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NOAA TECHNICAL REPORT ERL 323-PMEL 21

Nazca Plate Program of the International Decade of Ocean Exploration - OCEANOGRAPHER Cruise-RP-2-OC-73

BARRETT H. ERICKSON

BOULDER, COLO.
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NAZCA PLATE PROGRAM OF THE INTERNATIONAL DECADE OF OCEAN EXPLORATION - OCEANOGRAPHER CRUISE - RP-2-OC-73

Barrett H. Erickson

The NOAA Ship OCEANOGRAPHER sailed to the Southeast Pacific in the spring of 1973 as part of the International Decade of Ocean Exploration Nazca Plate Program. Measurements of the gravity and magnetic field were made, seismic refraction and reflection operations conducted, and sea floor sediments sampled along the East Pacific Rise and across the Nazca Plate to the continental margin of South America. Detailed surveys were conducted on measurements made while at Easter Island. The operations are described and profiles of bathymetry and of magnetic and free-air gravity anomalies along more than 30,000 nautical miles of trackline are presented.

1. INTRODUCTION

The Nazca Plate Program is one of several sponsored by National Science Foundation (NSF) as part of the International Decade of Ocean Exploration. The field program for 1973 was conducted from the National Oceanic and Atmospheric Administration (NOAA) Ship OCEANOGRAPHER and the Hawaii Institute of Geophysics R/V KANA KEOKI. This report covers the portion of the investigation made from the OCEANOGRAPHER.

The program was supported jointly by NOAA and the NSF, and investigations of the geophysical, geochemical, and marine geological processes

processes occurring at the boundaries of the Nazca Plate were emphasized. In particular, the East Pacific Rise has been identified as a potentially important locality of mineralization of marine sediments. Several studies, therefore, were conducted on the rise to test the hypothesis that mineral concentrations are the result of geological processes occurring at the rise crest.

2. CHRONOLOGY AND DESCRIPTION OF CRUISE

The cruise was comprised of four legs: Seattle to Callao, Callao to Antofagasta, Antofagasta to Valparaiso via Easter Island, and Valparaiso to Seattle (fig. 1).

The personnel who were responsible for scientific operations and acquisition of data are identified in table 1.

2.1 Leg One - Seattle to Callao

The OCEANOGRAPHER departed from Seattle, Washington on 12 February 1973 and proceeded to the gravity test range off the Washington coast at Cape Flattery. After completing a series of tests, the ship proceeded southward, making measurements of the water depth and the geomagnetic and gravity field while underway. Crossing the equatorial region at 108 1/2°W, a series of closely spaced XBT measurements were made at the request of the Pacific Oceanographic Laboratories (POL). Along with similar measurements to be made on the return trip, these measurements were to be used in an analysis of temporal changes in equatorial current behavior. Several attempts to core in the region of the rise crest near

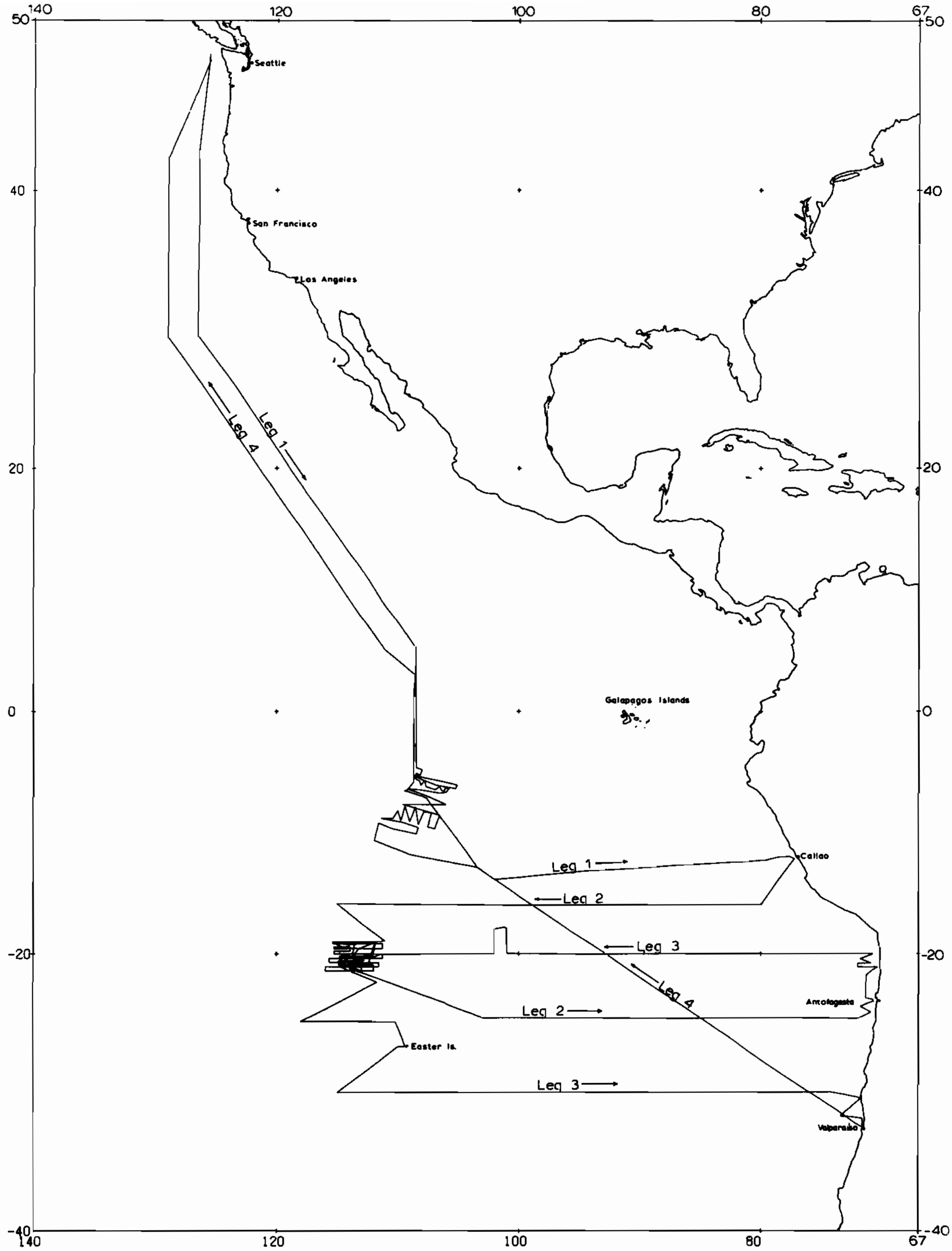


Figure 1. Track of the NOAA Ship OCEANOGRAPHER - Nazca Plate Project, 1973.

Table 1. Personnel Responsible for Acquisition of Data and Related Operational Activities

OCEANOGRAPHER Key Personnel	
Capt H. R. Lippold, Jr.	Commanding Officer
Cdr W. K. Jeffers	Executive Officer
LCdr R. V. O'Connell	Operations Officer
Lt L. K. Thomas	Navigation, Magnetics Officer
Lt R. W. Riley	Seismic and Coring Officer
Lt (jg) R. E. Karlin	Gravity Officer
Lt (jg) C. S. Nelson	Data Processing, Smooth Plotting Officer
Ens H. B. Thelen	Electronics
Scientific Personnel	
Leg One - Seattle to Callao:	
Dr. Robert E. Burns	POL Chief Scientist
William H. Lucas	POL
W. A. Stewart Wright, Jr.	USNOO
Peter Kalk	OSU
Leg Two - Callao to Antofagasta:	
Barrett H. Erickson	POL Chief Scientist
William H. Lucas	POL
LCdr John P. Vandermeulen	POL
W. A. Stewart Wright, Jr.	USNOO
Antenor Aleman	Petroleos del Peru
Lt Cesar Vargas	Ministerio De Marina, Peru
Leg Three - Antofagasta to Valparaiso via Easter Island:	
Barrett H. Erickson	POL Chief Scientist
LCdr John P. Vandermeulen	POL
Joe Bantum	USNOO
William Eklund	OSU
J. Frisbee Campbell	HIG) Antofagasta to Easter Island
Steven Dang	HIG) Antofagasta to Easter Island
Lauro Miranda	Instituto Hidrografico, Chile
Antenor Aleman	Petroleos del Peru - Easter Island to Valparaiso
Leg Four - Valparaiso to Seattle:	
Dr. Robert E. Burns	POL Chief Scientist
David K. Rea	OSU
Joe Bantum	USNOO

POL - Pacific Oceanographic Laboratory (now - Pacific Marine Environmental Laboratory.
OSU - Oregon State University
HIG - Hawaii Institute of Geophysics
USNOO - U. S. Naval Oceanographic Office

5°S were made without success because of problems with the deep-sea winch. The ship then proceeded eastward across the Nazca Plate and arrived at Callao, Peru on 2 March 1973.

2.2 Leg Two - Callao to Antofagasta

The ship left Callao on 7 March 1973 and proceeded westward, crossing the Nazca Plate at 16°S. West of the rise crest the ship turned southeastward and passed through a region which had been surveyed earlier by scientists from Lamont Geological Observatory aboard the R/V CONRAD. A survey of a region of the rise crest between 19°S and 21°S commenced on 15 March. Closely spaced east-west lines were run across the crest, extending on each side beyond the magnetic anomaly reflecting the Gilśa event. Two cores were taken, one in the survey area just east of the rise crest and one on the east flank of the rise. A single Sonobuoy ASPER run was made parallel to and east of the rise crest. Upon completion of this survey, the ship proceeded southeastward and then eastward along latitude 25°S to the margin of the South American Continent. Three crossings of the continental margin were completed while using a continuous seismic profiling (CSP) system before arriving at Antofagasta, Chile, on 30 March 1973.

2.3 Leg Three - Antofagasta to Valparaiso via Easter Island

Departing Antofagasta on 4 April 1973, a number of crossings of the continental margin north of Antofagasta were made while using the CSP system. Proceeding westward along 20°S, a series of ASPER runs were made across the eastern edge of the Nazca Plate and later across the Nazca Ridge. A core was taken on the western flank of the fossil rise near 94 1/4°W. Between 101°W and 102°W the ship moved north to 18°S for the initial 2-ship reversed seismic refraction profiles. Cores were taken and heat flow measurements made while the OCEANOGRAPHER was recording at each end of the profile.

Returning to 20°S the ship proceeded westward into the area of the rise crest which had been surveyed during Leg Two. A schedule was drawn up to occupy the coring sites efficiently, accommodate the planned 2-ship refraction work, and allow additional survey lines to be run in certain areas. Twenty coring stations were occupied before leaving the area.

Three 2-ship refraction lines were run. North-south reversed lines on the rise crest and on the east flank of the crest were completed. A long east-west "line" consisting of multiple Sonobuoy drops crossed the rise crest and intersected the northern ends of both north-south lines.

The ship proceeded southwestward and then southeastward to jog across the area north of Easter Island. This jog was coordinated with the track of the KANA KEOKI to better define characteristics of a small crustal plate located in that region.

After arrival at Easter Island on 27 April 1973 and while at anchor off Janga Roa, fuel and water were transferred from the OCEANOGRAPHER to the KANA KEOKI as previously arranged. Measurements of gravity on Easter Island were made by parties from the OCEANOGRAPHER AND KANA KEOKI to supplement similar measurements made during a previous visit of the OCEANOGRAPHER in 1970. Additional details are given in Appendix A.

The ship left Easter Island on 29 April 1973 and sailed southwestward before turning to proceed eastward along 30 1/2°S to the continental margin. Three cores were taken along the eastward track, two on the east flank of the rise and one in the southern extension of the Bauer Basin. Three crossings of the continental margin north of Valparaiso with the CSP system were completed before entering Valparaiso on 8 May 1973.

2.4 Leg Four - Valparaiso to Seattle

The ship left Valparaiso on 17 May 1973 after 9 days in port. Several days had been spent awaiting the abatement of heavy weather that closed the port and delayed refueling. The ship proceeded northwestward towards a core site in the Bauer Basin. After coring, extensive surveys in the rise crest area between 5°S and 11°S augmented work done in that area by OSU and HIG during the first Nazca Plate Program field effort in 1972. An additional core was taken near 8°S before sailing northward towards Seattle. A second series of XBT measurements were made across the equatorial region to complement those made on Leg One. Tests were conducted on the gravity test range off Cape Flattery before entering the Strait of Juan de Fuca and proceeding to Seattle, arriving there on 11 June 1973.

3. INSTRUMENTATION AND DATA ACQUISITION

Much of the instrumentation was an integral part of the OCEANOGRAPHER's basic instrumentation system. Additional equipment was brought aboard by project personnel to accomplish specific tasks such as seismic refraction and reflection, coring, and 3.5 kHz-sounding.

Data acquired were of three types: (a) underway data consisting of depths and magnetic and gravity field variations. These data were recorded on analog recorders and on magnetic and paper tape; (b) seismic reflection data obtained over the continental margins and recorded on an analog recorder only; (c) data obtained on station and composed of the seismic refraction and heat flow records and results from the coring operations.

Digitized values of water depth and of the earth's gravity and magnetic field were recorded each five minutes on magnetic and paper tape by an offline Raw Data Logger. Also recorded were date, time of day (GMT) and the gyro heading and EM log values.

The data from these tapes were then processed on the OCEANOGRAPHER's Univac 1218 computer. Each day the raw data from these tapes were listed to permit verification of the recorded values by comparison with the analog records. Raw data were edited as necessary. Navigation data were reviewed, smooth-plotted, and evaluated to select a set of geographical positions that best described the ship's track. These positions were then used, together with the edited observational data, to compute a set of edited data which provides a geographic position for each observation. Magnetic and gravity field anomalies were computed by removing theoretical regional fields that are dependent on geographic position.

3.1 Navigational Data

The prime source of information for navigational control was the satellite navigation system. Two shipboard systems were employed: a Magnavox 706 satellite navigator and an older prototype AN/SRN-9 unit. These two units were used simultaneously on closely spaced satellite passes or in a backup mode when necessary.

3.2 Water Depth Measurements

Soundings were made with a 3.5 kHz system which also recorded reflections from sub-bottom sediment interfaces. The system was composed of a Raytheon Correlation Echo Sounding Processor (CESP-1), Raytheon PTR-105 transceiver, and an array of twelve EDO 240-H transducers in a fresh water filled enclosure mounted in the ship's center well. Soundings were displayed on a Raytheon PF-101 recorder using a one-second (400 fathom) full-scale sweep. This display was complemented with a 10-second (4000 fathom) full-scale display from a 12 kHz system. The dual display was most advantageous as it not only provided a view of the regional bathymetry along the ship's track but eliminated uncertainties in determining which 400-fathom segment was being displayed by the 3.5 kHz system.

Each five minutes a sounding value was read from the graphic recorder and entered into the Raw Data Logger by setting thumb-wheels at a remote entry terminal. Graphic records were removed at the end of each day (GMT) and used to verify the digitized values from the Raw Data Logger.

3.3 Magnetic Field Measurements

Measurements of the earth's magnetic field were made with a Varian Direct Reading Magnetometer. The sensor was towed at least 750 feet behind the ship to minimize the influence of the ship's field on the measurements. Total field values were measured once a minute and displayed on a Texas Instrument Servo-writer analog recorder using a chart speed of six inches per hour and a full scale value of 1000 gammas. Each five minutes the values were sampled and recorded by the Raw Data Logger. The graphic records were removed each day and used to verify the digitized values from the Raw Data Logger.

3.4 Gravity Field Measurements

The earth's gravity field variations were measured with two seagoing gravity meters. The OCEANOGRAPHER's Askania GSS-2 gravimeter and Anshutz gyrotable were overhauled at the factory during the fall of 1972. Timely return of these instruments was uncertain and arrangements were made to borrow from the U. S. Navy a La Coste and Romberg gravity meter with a stablized platform. Both instruments were on board at sailing time.

The Askania system recorded continuously on its integral Honeywell multipen analog recorder and was sampled automatically each five minutes by the Raw Data Logger. No corrections were made to the data for cross-coupling errors.

The L&R sea gravity meter was a self-contained unit and recorded data on analog records, magnetic tape, and on a teletype printer.

Base ties were made at each port using Worden and L&R land gravity meters. Values for each base station were obtained from Aeronautical Charting and Information Center prior to departure. [Base tie data are given in table]

During the project the observed gravity values for the L&R and the Askania meters were compared daily to monitor their performance and response to changes in the gravity field. The comparisons were remarkably consistent although the Askania data were not corrected for cross-coupling errors and reflected a slower response time. The Askania meter constant is not known with great certainty, and a reflection of this was a gradual divergence of the data values from the two systems. A factory-assigned value of 101.0 did not provide satisfactory results. Analysis of data during the 1972 season which ranged from the latitudes of Honolulu to those of Kodiak indicated a constant of 101.7 to be more likely. Comparison of the data from the L&R meter with the data from the Askania similarly indicated a meter constant of 101.5 to 101.7. A constant of 101.6 was adopted.

Land gravity measurements were made on Easter Island, Chile on 28 April 1973. Details of this work are given in Appendix A.

3.5 Seismic Reflection Profiling

Continuous seismic profiling measurements were made over the continental margin near Antofagasta and Valparaiso. This system was composed of a 120-cubic-inch Bolt air gun, Model 1900C, a Model K98 Rix air compressor, Teledyne and Aquatronics hydrophone streamers, and a Teledyne amplifier/filter system.

Table 2. Gravity Base Tie Data - Askania Meter No. 22, K = 101.6

Date	Base	Base Value	ZMG	Change in ZMG
<u>Leg One</u>				
12 Feb 73	PMC*, Seattle	980 742.2	977 162.3	
2 Mar	Callao, Peru ACIC #0091-4	978 306.10	977 160.3	-2.0 milligals
<u>Leg Two</u>				
7 Mar	Callao, Peru ACIC #0091-4	978 306.10	977 158.96	
30 Mar	Antofagasta, Chile ACIC #0224-0	978 903.24	977 155.74	-3.2 milligals
<u>Leg Three</u>				
3 Apr	Antofagasta, Chile Woolard & Rose #WH 1063	978 908.3	977 158.79	-3.2 milligals
13 May	Valparaiso, Chile ACIC #0301-1	979 632.51	977 155.56	
<u>Leg Four</u>				
13 May	Valparaiso, Chile ACIC #0301-1	979 632.51	977 155.56	-3.0 milligals
11 June	PMC*, Seattle	980 742.2	977 152.06	

*Base located next to Hydrant at NW corner of warehouse at foot of the National Ocean Survey Pier, 1801 Fairview Avenue East. This station was established by a tie to ACIC #0252-1.

Alternately a system of HP 8875A amplifiers and Krohn-hite 3700 bandpass filters was used. Results were displayed on an EPC Model 4100 graphic recorder.

The air gun was mounted in a locally designed and fabricated towing assembly and towed from the starboard side of the fantail. The hydrophone streamer was towed from a boom extending off the port side of the fantail.

3.6 Seismic Refraction Measurements

Seismic refraction measurements were made in conjunction with HIG personnel on the KANA KEOKI. Explosives used as sound sources were carried and detonated by the KANA KEOKI: the OCEANOGRAPHER served in a listening and recording role only.

The seismic refraction measurements were made using modified SSQ-41 Sonobuoys as acoustic sensors. Transmission from the Sonobuoys were received with a pair of stacked yagi antennas mounted on rotators at each end of the aftermast yardarm. RF preamplifiers were located in a junction box on the mast. Realistic "Patrolman" tunable FM receivers were used to receive the transmissions; the output was conditioned by combinations of HP-8875A amplifiers and Krohn-hite 3700 bandpass filters prior to display on a Geospace Model 1800 electrostatic recording oscillograph. Communications with the KANA KEOKI were maintained with single-sideband radio transceivers furnished by HIG.

3.7 Coring Operations

Cores were taken in specific regions of the East Pacific Rise Crest and in the Bauer Basin to the east, primarily for the purpose of investigating the areal extent of the metal-rich sediments and their characteristics. These investigations are being pursued by scientists at Oregon State University who furnished the piston coring equipment and directed the sampling program.

Although operational problems precluded obtaining cores planned for Leg One, a successful sampling program was carried out for the remainder of the project. Cores on Leg Two were limited to those in the Bauer Basin. Detailed field work in the rise crest area during Leg Two was used to plan a sampling program for this area which was carried out on Leg Three. Locations of the cores obtained are shown in fig. 2.

3.8 Heat Flow Measurements

At the request of HIG, heat flow measurements were made with an HIG-furnished heat probe. The measurements were made at coring sites when sufficient time was available and sea-floor characteristics were suitable. Locations of the heat flow measurements are shown in fig. 2.

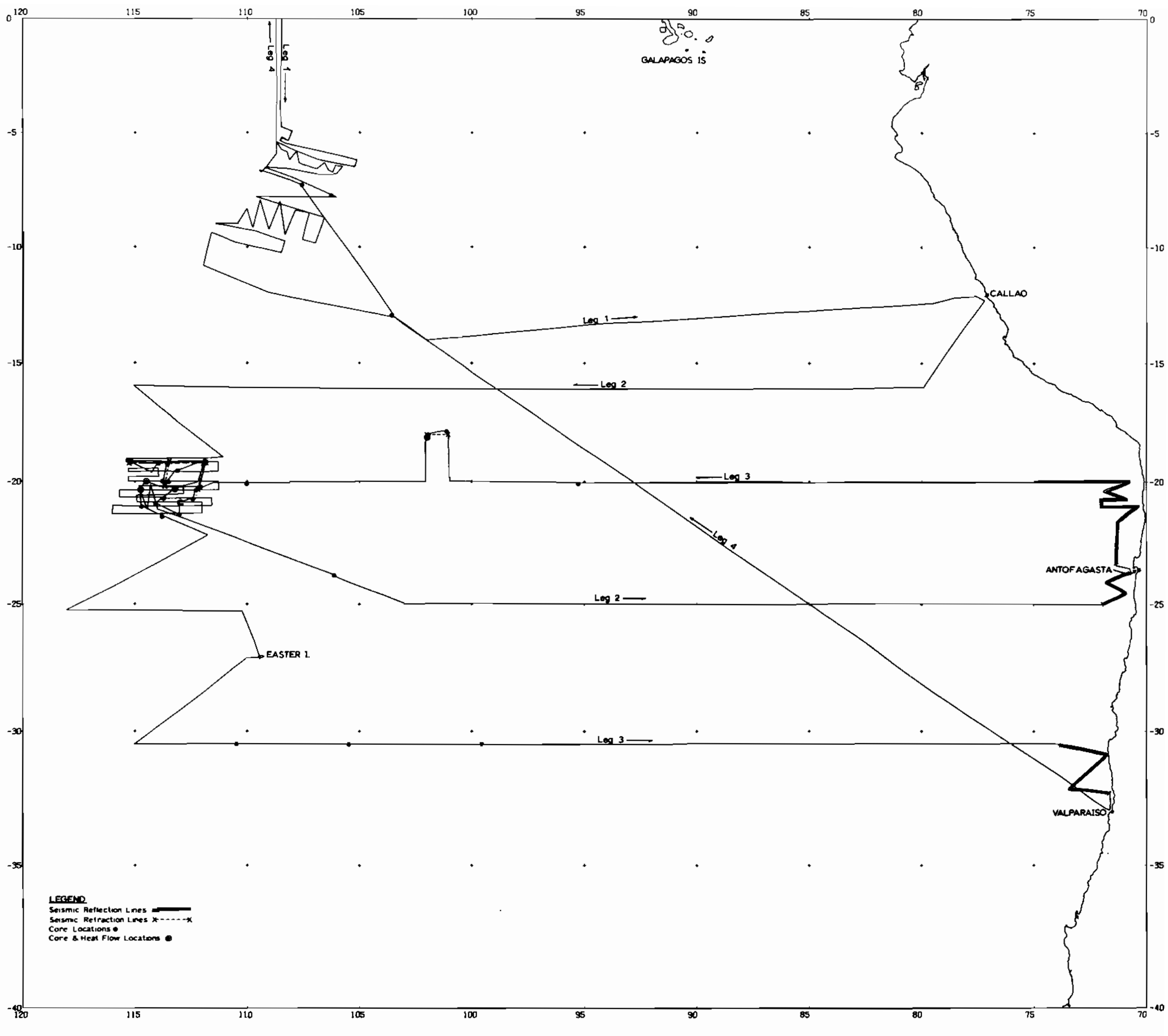


Figure 2. Location of tracklines, seismic measurements, cores and heatflow stations in the Nazca Plate Project Area.

3.9 XBT Measurements

Measurements of temperature variations to 450 meters were made with a Sippican Corporation Expendable Bathythermograph MK-3 Recorder and T-4 Probes. Measurements were made every four hours except in the waters north of the equator where they were made every six hours. The locations of the measurements are shown in fig. 3. These data [identified as NODC XBT Cruise No. 44546 (OCEANOGRAPHER),] are available from the National Oceanographic Data Center, Washington, D. C., on request.

3.10 Additional Measurements

Several programs were conducted during the Nazca Plate Project to take advantage of the capability to continuously sample the surface water while underway.

In response to a request of Battelle Northwest, a large-volume water sampler was operated to acquire samples of particulates in the surface water in support of a study of radionucleides and trace elements in ocean water.

Throughout the project, sea surface temperature and salinity were monitored continuously on analog recorders.

An experimental water sampling and analysis program was conducted to establish the feasibility of running routine on-board chemical analysis of water samples and obtaining data along upwelling zones.

In response to a request from POL, a line of closely-spaced XBT measurements were made along 108 1/2°W between 5°N and 5°S on Leg One and Leg Four. The data from these measurements will support studies of

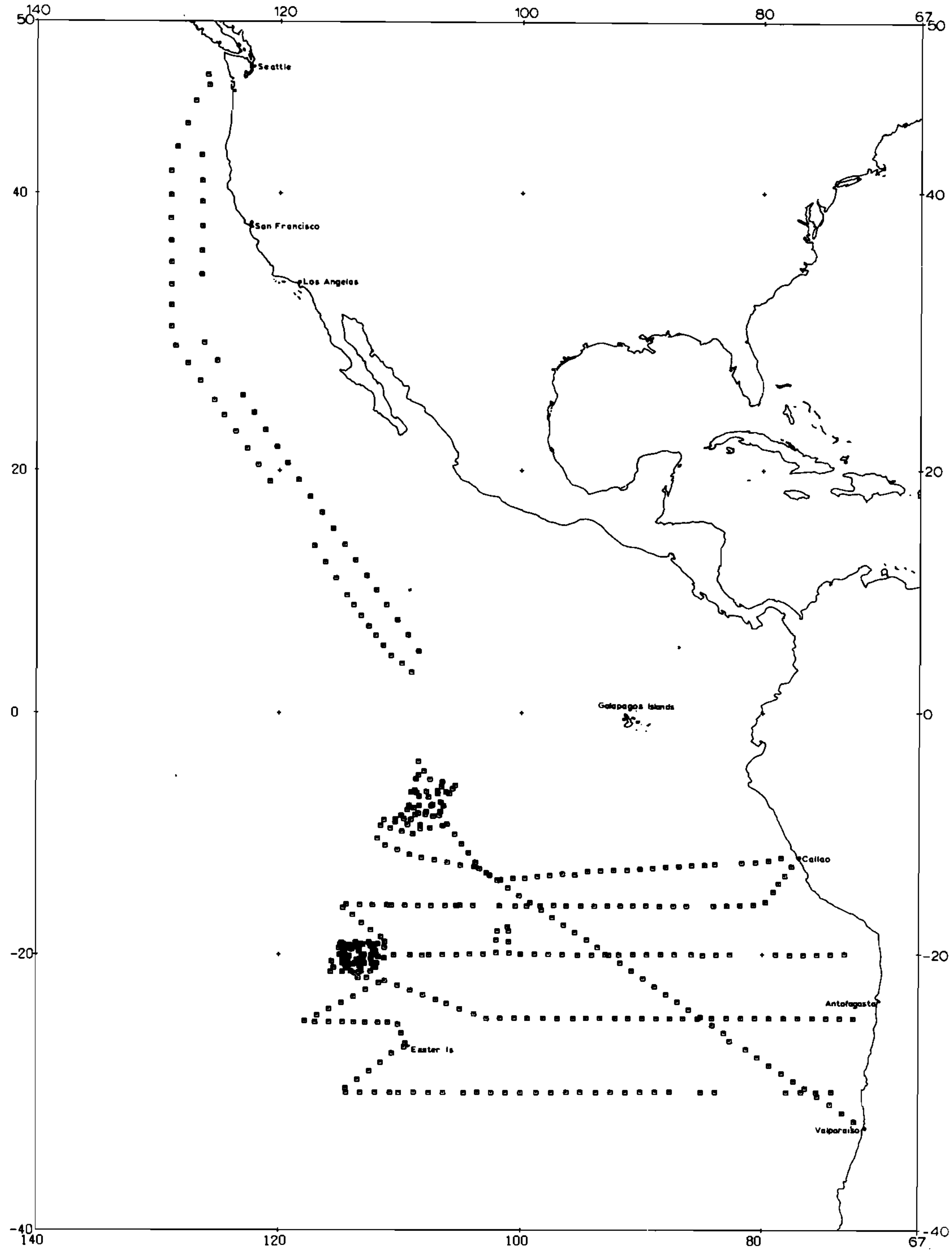


Figure 3. Location of XBT measurements. Not shown are the locations of closely spaced measurements taken at the equator for another project (see section 3.10).

the variability of the equatorial currents in the eastern Pacific.

4. FINAL DATA PROCESSING

Edited data from the OCEANOGRAPHER's Geophysical Trackline Data Acquisition and Processing System were recorded on punched paper tape for transmittal to PMEL. At PMEL the data were transferred to a punched card format and screened for improper time sequences, format errors, unreasonable values, etc., using established routines on IBM-1620 and CDC-6400 computers. Navigational information was reviewed for conformance to the actual ship's track. Information was added or deleted as necessary to achieve a set of non-redundant data which best described the ship's track. The data were then stored in the PMEL ARIES system (Archival, Retrieval, Information and Emendation System), edited as appropriate, and plots made of the measured variables vs. distance along the ship's track. The plots were then reviewed for gaps or inexplicable variations in the data and the original records again examined as necessary to achieve fidelity of the digital data. Profile plots of the final values are presented in Appendix B.

5. DISPOSITION OF DATA

The navigational information and measured values have been archived in digital form at PMEL in the ARIES format. The data, in the merged-merged format described in "Formats for Marine Geophysical Data Exchange", NAS/NRC, 1972, have been sent to OSU, HIG, and the Marine Geology and Geophysics Group of the Environmental Data Service (EDS) for use and further dissemination as appropriate. Original analog records have been sent to EDS for microfilming and archiving except for the seismic reflection and refraction records which were microfilmed by EDS and then forwarded to HIG and OSU. Copies of "Cruise Report - NAZCA Plate Project, RP-2-OC-73", prepared by OCEANOGRAPHER personnel to document in detail the operational accomplishments and procedures, have been forwarded to HIG, OSU, and EDS.

