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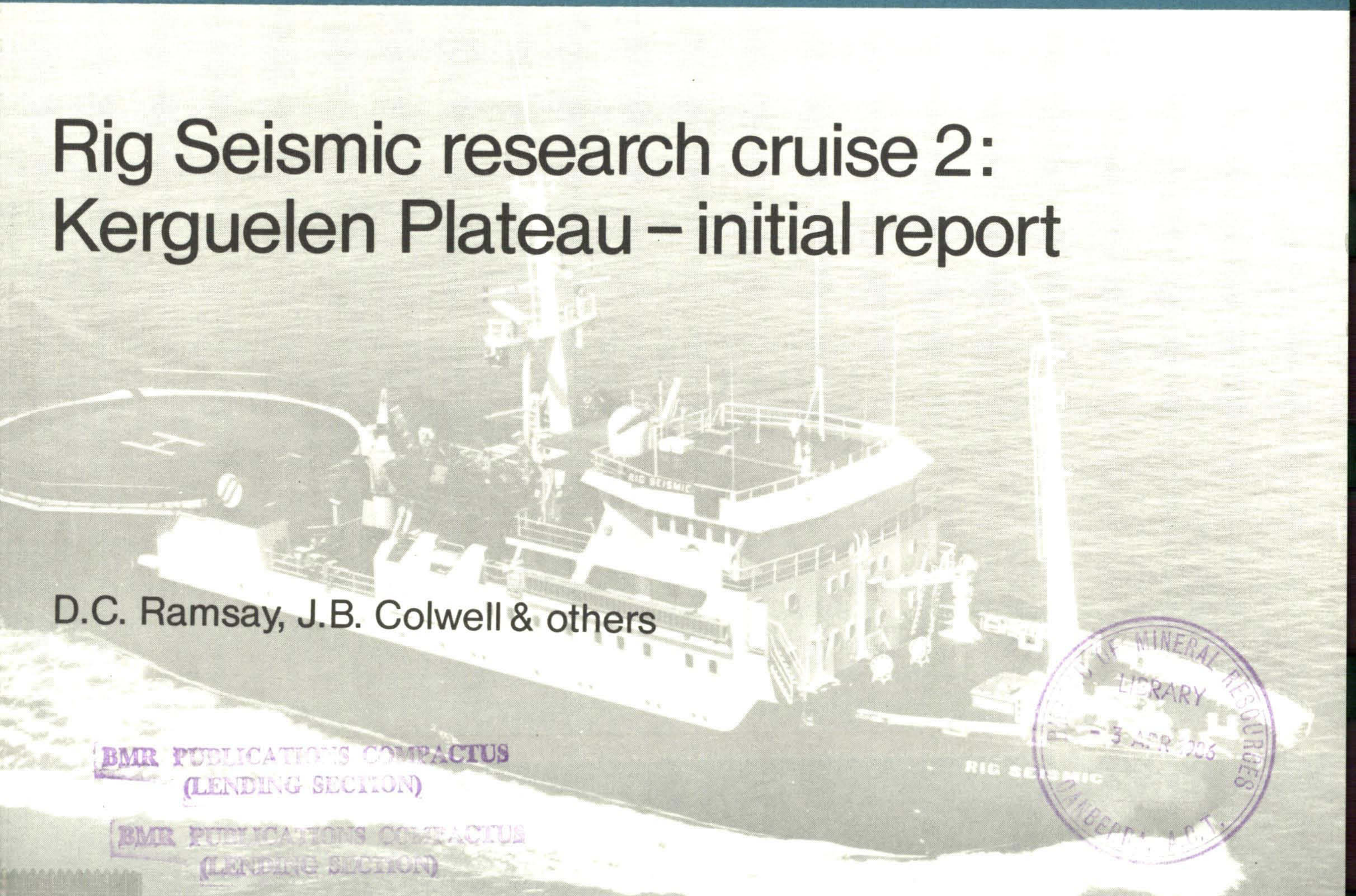

Rig Seismic research cruise 2: Kerguelen Plateau – initial report

D.C. Ramsay, J.B. Colwell & others

[Bur]eau of Mineral Resources, Geology & Geophysics

Department of Resources & Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

REPORT 270

RIG SEISMIC RESEARCH CRUISE 2:

KERGUELEN PLATEAU, SOUTHERN INDIAN OCEAN

INITIAL REPORT

by

Principal investigators

D.C. Ramsay & J.B. Colwell

Scientific staff,
M.F. Coffin, H.L. Davies, P.J. Hill, N.A. Johnston,
C.J. Pigram, H.M.J. Stagg

Technical Support Staff
J. Bedford, E. Chudyk, R. Curtis-Nuthall, S. Hall, R. McMahon,
J. Pittar, G. Saunders, D. Simington, J. Stuart, P. Walker

Division of Marine Geosciences & Petroleum Geology

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ABSTRACT

The Kerguelen Plateau cruise was the second in a series of research cruises to be undertaken by BMR under its new initiative in marine geoscience. Approximately 5500 km of high-quality multichannel seismic data and 15 000 km of gravity and magnetic data were recorded on the R/V Rig Seismic during a 58-day period in March-April 1985. The work was undertaken almost exclusively within the area of 'legal continental shelf' claimed by Australia on the central and southern parts of the plateau. The general cruise objectives were to elucidate the structure, stratigraphy, and tectonic framework of this poorly understood mid-ocean feature.

Initial interpretation of the data indicates that the plateau to the north of Heard Island is asymmetric. The eastern margin is a largely sediment-free steep slope buttressed by volcanic intrusions. The central part of the plateau is underlain by adjoining sedimentary basins that are strongly intruded under the eastern half of the plateau and bounded by apparently uplifted blocks of magnetic basement on the western margin. To the west, the plateau descends gradually to the abyssal depths of the Enderby Basin.

Most of the research program was concentrated on the eastern part of the southern sector of the plateau. The principal feature in this area is a hitherto poorly defined sedimentary basin (here called the Raggatt Basin) covering an area of at least 30 000 sq km. The total sediment thickness is unknown, but certainly exceeds 3000 m. The basin is relatively simple in cross-section and has apparently undergone a history of gradual subsidence without significant faulting.

Magnetic and gravity data acquired over the plateau strongly reflect the nature, configuration, and depth of basement. The expression of mafic intrusive rocks is particularly pronounced. Three small samples of rock recovered from the southern-central part of the plateau included fragments of volcanic rocks and of sedimentary and igneous rocks of continental affinity.

INTRODUCTION

The Kerguelen Plateau survey was the second research cruise using the R/V Rig Seismic to be undertaken by BMR under its new initiative in marine geoscience. During the cruise, which commenced in Sydney on 2 March 1985, and ended in Melbourne on 29 Aril 1985, approximately 5500 km of 48-channel (12-fold) reflection seismic data, 80 km of 24-channel (6-fold) seismic data, and 15 000 km of bathymetric, gravity, and magnetic data were recorded in the southern Indian Ocean (Appendixes 1 and 2). In addition, five days were spent at the beginning of the cruise carrying out trials and acceptance tests on a new marine gravity meter. As the main coring winch had not been installed before the ship sailed, no major geological sampling was undertaken.

The principal area investigated, the Kerguelen Plateau, lies in the southern Indian Ocean, approximately 4000 km west-southwest of Perth (Fig. 1). It is bounded on its outer margin by the 3000 m (1600 fm) isobath E (Fig. 2). Generally, it is asymmetric with steeper flanks in the east than in the west. The French Kerguelen Islands and the Australian Territories of Heard and McDonald Islands emerge from the plateau at approximately 49° S and 53° S, respectively.

Previous work in the region consists of surveys of the Eltanin and Robert D. Conrad (Houtz & others, 1977; Quilty, 1973), Gallieni (Schlich & others, 1971), Cape Pillar (Tilbury, 1981), Nella Dan (Stagg & others, 1983a, b), Marion Dufresne (Guglielmi, 19820, and Umitaka Maru (Fig. 3, Table 1). In addition, a large number of unpublished data have been collected by the French over the northern part of the plateau.

Under the terms of the yet-to-be-ratified Law of the Sea Treaty, Australia can lay claim to approximately three-quarters of the plateau as legal continental shelf (Fig. 4). This makes it the largest area (1.8 million km , about the size of Queensland) of continental shelf that can be claimed by Australia away from its own margins.

Acknowledgement

The enthusiasm, skill and cooperation of the master and crew of the Rig Seismic are gratefully acknowledged. They have made a major contribution to the success of the cruise.

Crew of the R/V Rig Seismic

Master	H. Foreman
Chief Officer	D. Harvey
2nd Officer	W. McKay
Chief Engineer	C. de Souza
2nd Engineer	P. Pittiglio
3rd Engineer	G. Wooler
Electrical Officer	P. Jiear
ERA/AB	K. Halliday
Chief Steward	R. Plenty
Cook	G. Conley
Steward	J. Caminitti
2nd Steward	S. O'Rourke
AB	N. Luscombe
AB	P. Holdsworth
AB	G. Pretzel

Table 1. Summary of previous cruises over the Kerguelen Plateau

Vessel	Cruise	Year	Bathymetry	Gravity	Magnetics	Seismics
Umitaka Maru	-	1962	X	-	?	-
Robert D. Conrad	0802	1964	X	X	X	A
Umitaka Maru	-	1967	X	-	?	-
Robert D. Conrad	1104	1967	X	X	X	A
Eltanin	46	1970	X	X	X	-
Gallieni	3	1970	X	?	X	B
Eltanin	47	1971	X	X	X	A
Eltanin	54	1972	X	X	X	A
Gallieni	5	1972	?	?	?	?
Marion Dufresne	1	1973	?	?	?	?
Robert D. Conrad	1704	1974	X	X	X	A
Marion Dufresne	5	1975	?	?	?	?
Cape Pillar	-	1980	X	-	X	-
Marion Dufresne	26	1981	?	?	?	C
Nella Dan	-	1979-82	X	-	X	D
Marion Dufresne	35	1983	X	?	?	?

X: acquired
-: not acquired
?: unknown
A: small-capacity air gun
B: Flexotir
C: Flexichoc
D: one line only, 500 cubic inch air gun

CRUISE OBJECTIVES

The principal objectives of the cruise were
(i) To define the basic structure and stratigraphy of the central and southern parts of the Kerguelen Plateau, and, in particular, to determine the location and orientation of horst and graben systems and the thickness of major sedimentary accumulations;
(ii) To clarify the major structural differences between the northern and southern sectors of the plateau; and
(iii) To better define the relationship of the Kerguelen Plateau to the ?post-Cenomanian oceanic crust in the northeast and the ?Cretaceous oceanic crust in the southwest.

A secondary objective was to define possible future sites for the Ocean Drilling Program (see Crook & others, 1984, and ODP timetable).

Complete or partial achievement of the main objectives should enable a first estimate to be made of the petroleum potential of the Kerguelen Plateau.

GEOLOGICAL BACKGROUND

Framework within the southern Indian Ocean

The Kerguelen Plateau is situated on the Antarctic plate southwest of the Southeast Indian Ridge (Fig. 1). It is bounded in the northwest by the Crozet

Basin, in the northeast by the South Indian or Australia-Antarctica Basin, and in the southwest by the Enderby Basin, and is separated from Antarctica by a trough 3500 m deep and 100 km across. Magnetic anomaly pattens in these basins (Le Pichon & Heirtzler, 1968; Schlich & Patriat, 1971; Houtz & others, 1977; Tilbury, 1981; Schlich, 1982) suggest that the oldest oceanic crust east of Heard Island is approximately 40-45 Ma old (anomaly 17 or 18) and the crust northeast of the Kerguelen Islands is approximately 33 Ma old (anomaly 11). The crust to the northeast of the plateau was apparently generated by NE-SW spreading between the Australian and Antarctic plates, beginning in the ?Cenomanian (Cande & Mutter, 1982), whereas the crust to the southwest was probably generated by spreading between India and Australia-Antarctica prior to the Late Cretaceous (?anomalies 33 and 34; Schlich, 1982). Small segments of relatively old crust may be present along the eastern margin of the plateau (see RESULTS).

It has been assumed by many authors that Broken Ridge-Naturaliste Plateau and Kerguelen Plateau were once joined; this assumption is based on the gross morphological similarities between the two features and the fact that they occupy roughly symmetrical positions about the Southeast Indian Ridge. However, reconstruction to total closure of Antarctica and Australia causes overlap of the northern Kerguelen Plateau and Broken Ridge that is unacceptable in terms of observed sediment ages. This mismatch is partly resolved if it is assumed that the northern Kerguelen Plateau is a volcanic excrescence younger than the remainder of the plateau.

Mutter & Cande (1983) employed their revised date of the initiation of spreading (120-90 Ma) and spreading rates for Australia-Antarctica to produce a model for the formation of Kerguelen Plateau-Broken Ridge. The more notable features of this are that there is no longer any conflict between the time at which overlap occurs and known age information, and that the Diamantina Zone off southwest Australia appears to have continued into the horst and graben province of the central Kerguelen Plateau. The model, however, does not throw any light on the nature of the crust beneath the central and southern Kerguelen Plateau, which, from the poorly constrained gravity model studies of Houtz & others (1977), may be either thickened oceanic crust or attenuated continental crust.

From deep refraction probes, Francis & Raitt (1967) concluded that Broken Ridge is 'almost continental'. However, Carlson & others (1980) used the same data to group Broken Ridge within the oceanic class of aseismic ridges. Other studies have noted that a crustal thickness of more than 20 km is well established for Broken Ridge, but that an oceanic origin is unproven.

Morphology of the Kerguelen Plateau

In general, the plateau is a NNW-trending broad ridge 2100 km long, about 500 km across, and standing 2-4 km above the adjacent sea floor. Basically, it can be divided into two parts, viz. northern and southern sectors.

The northern sector is a sub-rectangular block about 800 km long and 400 km wide, which stands 3-4 km above the surrounding sea floor (Fig. 2). It is dominated by Heard and Kerguelen Islands and generally lies at water depths of less than 1000 m. Bounding slopes are steeper in the east (5-10) than in the west 1-3), and commonly are interrupted by peaks and ridges (e.g. Fig. 13; Houtz & others, 1977, profiles 4A and 12A).

The southern sector of the plateau is generally deeper than the northern sector and has less relief above the adjacent sea floor. It can be divided into three zones: a central zone, which includes the Banzare Bank, and a southwestern salient (Fig. 2). Water depths are as shallow as 700 m, but are generally between 1500 and 2500 m.

General structure and stratigraphy of the plateau

From the SEASAT-derived free-air gravity field (Haxby & others, 1983), the plateau appears as a general NW-SE-trending high comprising several free-air gravity maxima. The more prominent of these highs are associated with the Kerguelen Islands, Heard Island, a series of banks between Kerguelen and Heard Islands, an edifice west-southwest of Kerguelen Island (Rogers Seamount*), Elan Bank, a spur extending east and east-southeast of Heard Island (Williams Ridge*), Corinthian Bank*, and Banzare Bank (Fig. 5). Conspicuous lows flank practically the entire northeast margin of the plateau except the Kerguelen massif proper. Between the Williams Ridge and the main plateau lies the Labuan Basin*, a prominent gravity minimum. The southwest sides of Kerguelen Island and Rogers Seamount, as well as the flanks of Elan Bank, show marked negative anomalies. Both the plateau and adjacent sea floor display free-air anomalies, trending northeast and northwest (Fig. 6), which may be correlated respectively with fracture-zone azimuths (Schlich, 1982) and the geologic structure of the plateau (Houtz & others, 1977).

Structurally, the plateau has been divided by Houtz & others (1977) on the basis of the regional single-channel seismic data into three distinct areas, viz. the northern, central, and southern sectors (Fig. 7). The northern sector is the shallowest, supporting the only islands, and displays significantly more relief than the central and southern sectors. The sub-seabed structure apparently changes from sedimentary troughs in the north, around Kerguelen Island, to NW-SE-trending horsts and grabens further south. Between Kerguelen and Heard Islands, Schlich & others (1971) described a basin containing up to 2.5 s of sediment that can be broadly divided into two sequences. The upper sequence is about 1 s thick and well layered, and shows extensive slumping and current erosion; low-velocity material has filled in the eroded structures. The lower sequence is 1-1.5 s thick, being thickest near the bounding faults, and was considerably eroded before deposition of the upper sequence. It contains low-frequency reflectors showing little folding, but numerous minor faults. At the base of the lower sequence, a succession of low-frequency reflectors is interpreted as the base of the sedimentary sequence.

In the central sector of the plateau, Houtz & others (1977) concluded that the fault trend changes to N-S, and recognised two major grabens (the 75 Degree and 77 Degree Grabens) on seven widely spaced crossings of the plateau.

The sedimentary section in the central and southern sectors can be divided into three major sequences by two major and one minor reflector (A, B, and C, respectively, in the terminology of Houtz & others, 1977). Reflector A (Fig. 8 & 9)) typically separates an overlying, almost reflection-free sequence (SB-A) from an underlying sequence (A-B) containing low-amplitude, but relatively continuous reflectors. Sequence A-B is absent over high areas in reflector B, which appears to have been extensively peneplaned. Reflector B, although commonly appearing to be acoustic basement, in some places overlies a zone showing several hundred metres of distinctive layering and structuring (Houtz & others, 1977). Reflector C is a rarely observed faint reflector several hundred milliseconds below reflector B (Fig. 9); no structuring has been observed below reflector C.

Information on the nature and age of sequences SB-A, A-B, and below B is sparse. From one piston core, it has been concluded that the acoustic basement immediately beneath reflector B is Upper Cenomanian chalk; this core may have been taken at the toe of a slump mass. However, a core taken at a

* name submitted to the Australian Hydrographer for formal recognition

similar location 100 km away recovered only volcanic ash and Pliocene fossils, and it must be presumed, as for the northern plateau, that at least part of the section consists of volcaniclastics. Reflector B has been interpreted from two cores as Eocene in age (Houtz & others, 1977).

Seismic sections from the southern sector of the plateau appear to show a change in the trend of faulting back to NW-SE, similar to that in the northern sector. Although the sedimentary sequences are similar in appearance to those in the central sector, they are generally thinner (Houtz & others, 1977.

Geology of the islands

Kerguelen Islands. The Kerguelen Islands are a glaciated and partly submerged volcanic complex, dissected by fjords and capped by permanent ice and snow in the west. The total area is about 6500 sq km, and the maximum elevation is 1850 m.

The complex was constructed by the superposition of four basaltic shield volcanoes, consisting of interbedded agglomerate and lava, upon which two stratovolcanoes developed subsequently - Ross volcano in the south, and Societe de Geographie in the north (Nougier, 1969; Dosso & others, 1979). In the southwest the basalts are intruded by granito-syenitic ring complexes, and elsewhere there are intrusions of gabbro, syenite, nepheline syenite, trachyte, and phonolite (Dosso & others, 1979). There is no historic record of eruption, but there are fumaroles in the southwest, and minor cones of youthful appearance.

The complex is remarkable for the great variation in chemistry of the volcanic and intrusive rocks, which range from olivine and quartz tholeiite through alkali basalt to nepheline-rich trachyphonolite and quartz-rich trachyte and rhyolite. Alkali basalt, hawaiite, and mugearite make up 87 per cent of the total volume of igneous rocks; the granito-syenitic plutons, 8.7 per cent; and dykes of trachyte and rhyolite, and domes, spines, and sheets of nepheline-rich phonolitic rocks, the remainder (Nougier, 1972b).

The early formed basalts are intruded by Eocene gabbro (39 $\pm$ 3 and 38 $\pm$ 1 Ma; Giret & Lameyre, 1983) and thus Eocene or older. K-Ar ages of the basalts are around 26-27 Ma, but Giret & Lameyre have demonstrated that these almost certainly reflect heating by later intrusives. The oldest of the more silicic volcanics are late Oligocene ryholites (25.9 Ma; Nougier, 1972a). Volcanic activity continued though the Miocene, Pliocene, and Quaternary, and included the development of the granito-syenitic ring complexes from 12 to 8 Ma (Dosso & others, 1979), the emplacement of syenites in the north at abotu 4.8 Ma (Giret & Lameyre, 1983), the construction of the Ross volcano at 2 Ma, and parasitic cones in the interval 400 000 to 40 000 years ago (Nougier & others, 1983).

Strontium, neodymium, and lead isotope studies indicate that the volcanics share a common source region and are derived from enriched mantle (Dosso & others, 1979; Dosso & Murthy, 1980). The data preclude the involvement of old continental crust in magma genesis, but not necessarily the possibility that continental crust underlies the volcanic complex. The range of isotope ratios in the different samples indicates melting of heterogeneous mantle or mixing of melts from an enriched lower mantle with material from a depleted upper mantle (Dosso & Murthy, 1980). It it is assumed that there is no continental substratum, then data from the Kerguelen rocks greatly extend the Nd-Sr correlation, or 'mantle array', observed for uncontaminated basalts from the oceanic mantle (Dosso & Murthy, 1980).

Heard Island. Heard Island lies 400 km south-southeast of the Kerguelen Islands. It is about 20 km across and dominated by the volcanic edifice Big

Ben, which rises to a maximum height of 2745 m at Mawson Peak. The volcano is 90 per cent concealed by snow and ice.

The island was constructed by volcanic activity on a basement of elevated pelagic limestone of mid-Eocene to mid-Oligocene age (Quilty & others, 1983) which is now exposed on the Laurens Peninsula in the northwest (Stephenson, 1964; Clarke, 1982; Clarke & others, 1983). Some of the sediment interbedded in this sequence is rich in volcanic debris (Quilty & others, 1983). The limestone is folded or tilted by faulting, and is intruded by dolerite sills and a gabbro body of probable late Miocene age (Stephenson, 1964; Clark & others, 1983).

The limestone is unconformably overlain by conglomerate, thin basaltic flows, tillites, mudstone, and volcanogenic sandy sediment of the Drygalski Formation, which is of probable late Miocene-early Pliocene age. Glacial striae indicate provenance from the east-northeast (Stephenson, 1964). Pillow lavas with interbedded brown sediment, which Stephenson (1964) observed on the south coast, at Long Beach, may be part of the same sequence. The south coast sediments have been tilted through 30-60 degrees, presumably by faulting (Stephenson, 1964).

The basaltic volcano, Big Ben, is a classic cone, constructed by successive basaltic lava flows, and characterised by a broad summit area, which appears to have developed as a caldera, breached to the southwest. Mawson Peak cone rises from within the former caldera. There are many minor eruptive centres on the slopes of Big Ben, including basalt scoria cones and lava fields. Small trachyte and trachyandesite cones form the Laurens Peninsula and adjacent bays in the northwest.

The igneous rocks of Heard Island are all of alkaline affinity, and variations in composition can be explained by accumulation or removal of olivine, clinopyroxene, and plagioclase (Stephenson, 1972). Basalt, dolerite, and gabbro have unusually high levels of alkalis, TiO_2, incompatible trace elements, and LREE (Clarke & others, 1983). The volcanic rocks contain presumably cognate xenoliths of gabbroic and wehrlitic cumulates, country-rock siltstone and chert, and mantle-drived lherzolite, consisting of olivine, orthopyroxene, chrome-diopside, and spinel (Stephenson, 1964; Clarke & others, 1983).

Alignment of eruptive centres in the northwest and the orientation of the breach in the Big Ben caldera may indicate that Heard Island volcanism was localised on a NW-SE trending fracture (Lambeth, 1952; Stephenson, 1964).

Volcanic debris in the older sediments indicates some volcanic activity in the mid-Eocene to mid-Oligocene. Sporadic volcanism in the late Miocene to early Pliocene is recorded in the Drygalski Formation; this activity may have been centred in an area to the northeast, which is now submerged. The main phase of basaltic volcanism that led to the construction of Big Ben probably began within the last million years (K-Ar ages for younger flows are around 130 000 years; Clarke & others, 1983) and was followed by development of minor eruptive centres in the last tens of thousands of years.

Eruptions on Heard Island have been recorded by passing ships earlier in this century (Stephenson, 1964), and most recently by French scientists in January 1985 (SEAN Bulletin, Smithsonian Institution). There are active fumaroles on Mawson Peak, and a red glow from the summit area at night has been reported by various observers.

McDonald Islands. The McDonald Islands are small islands about 70 km west of Heard Island They are made up of the eroded produces of phonolitic volcanism. The northern part is a plateau of laminated tuff with abundant clasts of white chalky limestone and some chert; Quilty & others (1983) reported early Eocene to early middle Eocene ages for the clasts. Phonolitic dykes are exposed on the east coast, and a phonolitic dome intrudes tuff in the south. K-Ar ages are in the range 36 000 to 79 000 years, and it is thought that the entire volcanic complex may be less than 100 000 years old (All information from Clarke & others, 1983).

EQUIPMENT PERFORMANCE

Although the main objectives of the Kerguelen Plateau research cruise were geological, data systems additions, modifications, and testing continued at almost as great a rate as during the Lord Howe Rise shakedown cruise (Whitworth, Willcox, & others, 1985). The long transit to the survey area was used to integrate new equipment and refine the navigation programs in the data acquisition system (DAS), and to refine the seismic acquisition system (MUSIC) and generally make it more user-proof. The manuals for both systems were completely rewritten and extensive user training classes were held to minimise down-time during the survey due to operator-induced problems.

During the main part of the cruise, over the Kerguelen Plateau, hardware experimentation and software modification were restricted to those times when they did not interfere with operations (i.e. during bad-weather breaks in the seismic operations). The return transit was used primarily for preliminary processing of the data.

A full list of the equipment used during the cruise is contained in Appendix C; this section of the report describes system performance and problems only.

Seismic

Although we originally intended to acquire seismic data from the main 2400 m streamer, bad weather on the outward transit (leading ultimately to the loss of a magnetometer cable) persuaded us to change to the 1200 m secondary streamer, also of 48 channels.

Over all, the 1200 m streamer performed very reliably. Two channels (14 and 29) remained dead after changing out the relevant sections, and the problem was not pursued further, as it was probably caused by a faulty connector in front of the problem channels. Most of the time, the streamer depth was controlled adequately by the Syntron cable levellers, and only occasional adjustments were required to keep the cable running at a depth of 10-12 m. Considerable time and effort were spent measuring the buoyancy of individual streamer sections prior to the cruise, contributing greatly to the observed good balance of the cable during operations. Noise levels at a speed of 6 knots were well below the level of reflection signals, and this speed was adopted whenever weather permitted.

The air-gun system (two 500 in^3 guns) also performed very reliably. The infrequent air-gun changes were usually made at the ends of lines and, as a consequence, only a minimal amount of data was shot with less than the standard 1000 in^3. The Input/Output SS-8 source sensors, however, did not give reliable operation. In the event, gun synchronisation was monitored using the air-gun signature phones mounted about 2 m from the gun ports. There was little apparent drift in the gun shot instant, and gun synchronisation was considered adequate.

