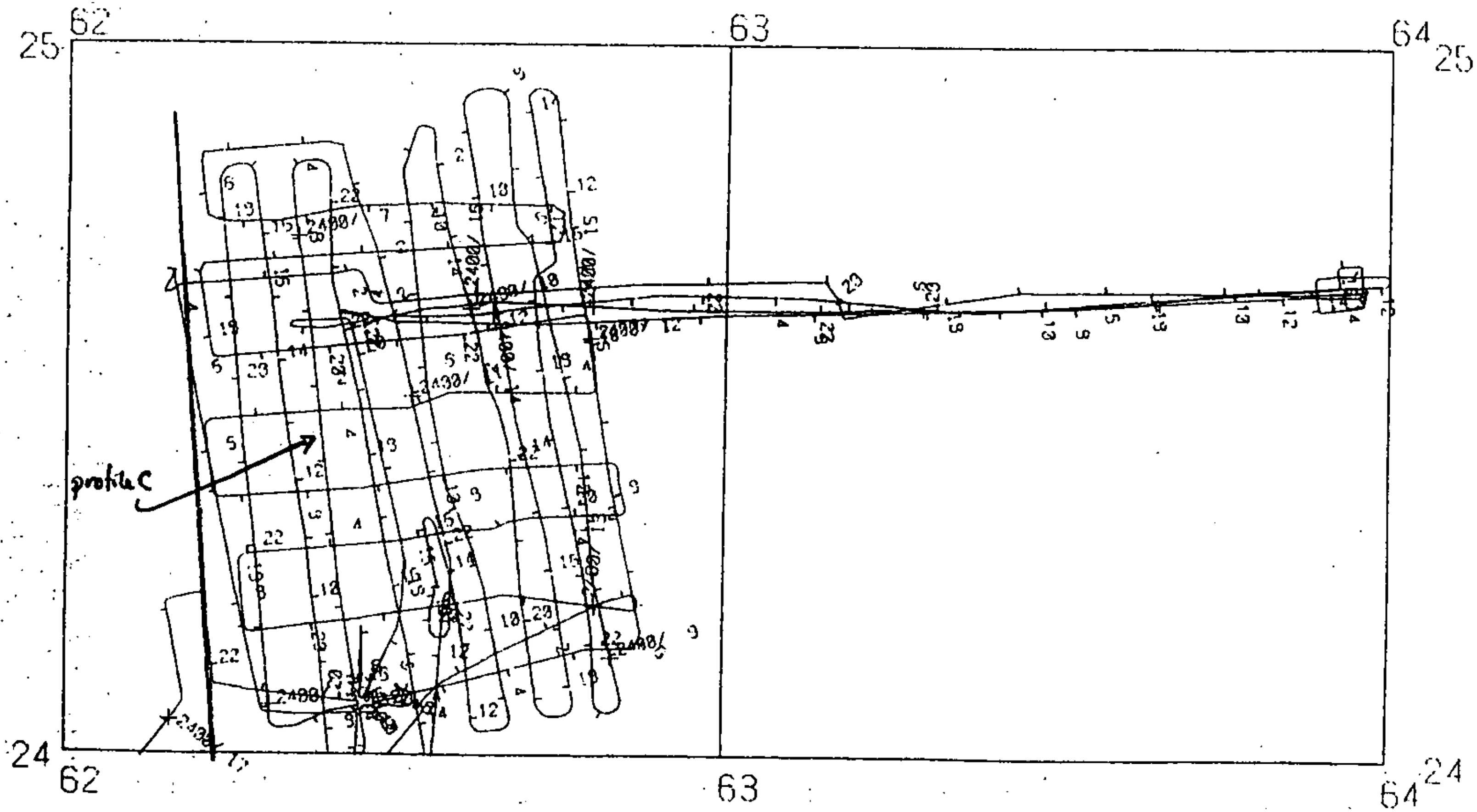
We are continuing analysis of the data collected on the cruise and expect to publish several more papers on the results including one on the deep structure deduced from gravity data and synthetic seismogram analysis of the refraction lines and another on the structure of the Murray Ridge.

