Geophysical Survey of the Gulf of Oman - Northern Arabian Sea

R. R. S. SHACKLETON Cruise 3/75

Djibouti, TFAI to Dubai, UAE

27 March 1975 to 15 April 1975

by

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Introduction

As part of the RRS Shackleton 1975 cruise, to the Indian Ocean, the Department of Geophysics, University of Cambridge conducted a geophysical survey of the Gulf of Oman - northern Arabian Sea. The survey region extended from just south of the Murray Ridge to the Makran coast of Iran and Pakistan and from 58°E to 64°E. The underway profiling systems included gravity, magnetics, bathymetry and seismic reflection. Their continuous, smooth operation, including over 4 sec. penetration with the reflection system, helped to make the cruise a success. Two 100 km long seismic refraction profiles were shot parallel to the Makran coast using free-floating Bradley buoys and disposable sonobuoys. The success of these 2 lines was limited by a 24% failure rate of the explosives and a 50% failure rate with the Bradley buoys. Sufficient coverage was obtained to ascertain the seismic velocity structure of the area to aid in the interpretation of the reflection and the gravity data. The scientific program also included a short magnetic survey in the Gulf of Aden for R. W. Girdler and a seismic refraction experiment with PUBS by R. B. Whitmarsh on the Sheba Ridge.

The purpose of this cruise was to investigate the tectonic environment of the northern Arabian Sea. Further to the south, McKenzie and Sclater (1971) had used magnetic lineations and bathymetric structures to unravel the tectonic history of the majority of the Indian Ocean sea floor. North of 20°N in the western Indian Ocean the apparent lack of sea-floor spreading magnetic anomalies and the thick blanket of sediments mask the history of the crust. A number of bathymetric and magnetic surveys have been carried out in this region (e.g. Admiralty 1963, 1965, 1966; Taylor 1968). These surveys delineated the 2 major features in the area, the Owen fracture zone (Matthews 1966) and the Murray Ridge (Barker 1966), but they did not have seismic reflection or gravity systems to relate these structures to the crust below the sediments. The only gravity information for this region was obtained on the FS METEOR 1965 cruise to the Arabian Sea (Dietrich 1965). A series of short seismic refraction lines also was shot during this cruise (Closs et al 1969). Before the SHACKLETON 3/75 cruise the only seismic reflection profiling in the region was collected in connection with the search for oil and mineral resources and was confined primarily to the continental margins. It was hoped that the combination of gravity and seismic reflection profiles would yield a clear tectonic connection between the oceanic crust to the south of the Murray Ridge, the crust to the north of the Murray Ridge and crust of the Asian plate.

Personnel

The scientific party aboard the RRS SHACKLETON included scientists and technicians from Cambridge, Institute of Oceanographic Sciences (IOS) Wormley and the research vessel base (RVB) at Barry. Dr Robert B. Whitmarsh (IOS) was chief scientists and Dr Kim Klitgord (Cambridge) was co-chief scientist.. The other members of the scientific party were A. W. Claydon, D. P. McKenzie, R. S. White and D. W. Wright of Cambridge, R. E. Kirk and J. J. Langford of IOS and S. Audley, M. Beney and S. Jones of RVB. The ship's officers were G. Shelby-Smith - Captain, P. Warm - 1st Officer, T. Gray - 2nd Officer, J. Evans - 3rd Officer and A. Coombes, Chief engineer.

Dr Ismail Elboushi from the Sultanate of Oman joined the ship on the 13 April while the SHACKLETON was off the coast of Oman. P. Styles from the University, Newcastle-upon-Tyne was supposed to be on the cruise but he was forced to withdraw at the last minute because of a case of dysentery picked up around Djibouti.

Scientific Equipment

Various types of equipment were used aboard the SHACKLETON to gather and store data. A towed fish with a transmit/receive capability was used with a precision echo sounder recorder to provide a 10kHz bathymetric record. A VARIAN magnetometer with about 200 feet between the ship and sensor head, was in operation on all of the profiling tracks and a gyro-stabilized Le Coste-Romberg gravimeter was in constant operation. The Warden portable gravimeter educator model belonging to UCL was used to calibrate the ship's gravimeter with the gravity base station in Djibouti and Dubai, The seismic reflection equipment was provided by Cambridge and RVB and it is described in a later section. The Cambridge seismic refraction gear also is described in a later section. The gravity, magnetic and EM-log information was recorded on magnetic tape with the Cambridge Maglog system. A Plessey acoustic sound velocimeter was used to take a sound velocity vs depth profile for the upper 2.4 km of the water column.

