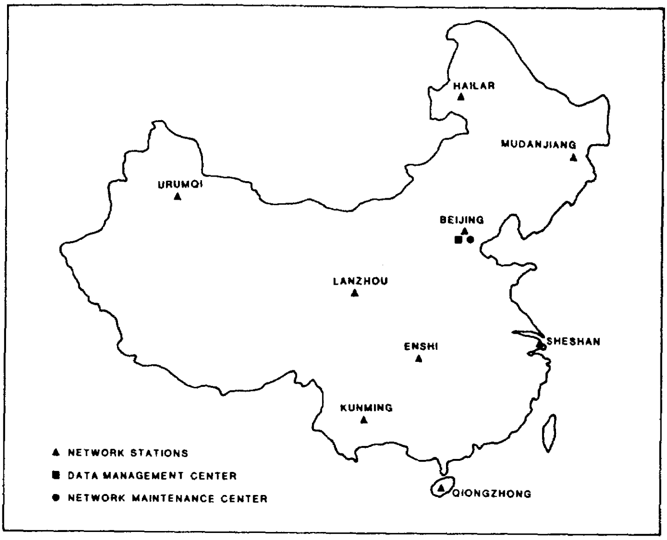
THE CHINA DIGITAL SEISMOGRAPH NETWORK



A JOINT REPORT

BY THE

INSTITUTE OF GEOPHYSICS
STATE SEISMOLOGICAL BUREAU

AND THE

ALBUQUERQUE SEISMOLOGICAL LABORATORY
U.S. GEOLOGICAL SURVEY

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Beijing, China

FOREWARD

This report was made possible by the work of the following people in China and the United States who were responsible for the planning, design, development, installation, and initial operation of the China Digital Seismograph Network.

Jon Peterson, Project Manager	Qu Kexin, Project Manager
Harold Clark	Zhou Gongwei
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Ed Tilgner	Zhang Yilin
Jim Murdock	Xu Zhonghe
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Rene' MacCallum	Liu Xiling

and all of the CDSN station operators.

Dr. David Russ and Xu Houde, the USGS and SSB Coordinators for the Earthquake Studies Protocol, provided leadership and worked together to solve the many knotty problems of coordination that arose during the course of this activity. USGS participation in this project would have been impossible without the support of Dr. Ralph Alewine, Defense Advanced Research Projects Agency. We also wish to thank Ge Zhizhou and Gu Ping of the State Seismological Bureau for their assistance in crafting the agreement-in-principle and Professor Xu Shaoxie of the Institute of Geophysics for his valuable advice and assistance. Debe Boles was especially helpful as the USGS contracting officer.

A technical report on a joint project, such as this, leaves much unsaid. During these past four years of intense effort on both sides, there have been a few misunderstandings and a few disappointments; but there have been many achievements and many memorable experiences, and together we have accomplished what we set out to do.

Contents

1 INTRODUCTION

In 1980 the State Seismological Bureau of the People's Republic of China, the U.S. Geological Survey, and the U.S. National Science Foundation signed the Earthquake Studies Protocol, thereby initiating research programs to benefit the earthquake hazards reduction programs in both nations. Very few countries of the world are not threatened by catastrophic damage, injuries and loss of life resulting from great earthquakes. During China's long history, earthquakes have repeatedly destroyed major urban areas. According to the State Seismological Bureau, in the Twentieth Century, 104 earthquakes of magnitude 7 or larger have stricken 21 of the 30 Chinese administrative provinces, autonomous regions, and municipalities. In the past 37 years alone, earthquakes in China have killed 237,000 people and injured 763,000 others (An, 1987). In this century there have been 20 earthquakes of magnitude 7 or larger in the United States that have resulted in 1,380 deaths and more than $5 billion in property damage. Because of the shared problems that need to be addressed to learn how earthquakes occur, to develop the capability to predict them, and to design earthquake-resistant structures, the United States and the People's Republic of China recognize the mutual advantages inherent in conducting cooperative scientific and engineering research. The Earthquake Studies Protocol establishes the mechanism under which these joint activities can be conducted.

High-quality observational data are essential to earthquake studies. A new or improved data base stimulates research progress; thus, the data acquisition systems must be continuously upgraded and modernized. China, where the first earthquake detection instruments were developed, has extensive facilities in place for monitoring earthquakes, including a national network of 24 standardized seismograph stations and several hundred regional stations. The modernization of these facilities is one of the primary goals of the State Seismological Bureau.

There have been major improvements during the past 20 years in the technologies used to acquire and record earthquake data. Recording technology has benefitted from the exploitation of microprocessors and improved analog-to-digital converters, and the dynamic range and bandwidth of the sensor systems have been increased significantly in order to make full use of the improved recording techniques. The combination of improved seismometers, digital data recording, and computers for data processing has stimulated progress in every field of earthquake research that depends on observational data. The introduction of this recent technology into China will benefit not only China but scientists throughout the world who will share the data and who have a common goal in the better understanding and prediction of earthquakes.

A preliminary plan for a Chinese digital seismograph network was prepared by a technical group in China for the State Seismological Bureau. Subsequently, there were discussions between Chinese and American scientists concerning this plan and its implementation. In May 1983 the State Seismological Bureau and the U.S. Geological Survey signed an agreement-in-principle to cooperatively establish the China

Digital Seismograph Network (CDSN). The network was planned as a nation-wide facility that would consist of nine digital seismograph systems located primarily at existing observatory sites, a data management center located in Beijing, and a network maintenance center, also located in Beijing. Both sides would be involved in the implementation of the program. Under the terms of the agreement, the U.S. Geological Survey (USGS) would design and develop the hardware and software for the network, provide four of the data acquisition systems, software for the data management system, parts and equipment for the depot maintenance center, and training for Chinese engineers and technicians. The State Seismological Bureau (SSB) agreed to purchase equipment for five data acquisition systems and hardware for the data management system, prepare all of the sites, including the construction of nine stations and two centers, the drilling of boreholes, and reconstruction of power lines and roads, and provide the staff needed for operations in China. Responsibility for assembly and installation of the equipment would be shared. It was agreed that the four U.S.-supplied systems would be installed at Baijatuan (near Beijing), Kunming, Lanzhou, and Mudanjiang, and that the PRC-supplied systems would be installed at Enshi, Hailar, Sheshan, Qiongzhong (Hainan Island), and Urumqi (see Figure 1.1). Data from the four U.S.-supplied systems and Urumqi will be provided to the USGS on a basically continuous basis for distribution worldwide to the research community. In return, the USGS will provide support for operating the U.S.-supplied systems. The agreement also anticipated joint research projects using the network data and joint activities to expand and improve the network in the future.

The task of implementing the agreement was assigned in China to the SSB Institute of Geophysics and in the United States to the USGS Albuquerque Seismological Laboratory. An important meeting of project personnel from both sides was held in Beijing during September 1983 to review plans and coordinate activities. Following this meeting, site preparations and the production and procurement of seismometers and analog recorders began in China, and system development began in the United States. A second agreement-in-principle had been signed between the USGS and the China National Instrument Import and Export Corporation that permitted the USGS to procure equipment for the SSB, thus insuring compatibility of specifications. USGS funding was on a multi-year basis; much of the equipment was purchased in 1984 and the remainder in 1985. The development, testing, and assembly of the data systems and data management system proceeded through 1985. Sensor systems were installed in China in early 1985, and power systems were installed later in the year. The data management system and a demonstration data system were shipped in late 1985 and installed in early 1986. The remaining eight data systems were installed in mid 1986, and distribution of data from the network to the research community began in October 1986.

The purpose of this joint report is to document the major activities and results of this very important cooperative project. Included in the report is a general description of the system design and network components, a description of major deployment tasks, and a preliminary evaluation of the network data. More detailed

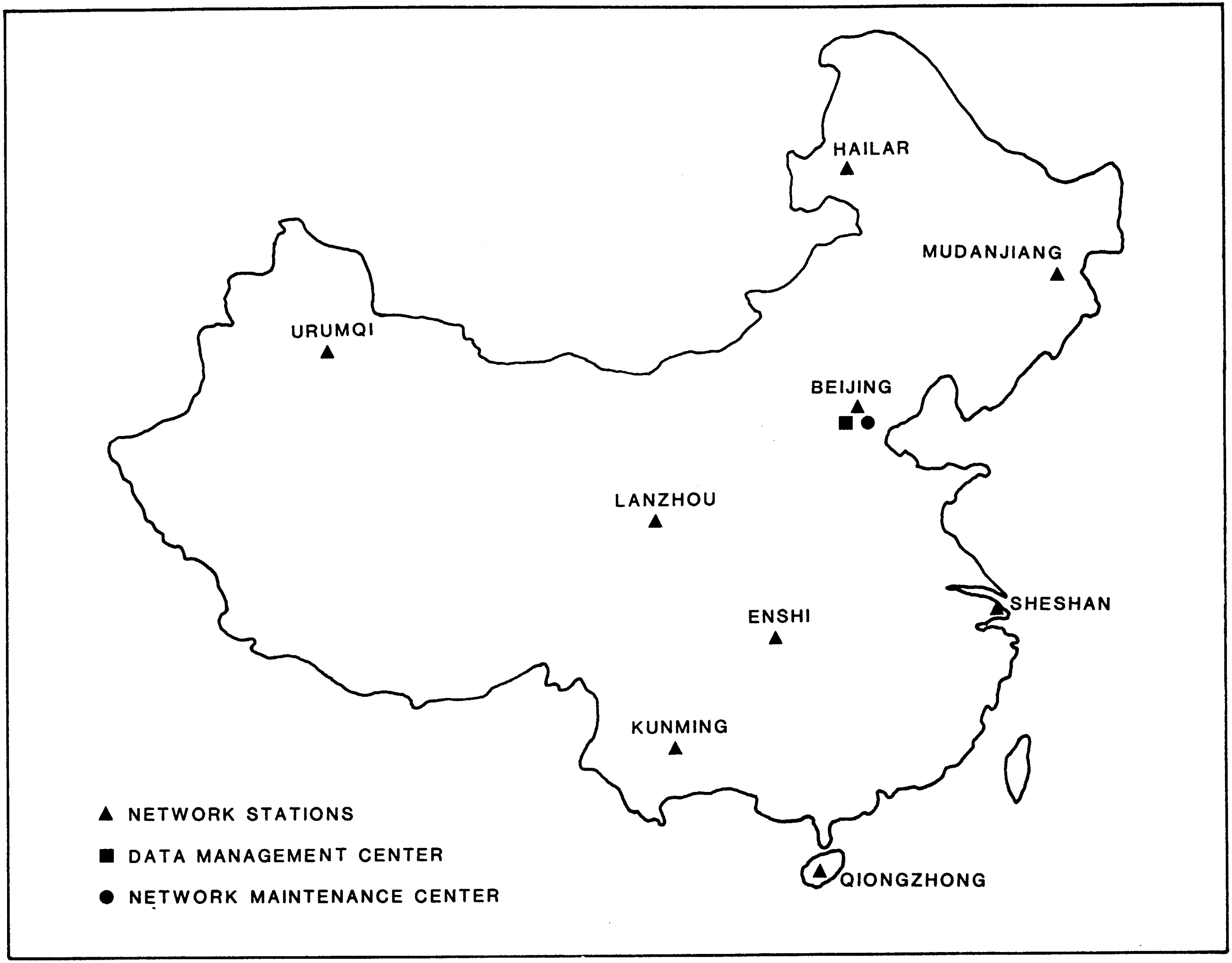


Figure 1.1. Map showing distribution of CDSN stations and support facilities.

descriptions of the instrumentation and CDSN facilities and tasks will be provided in forthcoming reports.

The CDSN is a major accomplishment that has been highlighted as a "success story" by the US-PRC Joint Commission on Science and Technology. The network is generating high-quality earthquake data that will be used for a variety of research applications in China, in the United States, and in many other countries that will share the new digital data. Nevertheless, the completion of the CDSN is more a milestone than a final objective. The cooperative program is continuing, and plans are already being made to insure that the CDSN remains a viable and dynamic scientific facility that evolves to meet the future needs of the research community.

2 NETWORK DESIGN AND INSTRUMENTATION

2.1 Design Objectives

The CDSN was conceived as a national network of seismograph observatories that will generate digital data useful for seismic source studies and a variety of other research applications. China is a very large country with widely distributed regions of seismic activity. The CDSN will be a sparse network, at least initially; thus, the value of the individual station depends on its capacity to record usable earthquake data from local, regional, and teleseismic sources. Recording range and bandwidth are the key design parameters in meeting this requirement. The data systems were designed to record signals over the frequency band from about .5 mHz to 20 Hz with a detection level at or below ambient earth noise and a clipping level that will permit linear recording of moderate size earthquakes (magnitude 7) at regional distances.

Bandwidth, linearity, and dynamic range are perhaps the most important attributes of a seismograph system from the standpoint of the data user. Other essential attributes are accurate transfer functions, operational reliability, and accessibility of the data. The calibration of modern seismograph systems to within 5% is not a difficult challenge, especially for the case of force-balance seismometers, which have much greater stability than conventional seismometers without feedback. Nevertheless, it is important to provide for the validation of the theoretical transfer functions and for periodic recalibration to maintain confidence.

Achieving a high degree of operational reliablity is a more difficult objective because it depends on many different factors—equipment design, adequacy of spare parts and components, turnaround repair time, training, stability of local line power, environmental conditions, and the dedication of the people involved in operating the network. An operational reliability of 80% is a reasonable target for a new research network. Higher reliability is achievable, but costs escalate very rapidly because of the need for redundancy and special design. The methods used in this program to deal with the factors affecting reliability include the use of proven off-the-shelf equipment, the establishment of a central maintenance depot well stocked with spare parts, boards, and test equipment, training for both station operators and support personnel, and robust backup power systems at the stations. Once the facilities are in place, however, the most important factor affecting reliability is the commitment of the organizations and personnel responsible for operation of the network.

Providing timely and convenient accessibility to the network data is the function of the data management center, which is the interface between the stations and the data users. The primary design objectives for a data management center are efficiency, reliability, and adequate data handling capacity.

An instrumentation plan for the CDSN was prepared and appended to the agreement-in-principle. The plan specified the concepts and instrumentation that would be used in developing the CDSN. The selection and detailed specification of

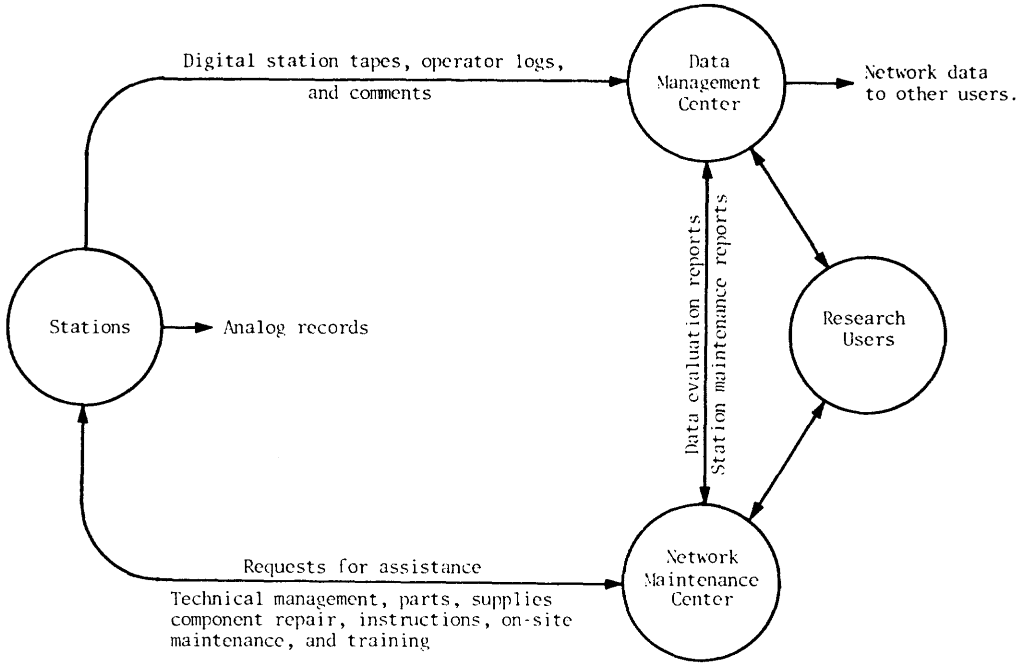


Figure 2.1. Interactive components of the CDSN network.

all hardware was necessary in order to define costs and receive preliminary export clearance, both of which were needed before the agreement could be signed. Although a few hardware changes have since been made, the CDSN is basically as described in the agreement.

2.2 Network Overview

The CDSN currently comprises nine stations, the data management center, and the network maintenance center. The SSB plans to expand the network in the future. One of the characteristics of a digital seismograph network is the interdependence of station operation, data management, depot-level maintenance, and the research users (as illustrated in Figure 2.1). Individual stations often do not have the computer facilities needed to process the digital data on site nor the expensive and complex test equipment needed to repair digital components. The stations and support facilities must be tightly coupled with good communications and oversight.

Digital data are recorded at the stations on high-density tape cartridges that are replaced at two-week intervals. The station tapes and concurrent station logs (terminal printouts) are sent by mail or other means to the data management center in Beijing. Analog records recorded at the stations are retained at the stations for local use. The station logs contain operator comments, a record of system operating parameters, and a listing of detected events.

The functions of the data management center are to collect the network data, perform data quality assessment, assemble network data volumes, archive the data, distribute the data to research users, and monitor network performance. Problems detected during the processing or any adjustments needed in system operating parameters are reported to the network maintenance center. Copies of station data from the U.S.-supplied systems are sent to the Albuquerque Seismological Laboratory where they are combined with data from the global networks on the ASL network-day tapes for further distribution.

The principal role of the network maintenance center is to support the stations. The maintenance center keeps an inventory of supplies and replacement parts for distribution to the stations, repairs defective components sent from the stations, provides instructions and advice when problems are reported either by the stations or the data center, sends technicians when necessary to assist the station operators, translates technical manuals, and conducts training for the station operators.

Research centers in China that utilize the CDSN data also have a vital role in supporting the network. Data evaluation naturally accompanies data analysis, and the more subtle problems are often detected by the data user. More important is the impetus that the research organizations provide for long-term consistency of data quality and for network improvements.

2.3 The CDSN Data Acquisition System

2.3.1 General

For purposes of description, the data acquisition system can be divided into three parts: a sensor subsystem, a digital recording subsystem, and a power subsystem. Except for some variation in the sensors used at two of the stations, the CDSN data systems are identical.

2.3.2 Sensor Subsystem

Four overlapping data bands are recorded at each station: short period (SP), broadband (BB), long period (LP), and very long period (VLP). Amplitude response curves for the four recorded bands are illustrated in Figure 2.2. The sensitivities of the STS channels (BB, LP, and VLP) are approximately the same at all stations. The SP sensitivities may be varied in 6 dB increments to adjust for differences in station background levels.

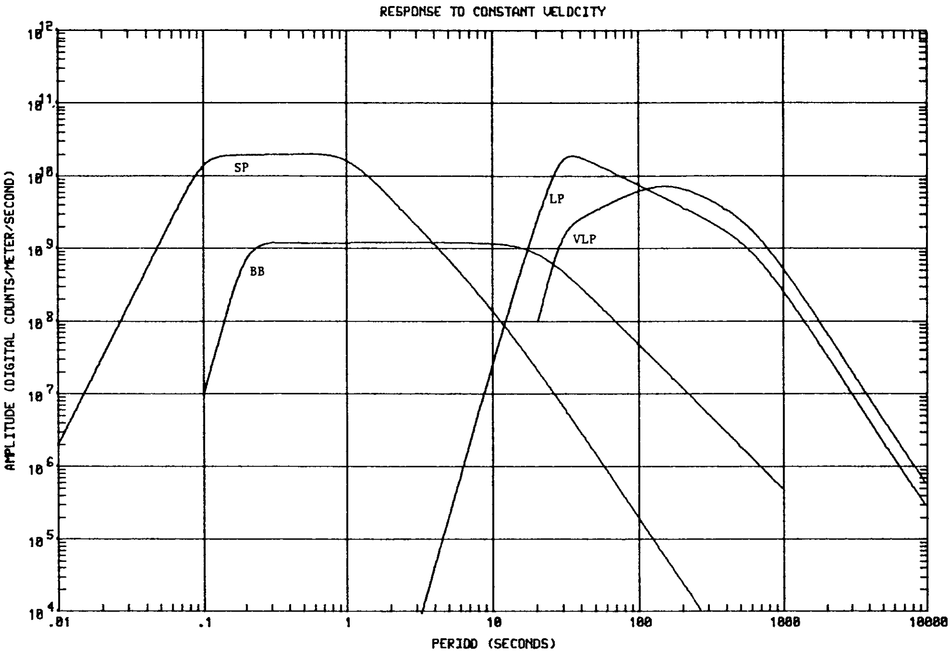


Figure 2.2. Amplitude response characteristics of the four digital channels recorded at a CDSN station.