Fig 1

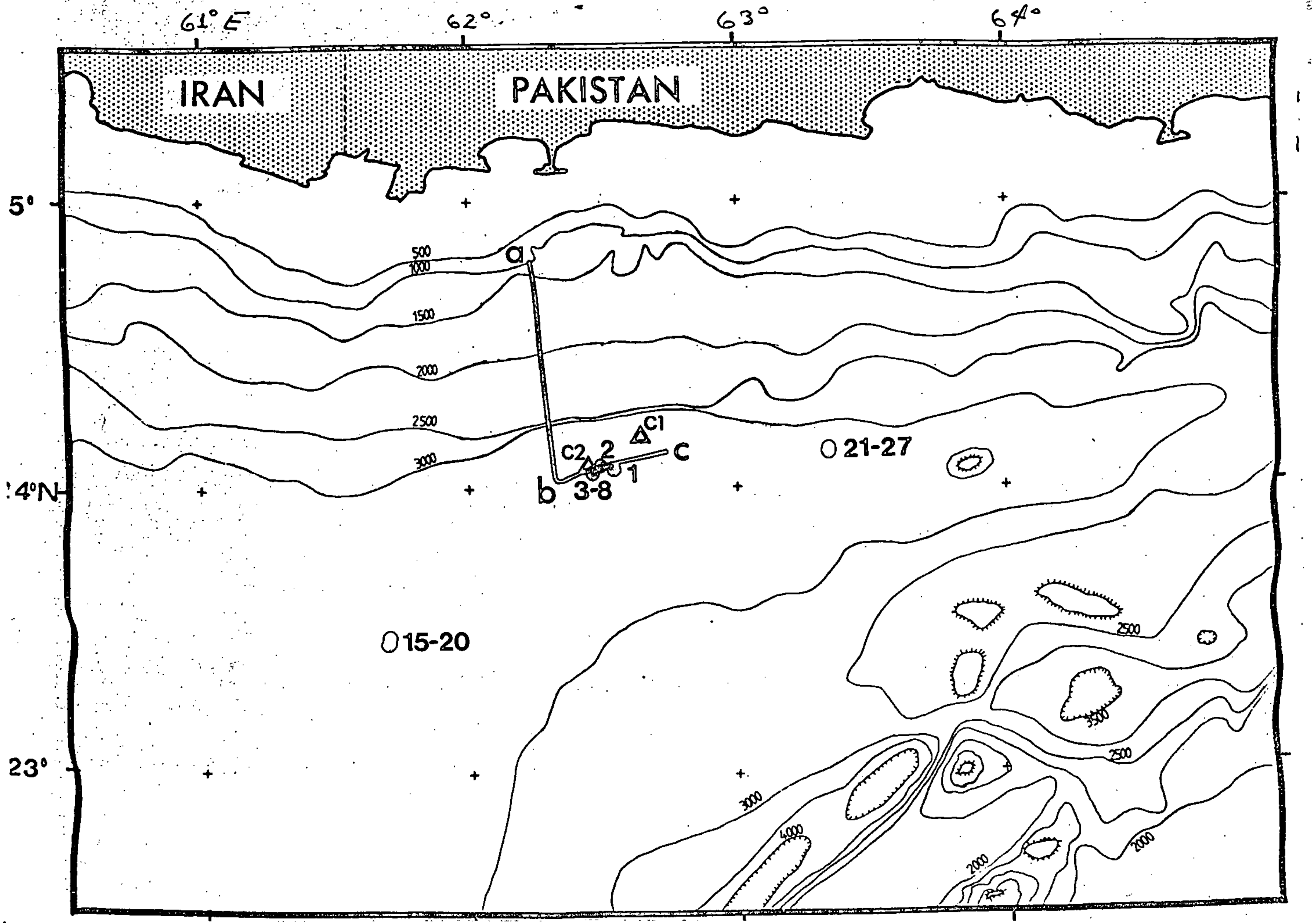


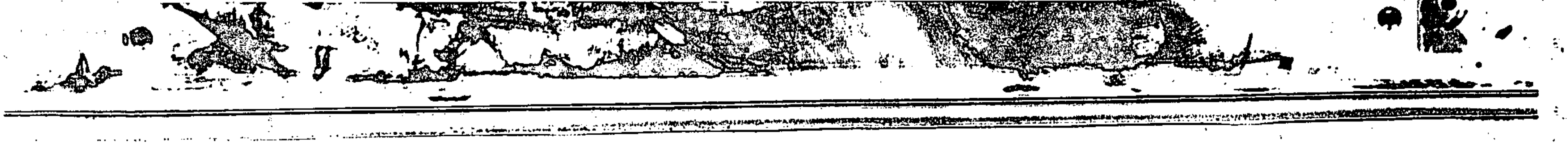
R.R.S. SHACKLETON CRUISE 1/80.

Fig 2



DEPTH DATA FOR CRUISE S180(SCALE***** UNITS/IN)


61° E
62°
63°
64°
IRAN
PAKISTAN
5°
500
1000
a
1500
2000
2500
3000
C1
C2
2
c
1
b
3-8
21-27
4°N
15-20
2500
3500
2500
23°
3000
4000
2000
2000



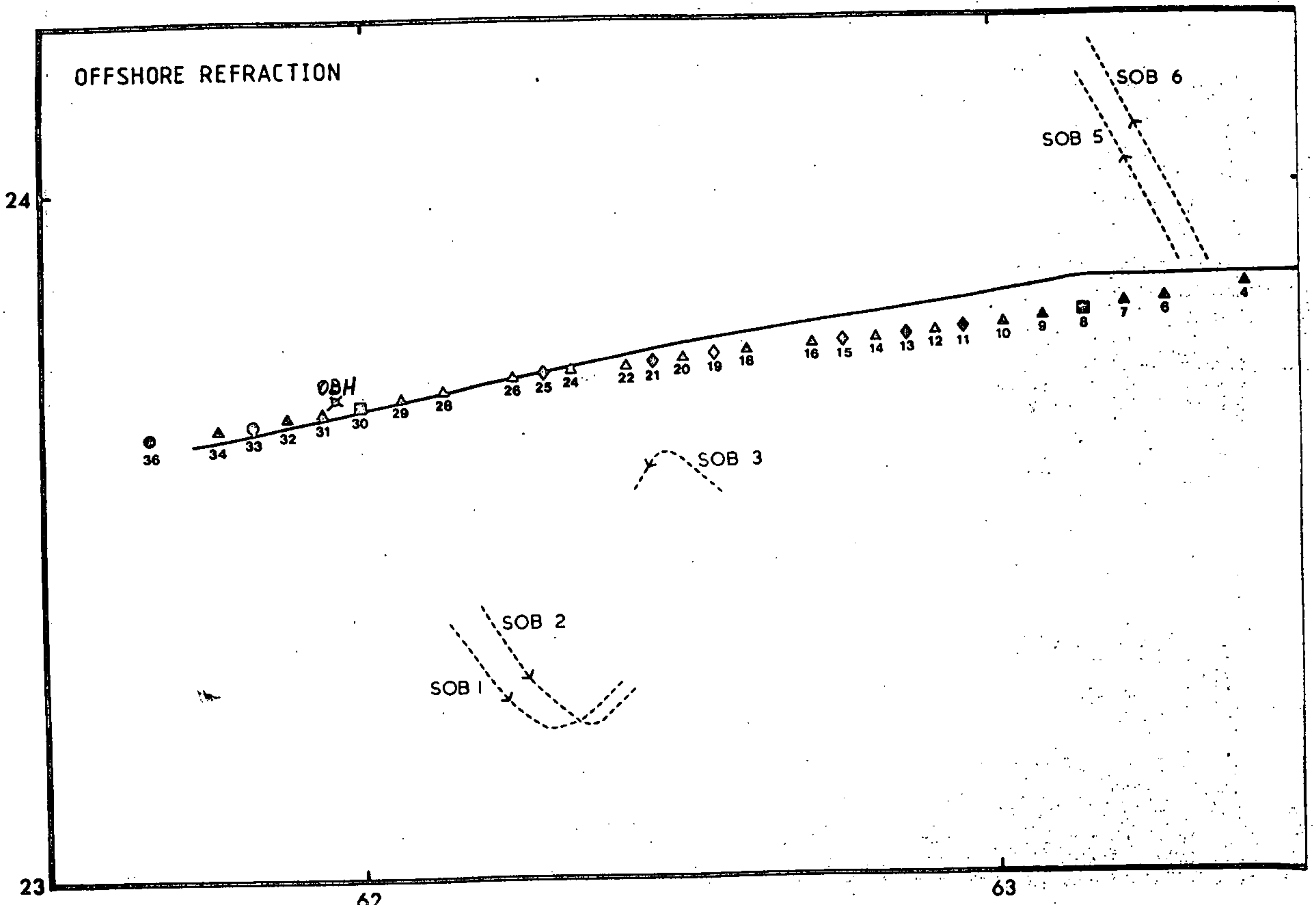

OFFSHORE REFRACTION
SOB 6
SOB 5
24
23
62
63
OBH
36
34
33
32
31
30
29
28
26
25
24
22
21
20
19
18
16
15
14
13
12
11
10
9
8
7
6
4
SOB 3
SOB 2
SOB 1