A number of very old but refurbished sonobuoys were deployed during the cruise. Of six launched, only one lasted long enough to transmit refracted arrivals. These data were recorded as an auxiliary channel in the seismic reflection system, and so were limited to the record length being acquired (7 s plus any delay). They were also displayed directly on an EPC graphics recorder.

In future, with more reliable sonobuoys, a longer recording time will be required. This can be achieved either by recording the refraction data on a system separate from the reflection seismic recordings or by slowing down the shooting rate to enable recording for a longer period if refraction data are to be integrated in the reflection recording system.

The major hardware change to the seismic system was the refinement of the SMF-1 preamplifier/filters and their integration with the recording system (MUSIC). Considerable effort was spent during the outward transit in testing and improving the performance of the SMF-1 to provide acceptable seismic data. Integration of the SMF-1 with MUSIC meant that all filter and gain settings and oscillator tests could be controlled by the operator from the system console rather than at the SMF-1 itself. This in turn allowed the appropriate settings to be recorded automatically on tape, thereby removing a potential source of error and simplifying processing. It is now possible to conduct noise and/or oscillator tests routinely between shots during normal recording.

Software problems that became apparent on the Lord Howe Rise survey led to some compromising of operations. The most serious problem was that which currently prohibits the overlapping of data acquisition from one shot with the writing to tape of the previous shot. Given the time taken to write a shot to tape (7-8 s) and the record length used (7 s), this means that the maximum shot rate that can be handled is approximately 15-16 s; at a ship speed of about 6 knots, this gives a distance between shots of 50 m, giving 12-fold coverage with the 1200 m cable.

Much effort was directed towards making the software more user-friendly, with the aim of keeping operator-induced system crashes to a minimum. Most system crashes during the cruise were caused by defective areas of magnetic tape, necessitating tape drives re-writing whole records, with the result that tape writing overran recording. These problems could not be avoided by the operator and appear to be the result of unacceptably low standard seismic tapes. System crash problems were somewhat reduced by software changes that allowed a rapid restart of the system, allowing most of the 17 system crashes to be recovered within a few minutes.

Magnetics

A magnetic gradiometer was deployed for the main part of the cruise on the plateau, although for 18 days at the beginning and 12 days at the end of the survey only one sensor was being recorded. Problems with the system, either the installation or in the magnetometers or sensors themselves, were never satisfactorily resolved, and noise levels recorded were always higher than expected.

Navigation

The primary navigation system was a Magnavox 1107RS dual-channel satellite receiver with velocity and heading inputs from a Magnavox 610D dual-axis sonar doppler and Arma-Brown gyro-compass, respectively. The secondary system was a Magnavox 1142 single-channel satellite receiver with velocity and headings from a Raytheon DSN450 dual-axis sonar doppler and Robertson gyro-compass. Neither sonar doppler system gave satisfactory results when in water-track mode, with consequence that all speeds had to be entered manually in both satellite receivers. The satellite receivers generally operated satisfactorily, although on occasions one or the other failed to receive what should have been acceptable fixes.

Bathymetry

Continuing problems with the 3.5 kHz Raytheon echo-sounder, including its inability to correlate a usable echo off the shelf and its interference with the Magnavox sonar doppler, were not resolved. The 12 kHz Raytheon echo-sounder usually gave a good echo, which could be tracked fairly consistently down to 2000-3000 m when seas were low. However, in other than low seas, and particularly with a head sea, the signal rapidly deteriorated to the point where an echo could not be seen.

Gravity

At the start of the cruise, a new Bodenseewerk Geosystem KSS-31 marine gravity meter was installed in the main instrument room. Acceptance tests and integration with the DAS were carried out during the four-day passage from Sydney to Devonport. The gravity meter generally performed satisfactorily, although certain apparent software shortcomings in the KSS-31 (turn manoeuvre and heavy seas compensation) are being pursued with the manufacturer.

Non-seismic data acquisition

The non-seismic data acquisition system (DAS) oversees the collection of navigational, bathymetric, magnetic, and gravity data. This system operated most reliably during the cruise, with very little downtime. The new software, which operates under the Hewlett-Packard RTE disc-based operating system, not only allows the acquisition and storage of large amounts of data, but also enables the computer to be used for processing of data, word processing, and general software development.

Additions to the software that were initiated and tested during the cruise included the collection of raw satellite data from the MX1107 receiver, the collection of gravity data from the KSS-31 marine gravity meter together with control of the gravity meter platform by supply of gyro-compass headings, and the display of magnetic gradiometer data. The need for this software was foresen before the cruise began and provision was made to install it on-line without interference to the existing data acquisition. Quality control of the navigation data has been enhanced by the addition of software that updates the ship's position between satellite fixes. This enhancement would have provided for the estimation of ocean currents except for the continuing inability of the sonar doppler logs to provide accurate velocities when operating in water-track mode. As a result, speeds obtained from satellite-fix data were used as manual inputs to the satellite navigators.

Data processing

For the first time on a BMR marine research cruise an attempt was made to begin processing of the non-seismic data while still at sea. The major limitation in this area is the lack of a system that can be dedicated to the task. Because of the small disc size (15 Mb) and the large number of channels being recorded (80), all processing must be done tape-to-tape. This is impossible in the DAS, where one tape drive is currently dedicated to recording raw data. In any case, large-scale processing on the DAS is probably not advisable if we are to avoid bogging down a system that is needed to acquire and pre-process data on a rigid and regular basis. All Kerguelen survey processing, with the exception of plotting, was done on the seismic system, when that system was available. This of course is only practicable on cruises with long transits.

The following processing was done during the cruise:

(1) All field tapes were transcribed to remove satellite fix information, which will be processed separately;
(2) All time errors and jumps were removed and data channels reassigned to their processing locations;
(3) All relevant raw-data channels were plotted as strip-charts on the CALCOMP 1044 drum plotter;
(4) Tie-points were digitised from the EPC records to enable processing of bathymetric data.

Conclusions

The seismic system is considered to be working reasonably well, except for the software problems mentioned above and for the fact that data can still only be recorded in integer. The highest priorities in this area are to enable the simultaneous recording of data and writing to tape, and to finalise the operation of the 16-bit IFP amplifier.

Although the other geophysical systems were operational during the Kerguelen cruise, major problems continue to plague the bathymetric and velocity log systems in particular, and the magnetometers to a lesser extent.

CRUISE SUMMARY

In general, the cruise followed the plan outlined by Colwell & others (1984). The only significant variations from this plan were:

(1) slight changes in the orientation of some lines (notably 11 and 12) because of the prevailing weather direction;
(2) use of the 1200 m rather than 2400 m streamer to minimise the chance of bad-weather damage to the main (2400 m) streamer prior to the Otway Basin cruise;
(3) the running of direct non-seismic transits to and from the plateau, as a consequence of time constraints;
(4) the shortening of some lines and the extension of others, based on geological considerations; and
(5) the elimination of major sampling work from the program because of the absence of a coring winch.

Details of the ship's tracks are shown in Figures 10 and 11. Most lines were oriented ESE-WSW, i.e. across the main structural grain of the plateau. Twenty-eight days were spent working on the plateau; and thirty-one days, in transit (see Appendix H). All seismic lines were run at speeds of 5-6 knots, whereas transits were run at maximum speed (up to 13 knots).

Total coverage for the cruise was as follows:

Line 01	-	Transit: bathymetry, magnetics, gravity	5352 km (2888 nm)
Lines 02-03	-	Oscillator and noise tests	-
Line 04	-	6-fold seismic, bathymetry, magnetics, gravity	82 km (44 nm)
Lines 10-29 & 33	-	12-fold seismic, bathymetry, magnetics, gravity	5527 km (2979 nm)
Lines 30-32	-	Transit to and from sampling sites: bathymetry, gravity	311 km (168 nm)
Line 34	-	Transit: bathymetry, magnetics, gravity	4432 km (2392 nm)

Geological work was carried out at five stations on the southern part of the plateau, using Benthos free-fall grabs. Three of the stations were successful Other work undertaken during the cruise included the launching of six sonobuoys and the deployment of three drifting weather buoys for the Bureau of Meteorology.

REFLECTION SEISMIC RESULTS

In this section we present a preliminary interpretation of the structure and stratigraphy as suggested by the reflection seismic data. It must be emphasised that this brief interpretation is based on examination of the shipboard single-channel reflection seismic monitor records. While we are confident that the basic interpretation is correct, it is likely that data processing will reveal greater detail and penetration, which may extensively modify our observations.

Our treatment of the acoustic stratigraphy is cursory for two reasons. Firstly, the long pulse train from the air-guns effectively masks most events for some hundreds of milliseconds below strong reflectors (particularly the sea floor), and secondly, the use of digital seismic monitors (see Appendix C) leads to some distortion of true reflection details. A good example of this second problem is seen in line 27 (Figure 27), from 100.12 to 100.18 at 2.7-3.0 s two-way time, where a band of apparently very low-frequency reflectors actually consists of a number of bands of high-frequency reflectors. Such problems should be largely alleviated by processing.

The findings are illustrated by reproductions and line drawings of all the seismic sections (Figs. 12-30) and by a simplified gross structure map of the southern sector (Figure 31); a comparable structure map has not been prepared for the northern sector, because of limited coverage.

Specific features are referred to by the day and hour number that appears on the seismic sections; for instance, 84.15 refers to Julian day 84, GMT hour 15. All time-depths or time-thicknesses are in seconds of two-way reflection time.

Northern sector

One-and-a-half transects were recorded across the Kerguelen Plateau north of Heard Island (lines 10-12, Figs. 12-13), and a single N-S line was recorded from this area to the southern sector (line 13, Fig. 14), passing to the east of Heard Island. While such sparse coverage precludes any detailed mapping of the structure, the data give a clear indication of the structural variation of the northern sector.

The most obvious aspect of lines 10-11 is the pronounced asymmetry of the northern plateau. The eastern margin is steep and largely sediment-free and is apparently underlain by volcanics. The scarp forming the eastern margin is formed by a volcanic pile. To the west, a succession of volcanic piles shoals towards the eastern plateau crest before deepening again under thickening sediment to the west.

The central part of the plateau is underlain by adjoining sedimentary basins of uncertain thickness. On lines 10-11, these sediments fill three troughs. Sediments of the eastern trough (82.23-83.09) generally show little deformation other than that caused by intrusion of volcanics. The sediments of the main central trough (83.12-83.21) and minor western (83.21-84.02) trough are not obviously affected by the volcanism, but are quite extensively folded.

The western edge of the plateau crust is characterised by a major uplifted flat-topped basement block. The block is fault-bounded on the east, but its relation to basement on the western plateau flank is unclear. The western plateau flank is far less steep than the eastern flank and is underlain by at least 1.5 s of sediment. Piercement structures appear in the sediment pile, and a massive slump is observed on line 11 at 84.12- 84.16.

The single N-S line (line 13) does not reveal much about the plateau to the east of Heard Island, because of shallow sea-floor multiples. The sedimentary section probably thins over basement at the latitude of Heard Island (86.12-86.20) before thickening again to more than 1.5 s south of the island.

Although no geological samples are available for estimation of age and lithology of the sediments, the presence of abundant volcanics on Heard and Kerguelen Islands and the work of French scientists (Schlich, personal communication, 1984) suggest that a major component of the sediment seen on lines 10-13 is volcanogenic.

Southern sector

Structure. The main focus of the Kerguelen Plateau study was the eastern flank of the plateau between 55°S and 60°S. The line spacing of approximately 50 km was considered the best compromise between coverage of the maximum area in the time available and sufficient density for correlation of structures between lines.

The principal feature identified here is a sinuous sedimentary basin (here called the Raggatt Basin) that extends from at least 56°S 78°E to 58°S 80°E (Fig. 20-27, 32). It covers an area of at least 30 000 km^2, is relatively simple in cross-section, and apparently formed by deposition on a steadily subsiding surface, which appears to correlate with reflector B of Houtz & others (1977).

Although faults are quite common, they do not appear to have been a major controlling factor in basin evolution. The principal faults offset reflector B (e.g. at 4 s depth in line 24; Fig. 24), and the time represented by this probable unconformity appears to have been the time of maximum fault motion. However, some faults have been reactivated much later (e.g. line 24 at 97.12-14), presumably in response to continuing basin subsidence. The maximum discernible sediment thickness in the basin is about 2.5 s (3-4 km); the actual thickness is presumed greater because the deeper reflectors are obscured by the sea-floor multiple. Although no immediate explanation is apparent for the sinuous trend of the basin, the over-all trend (NNW-SSE) is parallel to the general structural grain of the plateau.

The eastern margin of the Raggatt Basin is defined by a possibly faulted hinge zone, west of which the main unconformity (reflector B) of the eastern plateau descends rapidly. The northern margin cannot be defined; however, it appears to lie between lines 17 and 19. The southern boundary lies south of line 33.

The western margin of the Raggatt Basin is extremely complex: in the northwest (Fig. 31), it appears to merge with the 77 Degree Graben of Houtz & others (1977). The complexity of the structural relationship is exemplified by a reversal in polarity of the apparent bounding fault between the western ends of lines 19 and 22. In the west (lines 22, 24, and 27), the boundary appears to be a thinning of the sedimentary section in front of a major basement fault and scarp. This scarp is probably not a continuation of the western flank of the 77 Degree Graben, as implied in the structure map of Houtz & others (1977, fig. 3).

The western flank of the southern plateau descends to the Enderby Basin and appears to be bereft of significant sediment accumulations (lines 27, 29; Figs 27, 29). In general, about 1 s of sediment overlies a prominent reflector beneath which there are traces of deeper reflectors. The complexity of the southern plateau is again demonstrated here: prominent structures on one line are commonly not evident on the adjacent line (e.g. the fault zones on line 27 at 102.00 and on line 29 at 104.21). The western margin of this part of the plateau is structurally simple. The boundary marked on the structure map (Fig. 31) is the point at which plateau basement descends beneath flat-lying sediments of the Enderby Basin. Basement under the eastern Enderby Basin is quite smooth. Because of its anomalously shallow depth and the lack of a clear structural discontinuity between it and the basement of the western plateau, it may not represent 'normal' oceanic basement.

The eastern margin of the plateau and the adjacent deep ocean basins are structurally complicated, presumably because of the varied and complex breakup history of the area. On lines 15, 17, and 33 (Figs 15, 17, 30), the Labuan Basin is filled by up to 2 s of well-stratified draped sediment, which overlies a distinctive basement of well-developed faulted ridges and troughs (lines 14 and 33; Figs 12, 30).

The major basement ridges towards the eastern end of line 33 appear to correspond to the change in basement depth that Houtz & others (1977) considered a structural boundary on a transect approximately 500 km to the northwest. There it consists of a sharp offset in basement depth across a minor seamount from 5-6 s in the north to about 8 s in the south. Their explanation for the anomalous increase in depth to basement was a mantle hotspot, presumably weakening the lithosphere surrounding the plateau and resulting in a moat effect. They defined the boundary on the basis of a single crossing, and the similar discontinuity encountered on line 33 confirms its existence.

We hypothesise that the deep crust represents a spreading episode predating the separation of Australia and Antarctica, as opposed to the hotspot effect proposed by Houtz & others (1977). The implications of this for a tectonic framework for the Kerguelen Plateau are significant. All reconstructions to date have used a bathymetric contour to fit the Kerguelen Plateau and Broken Ridge, whereas it now seems that the crustal-depth discontinuity should be used to mark the northeastern boundary of the Kerguelen Plateau crustal province in the Australia-Antarctica reconstruction. (Corroborating evidence of a distinct "Kerguelen" crustal province comes from the 8 s deep basement in the Labuan Basin, off the Banzare Bank, and in the Enderby Basin). Preliminary calculations of the age of the deep crust employing the age-depth equations of Sclater & Francheteau (1970) and Parsons & Sclater (1977) indicate that it could be of roughly the same age as the Mesozoic crust off Western Australia, and may have been created during the same spreading episode.

Stratigraphy. To simplify discussion of the stratigraphy of the southern sector, we will consider two separate areas: (a) the Raggatt Basin, and (b) the remainder of the southern plateau covered by this study. Again, we emphasise that all descriptions that follow are preliminary and likely to be modified when processing of the data has been completed.

(a) Raggatt Basin. Within the basin (lines 19, 22, 24, 27, 33; Figs 19, 22, 24, 26, 27) we tentatively identify three major seismic units, which in order of decreasing age, are:

(1) A basal unit bounded above by a strong reflecting unconformity (e.g. at 100.16, 3.9 s depth in line 27; Fig. 26). We correlate the upper unconformity with reflector B of Houtz & others (1977). Downwarping of this faulted surface apparently resulted in formation of the basin. Like Houtz & others, we speculate that this unconformity may have formed at the time of postulated rifting apart of the Kerguelen Plateau and Broken Ridge.

(2) A sedimentary unit up to 1 s thick has been deposited over the basal unit with the depocentre generally on the western side of the basin (e.g. on line 24 from 97.04 to 97.18; Fig. 24). This sequence thins substantially over the eastern basin margin.

(3) The third unit forms a blanket, as much as 1 s thick, over the entire basin. Unconformities within this sequence are commonly obscured by the air-gun bubble pulse, and their mapping will have to await seismic processing.

(b) Plateau (non-basinal). In general, the seismic units on the southern plateau are relatively simple. The principal reflector (equivalent to reflector B of Houtz & others, 1977) is readily identifiable as a strong event overlying a zone of weak reflectors. In some places, up to 1 s of layering is visible beneath this reflector, while elsewhere it appears to mark the upper surface of crystalline basement. Above reflector B is a widespread blanket of sediment that ranges up to 1 s in thickness.

REFRACTION SEISMIC RESULTS

The only sonobuoy to produce usable results was launched on the western flank of the plateau, on line 29, at a less than ideal site. The monitor record was the direct analogue output of the sonobuoy receiver displayed on an EPC graphics recorder set initially to a sweep of 4.9 s. This was changed to a sweep of about 9.8 s towards the end of the recording. The data were also recorded on magnetic tape as an auxiliary channel of the seismic reflection system; i.e. 2 ms sampling for 7 s after a recording delay of 1 s. A better quality refraction record can likely be recovered from tape, and should yield more reliable velocities and layer thicknesses.

The shipboard refraction record (Fig. 32) indicates arrivals with apparent velocities of ?2200 m/s, 2900 m/s, and 4700 m/s. Since neither the time nor the distance axis is accurately calibrated, these velocities were scaled from the direct water wave velocity, assumed to be 1450 m/s for water at 0 C. The deep and middle refractors are considered fairly accurate picks, while the shallow refractor is far more dubious.

The solution indicates a water depth of 1550 m, compared with an average of 1650 m from the reflection record. The layer with the ill-defined velocity of 2200 m/s is 350 m thick, and probably represents poorly consolidated sediments near the top of the section. The 2900 m/s layer is 940 m thick and probably represents consolidated sediment. The 4700 m/s correlates with the top of acoustic basement.

This solution gives a total depth to acoustic basement of 1300 m below the sea floor, corresponding to a reflection time of 1 s. This may be compared to a reflection time of 0.8 s from the reflection record. In all the circumstances, this may be considered a reasonable solution for a first-time attempt.

GRAVITY AND MAGNETICS RESULTS

Presentation of data

For the Kerguelen Plateau area, preliminary potential-field data are shown as profiles above corresponding reduced seismic sections (Figs 12-30) and, in the case of the magnetics, as profiles on maps (Figs. 33-34). The transit magnetic data are presented separately (Fig. 35). These profiles permit preliminary interpretations to be undertaken; however, it must be remembered that the data require further processing before detailed studies are possible. Because reduced digital navigation data are not yet available, the magnetic data over the plateau have not been converted to anomaly values (based on a reference field, such as the IGRF), nor have any adjustments been made for temporal variations. In the case of the gravity data, raw gravity is shown in the profiles. Because course and speed were almost constant along seismic lines, the profiles are suitable for preliminary interpretations. However, the data have not been corrected for latitude, and determination of gravity meter drift and absolute gravity will be made once a gravity station tie has been completed at the Melbourne berth.

Gradiometer and total-field variation

High geomagnetic latitude areas such as the Kerguelen Plateau are frequently subject to magnetic storms, which can introduce serious non-geological noise into magnetic survey data. Geomagnetic observatories at Mawson and Kerguelen Island are too far distant from the survey area for their records to be used as suitable base-station references.

A preliminary assessment indicates that the gradiometer data will allow significant control over the unpredictable temporal variations in the magnetic field, enabling anomalies of geological origin to be distinguished from external field variations. With appropriate processing of the data, it appears feasible to reconstruct the spatial field along sections of line that have been particularly adversely affected by magnetic storms. After processing, the gradient-derived total-field data may be suitable for direct use in interpretational routines such as Werner deconvolution (Hsu & Tilbury, 1977).

Examination of the magnetometer records for the plateau area indicates that temporal variations significantly affected portions of some profiles, with total-field variations of up to several hundred nT during particularly severe storms. During the cruise, strong auroral activity was frequently observed during such storm periods.

An example of storm-related excursion and pulsation of the magnetic field is illustrated in Figure 37, which shows part of the gradiometer strip-chart record for line 29. After allowing for instrument recording noise, an approximate reconstruction of the magnetic field from the horizontal gradient produces an anomaly of very low amplitude, whereas the original total field varies by about 170 nT. This implies that the observed change in the total field is almost entirely the result of storm activity. To achieve a better result in reconstruction of the field, it is anticipated that final processing will require more sophisticated techniques.

Southern Ocean spreading anomalies

Transit lines across the Southern Ocean were sited to fill major gaps in the existing data (Weissel & Hayes, 1972; Tilbury, 1981; Stagg & others, 1983a; Vogt & others, 1983). The magnetic profiles presented along tracks in Figure 35 have been plotted as magnetic anomalies relative to the IGRF (Peddie, 1982).

Identification of geomagnetic time-scale anomalies (MA) and sea-floor spreading structure is complicated by the fact that the *Rig Seismic* tracks generally cross the magnetic lineations at oblique angles. Intersection angles increase towards the Kerguelen Plateau, so that in this region, and even in the Australia-Antarctic Discordance, no major correlation problems exist. Near south-east Australia, the lines are almost parallel to the lineations, making MA identification difficult. Despite the somewhat unfavourable line orientations, it is possible to make positive identification of MAs along the greater part of the ship's transits, particularly near the Kerguelen Plateau, which is only sparsely mapped. On the northern line, identification of MAs from 1 to 5D can be made on the Australian plate, and from 1 to 8 on the Antarctic plate. Corresponding identifications for the southern line are 1 to 5A (Australian plate) and 1 to 10 (Antarctic plate), with tentative identification out to MA 20, east of the basement ridges on line 33 at 109.05 to 109.12 (Fig. 30). Interpreted MAs and inferred fracture zones are mapped in Figure 35.

Preliminary interpretation

Northern Kerguelen Plateau. Over the northern plateau and adjacent slopes, prominent sets of magnetic and gravity anomalies are evident in the profiles; some anomalies exceed 1500 nT and 1000 $\mu m/s^2$, respectively. Over the western half of the plateau, the anomalies (particularly the magnetic) are narrow and clearly related to piercement structures seen in the seismic data. These structures appear to be relatively young dykes or plugs that have intruded the sedimentary section and commonly project above the sea floor. The larger of these bodies are associated with primary positive anomalies that suggest that the structures are normally magnetised. After allowing for the topographic effect, the gravity expression consists of minor highs that signify a positive density contrast with surrounding formations. It is likely that these bodies are of basaltic composition, because of their strong magnetic character and relative high density. The broad 400 $\mu m/s^2$ anomaly at 83.00 on line 10 (Fig. 12) coincides with a shallowing of acoustic basement, and may represent a relatively dense buried volcanic edifice or mound. Similar features can be seen at 83.21 and at 86.19 on line 13 (Fig. 14), though there is no major magnetic expression at these locations. It is possible that the features are merely basement highs or upwarps.

The gravity and magnetic data (Figs. 12, 13) indicate that the basement blocks that line the western edge of the plateau may represent relict strato or composite volcanoes. The large broad gravity anomalies associated with these blocks can also be seen in the SEASAT gravity data (Fig. 5). The magnetic response is seen as high-amplitude, high-frequency anomalies directly above the tops of the blocks, indicating magnetic heterogeneity at shallow depth, from sources at or not far below the upper surface. The high density and the intensity of magnetic anomalies suggest that at least parts of the volcanic cores are basic in composition. The magnetic heterogeneity may be due to compositional variations or magnetic reversals during volcanic emplacement, or both.

(b) Southern Kerguelen Plateau. As with the northern Kerguelen Plateau, gravity profiles indicate no major free-air variation from the southern Kerguelen Plateau to the adjacent deep ocean areas. A broad low of about 200 $\mu m/s^2$ is evident in the profiles over the lower plateau slopes, but is believed to be a terrain effect. Thus, the plateau appears to be largely in isostatic equilibrium, implying that there is significant crustal thicknening beneath the plateau. Houtz & others (1977) came to the same conclusion and calculated, on the assumption of compensation at the crust-mantle interface, that the crust-mantle boundary beneath the plateau is about 10 km deeper than it is beneath the adjacent oceanic crust.

The seismic data over the southern Kerguelen Plateau indicate widespread and locally intense development of normal block faulting, which primarily affects acoustic basement. This structural style is the dominant cause of the gravity and magnetic anomalies seen in the profiles. A positive density contrast with overlying sediment and its highly magnetised nature, suggest that acoustic basement may be largely basaltic. A particularly good example of normal block-fault stacking and the resultant magnetic and gravity response, can be seen on line 29 (104.17 to 105.04) (Fig. 29); line 27 (101.01 to 101.06) (Fig. 26) also indicates this structure and the characteristic magnetic/gravity response, as do a number of other sections from the southern Kerguelen Plateau.

GEOLOGICAL RESULTS

On days 105 and 106 (15-17 April 1985) five Benthos free-fall grab samplers were deployed over a prominent fault scarp intersected by seismic line 24 at about 58 20'S, 77 0'E (Fig. 37), on the western margin of a feature that Houtz & others (1977) had named the 77 Degree Graben. Three of these were recovered, and two contained significant quantities of rock (the third contained mostly hydrozoa). The two successful sites were Station 1 (200 g of sample) and Station 3 (500 g); the stations are 2.5-3 km apart, in water depths of 1810 m and 1750 m, respectively (Table 2).