6. APPENDIX A

Gravity Survey at Easter Island, Chili

Three years ago, on 22 March 1970, gravity measurements were made on Easter Island (Chile) by scientists from the Hawaii Institute of Geophysics (HIG) and the NOAA Ship OCEANOGRAPHER during an unscheduled stop for a medical evacuation. Gravity measurements were made along the roadways at identifiable locations; elevations were measured barometrically.

The OCEANOGRAPHER returned to Easter Island with the HIG R/V KANA KEOKI on 28 April 1973 for a scheduled stop during the 1973 IDOE Nazca Plate program field season. The occasion provided an opportunity to augment the previous work with measurements off of the roads, particularly over the three main volcanic centers: Rana Kao, Mount Terevaka, and the Poike Peninsula region. The work described here provided data over Mount Terevaka and was accomplished on 28 April 1973. Measurements on Rana Kao and the Poike Peninsula were made by HIG personnel and will be reported elsewhere.

The stations were located using a 1:25,000 scale contour map of Isla de Pascua prepared for the Chilean Air Force from aerial photographs taken in 1964. At each station horizontal angles between suitable landmarks were measured with a sextant. The position of each station was later determined with the use of a three-armed protractor; elevations were read from the contours on the map at that location.

The gravity base station at the boat landing near Hana Piko wharf (ACIC 4841-1) was used as reference and to determine drift. Two stations from the 1970 work were reoccupied; Vaitea Ranch and the road intersection near Ana Kena Cove. Total drift during the day's measurements was 0.17 milligals. The principal facts are shown in table A-1. The station locations are illustrated in figure A-1.

Gravity measurements were made with Worden gravity meter no. 113. The party chief was B. H. Erickson, PMEL; the gravity meter observer was Lt. R. E. Karlin; the horizontal angles were measured by Lt. Cdr. R. V. O'Connell.

The survey was made with the kind permission of Sr. Moises Sudy Castro, governor of Easter Island. Sr. Fred Dwyer-Jensen, administrator of the government ranch, personally provided transportation and guided the party throughout the area. Mr. Gerald Svat, scientific officer at the U. S. Embassy in Santiago, Chile, was able to obtain a copy of the scarce 1:25,000 map of Isla de Pascua. We thank these gentlemen and are indebted to them for their kind assistance.

The original log book has been archived and microfilmed by Environmental Data Service with the records of the Nazca Plate Program.

Table A-1. Gravity Measurements made on Easter Island, April 1973

	Grid Coordinates[1]						
	North	East	Elevation[1]	Meter Reading	ΔMilligals[2]	Free Air Anomaly	Bouguer[3] Anomaly
Base ACIC #4841-1 (4)	6,995,680	654,320	0	500.4	0	133	133
Vaitea Ranch	6,999,020	662,370	167	404.0	-40.76	145	128
1	7,000,160	661,650	290	348.0	-64.44	160	130
2	7,001,000	661,210	368	314.6	-78.56	171	132
3	7,001,970	660,760	442	285.3	-90.95	182	135
4	7,003,050	660 320	507	231.1	-113.86	180	127
5	7,003,100	660,510	465	266.9	-98.71	182	133
6	7,003,400	661,240	450	279.7	-93.29	182	136
7	7,003,830	661,710	400	302.6	-83.61	177	135
8	7,004,130	662,290	357	319.4	-76.48	171	134
Road Intersection near Ana Kena Cove	7,003,910	666,410	19	480.6	-8.23	135	133
Base ACIC #4841-1	6,995,680	654,320	0	500.0	0	133	133

(1) Grid coordinates and elevations, in meters, from the 1:25,000 scale map published in 1968 for the Air Force of Chile.
(2) Based on a meter constant of 0.423 milligals per scale division and corrected for meter drift.
(3) Bouguer anomaly based on an infinite plate with a density of 2.5 g/cc.
(4) ACIC #4841-1 at 27°09'S, 109°26'W has an adopted value of 979,254.32 milligals. Theoretical value from the International Gravity Formula is 979.121.59 milligals.

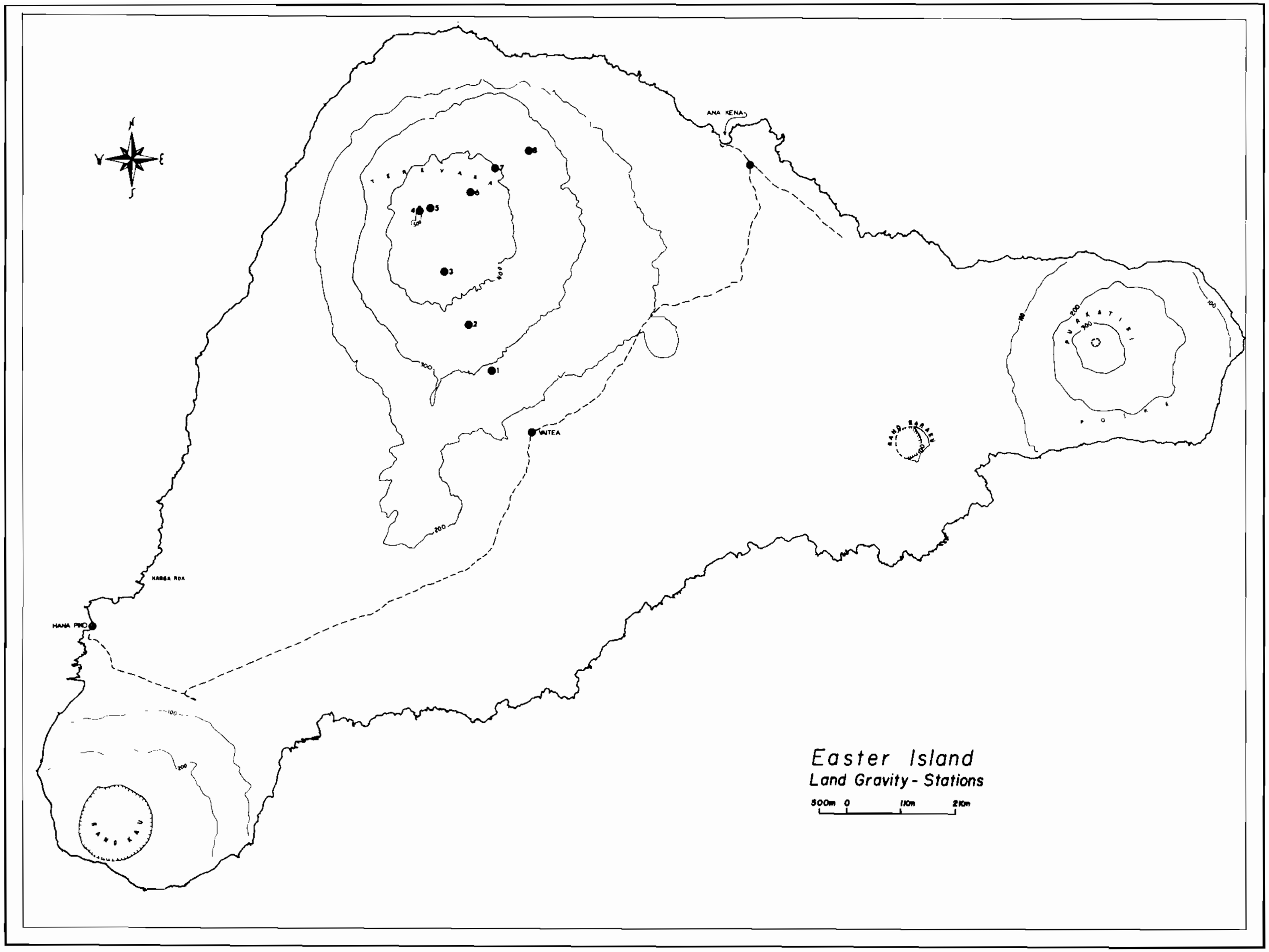
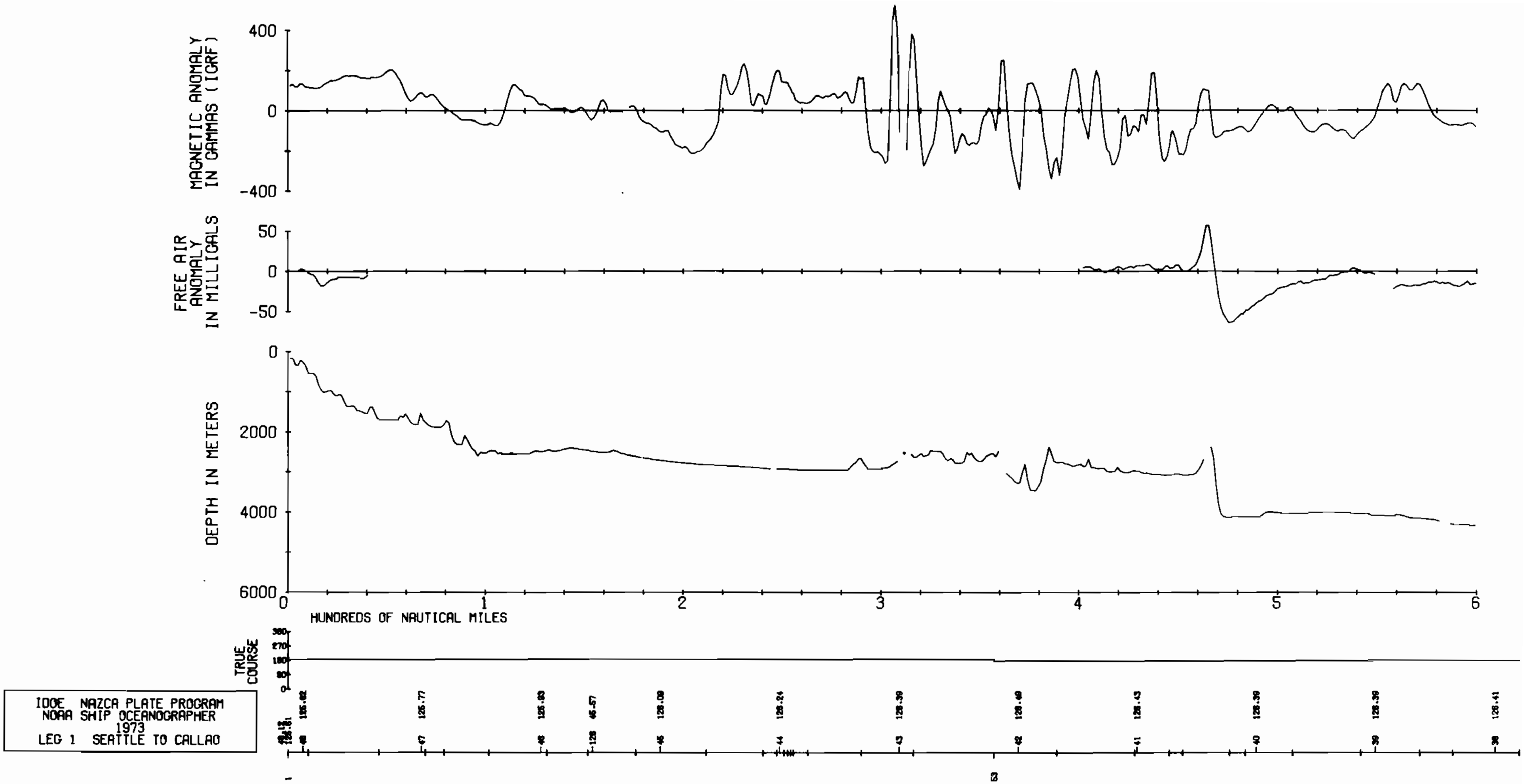


Figure A-1. Location of gravity measurements made by NOAA personnel during the 1973 Nazca Plate Project. Selected contours and roads are shown.

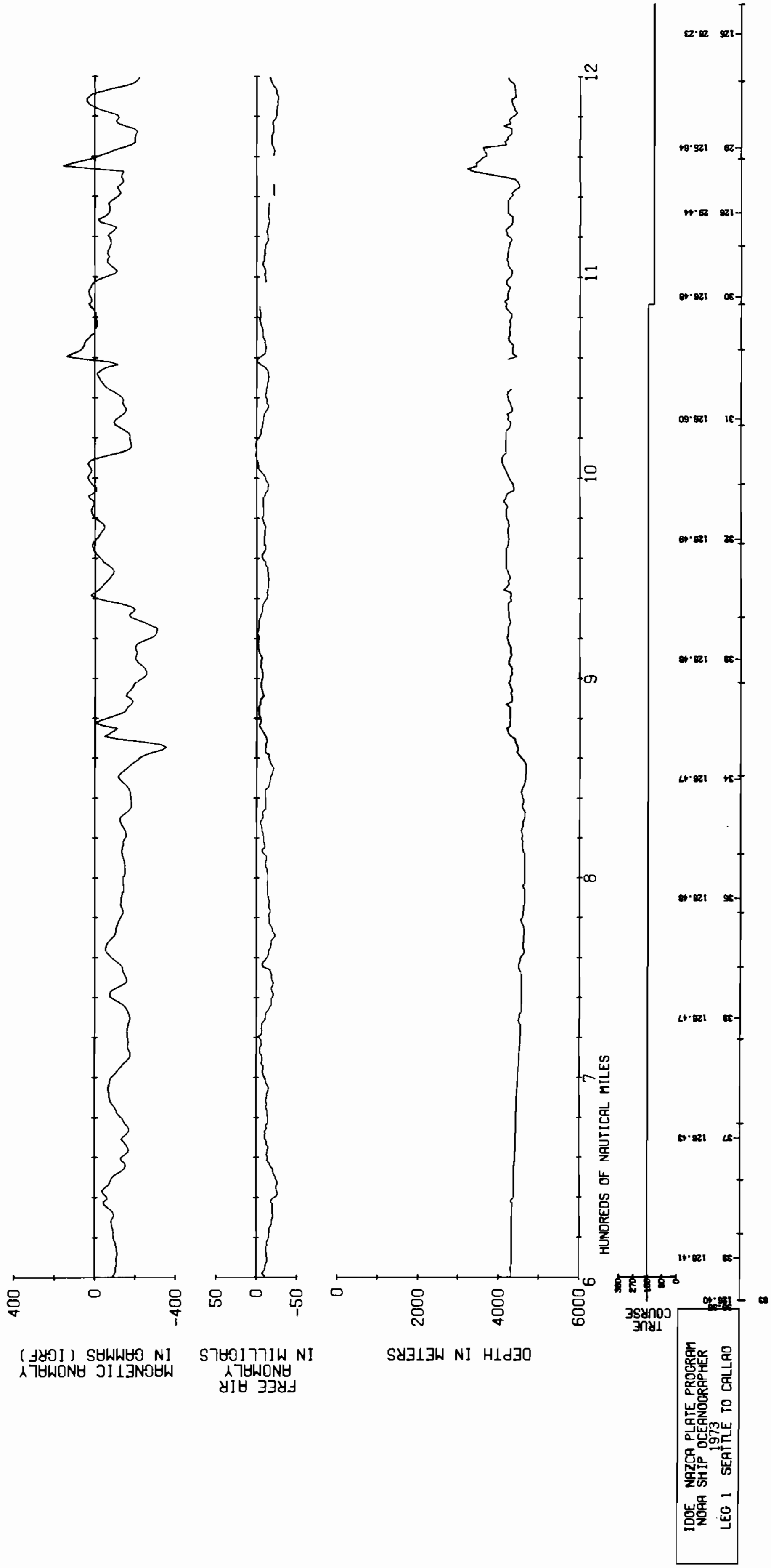
7. APPENDIX B

Profiles of Geophysical Data

In this appendix, profiles of the water depth and of anomalies in the earth's magnetic and gravity field are presented. The axes are labeled. Depths are given in uncorrected meters based on a sound velocity of 1463.04 meters per second (4800 feet per second). The course of the ship is shown graphically. Full ticks or half-ticks below the line at the very bottom of each profile show the location of navigational fixes. Where half-ticks below the line occur they are labeled with the fix identification number. Half-ticks above the line are labeled and mark the intersection of the trackline with each integer degree of latitude and longitude encountered.



MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
0
1
2
3
4
5
6
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 1 SEATTLE TO CALLAO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MAGNETIC ANOMALY IN GAMMAS (IGRF)
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FREE AIR ANOMALY IN MILLIGALS
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HUNDREDS OF NAUTICAL MILES
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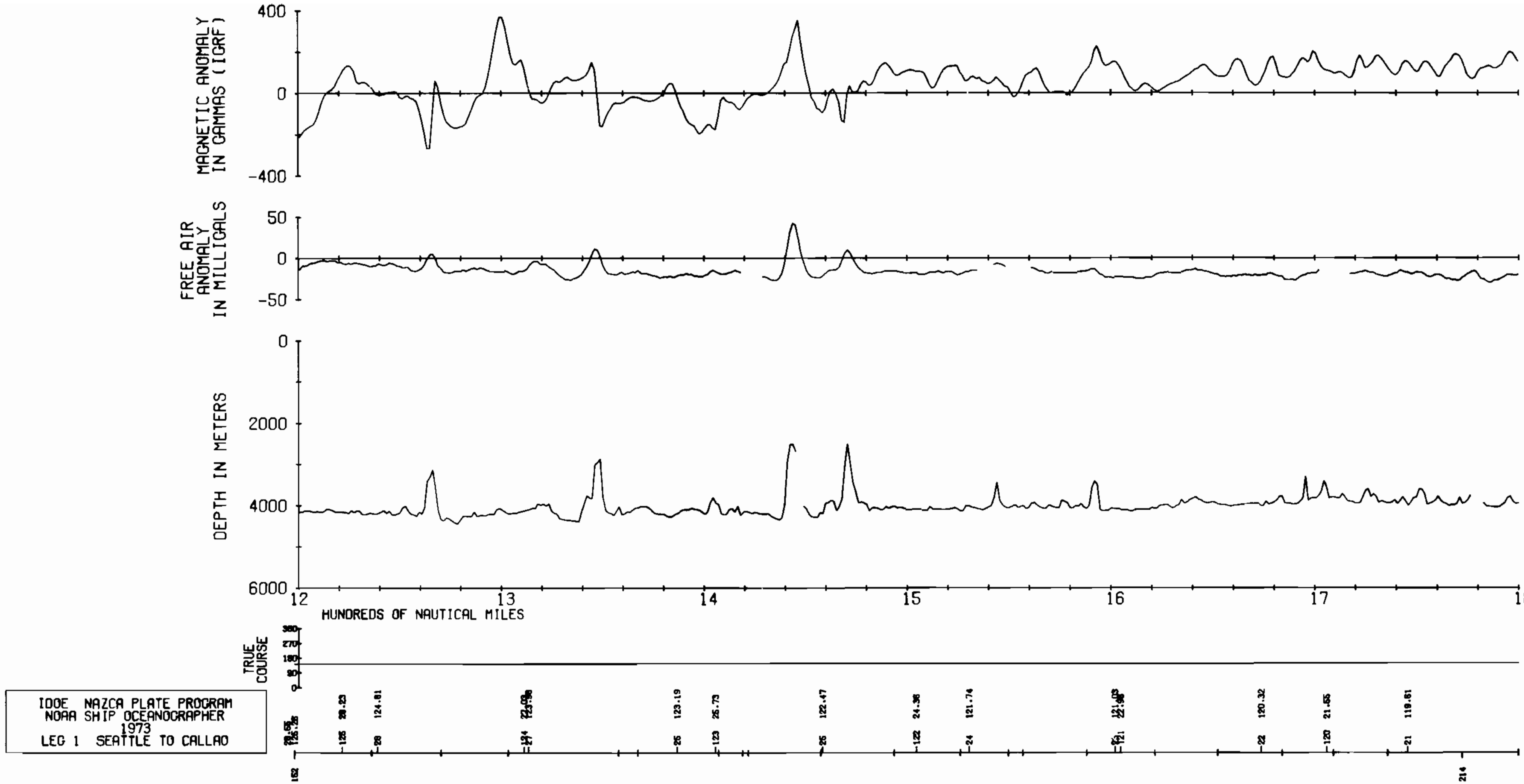
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FREE AIR ANOMALY IN MILLIGALS
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DEPTH IN METERS
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HUNDREDS OF NAUTICAL MILES
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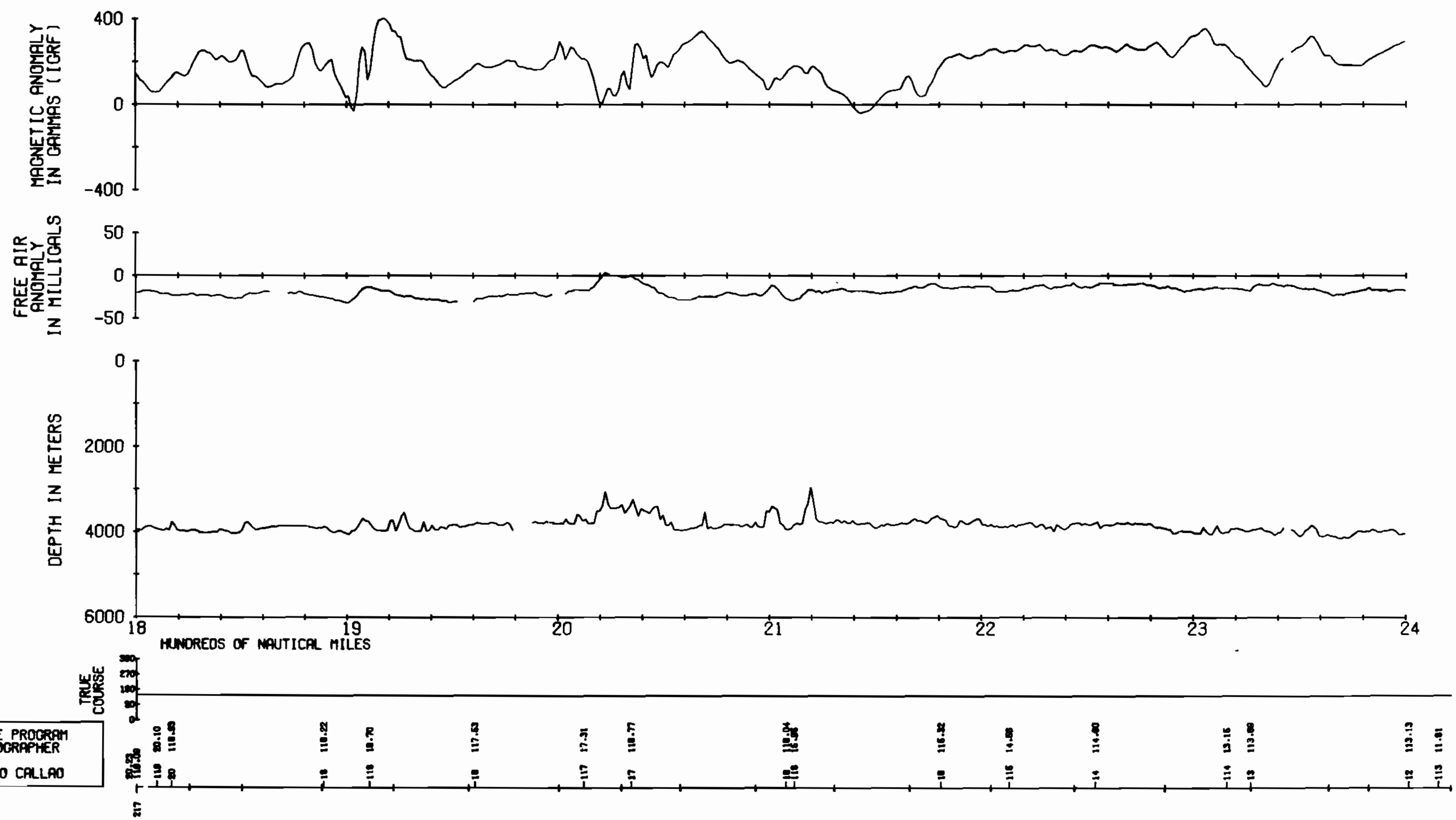
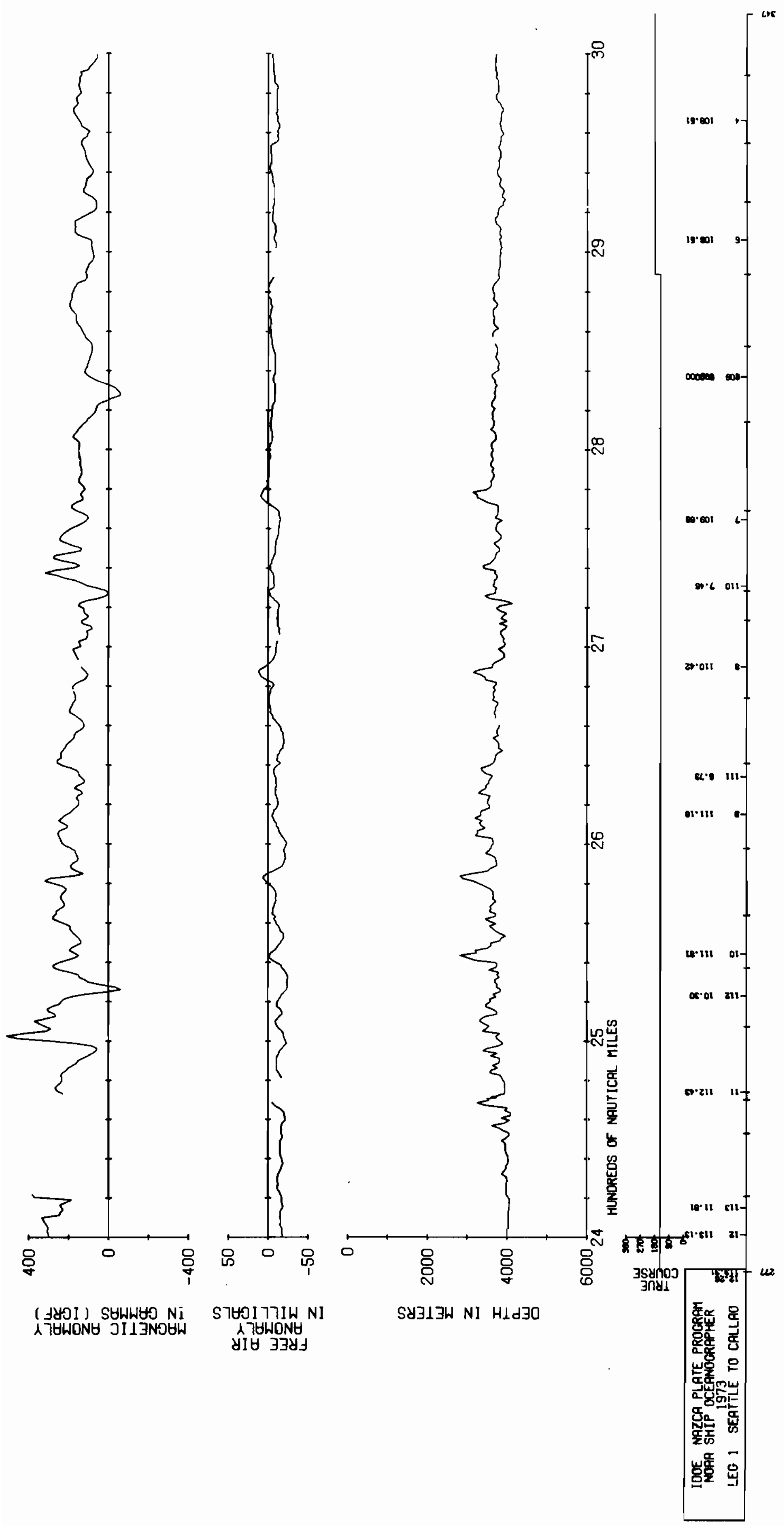
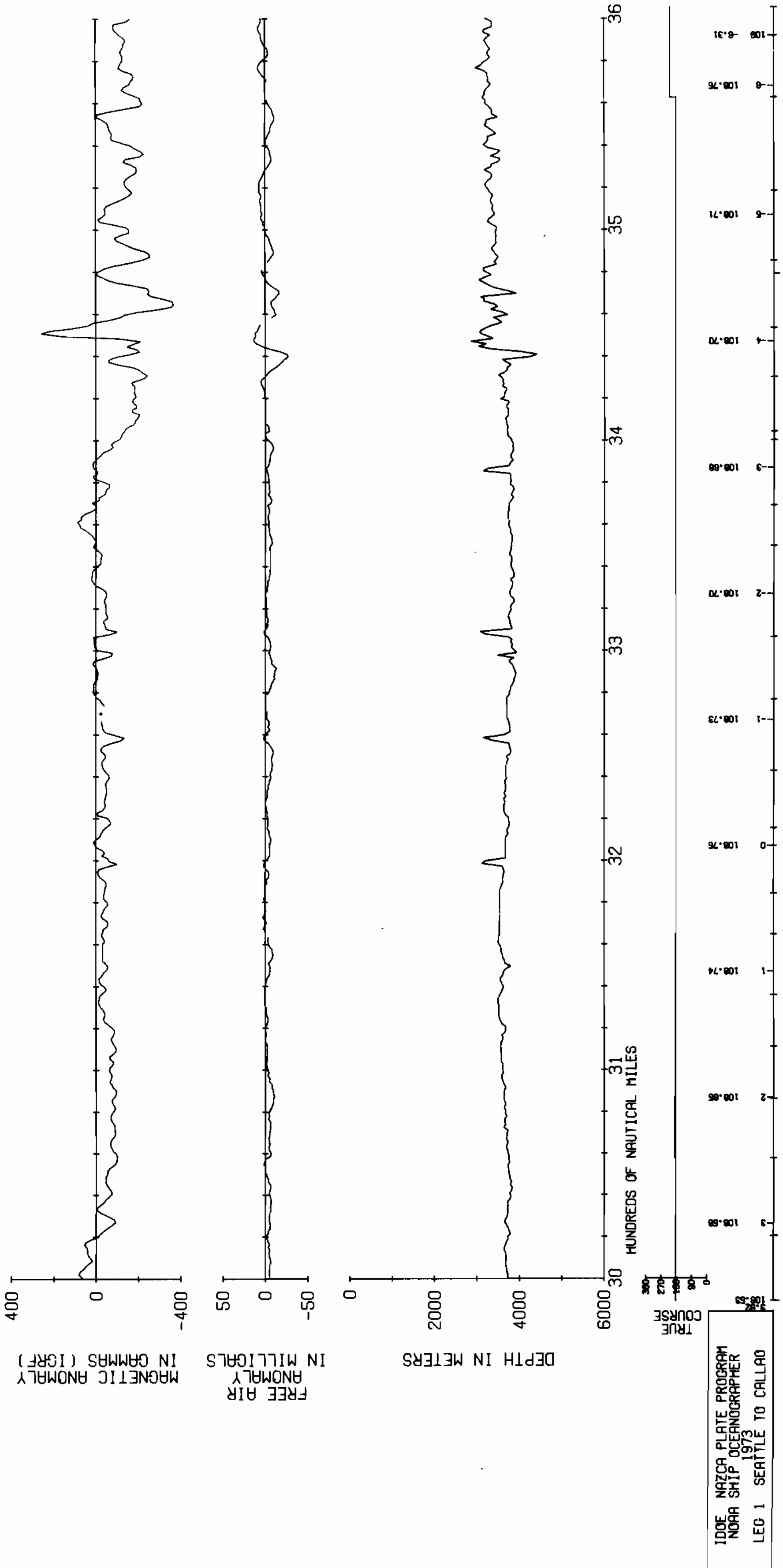
1973
LEG 1 SEATTLE TO CALLAO



