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A Survey of the Vertical Component of the Seismic Noise on the Falkland Islands
(UK UNCLASSIFIED)

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SUMMARY

To improve the detection and location of seismic disturbances in the southern hemisphere further recording stations need to be installed in that area. To obtain a more even geographical distribution, new stations will need to be located on islands which unfortunately could have high seismic noise levels due to microseisms generated by the surrounding ocean. A potential site is the Falkland Islands and a survey to establish the level of the vertical component of the noise was conducted there between 2nd and 12th December 1988.

A base station was operated continuously during the survey to provide conventional short period and long period paper chart recordings.

A portable digital recording system was operated sequentially at five widely spread locations on East Falkland and at a site on West Falkland. Spectra of ground motion in the frequency range 0.2 to 30 Hz from these sites show the variation in seismic noise due to wind speed and cultural activity. Whereas the ratio of the power spectral densities of the ground motion varies by less than a factor of 4 at 1 Hz, it can vary by a factor of 30 at 3 Hz and 100 at 20 Hz.

The amplitude of the short period noise level was determined to be between 15 and 28 nm (peak-to-peak) at 1 Hz corresponding to a 50% teleseismic detection level of ~ m_b = 5.0. The long period noise was found to be ~ 50 nm at 20 s period corresponding to a 50% detection level of M_s ~ 3.0 for events at a distance of 30°. These results indicate that a permanent seismic recording station located on the Falkland Islands could provide useful data to improve the detection and location of seismic disturbances in the southern hemisphere.

1. INTRODUCTION

Most of the seismograph stations in the world are located in the northern hemisphere with the result that the detection threshold for seismic disturbances in the northern hemisphere is much lower than for those in the southern hemisphere. The UN Ad Hoc Group of Scientific Experts (AHGSE) which meets in Geneva to consider co-operative measures to detect and identify seismic disturbances has repeatedly called for the establishment of more seismograph stations in the southern hemisphere particularly in areas such as Africa and South America to provide a more uniform detection capacity for the whole world.

It is possible to simulate networks of seismograph stations and predict the detection capacity of such networks. Studies of this nature have been conducted by the AHGSE but to be of value they require a knowledge of the ambient seismic noise level in the area of sites for possible stations. For many regions of the earth, particularly in the southern hemisphere, the ambient noise level has to be assumed because there are no observations. Confidence in simulation studies would be greatly improved if observed noise data were available. The shortage of observed seismic noise levels in the southern hemisphere is due largely to the fact that much of the hemisphere is covered by vast oceans which makes seismometer emplacement difficult and expensive. The alternative to deploying ocean bottom seismograph systems is to make use of stations installed on oceanic islands. However the ambient noise level on oceanic islands is generally very high and only the seismic waves from the largest of seismic sources are detected. This is particularly true of small islands and of atolls. However despite their high noise levels stations located on atolls or other oceanic islands in seismically active areas may provide useful additional data on seismic sources located at local or even regional epicentral distances.

One group of islands which could be of value in monitoring the seismically active areas of the South Atlantic including the South Sandwich Islands region are the Falkland Islands. The Falkland Islands are not atolls and are believed to be underlain by a continental crustal structure and for this reason it is possible that the noise levels are considerably lower than that observed on small oceanic islands and atolls. Because of the difficulty in estimating what the noise level is on the Falkland Islands it was considered to be worthwhile to conduct a seismic noise survey on the islands. The results would be informative and could be used to improve the quality of the AHGSE simulation studies.

A seismograph station on the Falkland Islands could be used to collect data on sources located almost anywhere in the southern hemisphere given that the seismic wave amplitudes are greater than the background noise. Figure 1 shows a map centred on the Falkland Islands with circles of different radii. These radii show the area covered out to distances of 15^{o} (regional), 30 to 90^{o} (teleseismic) and the PKP focus, the range between 140 and 145^{o} at which large P-wave amplitude may be recorded.

The detection capacity of both body and surface waves from these areas can only be determined once the ambient noise levels are known. This report gives an account of the experimental procedure used during a seismic noise survey and a summary of the short period noise spectra in the range 0.2 to 30 Hz and long period (T ~ 20 s) noise levels observed on the Falkland Islands.

2. GEOGRAPHY AND GEOLOGY OF THE FALKLAND ISLANDS

The Falkland Islands (approximately 60^{o} W, 52^{o} S) consist of two main islands, East Falkland and West Falkland with over a hundred smaller islands. They lie about 500 km east of the Straits of Magellan. West Falkland is about 130 km long and 70 km broad and the highest point on the island is Mount Adam which is 698 m high. East Falkland is 166 km in length and 80 km wide. It is separated from West Falkland by the Falkland Sound which is up to 40 km wide. Mount Usborne, 685 m, is the highest point in East Falkland.

The islands have a rather low relief with the hillier parts mainly in the north. They have a highly indented coastline with bays and inlets extending a long way inland. There are sea-cliffs on much of the coast.

The climate is cool, wet and very windy, but there is no permanent ice. The vegetation consists mainly of tussocky grass and the islands are virtually treeless. Large areas of the islands consist of peaty, saturated moorland which makes cross-country movement difficult.

The total population is a little over 2000, of which over half live in Stanley, the only town on the islands. There is a small airport at Stanley which is also the location of the main harbour and there is a new airport built to take large aircraft located to the west of Stanley in the Mount Pleasant area.

From the ocean bathymetry the Falkland Islands appear to be part of a continental shelf connected to the east coast of South America. Whether the Falkland islands are actually part of the continent of South America however is in doubt. The latest view is that the Falkland Islands are a microplate. Palaeomagnetic evidence indicates that the Falkland Islands were formerly situated adjacent to the Transkei area of South Africa (Mitchell et al, (1)). During the Jurassic, when Antarctica separated from southern Africa the Falkland Islands moved as a microplate some 500 km south-east of Cape Town and during the opening of the South Atlantic the Falkland Plateau, with the islands, drifted to their present position having undergone a total rotation of about 180°.

The rocks range in age from Lower Devonian to Upper Triassic and there is a small outcrop of Pre-Cambrian rocks at Cape Meredith in the south of West Falkland. The Pre-Cambrian rocks consist of crystalline gneisses and schists. The Upper Palaeozoic and Lower Mesozoic rocks are mainly mudstones, sandstones and conglomerates. They are thoroughly indurated and have been intruded by many dolerite dykes. In West Falkland the strata are folded with axes parallel to the east coast and in East Falkland the axes of folding are more nearly east-west.

3. SITE SELECTION PROCEDURES

The ambient seismic noise level at a location is measured using seismological recording instruments. Historically the required signal frequency bandwidth is 0.01 to 10 Hz split into two conventional bandwidths of 0.02 to 0.06 Hz (Long Period LP) and 0.5 to 10 Hz (Short Period SP). Recently much interest has been shown in the band of higher frequencies 10 to 50 Hz (High Frequency HF). This is because it has been suggested (Evernden et al, (2)) that spectral ratios based on HF recording can be used to discriminate between decoupled explosions and earthquakes. At present the technique is unproven but it is desirable to determine the availability of good HF sites. Only at a few stations such as those at Lajitas, Big Bend Texas, USA (Herrin (3)) and near Oslo, Norway (Bungum et al (4)) has the noise level been measured up to at least 50 Hz. For LP noise, experience has shown that the noise levels are roughly constant over most of the earth in contrast to the noise levels in the SP and HF bands which are sensitive to both cultural and wind generated noise. Ideally seismological stations should be sited on massive igneous or metamorphic rocks or on well consolidated sediments. Layered volcanics or unconsolidated sediments should be avoided if possible. It is important to be as far away as possible from seismic noise sources such as railways, roads, pipelines, lakes etc. Flat terrain or low relief with an absence of trees is also desirable to reduce the amplitude of the HF noise caused by the effects of wind on trees or other tall thin structures.

With these factors in mind a survey was carried out using two separate systems. A SP-LP system at a base station and a mobile SP-HF system which is readily transportable so that variations in SP-HF noise could be determined at different locations on the Falkland Islands.

The base station was essential for the following reasons:

(a) To allow the instrument to become thermally stable which required a few days of undisturbed operation and so record the long period signals.

(b) To provide a continuous record of noise for the period of the survey against which noise levels at other sites could be compared.

(c) To act as a reserve to enable some assessment of the noise to be made if some mishap occurred with the portable equipment.

Every attempt was made to select survey sites using the procedures described above but because of the difficulties of access only the survey locations given in figure 5 could be visited. Detailed inspections were made at each location to find the best position to emplace the seismometer.

4. RECORDING SYSTEMS

The two battery powered systems, SP-LP and SP-HF, were designed and developed at AWE Blacknest. Block diagrams of the systems are given in figure 2 and a list of the equipment and packaging is given in table 1.

4.1 Base station recording system

The transducer and electronic circuits are essentially those of a single channel of the Blacknest borehole seismometer system (Burch (5)) and provides analogue signals in the broad-band (BB) and long period narrow band (LPNB). The LPNB signal is directly recorded on a Geotech helicorder modified to operate on 12 V car batteries. A second, similar helicorder, is used to record signals in the SP band. This signal is obtained by filtering the BB signal using a two-pole high-pass filter to simulate a 1 Hz seismometer.

The response curves of the SP and LPNB seismographs are given in figure 3. The poles and zeros of the responses are listed in table 2.

4.2 Portable digital recording system

This system is designed around the SSMA-1000 strong motion digital accelerograph commercially available from Sensonics Ltd, Chesham, Bucks, UK. A microcomputer controls the recording of digital data into a 2 Mbyte RAM cartridge at a sampling rate of 100 sps. For the purposes of the noise survey the accelerometer provided was replaced by a Willmore Mk II SP seismometer and UK type array sender (Mowat & Burch, (6)) to provide amplified analogue input signals to the digital recorder.

The Sensonics system has a flat response from ~ 0.1 to ~ 32 Hz with a four-pole Butterworth antialiassing filter. To achieve a response that is flat to ground velocity from 1 to 32 Hz, the single pole at ~ 7 Hz in the standard UK type array sender was moved to 32 Hz, and a further two-pole low-pass filter at 32 Hz was added to produce a seven pole Butterworth antialiassing filter along with a switched gain amplifier stage with gain between 1 and 100. The response curve is given in figure 4 and the poles and zeros are listed at table 3.

In addition to providing continuous recording the system can be set to record for up to ten preset recording times. Typically, after installation, the recorder can be set to record for ten periods of 30 s duration at intervals of 1 min. At this rate the RAM cartridge can be used to obtain noise samples from 14 separate locations. After recording, any data file can be replayed in the field and displayed on the LCD screen of the microcomputer. A small battery-powered printer can be used to provide a paper record which can be useful for documentation purposes and subsequent analysis after the noise survey has been completed. The digital data can be processed wherever mains power is available. A Hewlett Packard HP85 computer and disc drive unit is used to transfer the digital data from the RAM cartridge onto floppy disc files. Due to the limited storage capacity of the HP85 only 5 s of data can be processed at any one time. A suite of computer programmes is provided that can be used to display the data in the time domain, perform fast Fourier transforms, average the spectra of the ten files recorded at any one location and deconvolve the spectra using the system response to produce spectra in terms of ground acceleration or ground displacement. Paper copies of all these processes are available as optional outputs from the HP85 and the data are stored on disc for each stage. This makes it possible for results to be made available rapidly so the field team are assured of the data quality before surveying further sites. High quality graphics can be readily made on return from the field by replaying the processed files using higher resolution devices.

5. OPERATIONAL DETAILS OF THE SURVEY

The survey was carried out by P G Robinson and T Budd of Hunting Engineering Ltd between 30th November and 15 December 1988. For the first week they were accompained by Col Blakiston, Senior Army Representative at AWE(A) who liaised with the staff at RAF Mount Pleasant where the team had accommodation.

The base station was established at a distance of approximately 1½ km from the living quarters on 1st December and provided continuous chart recordings from 1st to 12th December. This site was visited each day to change the SP chart (the LP was changed every third day).

Between 3rd December and 7th December six further sites were visited and recordings were made using the portable digital equipment. Every effort was made by the survey party on the Falkland Islands to follow the procedures described in section 3 but on most occasions it proved difficult to find good sites due to extensive weathering and an uncertainty that the rocks were part of the bedrock and not just large boulders. It is not easy to move around the island because there are few roads and off the roads the land is covered with peat and vehicles can easily become bogged down. To make travel easier RAF Mount Pleasant provided transport for the survey party and equipment to a few remote locations using four wheel drive vehicles and helicopters.

A map of the Falkland Islands showing the location of the sites is shown in figure 5. The co-ordinates, times of the survey and wind speed are listed in table 4.

5.1 Mount Pleasant Airport

It had been decided in advance that a base station should be sited near to the survey party's accommodation at Mount Pleasant Airport (MPA) so that it could be visited frequently with the party being independent of the availability of special transport. The site chosen was on a rocky outcrop in a fairly flat field of tussocky grass approximately 1 km from the top of the Mount Pleasant ridge towards the main runway (see figure 6). It was about 0.5 km from the road leading to a quarry and 1 km from the nearest buildings.

The noise levels quoted for this site are measured from the Helicorder charts. It had been planned to make SP measurements at this site identical to those made at the other locations so that a direct comparison on the SP noise spectra could be made. Unfortunately due to a technical problem with the digital recorder which could not be resolved before the survey party departed these measurements were not made.

5.2 Dougherty's Shanty

This is the name given to a deserted dwelling located approximately 30 kms NW of MPA close to the centre of the East Falkland Island. This site was visited by helicopter. A few long-horned cattle were grazing nearby. The quality of the rock in this area is poor; however a seismometer location was selected some 400 m from the shanty but it was on a steep slope (see figure 7).

At the time of the survey the average wind speed was 3 mph. A small virtually stagnant stream was situated some 6 m from the seismometer but it was felt that it would not affect the seismic noise levels. The survey party regarded this site as a "last resort" in view of its remoteness, lack of convenient access and unavailability of good rock that would make a suitable site for a permanent station.

5.3 Mount Kent

Mount Kent some 15 km west of Stanley, is a steep hill 458 m high mostly covered with rocks which appear to have broken away from the peak. There is a military radar installation on the top. A suitable outcrop of rock was found amongst the loose rocks some 75 m below the peak and the seismometer was placed on the outcrop (figure 8). Like most places on the island access is difficult. For example the journey down the hill took almost an hour and was made in a pair of tracked vehicles coupled together. Mains power is available in the area but seismic noise from power supply generators and personnel could be a source of high-frequency seismic noise. At the time of the survey the average wind speed was 3 mph gusting to 7 mph.