The primary source of navigation was a Magnovox Satellite Navigator. An Omega system was also in operation but the distribution of Omega base stations made it rather inaccurate for this region. Dead-reckoning navigation was aided by an EM-log and a microtechnica gyro compass. The EM-log was put out of operation during the first refraction station on the 7 April when the sensor head was knocked off. After that, the ship's Bergen/log was used to provide ship's speed through the water and distance travelled.

Commentary

The RRS SHACKLETON was scheduled to sail on 24 March 1975 from Djibouti, TFAI, but the departure was delayed for 3 days to 1000L, 27 March. This delay was caused by the failure of all 3 A. C. generators (one at a time) and we left port when 2 of them had been repaired. It was a relief for everyone when the ship finally left Djibouti because problems with the air conditioning, plus the loss of A. C. power when the generators failed, had resulted in the ship being rather warm at the best. After we had departed we had no trouble with the generators and the air conditioning eventually improved.

Shortly after leaving Djibouti we began a magnetic/bathymetric survey in the western part of the Gulf of Aden. This was to complete the survey which R. W. Girdler had started on the previous cruise of the SHACKLETON (2/75). Four tracks crossed the Gulf of Aden on a course of about 035^{o} and went almost to the 100 fathom contour on both sides of the gulf. On the 29 March starting at 0700L we tested the reflection system with a 12 hour profile using the 160 cu in gun and the 2-channel array. The profile went from the ridge crest to the 100 fm contour on a course of 030^{o} at about 76^{o}E from 12^{o}N to 13^{o}N. This was the only seismic reflection profiling until after we left the Sheba ridge because of the limited time for the cruise. We were seismic profiling at 6 knots while the maximum ship's speed was about 9 knots. During the 1st few days of the cruise a base station land magnetometer was set up by R. W. Girdler outside of Djibouti. It appears that it was very noisy, magnetically, at this time.

We reached the Sheba Ridge at about 0000L on the 2nd April and conducted a brief survey of the ridge crest in the vicinity of 15°N, 55°E. The magnetic anomalies and bathymetry were used to locate the centre of spreading and 3 IOS pop-up bottom seismometers (PUBS) were deployed: one north of the centre, one in the median valley, and one to the south. Three AQUAFLEX charges were fired for calibration purposes but one misfired and 2 did not unreel properly. Then the 1000 cu.in. airgun was used in a 12 hour refraction survey of the ridge crest. This survey, which was part of Bob Whitmarsh's scientific program in the area west of the Owen Fracture zone, took about 1½ days.

The 3 Bradley buoys were tested as soon as the 3rd PUBS was recovered. They were deployed in 40 minutes at the same place just south of the ridge crest. Four AQUAFLEX charges (200 foot length) were fired as the ship sailed towards the buoys, with all 4 exploding properly. It took 1 hour to pick up the buoys and after only 4 hours we had finished the test. Calm weather had made the deployment, locating and recovery of the buoys relatively simple. During the test we received seismic information from 1 buoy (#6) on the transmitter but we did receive the clocks on the transmitter from the other 2 buoys. The electronics in the 3 buoys appeared to be working properly and it was just a problem with the hydrophone on buoys # 1 and # 2. One had flooded and the other was too noisy. We left the 3 buoys running for 12 hours after recovering them. The batteries had not been fully charged at the start of the test and they were quite low at the end. They were all put on charge until the 1st refraction line. The tape recorders also appeared, at first, to be having trouble since nothing was recorded on the tapes of 2 of them. After several possible causes were checked, it was discovered that the 2 tapes had been spooled on backwards by the manufacturers. All of the tapes were checked to be sure that the record side was facing the right way on the spools.