Fig 4

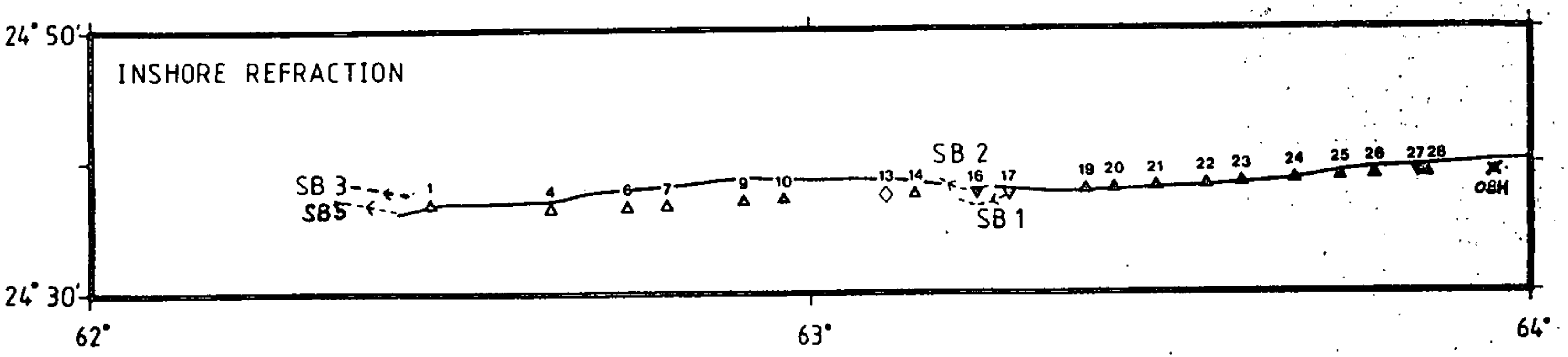
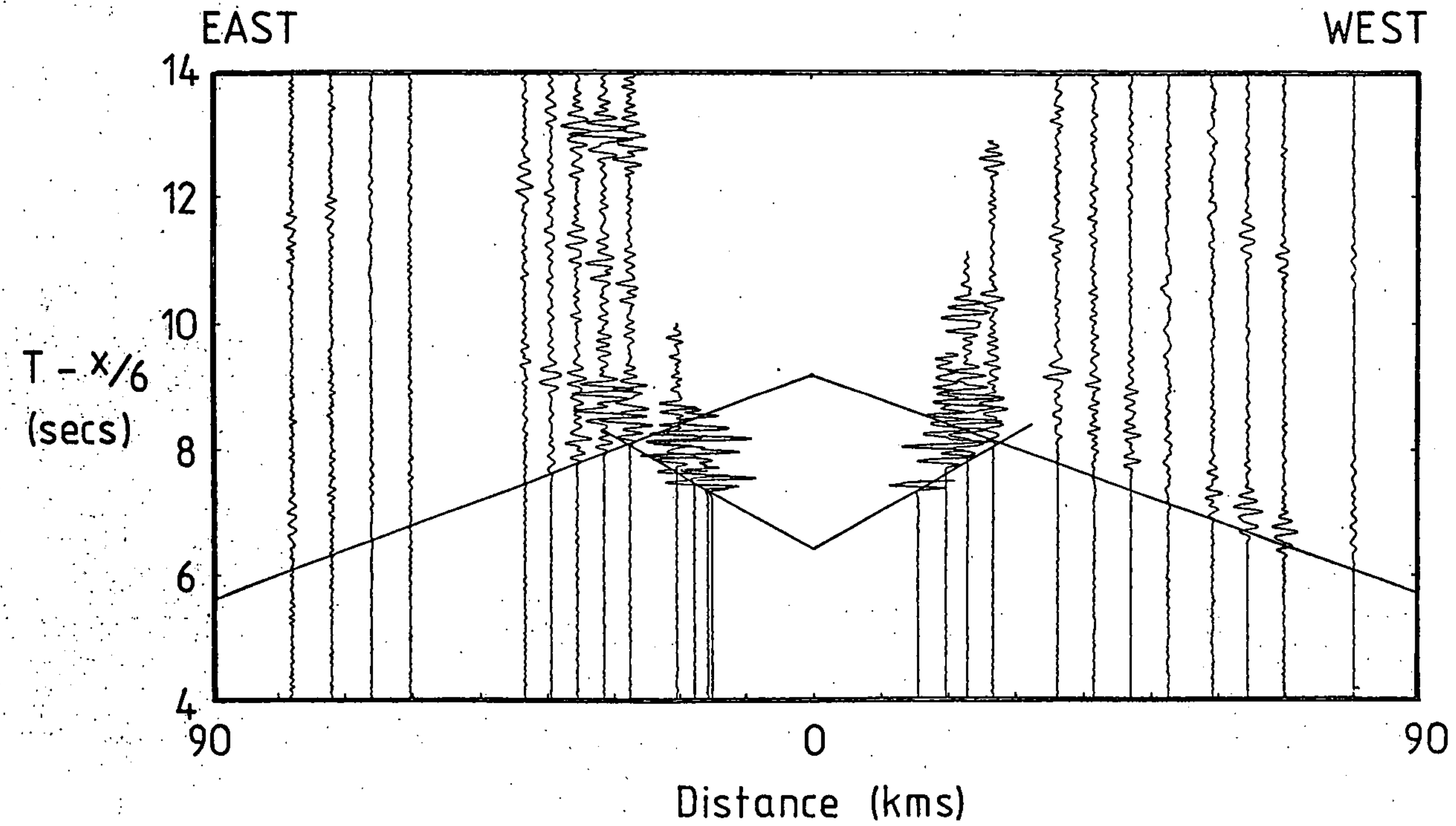
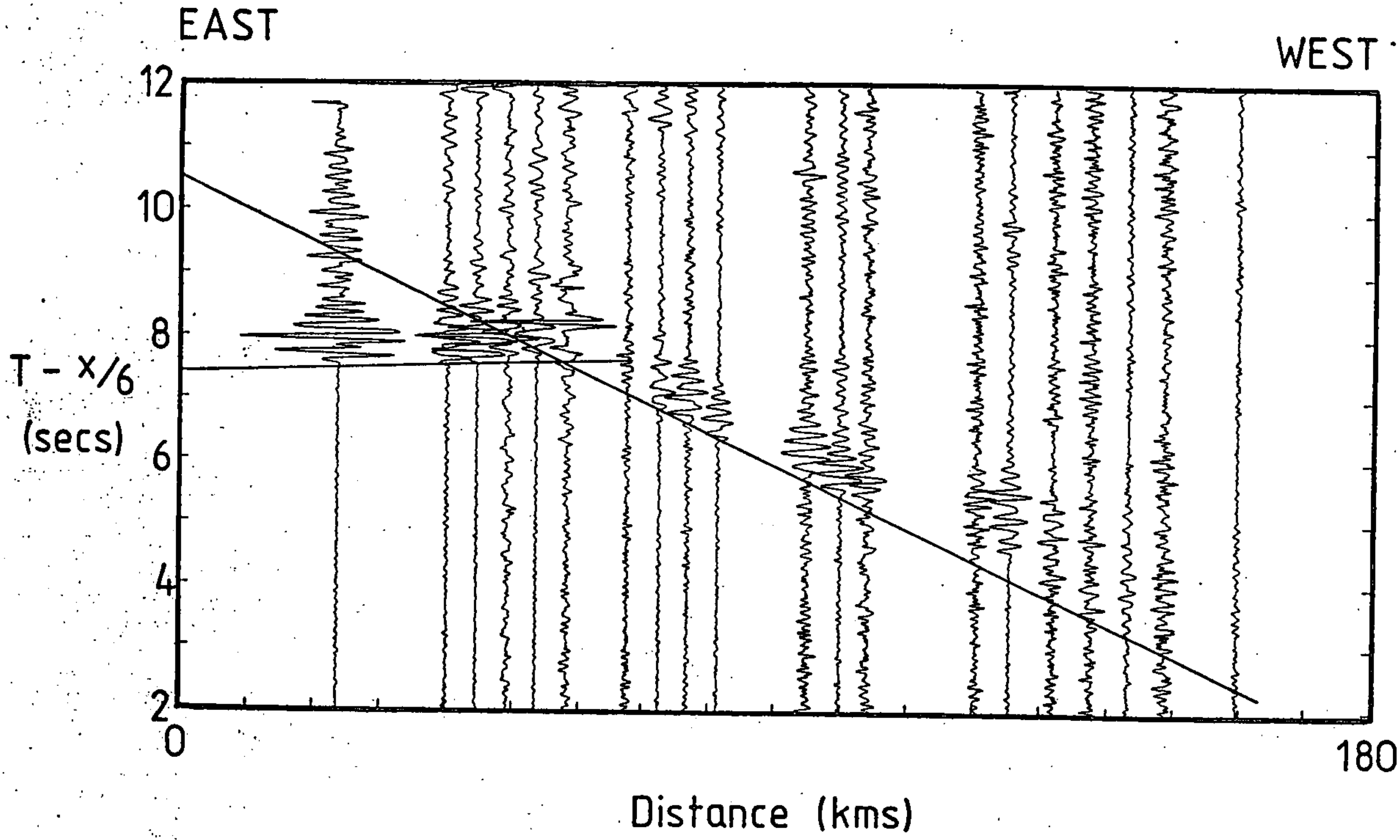