5.4 Canada Ronde

This name is given on the map to a particular area. The site chosen for the survey lies some 15 km west of MPA and is accessible by four-wheel drive vehicles along the main track from Stanley to Darwin. Progress along the track was slow; the original intention was to survey the Darwin area but the journey was found to be too difficult and time consuming so a noise survey was made in the Canada Ronde area. As can be seen in the photograph (figure 9) the area consists of loose rubble and gently undulating terrain. A suitable site was found for the seismometer and noise measurements were made. The average wind speed was 6 mph and was blowing from a southerly direction. Although the site was situated only some 125 m from the road there is very little traffic and so the effect on the noise level would be insignificant. Canada Ronde is remote from power sources or any services.

5.5 Bold Cove

Bold Cove is also known as Packe's Port Howard and is situated on the north-east coast of West Falkland Island, and lies about 75 km NW of MPA. It is the only noise sample from the west island. This site is accessible from the East Falklands only by ship or helicopter. An aerial survey failed to find any suitable rocks within a large area surrounding Bold Cove, but a suitable site was found below high tide level on the foreshore (see figure 10). The weather was particularly bad at the time with southerly winds averaging 50 mph. The view of the survey party was that this area would not make a good permanent site logistically and is far too near the coast. A farm house with generators is located nearby but it is not near any road or services.

5.6 Mount Kent access road

This site was selected as a convenient point on the way to Mount Kent. There are numerous outcrops in the area but these are extensively weathered. The seismometer was placed about 500 m from the road on an outcrop of rock (see figure 11). The road was under construction some 1½ km from the site. The average wind speed was 33 mph. There are no services or power supplies available in the immediate area. The survey party felt that this was not a suitable location for a permanent station.

5.7 Bluff Cove

The seismometer was sited on an outcrop near the road to Stanley, which lies about 20 km to the NE. The outcrop and road are clearly visible in figure 12. At the time of the survey it was wet and blustery with an average wind speed of 12 mph gusting to 25 mph. The seismometer was located about 150 m from the road; several vehicles per hour use the road and like most locations on the Falkland Islands there is little in the way of logistical services in the area.

6. RESULTS

6.1 Digital recordings from six remote sites

A direct replay of two samples of the recordings from Dougherty's Shanty is shown in figure 13 and for comparison figure 14 shows similar pairs of samples for the recordings taken at Bluff Cove. From these figures it can be seen that whereas LF microseism noise is comparable the HF noise is dramatically different.

The samples of digital recordings were processed as described in section 4 and the resulting ground motion spectra are shown in figures 15 to 17. For each figure the spectra are shown in two bandwidths, 0 to 30 Hz and then expanded to 0 to 4 Hz (for all results the value at DC, ie, 0 Hz is meaningless and has been ignored; the lowest frequency point is 0.2 Hz). All spectra have been converted to remove the system response to give ground acceleration power density expressed in terms of $(m/s^2)^2/Hz$.

The spectra for all six sites is shown superimposed on figure 15. From these plots it can be seen that although the noise variation between sites is only ~ 4 at 1 Hz at higher frequencies the variation increases to a factor of 100 at 20 Hz. It can be noted that in the frequency band 5 to 10 Hz the spectra appear to separate into three distinct noise levels. However for ease of annotation the six spectra have been split into the three quietest sites and the three noisiest sites and are illustrated in figures 16 and 17 respectively.

The quietest site at all frequencies was Dougherty's Shanty closely followed by Canada Ronde which was only slightly noisier at frequencies above 13 Hz. Both these sites are remote from cultural noise and were recorded at a time of low wind speed (3 and 6 mph). The noisiest site (especially at the higher frequencies) was found to be Bluff Cove. Although the wind speed at the time of recording was only moderate (12 to 25 mph) this site is near a road with regular vehicular traffic.

The noisiest site in the 1 to 5 Hz band was found to be Bold Cove (the only site on West Falklands). However conditions were particularly bad at this site situated on the shore below high water mark with 50 mph wind and a farmhouse with a power generator located nearby.

Differences in the spectra due to the effects of cultural and/or wind noise can be seen by comparing the spectra of the two average noise sites - Mount Kent, and Mount Kent access road. These spectra are reproduced for comparison as figure 18 and show that,

From 0.2 to 2 Hz the noise for both sites is identical.

From 2 to 4 Hz the noise from Mount Kent access road is greater.

From 4 to 30 Hz the noise from Mount Kent is significantly greater.

Whereas the wind speed at Mount Kent was only 3 to 7 mph it was 33 mph at Mount Kent access road.

Choosing the centre of the band where the windiest site was noisiest (at 3 Hz) reference back to figure 15 shows that the six sites have separate noise levels. They are shown plotted against windspeed as figure 19 and can be seen to correlate well with increasing wind speed from Dougherty's Shanty at 3 mph to Bold Cove at 50 mph. It would appear that the noise at all sites would be ~ 10^{-14} $(m/s^2)^2/Hz$ at 3 Hz in the absence of wind.

The increased noise level of Mount Kent over Mount Kent access road at frequencies above 8 Hz can be explained by cultural activity. The Mount Kent site was located within a few hundred yards of a manned military installation. Careful examination of the ten separate spectra taken at one minute intervals at this site reveals that peak amplitudes at frequencies of 22.6, 23.8 and 25 Hz were obtained on most runs with the relative amplitudes at these frequencies varying between samples. The sum spectra shows a peak at each of these frequencies. Although Mount Kent access road was distant from the military installation it was only 1.5 km from earthmoving equipment that was engaged in constructing the access road. Perhaps this explains the large peak at 24.3 Hz.

The average ground acceleration power density around 20 Hz is plotted against wind speed for all six remote sites as figure 20. From this figure it can be seen that although the 20 Hz noise increases with wind speed as shown by the line drawn to the plot, two sites - Mount Kent and Bluff Cove have anomalously high noise levels. As stated earlier Mount Kent is very close to sources of cultural noise and Bluff Cove is at the side of a frequently used road. This plot suggests that in the absence of both wind and cultural noise all sites would have a noise level of $\sim 10^{-14}$ $(m/s^2)^2/Hz$, ie, the same level as at 3 Hz in the absence of wind alone. Figure 15 shows that for the quietest site the noise spectrum is essentially flat between 2 and 20 Hz.

With hindsight it is unfortunate that further recordings could not be made at some of the sites under different wind conditions, eg, at Dougherty's Shanty on a windy day or at Bold Cove on a calm day. Analysis of such recordings may have enabled the hypotheses of wind and cultural noise to have been proved.

6.2 SP and LP seismograms

The system operating at the base station produced a SP helicorder chart recording each day and an LP recording every three days. A sample of each is shown as figures 21 and 22 respectively.

The SP recording shows predominently LF noise with a marked absence of noise at frequencies greater than 1 Hz. To be consistent with other conventional recording systems the response was deliberately chosen to be standard. However it can be seen from this figure that the detection of body waves from earthquakes and other sources could be significantly improved by the addition of a high pass filter to reject the ocean induced low frequencies. This would enable the system to be operated at a higher gain.

The LP recordings are typical of high gain narrow-band surface wave recordings. The system should be capable of detecting very small surface wave trains (see number 2 in figure 2). In common with most high gain LP systems it was found that few of the Rayleigh waves detected could be related to hypocentres reported by the National Earthquake Information Center (USA) (NEIC), Preliminary Determination of Epicentres (PDE) service.

7. CALCULATIONS

7.1 SP and LP helicorder recordings

From these time-domain measurements an estimate of the seismic noise can be obtained using a "percentage of occurrence" method. The technique used was to measure the peak-to-peak amplitudes of all noise at the specified frequency (1 Hz for SP, 0.05 Hz for LP) over a period of time in which no earthquake signals are recorded. Some 100 or more recordings are made and put into cells of different amplitude ranges. The amplitude ranges are converted to ground motion amplitude ranges using the magnification at 1 Hz for the SP and at 0.05 Hz for the LP. Starting with the lowest amplitude cell a cumulative total is made for each cell and the resulting total is plotted using linear/log paper to give the percentage of occurrence against ground amplitude. These plots are frequently termed "S" curves. These calculated curves are shown as figure 23 from which the 50% level is seen to be 24 nm peak-to-peak for SP and 50 nm peak-to-peak for the LP. Given this background noise level teleseismic disturbances of m_b5.0 or greater should be seen on the SP recordings. Examination of the NEIC PDE lists showed few seismic disturbances of m_b5 or greater within 90° of the Falkland Islands during the recording period. However during this period only one disturbance occurred that should have been recorded above the background level. This disturbance, with an $m_b = 5.4$ was detected and is located in the SW Atlantic about 30° from the Falkland Islands, the P wave is illustrated in figure 24. Only one or two local disturbances were detected. The largest of these occurred some 2° from Mount Pleasant. The LP 20 s period 50% noise level of ~ 50 nm's peak-peak amplitude is the noise level to be expected at good LP sites and is similar to the 20 s noise observed in the UK on a quiet day.

7.2 Spectra from remote sites

7.2.1 Comparison of spectra with that of a UK site

A comparison is shown as figure 25 for the noise spectra observed on the Falkland Islands with a typical spectra from a UK site (Wolverton, Hants). The spectra from the quietest (Dougherty's Shanty) and noisiest (Bluff Cove) sites are plotted with spectra obtained during the day at Wolverton (1000 Z) and at night (0400 Z). It can be seen that at frequencies below 1 Hz the Falkland Islands noise is higher than that observed in the UK. This confirms the high level of the predominently 6 s microseisms as mentioned above in section 6.2 which would require the addition of a high-pass filter to improve detection of body wave signals. Above 1 Hz at the quietest site the Falkland Islands noise appears to be very similar to the spectrum obtained during the night at Wolverton.

Referring to the Wolverton spectra two points to note are:

(a) For all the day and most of the night the noise spectrum is similar to the day value - only for a few hours around 0400 Z does the amplitude of the spectrum drop to the night value. There is a main road nearby which passes the site at a distance of 1 km and it is late night and early morning traffic that causes this effect.

(b) There is a constant noise peak at 15.5 Hz. This is probably due to a water pump or similar machinery possibly connected with the farm located nearby.

7.2.2 Comparison of spectra at 1 Hz with SP helicorder recordings

Berckhemer (7) suggests that a method of presenting a uniform value for the noise from spectral data in the frequency domain and visual recordings in the time domain is by calculating the power in a bandwidth of one third of an octave. For a centre frequency of 1 Hz this corresponds to a bandwidth of 0.89 to 1.12 Hz.

Calculations were made on the spectra as follows. The values available in terms of acceleration power density are at 0.8, 1 and 1.2 Hz. These were first converted to displacement power density by dividing by ω^4. The values of 0.89 and 1.12 were then calculated by extrapolation and the total area in the band calculated to give displacement power. Taking the square root and conversion using $2\sqrt{2}$ gives the following values of peak-to-peak amplitude for the six remote sites:

Dougherty's Shanty	15 nanometers peak-to-peak
Mount Kent	24 nanometers peak-to-peak
Canada Ronde	26 nanometers peak-to-peak
Bold Cove	16 nanometers peak-to-peak
Mount Kent access road	28 nanometers peak-to-peak
Bluff Cove	25 nanometers peak-to-peak

The mean noise level is 22 nm peak-to-peak with a standard deviation of 6 nm.

(A similar calculation for Wolverton gives 8 nm peak-to-peak by night and 13 nm peak-to-peak by day.)

The average value of 22 nm agrees very well with the 50% level of the base station "S curve" value of 24 nm.

8. CONCLUSIONS

The seismic noise survey conducted on the Falkland Islands during the summer time (December 1988) showed that:

(a) The SP noise at 1 Hz varied between about 15 and 28 nm peak-to-peak. (An average figure of about 20 nm is equivalent to a 50% detection threshold of magnitude $m_b = 5.0$.)

(b) The noise around 3 Hz correlates with wind speed.

(c) The noise at high frequencies appears to be due to cultural noise.

(d) The average long period noise level at 20 s period (0.05 Hz) was determined as 50 nm peak-to-peak amplitude equivalent to a 50% detection level of $M_s \sim 3$ for seismic sources at a distance of 30^o.

Such noise levels suggest that a station on the Falkland Islands could provide useful data to supplement that from existing networks and so improve the detection and location of seismic disturbances in the southern hemisphere. Although the location of the base station at MPA appeared to be satisfactory for conventional SP recording it may well be necessary to use a location more remote from cultural noise to obtain the lowest available noise levels in the higher frequency range.

The possibility of installing a permanent seismograph station on the Falkland Islands is currently under investigation. In the meantime the results may prove useful to research groups and members of the AHGSE who are conducting network detection and location simulation studies. It is hoped that it will encourage other research groups or AHGSE member states to conduct noise surveys in the southern hemisphere in areas which are reasonably accessible to them.

9. ACKNOWLEDGEMENTS

The survey was carried out by P G Robinson and T Budd of Hunting Engineering Ltd; during part of which Col Blakiston (Senior Army Representative at AWE(A)) did valuable liaison work and provided much assistance. The helicorder seismograms were read by Mrs D Porter and T Hampton both of IAL Ltd. Many others, particularly service and other personnel at RAF Mount Pleasant helped in various ways to make the survey possible. The help of all who contributed to the survey is gratefully acknowledged.