The SP sensor subsystem consists of a three-component set of seismometers and three amplifiers. The Model DJ-1 SP seismometers (Figure 2.3) are manufactured in China by the Institute of Geophysics. They have pendulum-type suspensions, high impedance velocity transducers, and adjustable period (normally set to 1 second), and their relatively small size makes them suitable for installation in boreholes as well as vaults. The short-period signals are amplified and filtered in Teledyne-Geotech Model 56130 amplifiers. These are low-noise amplifiers with high input impedances needed to match the DJ-1 seismometers. The amplifiers are mounted together with a regulated power supply in shielded and sealed enclosures. At the Baijatuan station the DJ-1 seismometers are mounted in a borehole package installed at a depth of 135 meters. At the Lanzhou station short- and long-period signals are derived from a Teledyne-Geotech Model KS 36000 borehole seismometer installed at a depth of 120 meters.

The BB, LP, and VLP seismic signals are all derived from a triaxial set of Streckeisen STS-1 force-balance seismometers described by Wielandt and Streckeisen (1982). Each seismometer produces two outputs: a broadband output proportional to earth velocity between 0.2 and 20 seconds period and a long-period output proportional to earth acceleration at periods greater than 20 seconds. The seismometer signals are shaped in an STS-CCU signal conditioner to produce the BB, LP, and VLP signals (see Figure 2.4). The signal conditioners also provide for remote monitoring and adjustment of the seismometer mass position. Special installation techniques were developed for the STS-1 seismometers to assure good

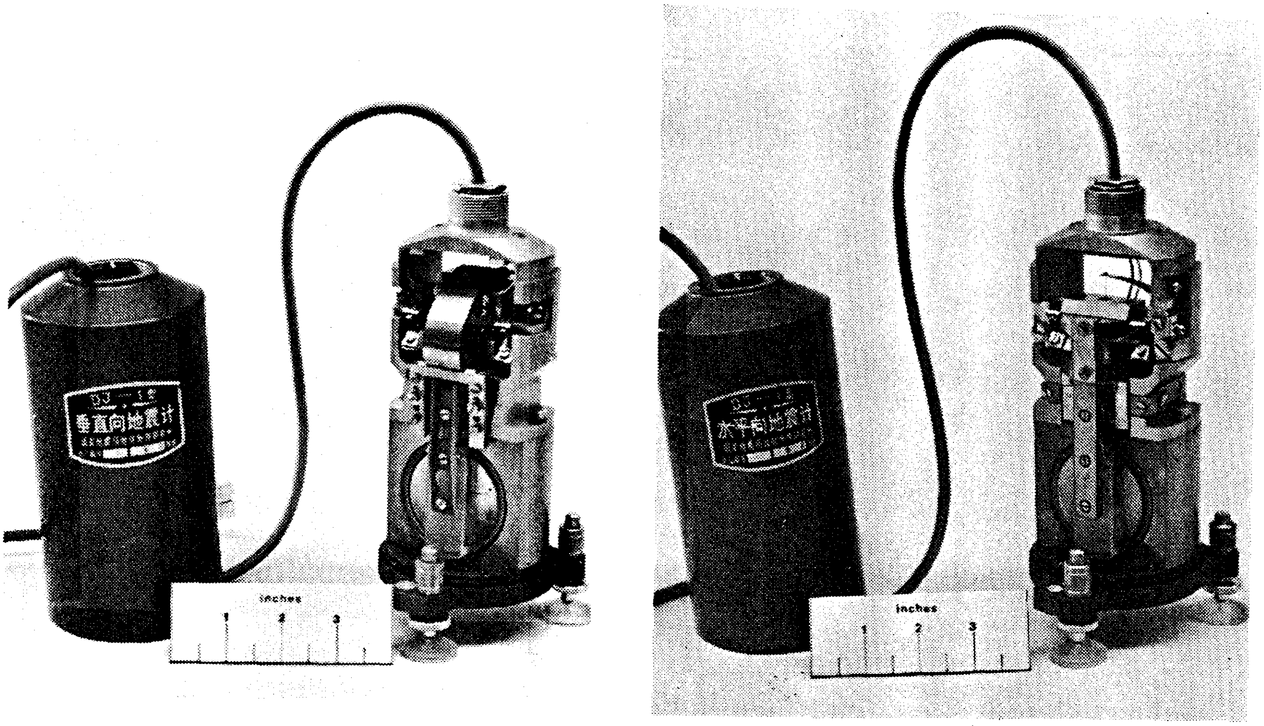


Figure 2.3. Chinese DJ-1 short-period seismometers. The vertical component is on the left, the horizontal component on the right.

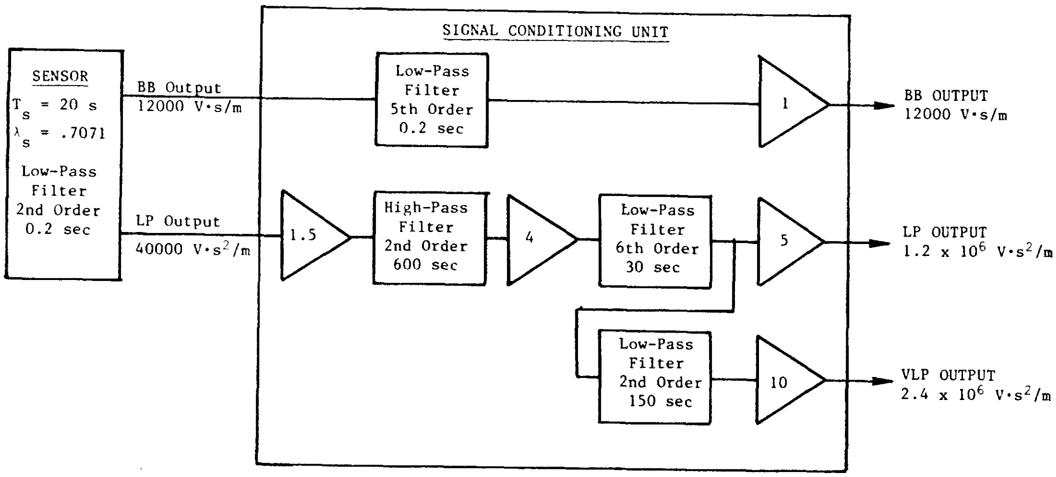


Figure 2.4. Simplified block diagram of the CDSN STS broadband sensor system.

coupling to the piers and to protect them from temperature changes in the vaults.

A detailed description of the CDSN sensor systems has been published by Peterson and Tilgner (1985). The report includes the development of transfer functions, preliminary test results, and a description of the STS installation procedures.

2.3.3 Digital-Recording Subsystem

A block diagram of the CDSN data system is shown in Figure 2.5. The digital-recording subsystem consists of an analog-to-digital converter (ADC) assembly, microprocessor assembly, tape drive assembly, terminal, digital clock, radio receiver, and a calibrator. Most of the hardware is mounted in a single full-sized rack (see Figure 2.6). A second smaller rack contains the STS signal conditioner, a signal distribution panel, and power supplies. A report being prepared by Clark, Young, and Medina describes the design of the digital recording system, and a second report being prepared by the same authors describes the CDSN electrical and mechanical assembly.

The ADC assembly contains a 16-channel multiplexer (MUX), a 16-bit ADC, and a digital-to-analog converter (DAC). The sensor signals, having peak values of 10 volts, are sampled sequentially by the MUX, then converted to 16-bit digital words by the ADC. Sampling rates are 40 samples/second for the SP signals, 20 samples/second for the BB signals, 1 sample/second for the LP signals, and .1 samples/second for the VLP signals. A gain-ranged data word format is used that provides 78 dB of resolution and 42 dB of programmable gain for a total recording range of 120 dB (14-bit resolution with sign and 2 bits used to specify gain steps of 1, 8, 32, and 128). The additional recording range is an advantage when it is important to record a wide range of signal amplitudes, as it is in this case. The DAC is used to convert digital data back to analog data for purposes of test and signal recording on site.

System control and recording functions, including event detection, reside in the software of the microprocessor assembly. This assembly consists of two 8-bit Intel microprocessors, one 16-bit Intel microprocessor, and 32 kilobytes of random access memory (RAM). The operating software is stored in programmable read-only memories (PROM). The programs may easily be replaced or modified by replacing the PROMS, which are mounted on plug-in sockets. The RAM serves as a scratch pad for signal detection operations and buffers all data channels during the formatting operations. The CDSN operating software is an essential, but not very visible, part of the data system; it is described in a report being prepared by Clark and Halbert.

The station timing subsystem consists of an Austron, Inc. digital clock and a True-Time WVTR radio receiver. The clock, which has a stability of 4 parts in 10^9, generates timing signals to synchronize ADC sampling, a digital time code that is recorded with the data on tape, and time marks for the analog recording. The radio receivers are used to synchronize the clocks to timing signals transmitted by station BPM located in central China.

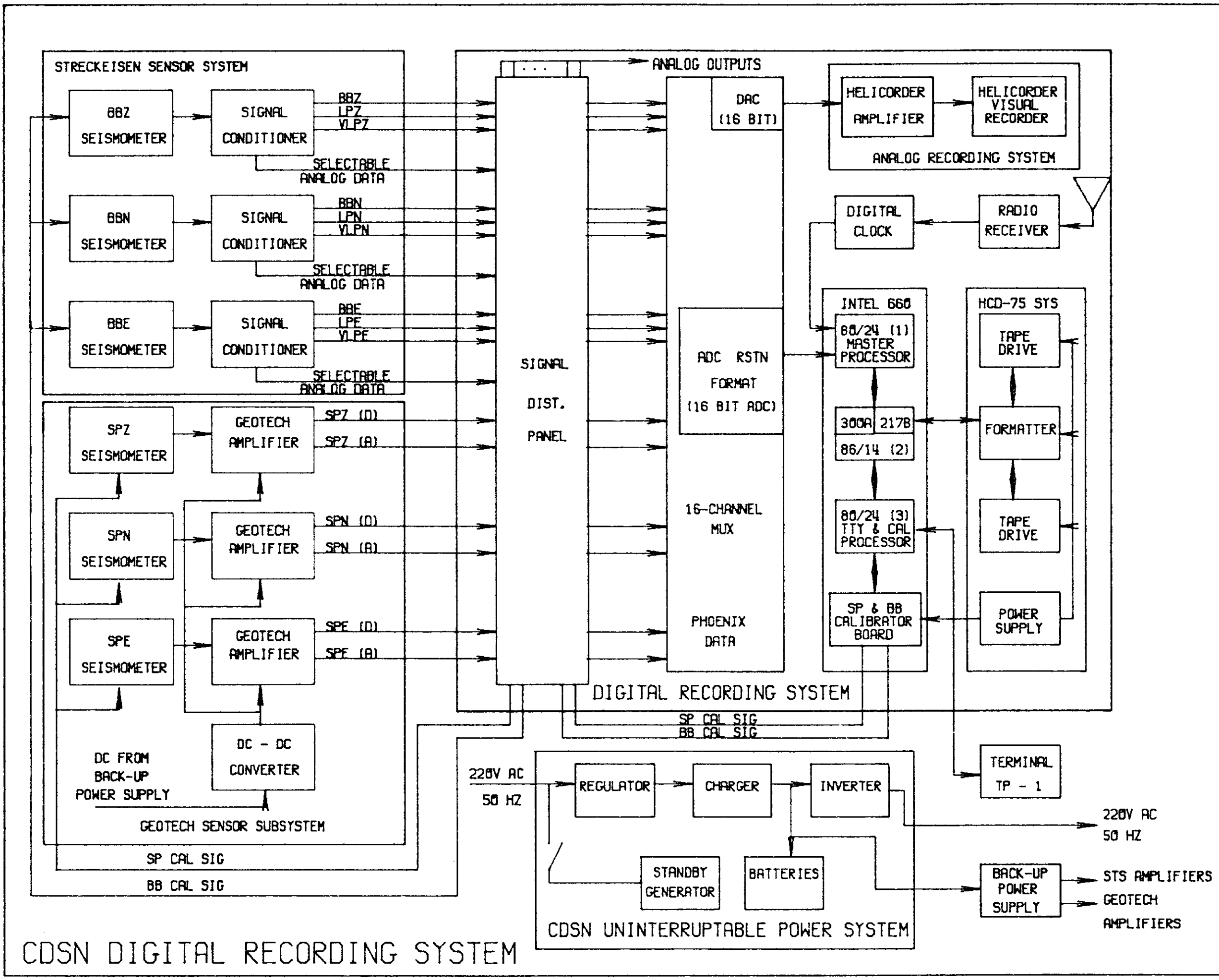


Figure 2.5. Block diagram of the CDSN data acquisition system.

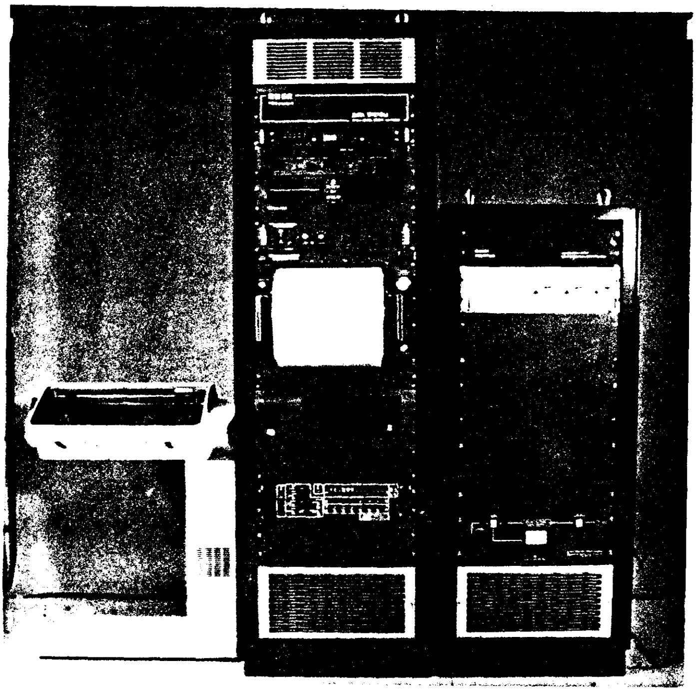


Figure 2.6. CDSN digital-recording system.

The tape drive assembly consists of a 3M formatter and two 3M HCD-75 tape drives. The high density cartridges used with these drives each store 67 megabytes of formatted data. The CDSN stations produce an average of 2 megabytes of data per day, so a single cartridge could store more than 30 days of data. However, the cartridges are changed every 14 days to speed up access to the data. The second tape drive insures that data will not be lost during tape changes or in event of a tape drive failure. Data are formatted for recording into 2048 byte-sized records. The first 20 bytes of each record contains station identification, sampling rate, time of year to the nearest 10 milliseconds, number of channels being recorded, miscellaneous and state-of-health information. The remaining bytes in the record contain data words multiplexed in a sequence of vertical, north, and east channels. Separate records are formatted and written for the SP, BB, LP, and VLP channels.

LP and VLP data are recorded continuously on the tape cartridges. The recording of SP and BB data is triggered by an automatic signal detector. The signal detector resides in the operating system software and is based on an algorithm described by Murdock and Hutt (1983) and Murdock and Halbert (1987). Separate detectors and a separate set of detection parameters are used for the SP and BB channels and operate on the vertical component signal. SP and BB data continuously cycle through a RAM buffer. When the presence of an event is detected in the ambient signal, the data stored in RAM are recorded on tape, and the recording continues until separate turn-off parameters are satisfied. A minimum of 8 SP records (67.6 seconds of data) are recorded, and a minimum of 16 BB records (240.4

seconds of data) are recorded. Recording is retriggered if the signal levels remain high. In addition to triggering recording, the detector provides an output of event parameters. The output includes event arrival time, direction of first motion, maximum amplitude of first four cycles, average period of first four cycles, and three values indicating background level and quality of onset. SP and BB data can be recorded continuously for tests and other purposes at the discretion of the station operator. Most of the settings that determine detector sensitivity and recording duration are adjustable at the station. However, an evaluation of the digital data is required over a period of time to optimize the settings for each station, and they often have to be changed seasonally.

A printer terminal has been provided with each data system. It is used by the station operator to transmit commands to the data system. All of the operator actions are logged on the printer, and the log is sent to the data management center with the station tapes. The terminal also prints the data output of the signal detector when events are detected.

A special calibrator was designed for the CDSN data system that produces step functions over a wide range of amplitudes used to calibrate the short-period and broadband seismometers. Sine-wave calibrations were performed during installation and are repeated during maintenance visits. Step functions are used for routine calibration; they are applied automatically at a preset time or manually, normally at intervals corresponding to tape changes.

A Teledyne-Geotech Helicorder has been furnished with each of the data systems. This is a visual drum recorder that is used to monitor any of the data channels through the switchable DAC. The analog recorder is used during installation and maintenance to record test data, such as sine-wave calibrations, and is routinely used by the station on a day-to-day basis to record the vertical short-period channel. In addition, a connector box in the signal distribution panel provides access to analog signals from all data channels; any of the SP, BB, or LP signals may be recorded at the station.

2.3.4 Power Subsystem

The failure of local line power is the most common cause of station downtime in a seismograph network. In addition, many of the problems and failures in digital electronic boards are directly related to transients and fluctuations in local power. Therefore, a very special effort was made to design and build a robust uninterruptible power subsystem (UPS) suitable for a CDSN station. A detailed description of the design of the CDSN UPS is provided in a report being prepared by Clark and Young.

The CDSN UPS consists of a voltage regulator, battery charger, inverter, and battery bank as the primary units. A photograph of the power subsystem is shown in Figure 2.7. Additional hardware includes system switches, transfer by-pass switches, a system status panel, and voltage/current metering.

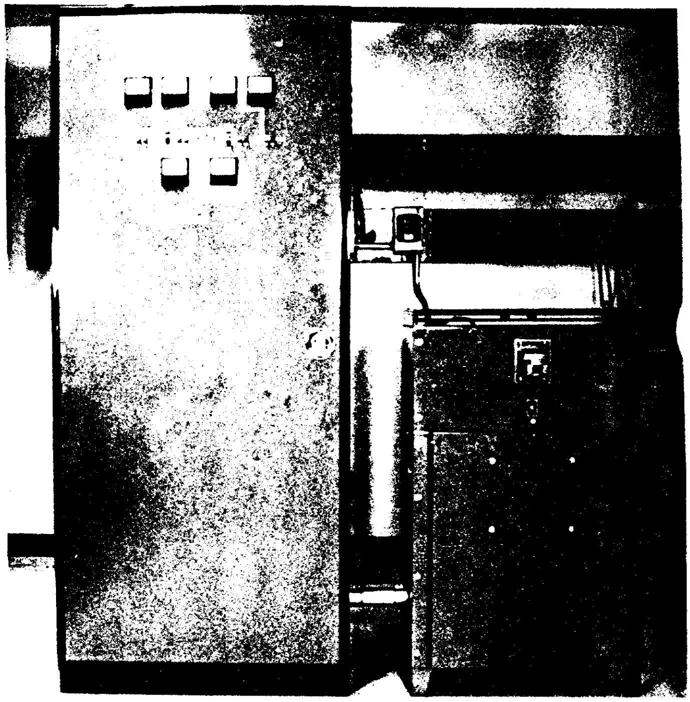


Figure 2.7. CDSN uninterruptible power subsystem; the battery rack is not shown.

The voltage regulator provides a constant 220 volts A.C. for power line voltage variations ranging from 190 to 240 volts A.C. The battery charger converts the regulated A.C. to 24 volts D.C. for charging the lead-acid battery bank. The inverter uses the 24 volts D.C. power to generate 220 volts A.C. power for use by the CDSN digital recording system and related electrical units. The battery bank provides power in the event of main line A.C. power outage for approximately four hours.

Input and output switches and fuses provide normal system connect and disconnect capabilities as well as system overload protection. Special by-pass switches provide the capability to by-pass defective regulator or charger/inverter units. This capability also allows system on-line operation when these units are serviced or repaired. It is possible to completely by-pass the regulator, charger, battery bank, and inverter and provide line power directly to the CDSN equipment.

The front panel of the power subsystem cabinet provides the station operator with a quick visual status of the entire power system. Red and green status lights are used to indicate the status of all of the critical areas of the system. If the system layout schematic shows all green lights, the system is operational. If voltage is missing at any point (which indicates a failed unit, switch open, fuse blown, or main line power outage), a red light is used to indicate the location of the problem. If any of the units are by-passed by the by-pass switches, a yellow light indicates which unit is being by-passed. Voltage and current meters are provided to monitor the status of the input power line, output power line and battery bank.

The inverter can provide 1.5 kilowatts of 220 volts, 50 Hertz A.C. power. The essential parts of the data system use approximately 600 watts of power, so there is capacity for future expansion. The 4-hour duration of backup power is based on the 600 watt power requirement. If more than the essential equipment is used, the backup time will be reduced. However, 6.5 kilowatt backup power generators are being installed at stations where line power outages are frequent.

2.4 Data Management Center

2.4.1 General

The principal functions of the data management center are to collect and process data from the network stations, assemble network-day tapes, distribute data to other organizations and research users, archive network data, and evaluate station and network operation. The routine processing of the incoming data includes cartridge to nine track copying, a computer scan of station data to detect errors, manual intervention and correction of header errors (mostly timing), a visual check of data quality and calibration, and the loading of station data into the large disk for temporary storage. The disk should be capable of holding at least 15 days of network data, about 300 megabytes in the case of the CDSN, with some excess capacity for network expansion. The network-day tapes are compiled from the data held in disk and become the media for distribution and archiving of the network data. The data management center must have the software tools needed for thorough analysis and evaluation of network data.