Almost all the rock fragments recovered in the two samples were coated with manganese oxide, most were subangular to subrounded, and none weighed more than 26 g. Samples were examined initially by cleaning one face on an abrasive pad and examining that surface under a binocular zoom microscope. Subsequently, most of the many fragments collected at Station 3 were cleaned by dissolving the manganese oxide coating in hydrochloric acid. Upon return to Canberra, samples were selected for thin sectioning and mineral analysis by electron microprobe. Station 1 rock fragments were numbered 47010001-36; and Station 3 rock fragments, 47030001-57; some of the sample numbers apply to a group of small fragments of similar rock. Details of samples are given in Appendix G.

The rock suites collected at both stations were remarkably similar, and consist of clasts of volcanic rock (70-75% by weight), granitic rock (17-20%), and quartzose metasediment (8-10%; Table 3).

TABLE 2. Summary of sampling stations (free-fall grabs)

Station no.	Position of deployment Lat (S)		Long (E)		Water depth (m)	Amount recovered (kg)
1	58	20.3	77	01.8	1810	0.2
2#	58	18.1	76	59.7	2000	0.0
3	58	18.9	77	00.7	1750	0.5
4	58	16.0	76	54.5	1500	0.6
5*	58	16.2	76	57.6	1900	0.0

failed to locate grab on surface
* failed to surface

TABLE 3. Comparison of composition of samples from Stations 1 and 3

<u>Number of pieces</u>	Station 1		Station 3	
	%	No.	%	No.
Volcanic	59.5	19	60.5	132
Granitic	32	10	32.5	71
Metasediment	9.5	3	7	15
<u>Mass</u>				
	%	grams	%	grams
Volcanic	70	140	75	359
Granitic	20	39	17	81
Metasediment	10	20	8	41

All the volcanic material is moderately altered to clay minerals with limonitic or hematitic colouring, and with a matted texture of former plagioclase laths apparent on some surfaces. One sample selected for probe analysis contains remnants of andesine and augite in an altered groundmass that has a basaltic chemical character (as determined by electron microprobe). Probably the rock was an andesite. Another volcanic fragment is trachybasalt or trachyandesite, with andesine phenocrysts and some large apatite grains in a K-rich ferrobasaltic groundmass that includes some K-feldspar. Much of the volcanic material is amygdaloidal or vesicular (10-15% amygdale or vesicle in any one fragment), with zeolite and, less commonly, silica as the cavity filling. The volcanic rock fragments typically are larger (10-25 g) and more angular than the fragments of other rock types, and many are plate-like: 0.5-1 cm thick and 2-4 cm across. Their appearance suggests an origin as talus below a face of jointed lava or high-level intrusive.

Most of the granitic material is not altered. All is medium-grained (2-5 mm), and texture in the hand specimen is granular and, in some cases, cataclastic. Quartz, K-feldspar, plagioclase, biotite, hornblende, apatite, magnetite (less commonly ilmenite) and, in two samples, zircon are the characteristic mineral phases. In some samples K-feldspar and albite have the appearance of secondary phases, partly replacing primary oligoclase. All the listed minerals are not present in all samples; for example, some of the granitic rocks are aplitic, consisting of K-feldspar, albite, and quartz only, while, in the other extreme, some are solely oligoclase and hornblende. There are all degrees of variation between these two apparent end members, and it is likely, although by no means proven, that all are of one suite. Common characteristics of most or all the granitic samples are prominent apatite, and some degree of cataclasis.

The granitic clasts are generally smaller than the volcanic clasts, having a maximum mass of 10 g. Granitic cobbles larger than 2 cm maximum dimension typically show some degree of rounding, as though water-worn, and three of the larger cobbles at Station 1 had little or no manganese oxide coating.

The most common metasediment is pink or red fine-grained quartzite; a little less common is impure quartz sandstone subschist, and least common, but perhaps most remarkable, is a small fragment of thinly bedded phyllitic schist with delicate crenulation cleavage. The quartzite and subschist are low greenschist metamorphic facies as indicated by development of sericite throughout. One fragment of quartzite has biotite throughout, and another, biotite associated with hornblende, apatite, sphene, and ilmenite. The biotite, hornblende, etc. appear to have been introduced, and in both samples the biotite plates (and hornblende prisms) are aligned, as though having crystallised in a field of oriented stress. The assemblage biotite, hornblende, apatite, and ilmenite is characteristic of the dredged granitic clasts, and their occurrence in quartzite is tentative evidence that the granitic suite is intrusive into the metasediments.

The question of ice rafting

The recovery of quartz-rich metasediment and granitic material from the southern Kerguelen Plateau is a significant new development. If the material is in situ, then it constitutes the first concrete evidence that the Kerguelen Plateau is partly continental, rather than of purely oceanic origin - a concept which is supported, incidentally, by seismic reflection evidence of thick sediments on the plateau. Because the two samples were collected from rubble resting on a relatively steep slope on the sea floor and not from outcrop, the possibility remains that they are not from a near source. Is it likely that they were transported by ice?

Huggett & Kidd (1984) have investigated criteria for recognition of ice-rafted material in marine dredge hauls. Ice-rafted material should show some degree of faceting and striation, a lack of Mn oxide coating or much thinner coating than the associated rock fragments, and a variation in rock type commensurate with transport from distant and diverse source regions. The samples we have collected contain no striated or faceted material, and do not include a great variety of rock types. As noted above, there were several granite clasts that lacked Mn oxide coating, but a vast majority of other clasts of the same rock type had a typical Mn oxide coating. Perhaps the most compelling evidence against exotic origin of the quartzose metasediment and granitic material is that a considerable number of pieces of both were collected at both sample locations, and in both cases the proportions of one to the other and of the two to the associated volcanics were almost identical (Table 3). The uniformity of the two samples suggests a homogeneity of composition in the debris strewn across the slope, which is probably at odds with an ice-rafted origin. In addition, the fragile detail preserved in the phyllitic schist fragment, a soft rock that is readily crumbled between the fingers, is evidence that at least this fragment was not transported far.

ORIGIN AND EVOLUTION OF THE KERGUELEN PLATEAU

The origin and evolution of the Kerguelen Plateau remain obscure, despite previous investigations and the preliminary results of this cruise. Three possibilities, not necessarily mutually exclusive, exist for the plateau's origin and crustal nature: (1) it is a microcontinent, composed of continental rocks, (2) it is a product of excessive oceanic volcanism, possibly hotspot-related, (3) it is a thermally or tectonically uplifted and possibly thickened block of oceanic crust. Arguments can be made for each of these origins, and it is quite likely that different portions of the plateau have different modes of formation.

The most fundamental question regarding the plateau is whether it is continental or oceanic. There is little positive evidence to support a continental nature: with the exception of the quartz metasediments and granitic rocks recovered during this cruise, no rock samples from the plateau show any geochemical evidence for a continental origin. Indeed, studies made on volcanic rocks from Kerguelen Island indicate strong similarities to rocks of the Ninetyeast Ridge, a probable hotspot trace. However, the petrology and geochemistry of Kerguelen and Heard volcanics do not rule out a continental origin for the Kerguelen and Heard massifs: the source magma for the volcanics may have remained uncontaminated by continental material during its passage through it. To further complicate matters, many workers have proposed that the northern portion of the plateau, including the islands of Kerguelen and Heard, is significantly younger than the remainder of the feature and thus may not share a similar origin and evolution. Seismic reflection data provide an ambiguous picture of the plateau, in that the sedimentary regime is similar to that of continental margins. Sedimentary basins have formed on the plateau, and both basement and sediments have been deformed. Most intraplate submarine plateaus, whether originating via constructional volcanics or thermal/ tectonic uplift, show little or no evidence of deformation following their formation.

The Kerguelen Plateau has not been the subject of a deep crustal seismic investigation, and the few shallow crustal wide-angle reflection and refraction velocity data do not allow discrimination of a continental or oceanic crustal nature. A single gravity model (Houtz & others, 1977), based on very limited data, indicates crustal thicknesses exceeding those of 'normal' oceanic crust, but this could result from any of the three origins suggested for the plateau.

Magnetic data collected during this cruise show that faulted crustal blocks on the southeastern plateau are high magnetised, providing support either for basaltic intrusion along fault planes or for a basaltic crust. Modelling of these data should shed some light on the crustal nature of basement on this portion of the plateau.

It is important to note that Williams Ridge, the segment of the Kerguelen Plateau that most resembles the conjugate feature (Broken Ridge), appears to be fundamentally different to the rest of the plateau. The gravity signatures of the Williams Ridge and Broken Ridge suggest that they are either fracture -zone ridges or extremely continuous seamount chains, and that they probably do not share a similar origin and evolution with the main Kerguelen Plateau segments.

Although it is clear that dredging and coring will provide valuable information on the nature of parts of the plateau, it is obvious that the only definitive solution to the question of the origin and evolution of the entire Kerguelen Plateau is going to come from drilling a suite of basement holes encompassing the major divisions of the feature. The Kerguelen Plateau is unique among submarine plateaus in that it has experienced significant tectonic deformation perhaps during and definitely subsequent to its formation. Although this obscures the plateau's origin, it has resulted in many reflectors cropping out and acoustic basement lying near the sea floor in many parts of the plateau. These present ideal sampling sites for addressing the nature and evolution of the plateau.

CONCLUSIONS

The Kerguelen Plateau cruise was successful in meeting its primary objectives. The principal conclusions that can be drawn from the study at this early stage are as follows.

(1) The structure and stratigraphy of the plateau are complex. Significant sedimentary accumulations exist on several parts of the plateau, notably the central part of the northern plateau and in the south, where a major sedimentary basin is observed on five of our lines. Faulting is generally widespread, but particularly concentrated in some parts of the southern sector, where horsts, grabens, and half-grabens are prominent.

(2) Extensional tectonism has affected the plateau, although its timing is difficult to define because of a lack of stratigraphic control.

(3) The major change in oceanic basement depths identified off the eastern margin of the plateau may mark the boundary between relatively old (?Mesozoic) crust immediately adjacent to the plateau, and younger crust further to the east.

(4) Igneous activity has made a major contribution to the structure of the northern part of the plateau, whereas in the south its contribution is not as obvious.

(5) The probable occurrence in situ of rocks of continental affinity in the southern sector has implications for the origin and evolution of the plateau.

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APPENDIX 1. Line details

Line	Start	Finish	Data collected	Seismic tapes
1	066.2027	081.0324	transit - b,g,m	
2	081.0324	081.0458	oscillator tests	1-4
3	081.0555	081.1623	noise tests	5-8
4	081.1716	082.0255	6-fold seismic	9-12
10	082.1507	084.0159	12-fold seismic, b,g,m	22-103
11	084.0159	084.2311	" "	104-147
12	084.2331	086.0446	" "	148-216
13	086.0459	088.1337	" "	217-358
14	088.1345	089.0249	" "	359-391
15	090.0709	091.0332	" "	392-439
16	091.0334	091.0805	" "	440-452
17	091.0830	093.0432	" "	453-563
18	093.0432	093.0912	" "	564-575
19	093.0912	094.1510	" "	576-646
20	094.1510	094.2134	" "	647-661
21	094.2134	095.0044	" "	662-669
22	095.1039	096.1724	" "	670-741
23	096.1726	096.2133	" "	742-752
24	096.2133	098.0503	" "	753-833
25	098.0504	098.1119	" "	834-848
26	098.1119	098.1140	" "	849
27	100.0528	103.0151	" "	850-1016
28	103.0151	103.0631	" "	1017-1027
29	103.0631	105.0845	" "	1028-1151
30	105.0919	105.1920	b,g	
31	105.1920	107.0108	b,g	
32	107.0112	107.0844	b,g	
33	107.1045	109.2232	12-fold seismic, b,g,m	1152-1301
34	110.0055		transit - b,g,m	

b: bathymetry (12 kHz)
g: gravity
m: magnetics

APPENDIX 2. Way points

Way point	Lat/Long	Line	Course	nm	km	hrs @ 5 kn
King I.	40° 21'/144° 57'					
		1-4	258.5	2952	5470	--
KP1	50° 30'/76° 05'					
		10	243	189	351	45
KP2	52° 31'/72° 11'					
		11	260	105	195	21
KP3	52° 50'/69° 20'					
		12	058	168	311	34
KP4	51° 28'/73° 19'					
		13	148	335	620	67
KP5	56° 13'/78° 17'					
		14	073	70	130	14
KP6	55° 54'/80° 18'					
		15	072	106	197	21
KP7	55° 21'/83° 17'					
		16	162.5	28	52	6
KP8	55° 48'/83° 32'					
		17	253	261	484	52
KP9	57° 04'/76° 00'					
		18	161.5	27	51	5
KP10	57° 30'/76° 16'					
		19	073	181	336	36
KP11	56° 37'/81° 35'					
		20	145.5	28	52	6
KP12	57° 00'/82° 04'					
		21	253	15	29	3
KP13	57° 02'/81° 36'					
		22	252	166	308	33
KP14	57° 54'/76° 42'					
		23	162.5	26	49	5
KP15	58° 19'/76° 57'					
		24	073	190	352	38
KP16	57° 22'/82° 37'					
		25	140	30	56	6
KP17	57° 45'/83° 13'					
		26	253	9	16	1
KP18	57° 40'/83° 26'					
		--	---	--	--	--
KP19	57° 55'/82° 10'					
		27	253	384	712	77
KP20	59° 48'/70° 20'					
		28	162.5	25	47	5
KP21	60° 12'/70° 35'					
		29	073	290	538	58
KP22	58° 47'/79° 42'					
		30	290	86	159	--
KP23	58° 17'/77° 08'					
		31	---	3	6	--
KP24	58° 81'/77° 02'					
		32	112	79	146	--

KP25	58°47'/79°22'					
		33	072	346	641	69
KP26	57°03'/89°43'					
		34	063	2392	4432	--
King I.	38°56'/143°35'					

APPENDIX .3. Equipment list

GEOPHYSICAL

Primary seismic systems

- 1200 m Teledyne hydrophone streamer cable; minimum group length of 12.5 m; maximum 96 channels.
- 2400 m Teledyne hydrophone streamer cable; minimum group length of 12.5 m; maximum 96 channels.
- Syntron RCL-2 individually addressable cable levellers.
- 3 Bolt 1500C air-guns, each of 500 cu. in.(8.2 L) capacity with wave-shape kits; one or two guns, fired simultaneously, are normally used.
- Teledyne gun-signature phones and gun-depth sensors, and Input/Output SS-8 shot-instant transducers (1 each per gun).
- 3 Price A-300 compressors, 300 s.c.f.m. each; output pressure 2000 p.s.i.
- 1 Price AGM W2 compressor, 200 s.c.f.m; output pressure 2000 p.s.i.
- BMR-designed and built computer-controlled preamp/filters (48 channels).
- BMR-designed seismic acquisition and display system (MUSIC) based on Hewlett-Packard 1000-Series computers.

Secondary seismic systems

- 2 Teledyne 28420 single-channel hydrophone streamers.
- 1 Bolt 1500C air-gun of 100 cu.in (1.6 L) capacity with wave-shape kit.
- Reftek 6 sonobuoy receiver.
- Teledyne 28990 acoustic beacon cable location system.

Bathymetric systems

- Raytheon deep-sea echo sounder; 2 kW maximum output at 3.5 kHz.
- Raytheon deep-sea echo sounder; 2 kW maximum output at 12 kHz.

Magnetic system

- 2 Geometrics G801/803 proton precession magnetometers; may be used as standard single-sensor cable or in horizontal gradiometer configuration.

Gravity-meter system

- 1 Bodenseewerk Geosystem KSS-31 Marine Gravity Meter.

GEOLOGICAL EQUIPMENT

-Benthos free-fall grabs with strobe lights and radio transmitter.

NAVIGATION

Prime system

- Magnavox MX1107RS dual-channel satellite receiver.
- Magnovox MX610D sonar doppler speed log.
- Arma-Brown SGB1000 gyro-compass.

Secondary system

- Magnavox MX1142 single-channel satellite receiver.
- Raytheon DSN450 sonar doppler speed log.
- Robertson gyro-compass.

COMPUTER EQUIPMENT

Non-seismic acquisition system (DAS)

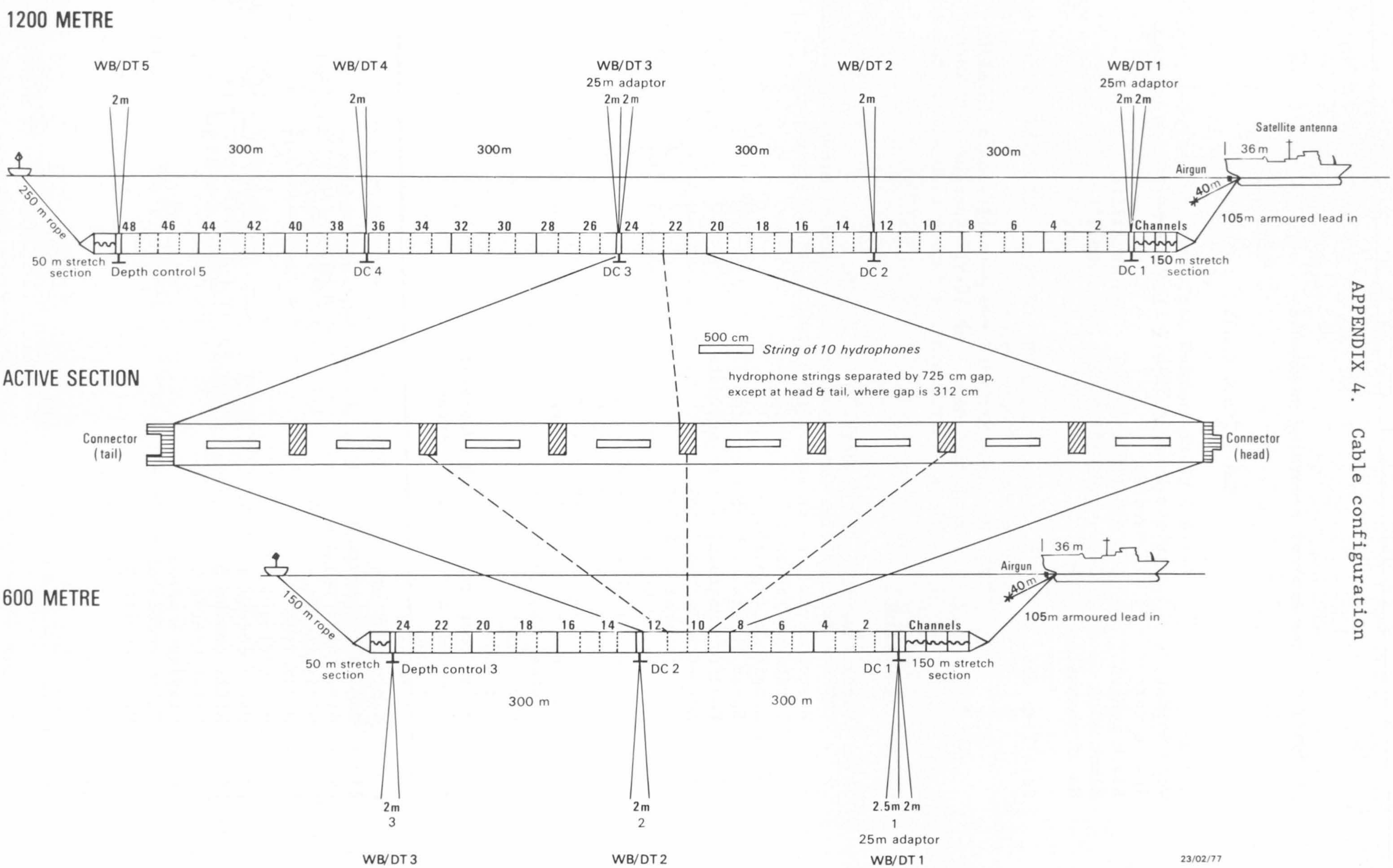
- Hewlett-Packard 2113 E-Series 16-bit minicomputer with 256 kb of memory.
- Hewlett-Packard 7905 15 Kb, moving-head disc and multi-access disc controller.
- Hewlett-Packard 7970E 1600 b.p.i., 9-track magnetic tape drives.
- Facit cassette recorder.
- Hewlett-Packard 12979 I/O extender.
- Hewlett-Packard 2748A paper tape reader.
- BMR-designed and built 16-channel digital multiplexer (up to 3).
- BMR-designed and built 16-bit gyro/speed log interface.
- Phoenix 6915 15-bit analogue-to-digital multiplexer.
- GED, NCE, or Chronolog digital clocks (x2).
- KSR-43 teletypes, Televideo TVI-910 VDUs, and Epson RX-80 line printers (various combinations).
- Kaga RGB colour monitors (up to 7) driven through RCA microcomputers.
- W & W 6-pen strip-chart recorders (x3).
- Calcomp 1044 8-pen high-speed 36-inch drum plotter.
- BWD single-beam and dual-beam CROs for monitoring magnetometer and sonar doppler signals.

Seismic acquisition system (MUSIC)

- Hewlett-Packard 2113 E-Series 16-bit minicomputer with 256 kb of memory (development system).
- Hewlett-Packard 2117 F-Series 16-bit minicomputer with 768 kb of memory (acquisition system).
- Hewlett-Packard 7905 15 Mb moving-head disc drive and multi-access disc/cpu controller.
- Hewlett-Packard 7970E 1600 b.p.i., 9-track magnetic tape drives.
- Phoenix 6915 15-bit analogue-to-digital multiplexer.
- BMR-designed 48-channel SMF-1 computer-controlled preamp/filters.
- KSR-43 teletype and Televideo TVI 910 VDU.
- Epson MX-100 dot-matrix line printers (x4).
- Epson MX-100 shot logger.
- Tektronix 611 X-Y storage CRO.
- BWD 804 single-channel CRO.
- BWD 845 dual-channel storage CRO.

- Chronolog digital clock.
- BMR-designed and built NTM-1 marine timing unit.

APPENDIX 4. Cable configuration



APPENDIX 5. Geophysical recording parameters

NON-SEISMIC (DAS)

Medium :	9-track phase-encoded mag tape (1600 b.p.i.)
Word format :	Hewlett-Packard 32-bit floating point
Sample rate :	10 seconds
Block length :	2.5 min (12 records) - non-satellite
Block size :	2400 words (16-bit) - non-satellite
No of channels :	80
Satellite data :	1) Magnavox MX1107RS fix data - HP 32-bit floating point; 20 words/block. 2) Magnavox MX1107RS raw satellite data in MX702 emulation mode - HP 16-bit integer, 600 words/ block every 2 minutes during each satellite pass.

<u>Channel allocations</u>

1 - Clock (survey & day number)
2 - GMT acquisition time from computer clock (hour, minutes, seconds)
3 - Master clock time at acquisition (hours, minutes, seconds)
4 - Latitude (radians)
5 - Longitude (radians)
6 - Speed (knots) - best estimate
7 - Heading (degrees) - best estimate
8 - Magnetometer No 1 (nT)
9 - Magnetometer No 2 (nT)
10 - Bathymetry No 1 (metres)
11 - Bathymetry No 2 (metres)
12 - Magnavox sonar doppler - fore/aft
13 - Magnavox sonar doppler - port/starboard
14 - Raytheon sonar doppler - fore/aft
15 - Raytheon sonar dopper - port/starboard
16 - Not used
17 - Not used
18 - Arma-Brown gyro-compass (degrees)
19 - Robertson gyro-compass (degrees)
20 - Not used
21 - Miniranger range 1
22 - Miniranger range 2
23 - Miniranger range 3
24 - Miniranger range 4
25 - Hifix fine A
26 - Hifix fine B
27 - Hifix fine C
28 - Hifix coarse A
29 - Hifix coarse B
30 - Hifix coarse C
31 - Gravity (m/s)
32 - Pitch acceleration (m/s)
33 - Roll acceleration (m/s)
34 - Sea state filter number
35 - Not used

36 - Not used
37 - Not used
38 - Magnetic gradient
39 - AGRF magnetic anomaly No 1
40 - AGRF magnetic anomaly No 2
41 - Latitude - Magnavox S/D + Arma-brown gyro
42 - Longitude - Magnavox S/D + Arma-brown gyro
43 - Latitude - Raytheon S/D + Robertson gyro
44 - Longitude - Raytheon S/D + Robertson gyro
45 - Latitude - radio nav or ship's log/gyro
46 - Longitude - radio nav or ship's log/gyro
47 - Not used
48 - Not used
49 - Not used
50 - GMT time from MX1107 sat nav
51 - Dead-reckoning time from MX1107
52 - Latitude (radians) from MX1107
53 - Longitude (radians) from MX1107
54 - Speed (knots) from MX1107
55 - Heading (degrees) from MX1107
56 - Set (degrees) from MX1107
57 - Drift (knots) from MX1107
58 - Set/drift flag, 0 = manual, 1 = auto
59 - GMT from MX1142 sat nav
60 - Dead-reckoned time from MX1142
61 - Latitude (radians) from MX1142
62 - Longitude (radians) from MX1142
63 - Speed (knots) from MX1142
64 - Heading (degrees) from MX1142
65 - Set (degrees) from MX1142
66 - Drift (knots) from MX1142
67 - Set/drift flag, 0 = manual, 1 = auto
68 - Vector speed Magnavox sonar doppler
69 - Vector speed Raytheon sonar doppler
70 - Vector speed ship's log
71 - Vector heading Magnavox sonar doppler
72 - Vector heading Raytheon sonar doppler
73 - Vector heading ship's log/gyro
74 - Not used
75 - Not used
76 - Not used
77 - Not used
78 - Not used
79 - Not used
80 - Not used

SEISMIC (MUSIC)

Medium :	9-track phase-encoded mag tape (1600 b.p.i.)
Word format :	2's complement 16-bit integer
Sample rate :	2 ms
Record length :	7000 ms
Recording delay :	variable, in units of 1000 ms
No of channels :	54

Channel allocations

1-48	-	active sections (1 at front)
49-51	-	water breaks
52	-	refractions
53-54	-	air-gun signatures

(Note : usable data are recorded in channels 49-51 and 53-54 only when recording delay is zero)

Tape format

BMR implementation of SEG-Y
- 1600 word ASCII header
- 200 word binary header
- each channel consists of a 120-word trace header and 3500 data values
- each tape terminated by 2 end-of-files

Cable configuration

No of active channels :	48
Active group length :	25 m (2 x 12.5 m)
Tow leader :	105 m (from stern)
Stretch (isolator) sections :	150 m (3 x 50 m)
Offset to first active channel :	252 m (typical)
Depth transducer/water breaks :	after channels 0, 12, 24, 36, 48
Cable levellers :	after channels 0, 12, 24, 36, 48
Cable adapters (2:1) :	after channels 0, 24
Cable towing depth :	10-12 m (typical)

Air-guns

No. and volume :	2 x 500 cu. in.
Offset from stern :	40 m
Orientation :	towed in parallel, about 5m apart
Gun towing depth :	7-10 m (typical)

Amplifiers

Gain :	512
Low-cut shoulder frequency :	12 Hz
High-cut shoulder frequency :	128 Hz

APPENDIX 6. SEASAT free-air gravity field: details of acquisition

The free-air gravity field of the Kerguelen Plateau and environs (Figs 5, 6) was derived from radar altimeter data collected during the 100-day life of the SEASAT satellite in 1978 (Haxby & others, 1983). Microwave radar pulses essentially recorded the geoidal surface, averaging wave height, to a precision of several centimetres. Perturbations not related to the potential field, notably geostrophic currents and sea ice, obviously introduce error into the geoid, but their distorting effects are limited primarily to regions of western boundary currents and to latitudes south of 60° South, respectively. The geoid is a direct function of mass distribution within the Earth, i.e. water piles up over mass excesses and is removed over mass deficiencies. Hence, accurate knowledge of sea-surface topography permits calculation of the free-air gravity field from the radial derivative of the geoid. Over all, the technique employed by Haxby & others provides accuracy to less than 50 $\mu m/s^2$, or not quite as good as shipboard gravimetrics. Yet in 100 days SEASAT compiled data for the entire oceanic realm, whereas shipboard measurements have been conducted over less than one per cent of the oceanic area. One limitation of the contour interval used in the maps is that is does not do justice to the most significant free-air anomalies observed on the Earth's surface, e.g. arcs, trenches, fracture zones, and major seamounts, which may display free-air anomalies a few thousand $\mu m/s$ in amplitude. SEASAT was in a polar orbit, and track spacing thus decreased with increasing latitude, but generally ranged from less than five to several tens of kilometres over the plateau. The data were computer-contoured with software designed to enhance linear trends. Caution must be exercised when viewing the maps: features of dimensions less than about 25 km may be artifacts from the gridding or contouring processes, and, as mentioned above, sea-ice effects are significant south of 60° South. Finally, it must be remembered that gravity anomalies do not necessarily correlate with bathymetric or topographic anomalies, and vice versa.