As we left the Sheba Ridge on the 3rd of April at 2000 L we sailed east for about 20 miles and then headed north towards the Cambridge survey area. We streamed the reflection gear and the magnetometer to obtain a decent geophysical profile parallel to, but west of, the Owen fracture zone. Our track was about half way between the Owen F. Z. and the F. S. METEOR track which also had gravity information. R. B. Whitmarsh was to return to this area on the next cruise (SHACKLETON 4/75) and the profile would provide him with very useful information for planning possible survey sites. The weather had remained calm, allowing us to steam at 6.5 to 7.0 knots with the seismic array towed behind the ship. At 21°N, 60.8°E we turned eastward across the Owen F. Z - Murray Ridge junction, heading for 21.8°N, 63.6°E which was south of the Murray Ridge. We then ran a long profile to the first refraction station (23.5°N, 62.1°E) crossing the Murray Ridge at about 0000 L on the 7 April.

The first refraction line (station # 1287) was over the flat abyssal plain which lies between the Murray Ridge and the Makraw coast. A 1½ hour sound velocity station (station # 1286) was taken when we arrived at (23.5°N, 62.1°E) at 1500 L, 7 April. The hydrophones, which had been wrapped in tape, were floated again since the seas were very calm. The 3 Bradley buoys were deployed with a half-mile spacing as the ship sailed eastward. Unfortunately the hydrophone became entangled with the EM-log as the second buoy (# 6) was being launched. The result was a loss of 1 hour of ship time and the loss of the EM-log sensor head. After this we had to rely upon the ship's Bergen log which was reading about 65% low. We launched the third buoy (# 1) just as the clocks were coming on the radio. We started to fire explosives at 1855 L, 7 April, about 15 min. before the tape recorders in the buoys switched on. At this point buoy # 2 was working properly but the hydrophones for buoy # 1 and buoy # 6 were not working very well.

The refraction line was shot at night and we could see the lights on all 3 buoys flashing to the north of the ship as we steamed by them on a course of 277° at 6 knots. Unfortunately we were not firing explosives as we passed them. Tape had been wrapped around the end of the firing cable and the charges were catching on the tape instead of the firing ball. As a result there were about 8 misfires at the beginning with 2 or 3 charges accumulating at the end of the firing cable. The cable was aboard with the tape being removed as we passed the buoys. We were trying to make good 270° without making any course changes. The north-west drift of the ship resulted in a course of 277° at about 7 knots over the ground. Disposable sonobuoy # 1 was deployed at 23.6°N, 61.5°E on this outward track. The refraction line was ended at 0245 L, 8 April near 23.7°N, 61°E after 8 hours of shooting. We returned to the buoys on a path slightly south of the outward track. The 2 channel seismic array, magnetometer and 300 cu in airgun with a depressor were streamed on this return track. Disposable sonobuoy # 2 was deployed as we began our return to the Bradley buoys. Disposable # 1 was still working when we passed it and we obtained refraction data at 3 points with the 300 cu in gun firing every 20 seconds.

The Bradley buoys had drifted about 7½ n. miles to the north-west during the refraction line. As we passed by them, heading for their original position, we received ranges from buoy # 2 indicating their approximate position. We had no trouble finding the buoy # 1 and buoy # 6 and retreived them quickly. Buoy # 2 took a while to find even though we were receiving ranges from it and knew that it was less than a mile away. A check of the 3 tape recorders indicated that buoy # 2 had worked properly and had recorded information from the whole line while the tapes from buoy # 1 and buoy # 6 were useless. The whole refraction line took 26 hours, including the sound velocity station, laying and recovering of the Bradley buoys. We started reflection, gravity and magnetic profiling at about 1630 L, 8th April.

There were 2 days between the 2 refraction lines, allowing time for personnel to recover, batteries to be recharged and the Bradley buoys and tapes to be checked. This time was spent reflection profiling the area traversed by the 2 refraction lines. We left the first refraction line heading ESE until we passed over a series of small bathymetric peaks which are lineated parallel to the Murray Ridge. Then we turned north and profiled up to 20 miles from the Makran coast of Pakistan. Turning to the south-west, we crossed the centre of the first refraction line and then headed north again towards the Makran coast of Iran. The 160 cu in airgun was firing continuously at a 10 sec rate and we obtained over 4 seconds of penetration into the sediments on the abyssal plain. The region between the abyssal plain and the Makran coast was folded into a series of peaks and valleys filled with sediments and we decided to shoot the second refraction line along one of these valleys.