The CDSN data management center has essentially the same functional requirements as the data collection center used to process data from the global digital network; thus, the design of the CDSN data management system (DMS) has been modeled on the hardware and software used at the Albuquerque Seismological Laboratory. The advantages of this similarity include cost and a compatibility of operations that enhances both training and support. The design of the CDSN data management system is described in a report being prepared by Hoffman.

2.4.2 DMS Hardware

A block diagram of the DMS hardware is shown in Figure 2.8, and a photograph of the installed system is shown in Figure 2.9. A Digital Equipment Corporation (DEC) PDP 11/44 was selected as the processor for the DMS in order to be compatible with the ASL hardware and because DEC maintenance is available in Beijing. DEC peripherals include two 10-megabyte RLO2 system disks, two RA-60 disk drives with a combined capacity of 410 megabytes, two 1600-bpi tape drives, a paper terminal, and one control terminal. A Tektronix graphics terminal with a hard copy unit has been provided for displaying and copying waveforms during data quality review. A digital plotter is also available for waveform plotting. A second Tektronix graphics terminal with a flatbed plotter is used for plotting filtered wave-

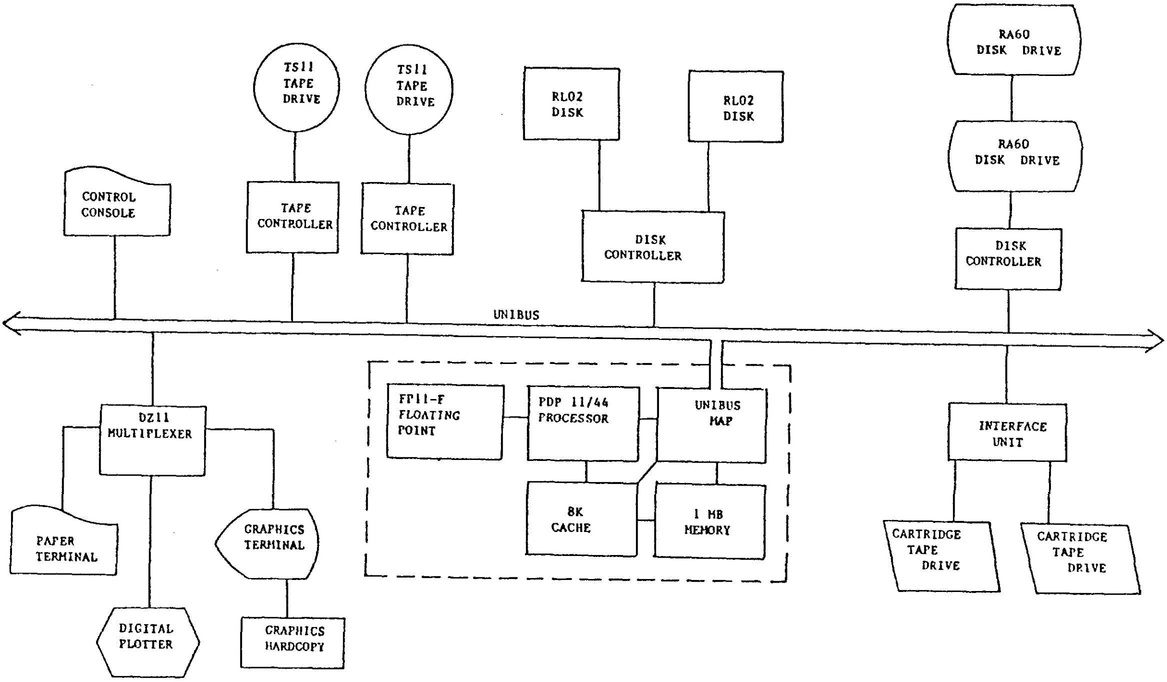


Figure 2.8. Block diagram showing major DMS hardware components.

forms, noise spectra, response curves, and other data resulting from more detailed analyses of the station data.

Finding a workable hardware interface between the HCD-75 cartridge drives and the DEC unibus proved to be one of the most perplexing problems in the DMS development. The first two interfaces purchased did not work, a third has functioned but with marginal reliability. Because the transfer of station data into the computer is a critically important process, the problem was ultimately resolved by developing a separate cartridge editing and copying system that consists of HCD-75 tape drives and formatters, a nine-track tape drive, terminal, and microprocessor assembly. The processor hardware and software is similar to that used in the field systems. The cartridge copying and editing system was installed at the Data Management Center in early 1987. It is being used to copy the station cartridges that are sent to Albuquerque and for transferring all data to nine-track tapes.

Experience with the DEC RA-60 disks since installation indicates that these are high-maintenance units, and there have been several head crashes. The use of the RA-60 disk with removable disk pack, rather than a more reliable winchester disk,

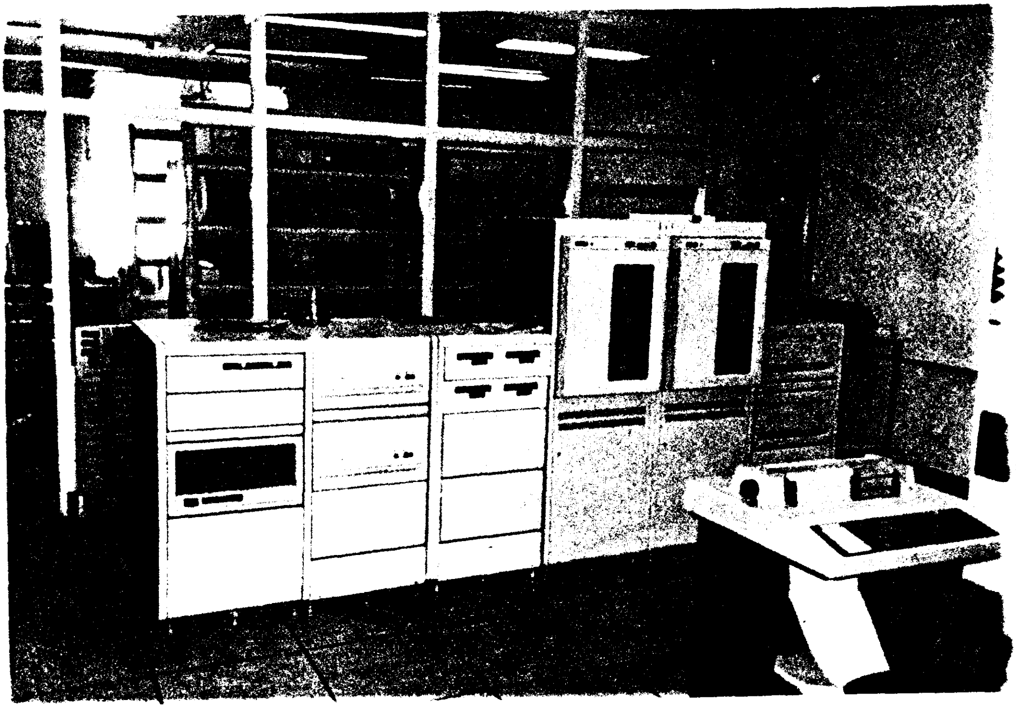


Figure 2.9. Major components of the data management system.

was dictated by the export regulations in force in 1983. The export restrictions on winchester disks have since been relaxed, so a DEC RA-81 winchester disk with a capacity of 456 megabytes has been ordered for the DMS and will be installed in late 1987 to replace the RA-60 disk system.

The DMS includes a LaMarche uninterruptible power system (UPS) consisting of a regulator, charger, battery bank, and inverter. The UPS has a capacity of 10 kilowatts and will provide backup power from the battery bank for 15 minutes, sufficient time for an orderly shutdown in case of a power failure.

The data management center has also been equipped with spare components (at a high level required by DEC and Tektronix for local maintenance) and miscellaneous equipment for the storage of tapes, logs, and files.

2.4.3 DMS Software

The DMS software has two major functions. The first is to scan and edit station data, locating and correcting errors where possible. This is done with an edit program that scans each station tape, prompting the operator for action when an error is detected. Most of the errors involve timing and other header information or parity and are easily repaired. No changes are made to the recorded data. The software contains programs for displaying and plotting waveform data to assist the operator in quality control checks. The second major function of the DMS software is the assembly of network-day tapes from the data stored in disk. The day tapes contain 26 hours of data organized by station and component. In addition to the data, the day tapes contain the essential information needed for analysis (station coordinates, timing offset, transfer functions, etc.) so that the processing can be fully automated. The tapes may also contain comments concerning the status of stations or individual components.

In addition to the major software used for routine processing of the station data, other software, mostly written in Fortran 77, has been furnished to provide a more detailed look at the network data. The analysis software includes routines for filtering, displaying, and plotting data, computing and plotting spectral data, computing and plotting response functions, reading network-day tapes, and similar processes. The DMC staff is writing additional programs of this type.

2.5 Network Maintenance Center

Full operation and maintenance of the CDSN in China by the Chinese is a common goal of the SSB and the USGS. The key to self sufficiency is a well equipped and well stocked network maintenance center with a proficient staff. The functions of the network maintenance center (NMC) are to resupply the network stations with operating material and replacement parts, replace and repair system components and boards sent in from the stations, send advice and instructions to the station operators, provide on-site maintenance at the stations when necessary, and provide training for the station operators.

The maintenance center has been equipped with a complete data system. Set up and fully operational, it is used to test modified or repaired system components and boards and for training in system operation and maintenance. Major test equipment provided to the center includes a microprocessor tester for testing Intel boards, a digital system analyzer for full system testing, an IC tester, a microcomputer with software for testing 3M formatters, cartridge drives, and tapes, and a digital storage scope. Other items of test equipment include oscilloscopes, multimeters, a voltage standard, a multifunction counter, strip-chart recorders, and function generators. The maintenance center is very well equipped to troubleshoot and repair CDSN modules and boards. Nevertheless, some boards and equipment will require factory repair because of the use of proprietary parts or test equipment.

The maintenance center has been stocked with well over $100,000 of spare equipment and component parts ranging from complete assemblies (sensors systems, ADC, microprocessor, tape drive, clock, etc.) to small parts. Equipment components that require factory repair (ADC boards, for example) have been stocked in higher quantities to allow for the long turnaround time for repair.

Equipping and stocking the network maintenance center is a relatively easy task. Developing the proficiency needed to operate the maintenance center will require training and experience. During the next few years, backup support will be provided by the Albuquerque Seismological Laboratory.

3 NETWORK DEVELOPMENT, DEPLOYMENT, AND OPERATION

3.1 System Development

All of the major components of the CDSN systems had to be chosen before the agreement could be signed. Partly as a result of this requirement, the decision was made to design and assemble the CDSN systems at the Albuquerque Seismological Laboratory rather than to contract with private industry for this work. The development of the data acquisition systems and the depot maintenance center was assigned to the ASL Engineering Section, headed by Harold E. Clark, Jr., and the development of the data management system was assigned to the ASL Data Processing Section, headed by John P. Hoffman.

Work began soon after the agreement was signed. Specifications were prepared for more than twenty separate contracts for hardware. A meeting to coordinate activities and make final decisions on system design was held in Beijing in September 1983. Soon after, orders were placed for the data management system components and components for six data systems.

Despite the extensive use of off-the-shelf hardware in the data system, it was necessary to design and construct interfaces, power supplies, the UPS systems, calibrators, and many mechanical assemblies. Software development was the most complex task. A development system was purchased so that the software could be written in a high level language and downloaded to PROMs in 8086 machine language. The event detector, which is the largest of the program modules in the data system, was converted to C language, then tested and optimized on the ASL PDP 11/70 using test data from the global networks. Other major software modules were developed for control and timing of the ADC, formatting and recording, and operator input and output. Part of the system software was developed in house and part by contract with a local software development firm.

Delivery of components for the data systems began in early 1984. All of the components were tested using special procedures developed for acceptance testing. The only item with a high failure rate was the Phoenix Data analog-to-digital converter; most of these units had to be returned to the factory several times before they successfully passed the tests. The 3M high-density tape cartridges were new, at least to the Albuquerque Laboratory, and a special test system was assembled using a microcomputer to verify the tape drives, controllers, and preformatted tape cartridges. Problems initially attributed to the tape drives or tape were later found to be caused by the custom interface used to load the cartridge data into the DEC computer. The testing of individual components and the assembly of the data systems took place over a two-year period because of multi-year funding for the program. Eleven data systems were assembled, nine for the network stations, one for the network maintenance center, and one that remained at ASL to serve as a testbed for software and hardware modifications. Because of their size and weight, the power subsystems were assembled first, tested, then packed and shipped via surface transport to China. They arrived in mid 1985. The fully assembled data systems (less sensor and power subsystems) were tested at ASL for several weeks. The first data system, called the demonstration system, was shipped in January 1986. The remaining nine data systems were shipped a few months later.

The development of the data management system, although modeled on ASL hardware and software, turned out to be more difficult than expected. The delivery of the hardware took nearly a year, a fully satisfactory interface between the 3M cartridge drive and the DEC Unibus was never found, and the conversion to UNIX Version 7 added significantly to the amount of software that had to be written. The DMS hardware was delivered by September 1984, the DEC RA-60 disks having the longest delivery time (prolonged by damage in shipment). The hardware was fully assembled at ASL so that the system could be used for software development and testing. Since the CDSN software is similar in function to the ASL software used to process global network data, a contract was awarded for the development of the DMS software to the Lisle Computer Company of Albuquerque, New Mexico, which had developed and supported the ASL software. The decision was made to use the more advanced UNIX Version 7 BSD 2.9 as the operating system in place of Version 6, which was being used at ASL. The new version lacked software drivers for the tape and disk drives and other peripherals. As a result, the software development took much longer than expected. However, the major development work was completed by late 1985. The hardware was carefully packed and crated, then air shipped to China in January 1986.

Test equipment and other hardware and software for the network maintenance center was purchased early in the program because much of the test equipment was needed during the development and testing of the data systems. Most of the maintenance equipment, major spare parts, storage cabinets and other material needed for the maintenance center were shipped before the data systems. However, boards and other smaller parts are still being ordered and supplied, as it is more economical to let experience rather than guesswork dictate the levels of spare parts.

One of the important tasks associated with systems development is the development and assembly of the documentation—reports, manuals, schematics, source codes, and related material—needed to operate and support the instrumentation. There are 15 manuals with each data system, about 20 books and manuals for the maintenance center, and about 30 manuals and books with the data management system. Many of these had to be translated into Chinese by technical personnel at the Institute. The schematics, drawings, source codes, and other final documentation will be sufficiently detailed to build reproductions of the data acquisition and data management systems.

3.2 Training

Training has been an important part of the program, and there have been three separate stages of training during the establishment of the network. In June 1984, a group of seven Chinese, led by Zhou Gongwei, arrived in Albuquerque for three months of training. Zhou Gongwei, Xia Enshan, and Chen Junliang concentrated on the data acquisition system and maintenance equipment and assisted in the testing and assembly of system components. Li Wenquang and Huang Yulin specialized in computer hardware; they were enrolled in DEC training courses at a school in Massachusetts. Mu Qiduo and Chen Qiang specialized in computer software; they received formal training in UNIX, Fortran, and C and informal training in data processing by assisting in the ASL data collection center. Unfortunately, much of the CDSN hardware had not been delivered at the time when this training took place.

The second phase of training planned by the Chinese CDSN staff took place during the installation of the equipment. In February 1986 station operators were brought from Lanzhou, Kunming, Qiongzhong, and Sheshan to take part in the installation of the Baijatuan system and receive training. In May 1986 station operators were brought from Enshi, Hailar, Mudanjiang, and Urumqi to assist with the installation of the Lanzhou station and receive training. The station operators were then prepared to assist with the installation and perform the calibration of their new equipment. Data management system training followed the installation of the DMS during February 1986 and the installation of the final software configuration in June 1986. During the first year of CDSN operation, a joint CDSN/USGS team visited all of the stations and provided on-site training during system maintenance.

Follow-up training for the station operators was provided after the stations had been in operation for some time. In April 1987 all of the station operators were gathered at two network centers, and they received additional training by Brian Brizzell and the CDSN staff. They were able to communicate and discuss their experiences in operating the CDSN data systems.

The several phases of training have been effective. The station operators are able to perform all of the routine maintenance and deal with many of the problems that cause minor recording interruptions. The data system at Urumqi was temporarily moved when the recording room floor was replaced and returned to operating condition and recalibrated by Lin Xiling and Yang Yife of the Network Maintenance Center without assistance.

3.3 Site Preparation

In 1982 the State Seismological Bureau and a Chinese technical group drafted a siting plan for the new digital network taking into account both the need to monitor earthquakes within China and the desire to cooperate in international research programs. The selection of sites was based on practical considerations rather than solely on seismic background noise. Existing observatories were selected for the new network, although this would limit the monitoring capability of the network to some extent. In August 1983 the SSB issued an "investment plan for general engineering implementation of the Chinese Digital Seismograph Network", and site preparations began.

At Baijatuan station a recording room was rebuilt and a new room for the power supply was added. The STS seismometers are installed in the original underground vault. Work began in March 1984 and was completed in September of the same year. The borehole for the short-period seismometers was completed in December 1984.

A new building was constructed at the Lanzhou station to house the digital and analog recording equipment. The construction began in October 1983 and was completed in December 1984. The STS seismometers are installed in the original vault and the power supply is installed in an original room. Boreholes for the DJ-1 seismometers and the KS-36000 seismometer were completed in May and August of 1984.

A new building was constructed at the Enshi station to house the digital and analog seismograph recording equipment and the power supply. New rooms in the vault were built for the seismometers. Work began in April 1984 and was completed in September of the same year.

The recording room at the Kunming station was rebuilt to house the digital equipment, and a new room was added for the power supply. The seismometers are installed in the original tunnel. Construction began in June 1983 and was finished by the end of 1984.

The Qiongzhong station has a new building with rooms for the digital recording equipment and main power supply, and new rooms in the vault for the CDSN seismometers. Construction began in June 1984 and was completed in February 1985.

All of the observatory rooms were newly built at the Sheshan station. Work began in December 1984 and was completed in May 1985.

The Urumqi station has a new building for the digital recording equipment. The seismometers are installed in an original vault. Construction began in September 1983 and was finished in October 1985.

A new observatory room for digital equipment was built at Hailar. Seismometers are installed in an original tunnel. Construction began in April 1984 and was finished in December of the same year.

A new observatory room for digital equipment was also built at Mudanjiang. The seismometers are installed in an original tunnel. Work began in July 1985 and was finished in September of the same year.

The data management center and network maintenance center are in adjoining rooms that have been reconstructed for this purpose. The construction began in

April 1984 and was finished in June of the same year.

There has been additional work at many of the stations since 1984. This includes road construction, reconstruction of power facilities, and installation of generators, air conditioners, and dehumidifiers.

3.4 Facility Installation

The installation of the CDSN was performed in phases. In January 1985 an ASL technician assisted the Chinese CDSN technical staff with the installation and testing of sensor systems at the Baijatuan and Lanzhou stations. Special techniques and special equipment are needed to insure that the broadband sensors are well bonded to the pier and isolated from ambient fluctuations in temperature and pressure. The installation procedures, testing, and curing of cement require several weeks, so it is good practice to install the sensor systems early. The sensor systems were installed at the other stations by the CDSN staff in the several months that followed.

The station uninterruptible power subsystems were also sent to China early because of the time required for installation. Conduit had to be installed, and building modifications or additions were often needed. In August 1985 an ASL technician assisted with the installation of station power subsystems at Baijatuan and Sheshan. The remaining power subsystems were installed by the CDSN staff and station personnel in the several months that followed. The power subsystem for the data management center was also installed early by the CDSN staff.

The first digital recording system was installed at Baijatuan in February 1986 by ASL and CDSN technical personnel, and the station was brought into operation. The data management system was installed during the same time period by ASL and CDSN technical personnel. The equipment had arrived undamaged, so the installation went smoothly and was completed within a week. During the following three weeks, ASL specialists trained DMC technicians in data center operations.

The purpose of installing the demonstration data system and the DMS before the rest of the network stations was to provide a period of a few months that could be used by the CDSN staff for hardware and software familiarization without being concerned about continuous data flow.

ASL personnel returned to China in May 1986 to install the digital recording systems at the remaining stations. During an eight-week period, the installation team, which consisted of ASL and CDSN staff personnel, made a complete circuit with stops in Beijing, Lanzhou, Kunming, Qionqzhong, Enshi, Sheshan, Urumqi, Hailar, and Mudanjiang. It was a grueling schedule that could not be modified easily because transportation arrangements had to be made for the complete itinerary in advance. Installation included the physical installation of the equipment and several days of calibration and noise tests, the results of which were carefully documented in installation reports. Most of the systems were installed without difficulty. The Qiongzhong station could not be operated initially because of problems with line power, and several of the stations required follow-up work to complete calibration tests cut short by the tight schedule and to replace marginal or defective components. Most of the follow-up work, including the new power line at Qiongzhong and backup generators at other stations, was completed by year end.