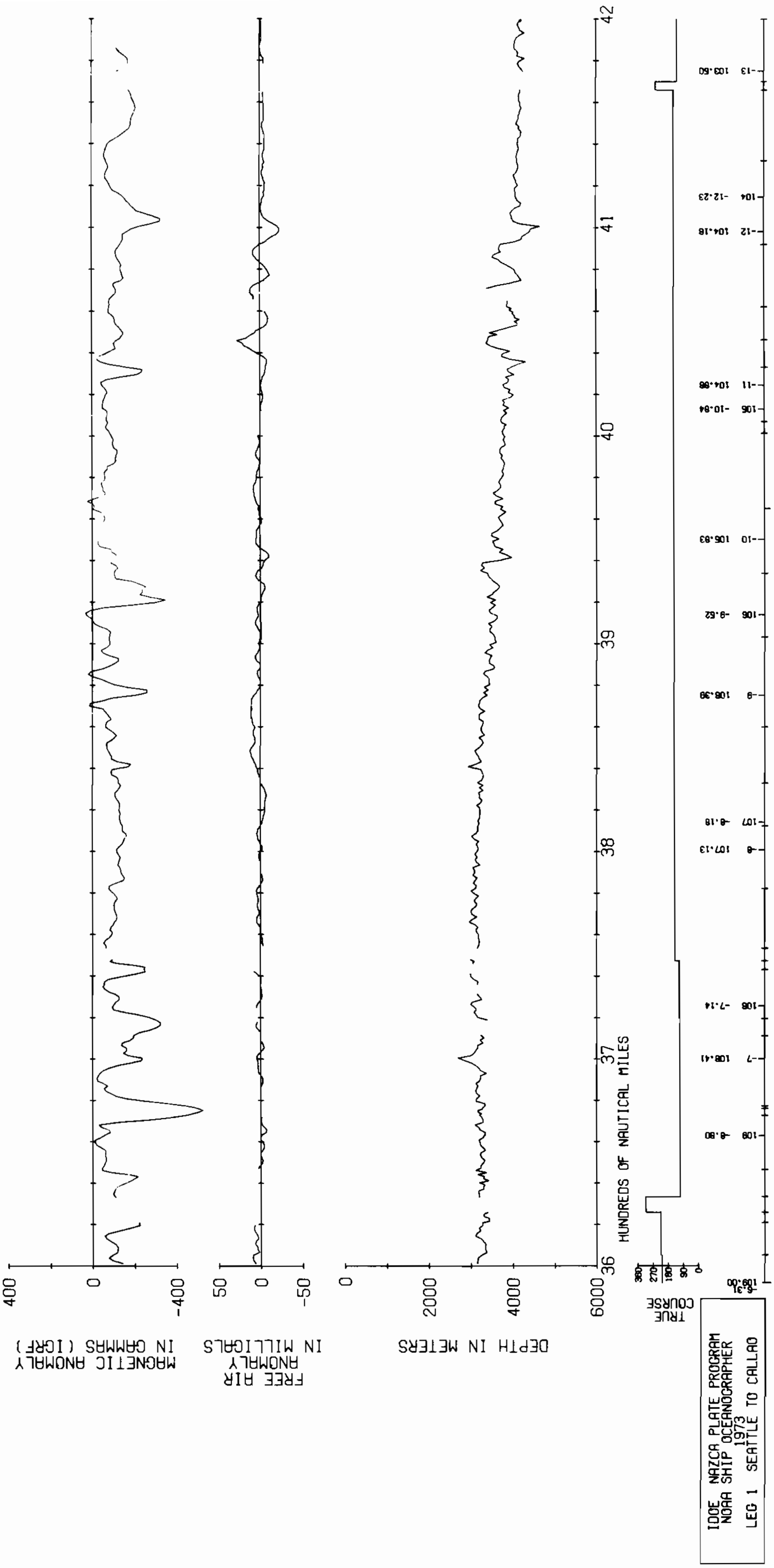
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 1 SEATTLE TO CALLAO

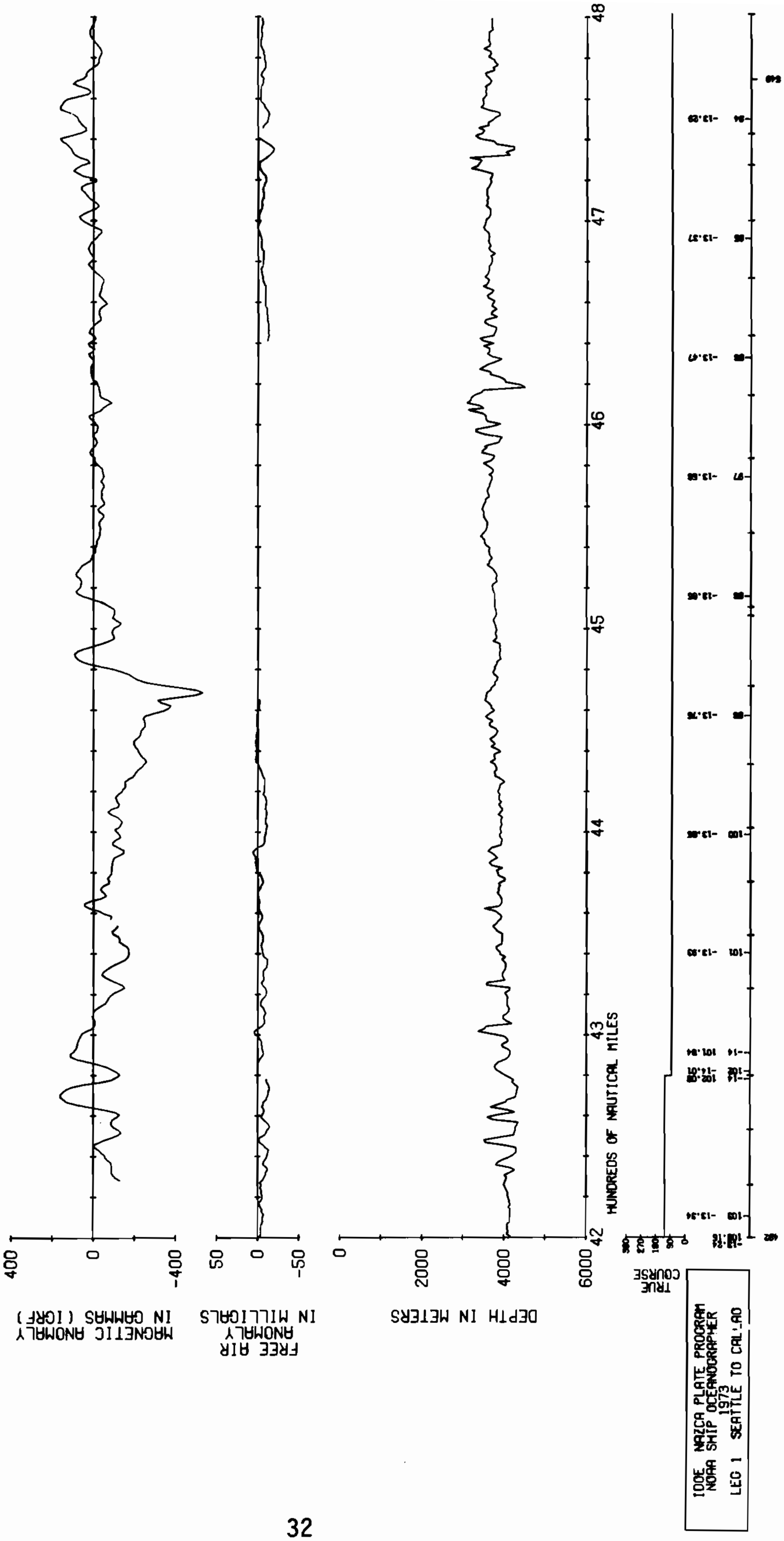


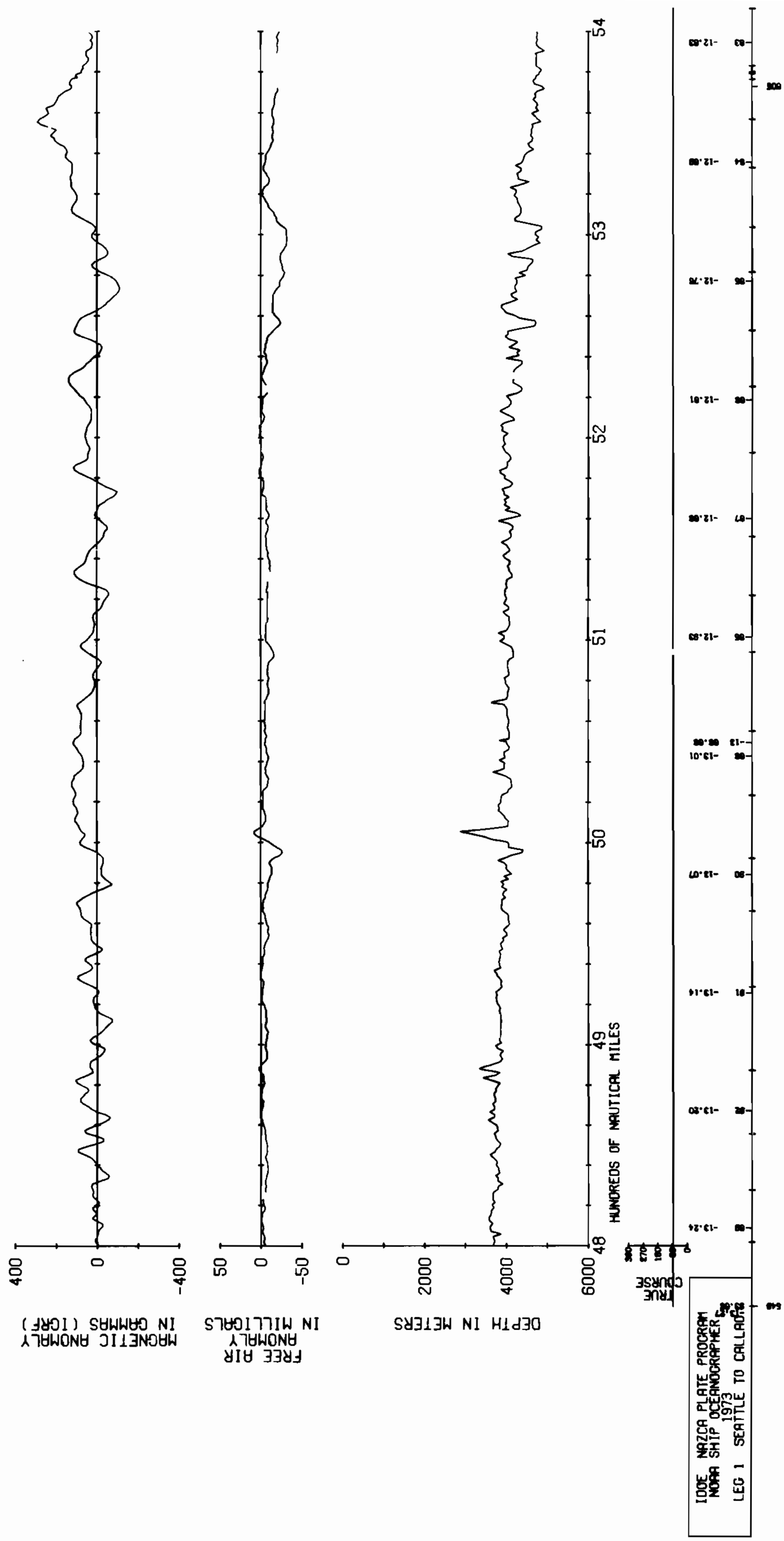
MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
24
25
26
27
28
29
30
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 1 SEATTLE TO CALLAO



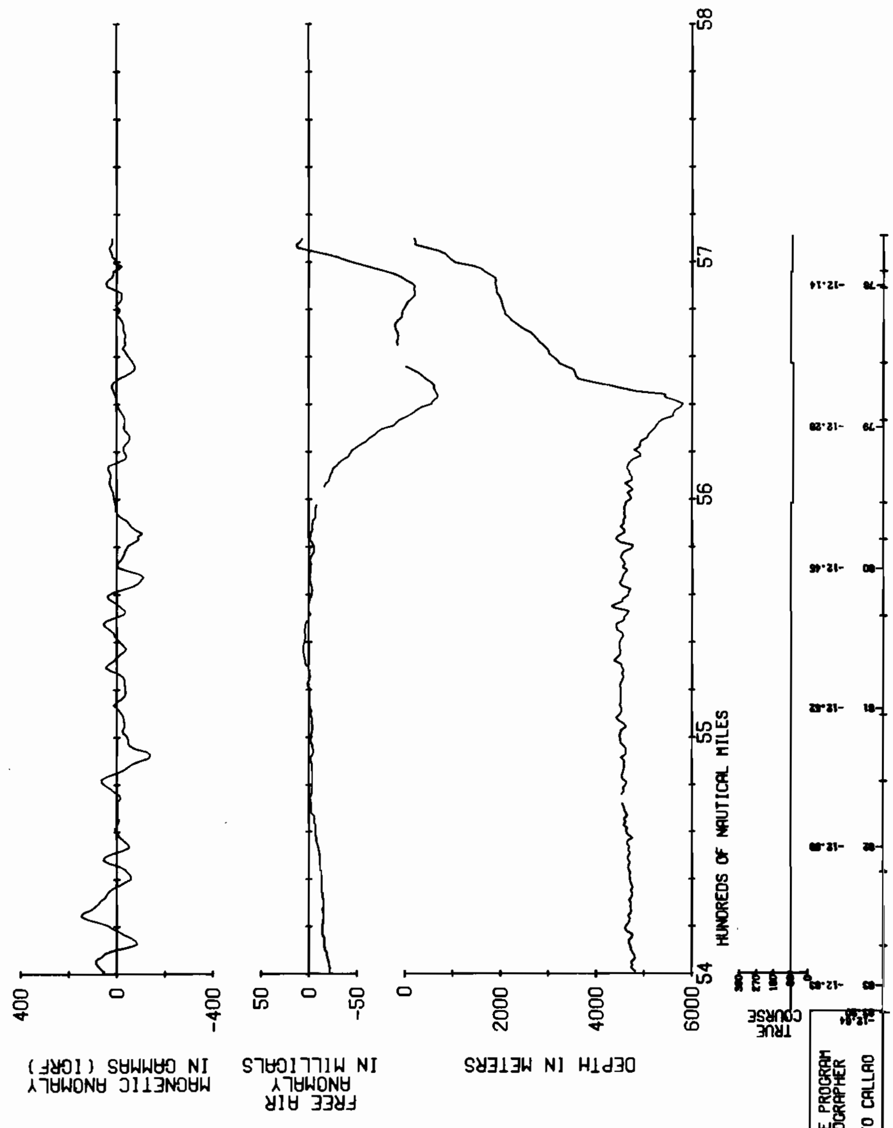
MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
30
31
32
33
34
35
36
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 1 SEATTLE TO CALLAO

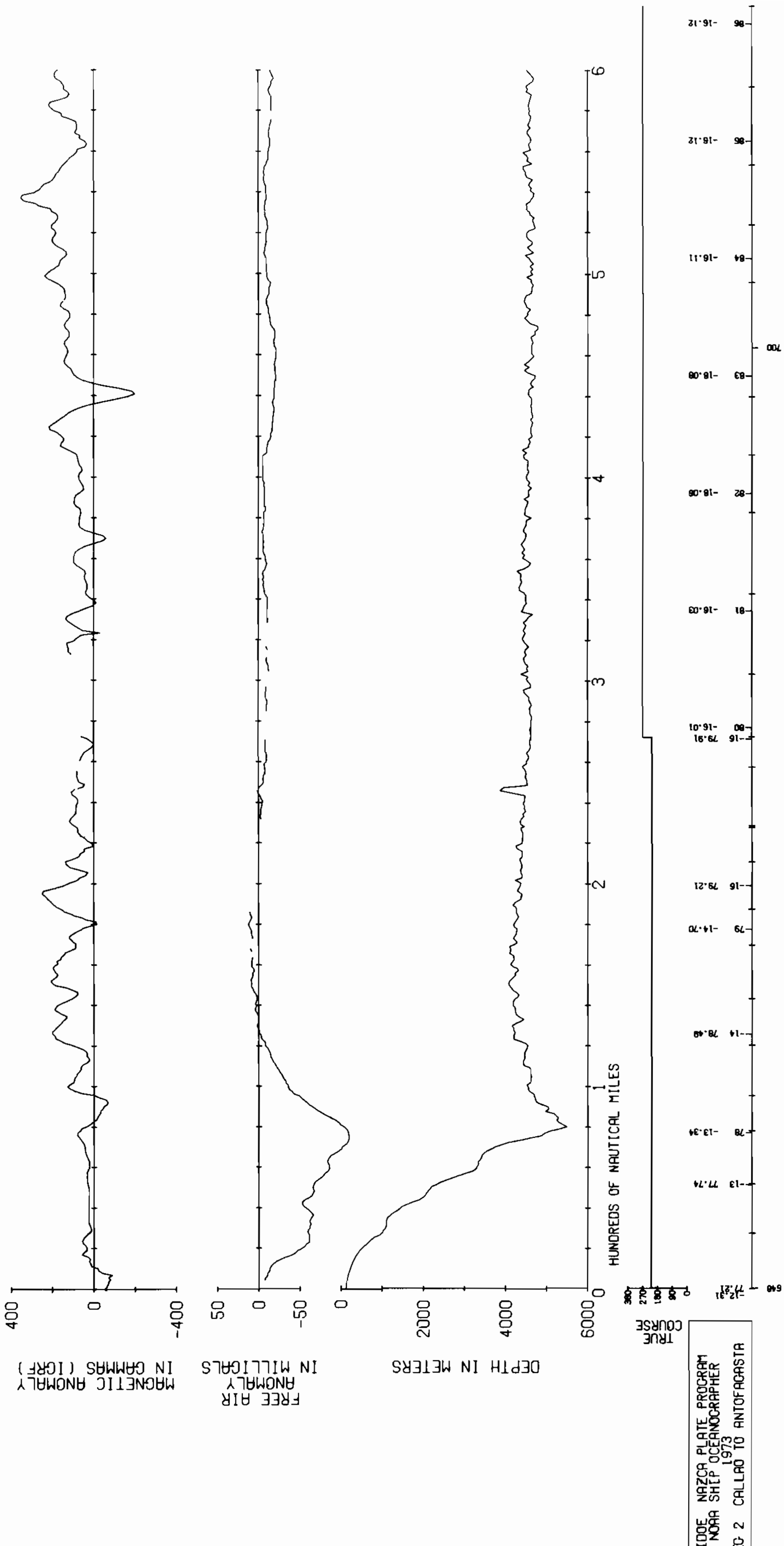

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
HUNDREDS OF NAUTICAL MILES
36
37
38
39
40
41
42
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 1 SEATTLE TO CALLAO


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
TRUE COURSE
HUNDREDS OF NAUTICAL MILES
42
43
44
45
46
47
48
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 1 SEATTLE TO CALLAO

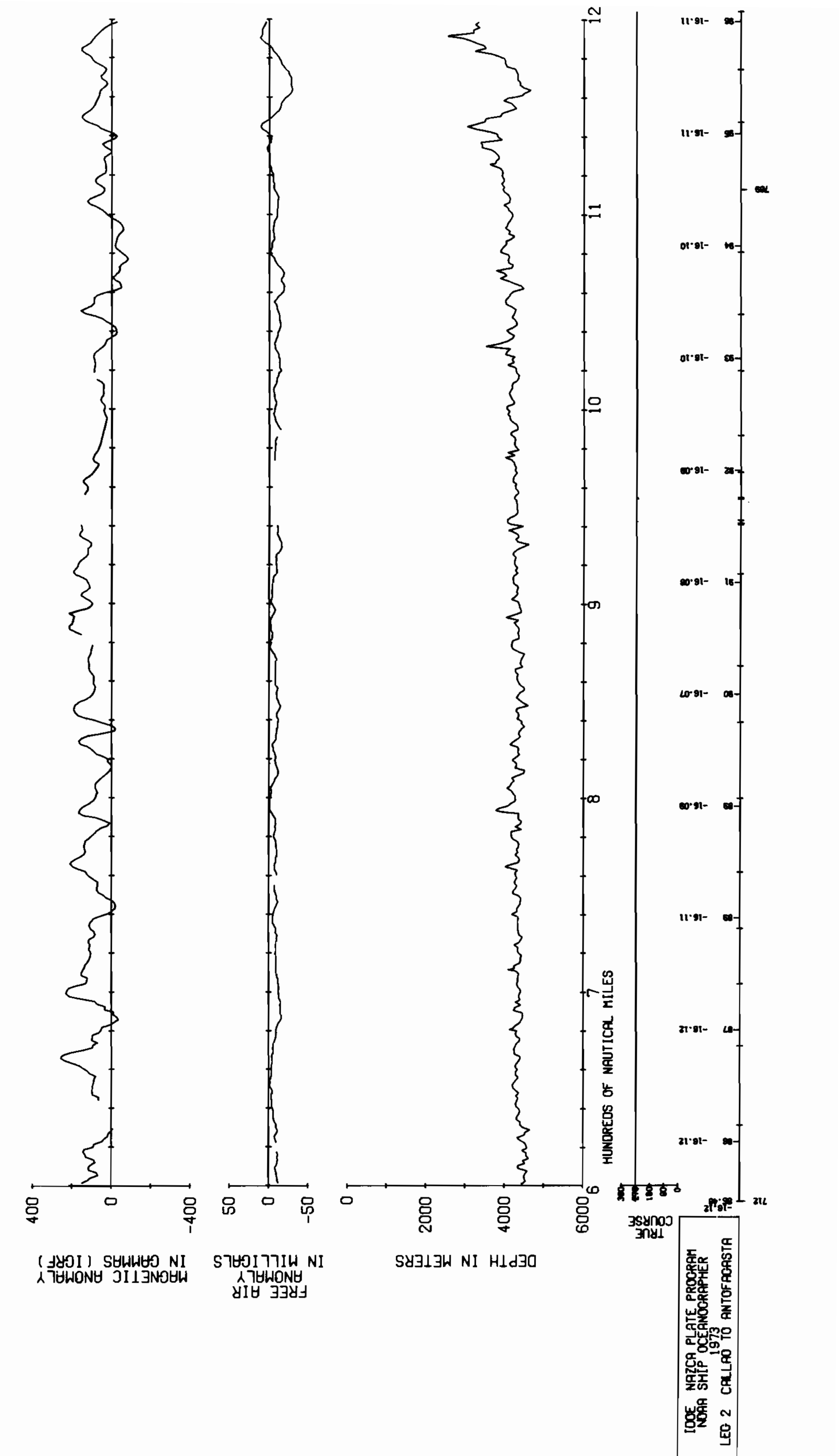


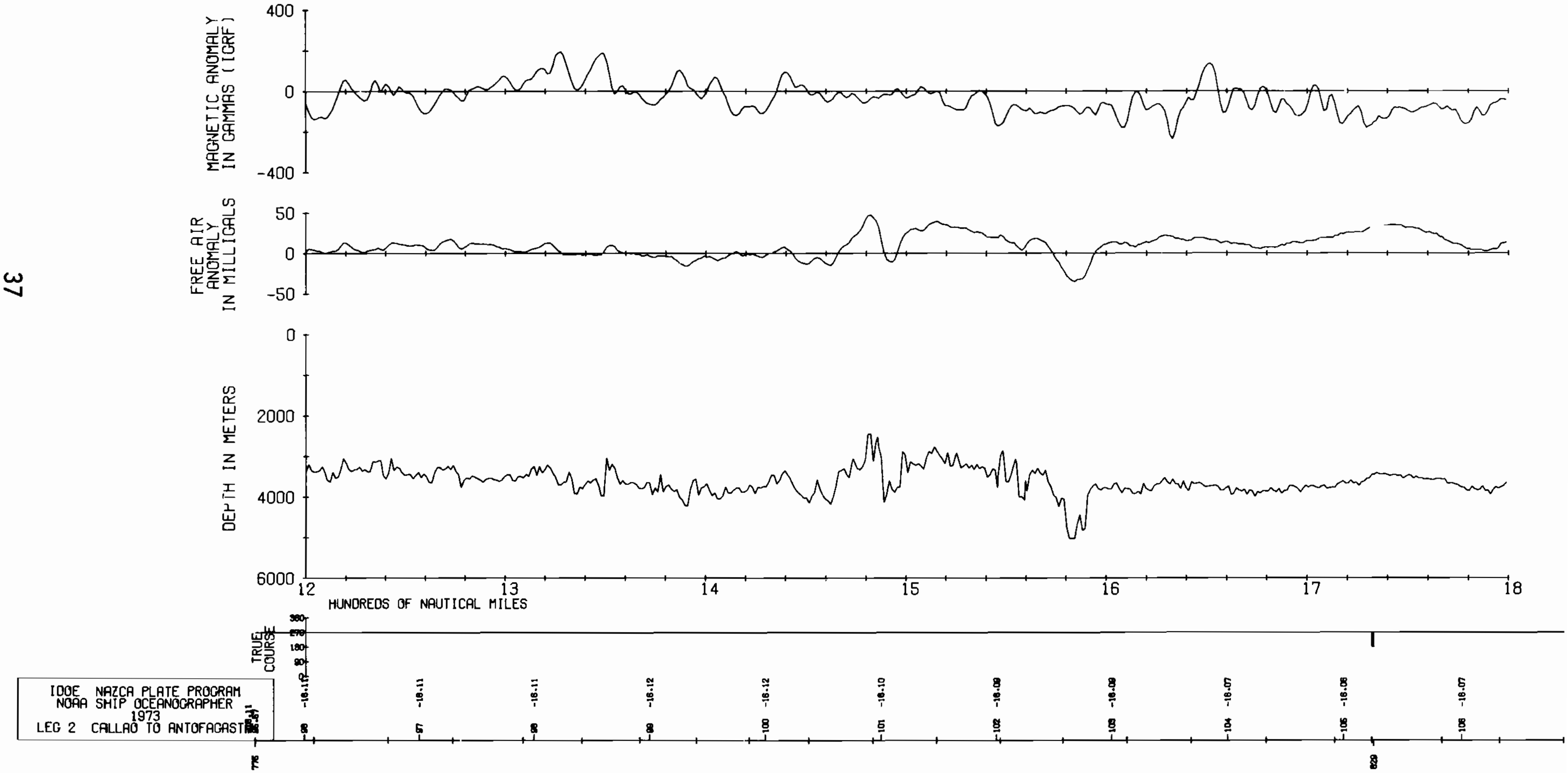
MAGNETIC ANOMALY
IN GAMMAS (IGRF)
400
0
-400
FREE AIR
ANOMALY
IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
48
49
50
51
52
53
54
HUNDREDS OF NAUTICAL MILES
TRUE
COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 1 SEATTLE TO CALLAO

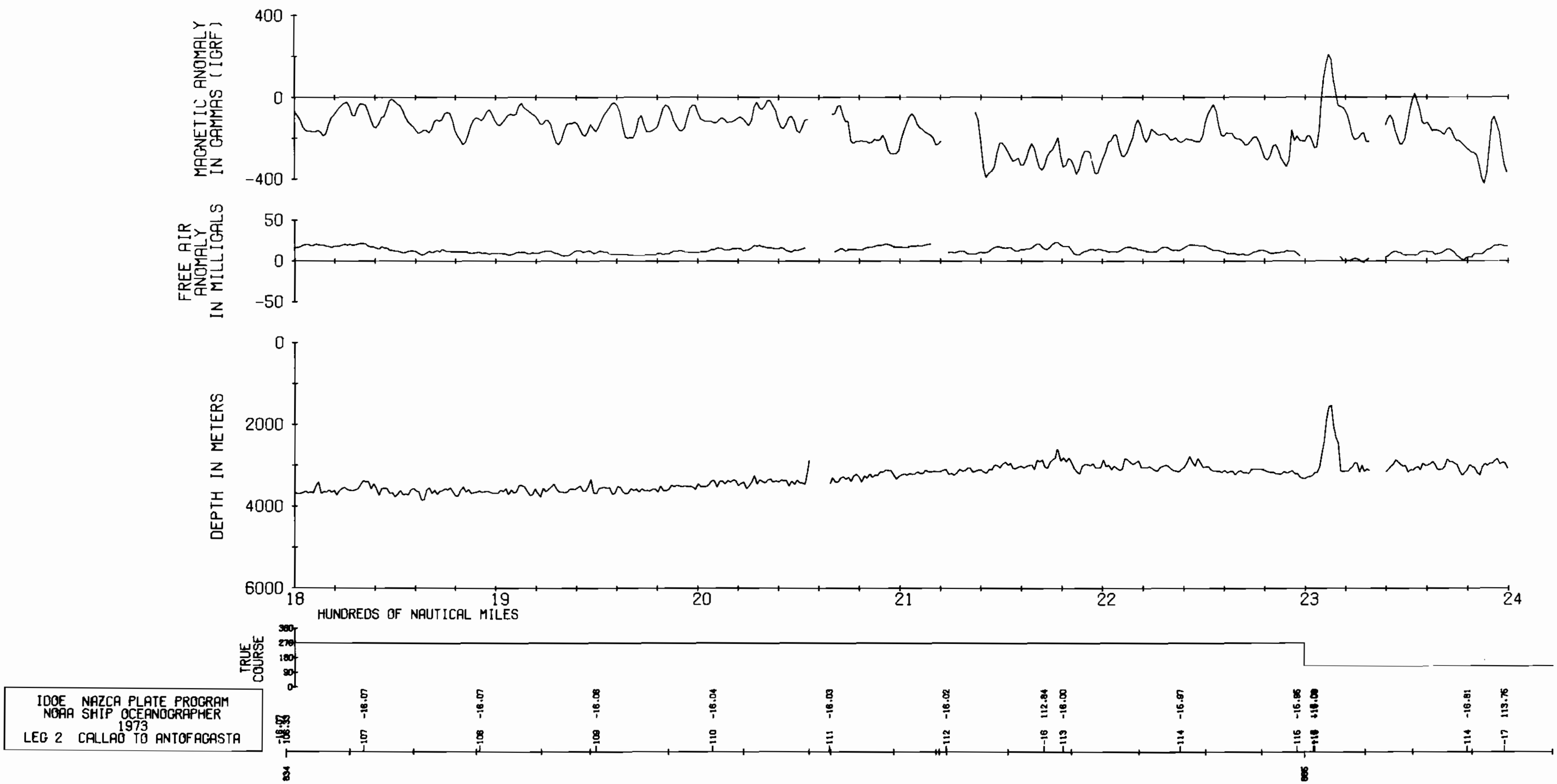

MAGNETIC ANOMALY
IN GAMMAS (IGRF)
FREE AIR
ANOMALY
IN MILLIGALS
DEPTH IN METERS
HUNDREDS OF NAUTICAL MILES
TRUE
COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 1 SEATTLE TO CALLAO