We arrived at the second refraction line (station # 1288) near 24.3°N, 61°E at 2330 L (1930 Z) on the 10th April. The Bradley buoys # 1, # 6 and # 2 were deployed at the southern edge of one of the valleys as we steamed to the west. It was hoped that even with the northern drift they would stay over the valley for about 10 hours. The deployment took less than 1 hour and we were ready to commence shooting 1 hour before the tape recorders in the buoys were scheduled to start. Buoys # 1 and # 2 were working very well at this time but buoy # 6 was still having trouble with its hydrophone. The first shot was at 0103 L. 11 April with the tape recorders in the buoys starting at

0124 Local. The line lasted for 9 hours and at 0925 L the last shot was fired. We made a few course changes on this line to keep the ship over the same valley. Our track was almost due east and the sea floor was fairly flat until we reached the eastern end of the valley, at about 50 n. m. from the Bradley buoys. Then we passed over a large hill, finishing the line at the eastern end of the hill. We had deployed disposable sonobuoy # 3 at about 30 n. m. from the Bradley buoys. We turned to the south at the end of the line and immediately went over a steep edge of this hill. As we streamed the 300 cu in airgun, the 2-channel array and the magnetometer we sailed north again to go back over the refraction line. On the return profile we deployed disposable sonobuoy # 4 on the flat part of the hill (about 45 n. miles from the Bradley buoys) and disposable sonobuoy # 5 at about 15 n. miles from the Bradley buoys.

Returning to the original position of the Bradley buoys we found that they had drifted 7 n. miles to the north. The recovery of the buoys went very quickly as the flashing lights made them easy to find at night. We left the station at 2100 L, 11 April with a total time of 25½ hours for the station. A quick check of the buoys showed that buoys # 1 and # 2 had worked properly while buoy # 6 had nothing but garbage on its tape recorder. The batteries had not been fully charged at the beginning of this line, but they were still sufficiently charged at the end of the line to run the equipment. They were immediately put on charge again so that they could be sent back to England fully charged but minus their fluid.

Leaving the station #1288 we streamed the 160 cu in airgun, the 2-channel array and the magnetometer and headed for the coast of Oman. The depressor was not used on the gun because it was felt that the small amount of depth gained with it did not justify the additional strain on the airgun cables. At 22.8°N, 59.5°E, within sight of the coast of Oman, we turned north towards the Makran coast at 25°N, 60°E. A fishing boat with scientist from Oman caught up with us at about 0000 L on the 13th April and at about 0600 L we slowed down 4 knots to allow the fishing boat to come along side and transfer him to the SHACKLETON. We deployed disposable sonobuoy # 6 at about 23.6°N, 60.3°E over the abyssal plain. Disposable sonobuoy # 7 was deployed at 23.8°N, 59.6°E but it failed to transmit. The rest of the cruise from the refraction station to Dubai was relatively quiet and the time was spent packing all of the Cambridge gear for shipping back to England. While the weather had been relatively cool near the Makran coast, it became warmer and more humid as we neared the coast of Oman. Finally at 0500 L on the 14th April we stopped reflection profiling and increased speed to $8\frac{1}{2}$ knots to make it to Dubai by 0900 L on the 15th. The magnetometer was pulled in at 1300 L on the 14th as the shipping traffic became heavier. In general we had very few problems with the large number of ships passing through the Gulf of Oman. They stayed clear of our array and their noise was hardly noticable on our reflection system.

The R. R. S. SHACKLETON arrived at the port of Dubai, UAE at about 0900 L on the 15th April. The temperature was cooler than most of us had anticipated and the seas were still calm, as they had been through out the entire cruise.

Gravity Base Station-Djibouti, TFAI

The ship's gravimeter was calibrated against the Djibouti base station (22) on the quay in Djibouti, established in 19 by G. A. Day ( ). After the Worden meter had temperature stabilized (it had no heater), readings were taken at the quay adjacent to the ship and 2 readings were taken at the base station a short distance away. The quay position near the ship was about 0.2 metres higher than the gravimeter on the SHACKLETON. (

Refraction work on R.R.S. Shackleton; leg 3/75

Introduction

Two major refraction lines were shot on the Cambridge part of Leg 3, the first on days 097/098 and the second on days 100/101. Both were run in an East-West orientation, the first for 60 n.m. westward of 23°41'N, 62°01'E and the second for 50 n.m. eastward of 24°20'N, 61°00'E Three Cambridge Bradley buoys were laid at one end of each line, spaced at ½ n.m. intervals on the line of shooting. It was felt to be unwise by the I.O.S. technicians to stream an array whilst firing aquaflex, so a return profile was made as closely as possible along the outward path, firing the 300 inch Bolt airgun at 20 sec. intervals. A sound velocity versus depth profile was taken at the first refraction station for the upper 2.4 km of the water column.