While station installation was in progress, work was also underway at the data management center to install and test the data processing software in its final configuration, repair software bugs, and train the computer operators in the assembly of network-day tapes. Most of this work went smoothly, although there were hardware problems with the RA-60 disk and the custom interface board between the cartridge drives and the DEC computer. The RA-60 disk was later repaired by a technician from the DEC Hong Kong office.

The assembly of CDSN network-day tapes began on October 1, 1986. This is considered to be the date that the network became operational, although it was clear at the time that much work remained to get all of the stations and other facilities operating at peak performance levels.

3.5 Inventory of CDSN Facilities

3.5.1 General

The operational facilities of the CDSN are briefly described below. More detailed descriptions of the stations, together with test and calibration data, are provided in the station installation reports, which are on file at the Institute of Geophysics in Beijing and at the Albuquerque Seismological Laboratory in Albuquerque, New Mexico.

3.5.2 Baijatuan (BJI)

Station Location:	40° 02' 25" N 116° 10' 30" E
Station Elevation:	BB/LP/VLP: 43 meters SP: -107 meters
Vault Type:	Subsurface, 3 meter depth
Borehole Depth:	170 meters
Geologic Foundation:	BB/LP/VLP: gravel SP: Limestone
Station Chief:	Xi Yunzao
Station Operators:	Yang Xiaoning Yao Liping

The Baijatuan station, located about 20 kilometers north of Beijing, has been in operation since 1957 as a combined seismological and geomagnetic observatory. The station and nearby facilities are used for development and testing of new instruments and for training as well as observatory operations. The station is situated in a hilly, mostly agricultural region. There are nearby rock quarries and rock crushers. The broadband seismometers are installed in a subsurface vault three meters below the surface on piers that rest on gravel. The short-period seismometers are installed in a borehole at a depth of 170 meters in limestone. Station power is very stable. There is an excellent subsurface vault tunneled into a limestone hill a few kilometers from the present station site, and plans to move the CDSN system to the new vault are being considered.

3.5.3 Enshi (ENH)

Station Location:	30° 16' 55" N	109° 29' 51" E
Station Elevation:	487 meters	
Vault Type:	Surface	
Geologic Foundation:	Limestone	
Station Chief:	Li Jiagying	
Station Operator:	Sun Bolin	

Enshi is a small town in southwest Hubei Province. The station is located on a hill about one kilometer from the main street of Enshi. Both broadband and short-period sensors are installed in a surface vault. The remoteness of Enshi (2-3 days full travel from Beijing) makes this station somewhat difficult to support.

3.5.4 Hailar (HAI)

Station Location:	49° 16' 00" N	119° 44' 30" E
Station Elevation:	610 meters	
Vault Type:	12 meter tunnel, 15 meter depth	
Geologic Foundation:	Andesite	
Station Chief:	Wang Chunshan	
Station Operator:	Ji Fengyou	

The station is located outside Hailar City on the bank of the Hailar River in the Inner Mongolia Autonomous Region. The sensors are located about 12 meters from the entrance of a vault that has been tunneled into an andesite hill. There are quarries operating nearby. Initial problems with station line power were corrected when the station was connected to a more reliable power substation.

3.5.5 Kunming (KMI)

Station Location:	25° 08' 53" N 102° 44' 50" E
Station Elevation:	1952 meters
Vault Type:	30 meter tunnel, 27 meter depth
Geologic Foundation:	Limestone
Station Chief:	Pan Debao
Station Operators:	Pan Zhihong Miao Jun

The station, located in the outskirts of Kunming in Yunnan Province, began operation in June 1957 and is one of the standard seismological stations of China. The region where the station is situated is hilly and mostly agricultural although there are major industries within five kilometers of the station. Facilities are excellent. The sensors are installed some 30 meters from the entrance of a vault tunneled into a limestone hill.

3.5.6 Lanzhou (LZH)

Station Location:	36° 05' 12" N 103° 50' 40" E
Station Elevation:	BB/VLP: 1560 meters SP/LP: 1440 meters
Vault Type:	Surface
Borehole Depth:	120 meters
Geologic Foundation:	BB/VLP: Loess SP/LP: Sandstone
Station Chief:	Yang Jiawen
Station Operators:	Peng Weirong Liu Jianyi

The station, located on the northern outskirts of Lanzhou in Gansu Province, is one of the standard seismological stations of China. It opened in 1954 at the Lanzhou University and was relocated to its present site in 1957. The broadband sensors are installed in a buried surface vault built on loess. Only the BB and VLP signals are derived from the STS sensors; SP and LP signals are obtained from an SRO-type KS 36000 borehole seismometer. Within one kilometer of the station there is a large broadcasting antenna network used for Post Office communications, plus a very large industrial complex. The antenna network is suspected of causing some noise in the long-period signals.

3.5.7 Mudanjiang (MDJ)

Station Location:	44° 36' 59" N 129° 35' 31" E
Station Elevation:	250 meters
Vault Type:	50 meter tunnel, 50 meter depth
Geologic Foundation:	Granite
Station Chief:	Sun Wenbin
Station Operators:	Wang Enze He Yueshi

The station is located on the edge of a valley in the outskirts of the city of Mudanjiang in eastern Heilongjiang Province. Mudanjiang is one of the standard seismological stations of China and has been in operation since 1972. The station has excellent vault and recording facilities with the vault tunneled into a granite hill. There are two factories about 1 kilometer south of the station.

3.5.8 Qiongzhong (QIZ)

Station Location:	19° 01' 46" N 109° 50' 36" E
Station Elevation:	230 meters
Vault Type:	Surface
Geologic Foundation:	Granite
Station Chief:	Wang Kangping
Station Operators:	Liang Hong Lu Yongjian

The station is located in an isolated region in the center of Hainan Island about a three hour drive from Haikou. It was opened in 1977. The sensors are installed in a surface vault built on a granite hill. Early problems with line power have been resolved by the installation of a new power line to the station.

3.5.9 Sheshan (SSE)

Station Location:	31° 05' 44" N 121° 11' 12" E
Station Elevation:	10 meters
Vault Type:	Surface

Geologic Foundation: Andesite

Station Chief: Ding Weiguo

Station Operator: Zhuang Jinlong

The station is located 60 kilometers west of Shanghai at the base of a large hill surrounded by rice paddies. Sheshan is one of the standard seismological stations of China. It was originally opened in 1907 under the name Zi Ka Wei, relocated in 1952, and again in 1976 to its present site.

3.5.10 Urumqi (WMQ)

Station Location: 43° 49' 16" N 87° 41' 42" E

Station Elevation: 970 meters

Vault Type: Subsurface, 6 meter depth

Geologic Foundation: Sandstone

Station Chief: Zhang Yunfeng

Station Operators: Liu Xianlun
Zhou Huisheng
Ma Shigui

Urumqi is one of the standard seismological stations of China and has been in operation since 1964. The station is located on the outskirts of Urumqi City in western Xinjiang Uygur Autonomous Region. There is a quarry within two kilometers of the station. The sensors are installed in a subsurface vault tunneled into a sandstone hill.

3.5.11 Network Maintenance Center (NMC)

Location: Academy of Sciences Building
Sanlihe, Beijing

Staff: Zhou Gongwei, Chief
Xia Enshan, Depot Engineer
Liu Xiling, Depot Technician
Yang Yifei, Depot Technician

3.5.12 Data Management Center (DMC)

Location:	Academy of Sciences Building Sanlihe, Beijing
Staff:	Mu Qiduo, Chief Chen Qiang, Data Processing Zhang Decun, Data Processing Mu Weili, Station Tape Processing Liang Jing, Day-Tape Processing Liu Chun, Programmer/Operator Fu Zuqiang, Equipment Engineer Zhang Boming, Data Services and Research

3.6 Operational History

3.6.1 General

The first full year of CDSN operation has been a busy one with significant progress in generating a steady flow of data from the stations and in organizing data management and network support activities. All of the early problems with power and equipment at the stations have been resolved, and the outlook for reliable network operation is very good.

3.6.2 Station Performance

Data availability from the network for the year beginning August 1986 was about 75%. For the last four months of the year, the data availability has been 95%. The improvement reflects the amount of hard work and commitment from both sides since the installation of the network. Three of the stations had long downtimes because of line power deficiencies. These problems have been corrected by the State Seismological Bureau, and backup power generators have been provided to all stations. At several stations the data were degraded by noise attributed to poor cabling and grounding. These problems have also been corrected. Early in the year there were numerous hardware problems at the stations. Board failures have declined significantly during the past six months, consistent with a typical burn-in pattern. Fewer outages and cleaner station power also help to reduce board failure. The only known software bug, a defect in the event detector that prevented retriggering for large events, has been fixed, and event detector settings have been adjusted at all stations. A station-by-station summary of performance is provided below.

Baijatuan. In August 1986 the cabling was rerouted and a full calibration was made, and the station has operated continuously since then except for minor outages. In February the station clock was replaced, and a broken wire was repaired in the STS signal conditioner. Recent intermittent spiking in the SP channels has been traced to the borehole seismometer, which is submerged in water. The problem is under investigation.

Enshi. In November 1986 the STS vertical and north channel electronics were replaced, having been defective since installation. In December an Intel 86/14 board, an SP amplifier/filter, and an STS VLP FGA board were all replaced. In May the STS vertical component sensor and electronics were replaced, the ADC boards were replaced, and the station was recalibrated. Power outages were frequent. In June the substation transformer was replaced, and the station has since been operating normally. Excessive vault humidity may be the cause of sensor component failures. The remoteness of the station and poor telephone communication make this the most difficult station to support.

Hailar. The Hailar station had long and frequent power outages from installation until mid November when the station was connected to a major substation. A back-up generator was also installed. In December 1986 the HCD 75 formatter was replaced. In March 1987 an Intel 80/24 board was repaired, and the station was recalibrated. Since then, the station has operated continuously.

Kunming. The Kunming station was visited for maintenance in September 1986. The short-period sensor system was completely recabled to eliminate spiking noise, the UPS inverter was repaired, and the printer was replaced. The station has operated continuously since the September visit.

Lanzhou. The Lanzhou station was plagued by spiking and other electronic noise in the long-period channels during much of the first year of operation. However, after several maintenance visits and complete recabling and grounding, the noise was eliminated. Line power at this station is very stable, and a backup generator is available if needed. An HCD-75 cartridge drive was repaired on site, and two problems with the STS signal conditioner were repaired on site. Except for downtime because of maintenance, the station has operated continuously since early 1987.

Mudanjiang. Line power to the station was disconnected for most of the winter beginning in mid November 1986. A new 26 KVA backup generator was installed in late January, and the power company has indicated that power will be provided to the station in subsequent winters. In December a defective STS board, ADC board, HCD-75 formatter, and SP amplifier/filter were all replaced, and the station was recalibrated (power was temporarily restored for the maintenance visit). In March an Intel board that interfaces with the HCD-75 drive was replaced, and in April a horizontal DJ-1 seismometer was replaced. The station has been operational since the March visit.

Qiongzhong. This station was not operated following installation because of low line voltage. Although the power subsystem was designed to handle the low input voltage, the air conditioners would not function and heat in the recording room rose above the critical operating range of the digital equipment. In November 1986 a new substation was installed, and the station has operated continuously since then. Minor repairs were made on site during a maintenance visit in February and an HCD-75 drive was replaced in May.

Urumqi. This station has a good operational record despite numerous equipment failures during the first year. In September 1986 an Intel interface board and the radio receiver were replaced, and SP sensors were adjusted and recalibrated. In February an Intel power supply and the DJ-1 horizontal seismometers were replaced, an STS board was repaired on site, and the SP system was recalibrated. In May the clock oscillator was replaced. In July the system was down for one week in order to replace the recording room floor, and a printer keyboard was replaced. Line power is stable, but there are outages once or twice a month. A backup generator has been installed.

3.6.3 Network Maintenance Center

The Network Maintenance Center is critically important to network operations. It must be well equipped and well staffed. The NMC not only supports the network stations, but it is responsible for the technical management of the stations. This assures that standard procedures are in effect throughout the network.

The personnel assigned to the maintenance center participated in both the installation of the stations and the follow-up maintenance visits; therefore, the full equipping and organization of the NMC was delayed until the network was well established. However, much progress has been made during the past year by the NMC staff in organizing the center, setting up inventories of parts and supplies, and in establishing test and repair procedures. The stocking of additional spare parts and components has proceeded throughout the year.

The depot personnel react quickly to station problems, by shipping spare components, troubleshooting by phone or telegram, or by a maintenance visit. There have been a total of 26 maintenance visits during which equipment was serviced, calibrations were performed, and the operators were trained.

Defective equipment and boards not requiring factory service are repaired in the maintenance center. Types of equipment that have been repaired at the center include SP amplifier/filter assemblies, crystal oscillators, STS-1 sensor system electronics, and recorders.

A variety of technical manuals have been prepared by the NMC staff, including a "Working Manual for Digital Seismograph Stations", "Observatory Standards for Digital Seismograph Stations (first draft)", "UPS Main Power Supply", and a "Booklet on the STS-1 Seismograph". An "Operation Standard for Digital Seismograph Stations" was published and put into use. Also, a report entitled "Station Dispatches" has been distributed to advise all stations of experiences that individual stations have had in equipment operation.

3.6.4 Data Management Center

The DMC processed 186 station tapes during 1986 and 217 station tapes through July 1987. Ninety-two network-day tapes were compiled in 1986, and 127 through July 1987. Data quality is checked as soon as the tapes arrive from the stations. Checks are made of SP and BB calibration, and samples of SP, BB, LP, and VLP noise background are selected for playback and analysis. The amplitudes of the step responses are studied statistically for monitoring the stability of the seismograph systems. In July and August problems with the RA-60 disk drives caused some delays in compiling network-day tapes and in cataloging earthquake events. The disks were repaired in early September by a DEC technician, and operations are now normal.

Data exchange takes place on a regular basis. Copies of tape cartridges from the five designated stations are sent out weekly. Through July 1987, 279 station tapes were sent to the USGS, and 39 event tapes have been received from the USGS. The DMC staff has also developed the software to compile event data for Chinese scientists, and more than 200 earthquake data files have been provided.

The data management system hardware has operated during the year quite well with the exception of the RA-60 disk drives. The space tolerance between the heads and the disk surface is exceedingly small, and there have been three head crashes during the year. A contributing factor is the relatively severe dust problem in Beijing, especially during the winter coal-burning season. Day tapes can still be assembled when one of the drives is inoperable, but at a slower pace. The drives must be serviced by DEC through their Hong Kong office. A DEC RA-81 winchester disk has been ordered to replace the RA-60 disk drives. The winchester disk drives are sealed and expected to be more reliable.

A second hardware problem exists with the HCD-75 formatters manufactured by the 3M Corporation. These units are part of the hardware used to make copies of the station tapes. Formatter problems have caused some timing errors in data distributed through ASL. However, both sides have worked together to insure that there has been no serious disruptions in the flow of data.

The DMC staff has prepared manuals for day tape assembly and hardware diagnostics and developed improved and new software for data processing and research. In addition, the staff has provided software for setting up network management files on an IBM microcomputer that include station tape recording times, a progress chart of day-tape assembly, lists of spare parts and consumable supplies stored at the stations, and general information on station maintenance.

The NMC and the DMC personnel cooperate closely, communicating information on data quality and the operational status of the stations. A group comprised of members from each center meets daily to evaluate data quality.

4 PRELIMINARY EVALUATION OF CDSN DATA

4.1 General

The most critical and important evaluation of a new seismic data base is performed by the scientists that use the data. Feedback from the research community is an essential part of network management and plays the major role in shaping the plans for improvements and modernization. At this point, there has been little opportunity to gather information from CDSN data users; therefore, this preliminary evaluation of the network data is based for the most part on early testing and the analysis of background signals at the stations. The latter is useful both for validating the operation of individual sensors and for characterizing background noise at the stations.

The CDSN recording format of continuous LP and VLP data and triggered SP and BB data is illustrated in Figures 4.1 through 4.4, in which data from the Urumqi station have been plotted much like 24-hour seismograms. As in this case, most stations have higher levels of horizontal-component noise during the daytime hours. The SP and BB channels trigger separately, record for minimum preset times, and continue recording if signal levels remain high. The detectors are sensitive. A few close-up examples of event data are shown in Figure 4.5. However, automatic signal detection is a compromise, especially in broadband recording. The detector operates through a narrow-band filter to prevent false detections by microseisms; as a result, it is unlikely to retrigger on teleseismic S-waves and surface waves. Some adjustments are possible to extend broadband recording of teleseismic signals.

A few representative earthquake signals recorded on the CDSN systems are displayed in Figures 4.6 through 4.10 to demonstrate the capability of the system to record local, regional, and teleseismic signals. The recording system clipping level is slightly more than 1,000,000 digital counts, zero to peak.

4.2 Preliminary Sensor System Test Results

The major objectives of the early sensor system tests were to insure that system noise does not mask signals of interest at quiet sites, to develop and validate system transfer functions, to investigate sensor installation methods, and to integrate sensor system components. Linearity tests on the STS sensor system had already been performed and reported by Wielandt and Streckeisen (1982).

The DJ-1 seismometers and Teledyne short-period amplifiers were operated together in the ASL vault. The transfer functions for the amplifier and the seismometer-amplifier combination were computed and validated by measurement (see Figures 4.11 and 4.12). The maximum digital sensitivity of the SP sensor system was designed to be 2 x 10^{10} digital counts per meter per second. However, the sensitivity can be adjusted to match background levels, and all of the CDSN stations have SP sensitivities set at least a factor of 10 lower than the maximum setting. Examples of computed and measured step responses for the SP sensor system are shown in Figure 4.13. A step function input will be used for routine calibration, and analysis will be automated. The stability of parameters subject to drift (seismometer period and sensitivity constants) can be monitored by measurement of the peak amplitude of the step response, and with a good signal-to-noise ratio, which is obtained by driving the system to one-half of full scale, it should be possible to derive individual transfer functions from the step responses through direct Fourier transformation or by least-squares fitting. The development of automated calibration techniques is one of the projects that will be undertaken by the CDSN staff in China.

Noise tests were made on the short-period sensor system to insure that the noise levels were below expected seismic background levels and also to provide a baseline for additional testing during installation and maintenance. Two vertical-component seismometers were operated side by side in the ASL vault, and their recorded signals were compared. The displacement power spectral densities computed from the signals are shown in Figure 4.14 and a plot of the coherence function is shown in Figure 4.15. The signal-to-noise ratio in the period range from .05 to 0.1 seconds, where it is lowest, is about 12 dB (assuming equal noise power in the two test systems), which is more than adequate for resolving signals at locations having background noise levels similar to those at the Albuquerque observatory. Equivalent test data from two DJ-1 horizontal-component seismometers operated in parallel are shown in Figures 4.16 and 4.17. Although coherence between the horizontal instruments at high frequencies is somehat lower than for the vertical components, the difference is not significant. The DJ-1 seismometer is clearly capable of producing high-quality short-period data.

The reference curve labeled LNM (low-noise model) in Figure 4.14 and subsequent figures in this report is a straight-line approximation of noise spectra published by Li and others (1984) for the period range from .04 to 0.4 seconds, by Peterson (1980) for the period range from 0.4 to 100 seconds, and by Agnew and Berger (1978) for periods greater than 100 seconds. It is useful as a baseline for noise power comparison. The curve is a composite of noise spectra from dozens of sites throughout the world. There is no known site that has noise characteristics that match the low-noise model.

The relative amplitude response and phase response of the STS broadband channels computed from the transfer function are shown in Figure 4.18 together with measured points. Examples of computed and measured step responses are shown in Figure 4.19. The velocity sensitivity of the broadband recording at the CDSN stations is nominally 1.2×10^9 digital counts per meter per second. It was not intended that BB sensitivity adjustments be made at each station. At the current nominal sensitivity, the stations will record body-wave signals from a magnitude 7+ earthquake at a distance of 8° without overdriving. Noise power spectral densities computed from three-component BB signals recorded in the ASL vault are shown in Figure 4.20.

The relative amplitude and phase responses of the STS long-period channels computed from the transfer function are shown in Figure 4.21. The acceleration sensitivity of the LP channels is nominally 6 x 10^{11} digital counts per meter per second^2 at all of the CDSN stations. Noise tests at ASL on the STS sensor systems at long periods have shown that, when properly installed, these instruments are exceptionally quiet. Noise power computed for a three-component set of STS sensors during a quiet wind-free period and coherence between the two horizontal components, which were operating in parallel, are shown in Figure 4.22. A comparison of noise power computed from an STS horizontal component operated in the vault and from an SRO-type borehole sensor installed at a depth of 100 meters is shown in Figure 4.23. Little difference can be noted. STS sensor installation procedures were found to be important during the testing to provide good isolation from pressure and temperature changes, and to obtain good bonding with the pier. Despite careful installation in a good vault, horizontal sensors operated near the surface respond to pressure-induced tilt deformation caused by wind and turbulence from heating. An example of increased noise as a result of wind is shown in Figure 4.24. The magnitude of the tilt noise is dependent on the depth of the vault and the rigidity of the rock. Long-period data from horizontal sensors operated in a surface vault on a poor geologic foundation are very noisy and of limited usefulness.

The relative amplitude and phase responses of the STS VLP output are shown in Figure 4.25. The VLP output is essentially a decimated version of the LP output with a slightly higher sensitivity at long periods.