APPENDIX 7. Grab-sample descriptions

Station 1 rock samples
All have prefix 4701(0000)
All volcanics are moderately altered; most are amygdaloidal.

Sample No.	Description	Number of pieces	Mass (grams)	Thin Section	Micro probe
1	Volcanic: 'trachyandesite'	1	26	x	x
2	Volcanic	1	11		
3	Volcanic: 'alkali olivine basalt'	1	10	x	x
4	Volcanic	1	15		
5	Granite	1	6	x	x
6	Granite, with hornblende	1	3	x	x
7	Volcanic	1	7		
8	Volcanic	1	11	x	x
9	Volcanic	1	8		
10	Granite	1	5		
11	Granite	1	5		
12	Granite	1	5	x	x
13	Volcanic	1	2		
14	Granite	1	3		
15	Metasediment: quartz sandstone with chlorite	1	14	x	x
16	Volcanic: 'trachyandesite'	1	10	x	x
17	Volcanic: 'trachyandesite'	1	9	x	x
18	Volcanic	1	5		
19	Volcanic 'trachyandesite'	1	5	x	x
20	Volcanic	1	5		
21	Volcanic	1	3		
22	Granite	1	5		
23	Granite	1	5		
24	Volcanic	1	2		
25	Volcanic	1	2		
26-29	No sample				
30	Volcanic	1	3		
31	Volcanic	1	3		
32	Manganese oxide thin crust	1	1		
33	Volcanic	1	3		
34	Metasediment : arkosic sandstone with chlorite and epidote	1	3	x	x
35	Metasediment	1	3		
36	Granite	2	2		

Station 3 rock samples

All have prefix 4703(0000)
All volcanics are moderately altered

Sample No.	Description	Number of pieces	Mass (grams)	Thin Section	Micro probe
1	Volcanic: 'trachyandesite'	1	11	x	x
2	Volcanic	1	16		
3	Volcanic	1	7		
4	Volcanic	1	15		
5	Volcanic	1	10		
6	Volcanic: 'high-K trachyandesite' autobrecciated lava	1	15	x	x
7	Volcanic	1	7		
8	Volcanic	1	6		
9	Aplite	1	4	x	x
10	Sediment: quartz sandstone with detrital muscovite and rutile	1	8	x	x
11	Metasediment: quartzite with intergranular phyllosilicate	1	7	x	x
12	Volcanic	1	4		
13	Volcanic	1	10		
14	Volcanic 'trachyandesite'	1	10	x	x
15	Volcanic	1	10		
16	Volcanic	1	10		
17	Volcanic	1	10		
18	Volcanic	1	10		
19	Volcanic	1	10		
20	Granite	1	10	x	x
21	Granite, with hornblende	1	7	x	x
22	Volcanic: 'trachyandesite'	1	10	x	x
23	Metasediment: quartz sandstone	1	5	x	x
24	Granite, with hornblende	1	5	x	x
25	Volcanic	1	10		
26	Metasediment?	1	10		
27	Volcanic	1	2		
28	Volcanic	1	5		
29	Volcanic	1	7		
30	Volcanic	1	10		
31	Granite	1	5		
32	Granite cataclasite	1	5	x	x
33	Granite, sub-cataclastic	1	5	x	
34	Volcanic	1	5		
35	Volcanic	1	7		
36	Volcanic	1	5		
37	Diorite	1	4	x	x
38	Volcanic	1	5		
39	Metasediment: quartzite with later granite	1	4	x	x
40	Granite, weathered	1	5		
41	Volcanic	1	5		

42	Volcanic	1	3		
43	Metasediment: phyllitic schist	1	2		
44	Granite cataclasite	1	2		
45	Granite	38	21		
46	Pink granite	8	5		
47	Hornblende-rich fragment, dioritic	2	1		
48	Metasediment: quartz sandstone	7	2.5	x	x
49	Granite, and	9	3		
	Volcanic?	2	2		
50	Hornblende-rich fragment, dioritic	2	1		
51	Granite?, porphyritic, fine-grained	1	2		
	Volcanic?	4	3		
52	Volcanic, felsic, amygdaloidal	99	64		
53	Metasediment: fine arkosic sandstone	1	1		
54	Scoriaceous basalt	1	1	x	x
55	Scoriaceous olivine basalt	1	1	x	x
56	Metasediment: Fine quartz sandstone with later biotite	1	1	x	x
57	Volcanic	1	1		

APPENDIX 8. Cruise narrative

(All times are local time. Kerguelen Plateau time: GMT + 5 hours).

Saturday 2 March. Sydney

Sailed 1200 hrs from Sydney. Remainder of day spent testing the ship's dynamic positioning system off Sydney Heads.

Sunday 3 to Wednesday 6 March. Sydney to Devonport.

Installation and testing of marine gravity meter. Automatic shutdown and draining systems installed on compressors. Problems caused by poor tracking of sonar doppler speed logs and poor 12 kHz bathymetric record. Seas moderate to rough. Docked Devonport 1630 hrs.

Thursday 7 March. Devonport.

Ship's fuelling completed. Personnel exchanged. Sailed 2000 hrs. Running air-gun tests.

Friday 8 to Thursday 21 March. Bass Strait to Kerguelen Plateau.

Cleared Bass Strait 0700 hrs on 8 March. Collecting 12 kHz bathymetric, gravity, magnetic, and navigation data. Ship's speed initially 11-12 kn. Bathymetric records were generally very poor, probably owing to aeration beneath ship's hull. Speed log switched to manual setting on 10 March (poor water column tracking) and remained on manual setting for remainder or research project. The Magnavox sonar doppler transducer head was lowered by 10 cm with a negligible improvement in the quality of the data received.

Poor weather from 15-18 led to the ship's speed being reduced to between 4 and 6 kn. Minor damage was caused to the ship's forecastle in a storm on the night of 18 March. This resulted in ship backtracking to keep water off foredeck for eighteen hours while repairs were made.

The single-channel magnetometer head and cable were lost in very rough weather on 20 March. The first part of the gradiometer cable was subsequently deployed as a substitute.

Friday 22 March. East of Kerguelen Plateau.

Calm seas. Weather buoy launched at 0115 hrs at lat. 50°05'S, long. 77°55'E. 600 m streamer deployed at 1730 hrs. Tests carried out on streamer buoyancy, noise levels, etc. Started shooting 6-fold seismic data from way point KP1.

Saturday 23 March.

Stopped shooting and seismic streamer increased in length to 1200 m by adding 600 m from the other reel. Commenced first crossing of the plateau. Collecting 12 kHz bathymetry, gravity, magnetic, navigation, and 48-channel (12-fold) seismic data shooting with two 500 cu.in. guns. Seas calm.

Sunday 24 to Tuesday 26 March. Northern Kerguelen Plateau.

Routine collection of data. Speed between 5 and 6 kn. Increasingly rough seas resulted in a change in the orientation of the first line to 260 at 0700 hrs on 26 March. Continuing problems with both magnetometer consoles.

Wednesday 27 to Friday 29 March. Southern Kerguelen Plateau.

Routine. Running Line 13 to south on low to moderate seas. Commenced Line 14 at 1700 hrs on 29 March. Deployed magnetic gradiometer cable for first time.

Saturday 30 March.

Rapid deterioration in weather. All gear including streamer pulled in at 0730 hrs. Hove-to all day.

Sunday 31 March.

Began streaming cable again at 0800 hrs. All gear deployed and running by 1200 hrs. Started Line 15.

Monday 1 to Thursday 4 April

Routine. Seas calm. Speed 5-6 kn. Lines 16-21 completed.

Friday 5 April.

Minor problems caused by compressor overheating because of failure of saltwater pump. Rough seas prevented work for most of day. Hove-to. Multichannel work restarted at 1930 hrs.

Saturday 6 to Monday 8 April.

Routine. Seas calm. Completed Lines 22-25. Speed 5.5-6.0 kn. Designed and installed compressor shutdown alarm in instrument room. Two sonobuoys deployed on 7 April; both unsuccessful. Seismic abandoned at 1700 hrs on 8 April because of rapid deterioration in weather. All gear except streamer brought back on board. Hove-to.

Tuesday 9 April.

Hove-to all day in very rough seas.

Wednesday 10 to Saturday 13 April.

Seismic recommenced 0800 hrs 10 April. Routine. Seas calm. Lines 27 and 28 completed.

Sunday 14 April.

Routine. Sonobuoy successfully deployed. Single-channel geological streamer tested.

Monday 15 to Wednesday 17 April.

Continuing Line 29. One sensor on gradiometer cable not recording; retrieved cable. At 1300 hrs on 15 April seismic gear pulled in to go and undertake geological sampling. Weather buoy deployed at 2145 hrs on 15 April at lat. 58° 22'S, long. 77° 59'E.

Two sampling stations occupied between 0000 and 0900 hrs on 16 March, when sampling abandoned, owing to rough to very rough seas. Ship hove-to. Recommenced sampling at 2300 hrs on 16 March. Three stations occupied.

Commenced transit back to seismic line at 0600 hrs 17 April. Recommenced seismic and single-channel magnetic recording at 1700 hrs.

Thursday 18 to Friday 19 April.

Routine. Continuing Line 33. Low-moderate seas.

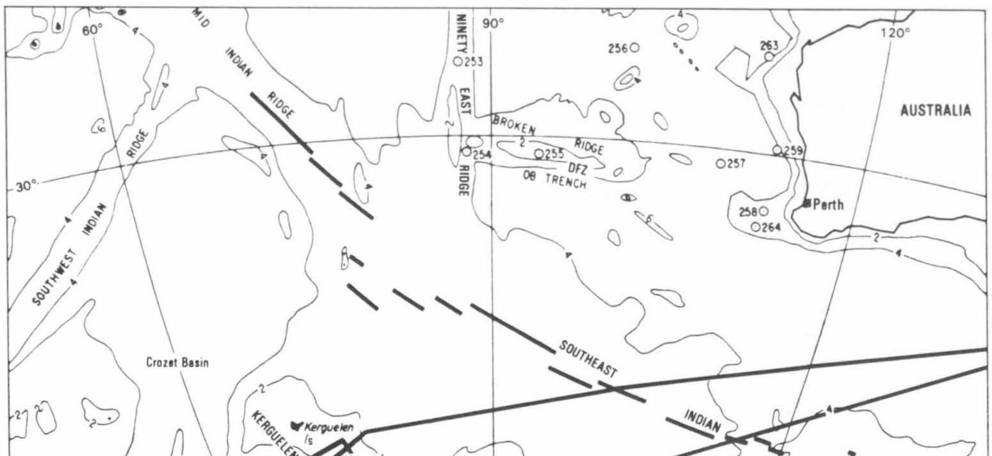
Saturday 20 April. East of Kerguelen Plateau.

0430 hrs finished Line 33 10 miles short, owing to burst air-line. All seismic gear pulled in.

0630 hrs commenced transit back to Melbourne. Running bathymetry, single- channel magnetics, and gravity.

Last weather buoy deployed at 2300 hrs at lat. 55° 37'S, long. 94° 46'E.

Sunday 21 to 1600 29 April. Kerguelen Plateau to Melbourne.



⊙ DSDP hole

(Base map after Johnson and others, 1976)

Figure 1. General location map.

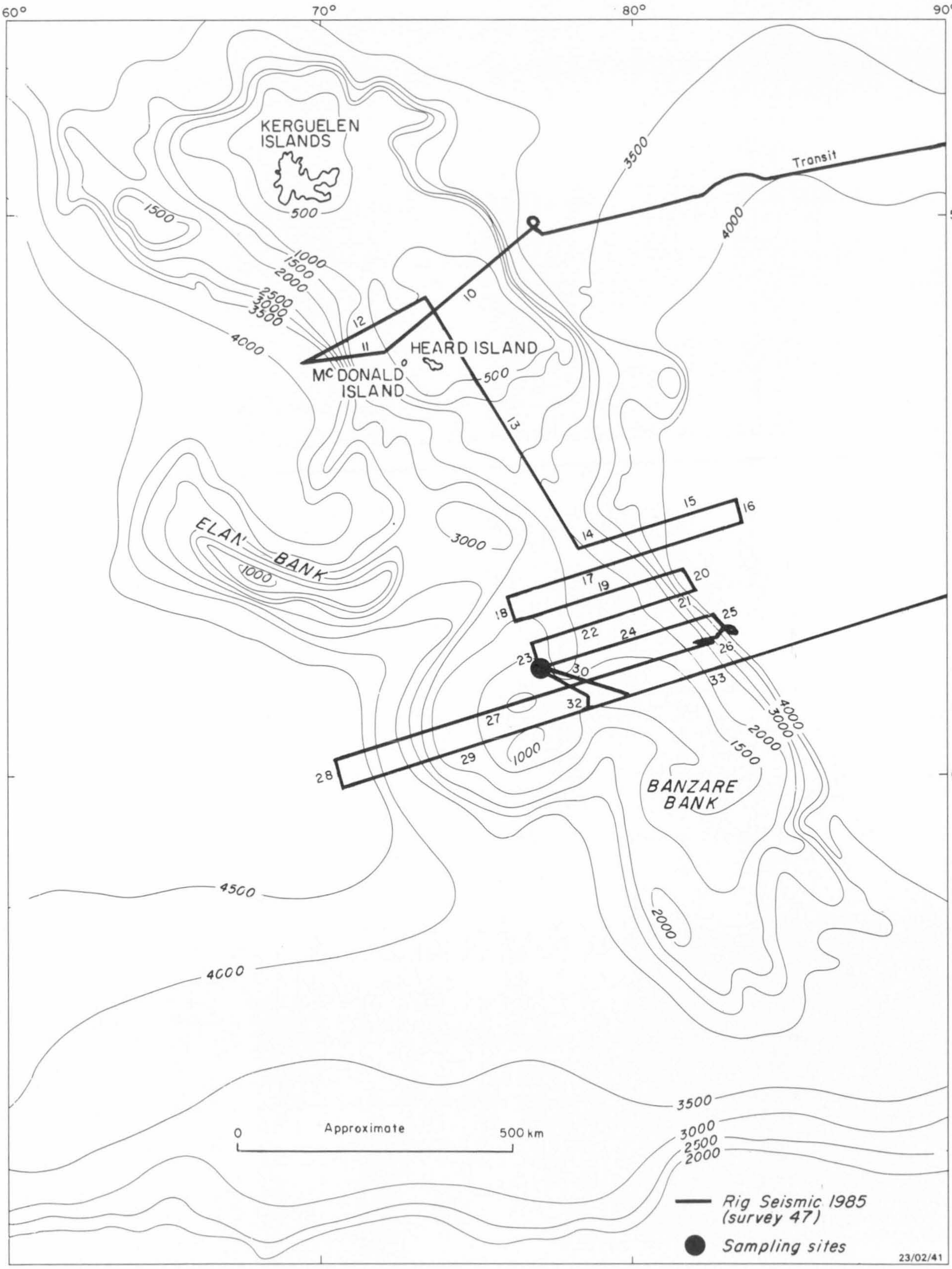


Figure 2. Bathymetry of the Kerguelen Plateau (in metres) showing tracks of the R/V Rig Seismic and sampling sites.

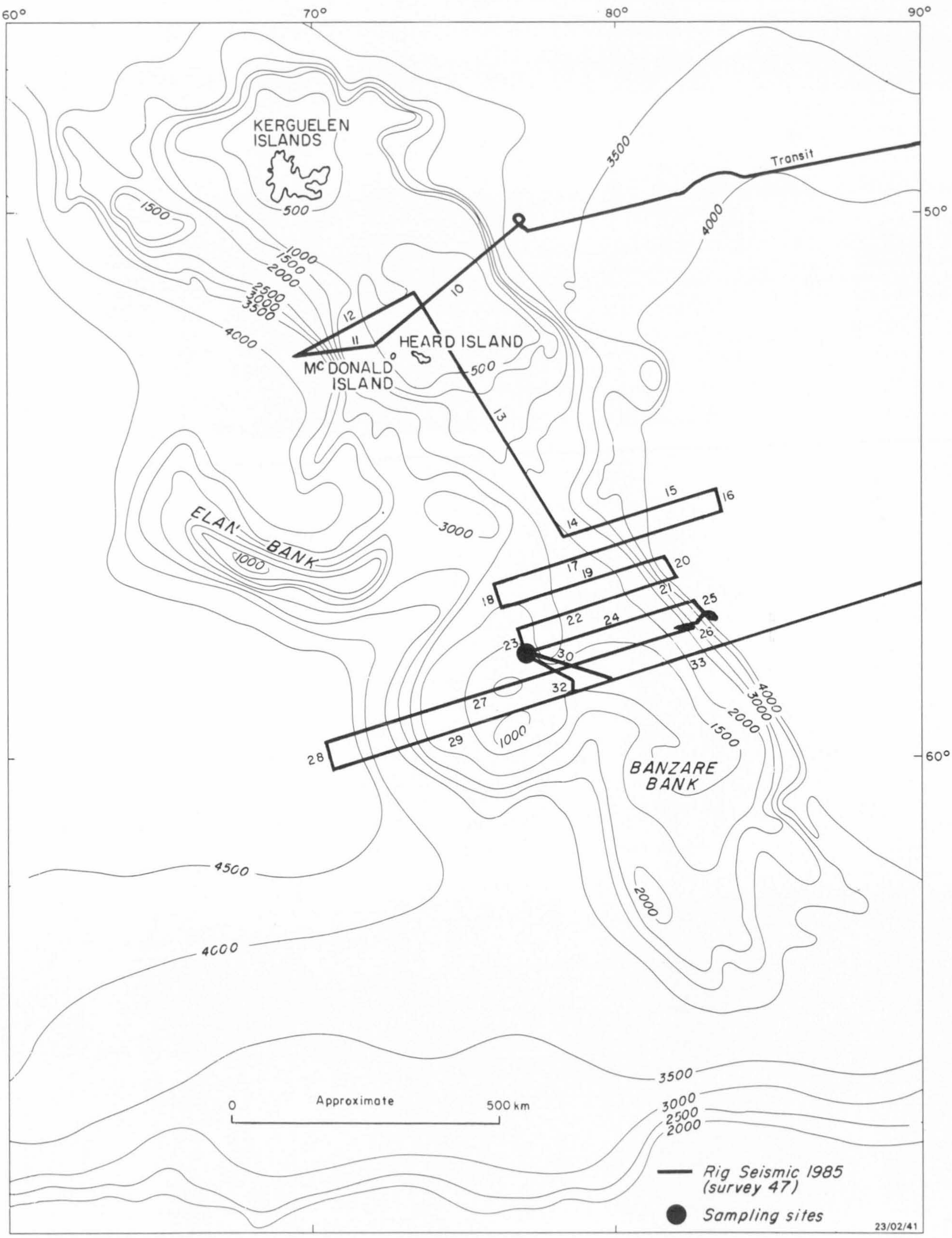


Figure 2. Bathymetry of the Kerguelen Plateau (in metres) showing tracks of the R/V Rig Seismic and sampling sites.

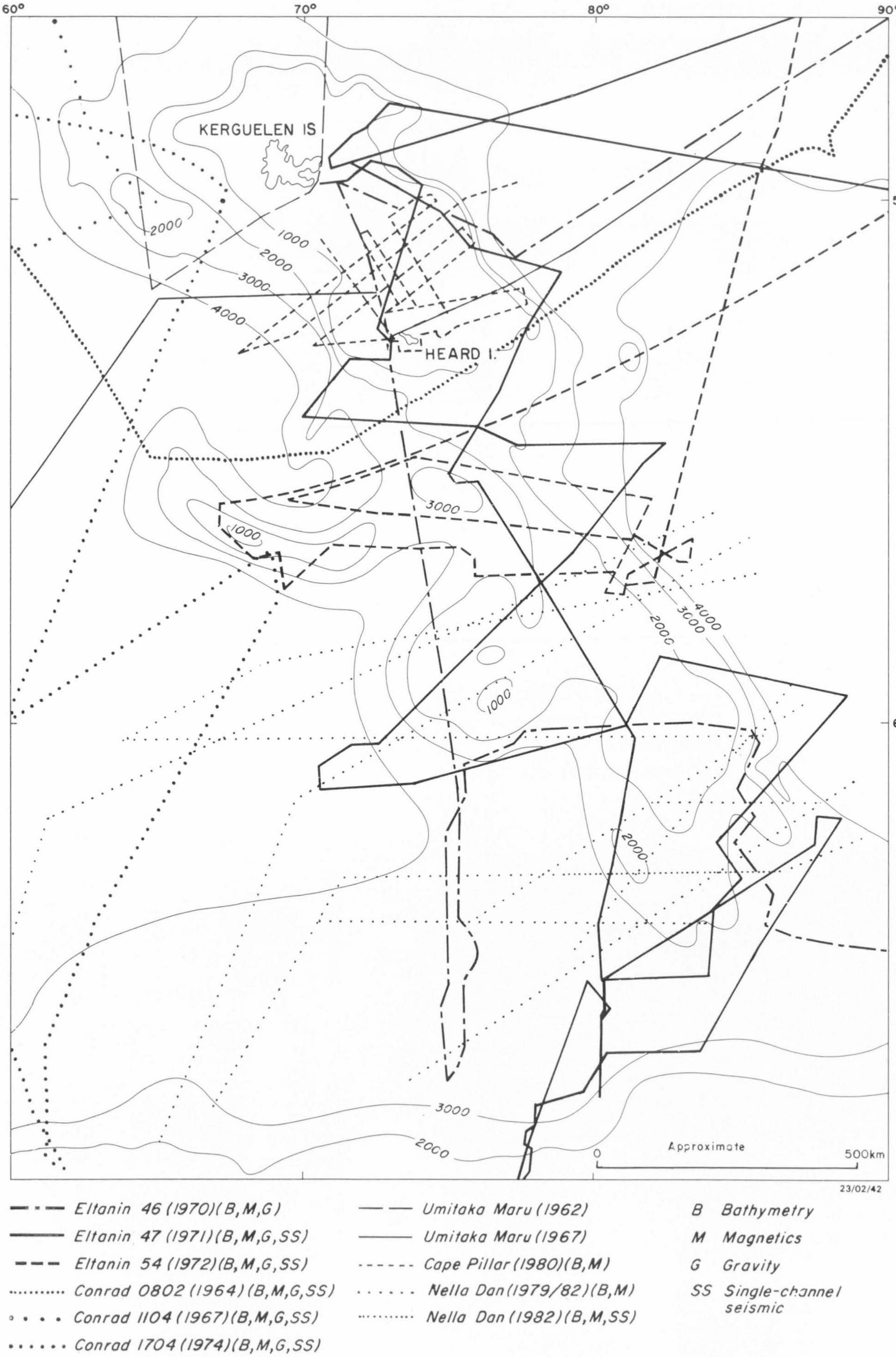


Figure 3. Previous ship's tracks.

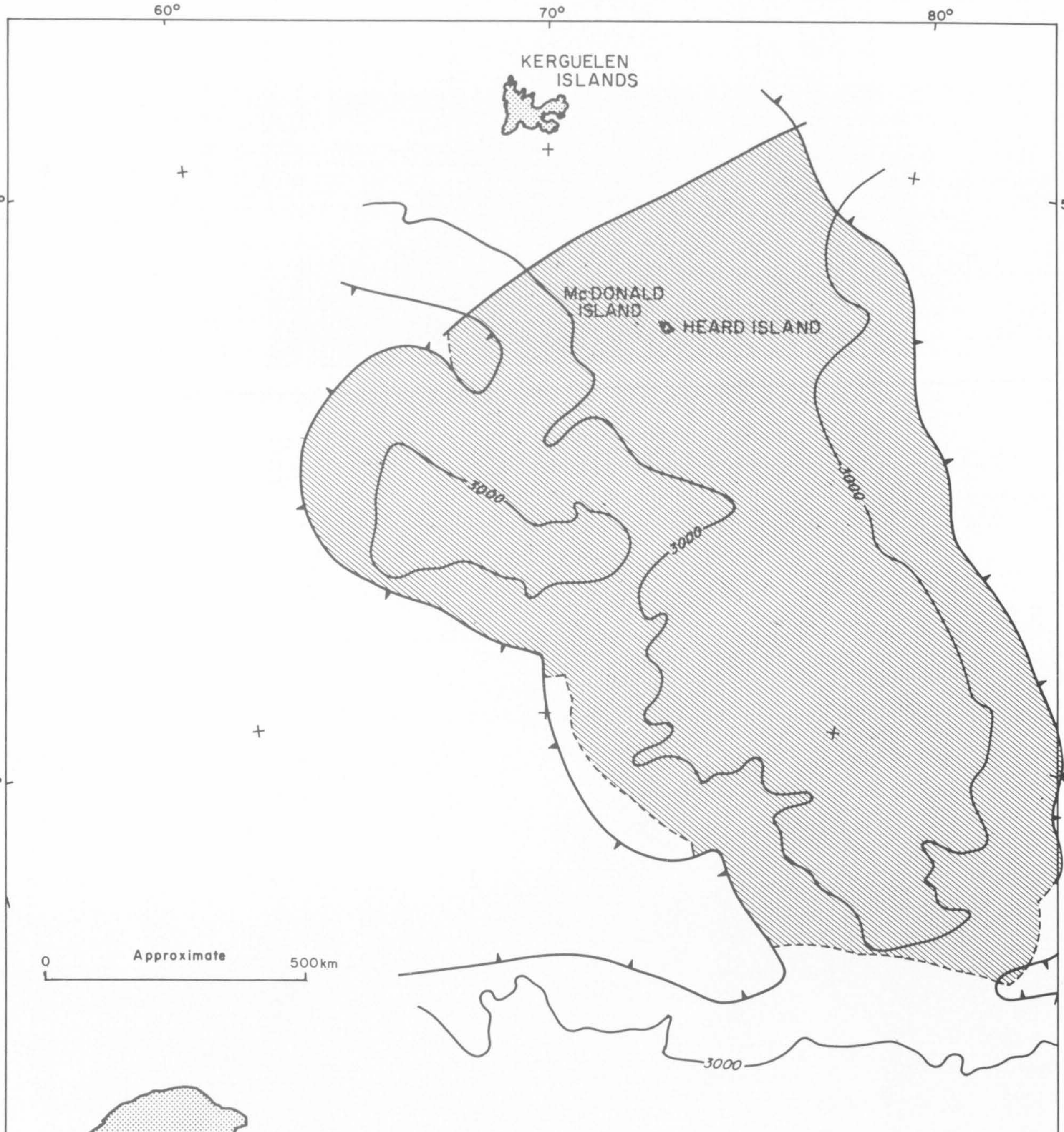


Figure 4. Area of 'legal continental shelf' claimed by Australia around Heard and McDonald Islands.