Aquaflex was fired into the buoys at 3 min intervals, steaming at a steady 6 knots. On the first line 25 x 200 ft. lengths of 200 grain explosive were fired, followed by 102 x 100 m lengths and 18 x 200 m charges. On the second line, we used 24 x 200 ft and 140 x 100 m charges.

Disposable sonobuoys manufactured by U.E.L. and modified to reduce their sensitivity by 20 dB were deployed in order to reverse the line and obtain an estimate of the variation in shallow strucure along it. Two were used on the first line and three on the second. All worked satisfactorily, with refracted arrivals received up to 16 miles away using the airgun.

Relocation of the Bradley buoys was markedly easier at night, when their flashing lights were seen from over 5 miles away on the bridge. Despite calm seas, surface currents were strong and they drifted about $7\frac{1}{2}$ mls during the 24 hours we were away from them.

Reduction of the data will be hampered by the large number of early or late shots on the first line and the rapidly varying sub-bottom structure on the second. However, it is hoped that these refraction results will give control on the excellent reflection records and gravity data obtained on the cruise.

Aquaseis System

a) A very disturbing fault which recurred 5 times on the first refraction line and 12 times on the second was premature triggering in the remote mode. In these cases the control thyristor triggered as soon as the firing button was depressed, instead of waiting for the clock pulse.

b) The number of misfires or only detonaters firing during the first line was 41 out of 145 (28%), and on the second was 35 out of 174 (20%). Although some of these may have been due to operator error, such as streaming the explosive too early and allowing it to deactivate, it is probable that most were due to poor explosive. Perhaps this was due to their long storage in tropical climates. Some of the detonaters were also found to have rusty parts.

Altogether, the firing cable had to be pulled in three times with unexploded charges on it. In view of the dangers involved in this, it might be wise to always leave the explosive in the water for 5 mins. to deactivate, before pulling it in.

The number of charges fired is near to the maximum the ball on the end of the firing cable can withstand. On the first refraction line, it was missing when the cable was finally brought in, presumably blasted off on the last shot. By the end of the second line, a new ball was cracked almost right through.

Hydrophone

At various times and despite a great deal of attention by myself, all four hydrophones failed catastrophically, leading to considerable loss of data. This is believed primarily to be due to poor design in using piston o-rings as seals. These are not capable of withstanding 5 atmospheres overpressure, as was demonstrated after an initial test lay of three sonobuoys during which two units leaked and ceased to function. It is by no means the first time that this has happened and before any further use of the hydrophones is made, properly waterproofed units should be built.

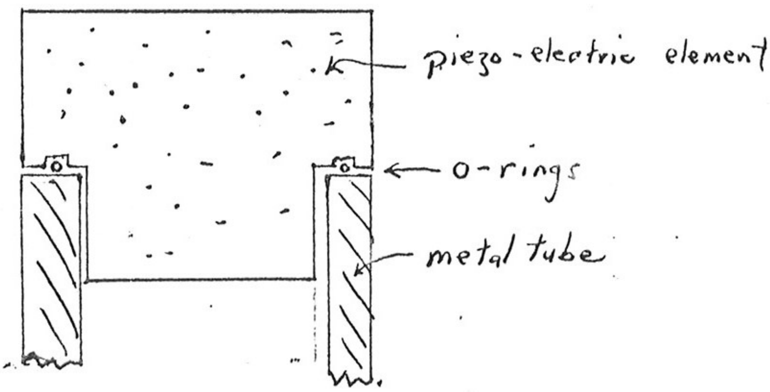
In order to prevent further leakage, the units were stripped and dried, then every joint in the hydrophone cable and both ends of the preamplifier housing were coated with silastic, sheathed by several layers of self-vulcanising rubber tape and covered with Lassovic tape. As a temporary measure, this was successful. However, further failure during the first refraction line occurred due to a break in the positive power supply line in the cable of hydrophone No. 2 (Buoy # 1) and the failure of the preamplifier of hydrophone No. 1 (Buoy # 6). The latter was probably due to water seaping in through cut s in the rubber sheathing of the cable sustained during deployment, and thence to the preamplifier housing. The hydrophone was rebuilt with a new preamplifier and the cable thoroughly wrapped with self-vulcanising tape, but it failed again on the second refraction line.