As a result of the testing at Albuquerque, it was concluded that the DJ-1 and STS sensor systems were well suited for the CDSN. Suitable installation techniques were developed and tested, and the sensor systems were successfully combined with the other components of the data acquisition system.

4.3 Station Data

Data from each CDSN station have been analyzed to insure that the individual components are operating properly and to characterize the background noise levels at the stations. SP, BB and LP data segments are displayed in Figures 4.26 through 4.52 together with power spectral densities computed from the segments shown. SP and BB data were taken from test tapes made during installation or maintenance visits when the SP and BB channels were recorded continuously for a 24-hour period to provide data needed for background measurements and for evaluating the settings of the automatic event detector. The selected data shown were recorded during quiet, event-free periods, usually at night; thus, the noise power presented in the figures represents minimum noise at the stations. In almost all cases, short-period (0.1 to 1.0 seconds) noise increases 6 to 12 dB during the daytime hours. The short-period cultural noise is relatively high at most of the CDSN stations because they are located close to populations centers. The level of noise in the long-period band is related directly to the depth of the sensors and the geologic foundation. At stations with surface vaults, the background noise in the horizontal-component data may increase as much as 20 dB during daytime hours.

The relationship between long-period tilt-induced noise and geologic foundation is apparent in the Baijatuan data (Figure 4.28). The STS sensors are installed in a shallow subsurface vault built on a gravel base, and the amplitude of horizontal noise is correspondingly high. Despite the large amplitude of the horizontal noise at BJI, the magnitude of the tilt is very small—less than 6 x 10^{-10} radians rms in a one-octave band centered on 100 seconds period. The vertical component is not measurably affected by the tilt. Short-period noise power is also a function of sensor emplacement, as demonstrated by comparing the SP and BB noise power between periods of 0.2 and 1.0 second at BJI where the SP sensors are installed at a depth of 170 meters in limestone. Similar data are shown for the Lanzhou station (Figures 4.38 and 4.39) where the BB sensors are installed at a surface vault on loess and the SP sensors are installed at a depth of 120 meters in sandstone. The relocation of the BJI system to a new vault tunneled into a nearby hill is being considered.

A comparison of data from all stations and from individual channels shows a very high consistency of data quality. Early problems with system noise at several stations have been resolved. There is no easy solution to the relatively high short-period noise levels at the stations. Three of the stations (MDJ, QIZ, and SSE) have short-period noise spectra typical of coastal locations; at the other stations, the short-period spectra are dominated by cultural noise, which can only be avoided by moving the stations to remote locations. This happens to be a problem that is worldwide. As in China, most seismograph observatories were constructed more than 20 years ago, and, although many of the sites were isolated at the time, there has been a steady encroachment over the years that has degraded the short-period data. Solving the problem of long-period horizontal noise is also difficult and expensive, as it could require the construction of new vaults or the use of borehole seismometers.

4.4 Conclusions and Recommendations

The installation of the CDSN has significantly improved the quality of digital data available for earthquake research in China. The new network is also a source of superior digital data for augmenting the global database. There are certain to be modifications and improvements to the CDSN. A network that is not dynamic in this respect will become obsolete very rapidly.

Although any major changes should await a more thorough evaluation of the CDSN data by analysts who are using the data for research, there is at least one recording modification that seems to be indicated as a result of the preliminary evaluation. Because of the relatively high short-period noise levels at the stations, the SP recording sensitivity is 20 dB less than originally planned and only slightly higher than the BB recording sensitivity. The BB recording sensitivity should be decreased. This will improve the capability of the network to record signals from the very large earthquakes that are certain to occur in China.

The network detection capability would be improved by increasing the SP sensitivity. However, this could only be achieved by relocating the systems to quieter sites.

Some additional work needs to be done on the broadband event detector so that all principal body- and surface-wave phases will be recorded from large earthquakes at distances equivalent to the dimensions of the network (about 40°). The quick solution is to extend the recording time following each trigger or retrigger. A decrease in BB sensitivity will result in fewer detections, so an increase in recording time will not necessarily produce more data. A better long-term solution is to develop a special broadband detector with a turn-off algorithm sensitive to long-period phases.

The testing of the systems and the preliminary evaluation of the network performed by the CDSN and USGS staffs show that the main configuration of the systems have been established as originally planned. The CDSN, which is the first digital seismic network in China, is one of the most advanced digital networks in the world. As intended, it has a large dynamic range and a wide bandwidth that covers the seismic spectrum from short to very long periods. The establishment of the CDSN has created a new source of digital data that will benefit research and encourage new studies in theoretical seismology and earthquake prediction.

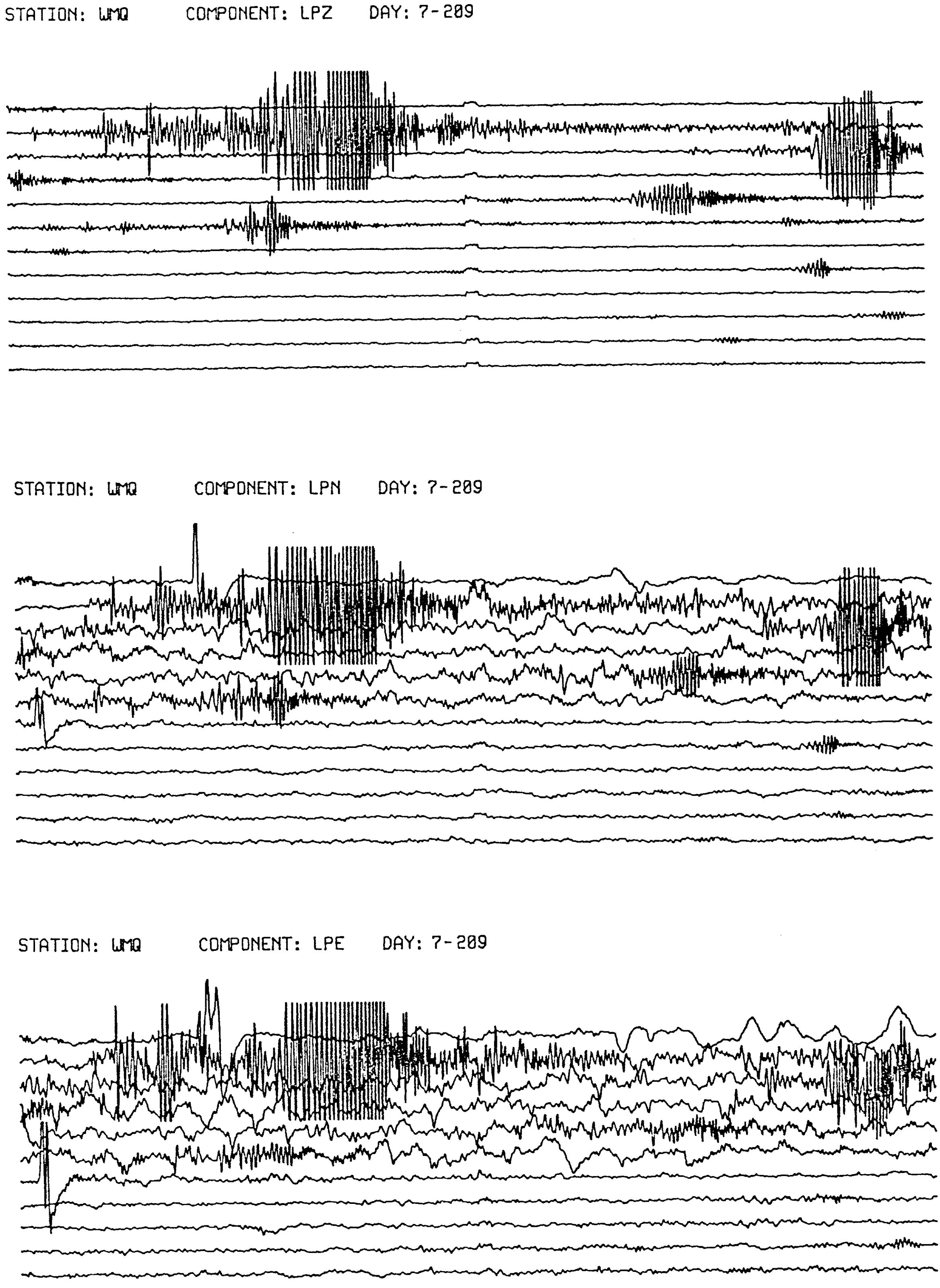


Figure 4.1. Twenty-four hours of long-period data recorded at Urumqi. Each trace is 2 hours in length, and the upper trace begins at 00 hours GMT. The magnification of the original plots before reduction was 25,000 at a period of 25 seconds.

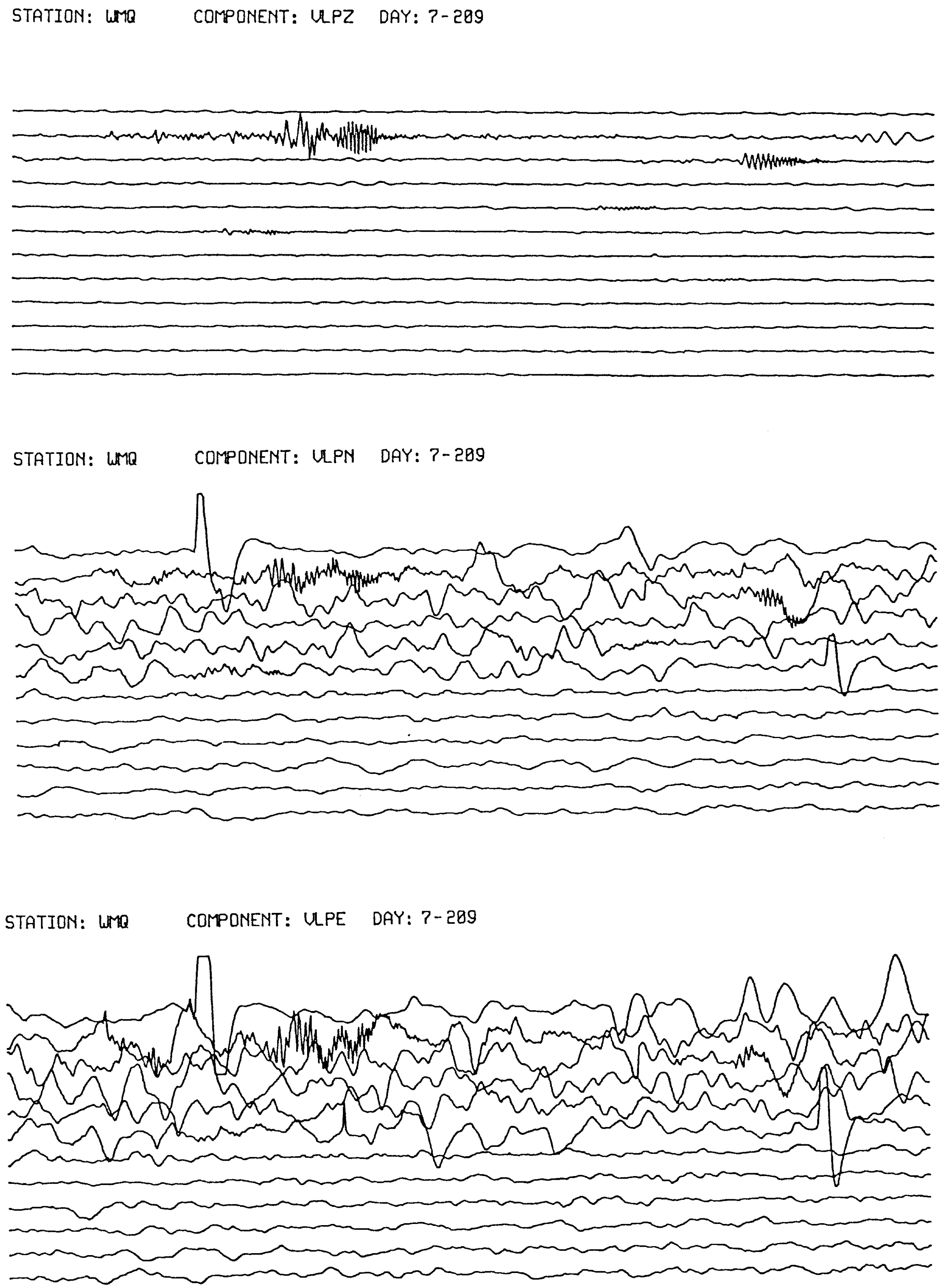


Figure 4.2. Twenty-four hours of very-long-period data recorded at Urumqi. Each trace is 2 hours in length, and the upper trace begins at 00 hours GMT. The magnification of the original plots before reduction was 5,000 at a period of 100 seconds.

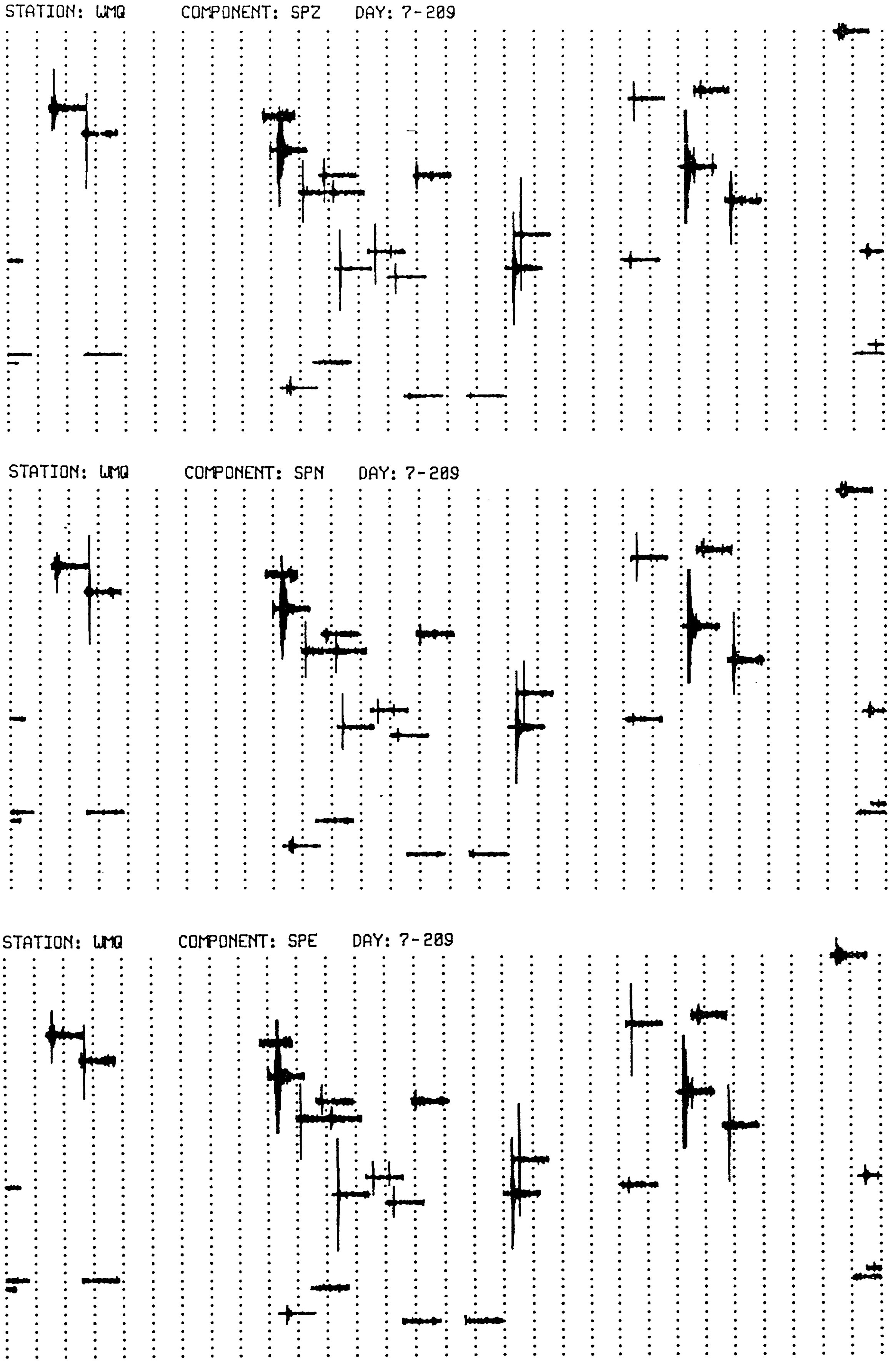


Figure 4.3. Twenty-four hours of short-period event recording at Urumqi. Each trace is 30 minutes in length, and the upper trace begins at 00 hours GMT. The magnification of the original plots before reduction was 100,000 at a period of 1 second.

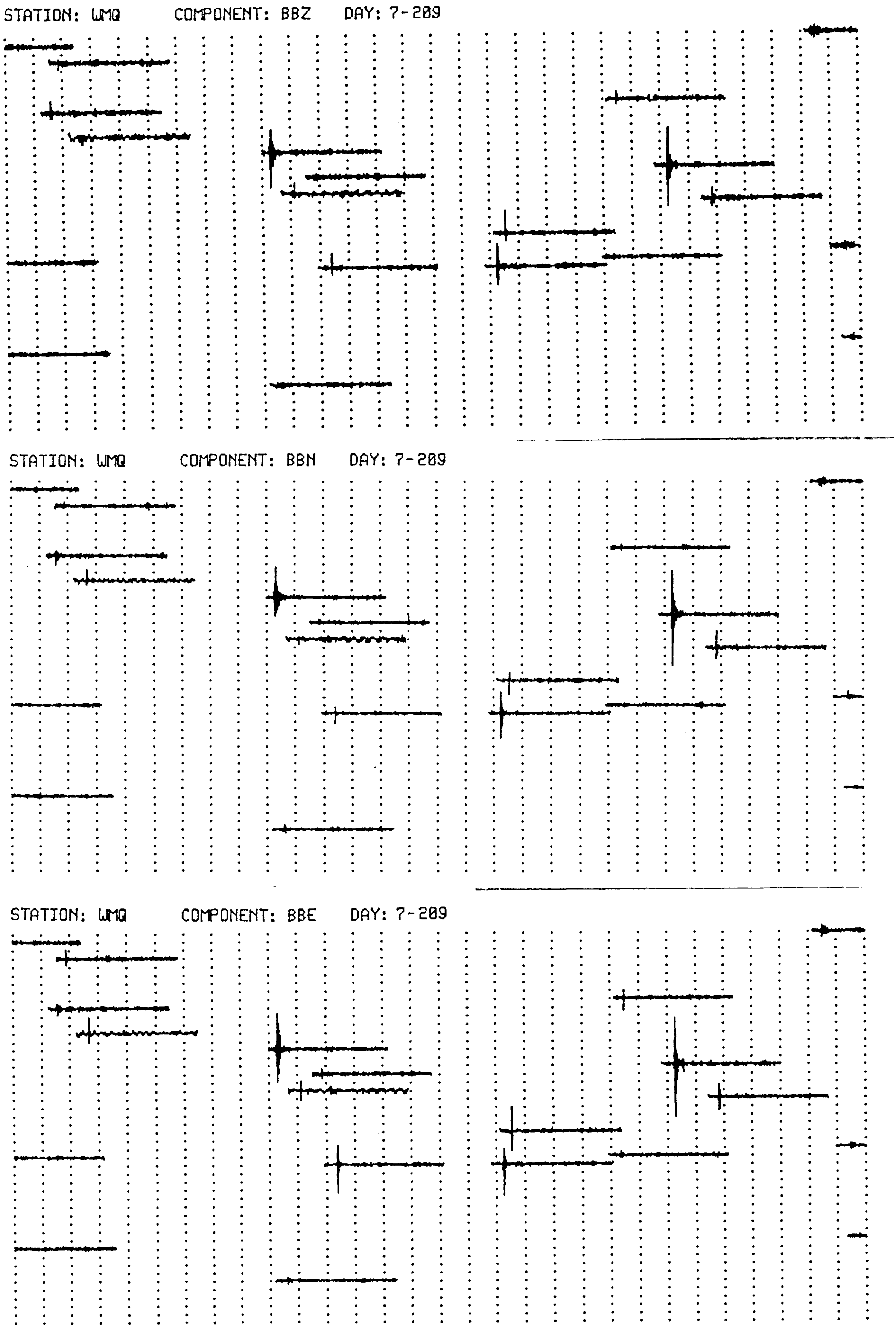


Figure 4.4. Twenty-four hours of broadband event recording at Urumqi. Each trace is 30 minutes in length, and the upper trace begins at 00 hours GMT. The magnification of the orginal plots before reduction was 50,000 at a period of 1 second.