REFERENCES

1. C Mitchell, G K Taylor, K G Cox, J Shaw: "Are the Falkland Islands a Rotated Microplate?". Nature, 319, 131-134 (January 1986)

2. J F Evernden, C B Archambeau, E Cranswick: "An Evaluation of Seismic Decoupling and Underground Nuclear Test Monitoring using High-Frequency Seismic Data". Rev of Geophys, 24, 2, 143-215 (May 1986)

3. E Herrin: "The Resolution of Seismic Instruments used in Treaty Verification". Bull Seis Soc Am, 72B, 6, 561-568 (December 1982)

4. H Bungum, S Mykkeltveit, T Kvaerna: "Seismic Noise in Fennoscandia, with Emphasis on High Frequencies". Bull Seism Soc Am, 75, 1489-1513 (1985)

5. R F Burch: "The Blacknest Three Component Borehole Seismometer System". AWE O Report (In preparation) (1990)

6. W M H Mowat, R F Burch: "Handbook for the Stations which Provide Seismograms to the Blacknest Seismological Centre, UK". AWRE Blacknest Tech Report 44/47/29 (1977)

TABLE 1

List of Equipment used for Survey

Box No.	Item	No. Off
1	SP Helicorder Geotech Type RV 301 (adapted for 12V)	1
	Drgs HR/4/BN/165-167	Set
	Blacknest-Guralp Seismometer	1
	Hand held Anemometer Munro IM 159	1
	Polaroid Camera	1
	Handbook for HP 85 Computer, Epson Printer and Sensonics Recorder	3
	BAO Type Sender Can	
	BNC/BNC Cable 15 m Long	2
2	LP Helicorder Geotech Type RV 301 (adapted for 12 V)	1
	Electronics Box for Blacknest Guralp Seismometer	1
	Box of Spare Electronics for Helicorders	1
	Box of Battery Cables and Connectors	1
	BAO Type Sender Can	2
	BNC/BNC Cable 15 m Long	2
3	HP 85 Computer + Ram Cards and Leads	1
	Blacknest Guralp Seismometer (Spare)	1
	Filter Card in Box + Spare Card	1
	Willmore Seismometer	2
	Epson Printer PX4	1
	Sensonics Digital Event Recorder	1
	Model SSDR-1000 + Battery Charger	2
	Helicorder Paper	2
	Printer Paper	2
	HP 85 Paper	1

(The recording system was despatched in 3 aluminium containers size: 750 × 580 × 580 mm)

TABLE 2

Poles and Zeros of the SP and LP Systems
at the Mount Pleasant Base Station

FALKLANDS NOISE SURVEY SP HELI WITH 62 K RESISTOR	
8 Poles	
- 1.4700E+03	+ 0.000E+00
- 1.7240E+02	+ 6.8190E01
- 7.7240E+02	- 6.8190E+01
- 5.6080E+01	+ 0.0000E+00
- 2.3710E-01	+ 2.0340E-01
- 2.3710E-01	- 2.0340E-01
- 4.5450E+00	+ 4.5450E+00
- 4.5450E+00	- 4.5450E+00
6 Zeros	
- 4.5250E+02	- 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
Constant 1.811E+10 (Magnification)	

NOISE SURVEY LPNB WITH HELI AT 2 VOLTS/CM	
15 Poles	
- 5.6056E-01	+ 0.0000E+00
- 1.7240E+02	+ 6.8253E+01
- 1.7240E+02	- 6.8253E+01
- 1.4704E+03	+ 0.0000E+00
- 1.0324E+07	+ 0.0000E+00
- 2.3710E-01	+ 2.0340E-01
- 2.3710E-01	- 2.0340E-01
- 1.4663E-01	+ 1.4663E-01
- 1.4663E-01	- 1.4663E-01
- 1.7030E-01	+ 2.4130E-01
- 1.7030E-01	- 2.4130E-01
- 1.7030E-01	+ 2.4130E-01
- 1.7030E-01	- 2.4130E-01
- 3.1570E-02	+ 0.0000E+00
- 2.5640E+01	+ 0.0000E+00
7 Zeros	
- 4.5250E+02	+ 0.0000E+00
- 1.0324E+07	+ 0.0000E+00
- 1.0030E+04	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
Constant 1.230E+06 (Magnification)	

TABLE 3

Poles and Zeros of the Portable Digital Recording System with Switched Gain = 1

DIS.409 TO GIVE DIGITS/METER

16 Poles

- 3.8330E+00	+ 4.9790E+00
- 3.8330E+00	- 4.9790E+00
- 9.1830E+02	+ 0.0000E+00
- 1.0101E+03	+ 0.0000E+00
- 1.8267E+02	+ 7.4532E+01
- 1.8267E+02	- 7.4532E+01
- 6.5763E+01	+ 1.8601E+02
- 6.5763E+01	- 1.8601E+02
- 1.0010E+03	+ 0.0000E+00
- 4.9952E-01	+ 0.0000E+00
- 1.0000E+03	+ 0.0000E+00
- 5.3780E-01	+ 0.0000E+00
- 1.9320E+02	+ 0.0000E+00
- 7.5200E-01	+ 0.0000E+00
- 1.2333E+02	+ 1.5473E+02
- 1.2333E+02	- 1.5473E+02

8 Zeros

- 3.9490E+03	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
- 5.5560E+04	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00
+ 0.0000E+00	+ 0.0000E+00

Constant 9.000E+27 (DIGITS/M)

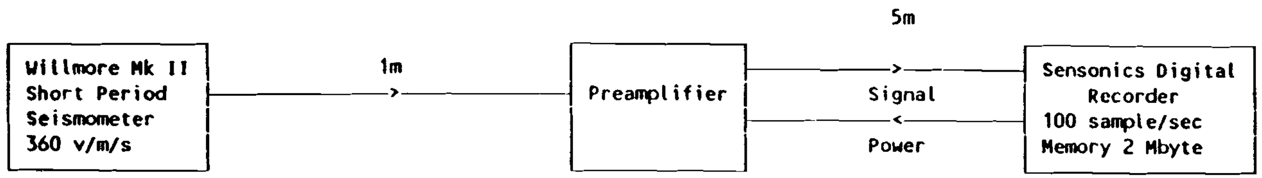
TABLE 4

Details of Survey Sites with Times of Recording and Wind Speed

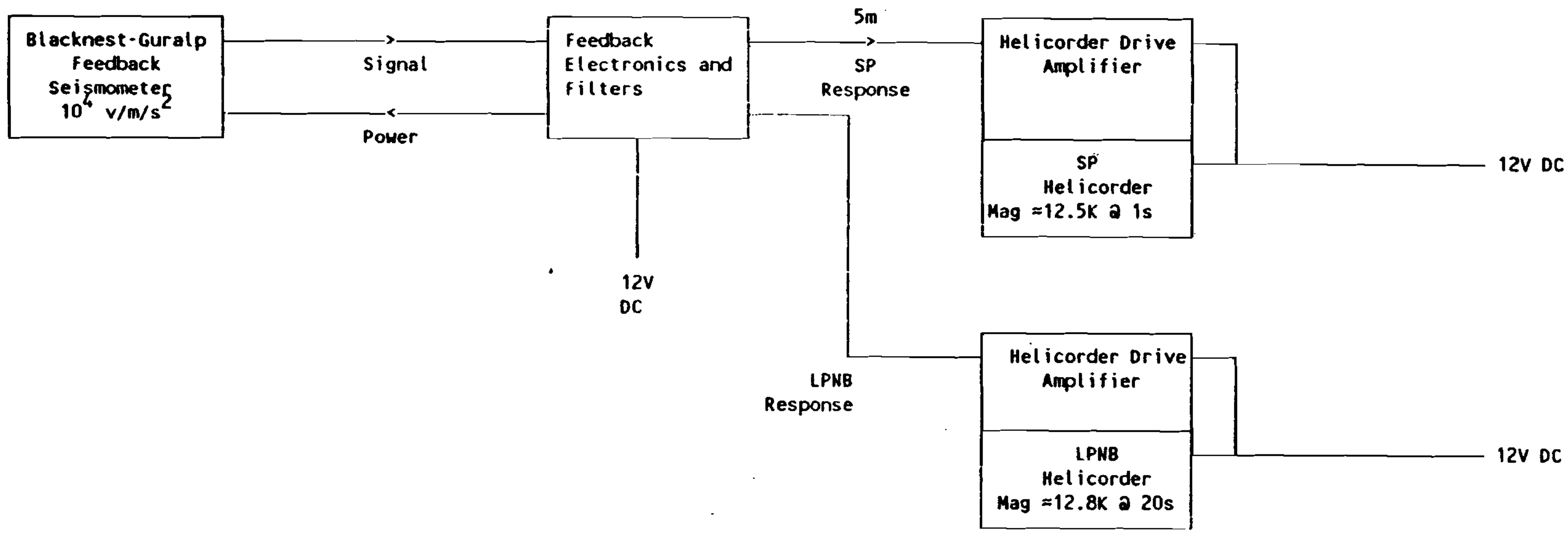
				Recording Time		Wind Speed (mph)
1	Mount Pleasant Airport (Base Station MPA)	51°48½S	58°27½W	Continuous from 1400 2 Dec to 1630 12 Dec		0-28
2	Dougherty's Shanty	51°38½S	58°44W	1401-1410Z	3 Dec	2-3
3	Mount Kent	51°40½S	58°06½W	1845-1855Z	3 Dec	3-7
4	Canada Ronde	51°48½S	58°41W	1509-1518Z	4 Dec	6-7
5	Bold Cove	51°35S	59°30W	1616-1625Z	6 Dec	50
6	Mount Kent Access Road	51°41½S	58°03½W	1751-1800Z	7 Dec	33-37
7	Bluff Cove	51°44S	58°10W	1900-1911Z	7 Dec	12-25

Note: Times shown above are Standard Time which was 3 hours ahead of Local Time

FIGURE 1. AZIMUTHAL GREAT CIRCLE PROJECTION CENTRED ON THE FALKLAND ISLANDS

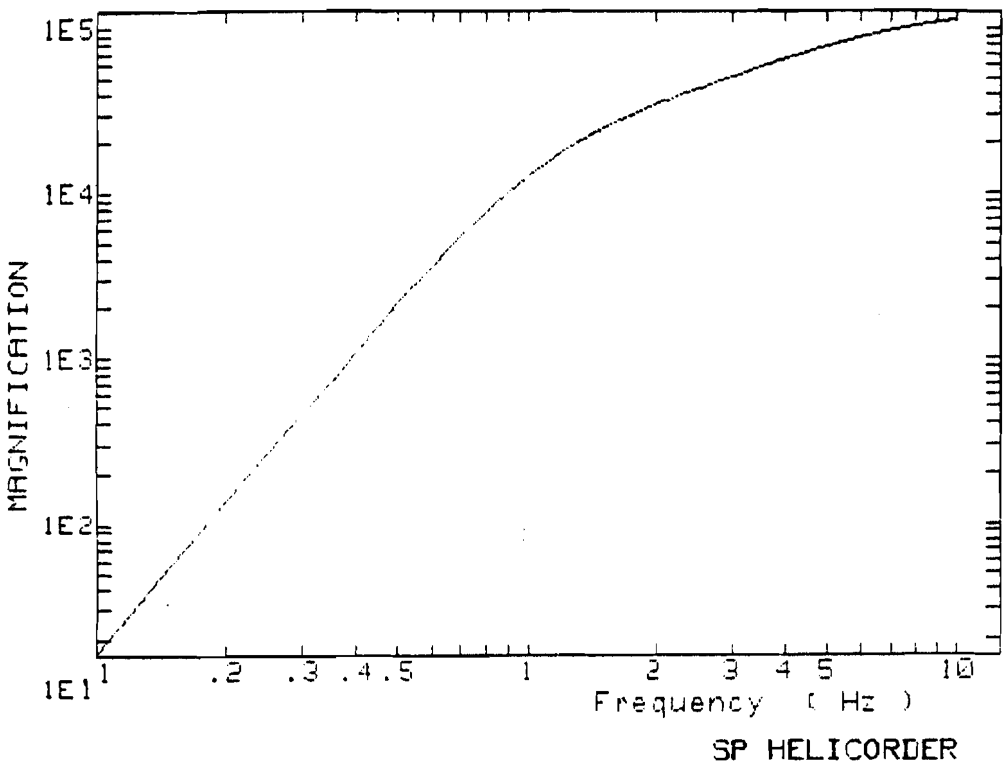


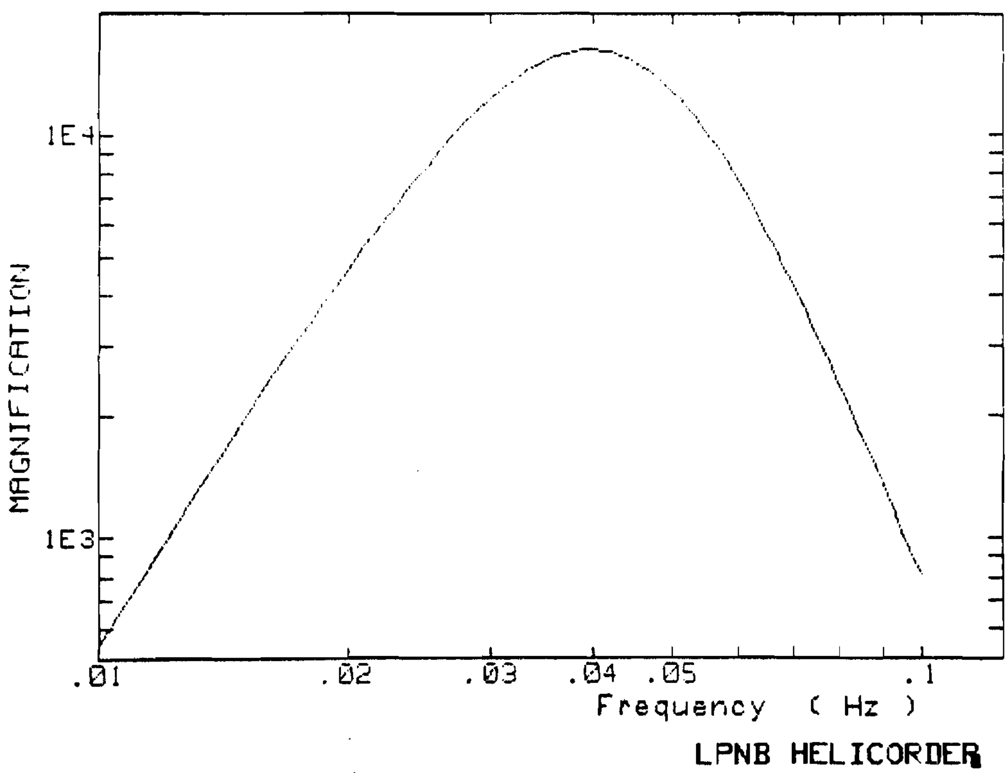
(a) Block diagram of High Frequency Portable Recording System



(b) Block diagram of Base Station System

FIGURE 2. BLOCK DIAGRAM OF RECORDING SYSTEMS





<u>**FIGURE 3. RESPONSES OF SP AND LP HELICORDERS AT BASE STATION**</u>

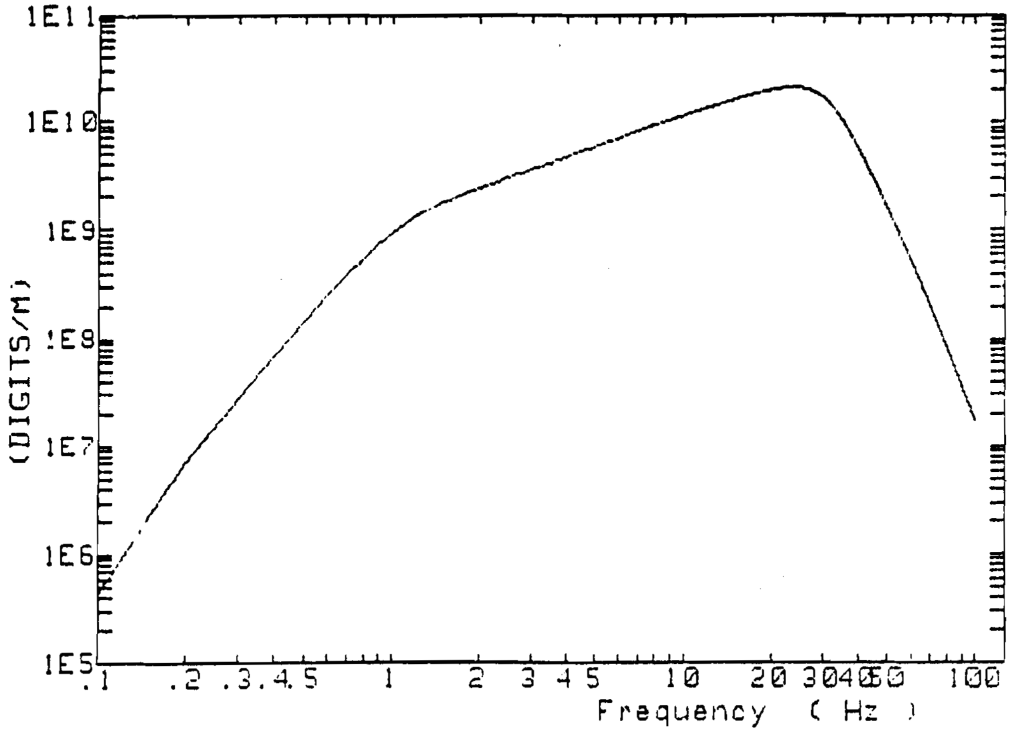


FIGURE 4. RESPONSE OF PORTABLE DIGITAL SYSTEM WITH GAIN SET TO 1.