24° 50'
24° 30'
62°
63°
64°
INSHORE REFRACTION
SB 3
SB5
SB 2
SB 1
1
4
6
7
9
10
13
14
16
17
19
20
21
22
23
24
25
26
27
28
OBH

Fig 4b

Fig 5a



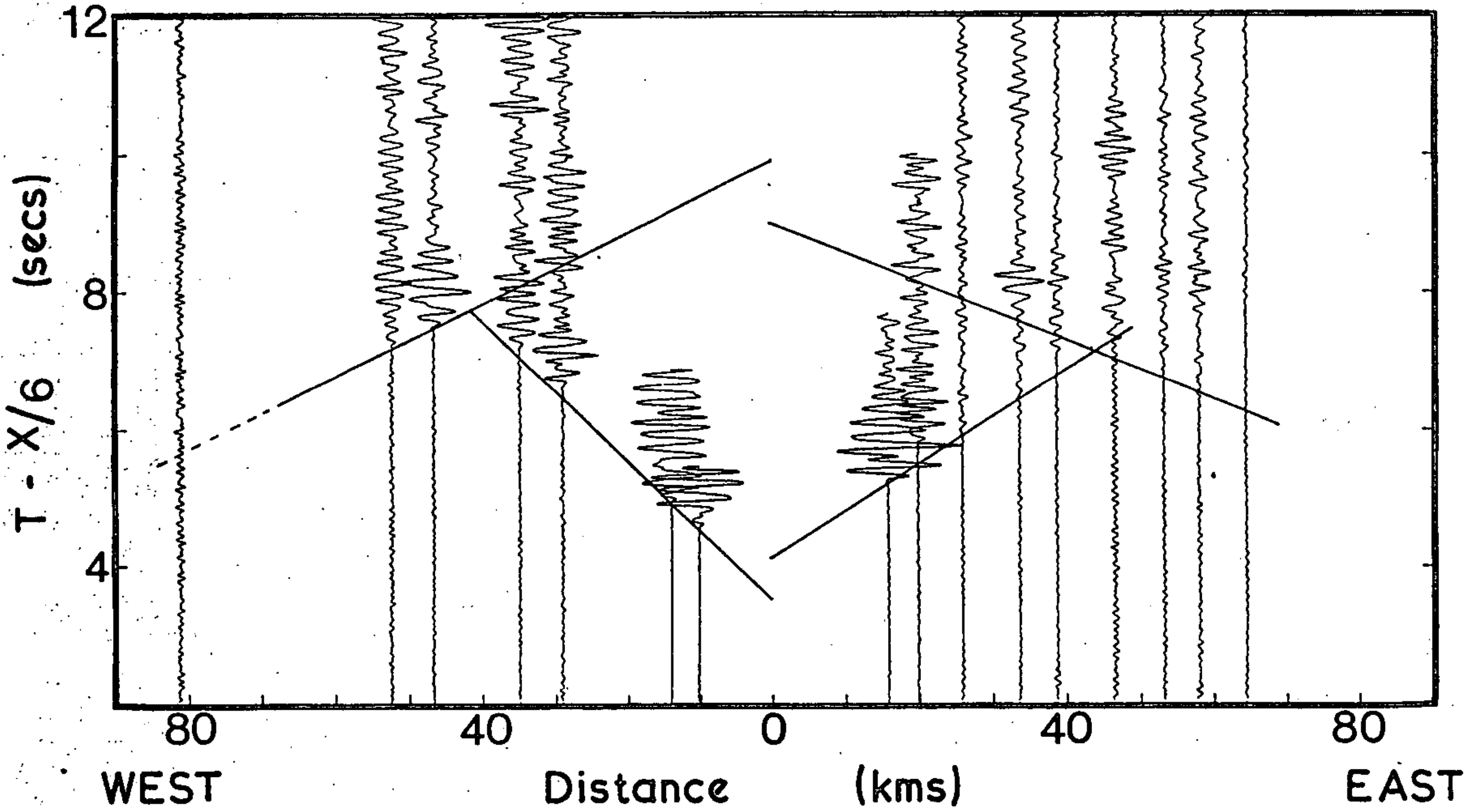
OFFSHORE SB 3



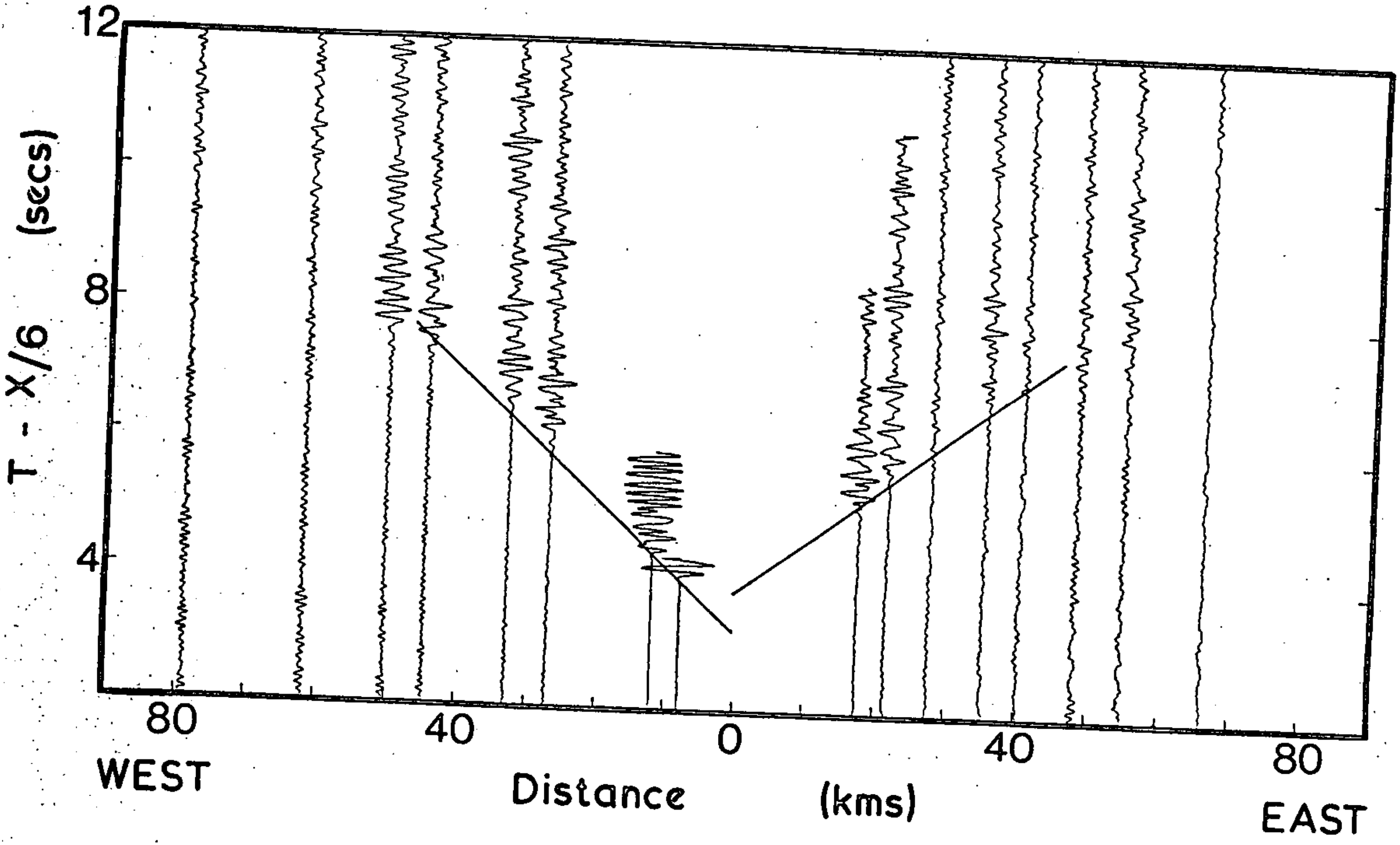
OFFSHORE SB 5

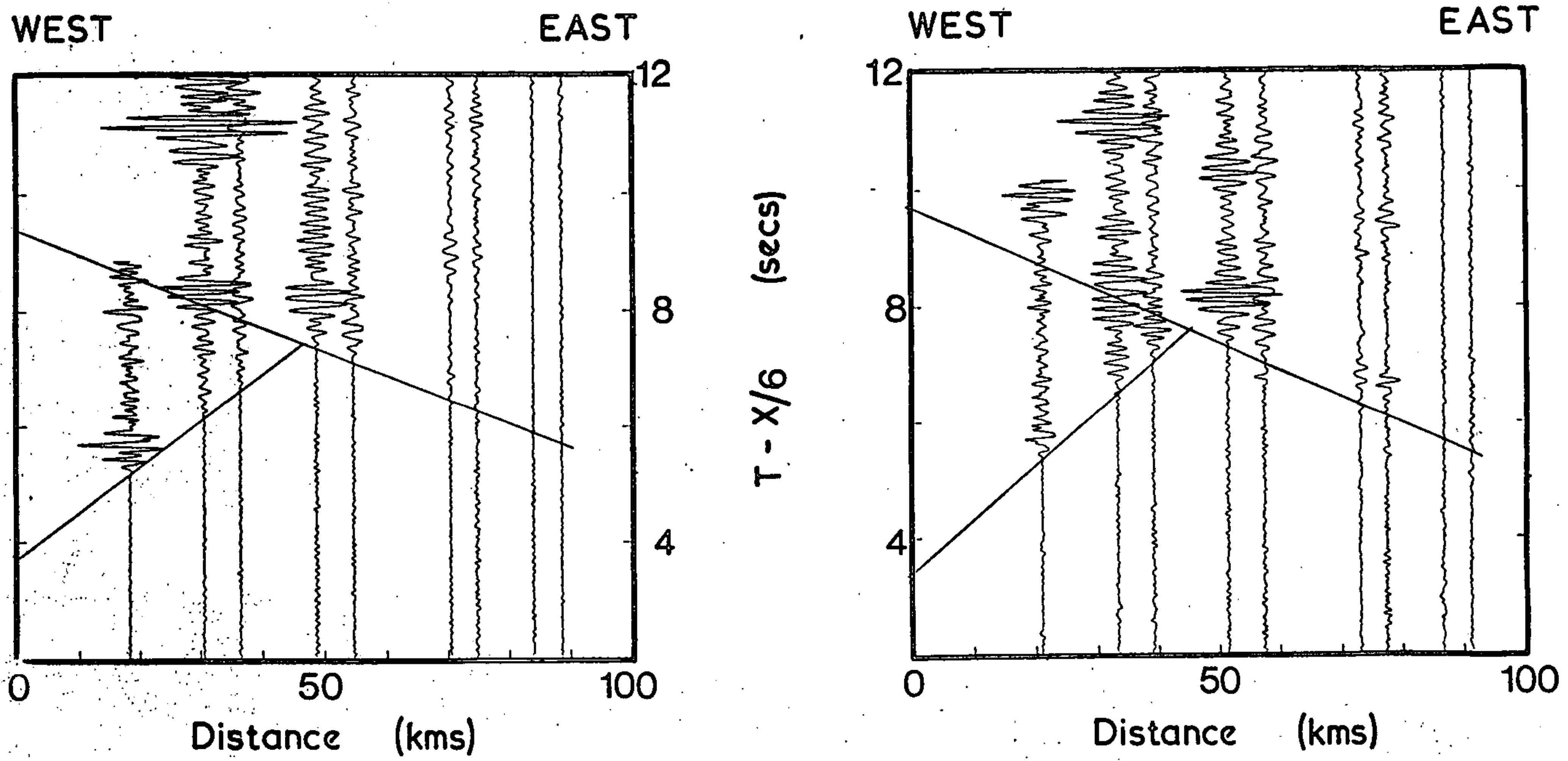
Fig.