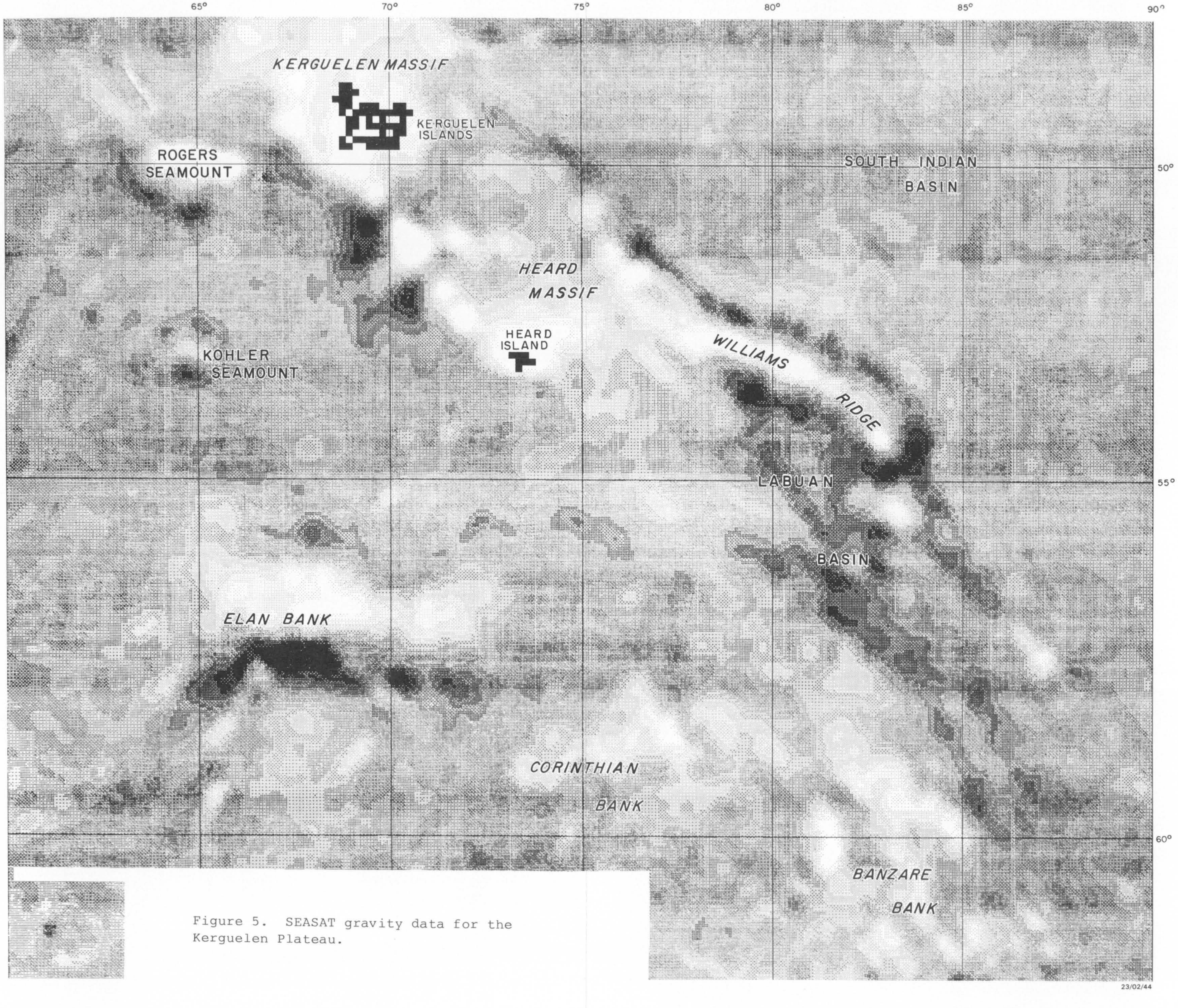


Figure 5. SEASAT gravity data for the Kerguelen Plateau.

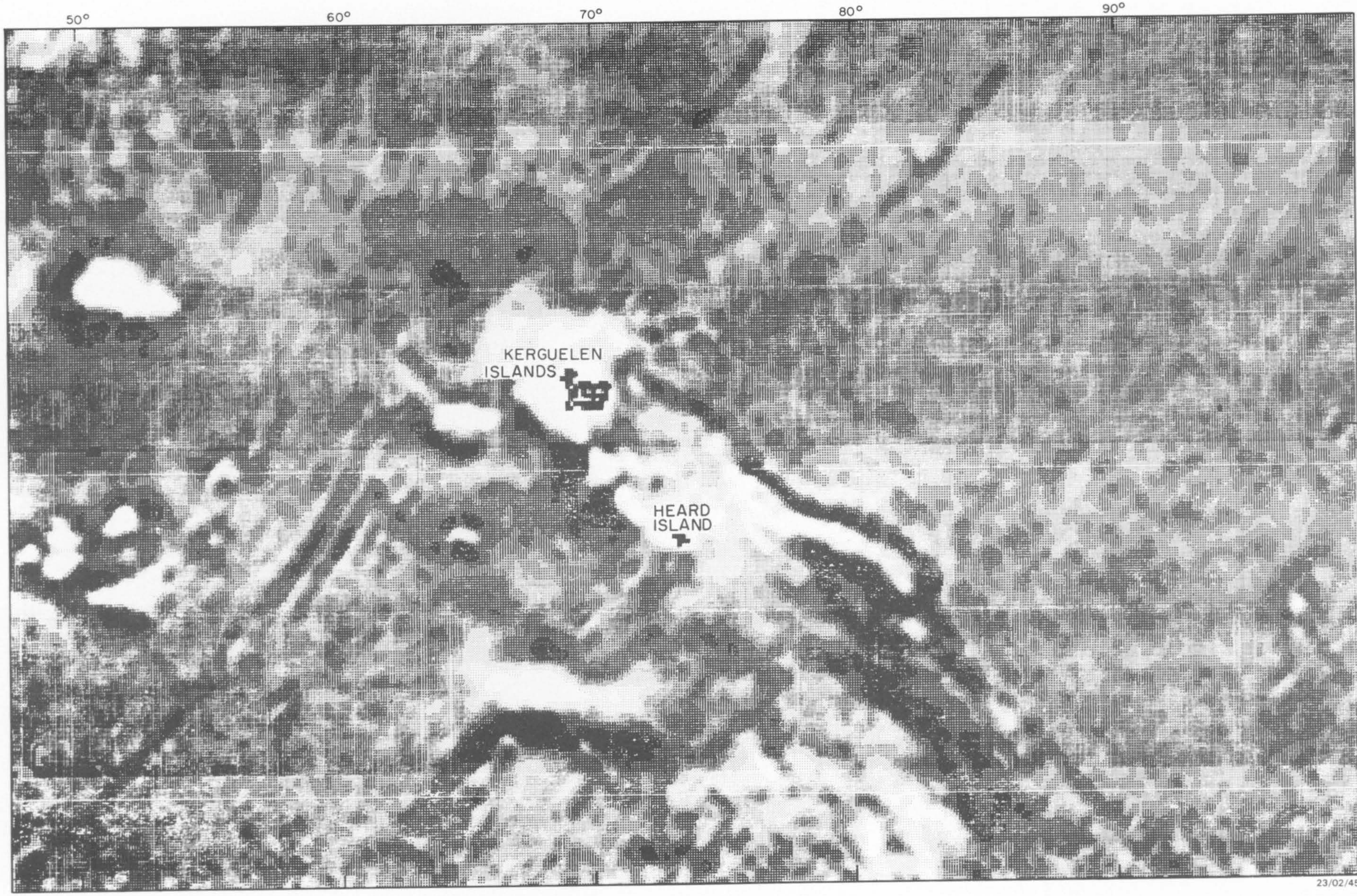


Figure 6. SEASAT gravity data for the
area surrounding the Kerguelen Plateau.

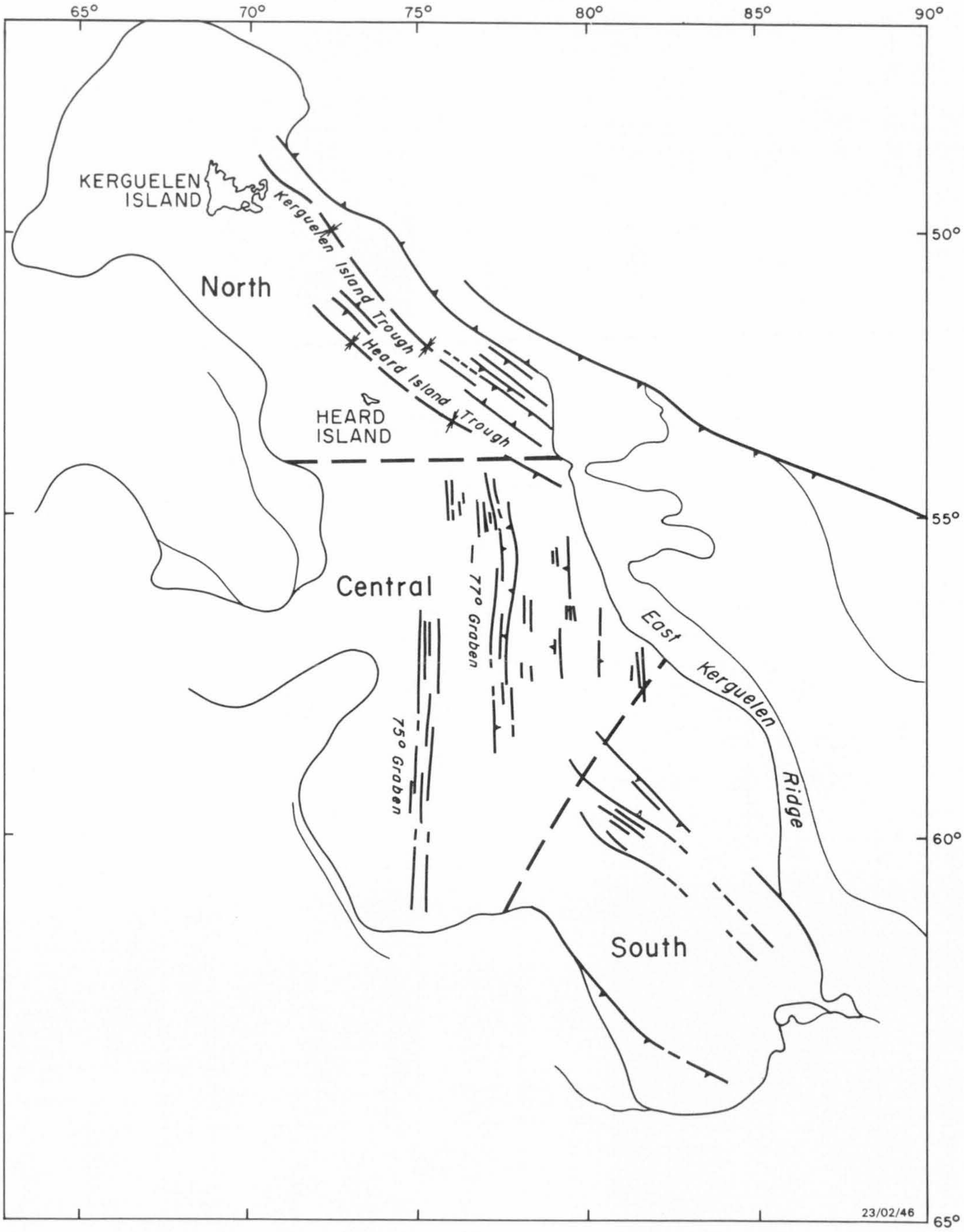


Figure 7. Structural map of the Kerguelen Plateau (after Houtz & others, 1977).

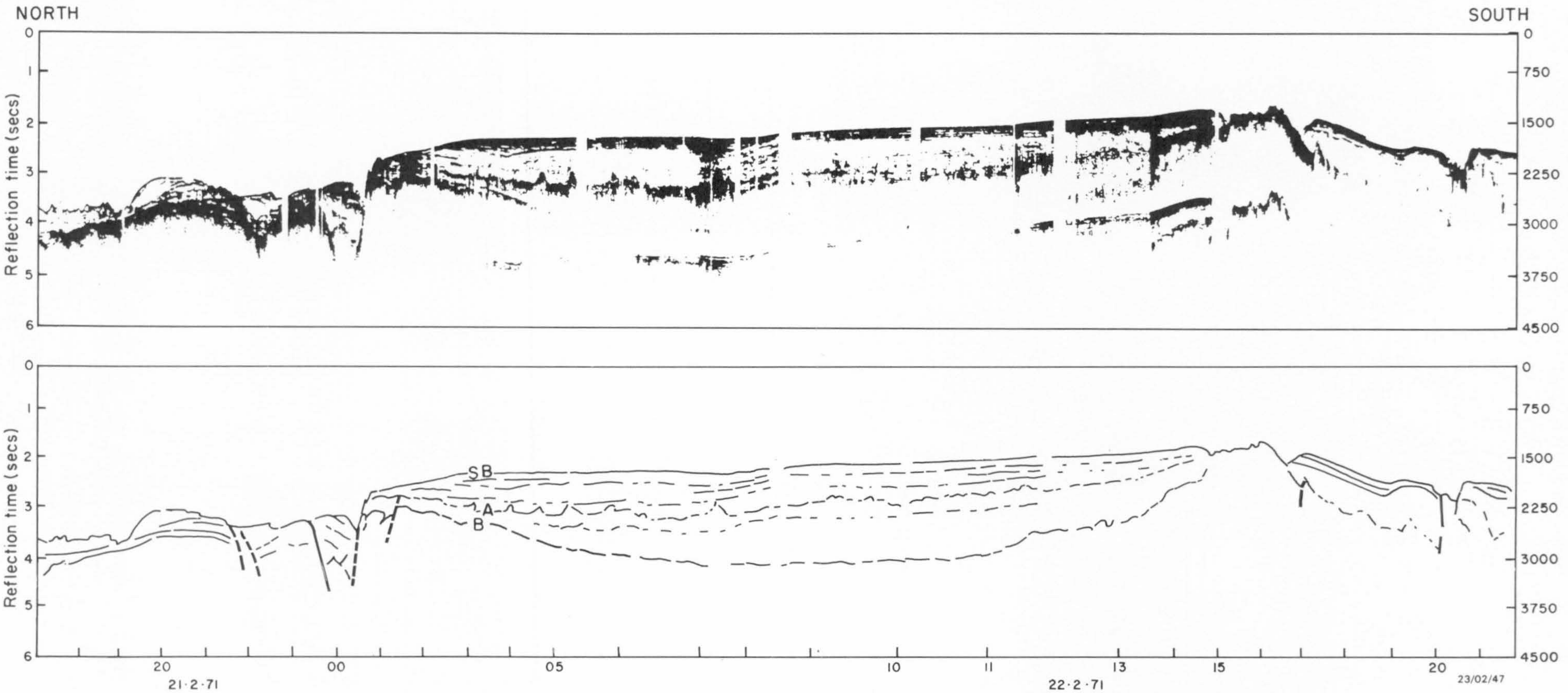


Figure 8. Single-channel seismic record from the southern Kerguelen Plateau (after Houtz & others, 1977).

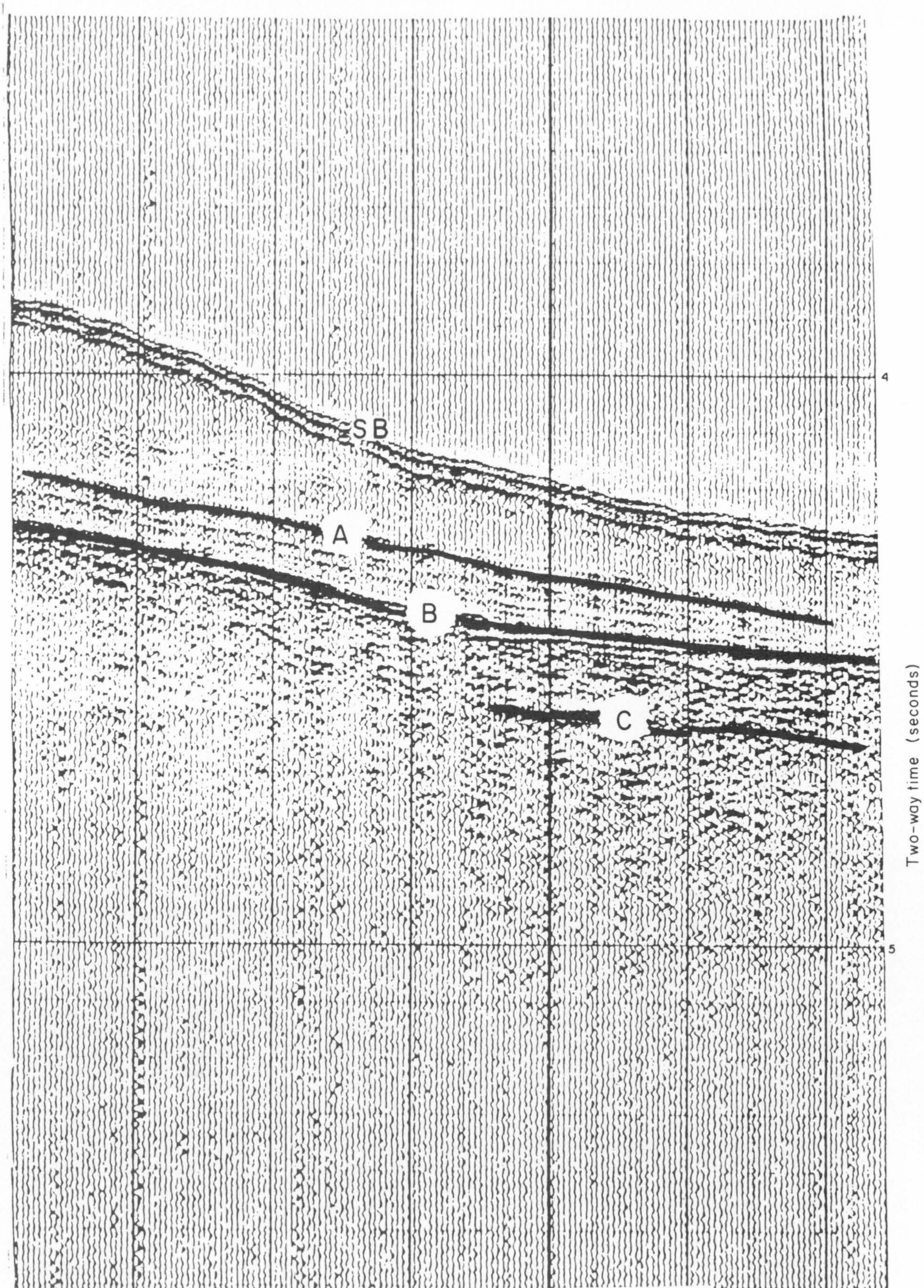


Figure 9. Single-channel seismic record from the southern Kerguelen Plateau illustrating character of reflectors A, B, and C.

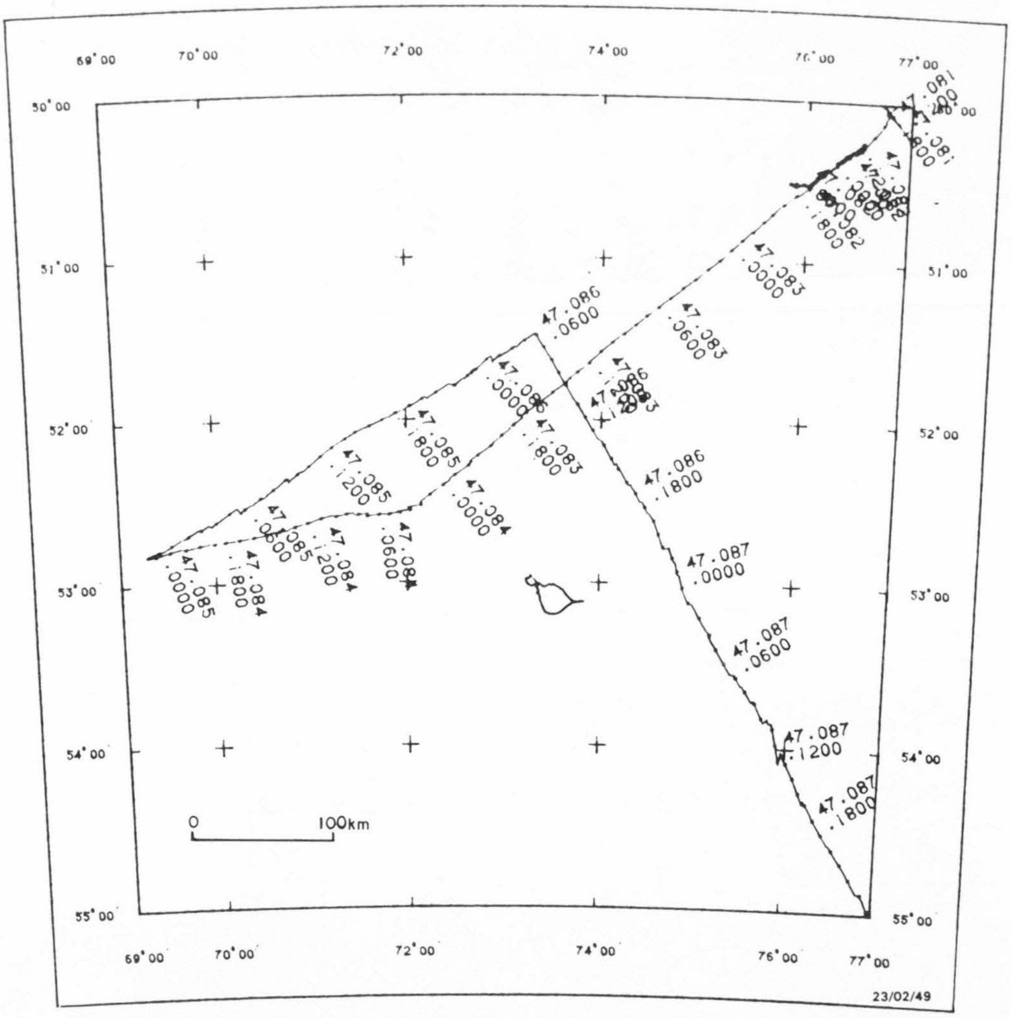


Figure 10. Track map - northern sector.

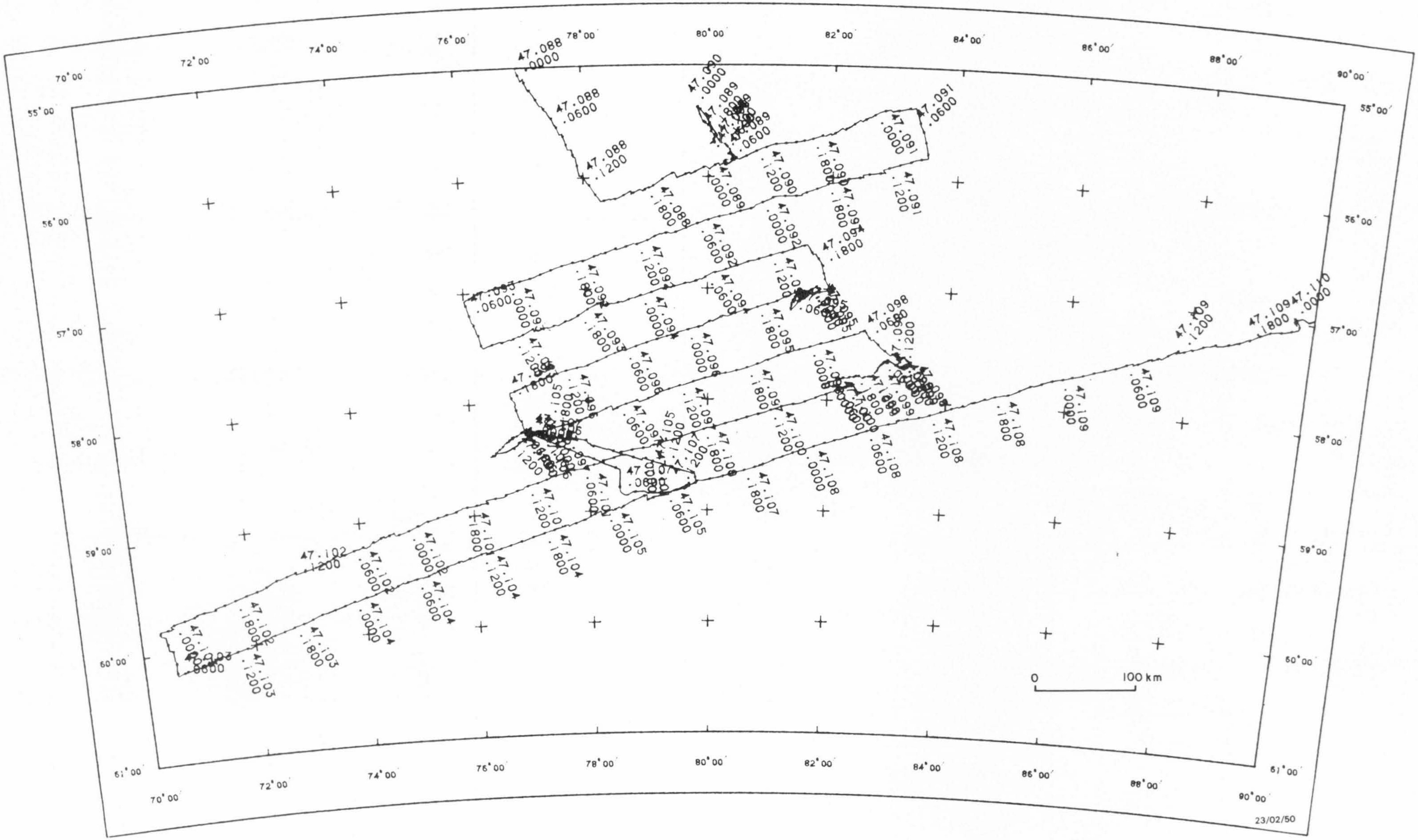


Figure 11. Track map - southern sector.