THE FALKLAND ISLANDS

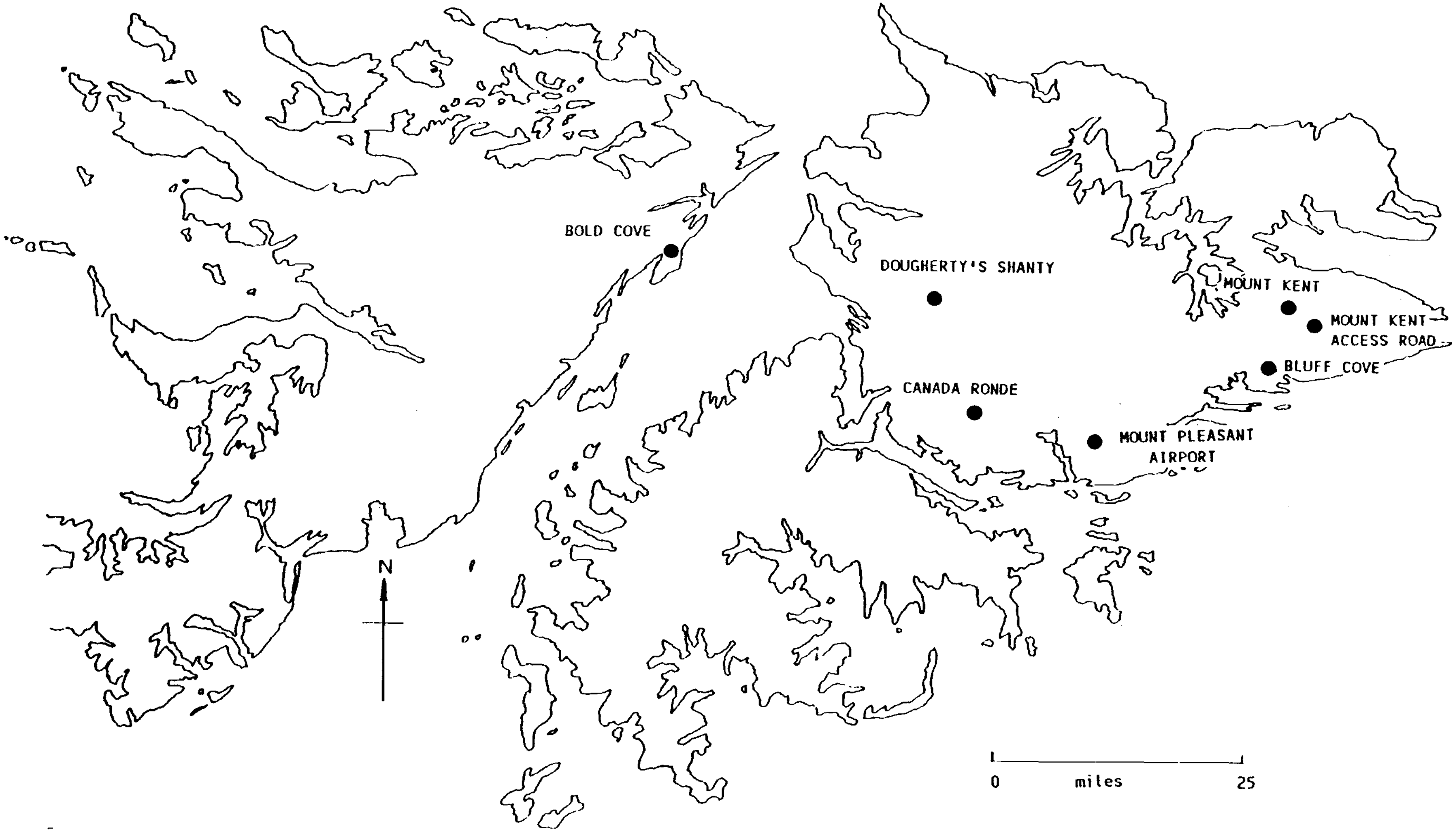


FIGURE 5. LOCATION OF SURVEY SITES ON THE FALKLAND ISLANDS

BASE STATION
MT PLEASANT RIDGE
IN BACKGROUND

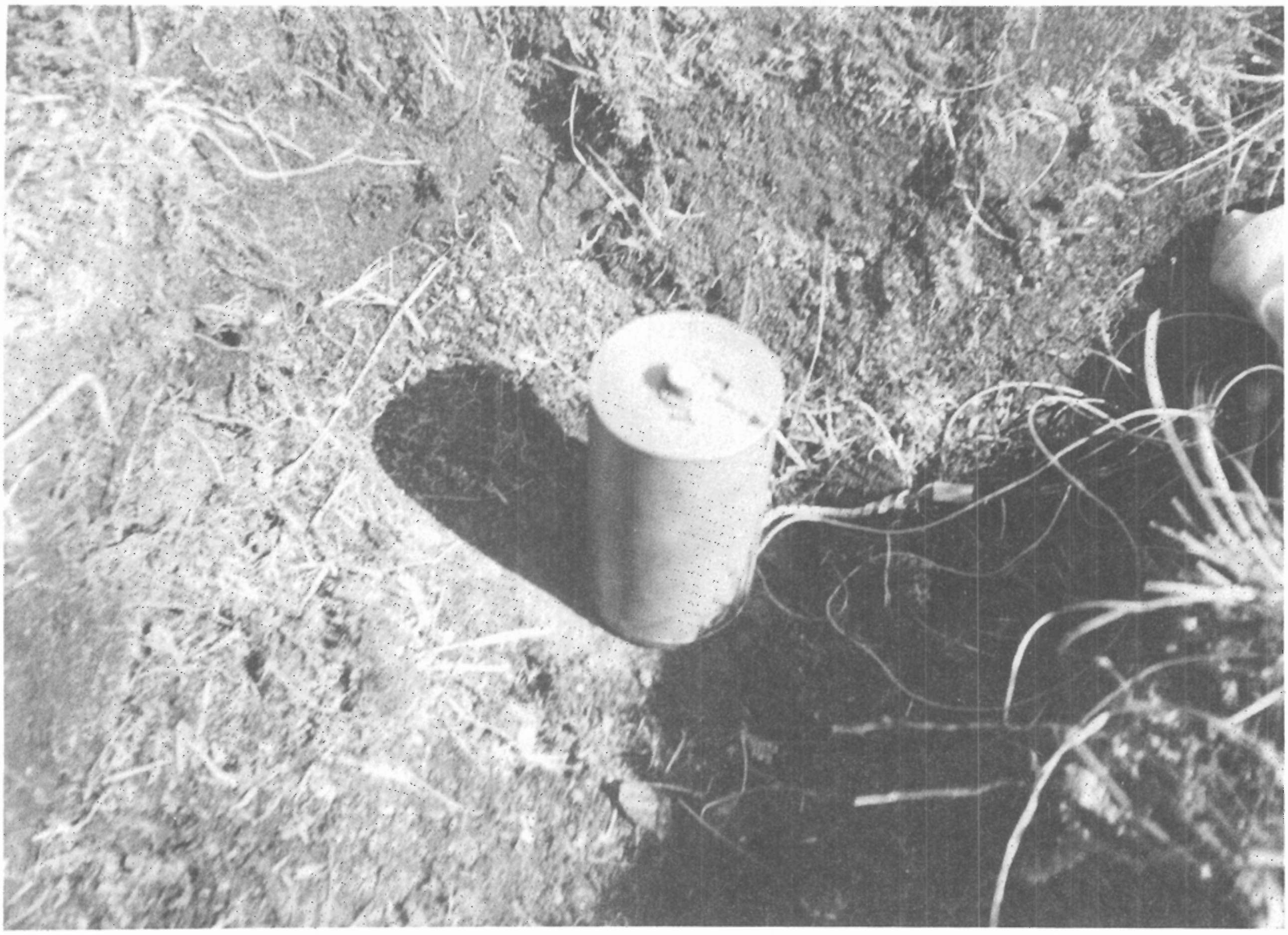
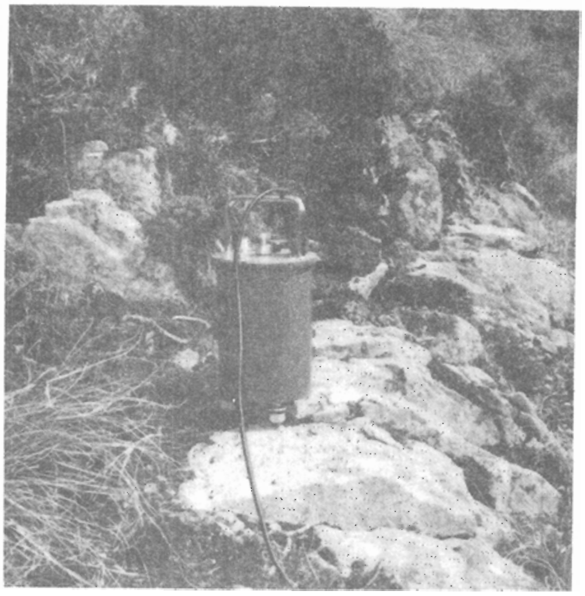


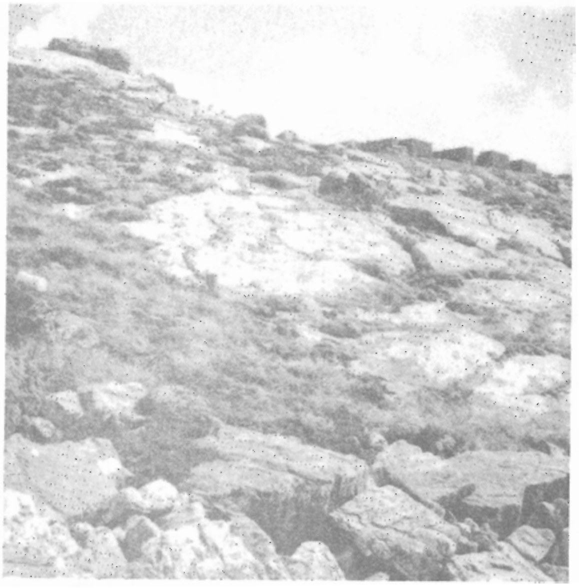
FIGURE 6. SITE AT MOUNT PLEASANT AIRPORT (BASE STATION)



SEISMOMETER
IN RECORDING
POSITION

VIEW LOOKING WEST TOWARDS SITE

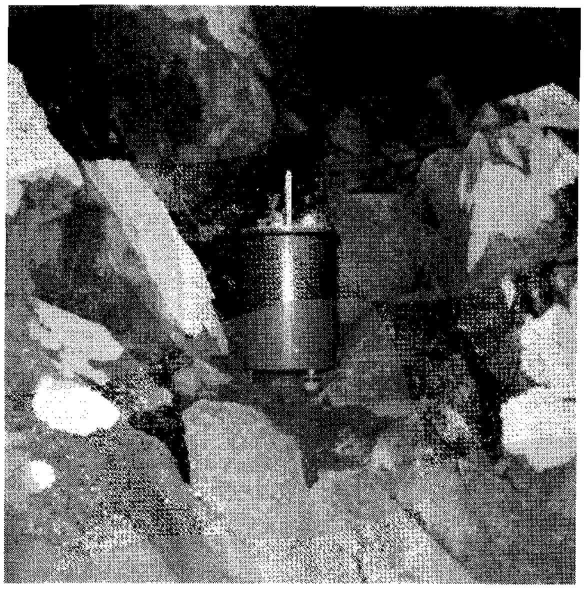
FIGURE 7. SURVEY SITE AT DOUGHERTY'S SHANTY