INSHORE SB 1

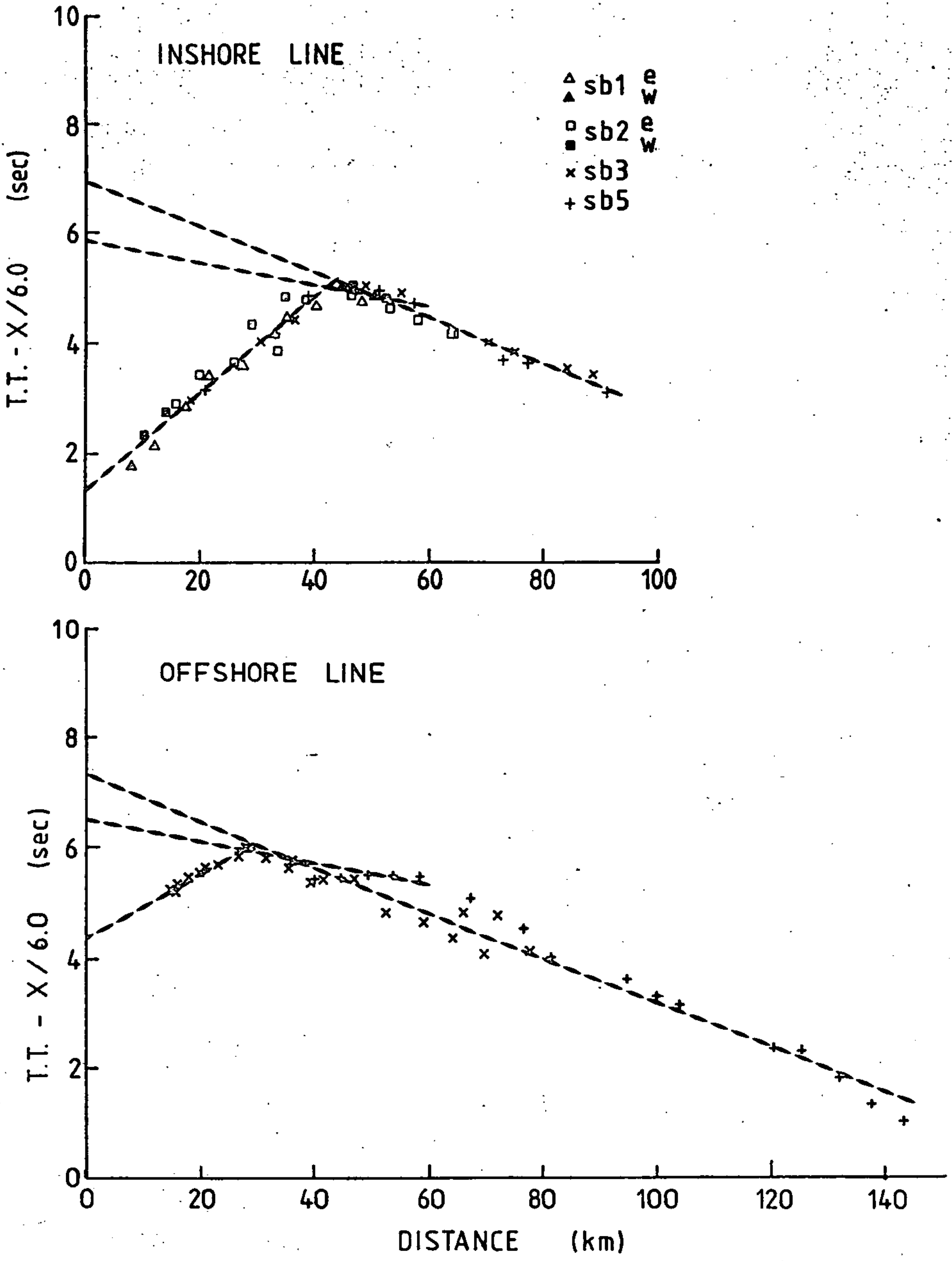


INSHORE SB 2





SB 3 INSHORE SB 5


INSHORE LINE
△ sb1 e
▲ w
□ sb2 e
■ w
× sb3
+ sb5
T.T. - X/6.0 (sec)
10
8
6
4
2
0
0
20
40
60
80
100
OFFSHORE LINE
T.T. - X/6.0 (sec)
10
8
6
4
2
0
0
20
40
60
80
100
120
140
DISTANCE (km)