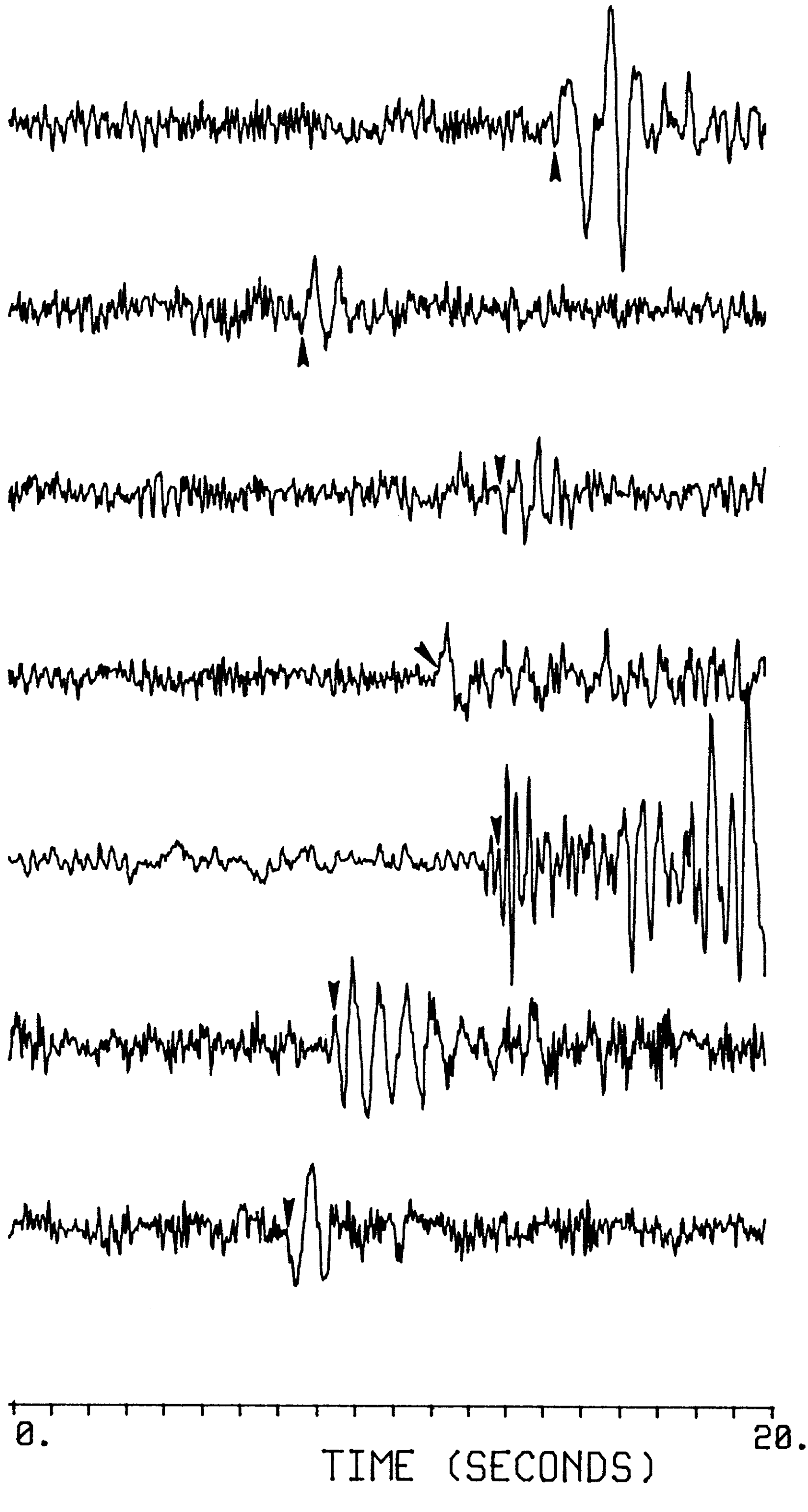


Figure 4.5. Examples of short-period triggered events recorded at Urumqi (last seven events from Figure 4.3). Only the first 20 seconds of the minimum of 67.6 seconds of recorded signal are shown. The arrowheads indicate the points in the waveforms where the detector was triggered.

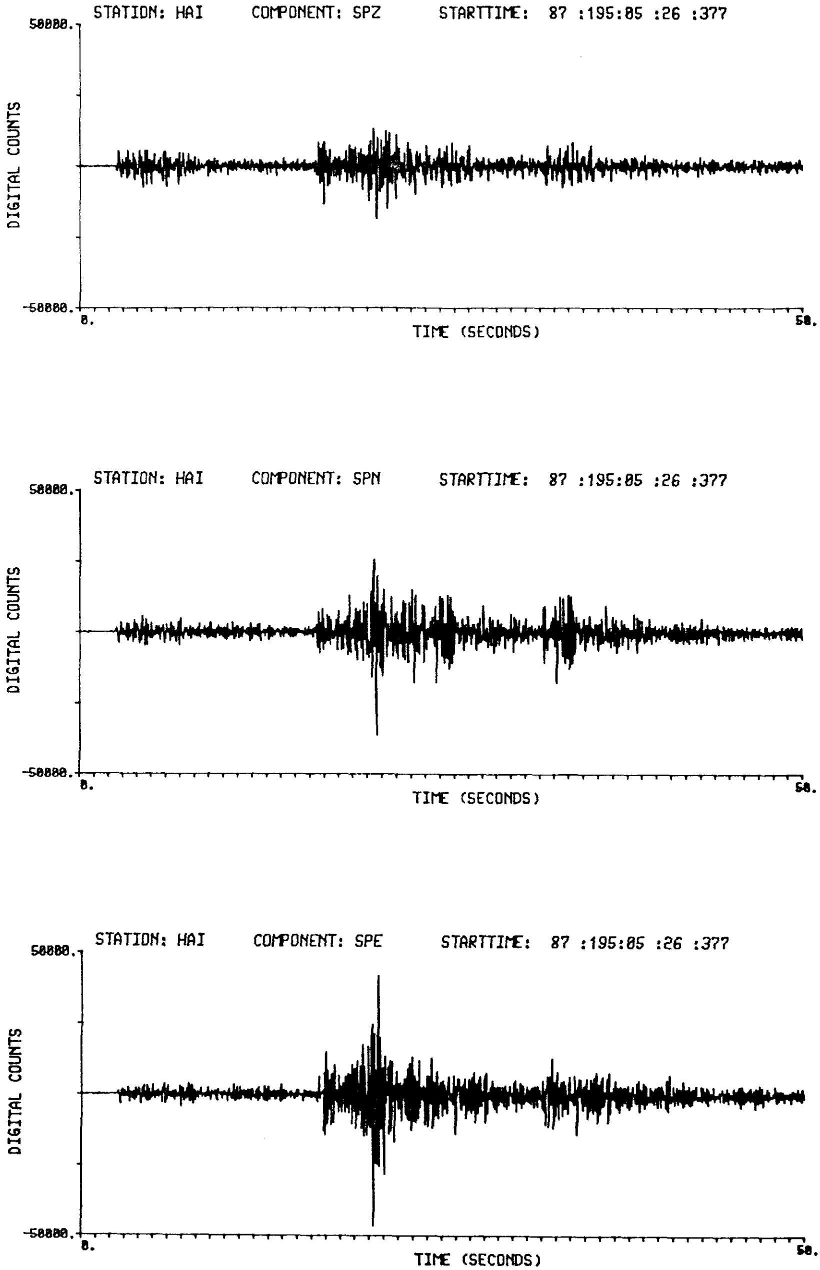


Figure 4.6. A local event of unknown origin recorded on the SP channels at Hailar.

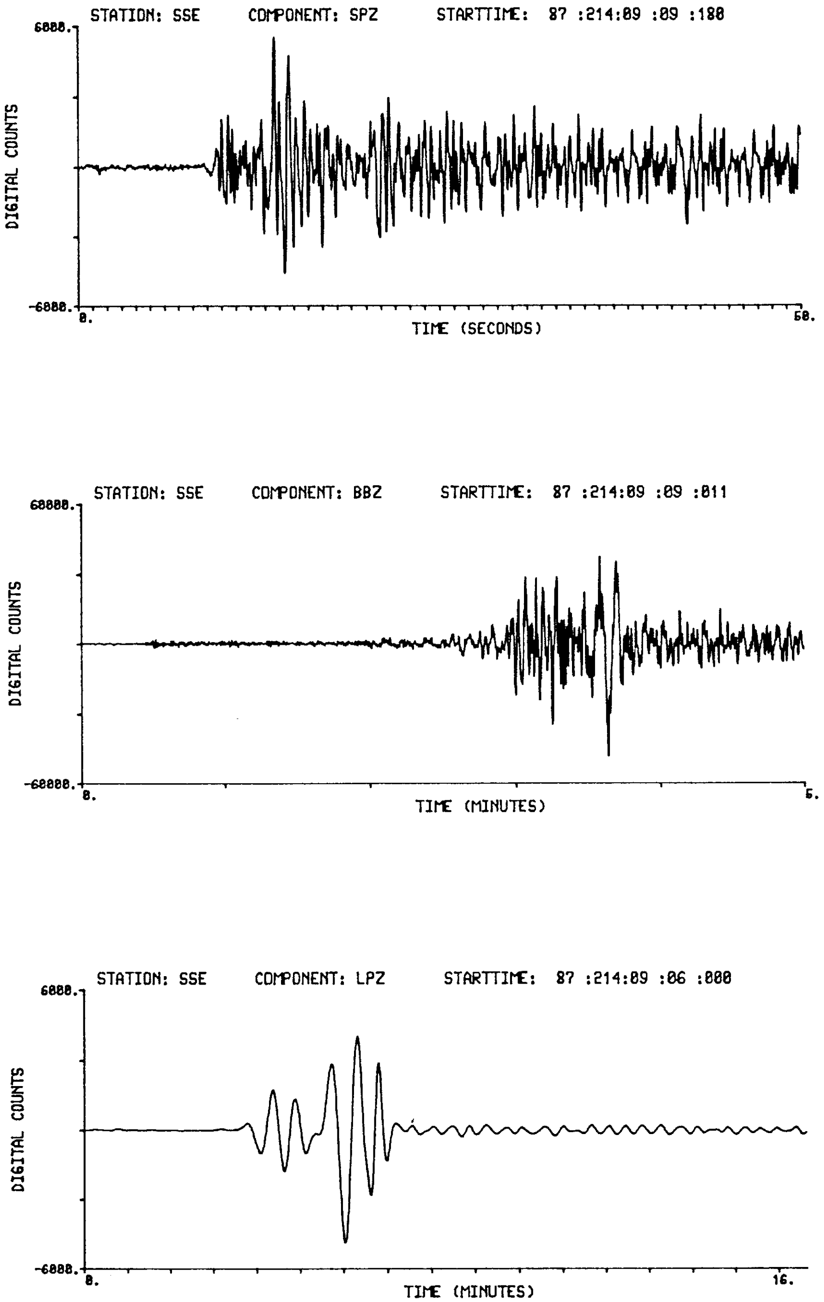


Figure 4.7. A magnitude 4.9 earthquake located near the southeastern coast of China recorded on the vertical-component SP, BB, and LP channels at Sheshan. The segments are not time aligned. Horizontal components were recorded, but not shown.

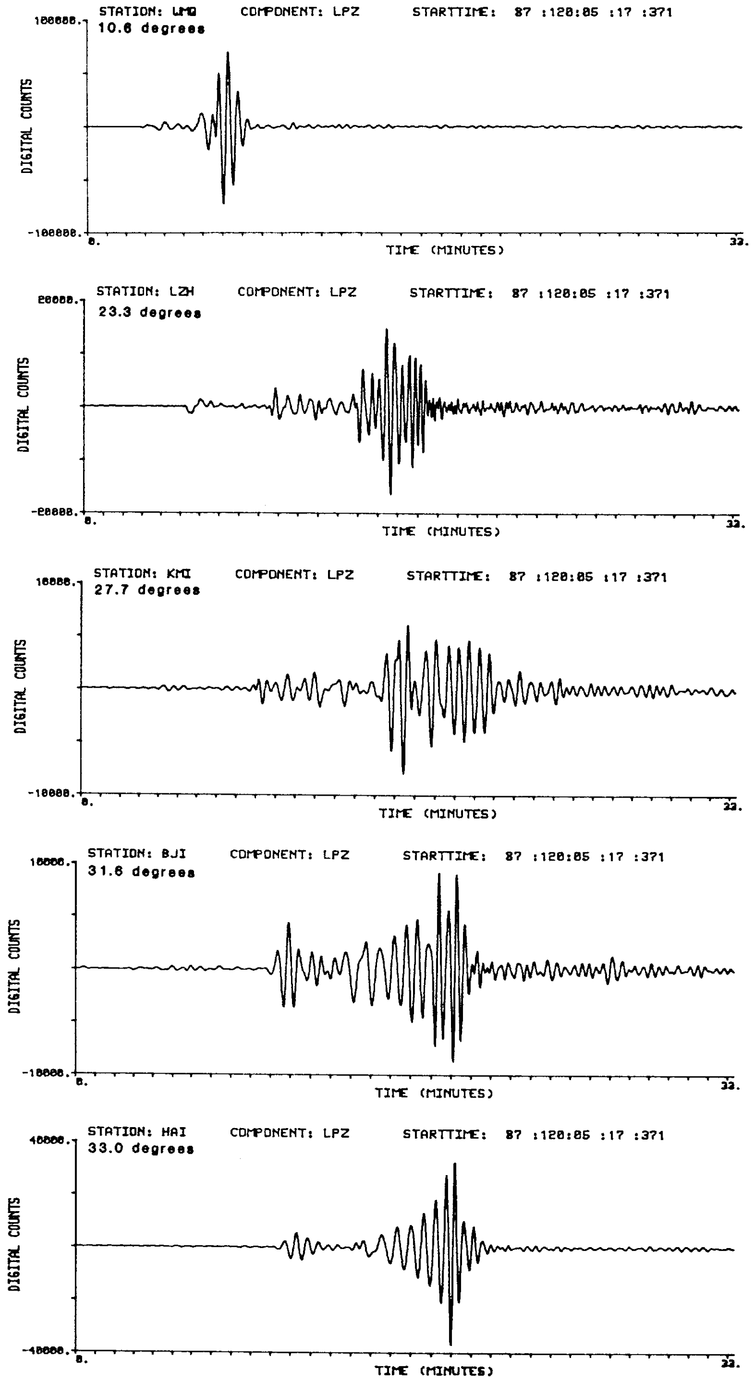


Figure 4.8. Long-period vertical-component signals of a magnitude 5.6 earthquake in western Xinjiang Province recorded at five of the CDSN stations. Segments are aligned on time of origin.

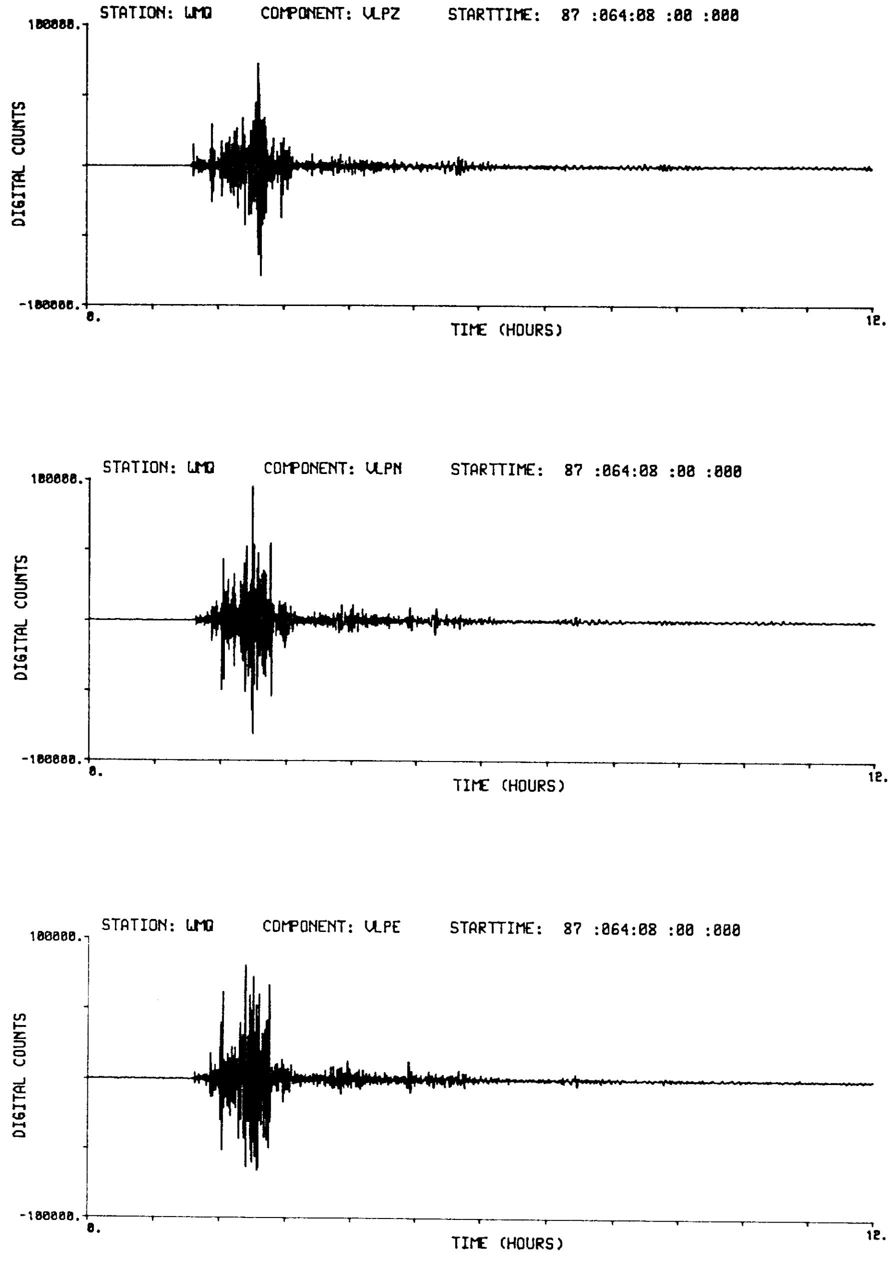


Figure 4.9. Very-long-period recording at Urumqi of an Ms 7.3 earthquake located near the coast of northern Chile.

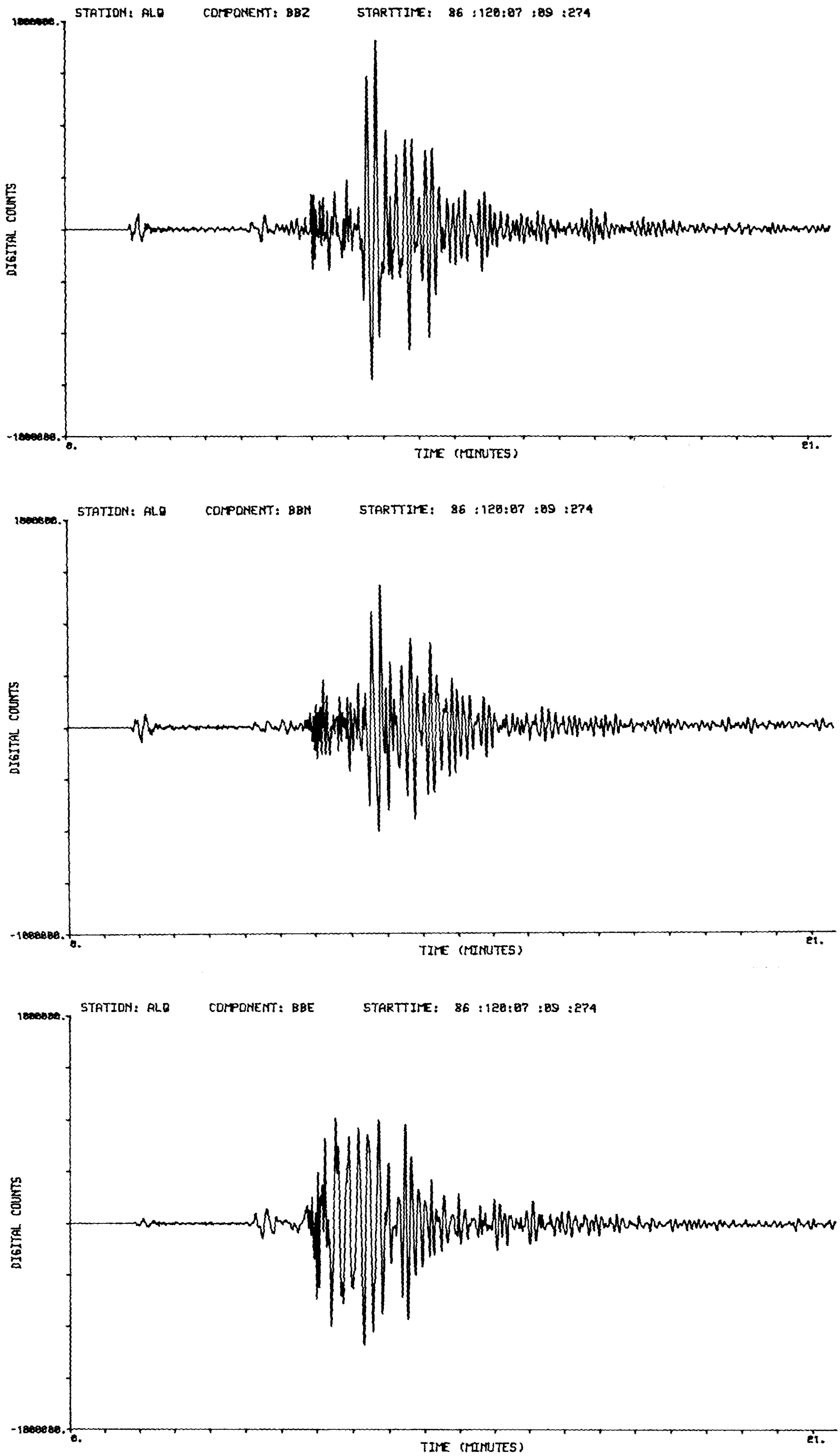


Figure 4.10. An Ms 7.0 earthquake near the west coast of Mexico recorded by the BB channels on the CDSN test system at the Albuquerque Seismological Laboratory. The distance to origin is 16.8°. The surface wave amplitude is within 6 dB of clipping the vertical channel.