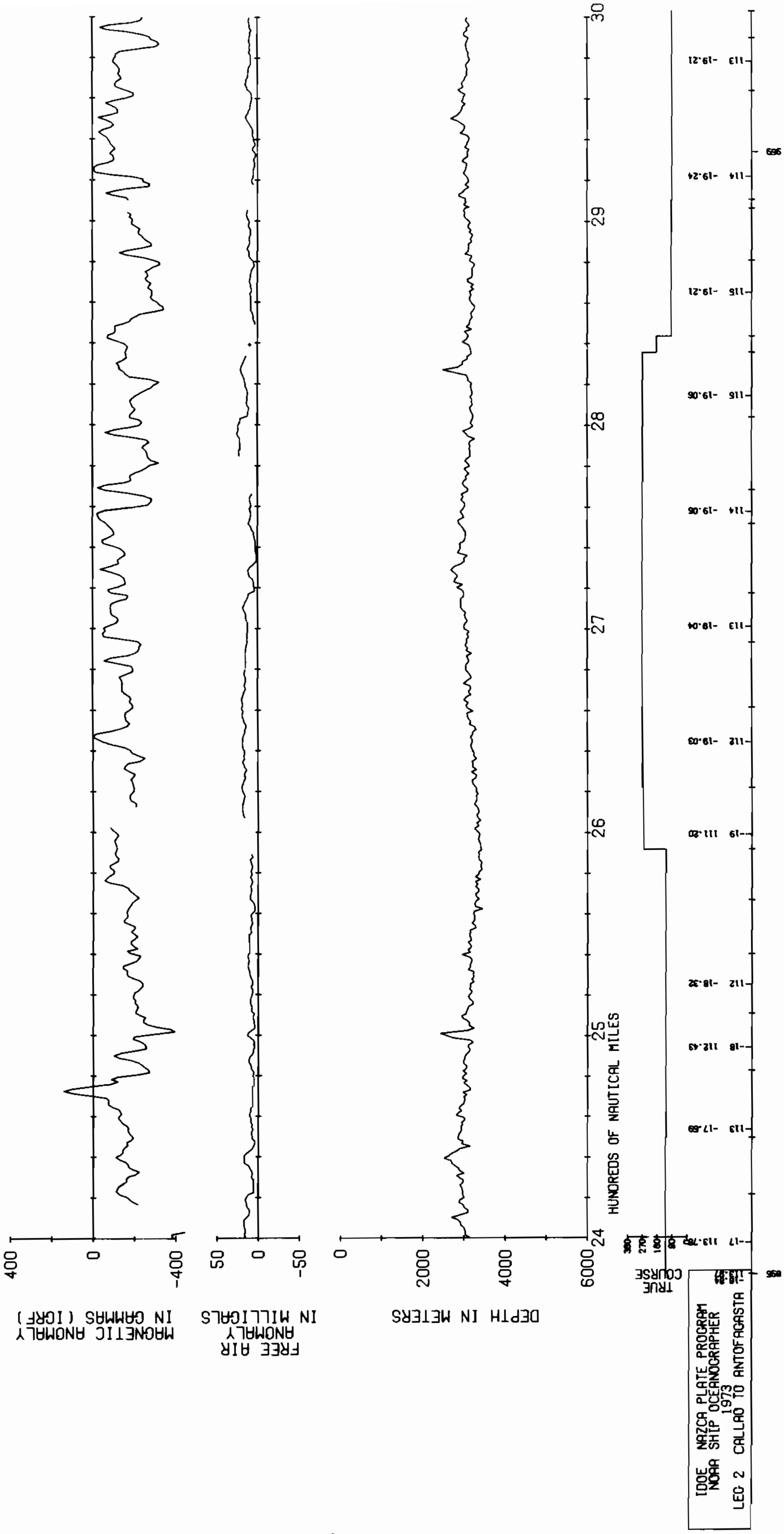


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
HUNDREDS OF NAUTICAL MILES
0
1
2
3
4
5
6
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA


MAGNETIC ANOMALY
IN GAMMAS (IGRF)
400
0
-400
FREE AIR
ANOMALY
IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
HUNDREDS OF NAUTICAL MILES
6
7
8
9
10
11
12
TRUE
COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
12
13
14
15
16
17
18
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
18
19
20
21
22
23
24
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA


MAGNETIC ANOMALY IN GAMMAS (IGRF)
FREE AIR ANOMALY IN MILLIGALS
DEPTH IN METERS
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
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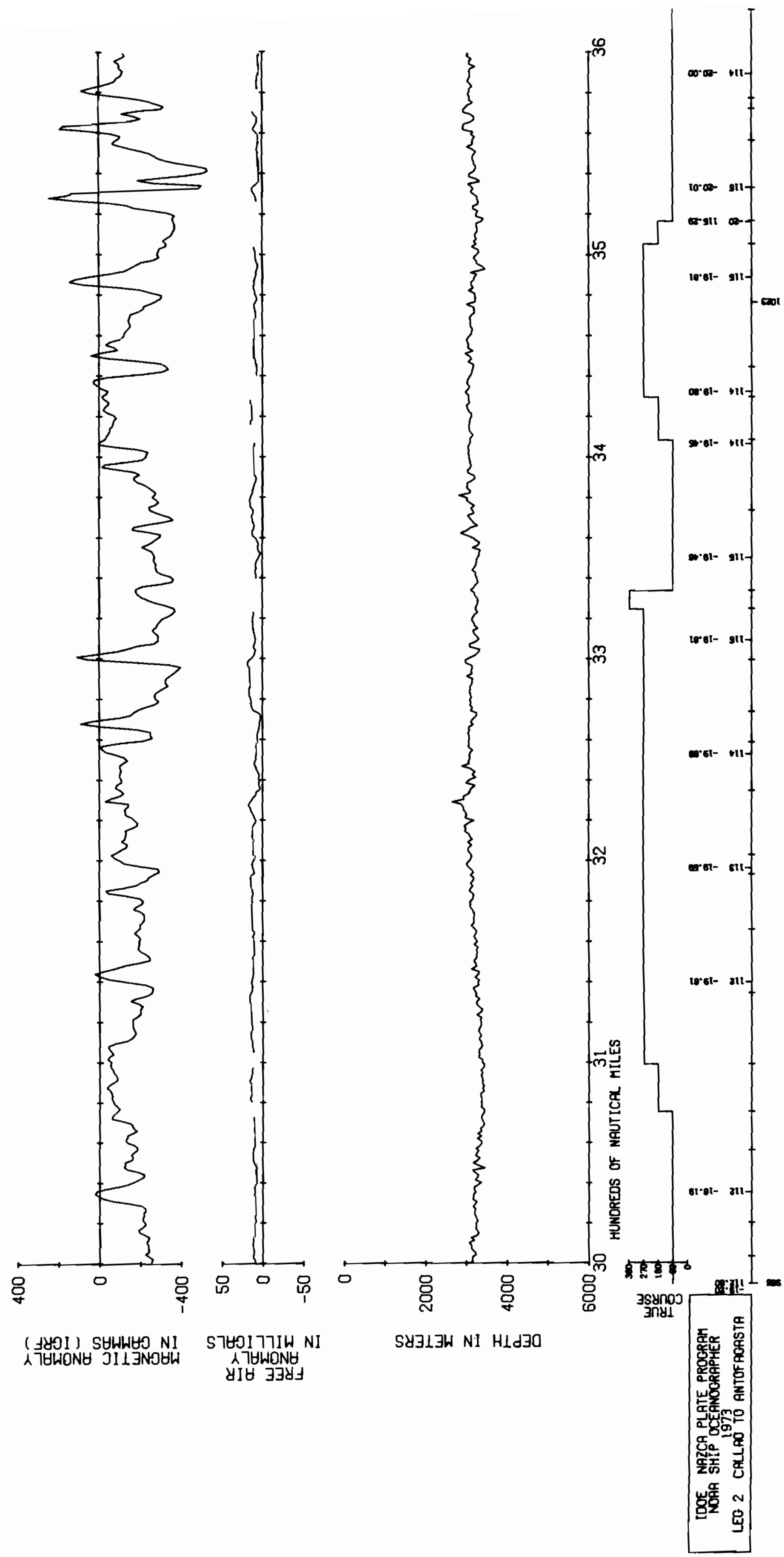
LEG 2 CALLAO TO ANTOFAGASTA


IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA
MAGNETIC ANOMALY IN GAMMAS (IGRF)
FREE AIR ANOMALY IN MILLIGALS
DEPTH IN METERS
TRUE COURSE
HUNDREDS OF NAUTICAL MILES
400
0
-400
50
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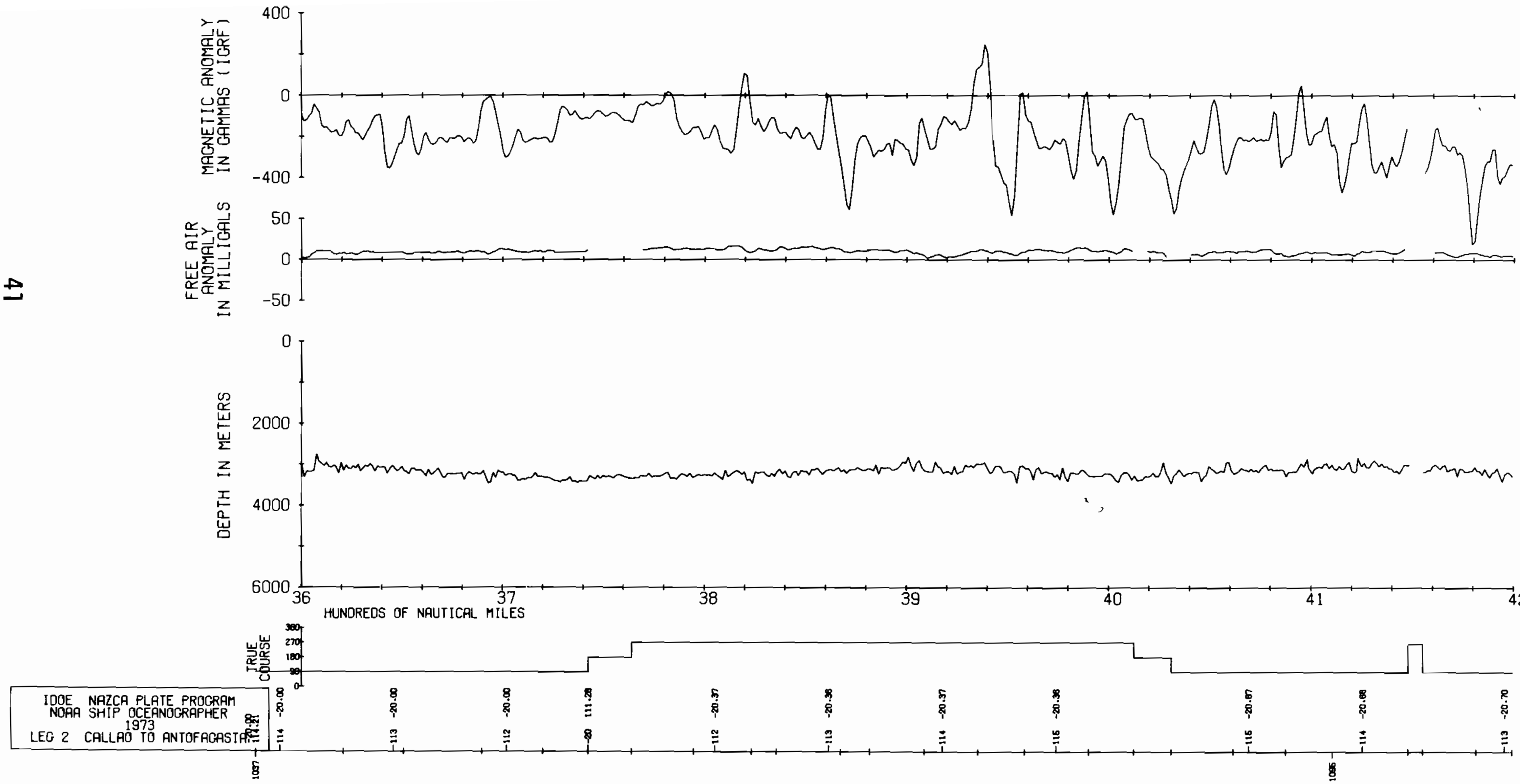
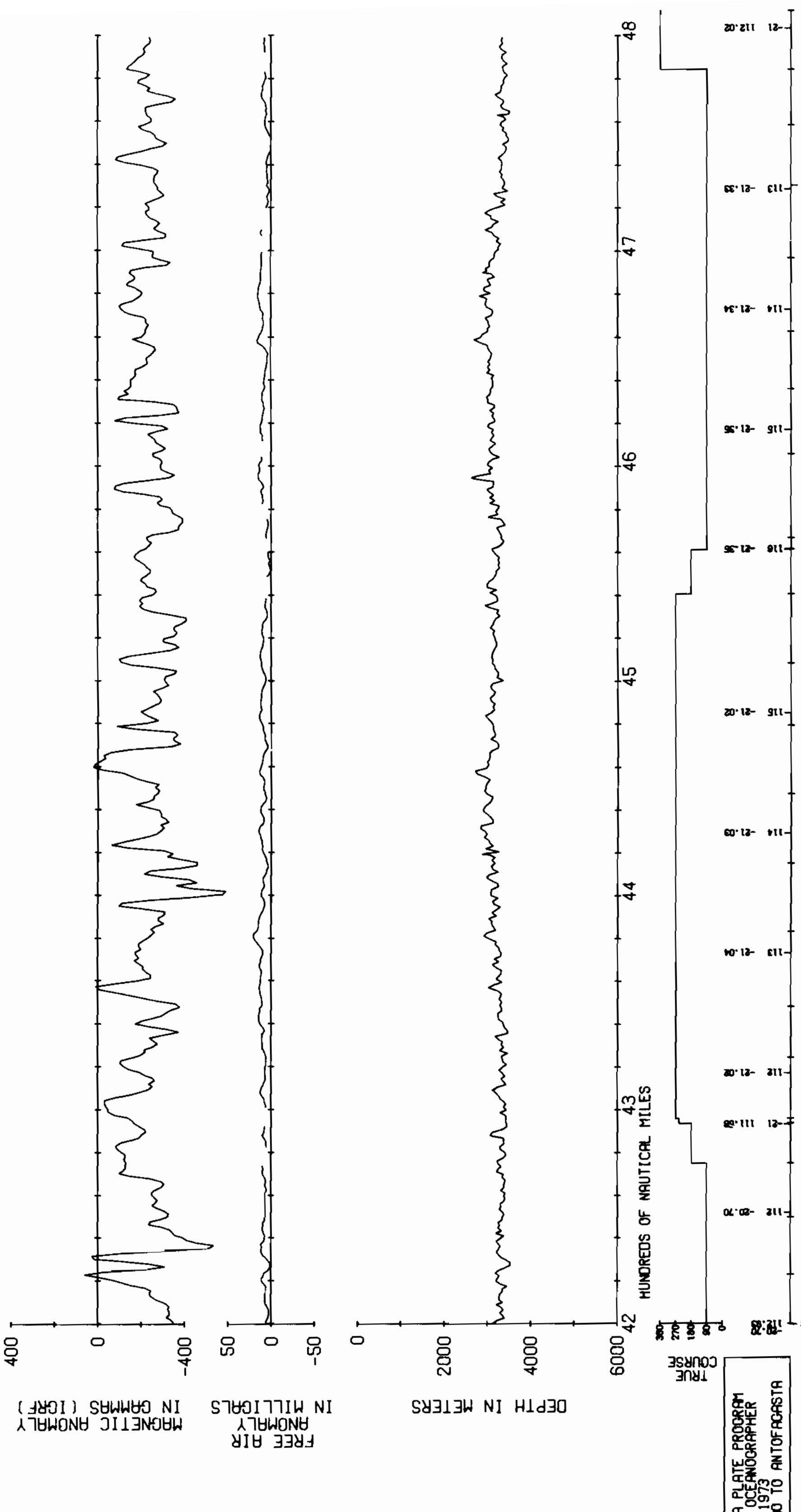
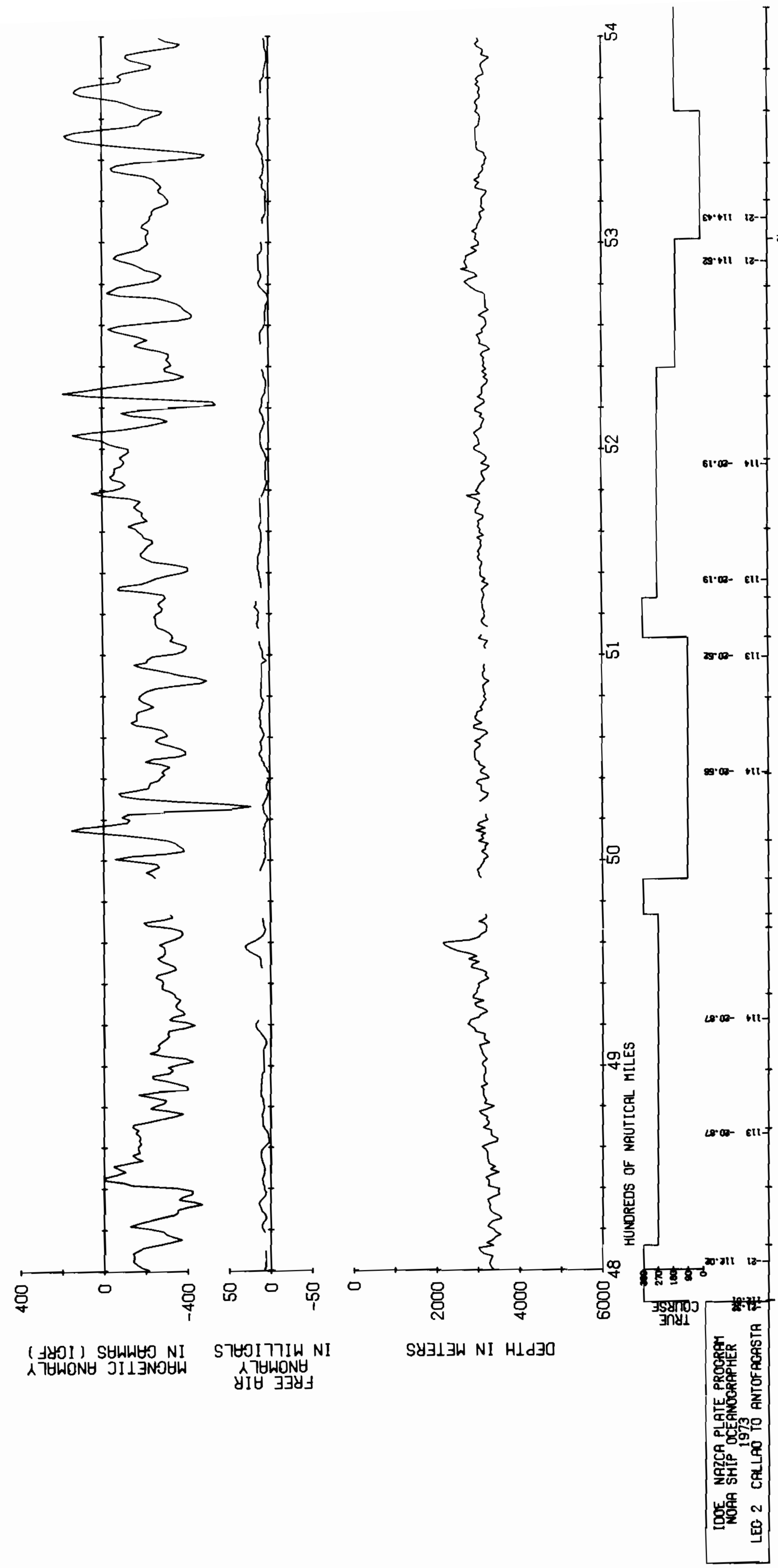
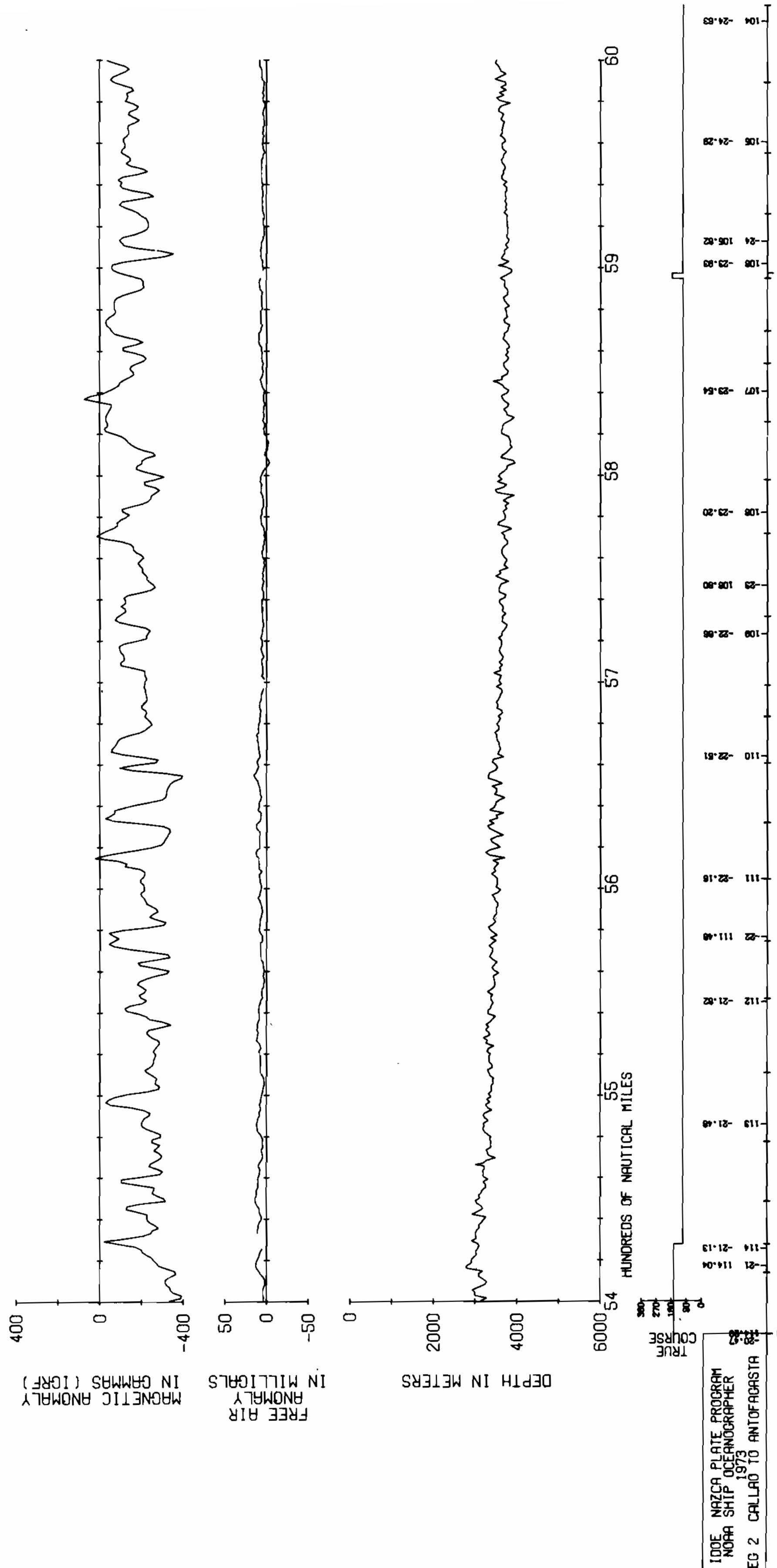
32
33
34
35
36


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
36
37
38
39
40
41
42
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA

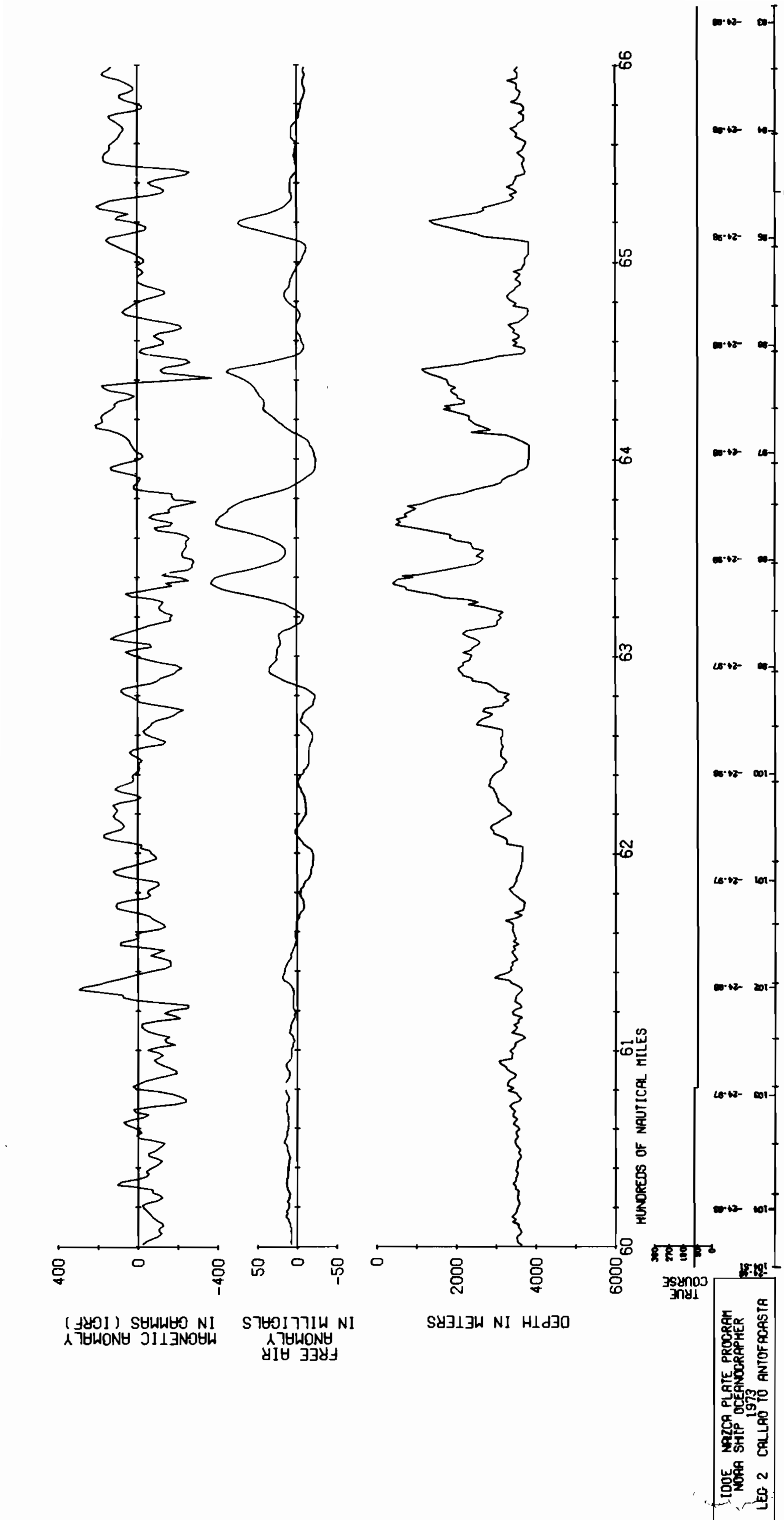

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
TRUE COURSE
HUNDREDS OF NAUTICAL MILES
42
43
44
45
46
47
48
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA



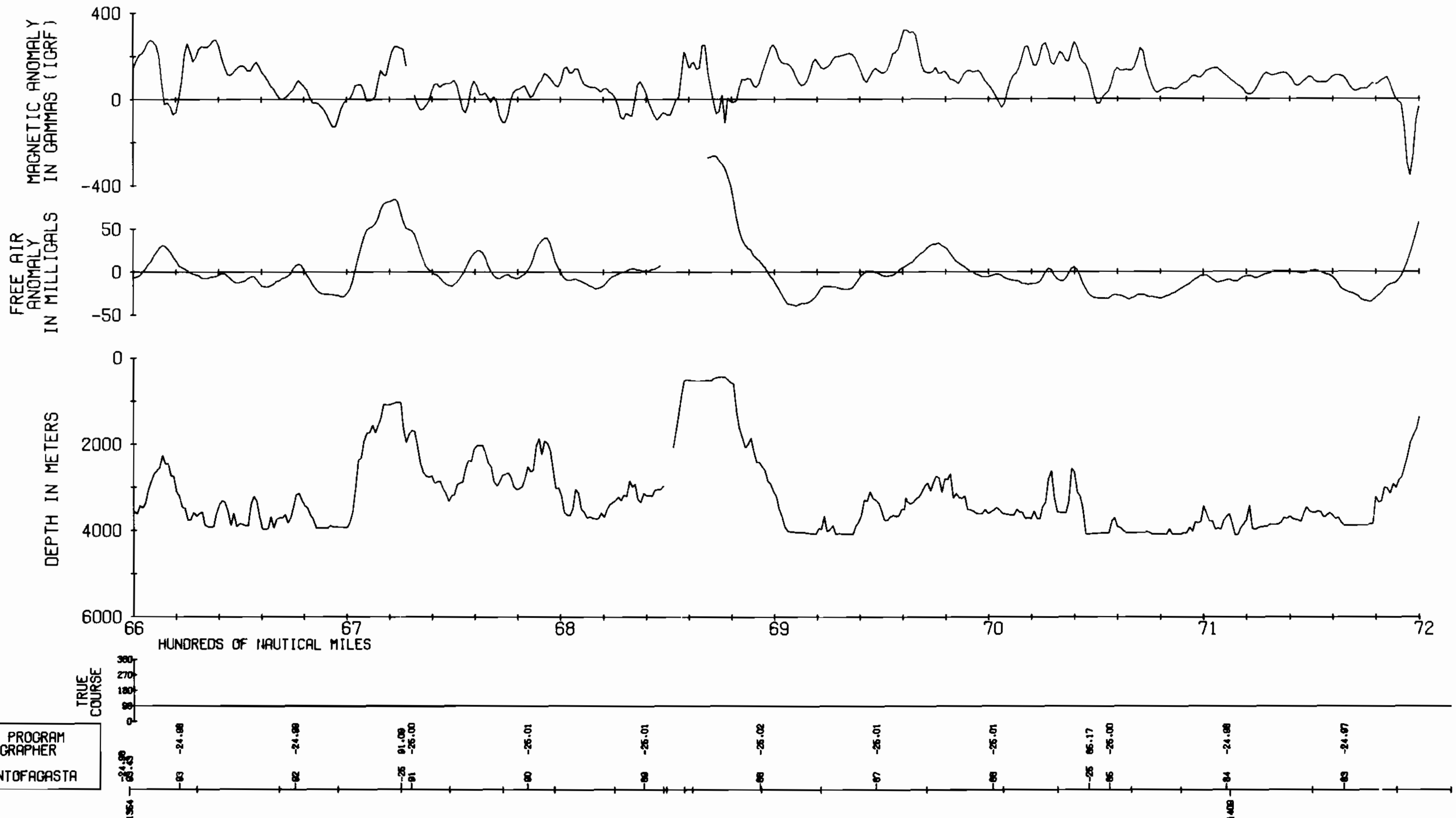
MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
TRUE COURSE
HUNDREDS OF NAUTICAL MILES
48
49
50
51
52
53
54
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA



MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
54
55
56
57
58
59
60
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA



MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
60
61
62
63
64
65
66
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA



IDOE NAZCA PLATE PROGRAM
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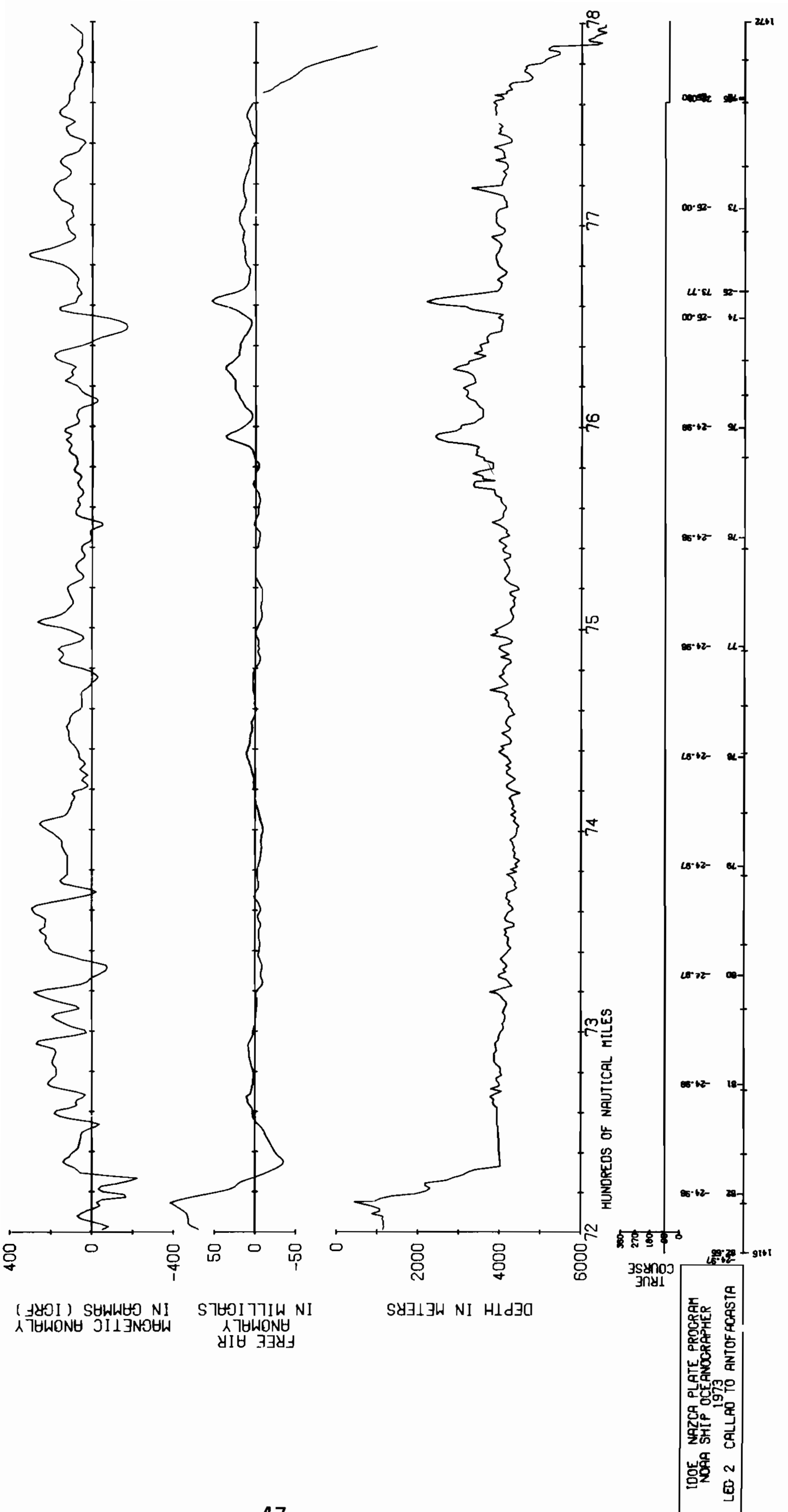
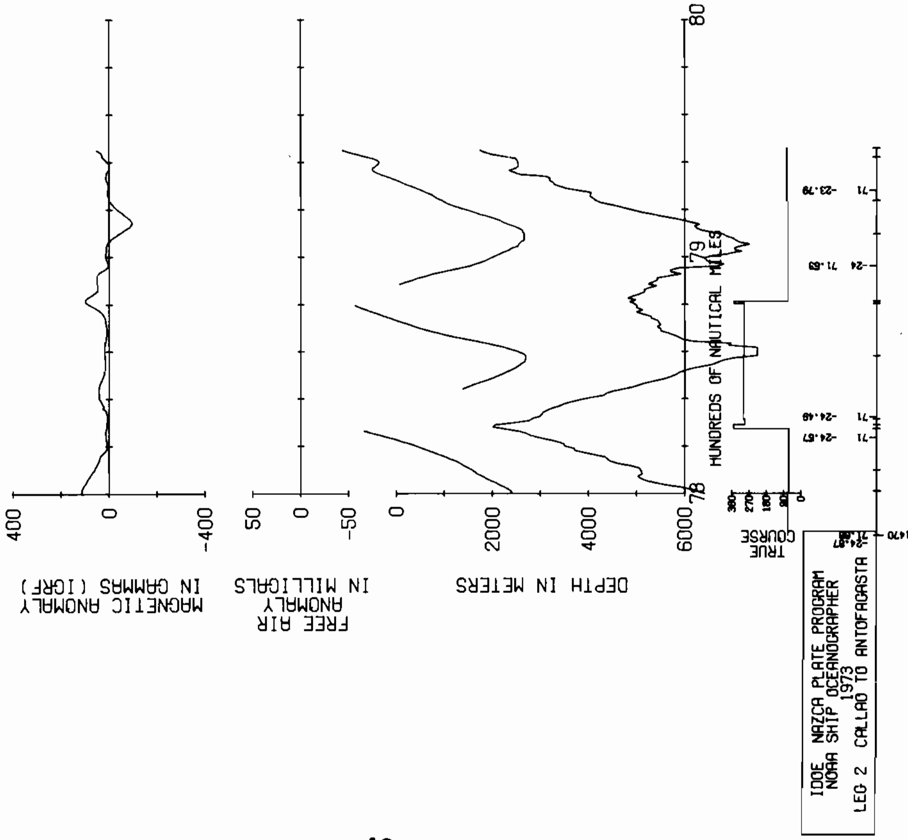
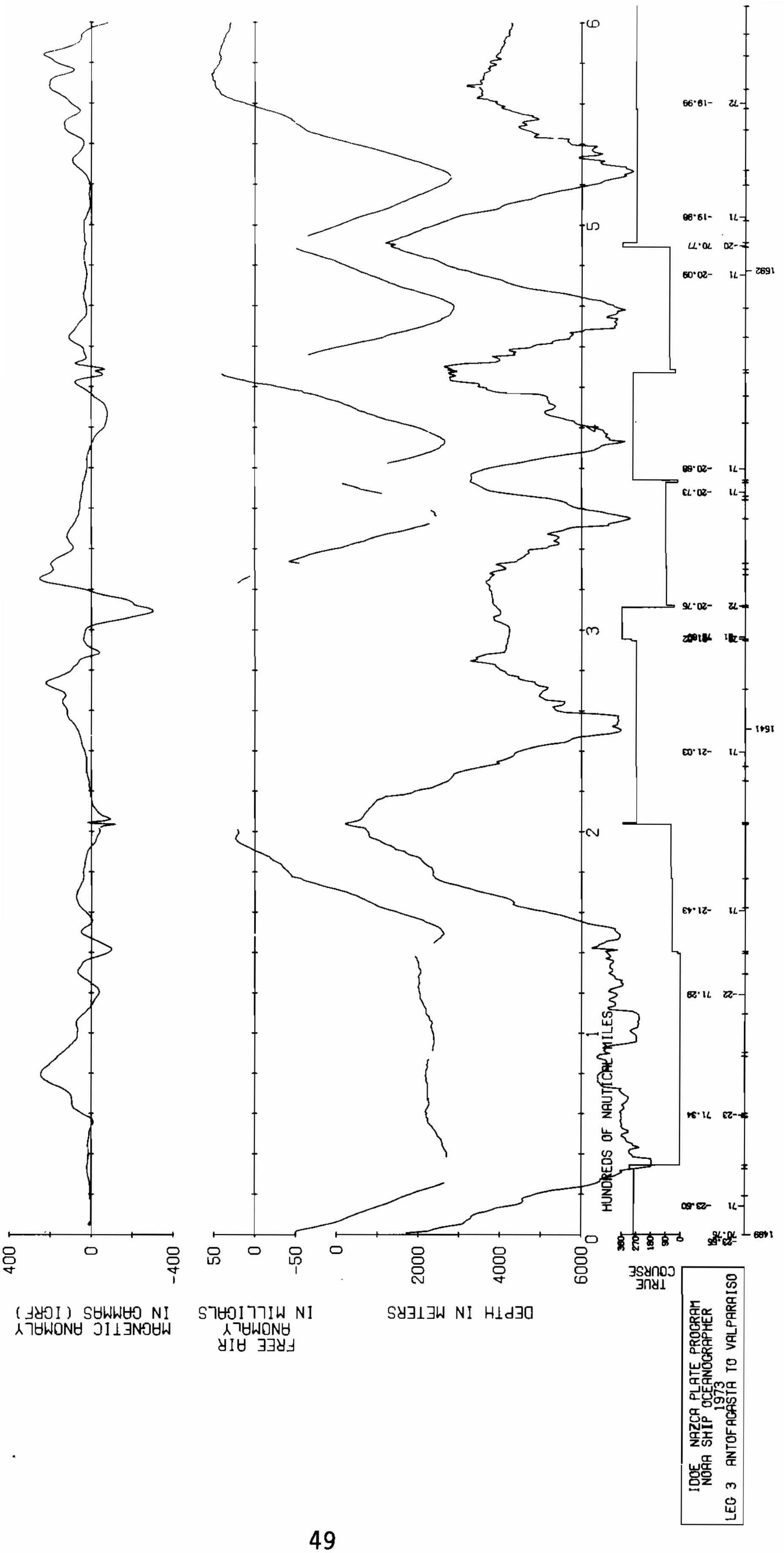
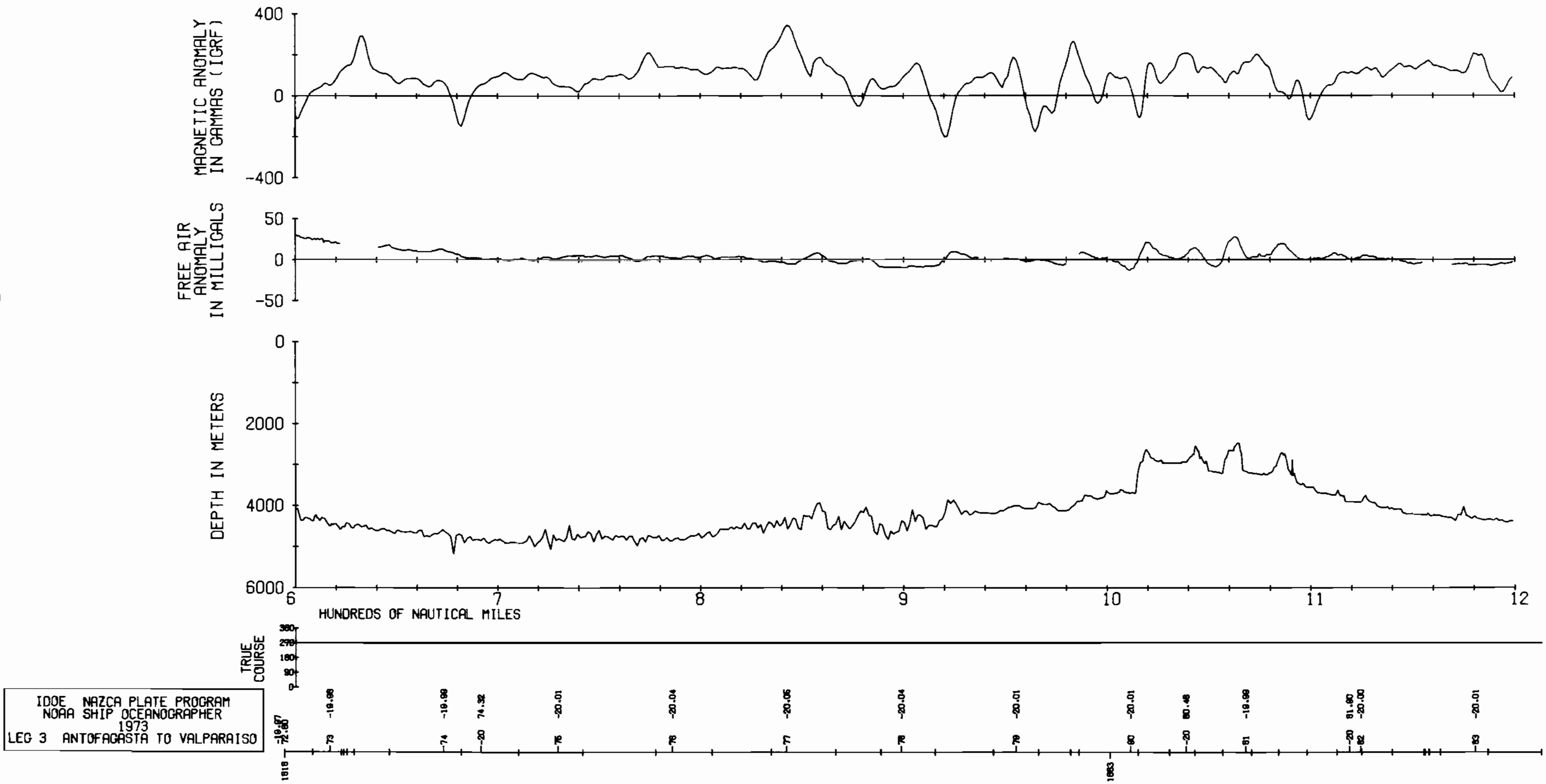
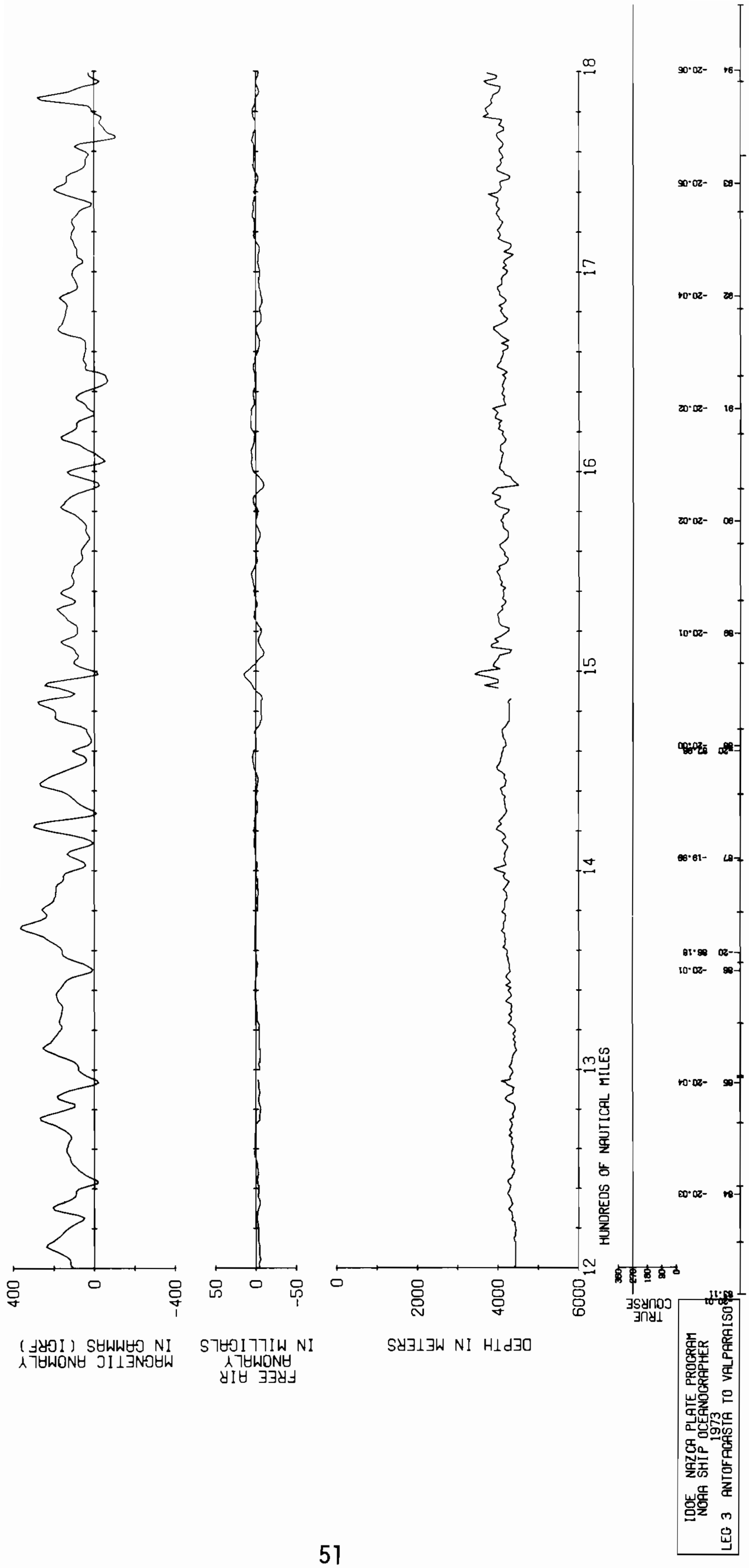
LEG 2 CALLAO TO ANTOFAGASTA


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
72
73
74
75
76
77
78
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA


MAGNETIC ANOMALY
IN GAMMAS (IGRF)
400
0
-400
FREE AIR
ANOMALY
IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
HUNDREDS OF NAUTICAL MILES
78
79
80
TRUE
COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 2 CALLAO TO ANTOFAGASTA


IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO
MAGNETIC ANOMALY IN GAMMAS (IGRF)
FREE AIR ANOMALY IN MILLIGALS
DEPTH IN METERS
TRUE COURSE
HUNDREDS OF NAUTICAL MILES


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
6
7
8
9
10
11
12
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
360
270
180
90
0
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO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400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
HUNDREDS OF NAUTICAL MILES
12
13
14
15
16
17
18
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO

IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
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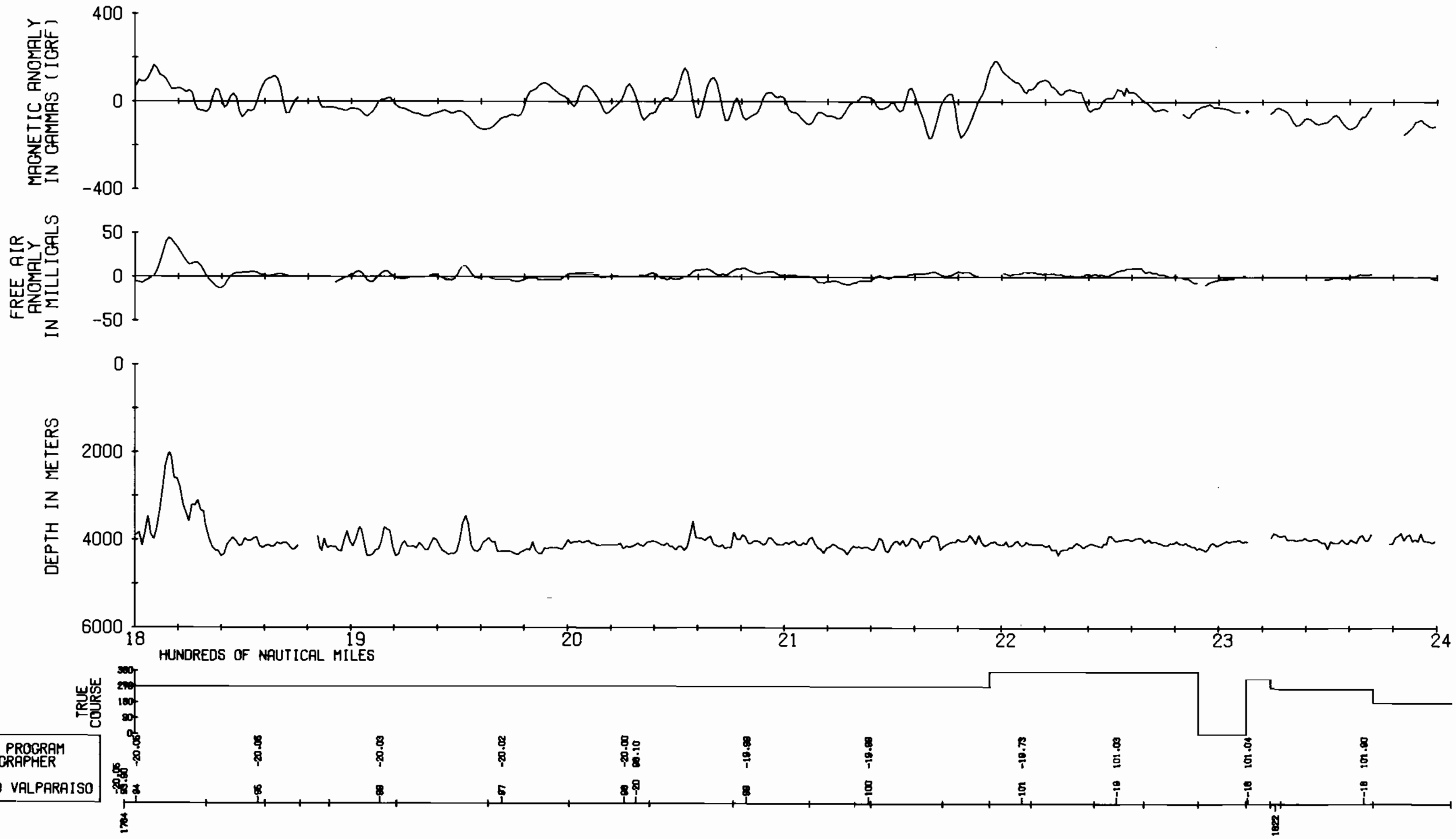

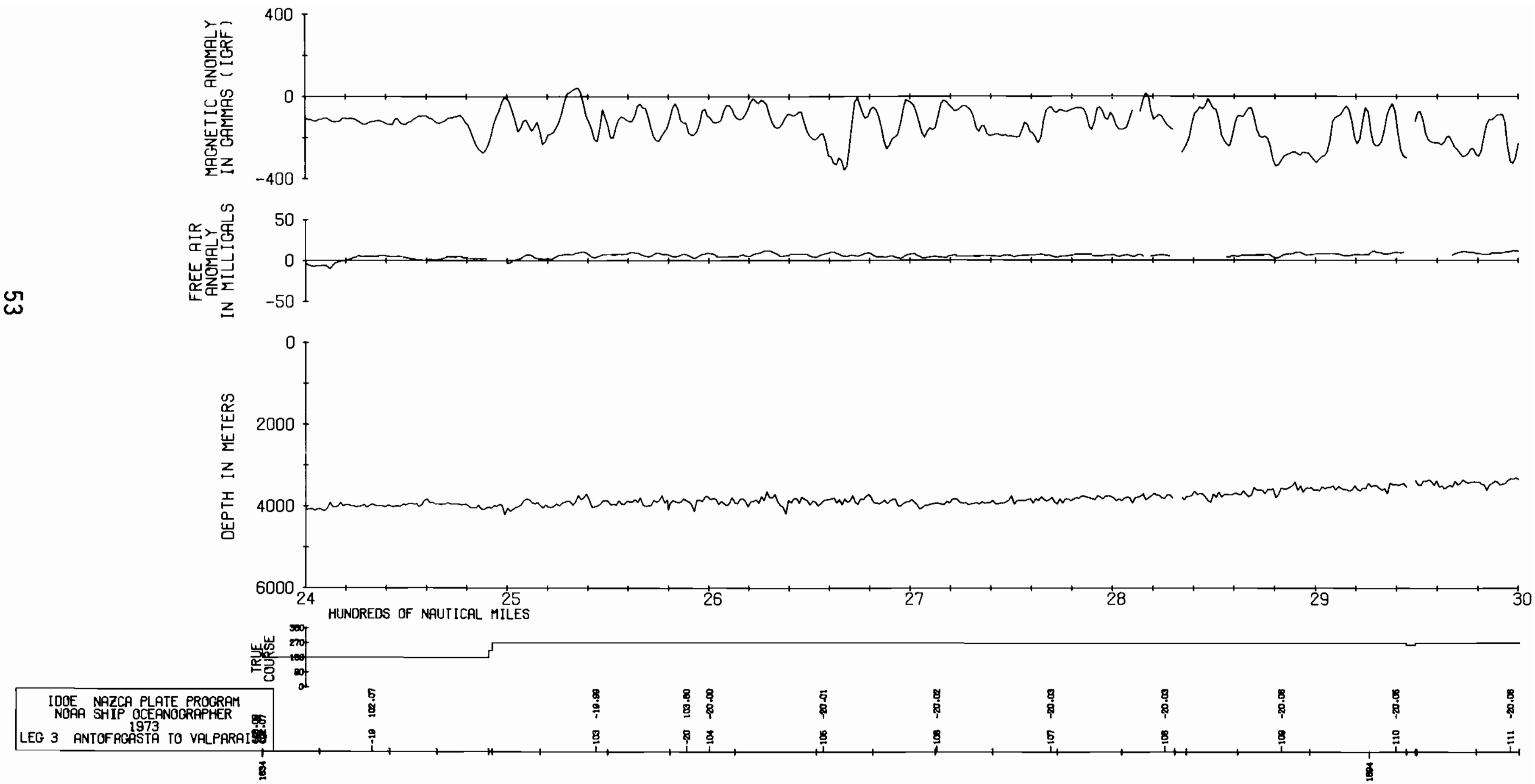
MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
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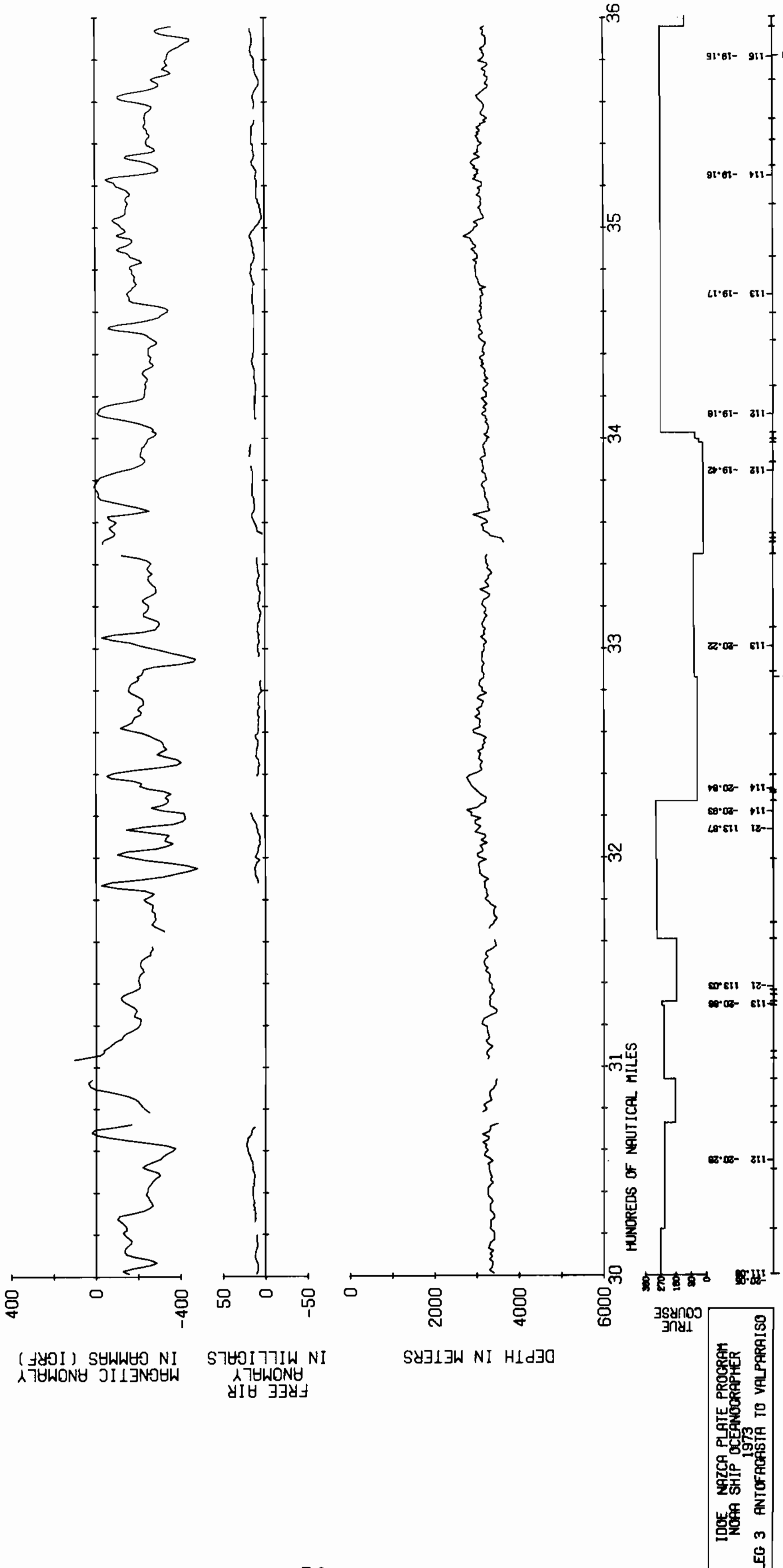
2000
4000
6000
24
25
26
27
28
29
30
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO