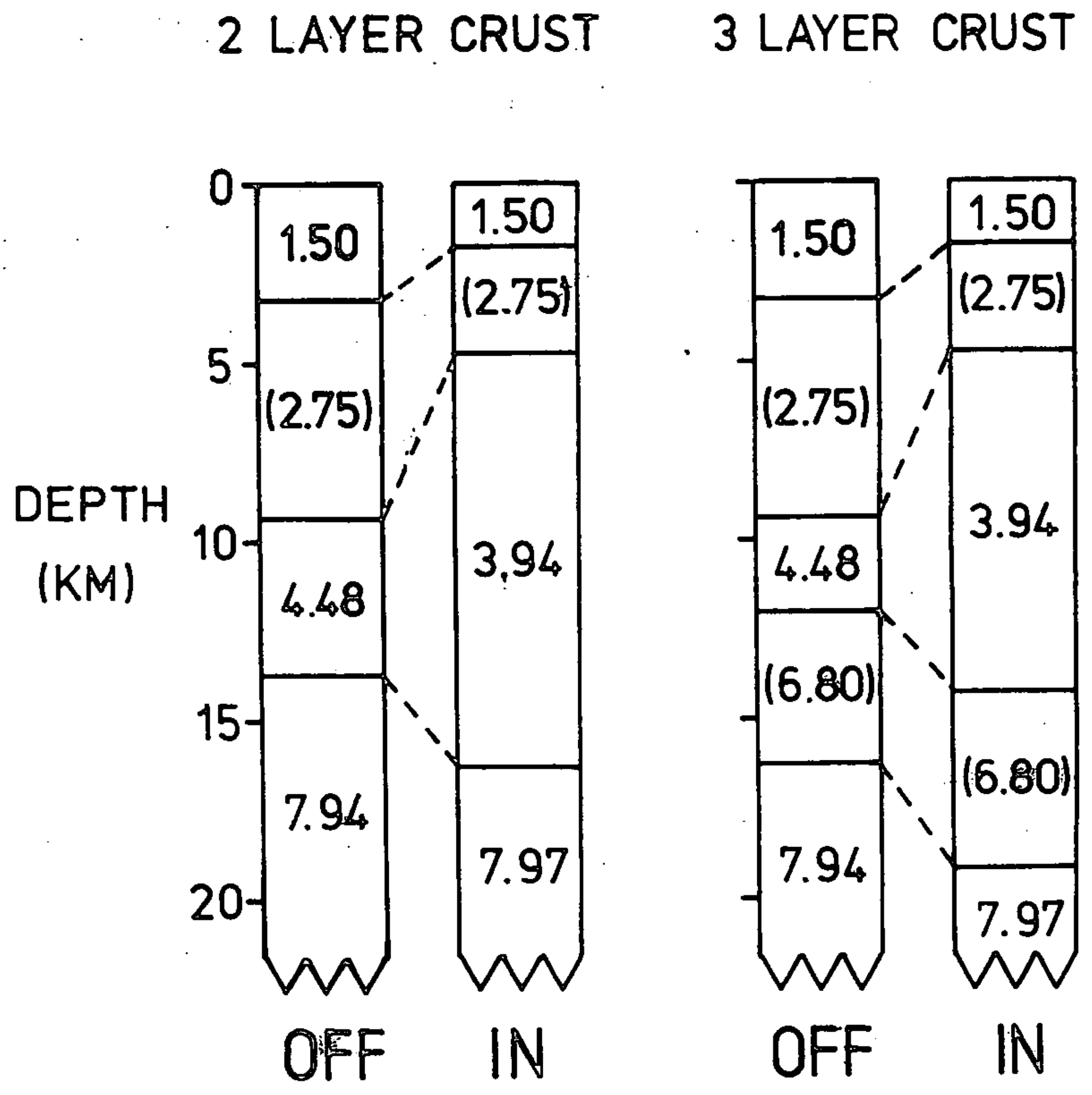

2 LAYER CRUST
3 LAYER CRUST
DEPTH
(KM)
0
5
10
15
20
1.50
(2.75)
4.48
7.94
1.50
(2.75)
3,94
7.97
1.50
(2.75)
4.48
(6.80)
7.94
1.50
(2.75)
3.94
(6.80)
7.97
OFF
IN
OFF
IN

FIG 7

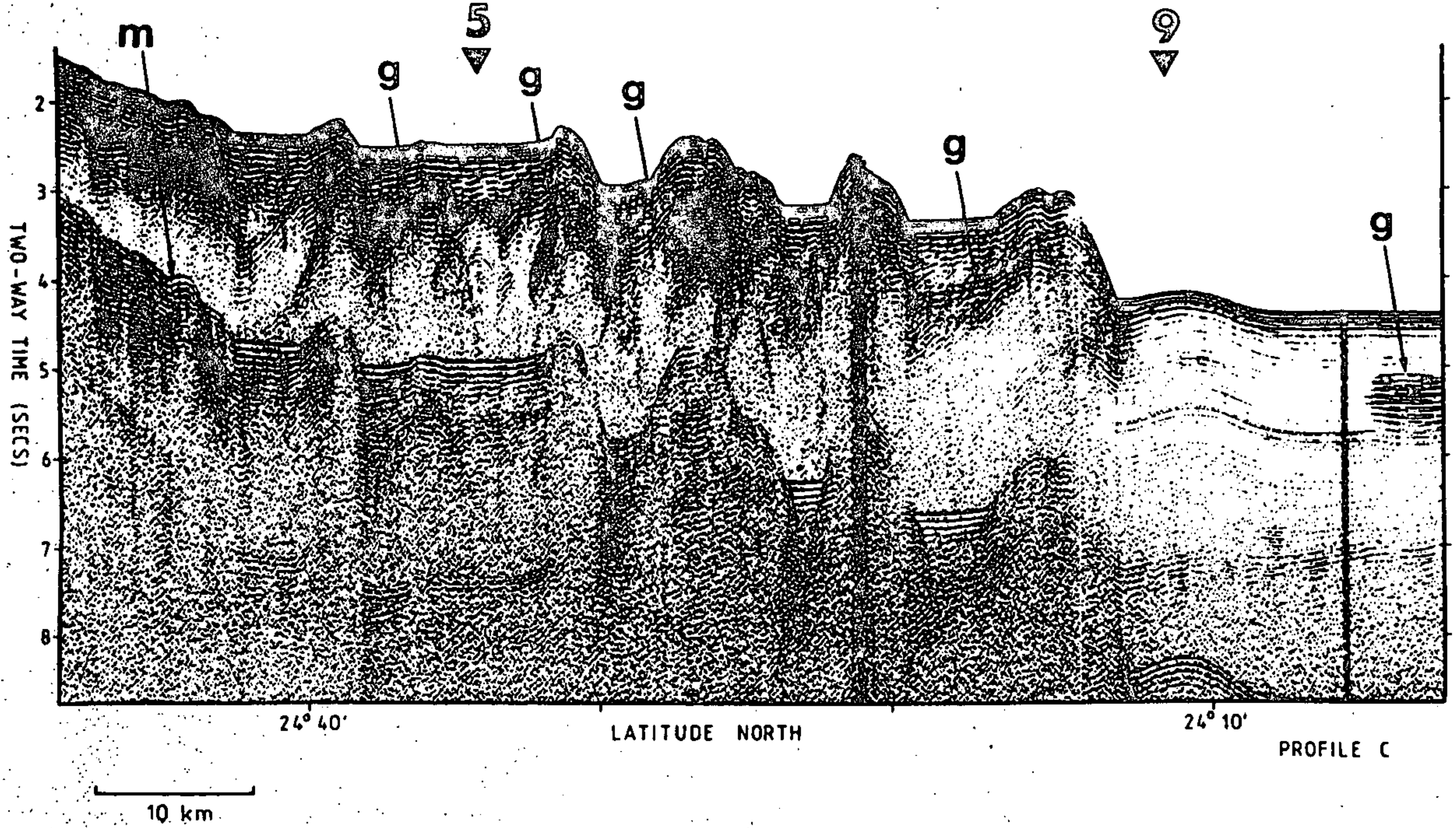

m
5
g
g
g
g
9
g
TWO-WAY TIME (SECS)
2
3
4
5
6
7
8
24° 40'
LATITUDE NORTH
24° 10'
PROFILE C
10 km

Fig 8

Temperature vs Depth for all stations after normalization of the uppermost Thermistor to the origin