SEISMOMETER
IN RECORDING
POSITION

VIEW LOOKING EAST TOWARDS SITE

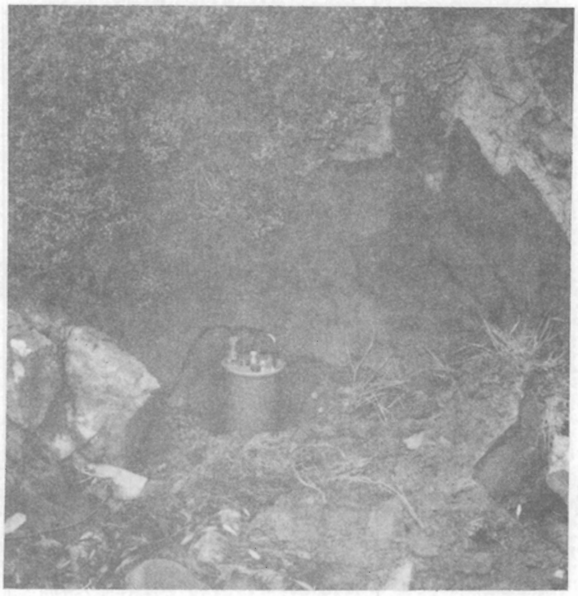
FIGURE 8. SURVEY SITE AT MOUNT KENT



SEISMOMETER IN RECORDING POSITION

VIEW LOOKING EAST TOWARDS SITE

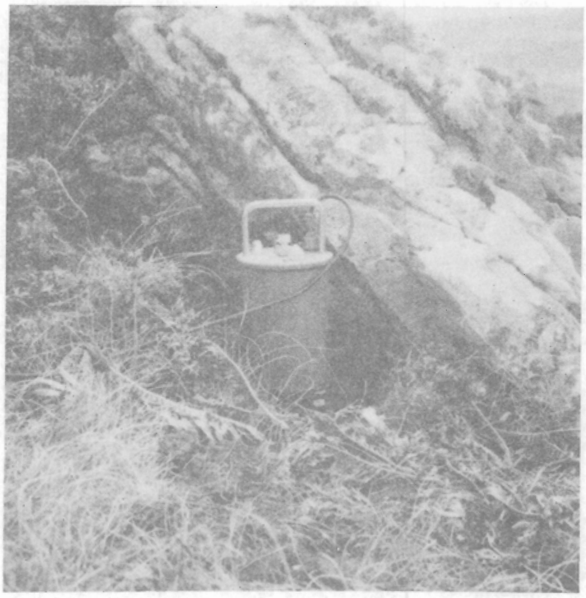
FIGURE 9. SURVEY SITE AT CANDADA RONDE



SEISMOMETER IN RECORDING POSITION

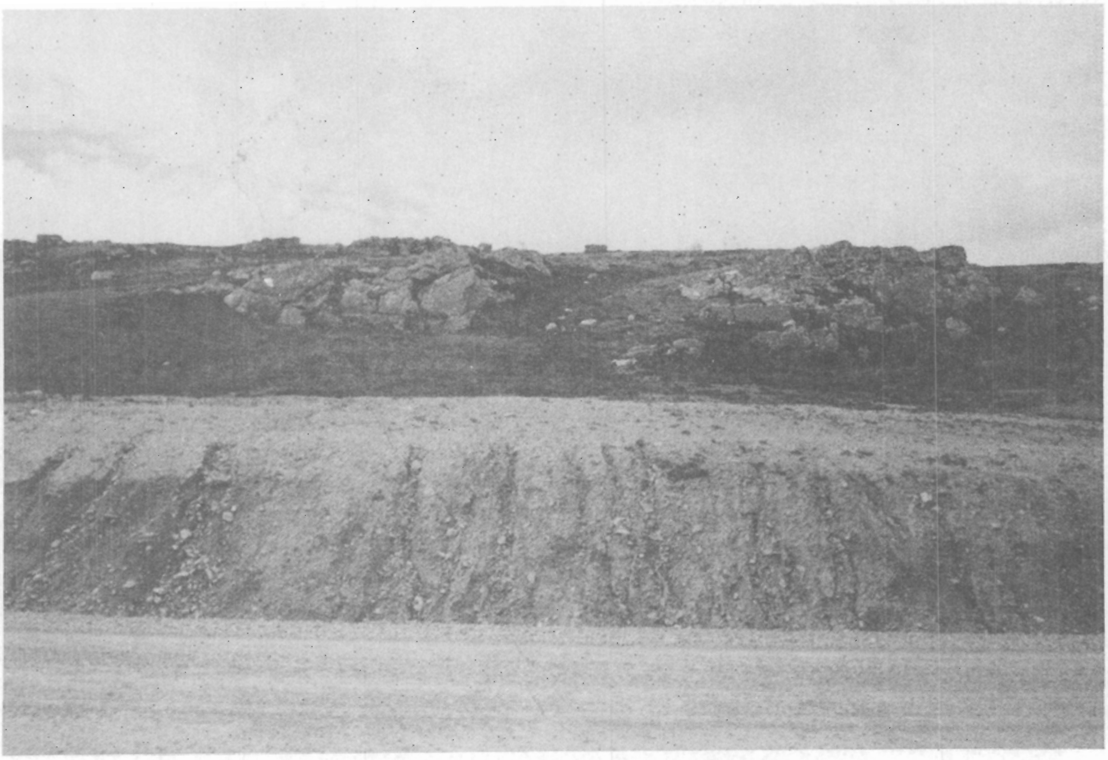
VIEW LOOKING EAST TOWARDS SITE

FIGURE 10. SURVEY SITE AT BOLD COVE



SEISMOMETER
IN RECORDING
POSITION

FIGURE 11. SURVEY SITE AT MOUNT KENT ACCESS ROAD



SEISMOMETER WAS SITED IN LEFT HAND OUTCROP
VIEW FROM THE ROAD

FIGURE 12. SURVEY SITE AT BLUFF COVE

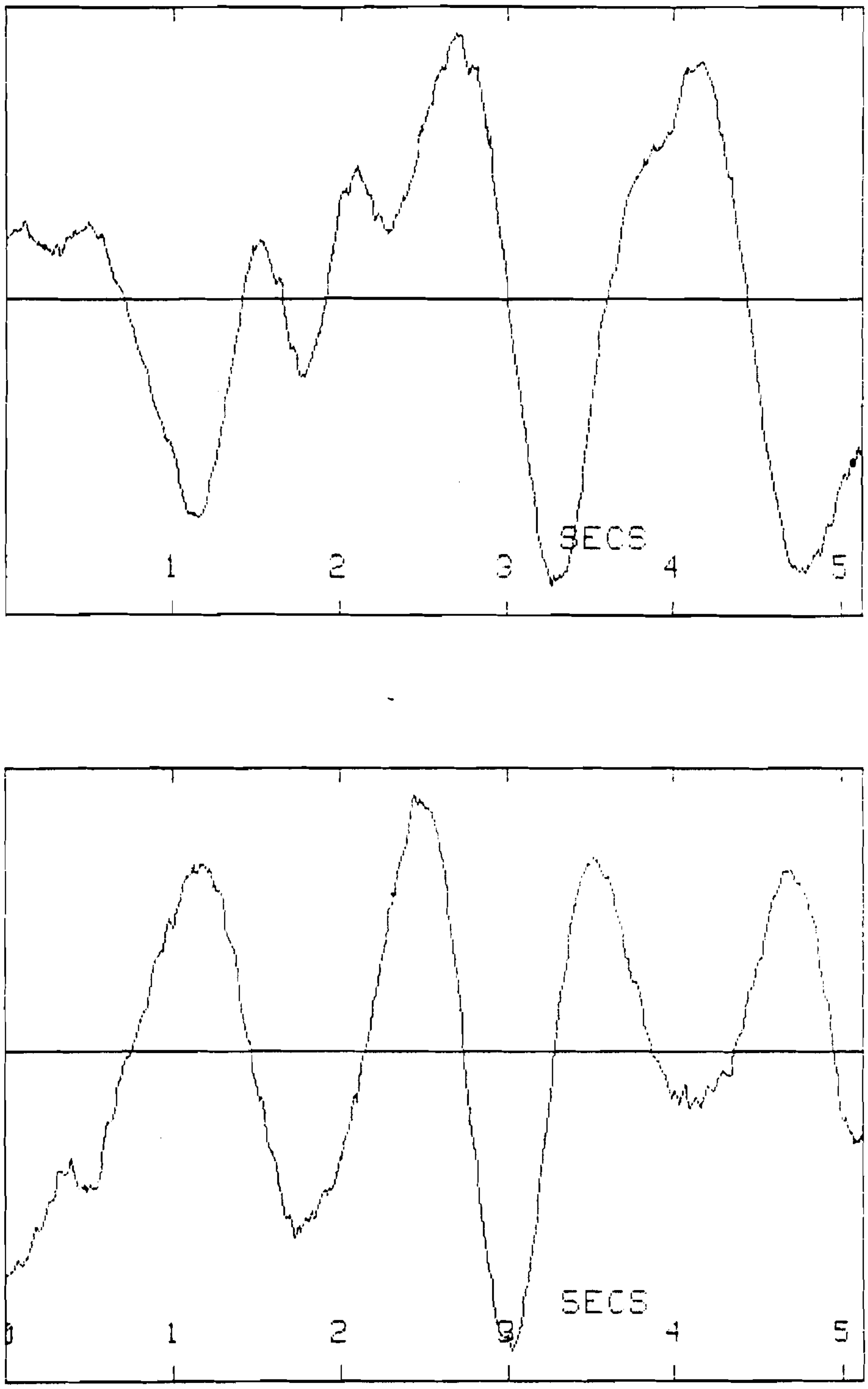
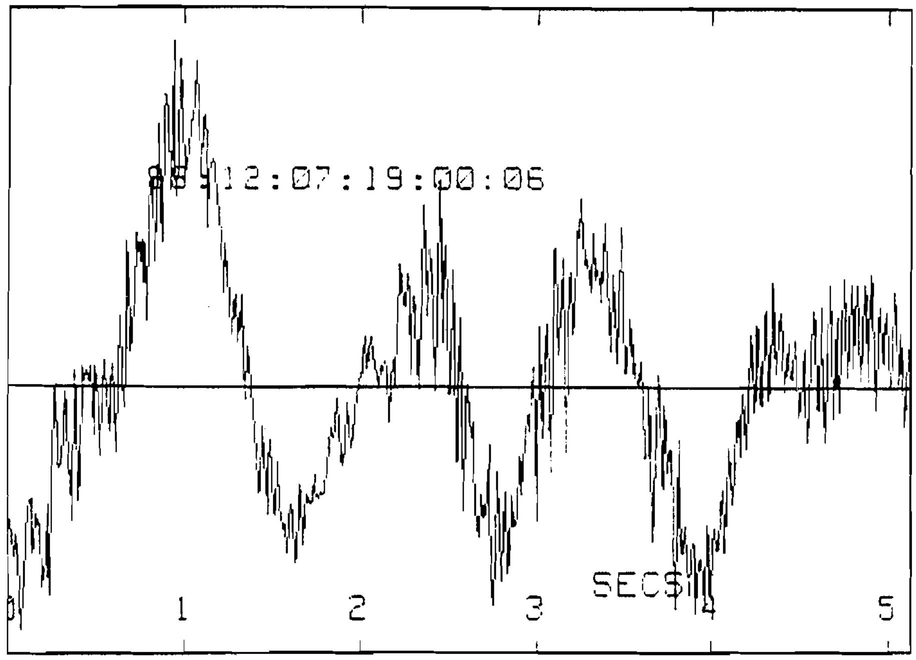


FIGURE 13. TWO SAMPLES OF GROUND MOTION RECORDINGS IN THE TIME DOMAIN (DOUGHERTY'S SHANTY)



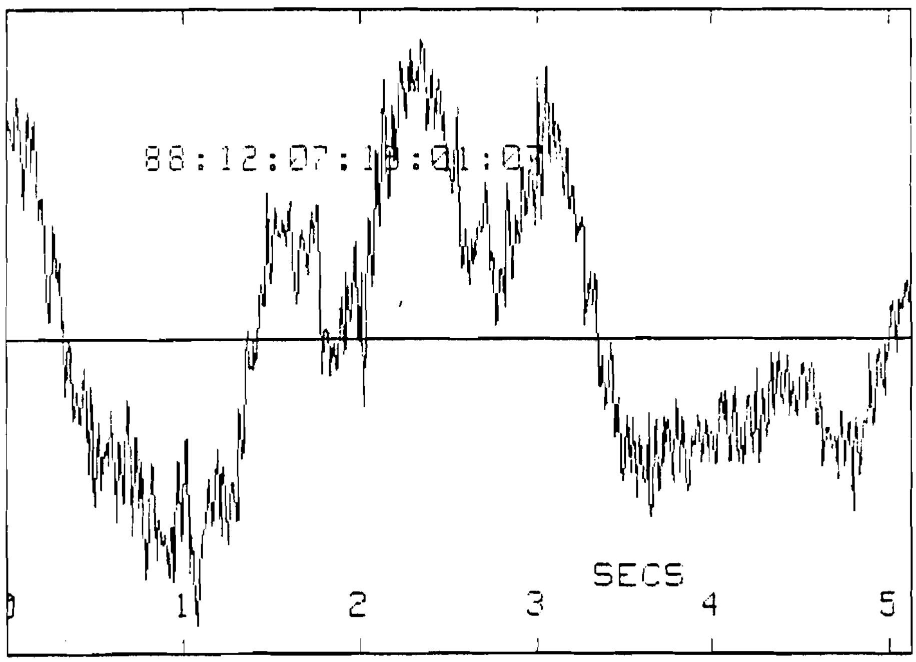
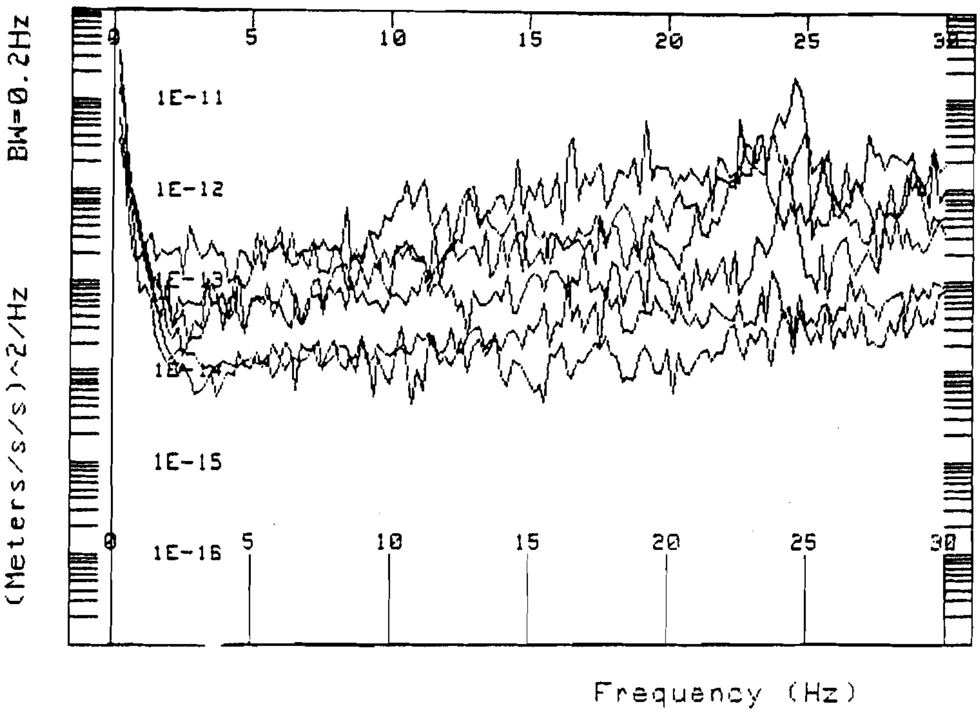