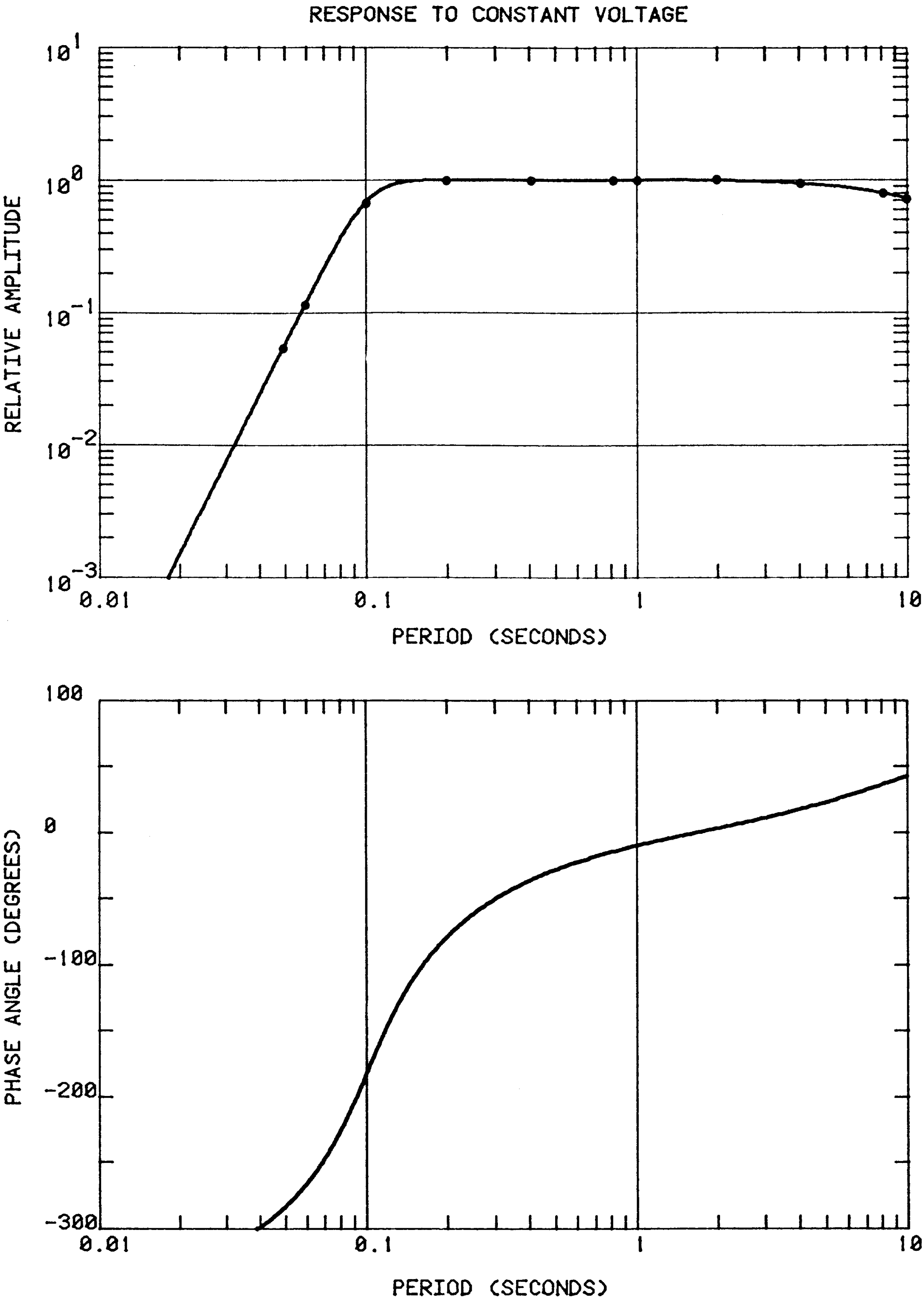


Figure 4.11. Amplitude and phase responses computed for the Teledyne Model 56130 short-period amplifiers. Points on the amplitude curve are average measured values.

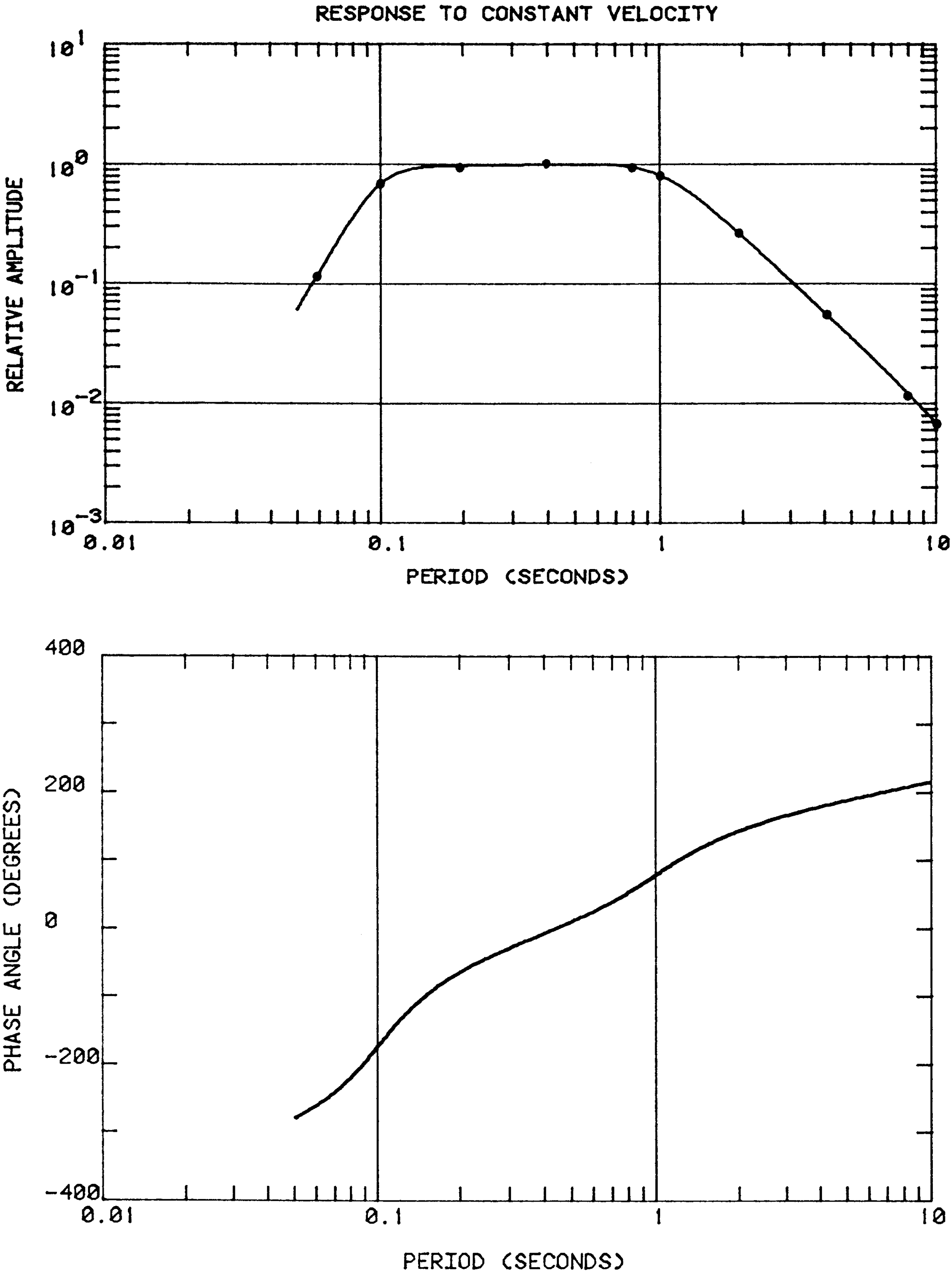


Figure 4.12. Amplitude and phase responses of the CDSN SP sensor system computed from the transfer function. Points on the amplitude curve are average measured values.

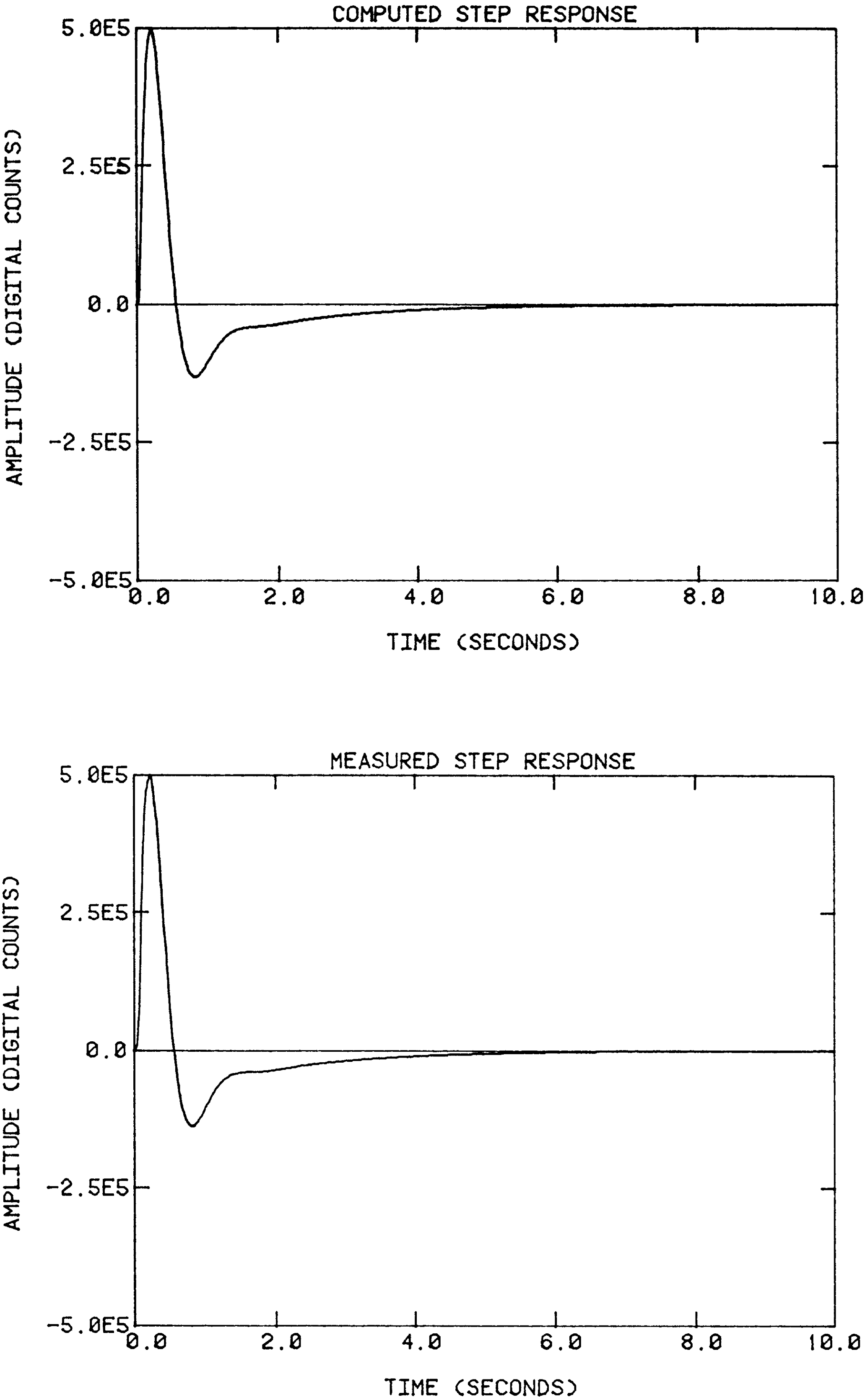


Figure 4.13. Examples of computed and measured step responses with amplitudes normalized to one half of full scale.

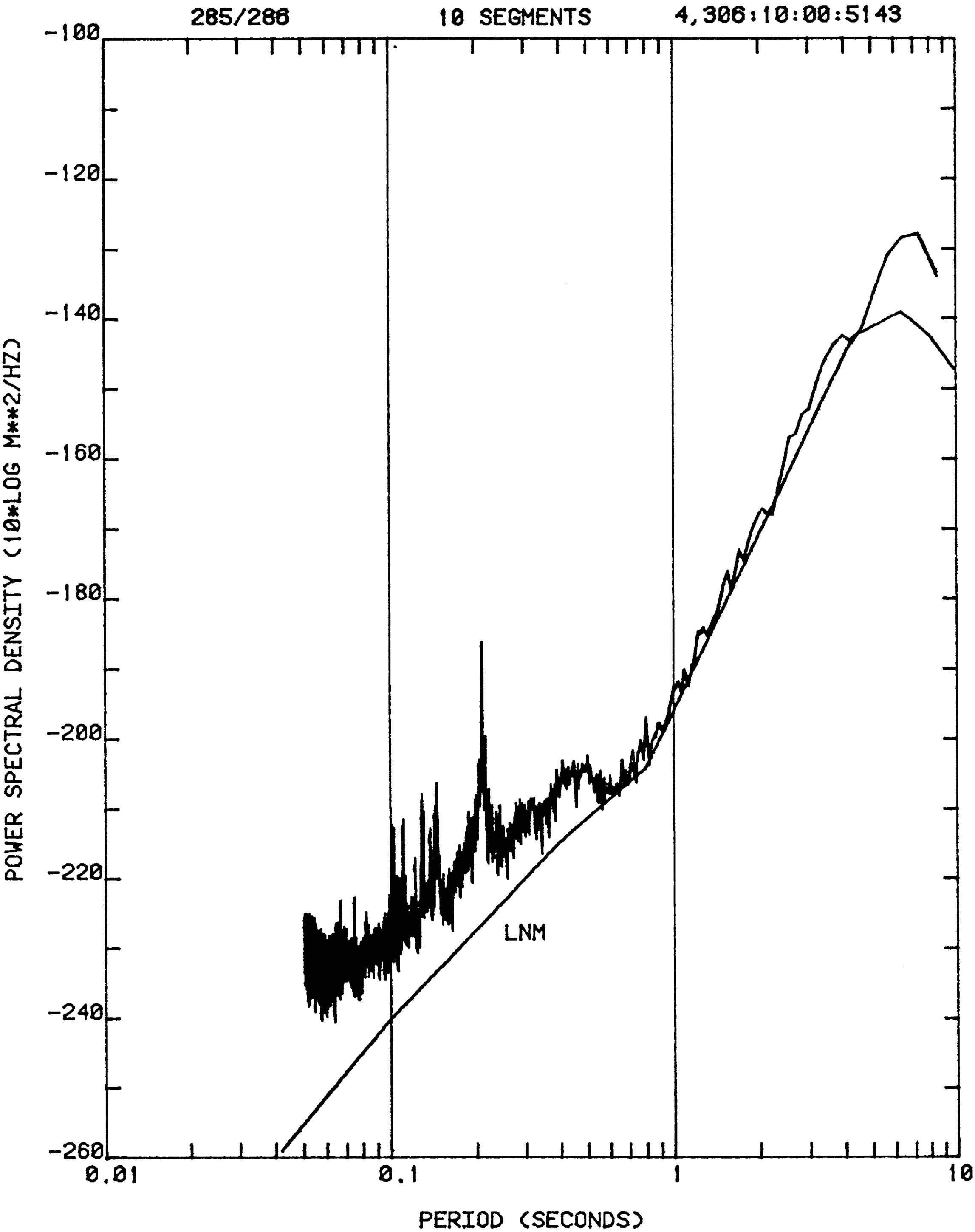


Figure 4.14. Power spectral densities computed from signals taken from two vertical-component DJ-1 seismometers during a quiet period in the ASL vault. See text for explanation of the LNM curve.

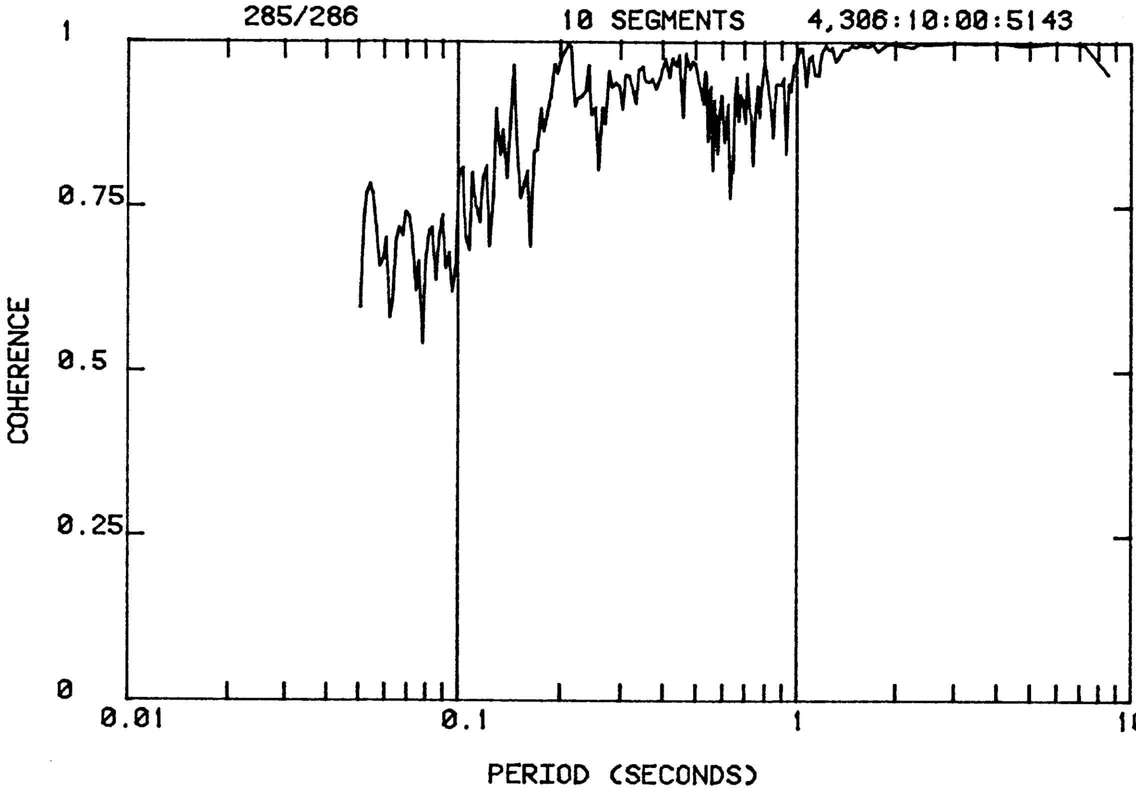


Figure 4.15. Coherence between signals from two vertical DJ-1 seismometers during a quiet period.