There are three main approaches to curing these problems:

1) Fill the preamplifier housing with oil, thus equalising the pressure access seals.

2) Mould the preamplifier and piezo-electric element in a single block. This would mean that failure of any part would involve discarding the whole unit.

3) Use O-rings which seal with increase in pressure; this is the normal approach in high pressure applications (see diagram).



Bradley Buoys

a) Tape recorders: The Uher Report 4000 L tape recorders had difficulty winding the tape (Scotch Double Play type 220), similar to that experienced in the Mediterranean in 1974. One of the four (No. 4), was never able to spool through a complete reel at the low speed, but fortunately the other three could manage it, though sometimes accompanied by squeaks. Part of the trouble was due to the fact that the tapes had been stored for five months in temperatures reaching 130°F and 95% humidity. Before use they were fast wound and rewound, in an attempt to stop the tape sticking to itself. The average duration of 1200 ft of tape was 9 hrs 10 mins.

b) Clocks: These drifted less than a second in 24 hours in all three buoys. The modulation frequency has still not been changed, causing the replay gear to produce very fuzzy second marks on Osscilomink playouts.

c) The hydrophone amplifier No. 5 was found to be faulty on arrival and was replaced by No. 1 (mark I version). . This had a gain of approximately half the other two buoys. It would be a good idea to include a working FM modulator, clock, transmitter and hydrophone amplifier in the spares so that whole units could be easily changed.

d) The main power switches in two buoys had to be replaced, leaving only one spare. The large O-rings on which the guts of the sonobuoys sit were all stretched and were replaced by the only three remaining spares.

e) Batteries: On arrival in Djibouti the lead-acid batteries were found to be flat and some almost completely dry, again through having been stored in the very hot hold. After two days charging, they still wouldn't register on the hydrometer, so the cells were separated and discharged then charged several times, keeping careful records of their performance. Eventually, about 18 of them were registering on the "Fully charged" section; 12 had to be totally discarded. Before leaving Djibouti we purchased four non-spill 6v batteries; the smallest we could get was 66 a-hrs. This gave us enough battery power to confidently run the three buoys. New packing material was cut for the cans. In future, the batteries should be fully-charged before leaving Cambridge, then the battery acid emptied out for transport.

We also had some trouble with one battery charger not working, but were able to make use of two heavy-duty R. V. B. charges on board. The present method of charging a whole buoy-pack at a time, though convenient is very poor. If one cell of the 12v series-parallel section is duff, it will not become charged by this method. It would be much better to split the battery pack into three 12v sections and charge them all independently.

f) Shot clock: The ship's clock used to control the aquaseis firing jumped twice during the first refraction line. Once by 3 secs. and later by a further 10 secs. No trouble was experienced on the second line.

Bob White
21 April 1975

Summary

The RRS SHACKLETON cruise 3/75 accomplished most of its aims in the Gulf of Oman - northern Arabian Sea. A reconnaisance of the region was carried out with a 160 cu. in. airgun and 2-channel array in connection with the Cambridge reflection system. This continuous reflection data along with the gravity and magnetic data provide a fairly simple picture of the deep structures in the area. The two refraction lines were shot in the desired regions, the abyssal plain and the zone of folding to the north, with relatively little trouble. The failure of 3 of the 6 Bradley Buoys did not hurt the refraction lines because it was only necessary for one to work on each line. It was unfortunate that about 24% of the explosives did not detonate, resulting in some large gaps in the refraction profile. It could be difficult to trace individual refractors across them. The use of the 300 cu. in. airgun and disposable sonobuoys was quite successful on both refraction lines. Very adequate sound velocity data should be available for the shallower sediment layers at several points on both lines. The calm weather on the whole cruise resulted in a low noise level during the refraction stations. It also permitted the reflection profiling to be conducted at $6\frac{1}{2}$ - 7 knots, reducing the amount of the scientific program which had to be curtailed because of the 3 day delay leaving Djibouti.

Acknowledgements

We wish to thank all of the members of the scientific party and the captain, officers and crew of the RRS SHACKLETON for helping to make this cruise a success. We also thank D. H. Matthews who did the initial planning for this cruise. This project was funded by the National Environmental Research Council.