MAGNETIC ANOMALY IN GAMMAS (IGRF)
FREE AIR ANOMALY IN MILLIGALS
DEPTH IN METERS
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
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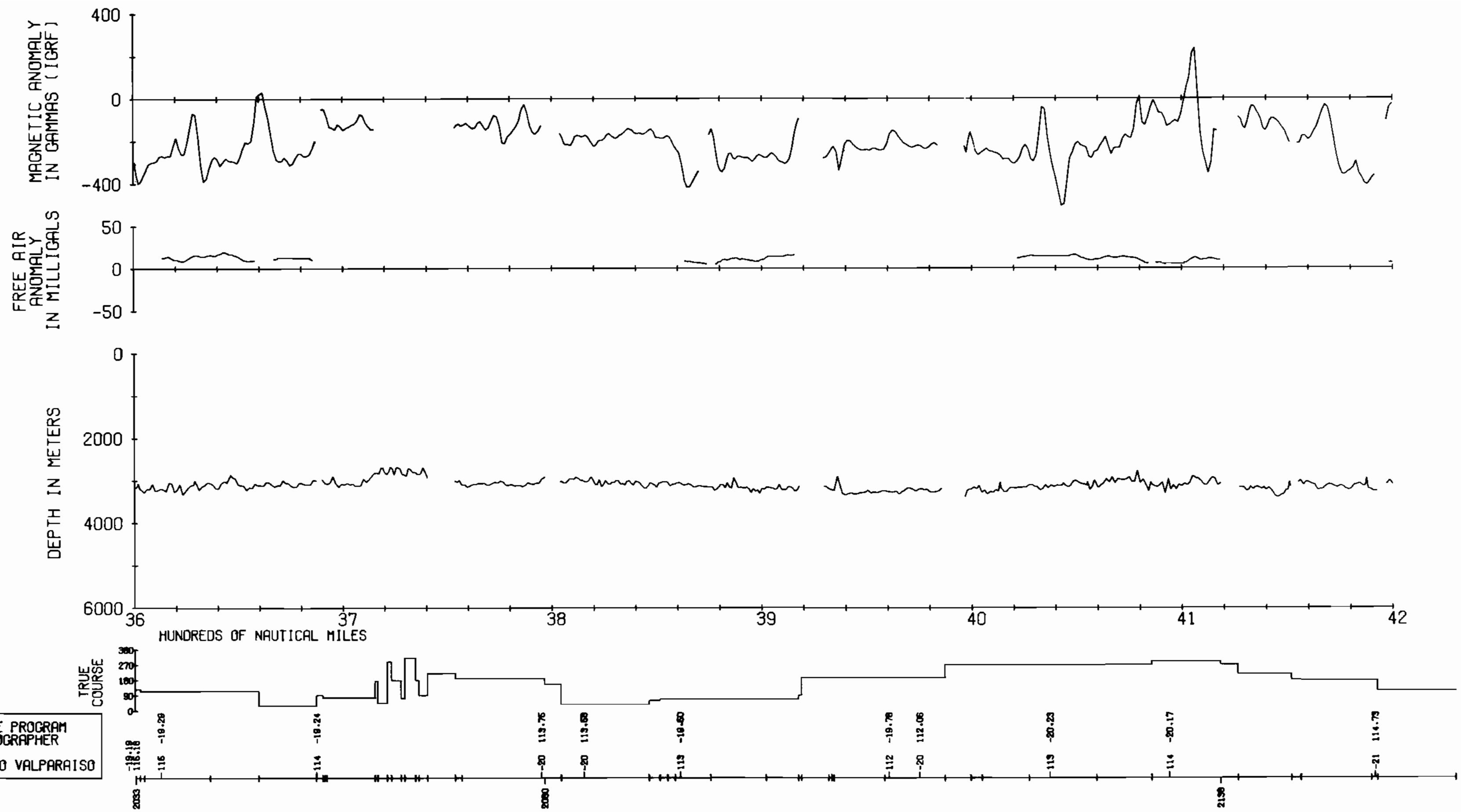
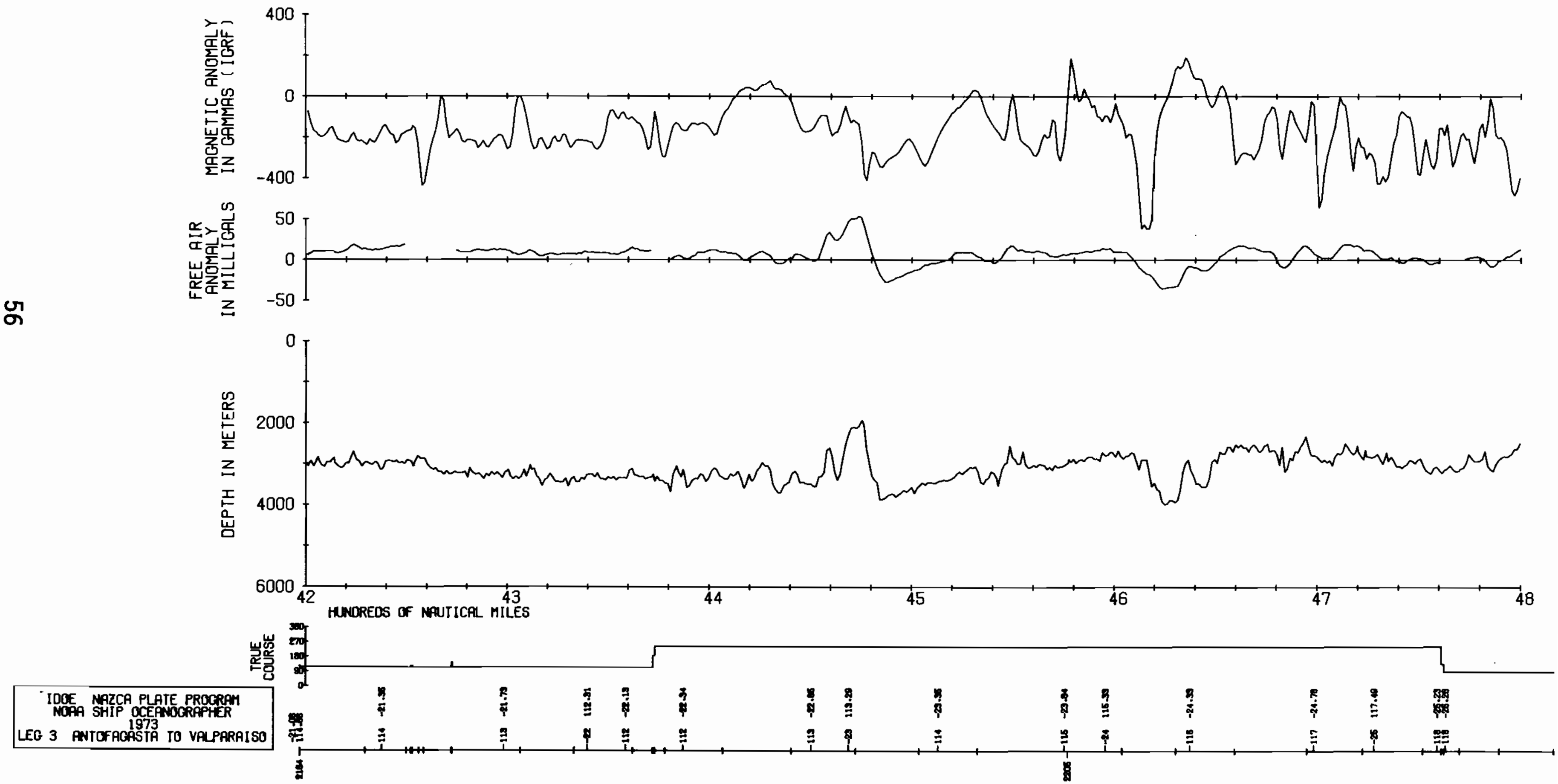
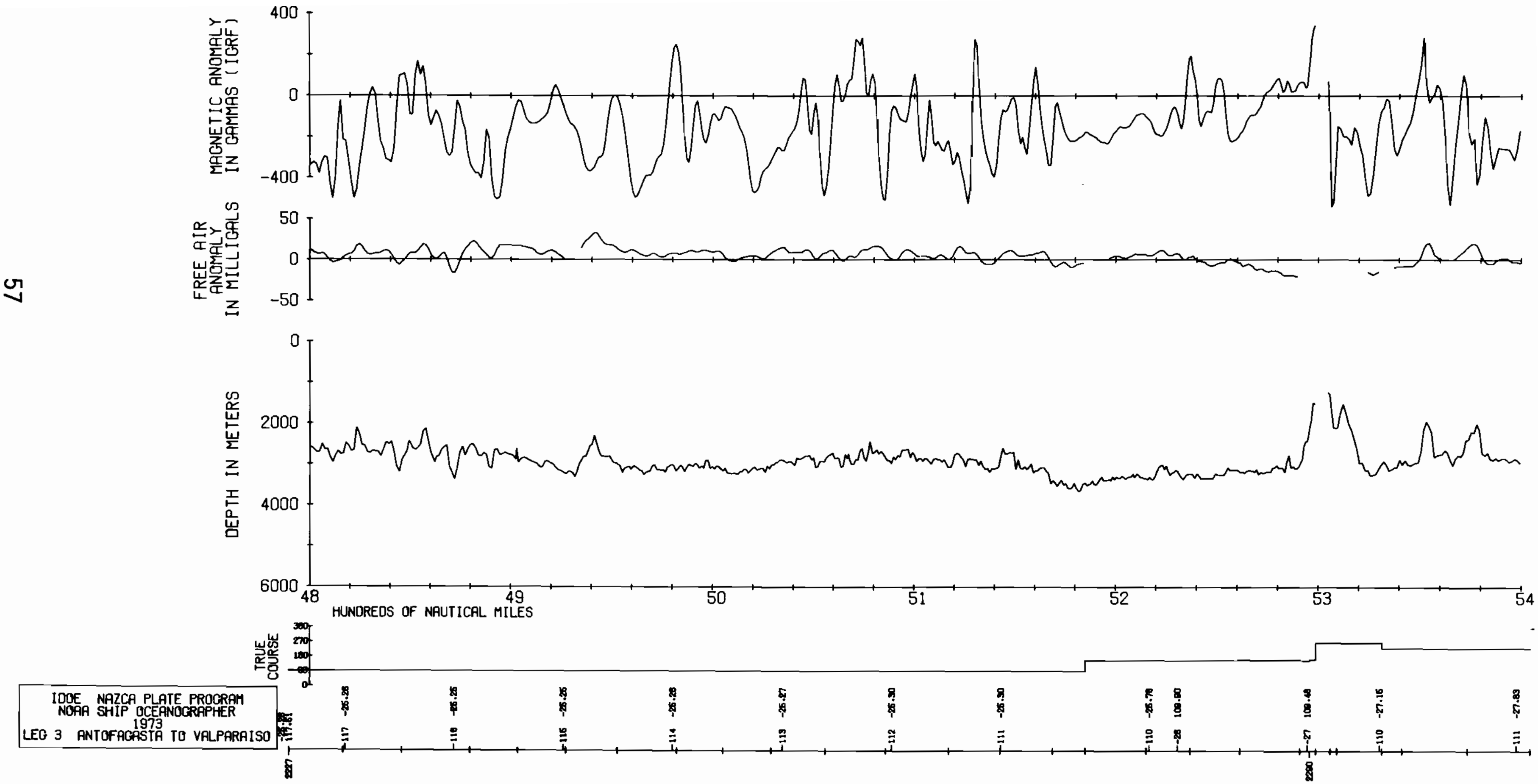
LEG 3 ANTOFAGASTA TO VALPARAISO



IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
42
43
44
45
46
47
48
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO



MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
48
49
50
51
52
53
54
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
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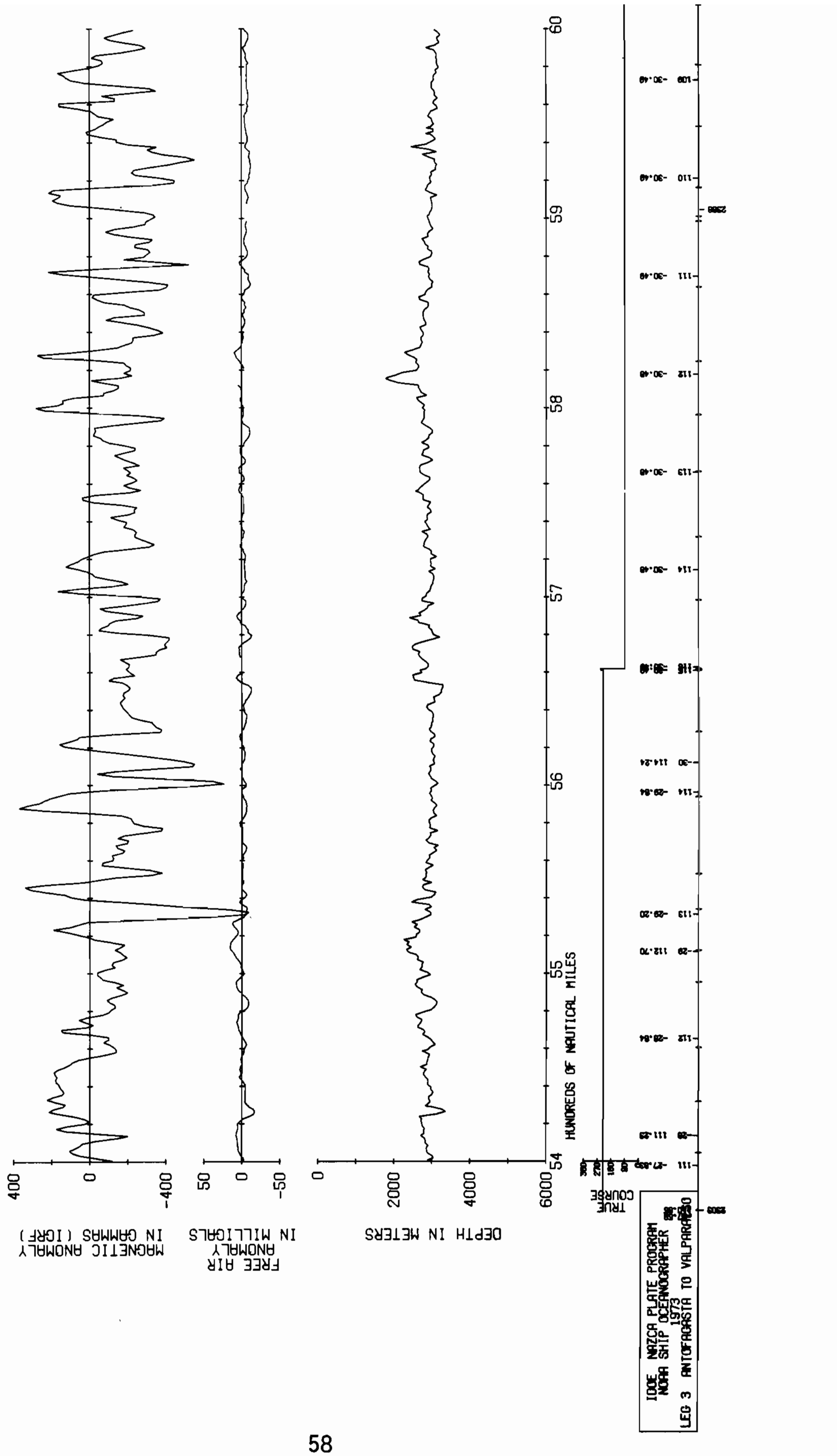
LEG 3 ANTOFAGASTA TO VALPARAISO


MAGNETIC ANOMALY IN GAMMAS (IGRF)
FREE AIR ANOMALY IN MILLIGALS
DEPTH IN METERS
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
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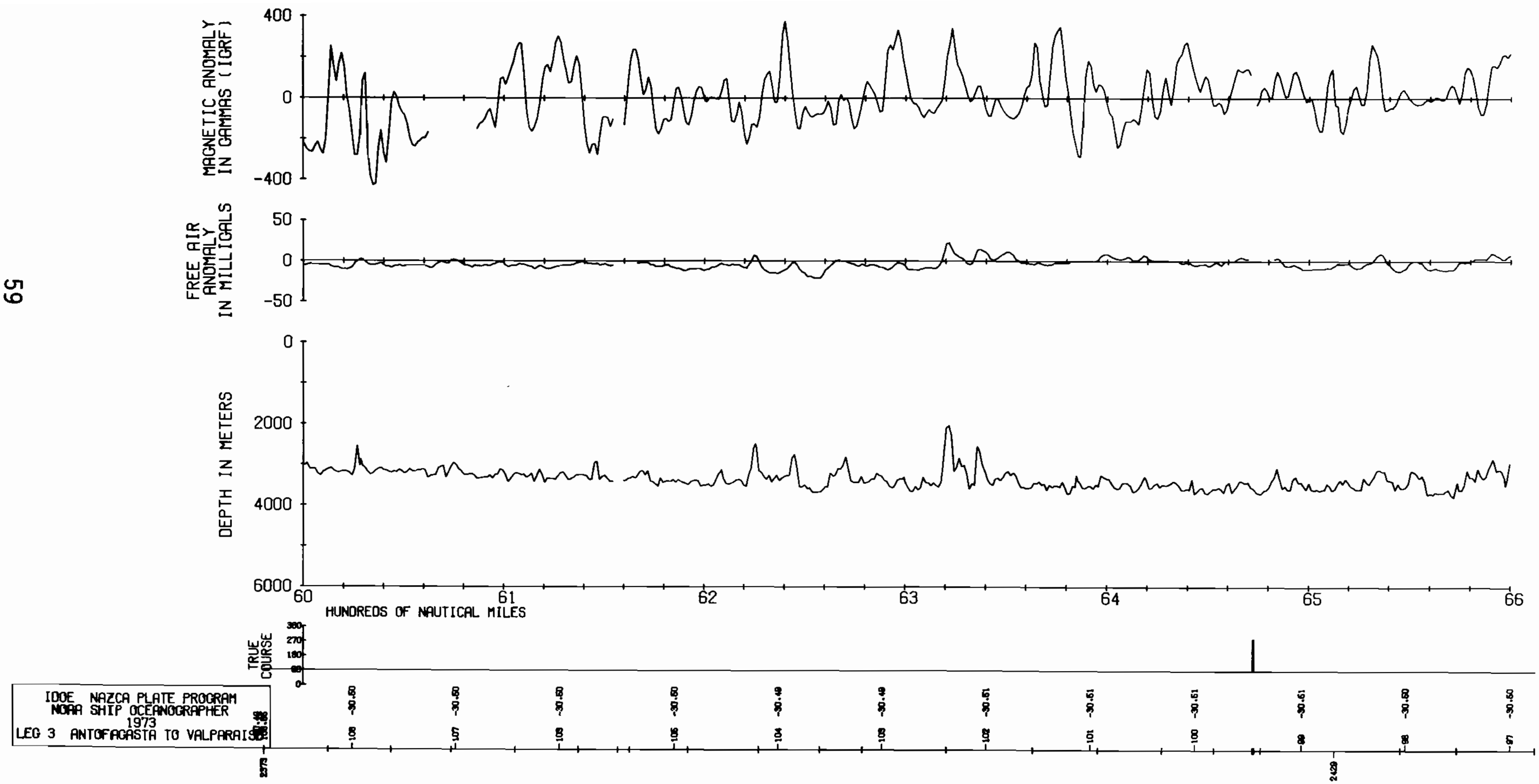
LEG 3 ANTOFAGASTA TO VALPARAISO


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
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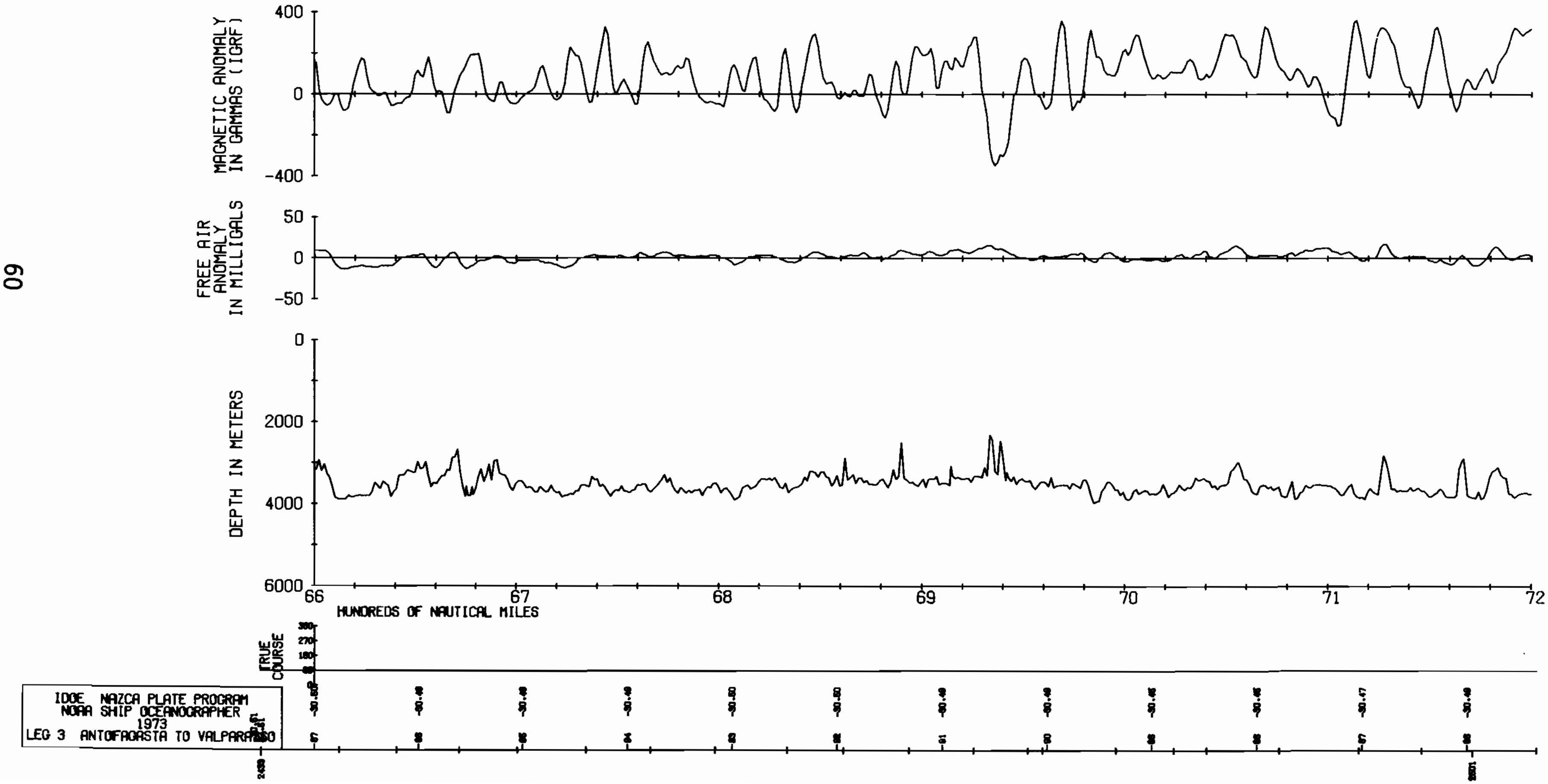
2000
4000
6000
60
61
62
63
64
65
66
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
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2000
4000
6000
66
67
68
69
70
71
72
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
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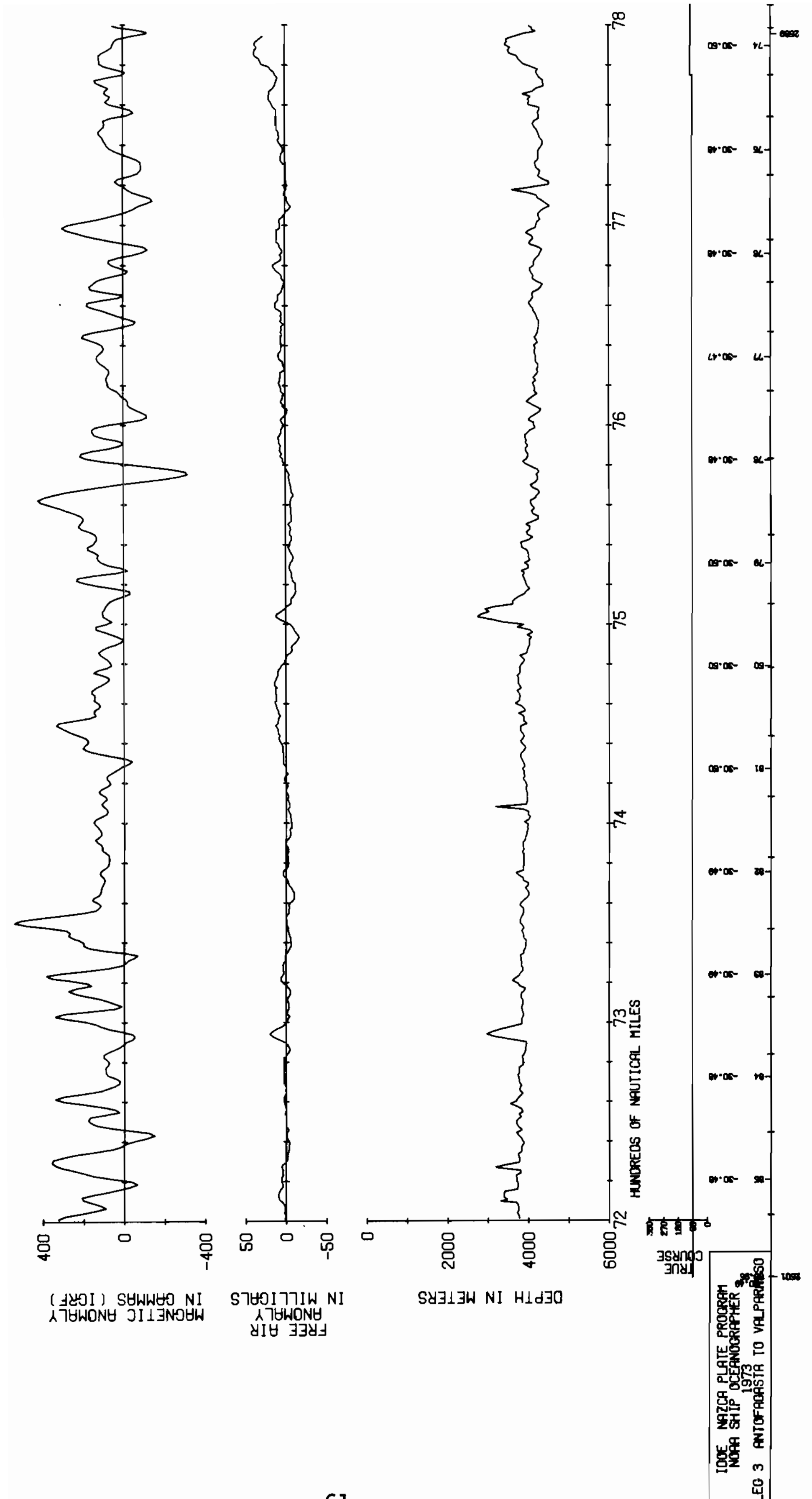
LEG 3 ANTOFAGASTA TO VALPARAISO