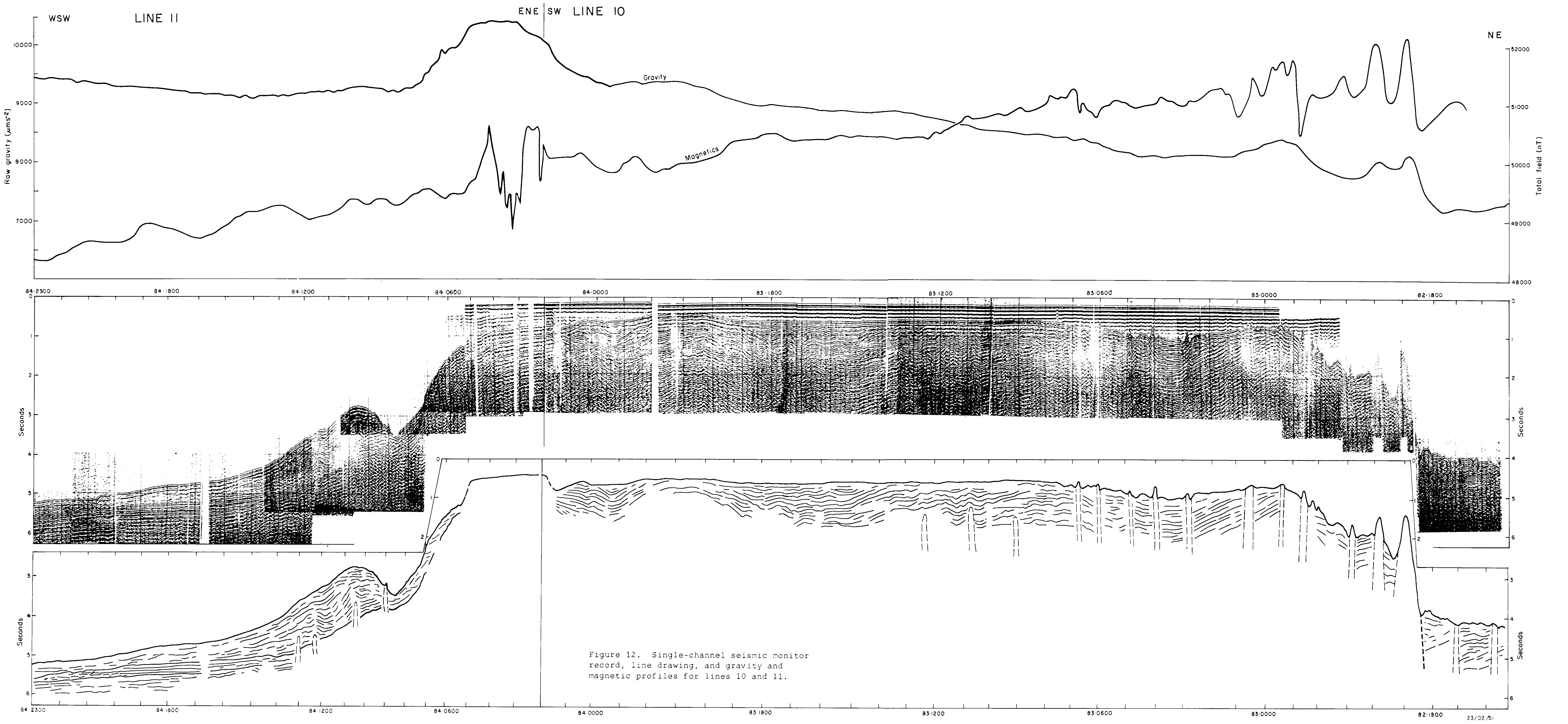


Figure 12. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for lines 10 and 11.

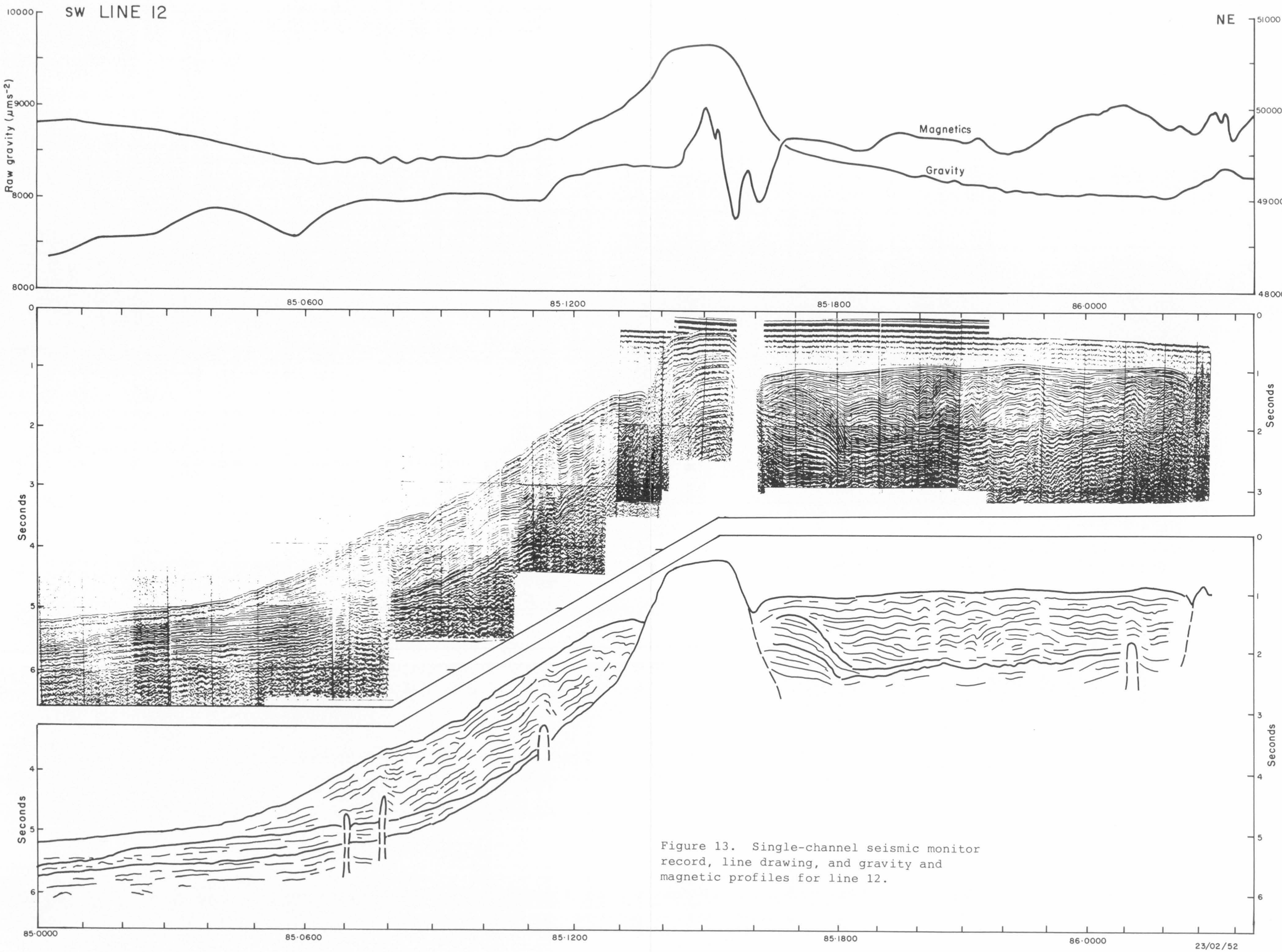


Figure 13. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 12.

Figure 14. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 13.

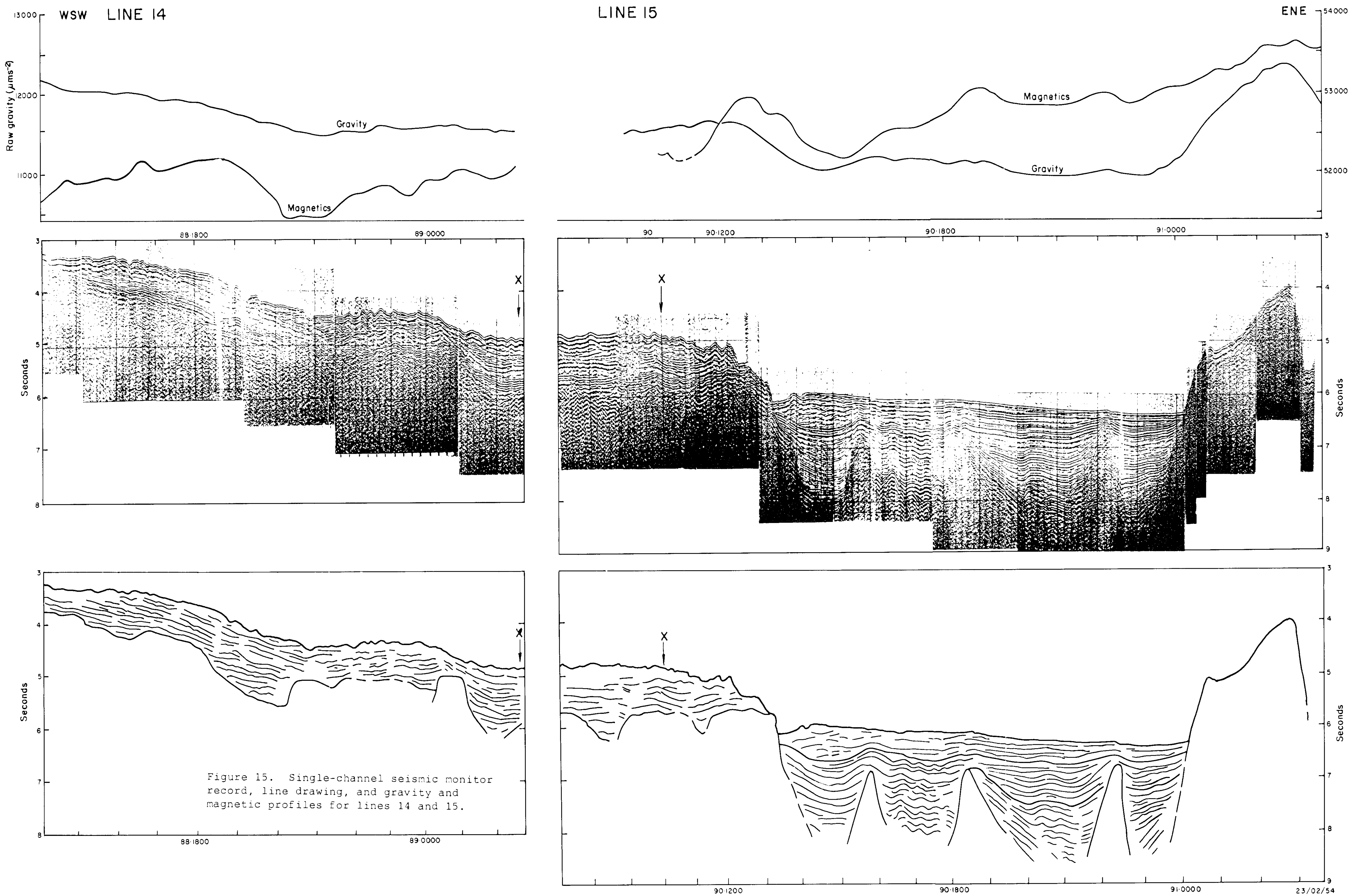


Figure 15. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for lines 14 and 15.

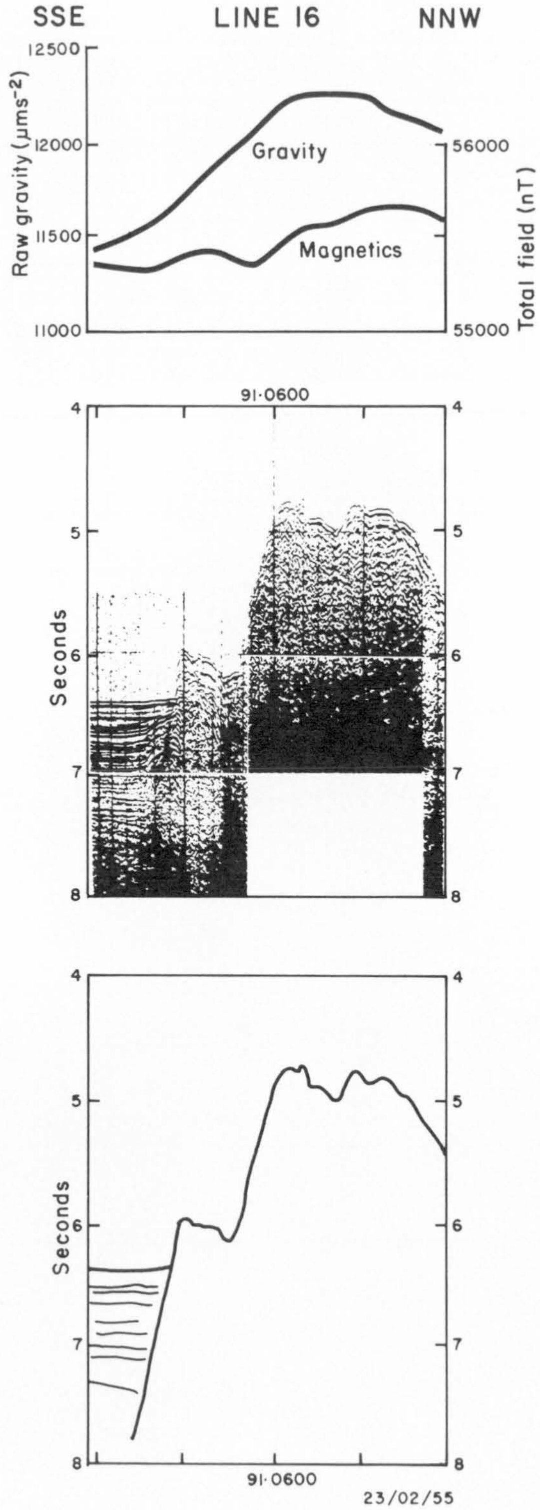


Figure 16. Single-channel and seismic monitor record, line drawing, and gravity and magnetic profiles for line 16.

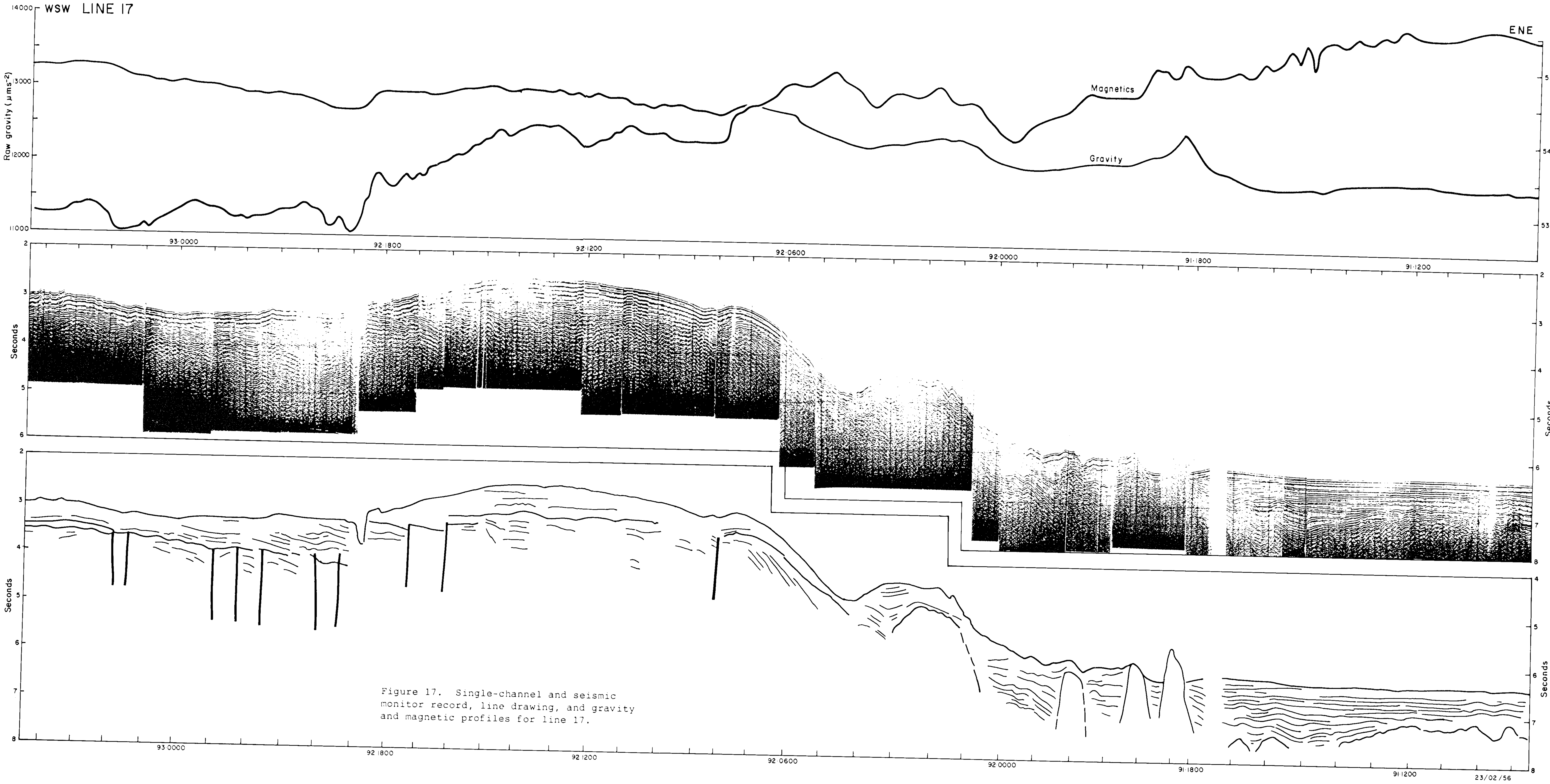


Figure 17. Single-channel and seismic monitor record, line drawing, and gravity and magnetic profiles for line 17.

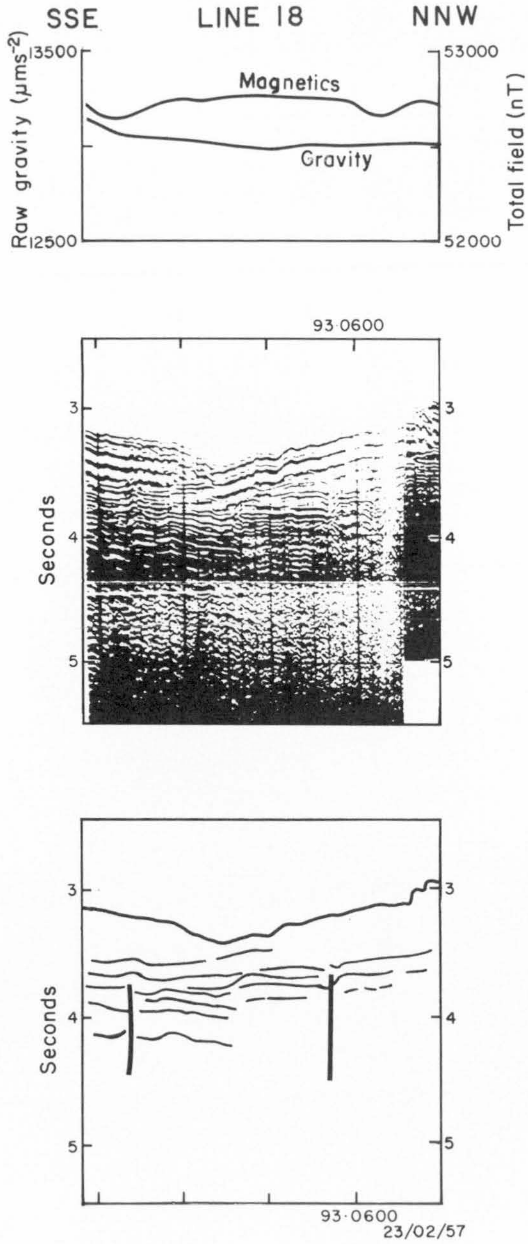


Figure 18. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 18.

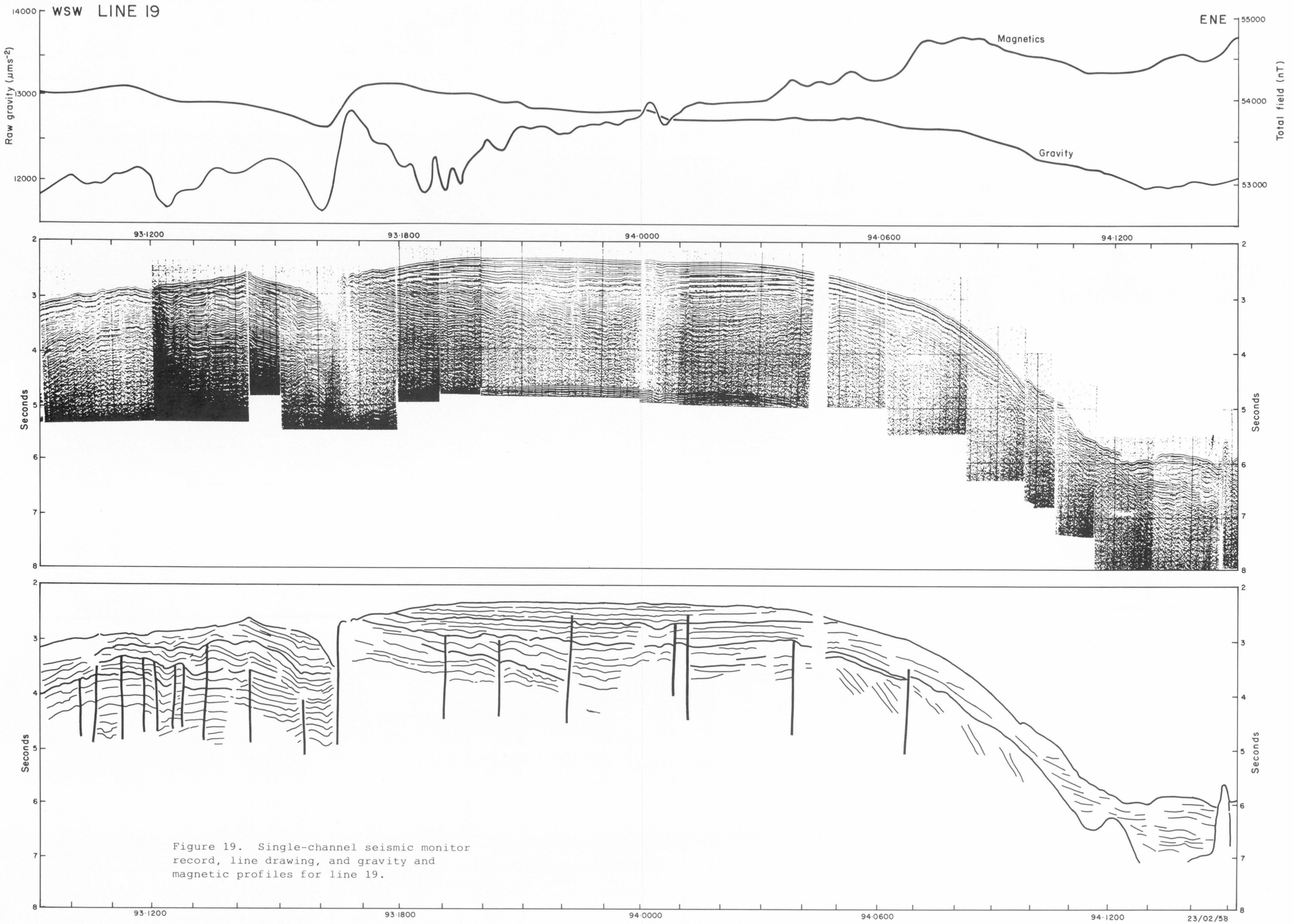


Figure 19. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 19.

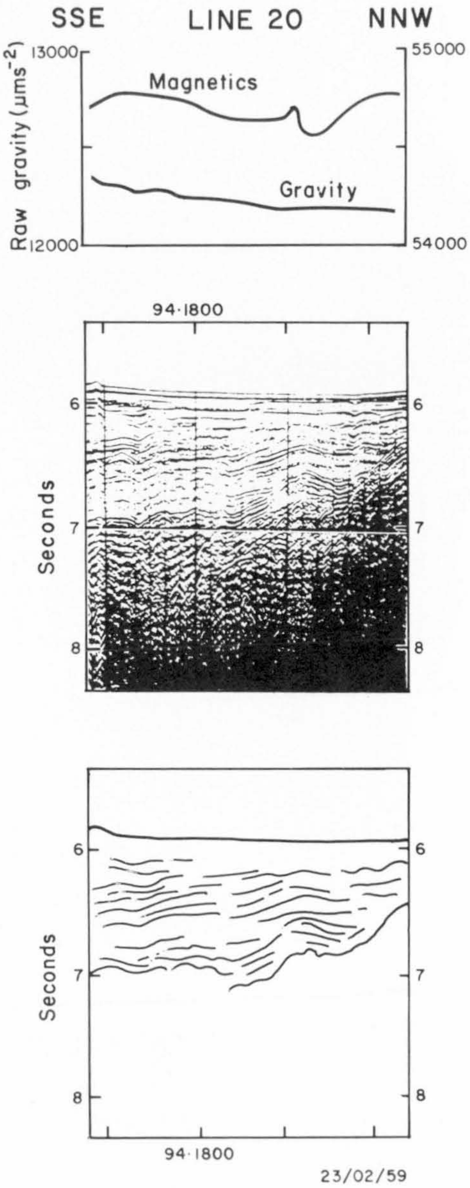


Figure 20. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 20.