FIGURE 14. TWO SAMPLES OF GROUND MOTION RECORDINGS IN THE TIME DOMAIN (BLUFF COVE)



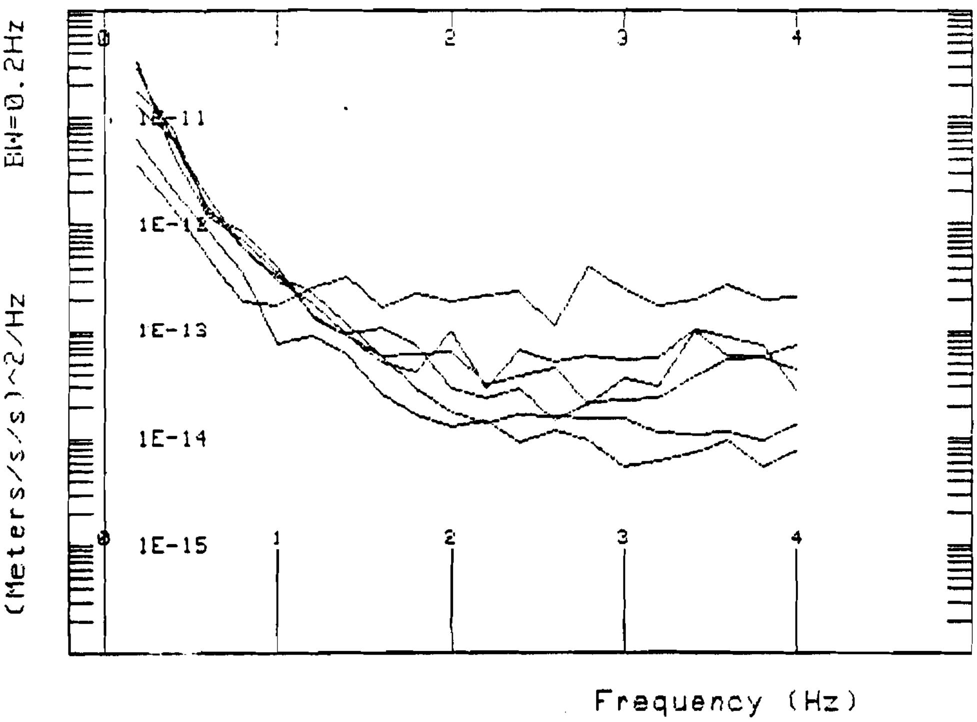
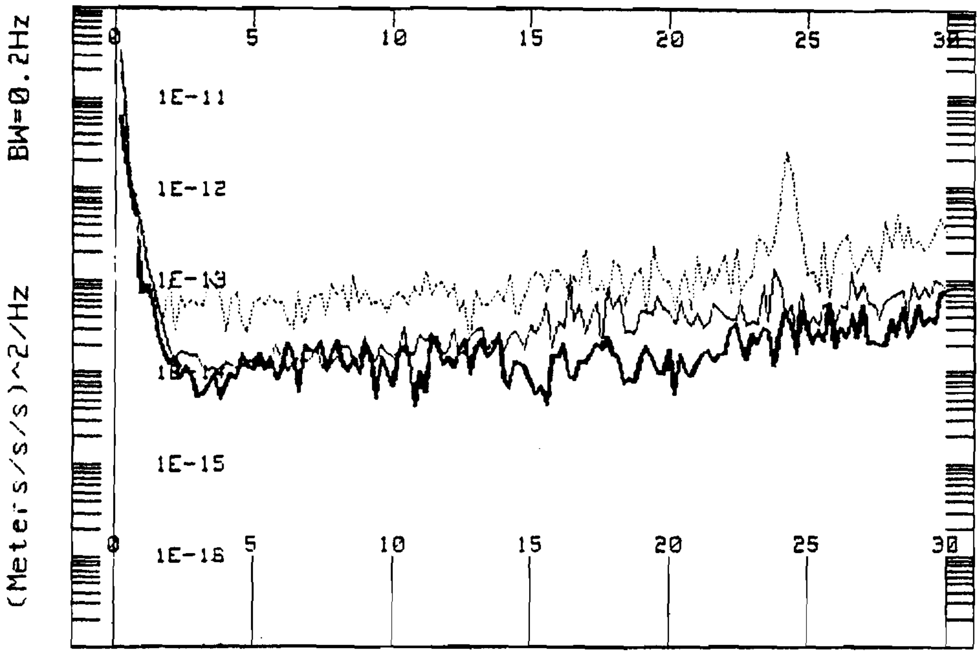
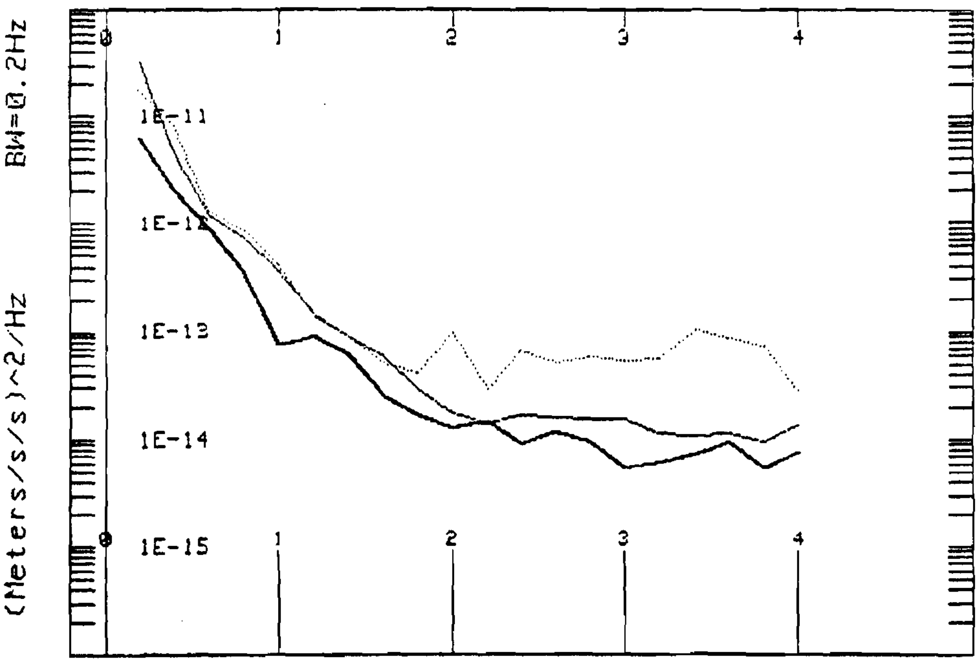


FIGURE 15. POWER DENSITY SPECTRA FOR ALL SIX REMOTE SITES



THICK Dougherty's Shanty
NORMAL Canada Ronde
DOTTED Mount Kent access road

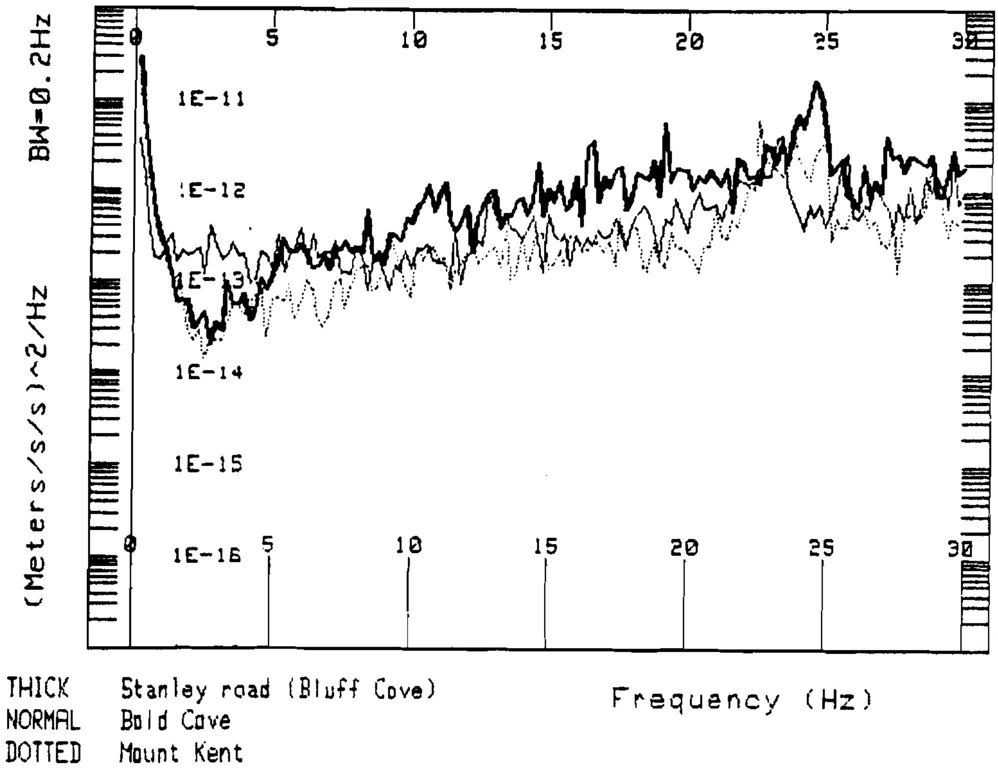
Frequency (Hz)



THICK Dougherty's Shanty
NORMAL Canada Ronde
DOTTED Mount Kent access road

Frequency (Hz)

<u>FIGURE 16. POWER DENSITY SPECTRA FROM THREE QUIETEST SITES</u>



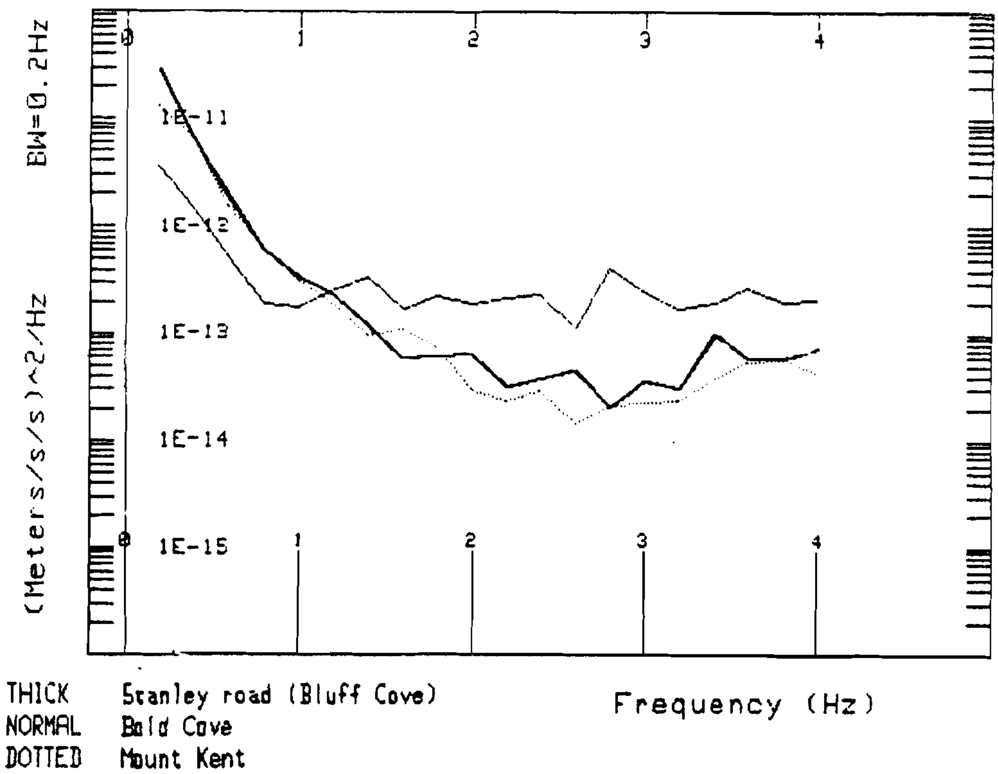
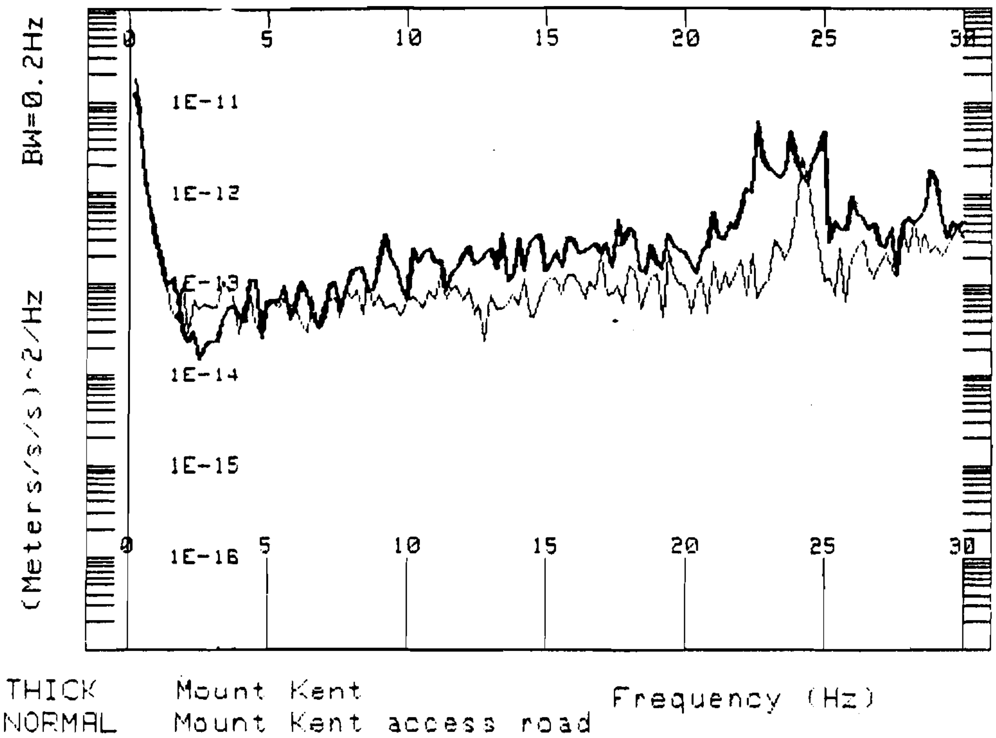