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
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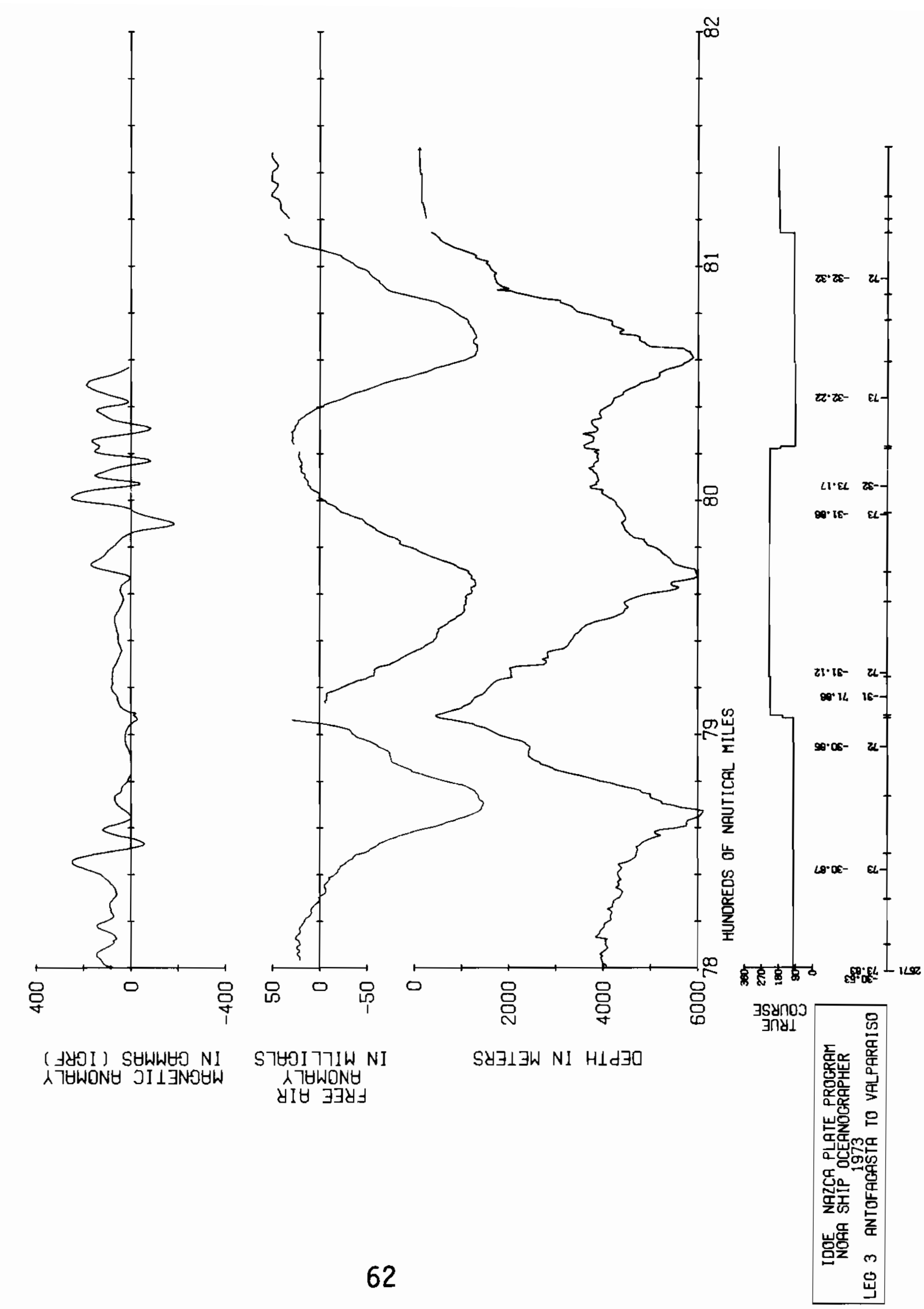
2000
4000
6000
72
73
74
75
76
77
78
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
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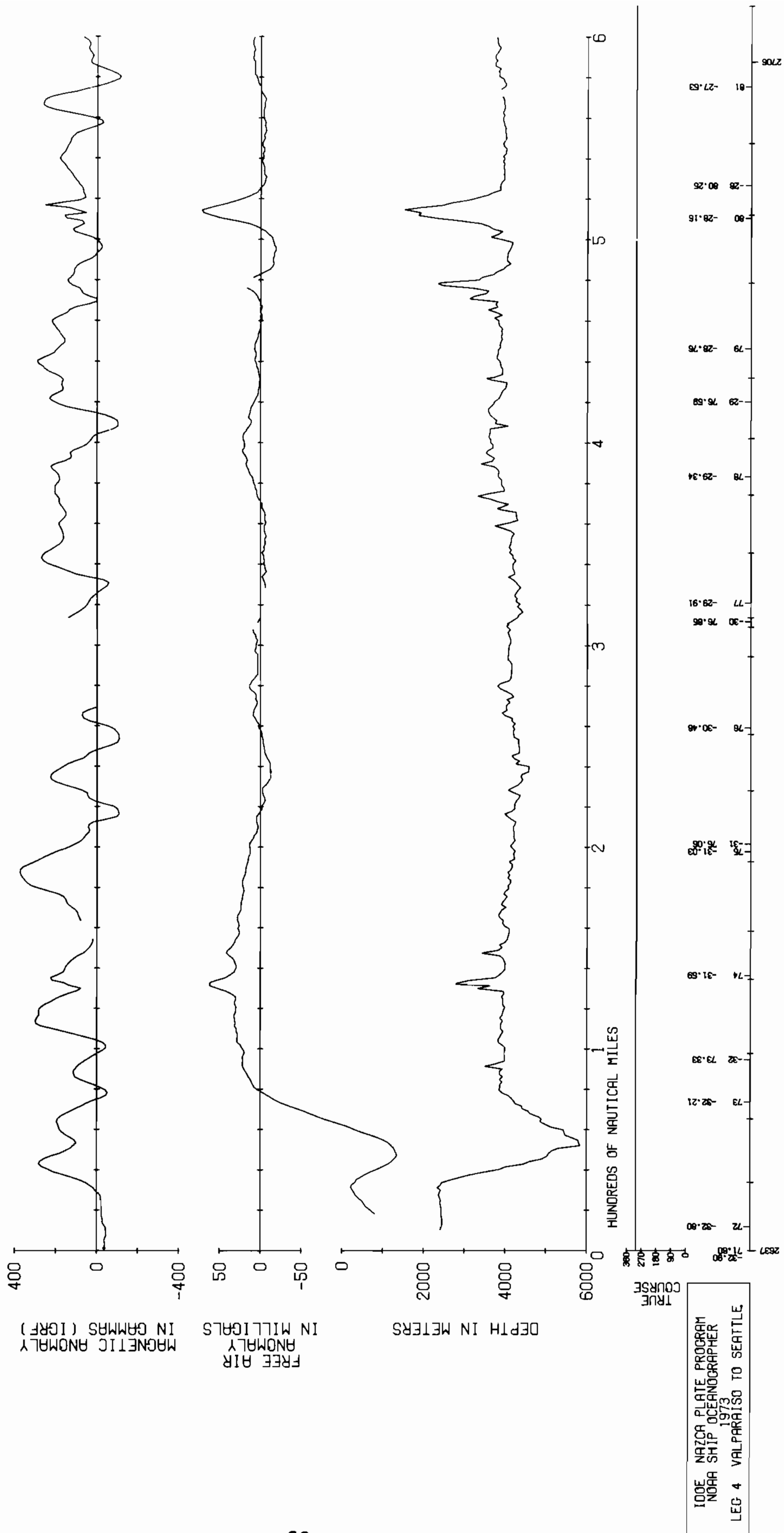
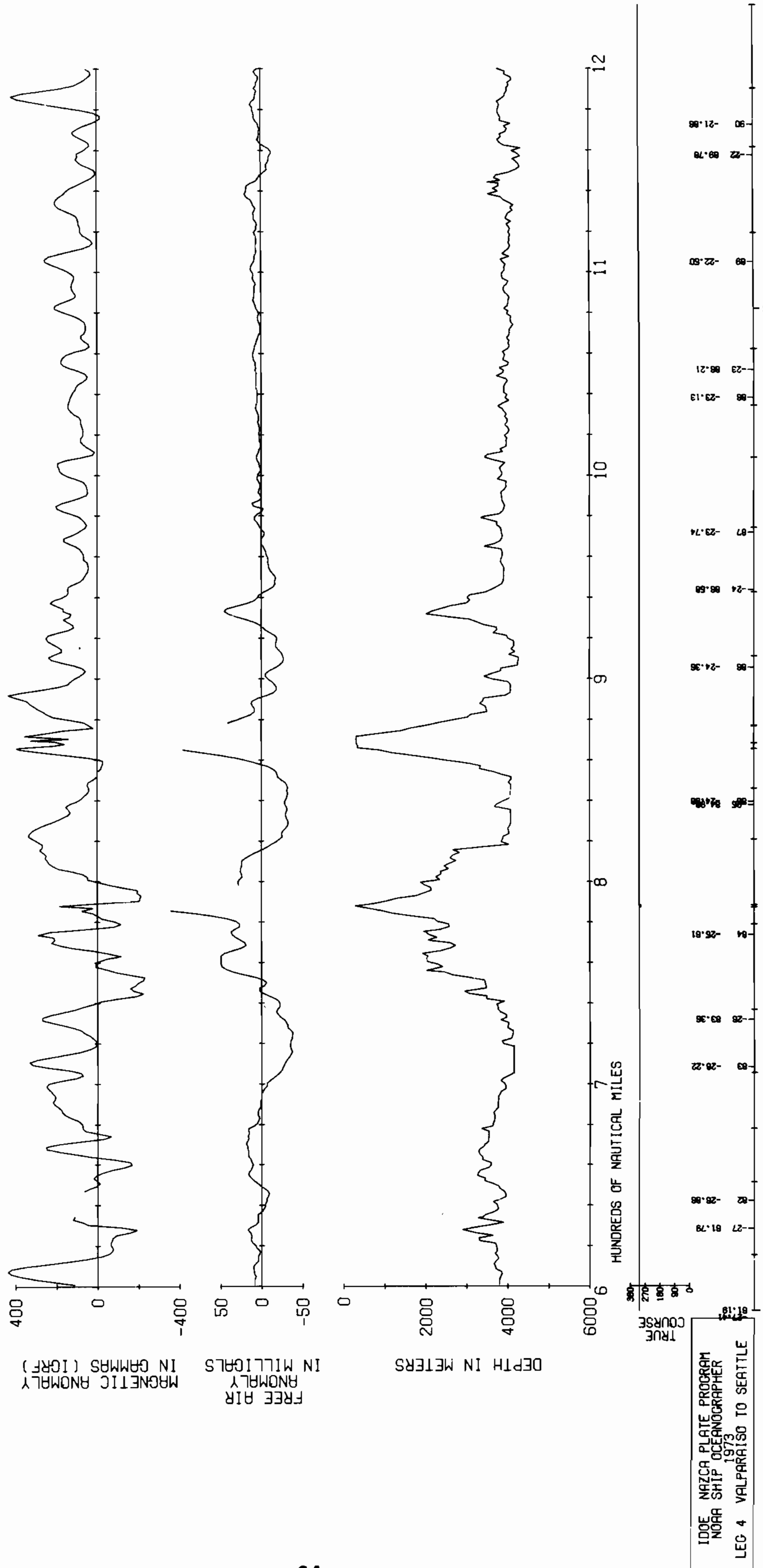
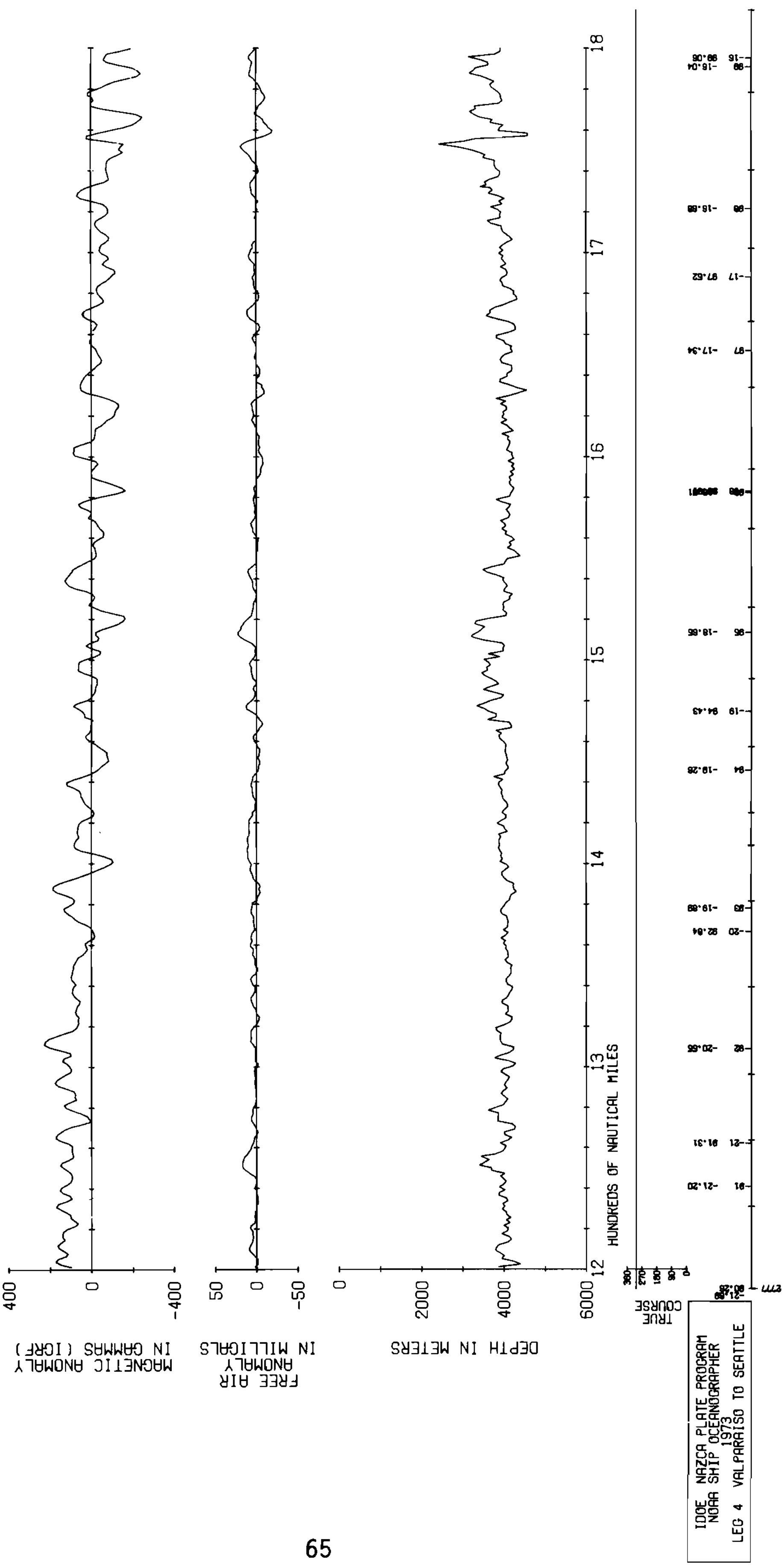
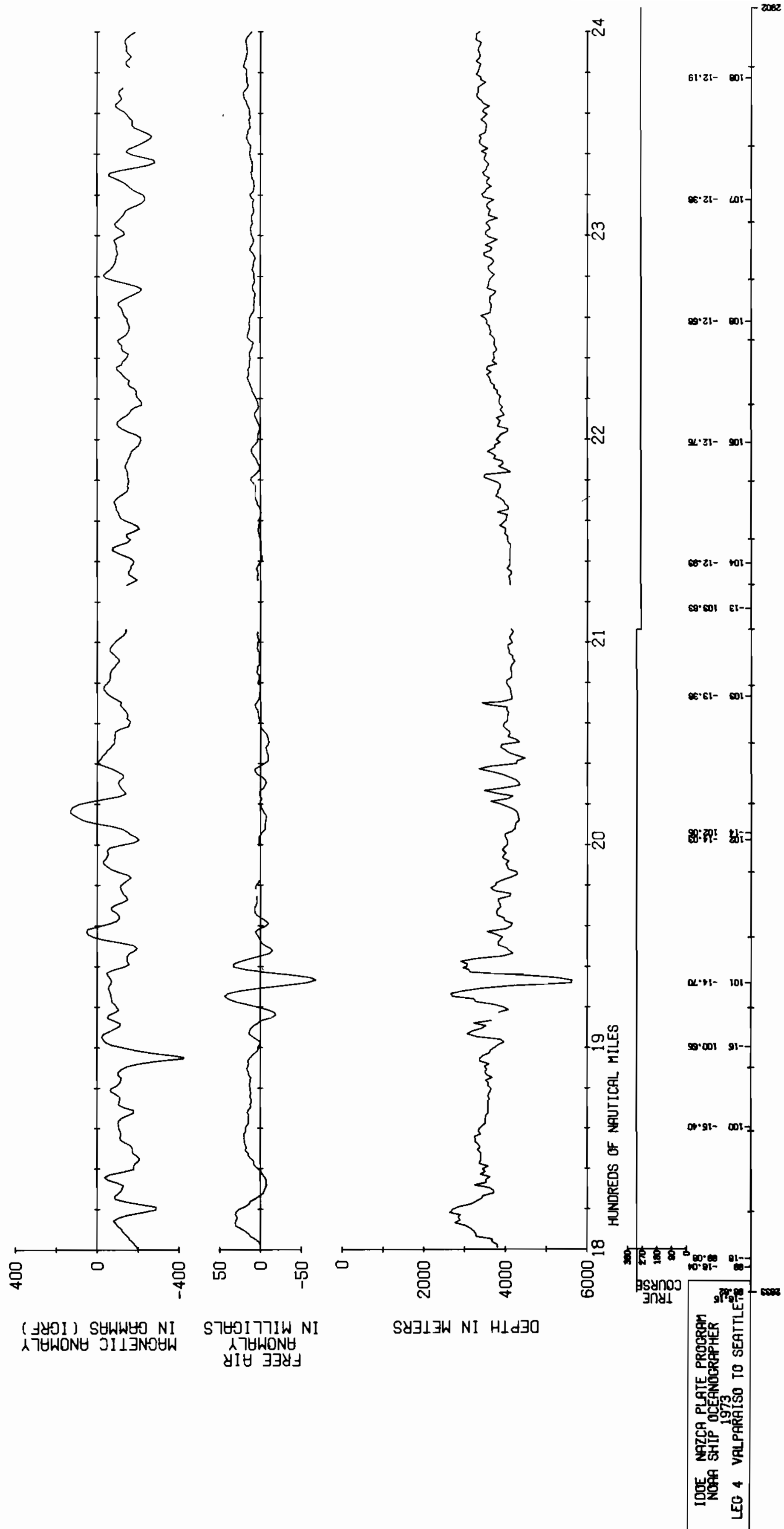
0
-50
DEPTH IN METERS
0
2000
4000
6000
78
79
80
81
82
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 3 ANTOFAGASTA TO VALPARAISO

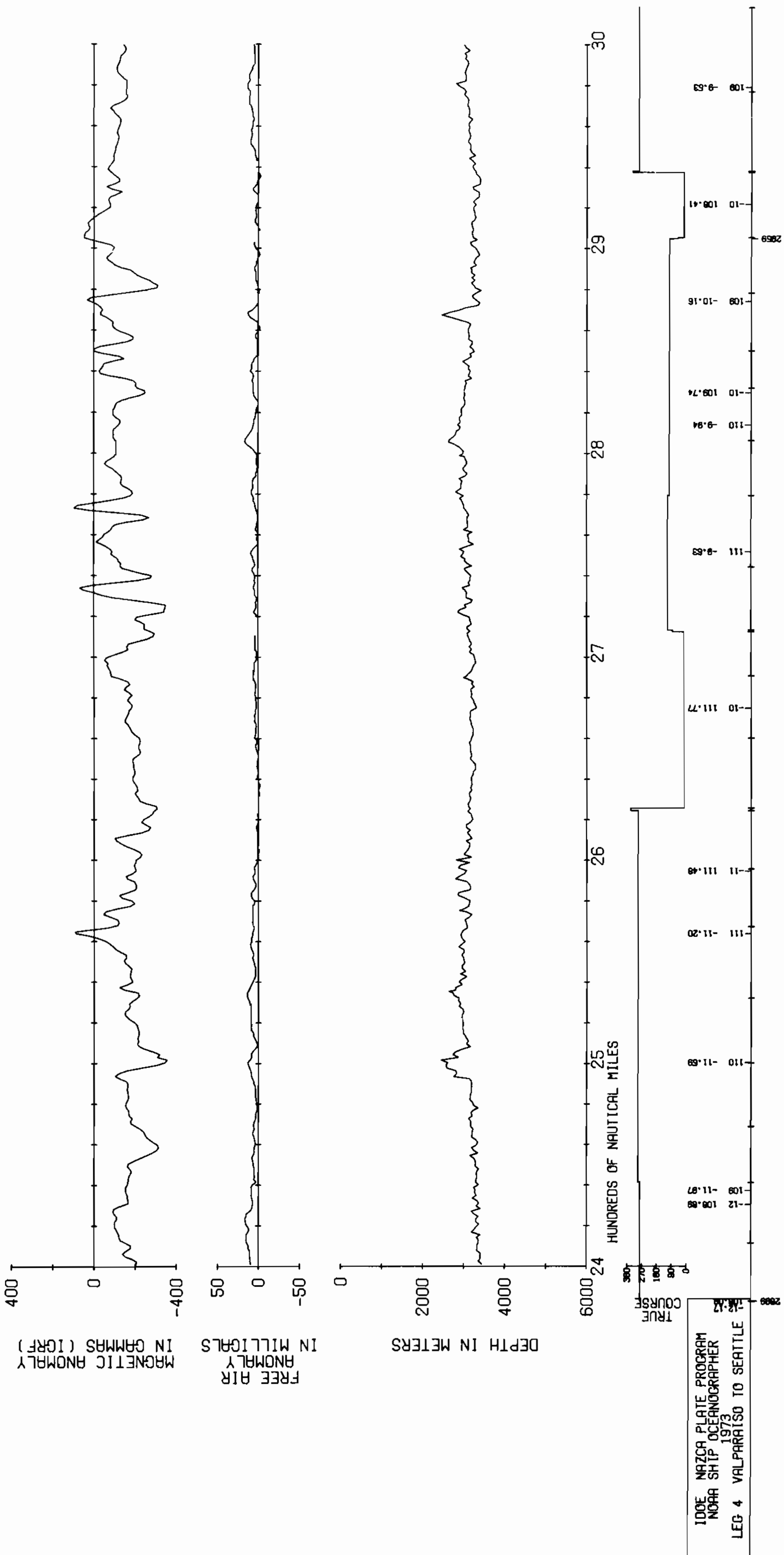


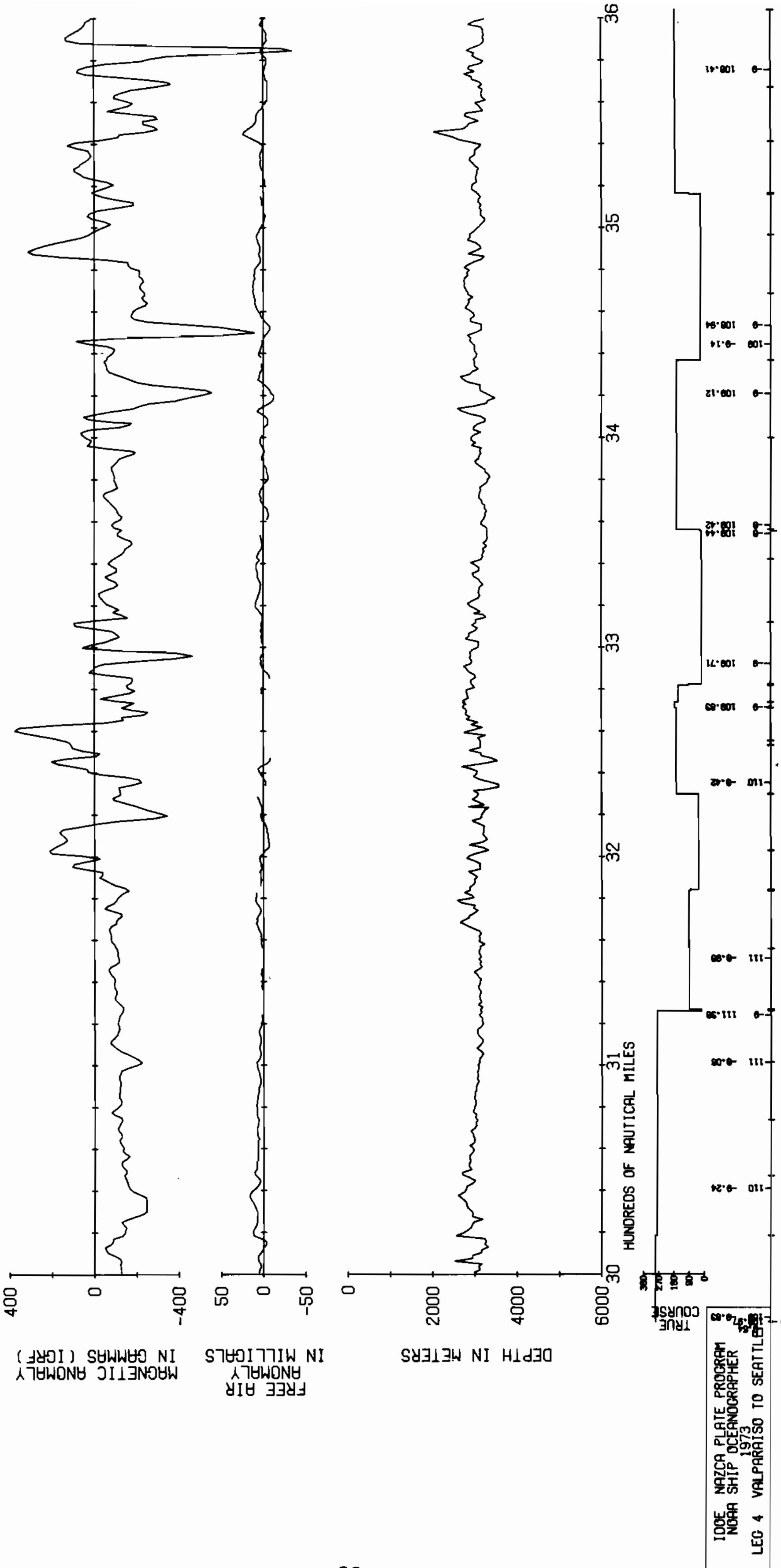
MAGNETIC ANOMALY IN GAMMAS (IGRF)
FREE AIR ANOMALY IN MILLIGALS
DEPTH IN METERS
TRUE COURSE
HUNDREDS OF NAUTICAL MILES
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

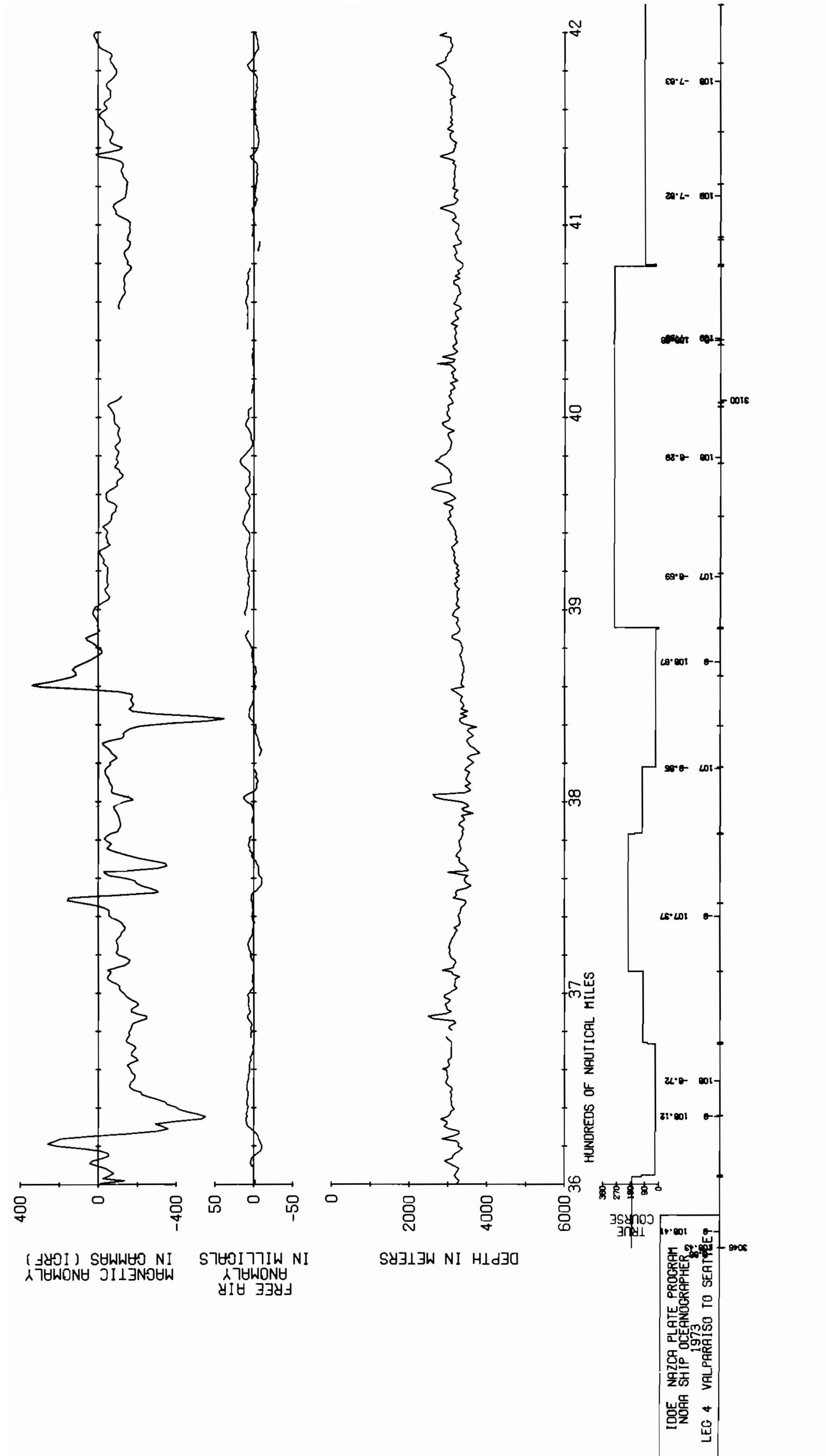

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
HUNDREDS OF NAUTICAL MILES
6
7
8
9
10
11
12
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

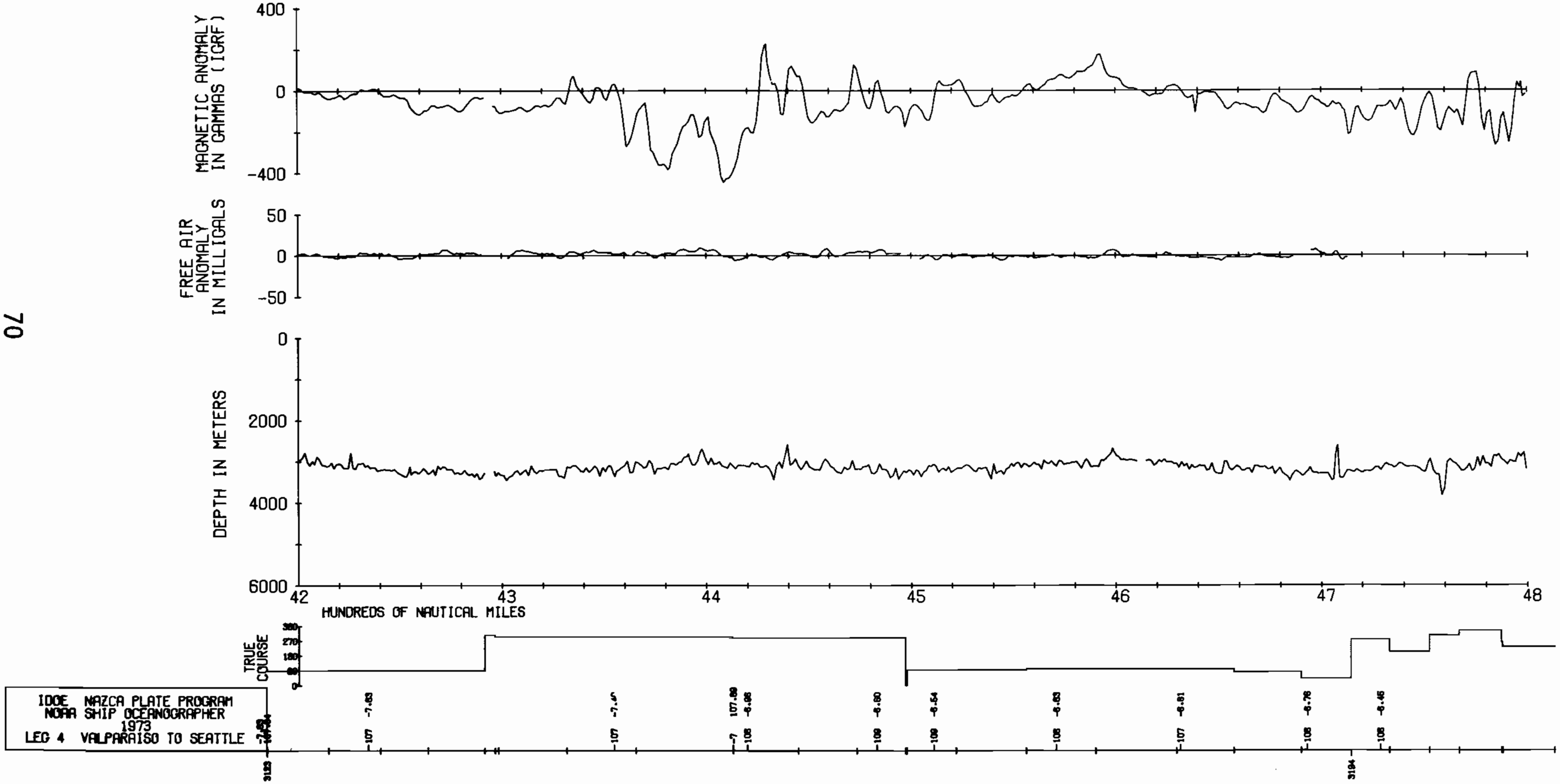

IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE
MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
TRUE COURSE
HUNDREDS OF NAUTICAL MILES
12
13
14
15
16
17
18