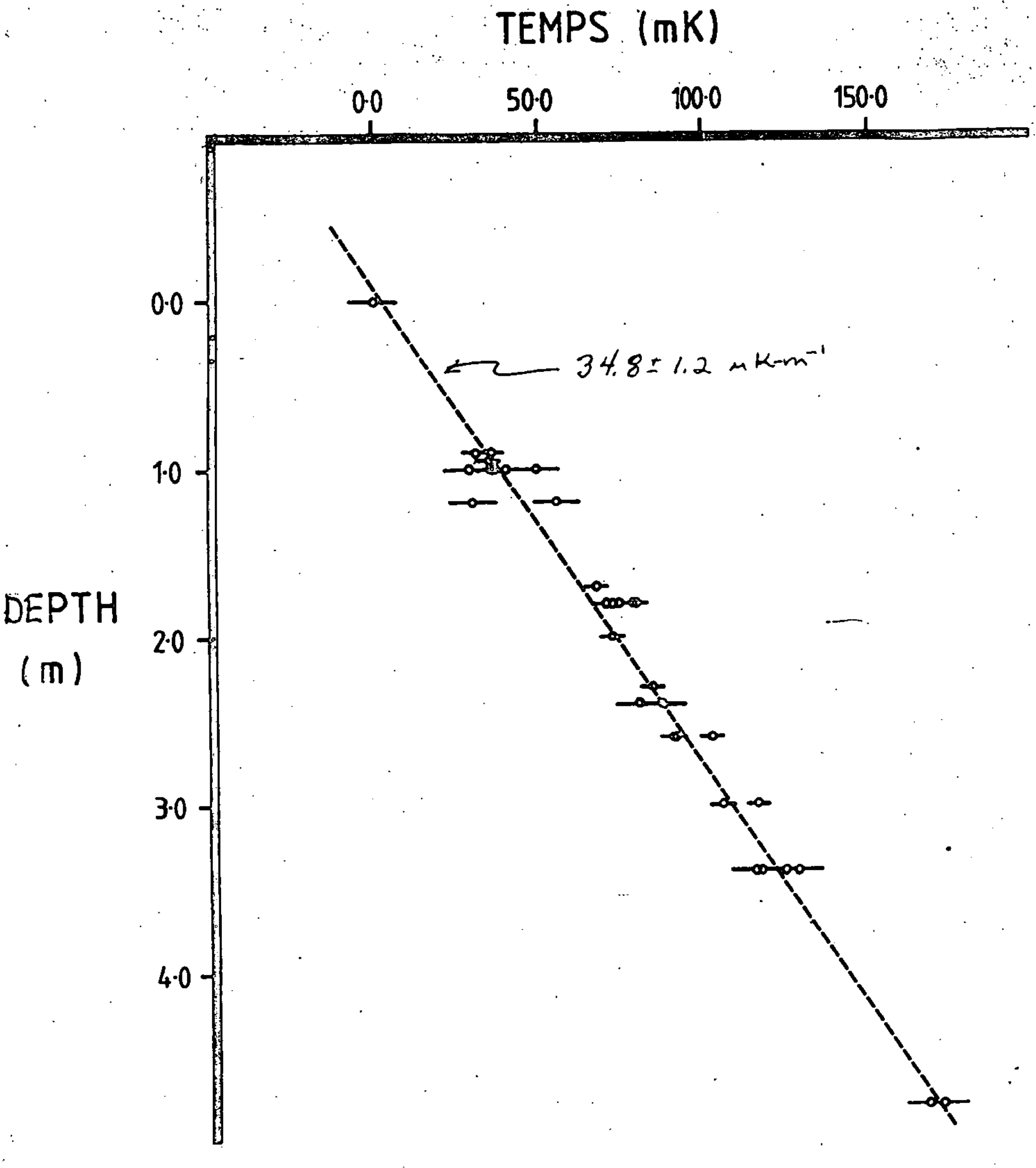


Fig 9

TABLE 1

Station	Location	Water Depth (M)	Temp. Grad. (MK m^{-1})	Heat Flux (mWm^{-2})	Class
1	24° 04.0'N,62°32.5'E	3291	36	43	4, 5.0
2	" 04.4' , " 30.5'	3282	35	42	4, 5.0
3	" 03.9' , " 27.0	3289	38	45	3, 3.0
5	" 03.4 , " 26.8	3291	35	42	2, 3.0
6	" 03.3 , " 28.0	3297	36	43	2, 1.0
7	" 04.2 , " 27.2	3280	36	43	2, 1.0
8	" 05.0 , " 27.0	3280	37	44	2, 1.0
15	23° 29.2' ,61°40.8	3348	49	58	2, 1.0
16	" 29.2' , " 40.8	"	36	43	2, 1.0
17	" 29.2' , " 40.7	"	35	42	2, 1.0
18	" 27.9', " 40.6'	"	36	43	2, 1.0
19	" 27.9', " 40.6'	"	29	35	2, 1.0
20	" 27.9', " 40.6'	"	40	48	2, 1.0
21	24° 07.4", 63°20.1'	3191	35	42	4, 3.4
22	" 07.4", " 20.1'	"	35	42	3, 3.4
23	" 07.6". " 20.1'	"	37	44	3, 3.4
24	" 07.6" " 20.1'	"	38	45	4, 3.4
25	" 07.6", " 20.1'	"	36	43	5, 3.4
26	" 07.6", " 20.1'	"	36	43	4, 2.6
27	" 07.6", " 20.1'	"	36	43	4, 2.6

Heat fluxes have been calculated from the temperature gradiants using a thermal conclectivity of 1.19 + .03 Wm^{-1} K^{-1}.

Class is any measurement evaluation based on the number of temperature records recovered and the maximum probe separation.