FIGURE 17. POWER DENSITY SPECTRA FROM THREE NOISIEST SITES



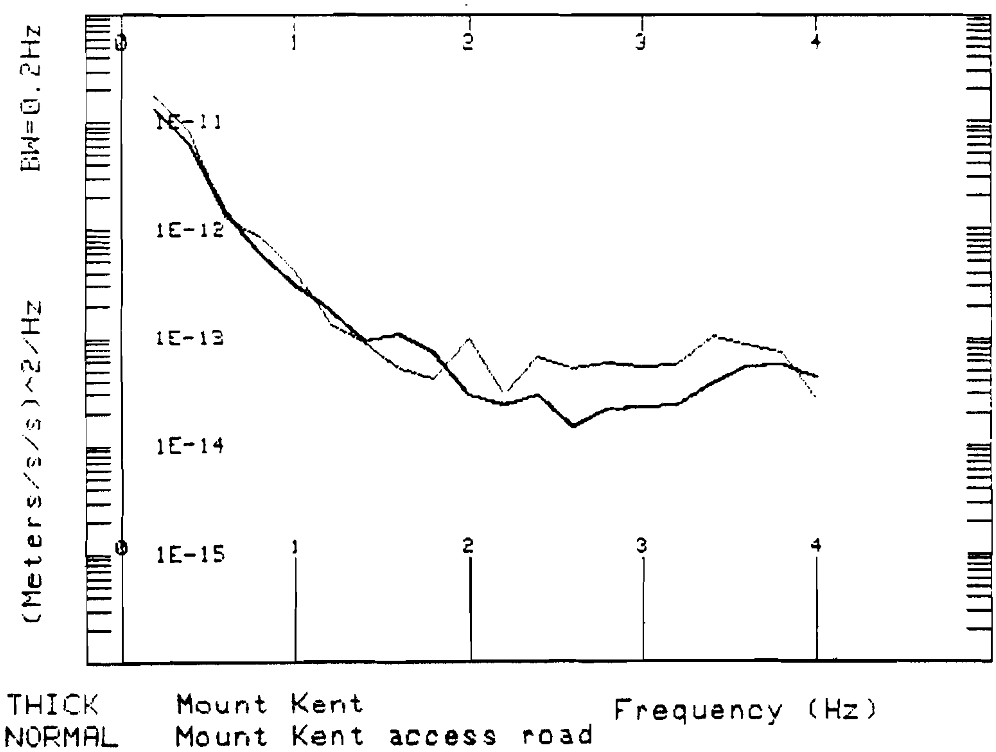


FIGURE 18. COMPARISON OF POWER DENSITY SPECTRA OF TWO "AVERAGE NOISE" SITES

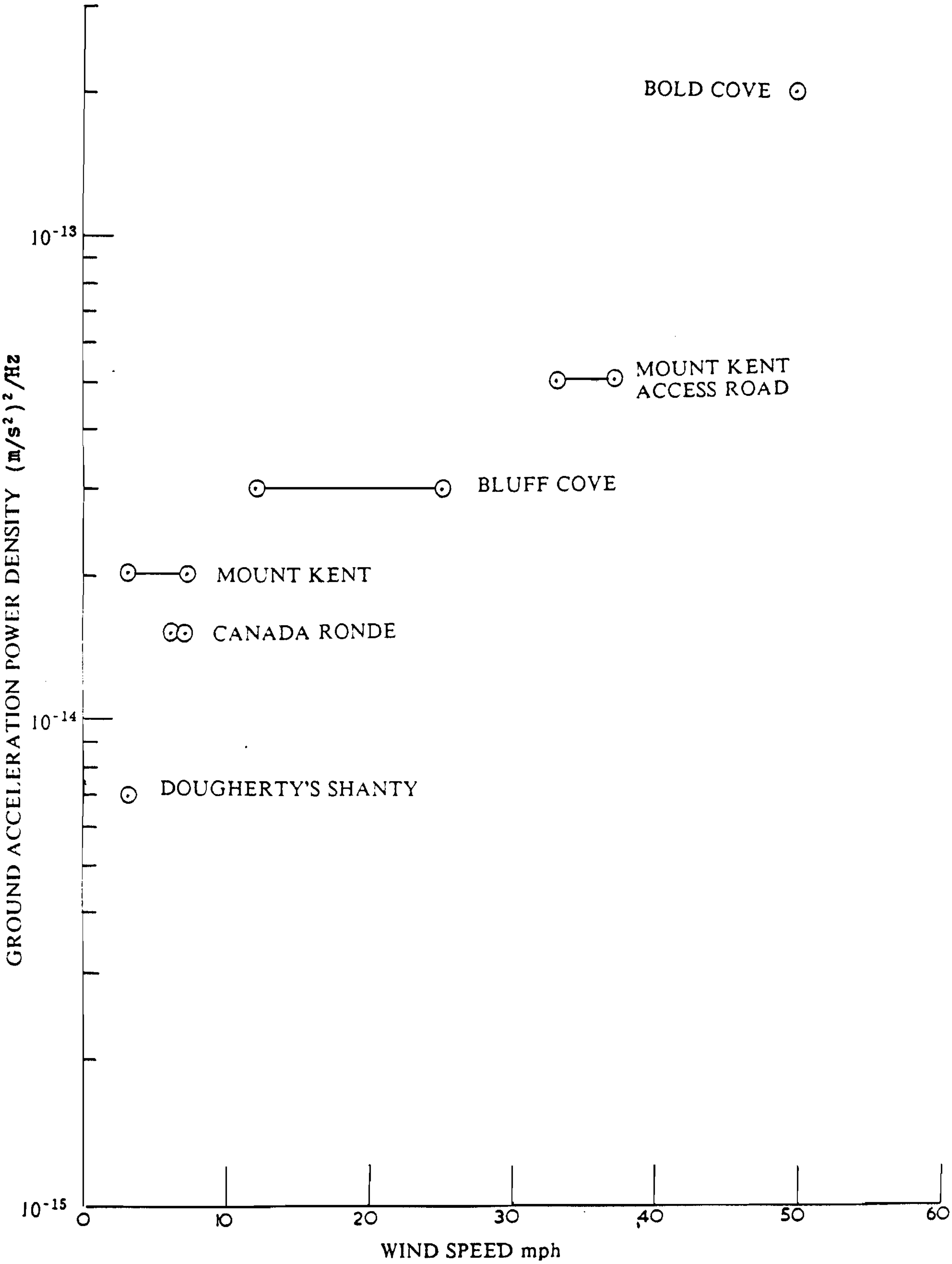


FIGURE 19. POWER SPECTRAL DENSITY AT 3 Hz OF SIX REMOTE SITES, WIND SPEED (MPH)

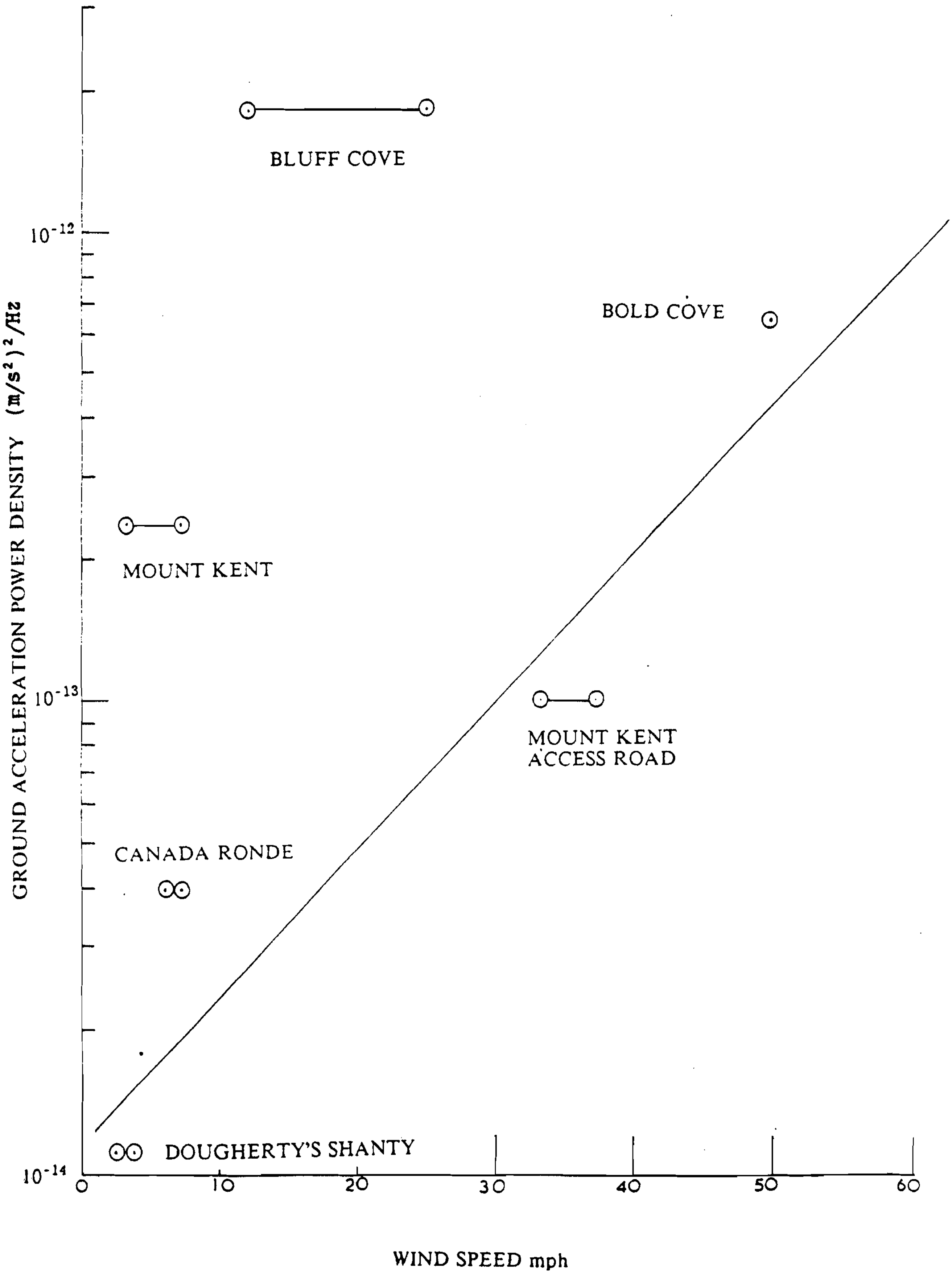


FIGURE 20. POWER SPECTRAL DENSITY AT 20 Hz OF SIX REMOTE SITES, WIND SPEED (MPH)

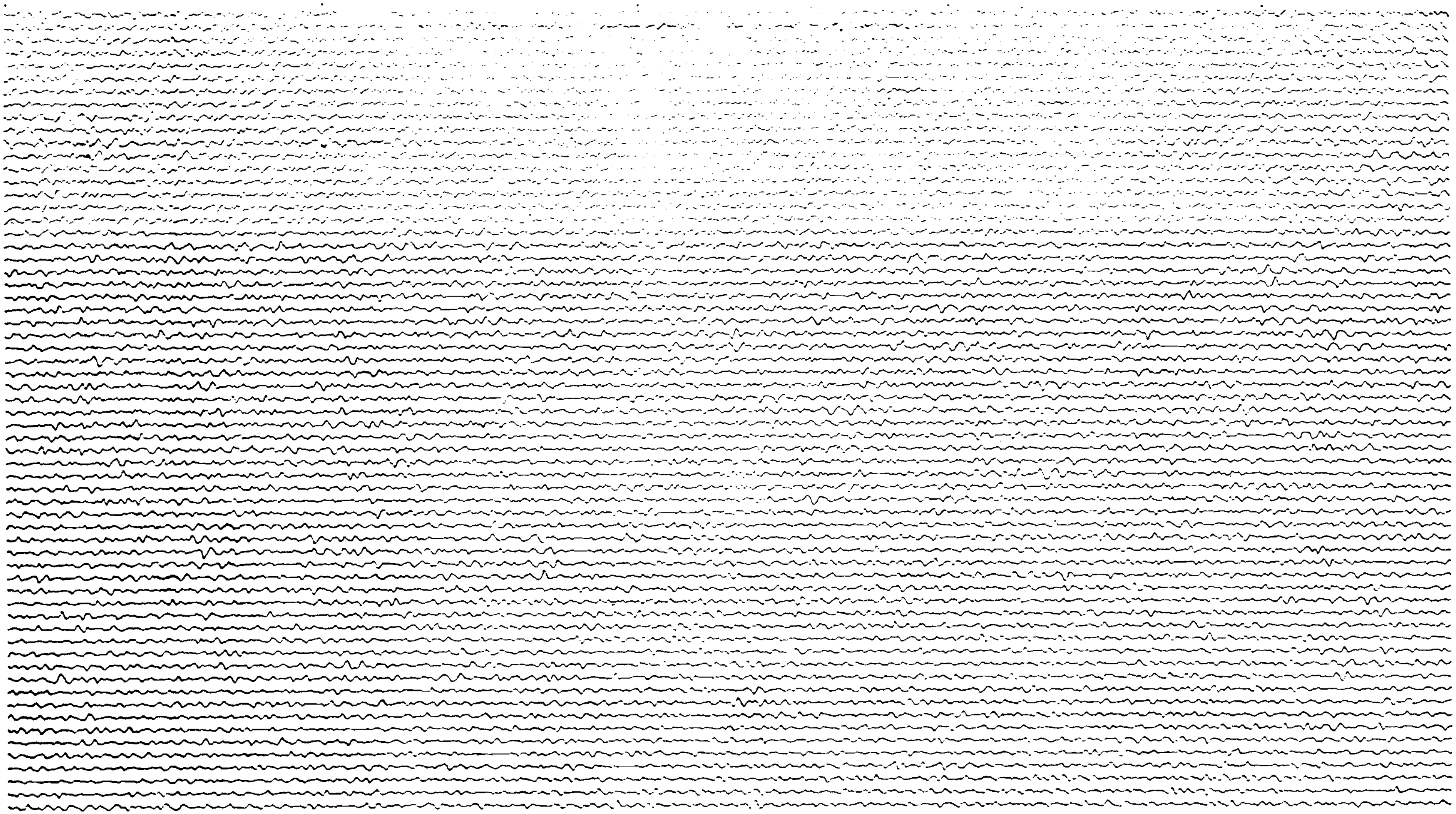


FIGURE 21. AN EXAMPLE OF A SHORT PERIOD HELICORDER RECORDING MADE AT MOUNT PLEASANT, FALKLAND ISLANDS
1 mm = 1 s. MAGNIFICATION 12.5 K AT 1 S