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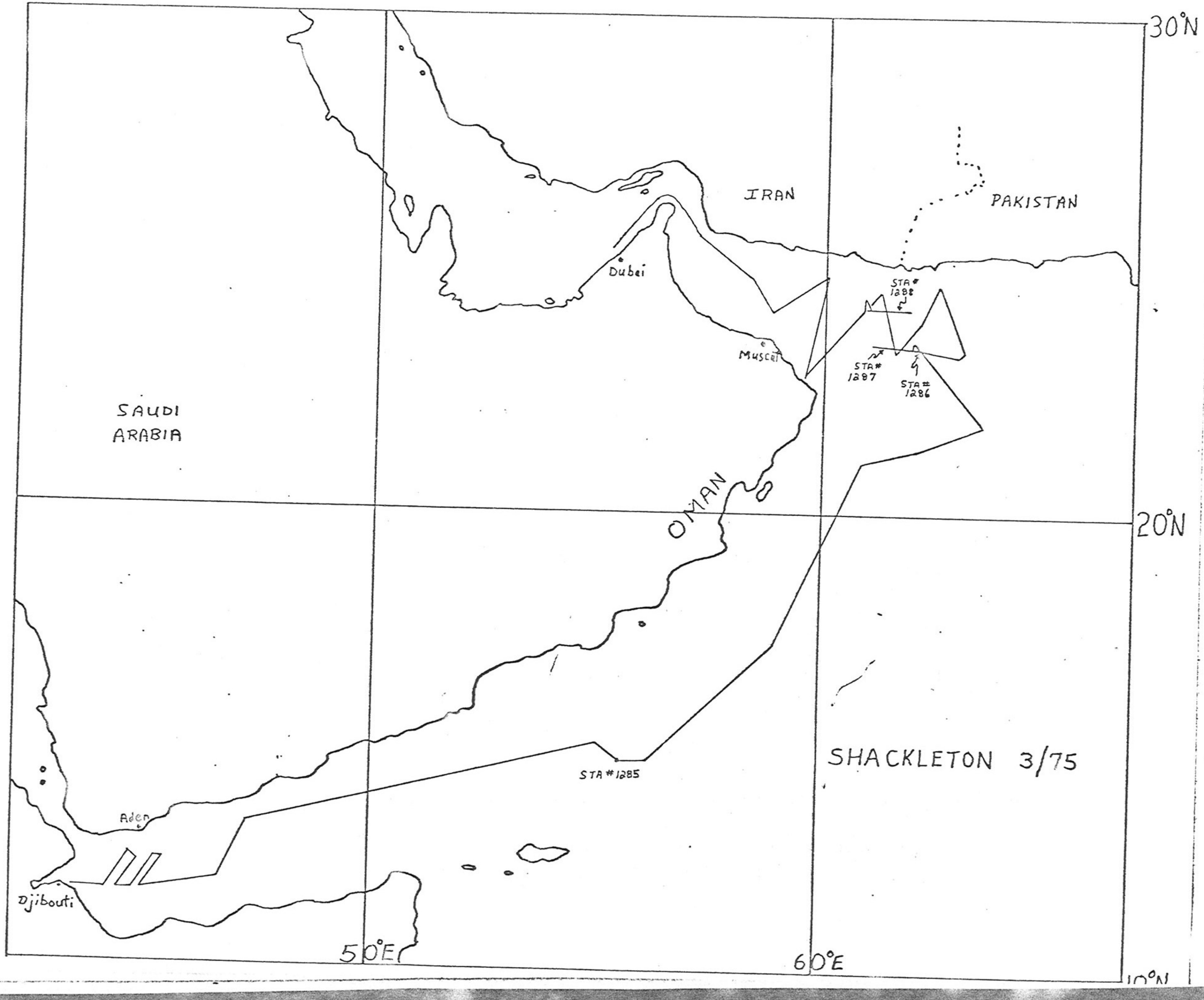
30°N
20°N
10°N
50°E
60°E
IRAN
PAKISTAN
SAUDI
ARABIA
OMAN
Dubai
Muscat
Aden
Djibouti
STA# 1288
STA# 1287
STA# 1286
STA# 1285
SHACKLETON 3/75

SHACKLETON 3/75 INTERPOLATED NAVIGATION