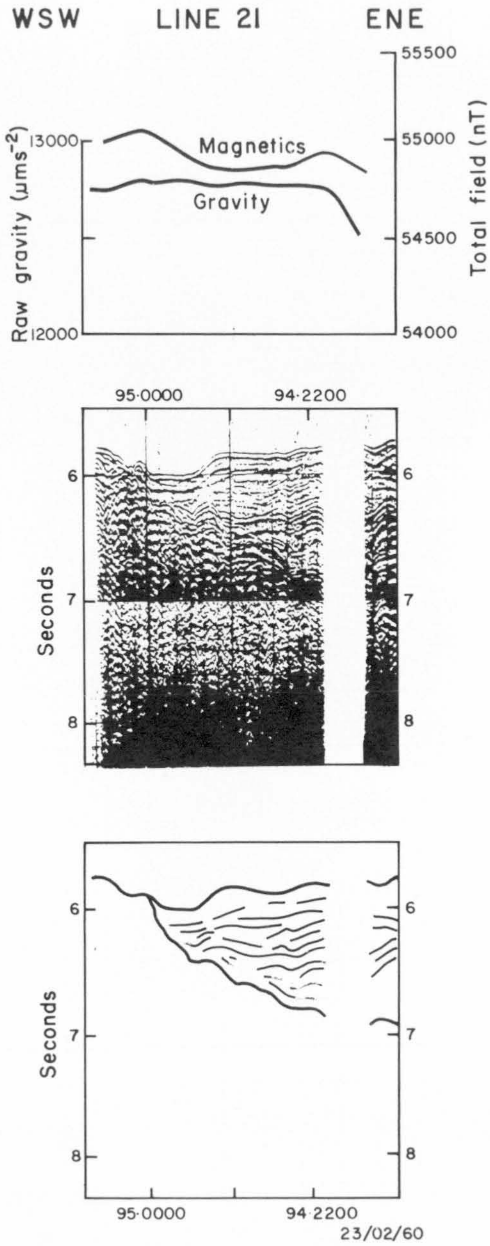


Figure 21. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 21.

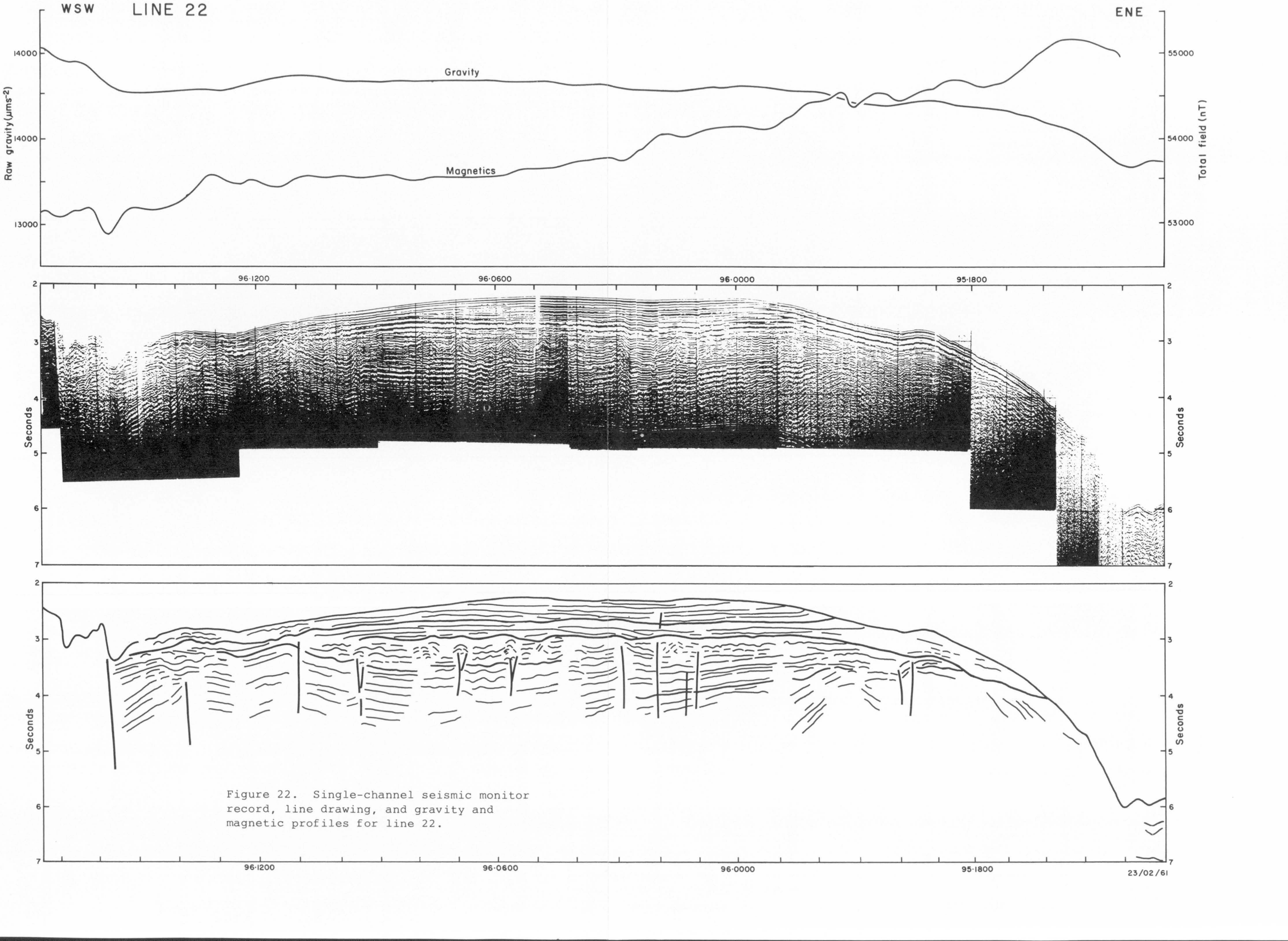


Figure 22. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 22.

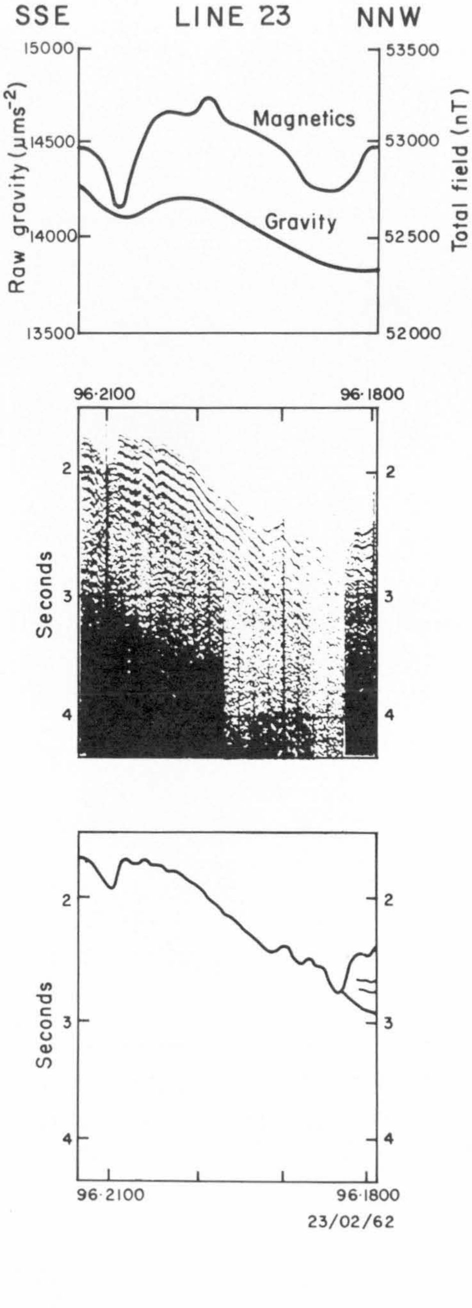


Figure 23. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 23.

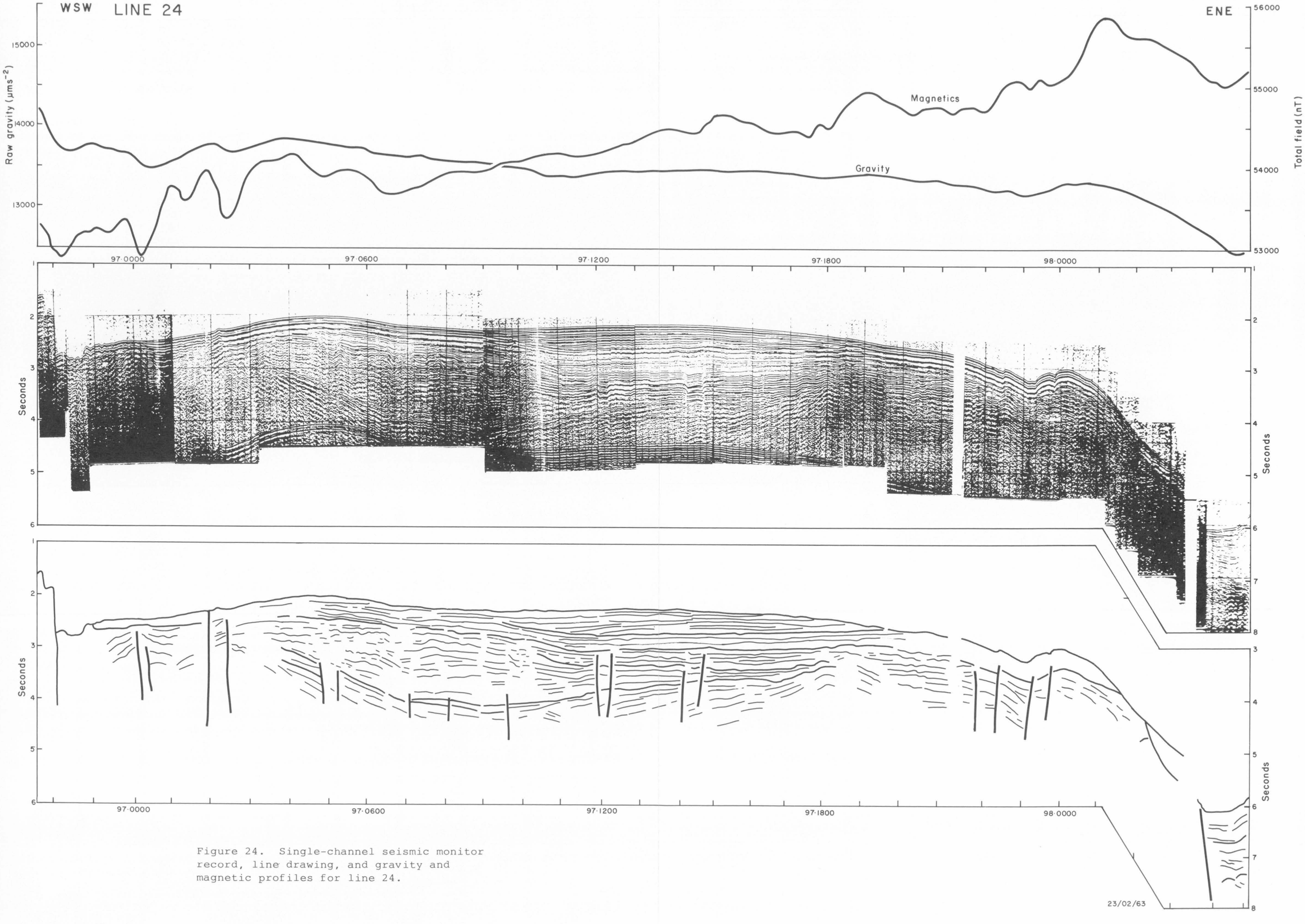


Figure 24. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 24.

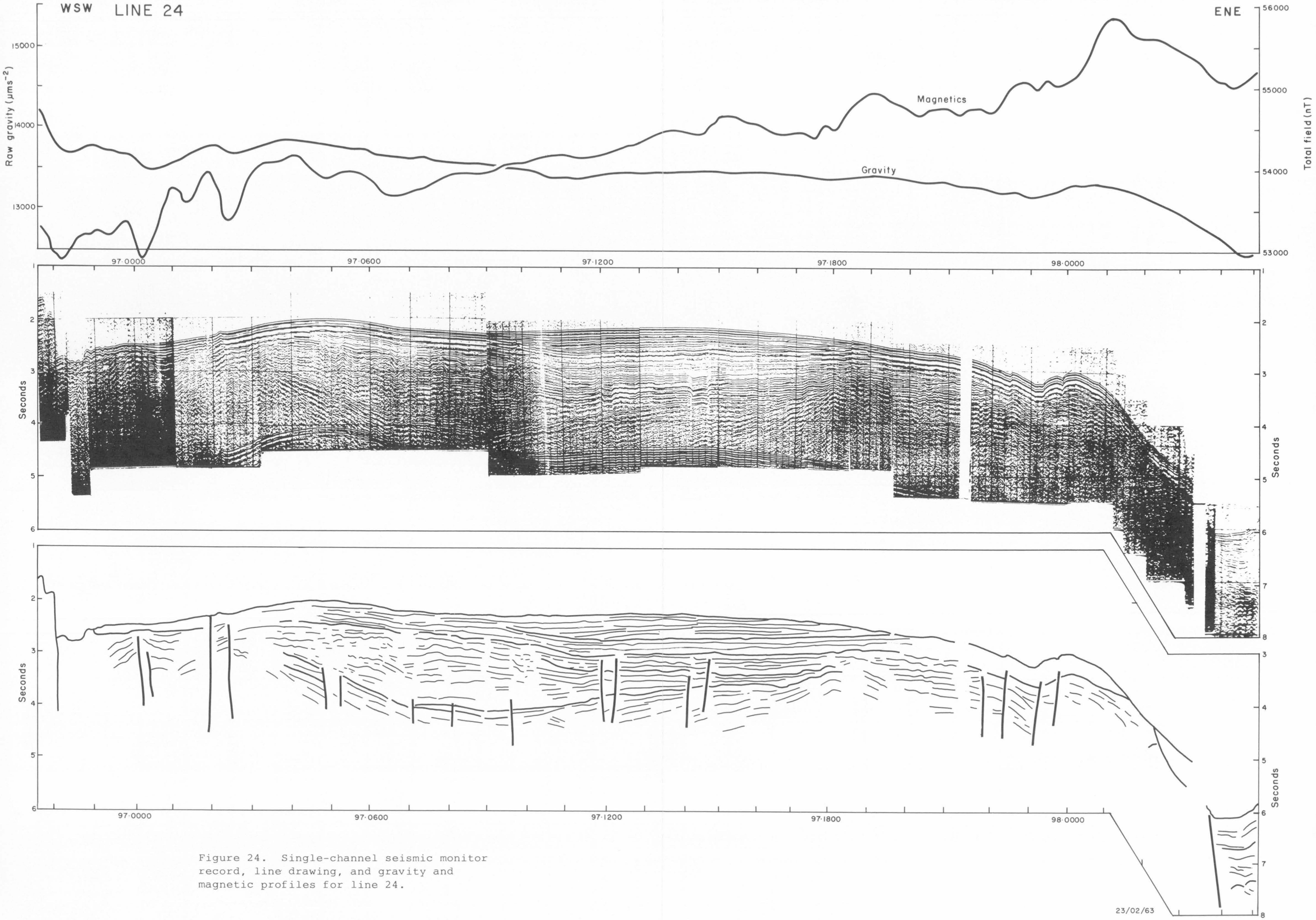


Figure 24. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 24.

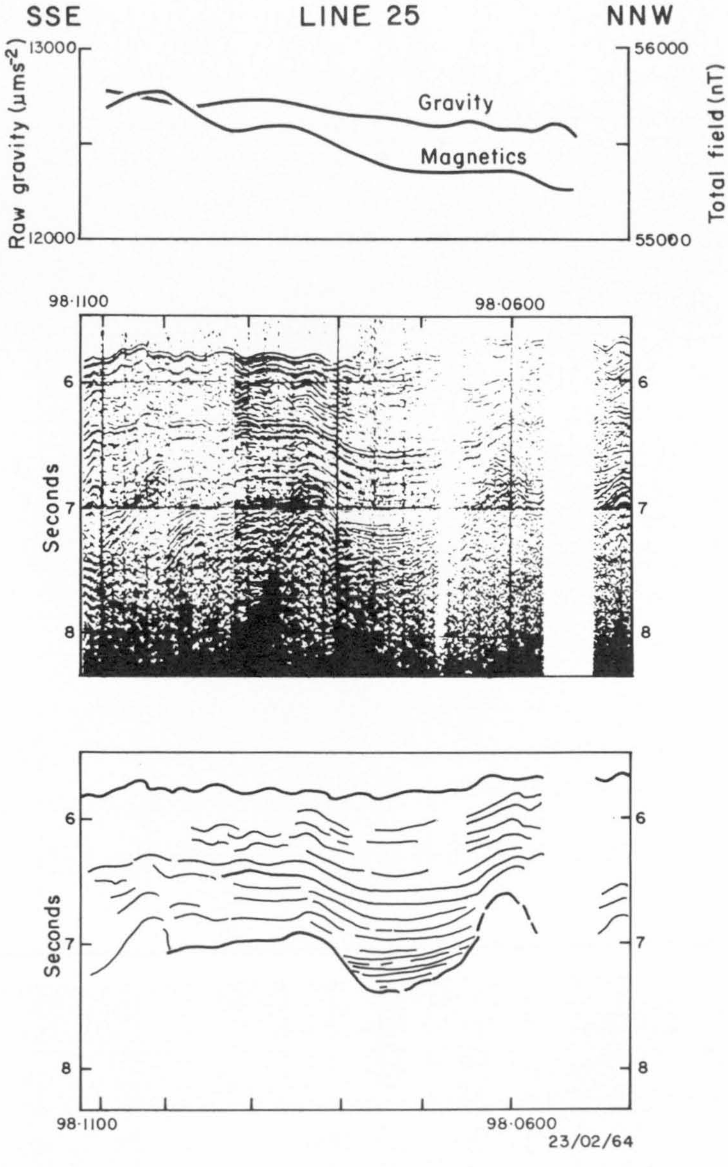


Figure 25. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 25.

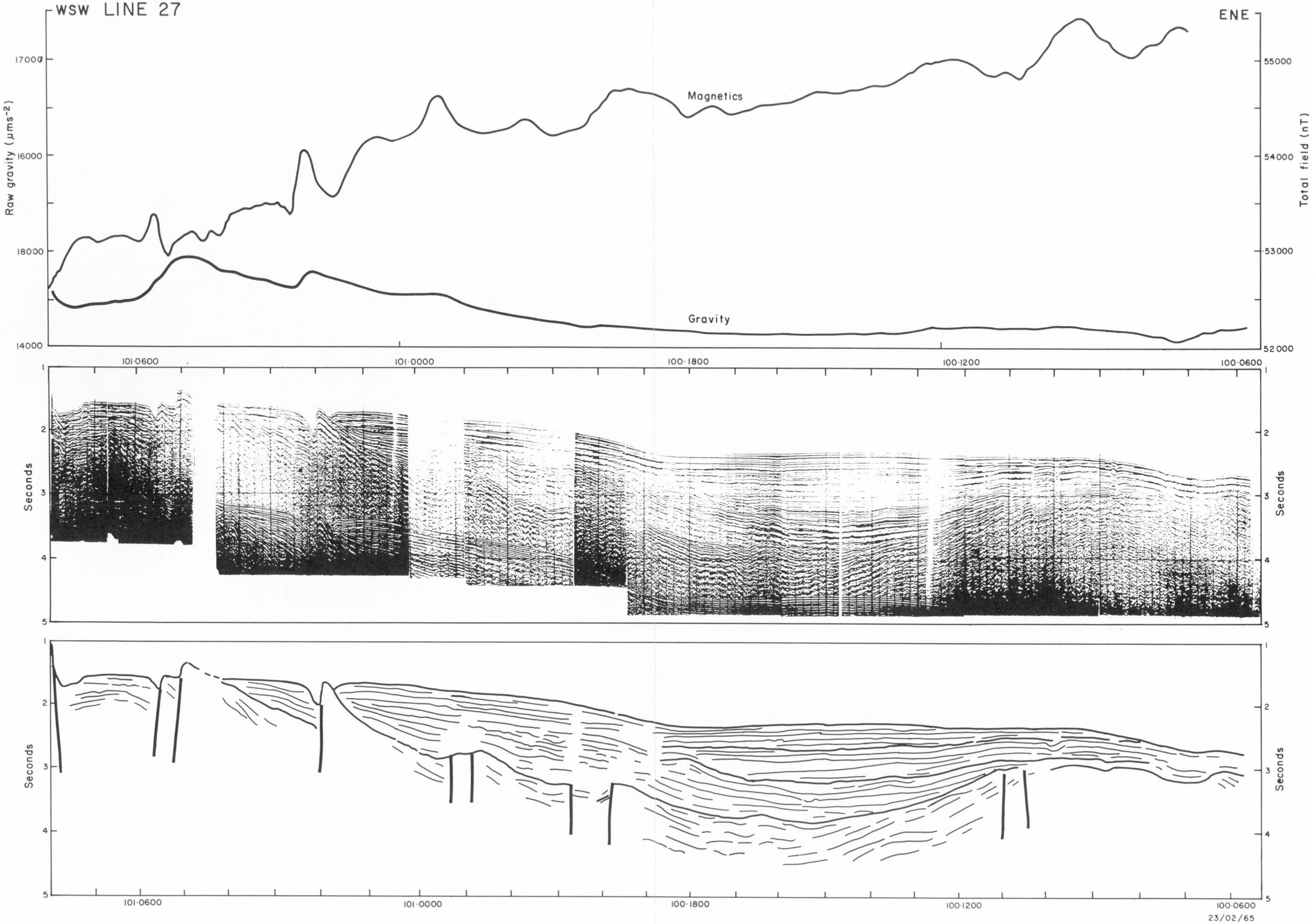


Figure 26. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 27 (east).

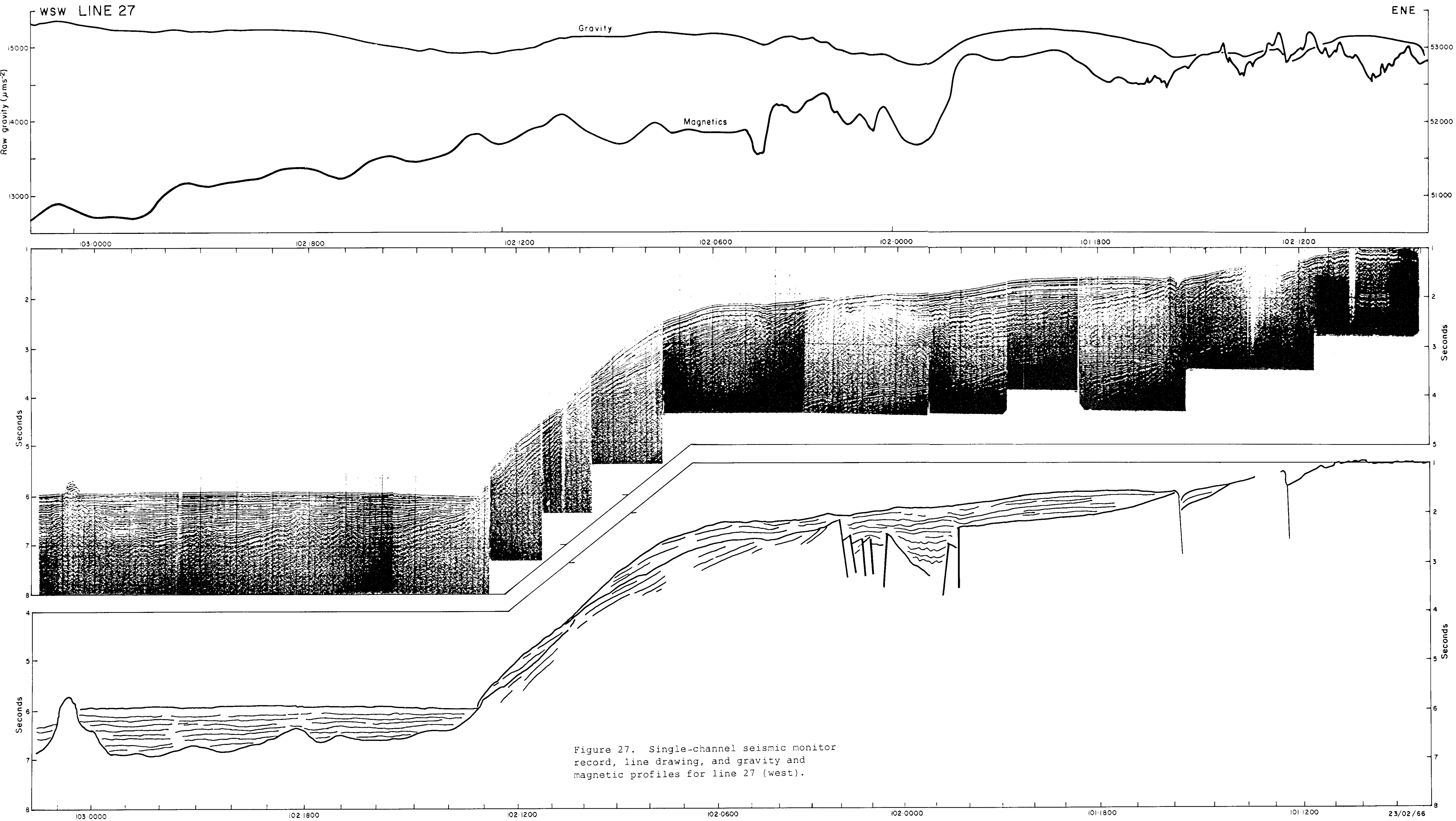


Figure 27. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 27 (west).