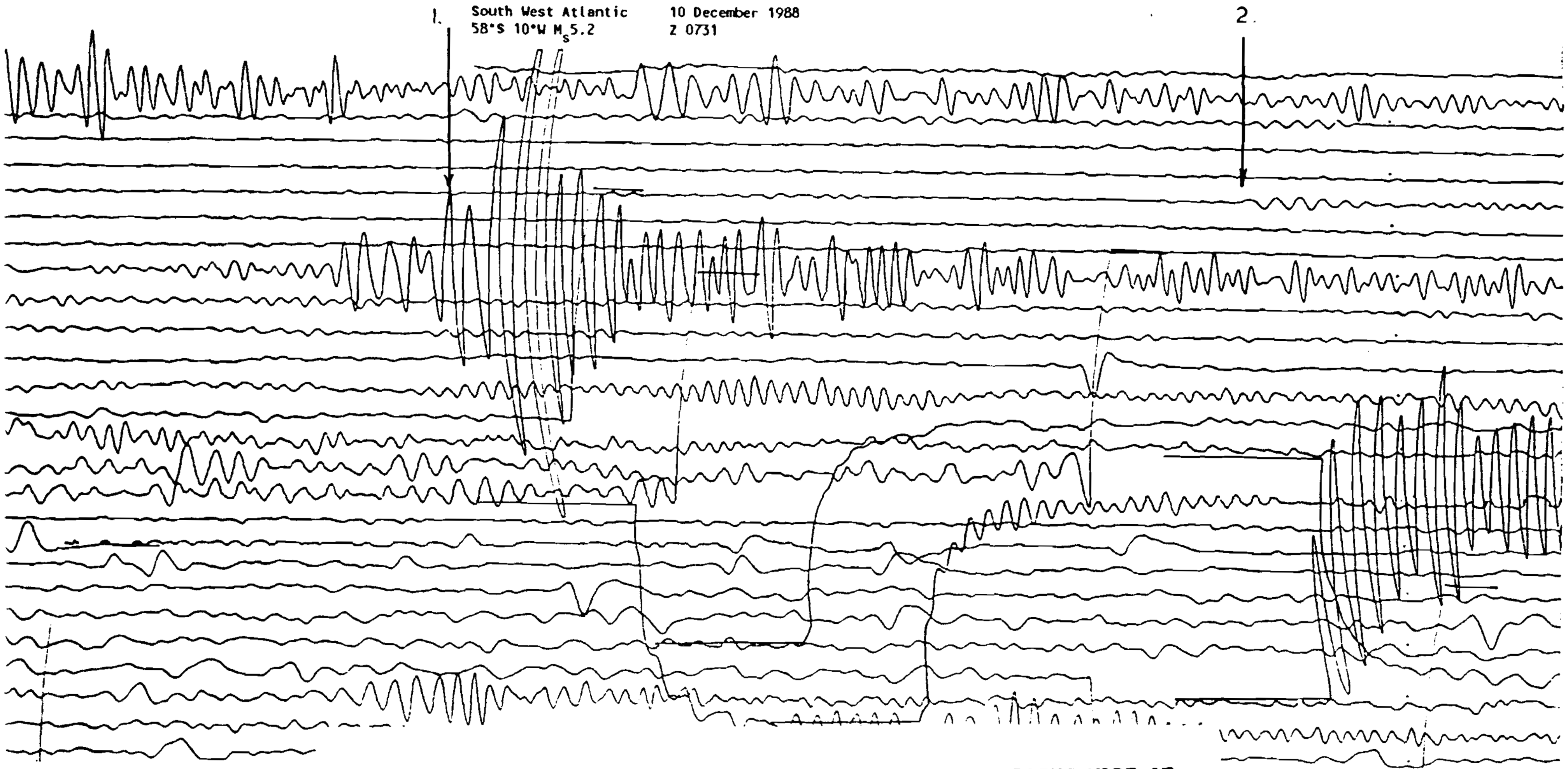


FIGURE 22. AN EXAMPLE OF THE LONG PERIOD HELICORDER RECORDING MADE AT MOUNT PLEASANT
1 mm = 6 s MAGNIFICATION 12.8 K AT T = 20 s

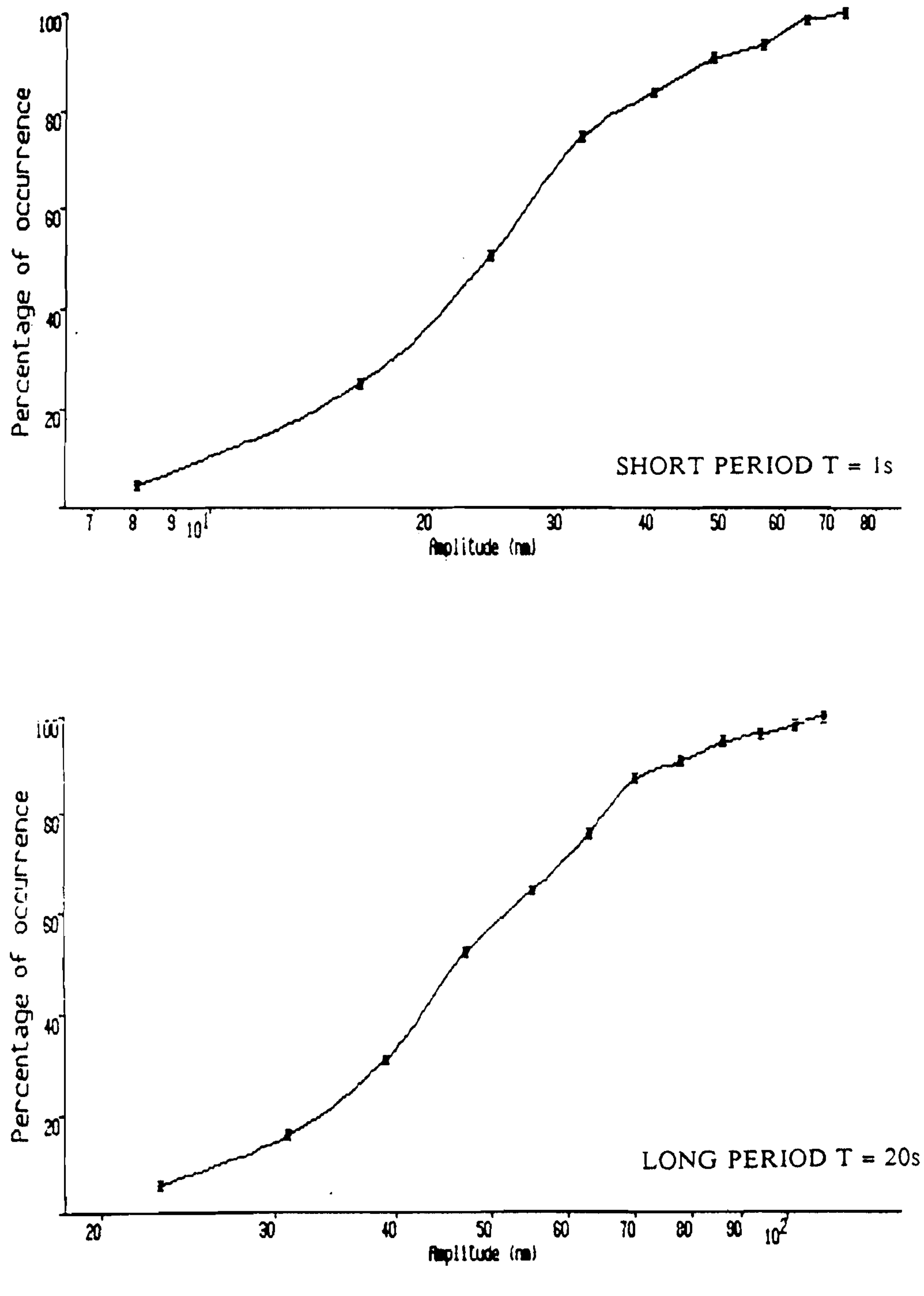


FIGURE 23. PERCENTAGE OF OCCURRENCE AS A FUNCTION OF PEAK-TO-PEAK AMPLITUDE IN NANOMETERS FOR SHORT AND LONG PERIOD RECORDINGS

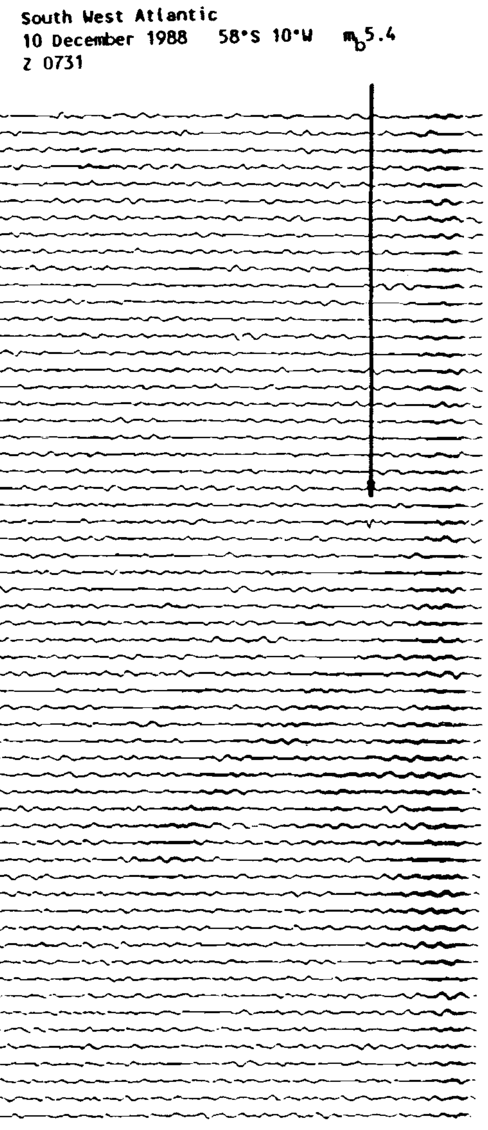
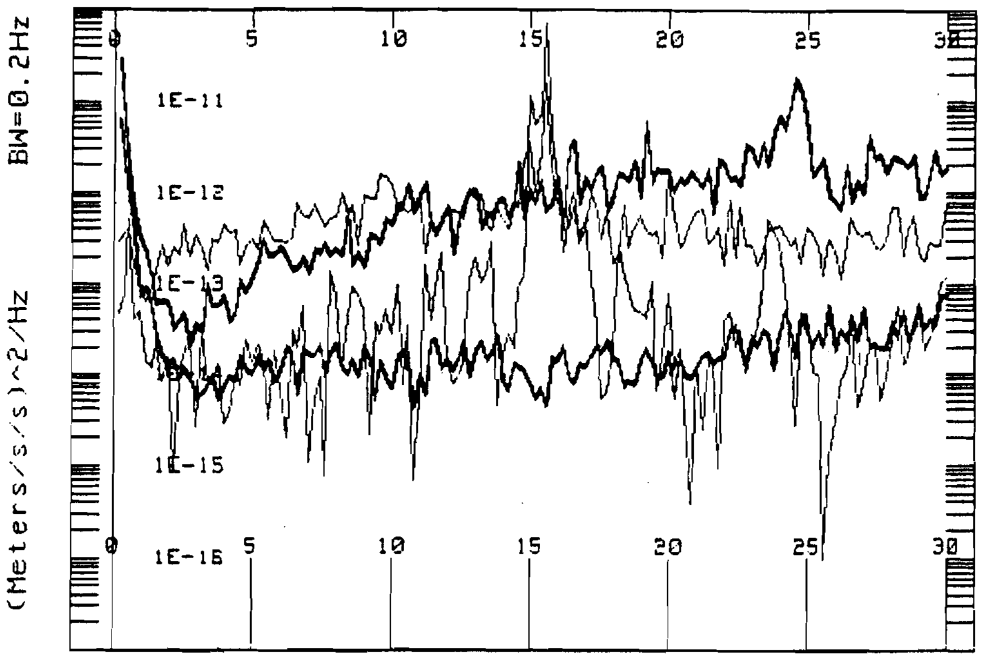
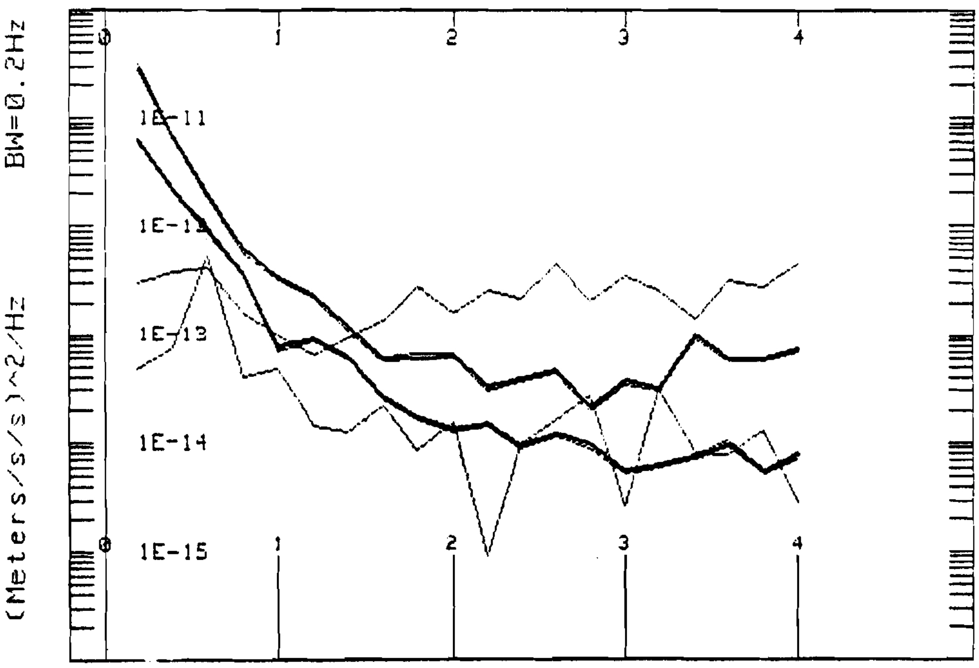


FIGURE 24. EXAMPLES OF A TELESEISMIC P WAVE RECORDED AT MOUNT PLEASANT BASE STATION



THICK Dougherty's Shanty
THICK Stanley road (Bluff Cove)
NORMAL Wolverton vault (NIGHT) (one sample only)
NORMAL Wolverton vault (DAY)

Frequency (Hz)



THICK Dougherty's Shanty
THICK Stanley road (Bluff Cove)
NORMAL Wolverton vault (NIGHT) (one sample only)
NORMAL Wolverton vault (DAY)

Frequency (Hz)

FIGURE 25. POWER DENSITY SPECTRA OF QUIETEST AND NOISIEST SITES COMPARED WITH WOLVERTON (UK)

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