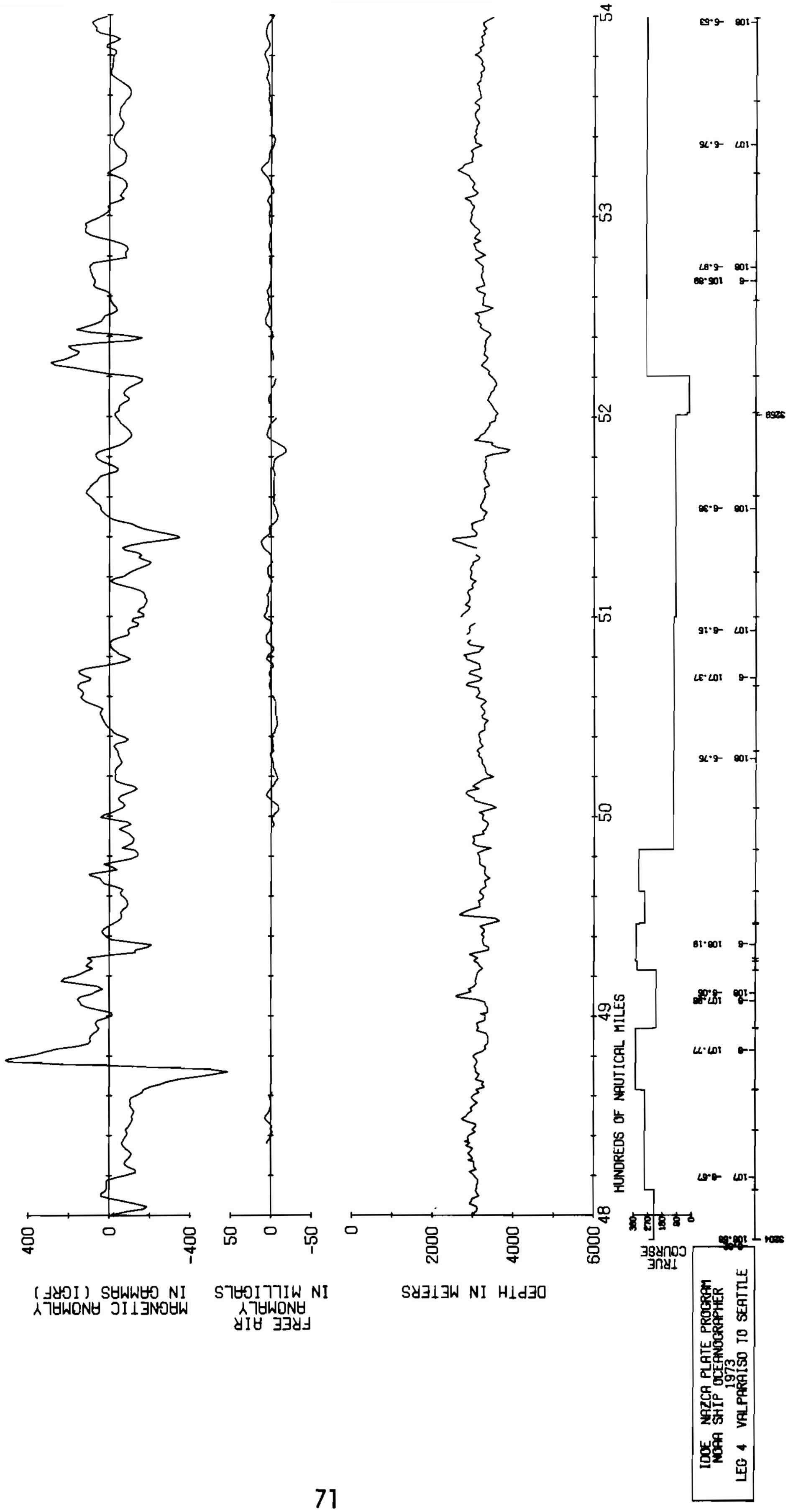

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
18
19
20
21
22
23
24
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

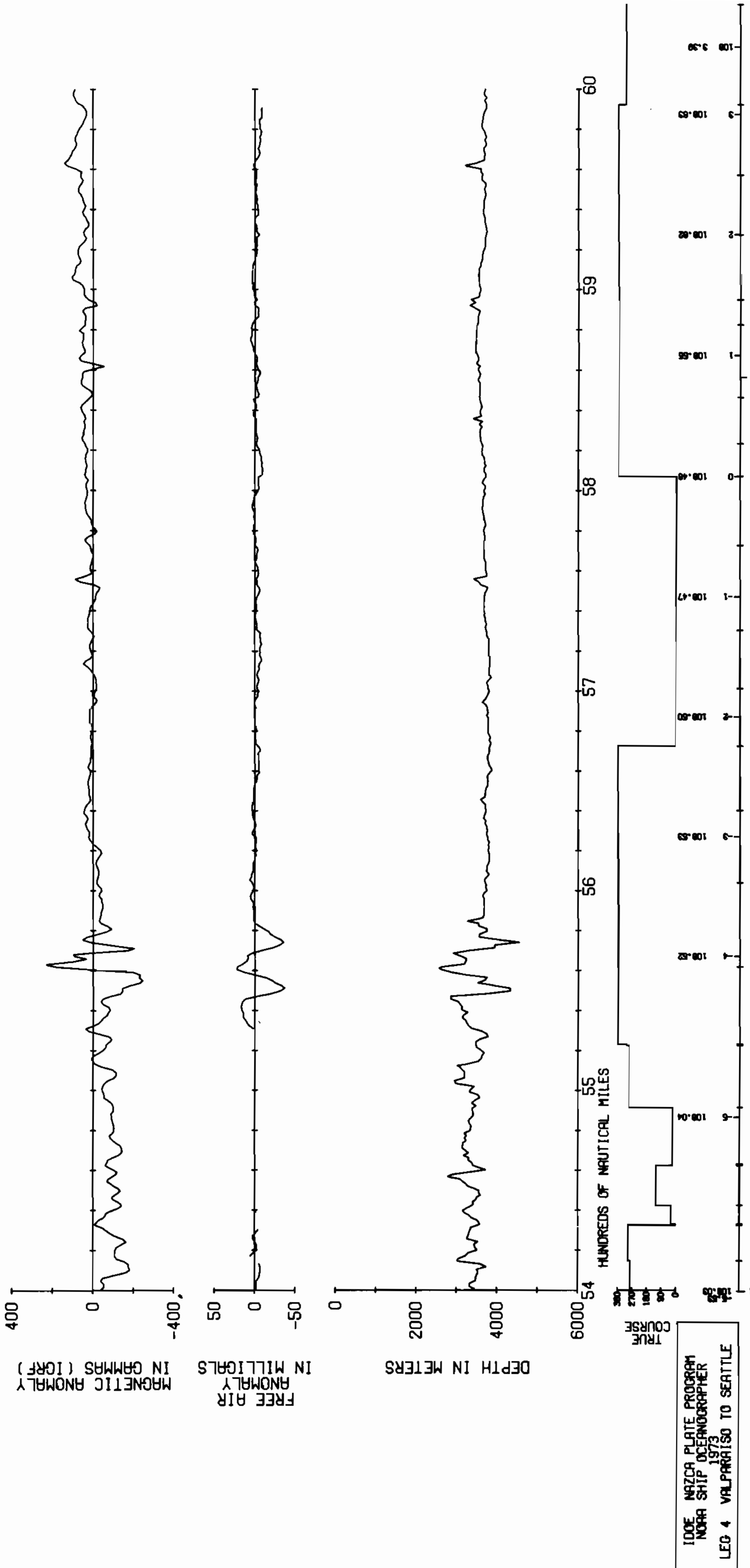

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
24
25
26
27
28
29
30
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

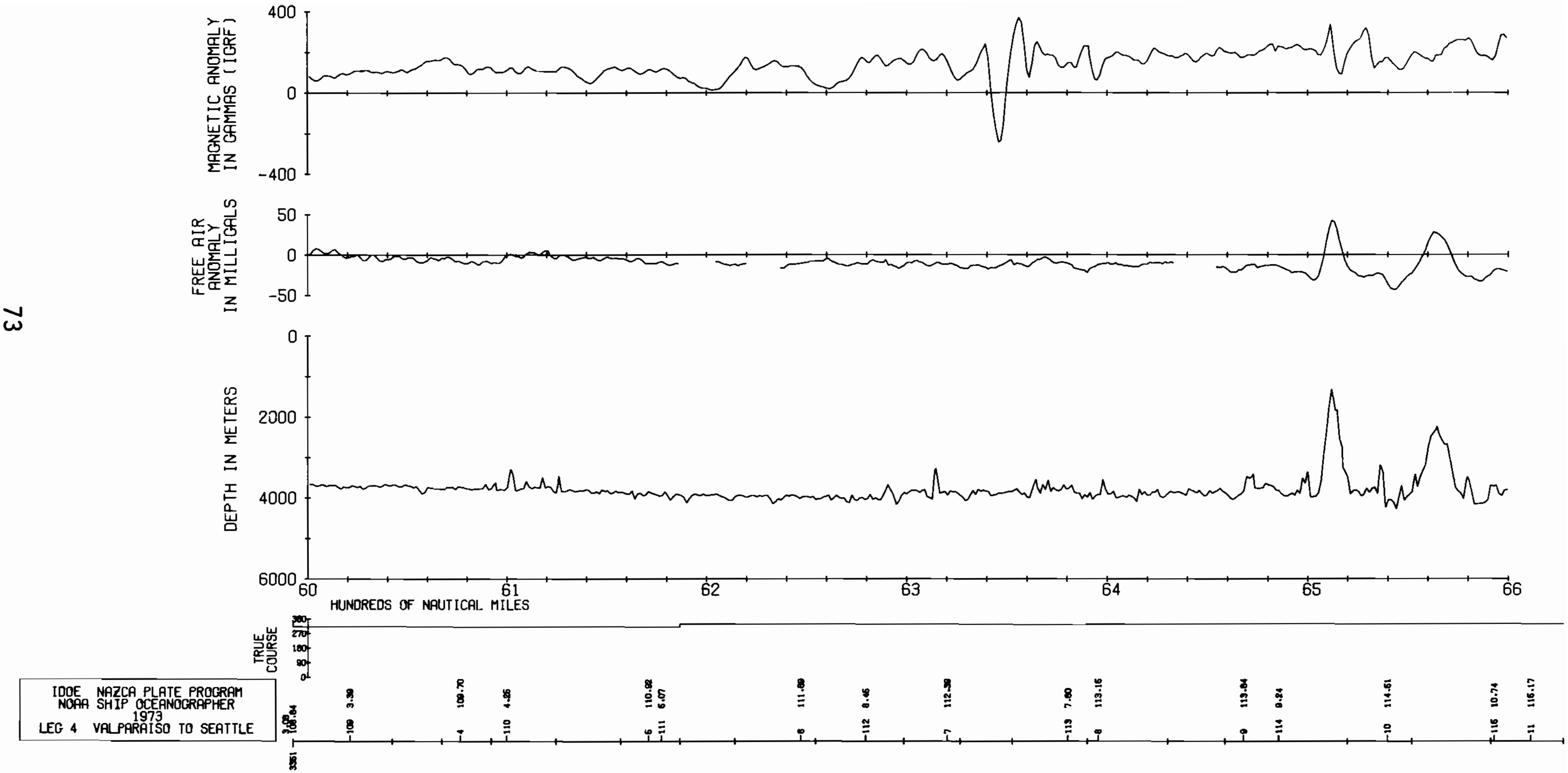

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
30
31
32
33
34
35
36
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

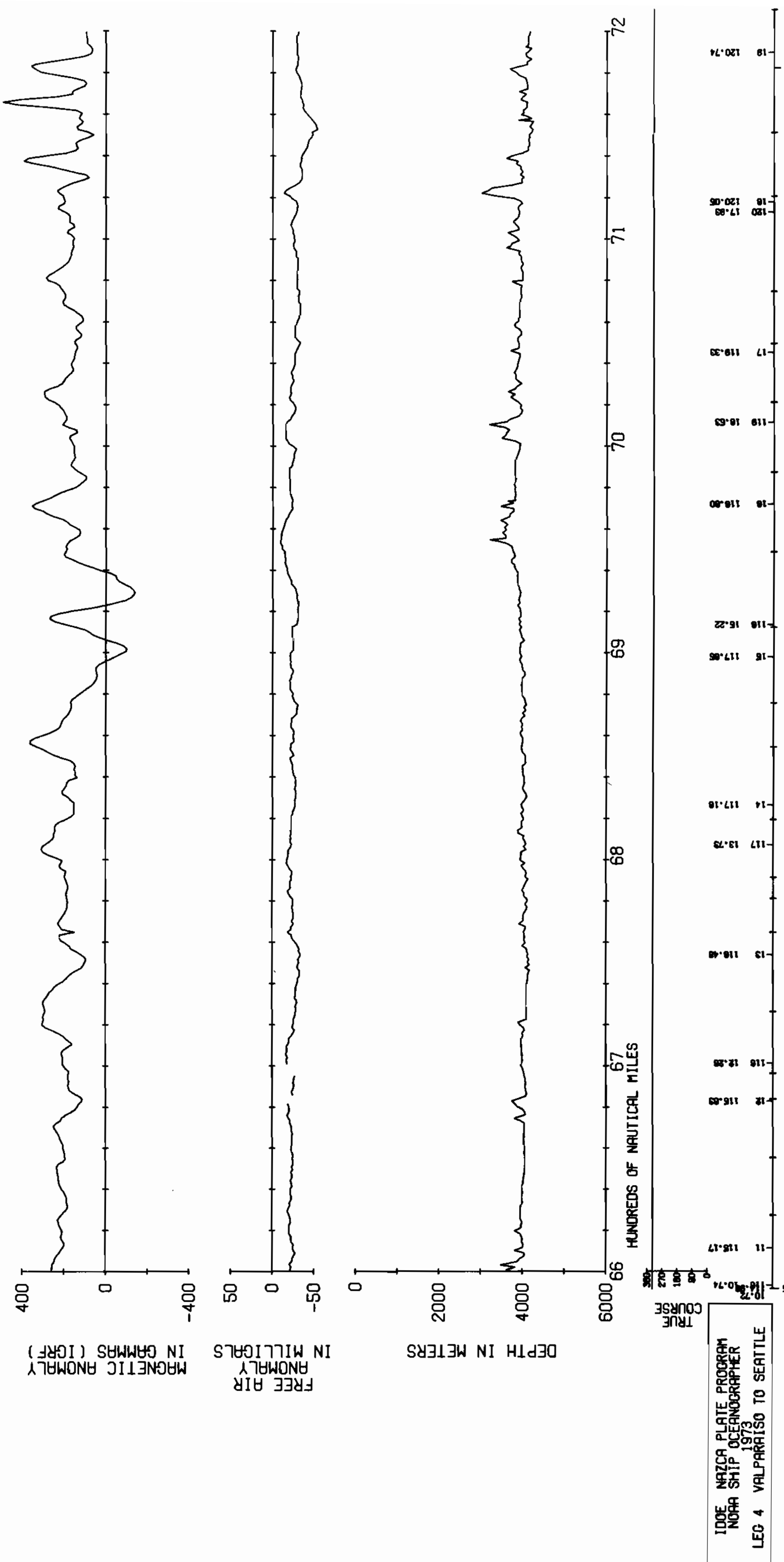

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
36
37
38
39
40
41
42
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

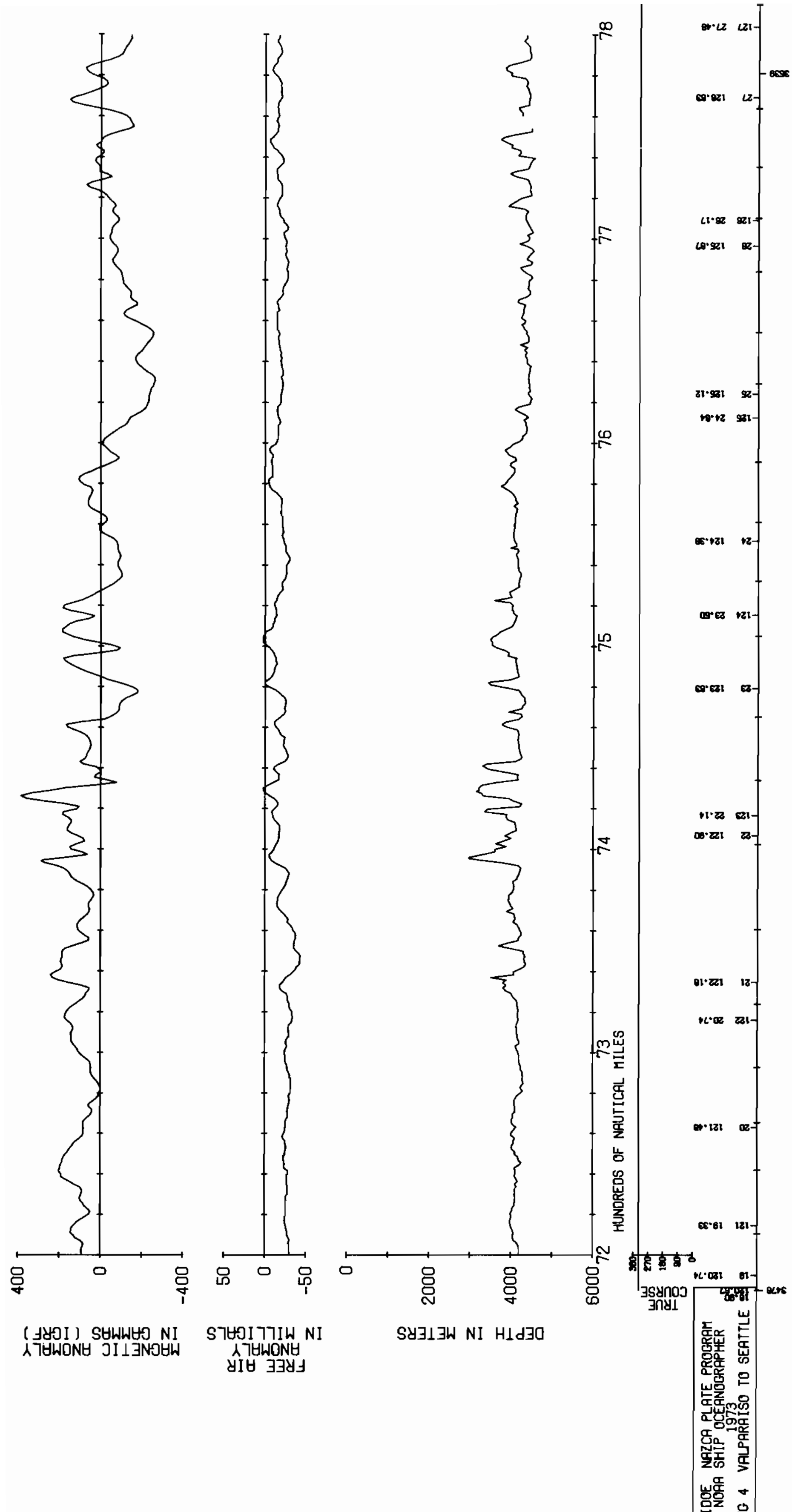

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
42
43
44
45
46
47
48
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE


MAGNETIC ANOMALY
IN GAMMAS (IGRF)
400
0
-400
FREE AIR
ANOMALY
IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
48
49
50
51
52
53
54
HUNDREDS OF NAUTICAL MILES
TRUE
COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

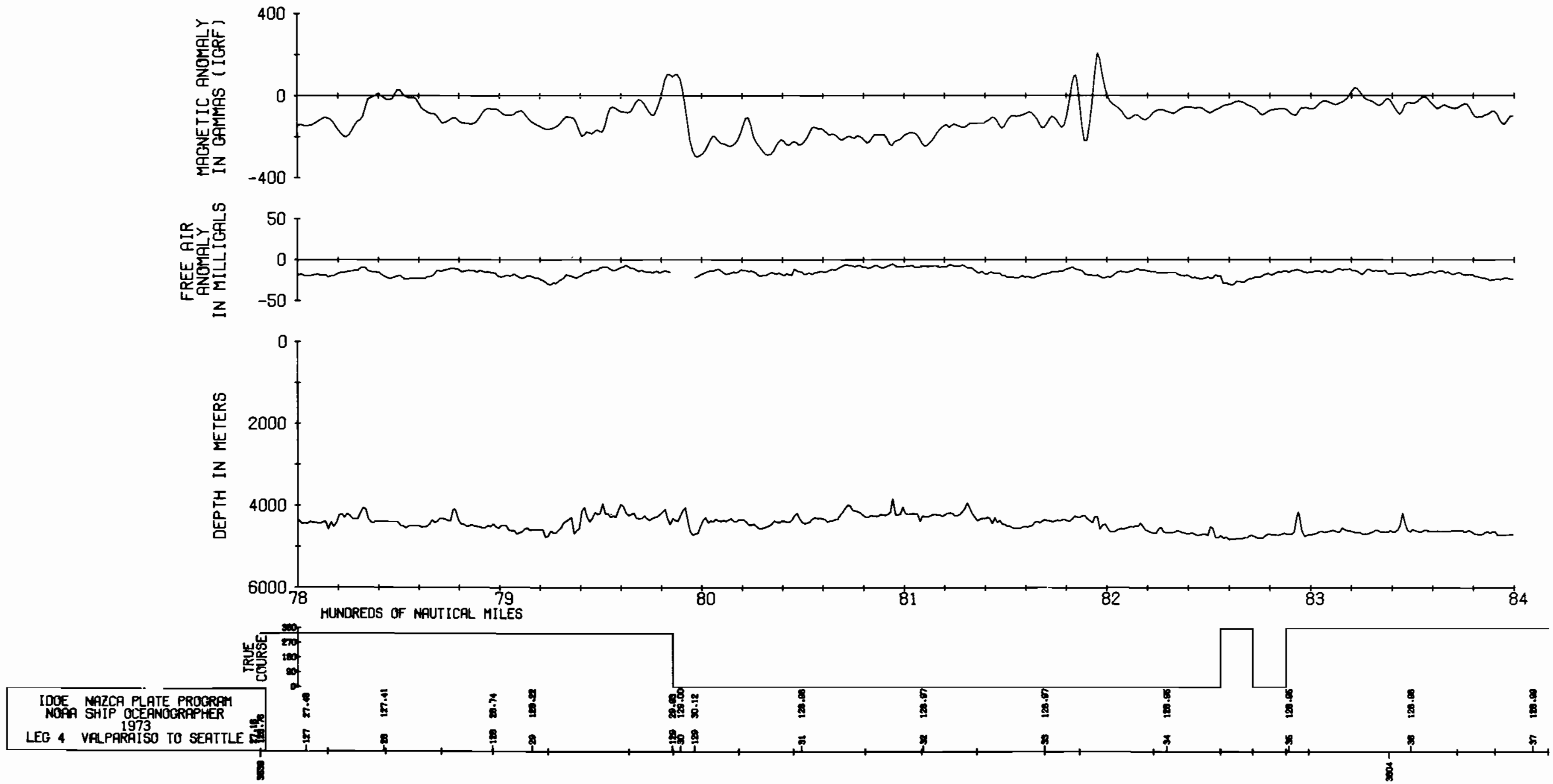

MAGNETIC ANOMALY IN GAMMAS (IGRF)
FREE AIR ANOMALY IN MILLIGALS
DEPTH IN METERS
TRUE COURSE
HUNDREDS OF NAUTICAL MILES
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
60
61
62
63
64
65
66
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

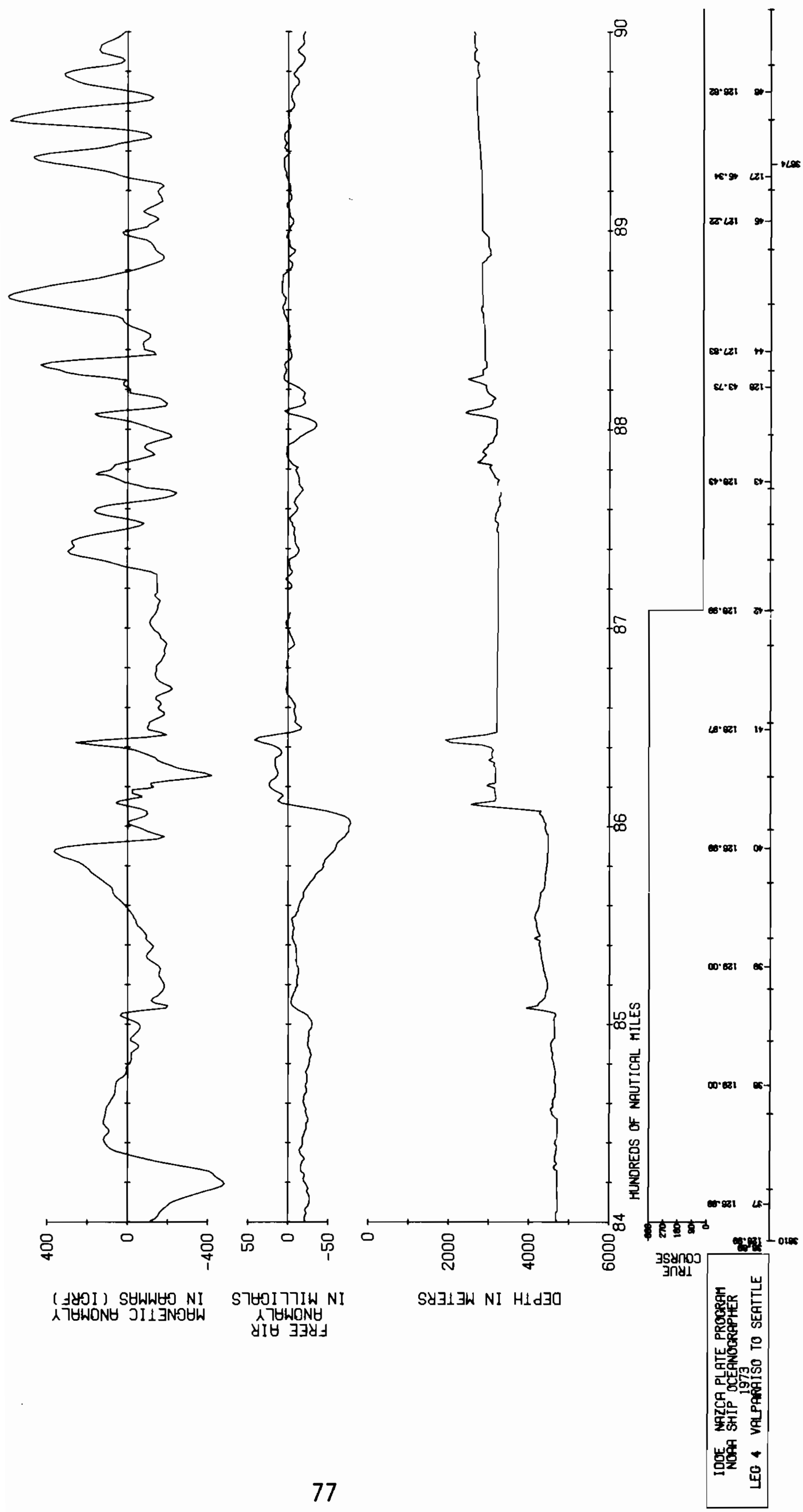

MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
HUNDREDS OF NAUTICAL MILES
66
67
68
69
70
71
72
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE

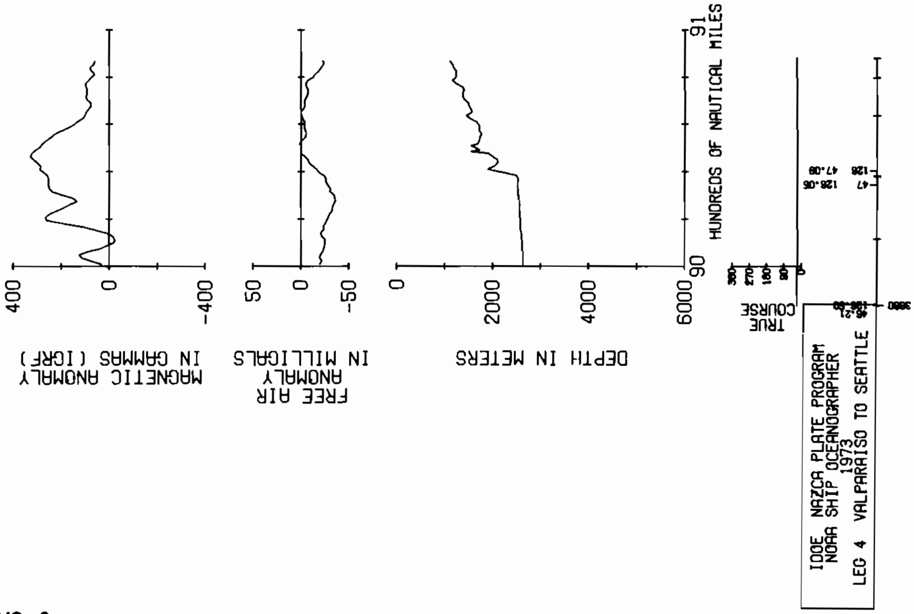


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
72
73
74
75
76
77
78
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE



MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
78
79
80
81
82
83
84
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
84
85
86
87
88
89
90
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE


MAGNETIC ANOMALY IN GAMMAS (IGRF)
400
0
-400
FREE AIR ANOMALY IN MILLIGALS
50
0
-50
DEPTH IN METERS
0
2000
4000
6000
90
91
HUNDREDS OF NAUTICAL MILES
TRUE COURSE
IDOE NAZCA PLATE PROGRAM
NOAA SHIP OCEANOGRAPHER
1973
LEG 4 VALPARAISO TO SEATTLE