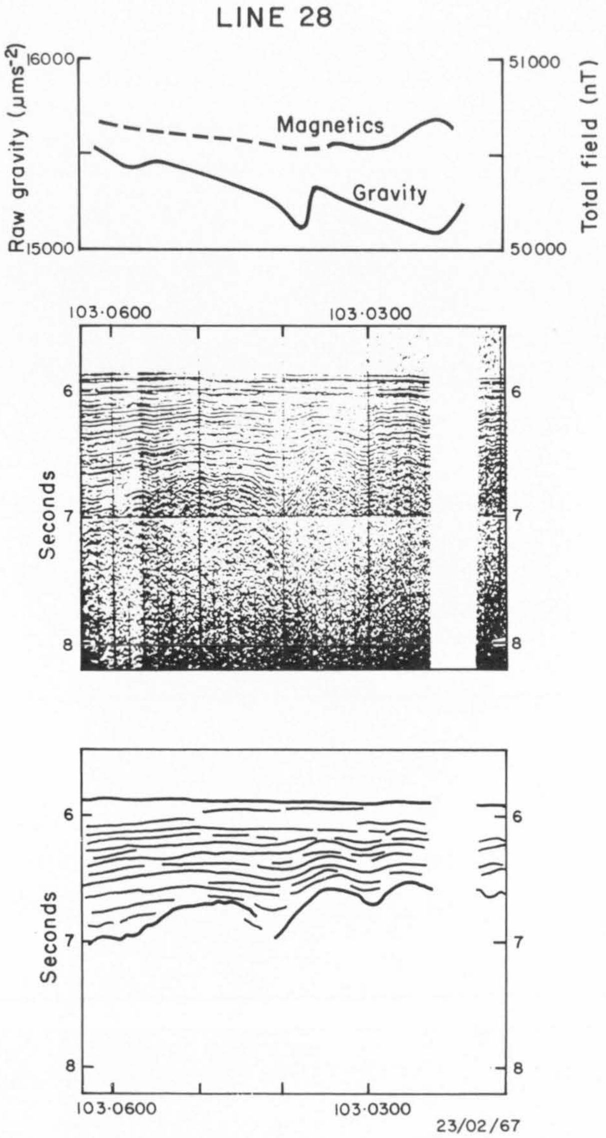


Figure 28. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 28.

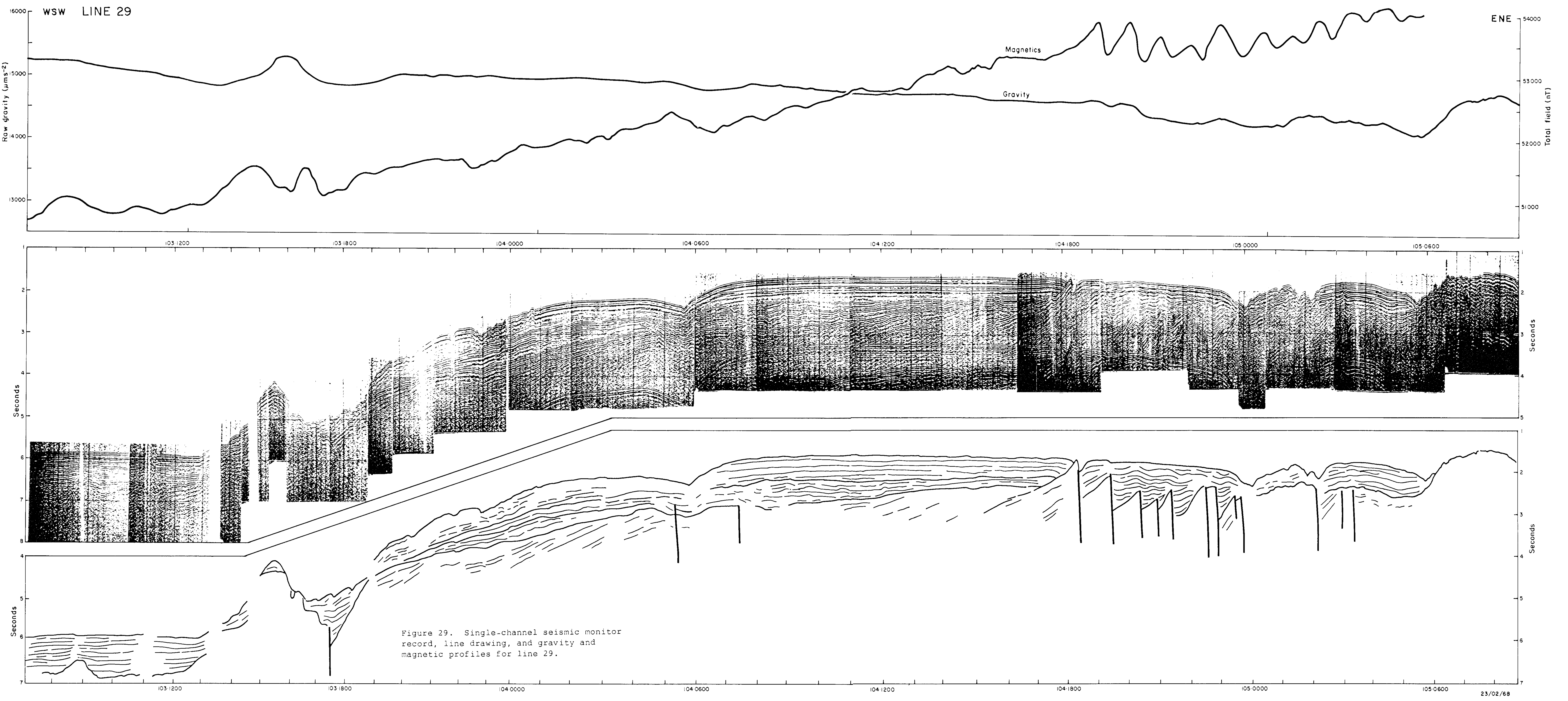


Figure 29. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 29.

Figure 30. Single-channel seismic monitor record, line drawing, and gravity and magnetic profiles for line 33.

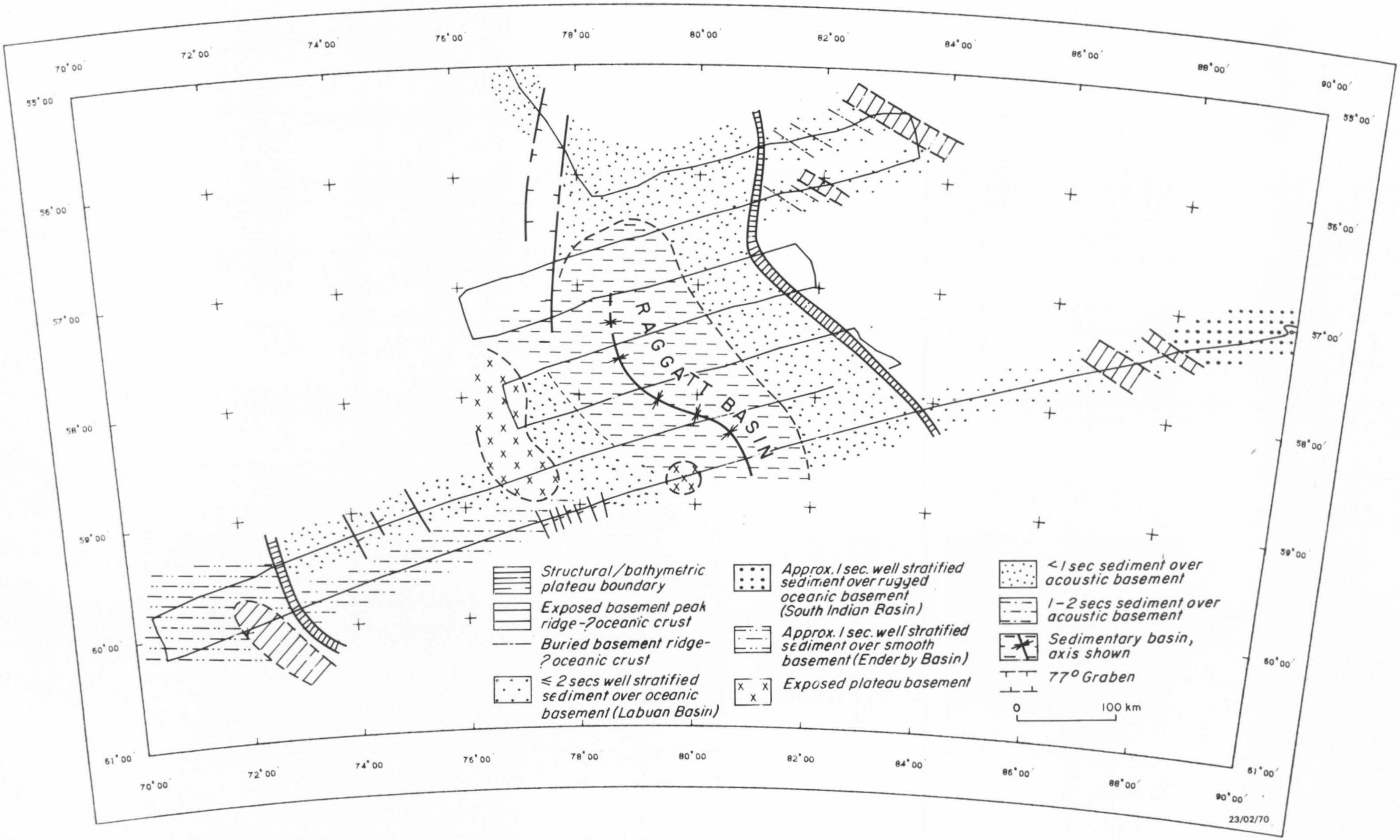
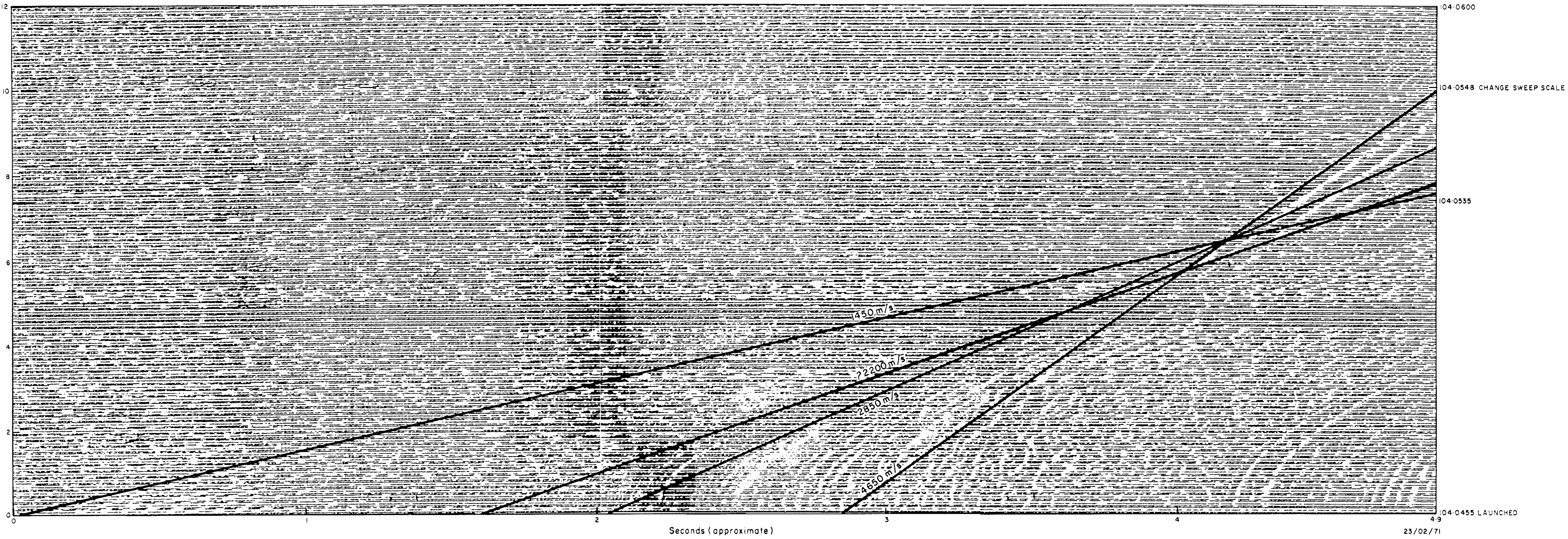


Figure 31. Structure map of southern sector of kerguelen Plateau.



POSSIBLE SOLUTION

Layer velocity (m/s)	Thickness (m)
1450	1550
?2200	350
2850	940
4650	

Figure 32. Sonobuoy refraction solution.

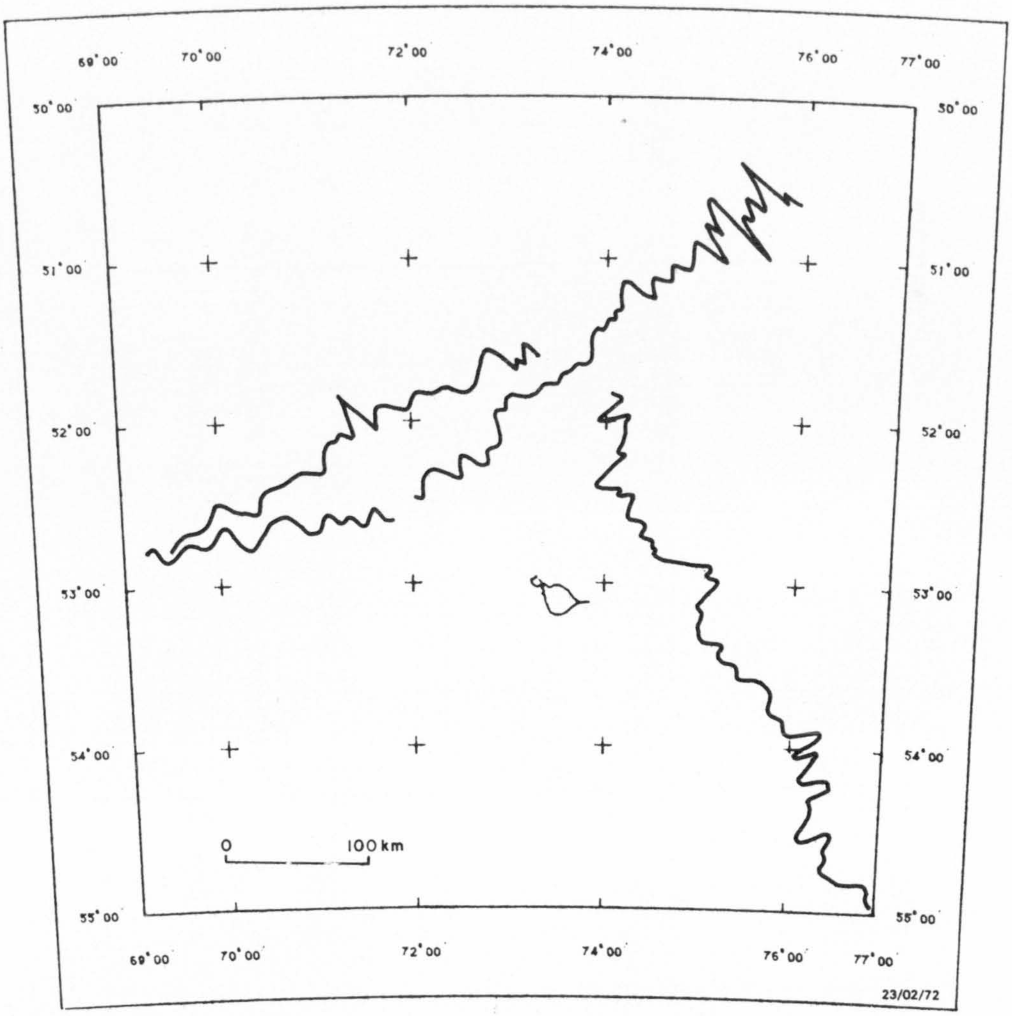


Figure 33. Magnetic profiles - northern sector.

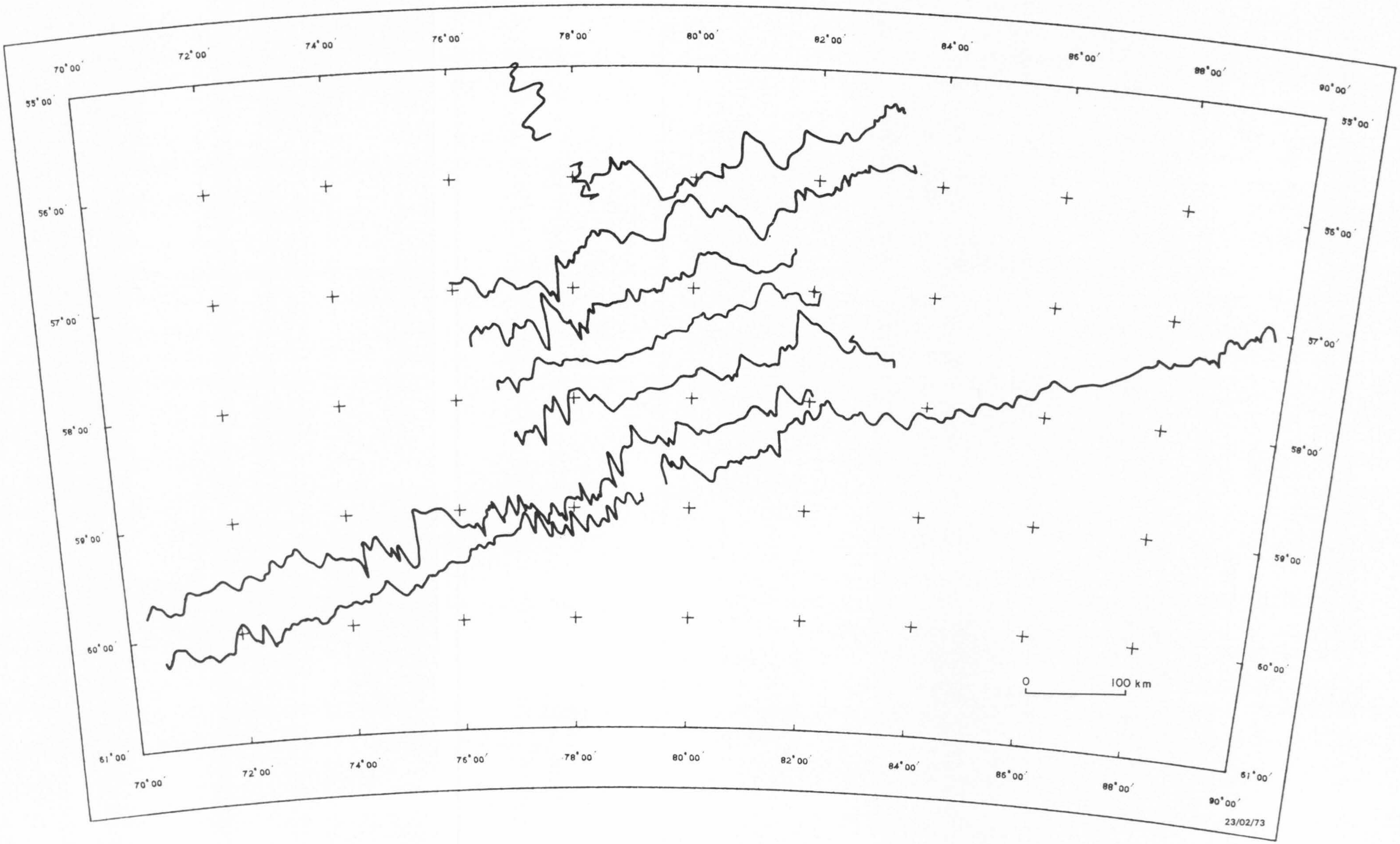


Figure 34. Magnetic profiles - southern sector.

Figure 35. Magnetic profiles - Southern Ocean transits.

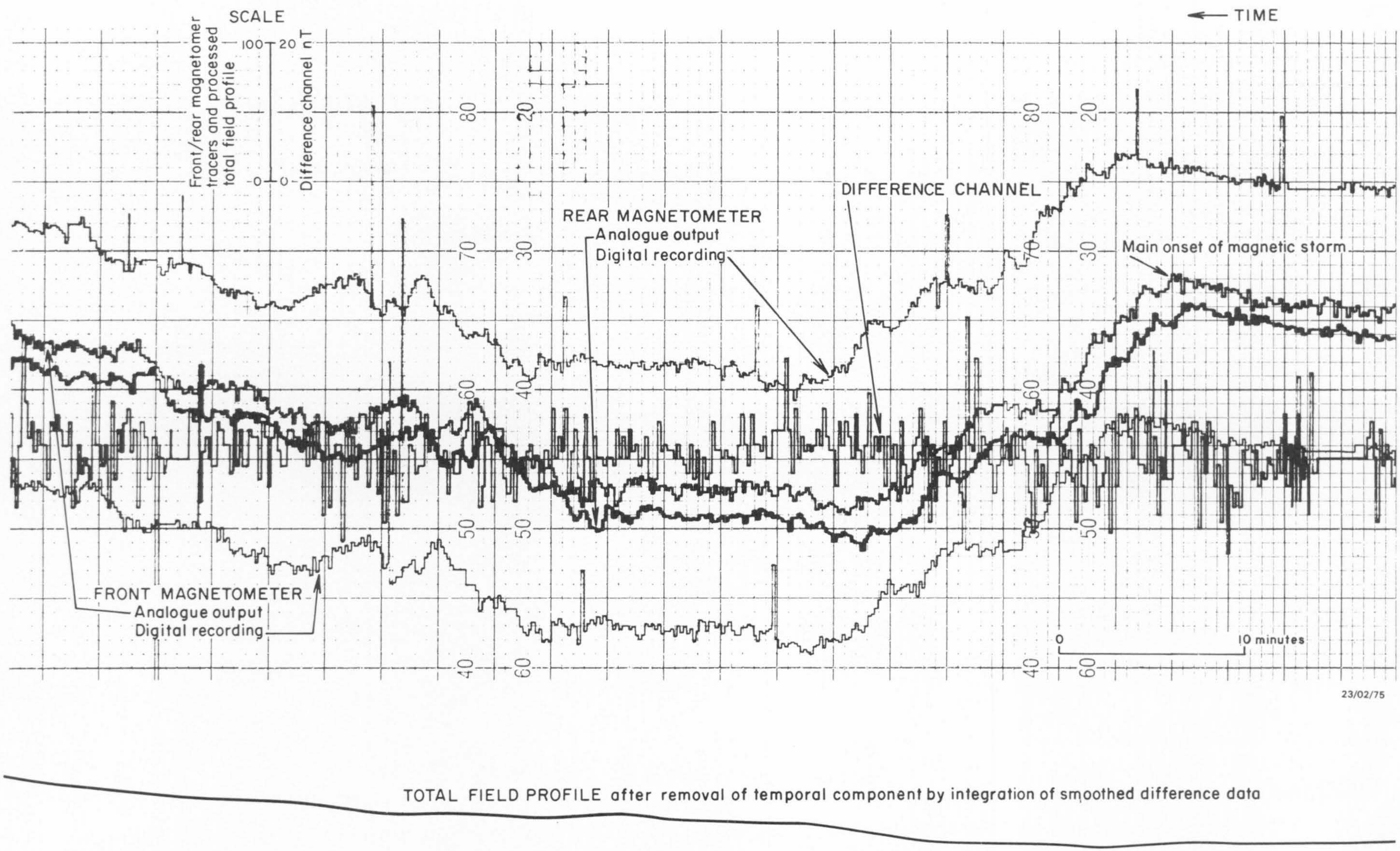


Figure 36. Magnetic gradiometer record.

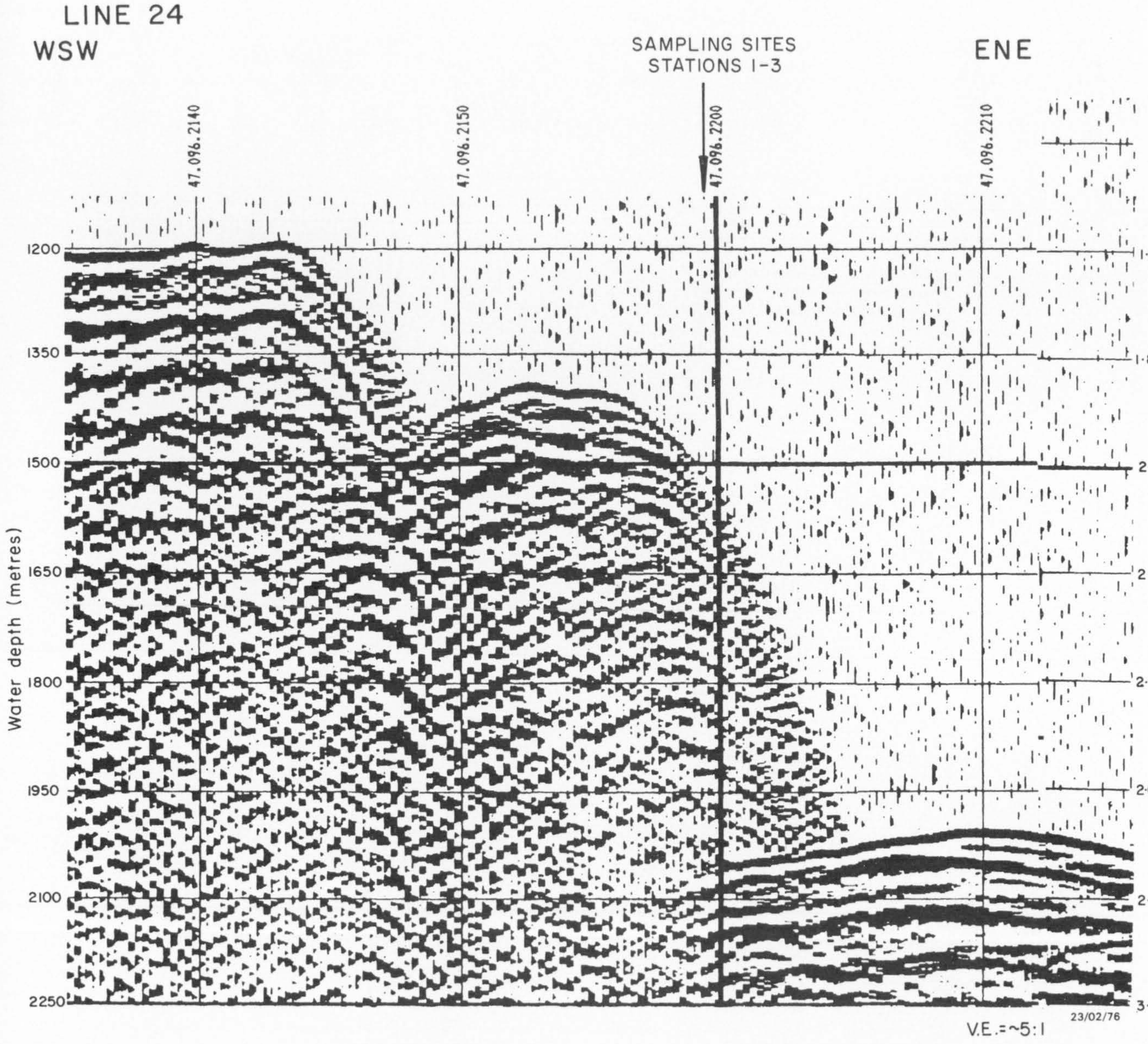


Figure 37. Single-channel seismic monitor record showing location of sampling sites.

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