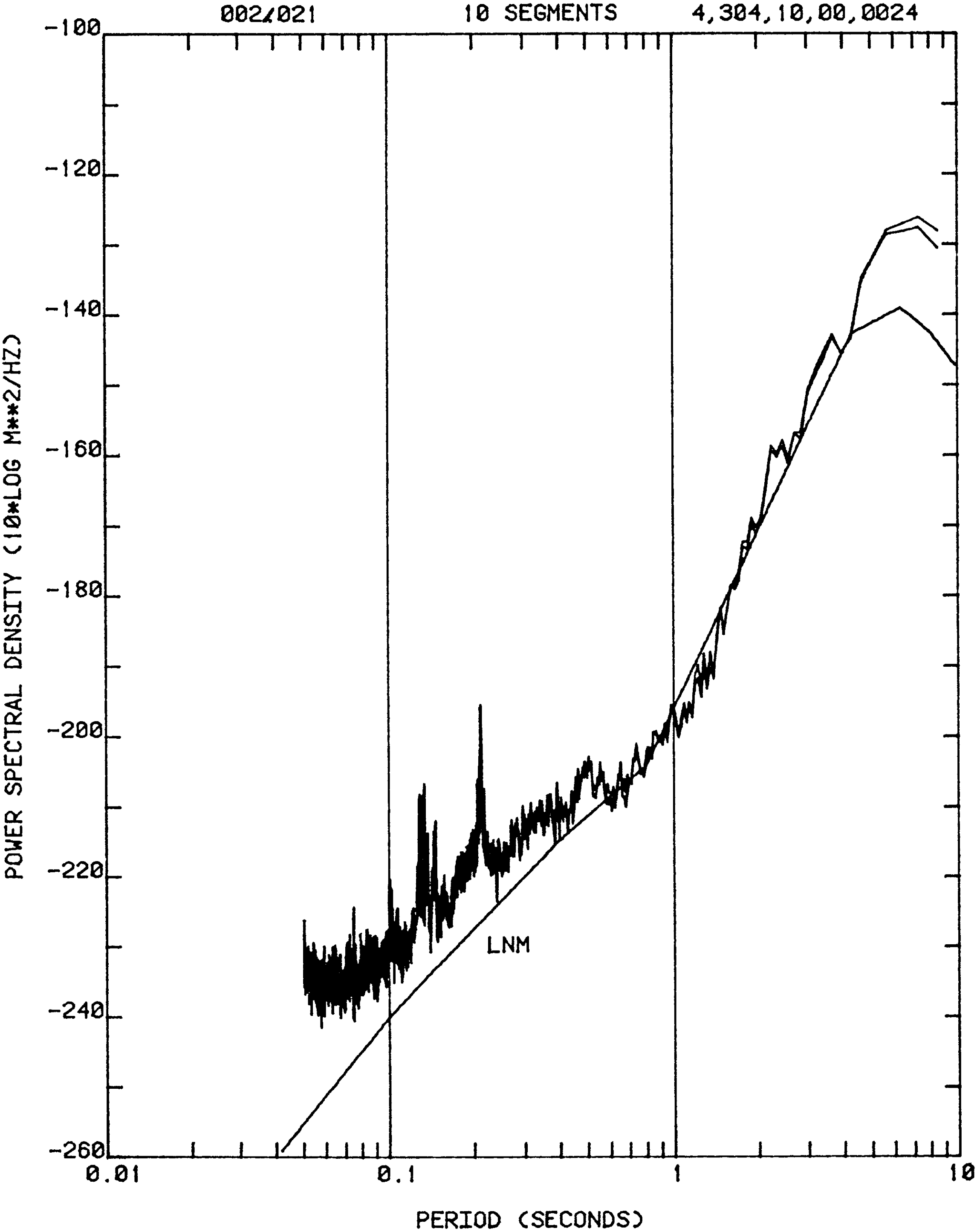


Figure 4.16. Power spectral densities computed from signals taken from two horizontal-component DJ-1 seismometers in the ASL vault during a quiet period.

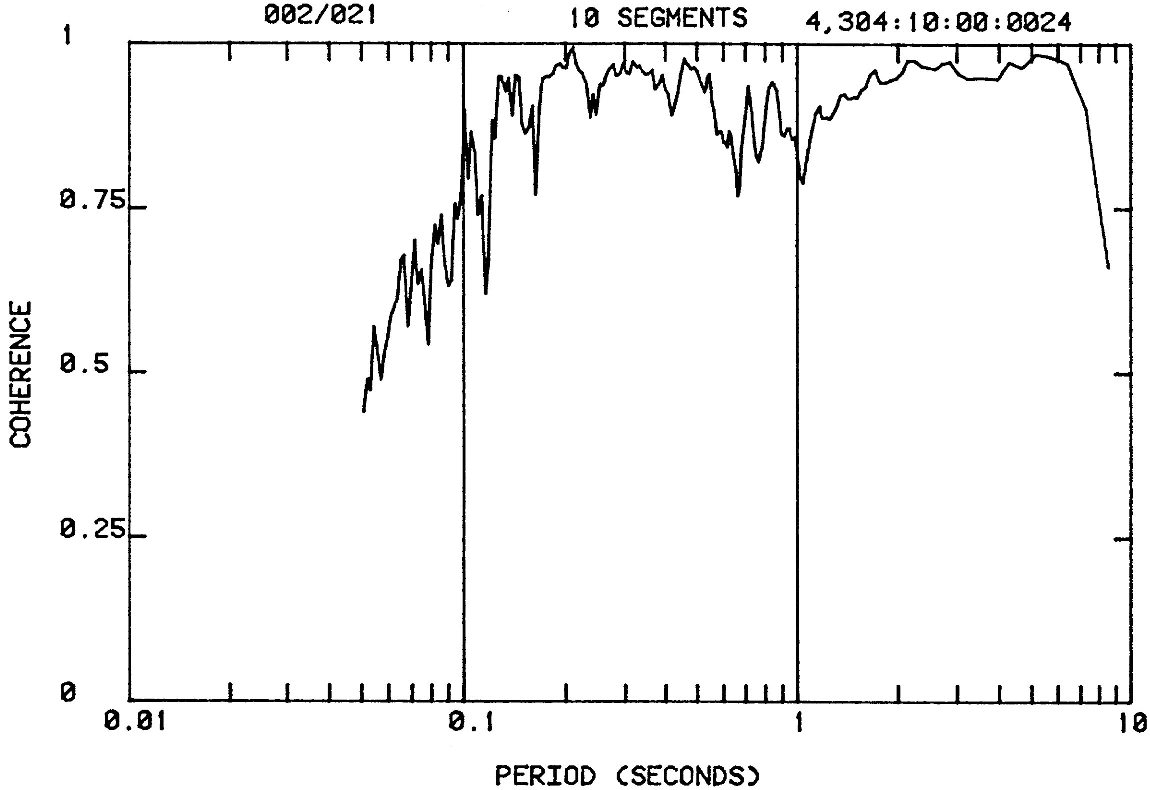


Figure 4.17. Coherence between signals from two horizontal DJ-1 seismometers during a quiet period.

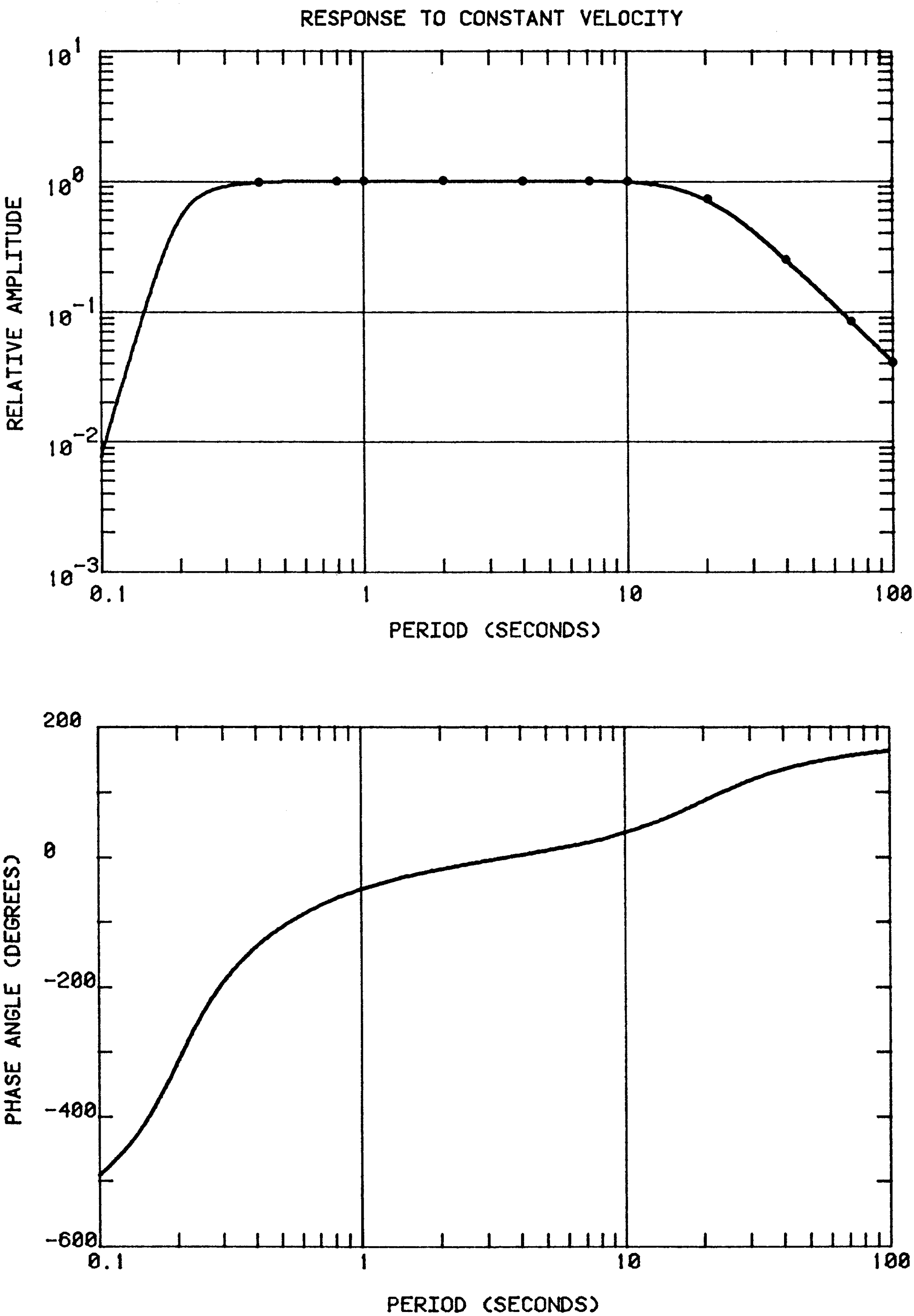
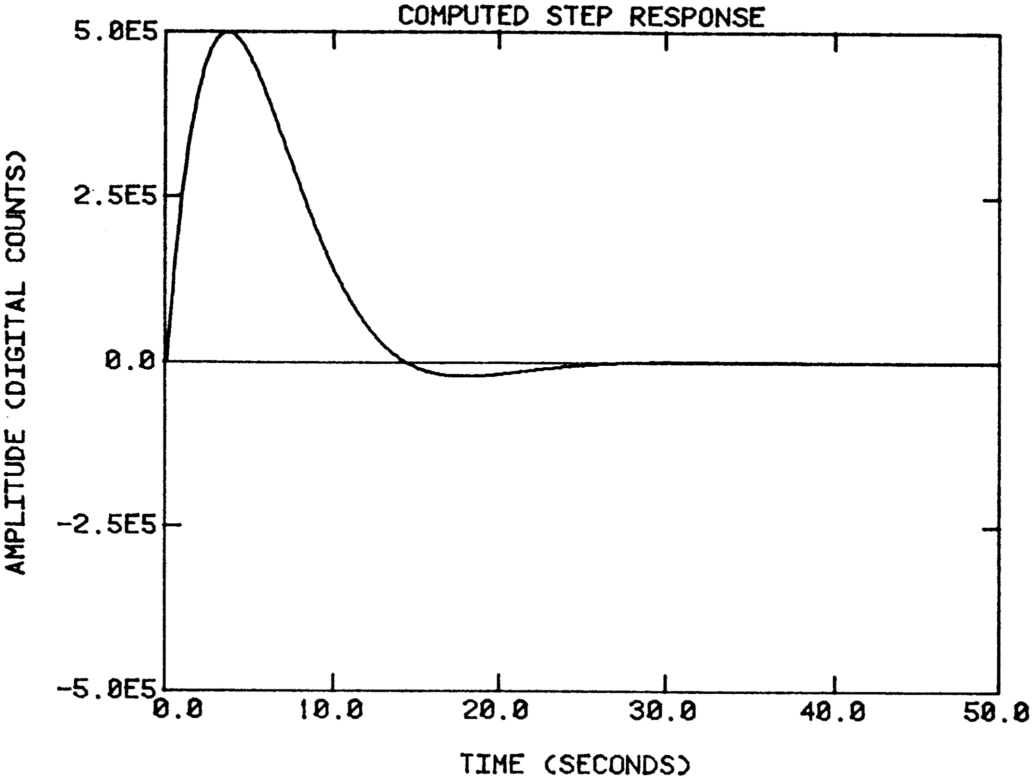


Figure 4.18. Amplitude and phase responses of the BB channel output of the STS sensor system computed from the transfer function. Points on the amplitude response curve are average measured values.



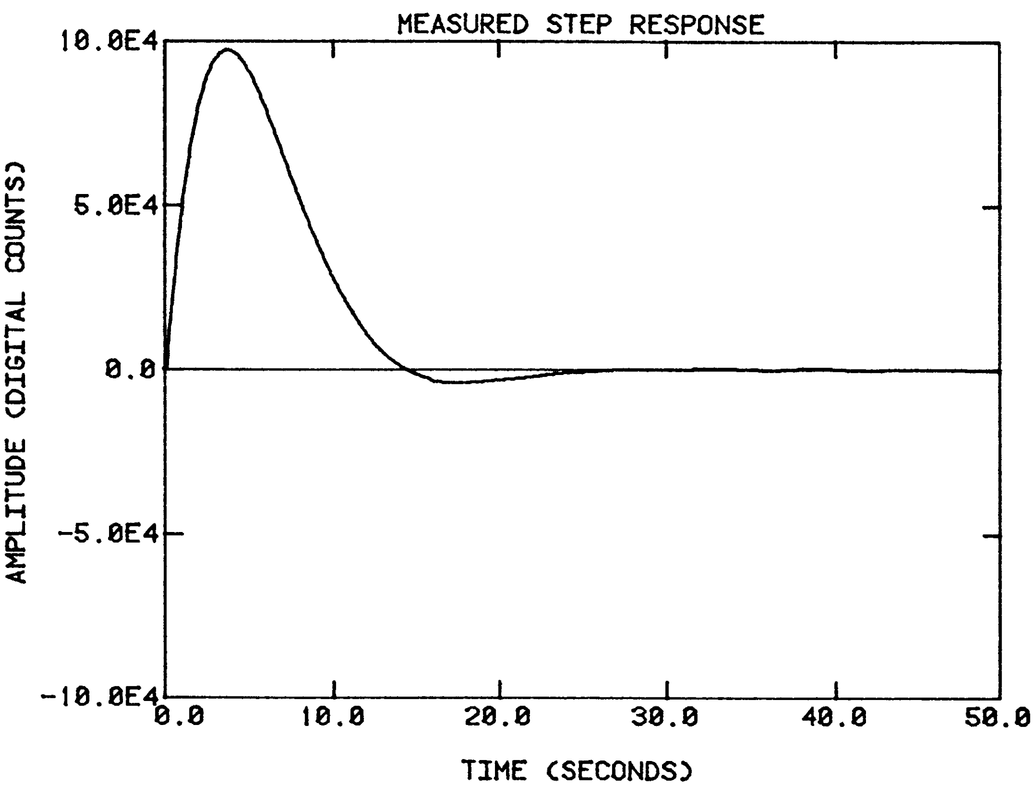


Figure 4.19. Examples of computed and measured step responses for the BB output of the STS sensor system. In routine operation, the amplitude of the step response will be five times the amplitude of the example to achieve a good signal-to-noise ratio.

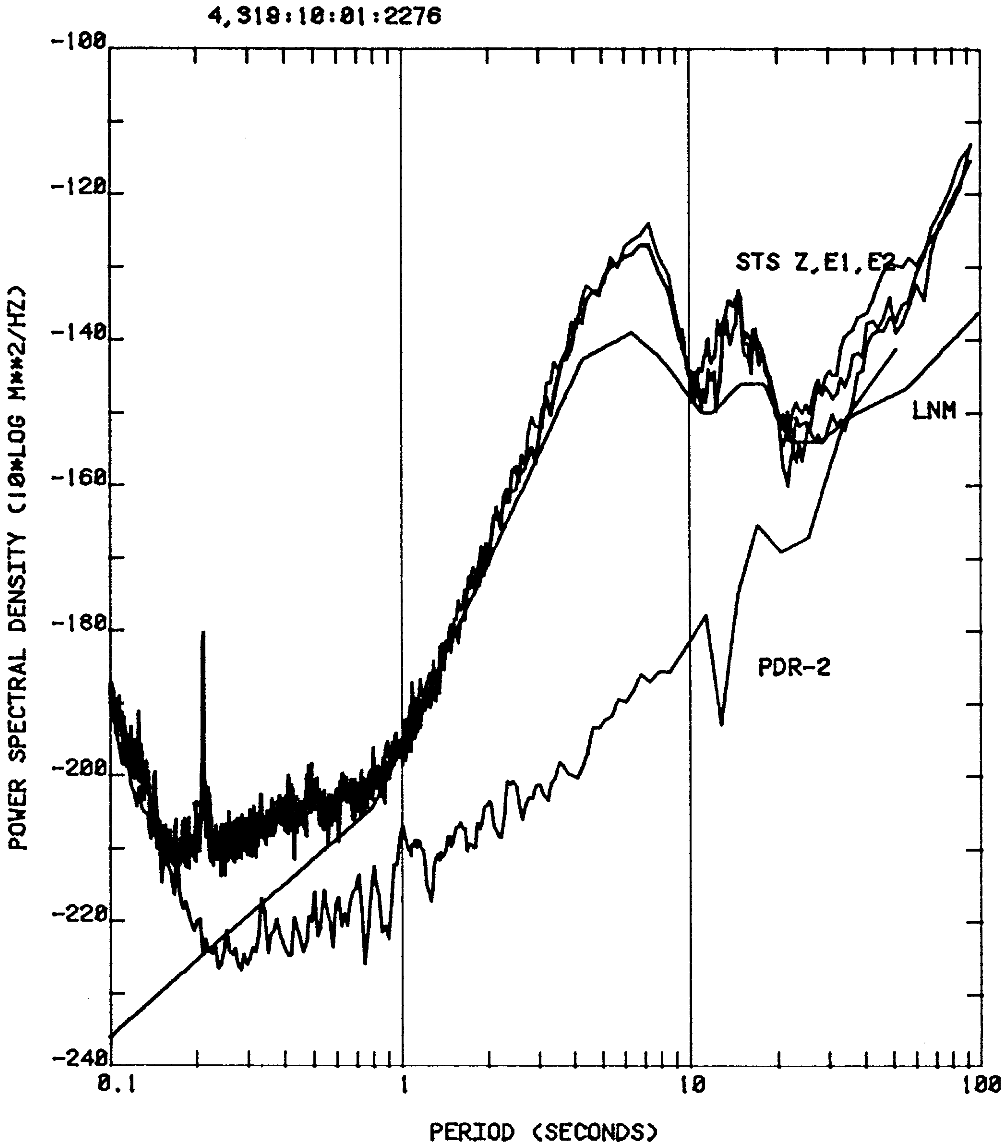
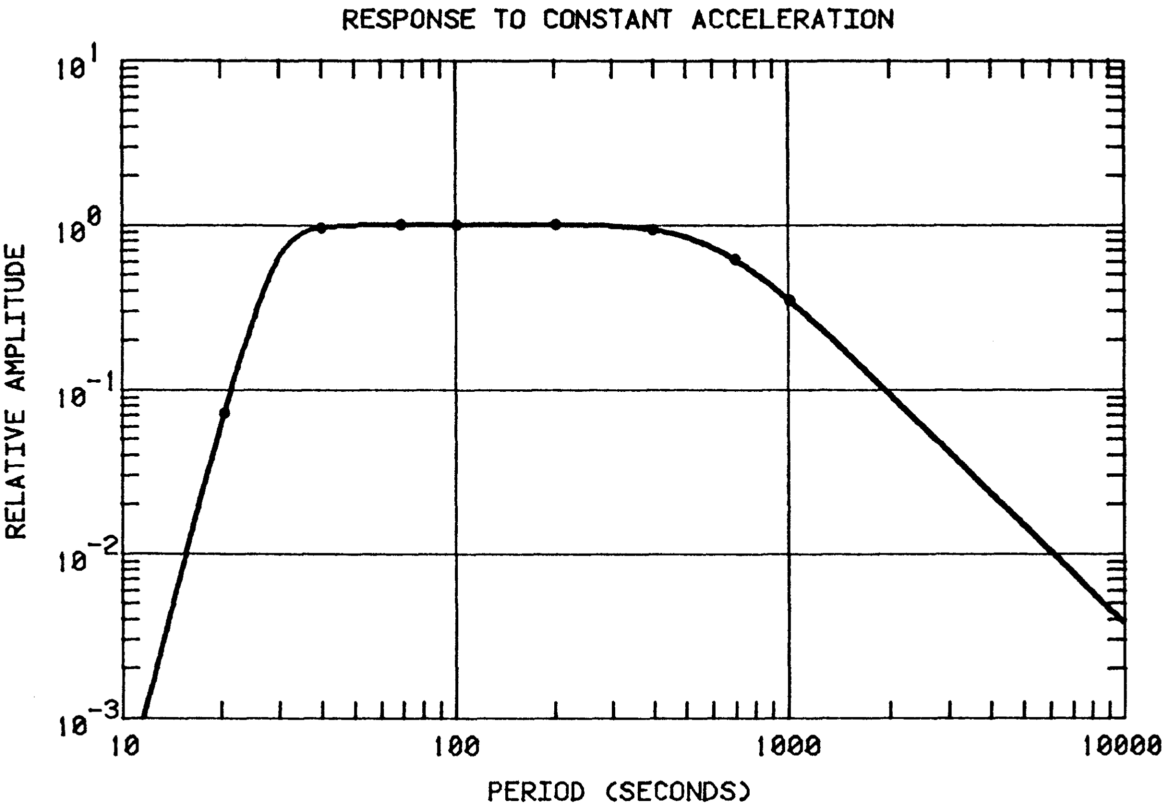


Figure 4.20 Power spectral densities computed from signals taken from the three STS BB outputs during a quiet period in the ASL vault. The curve labeled PDR-2 represents measured least-count noise of the digital recorder used in the test.



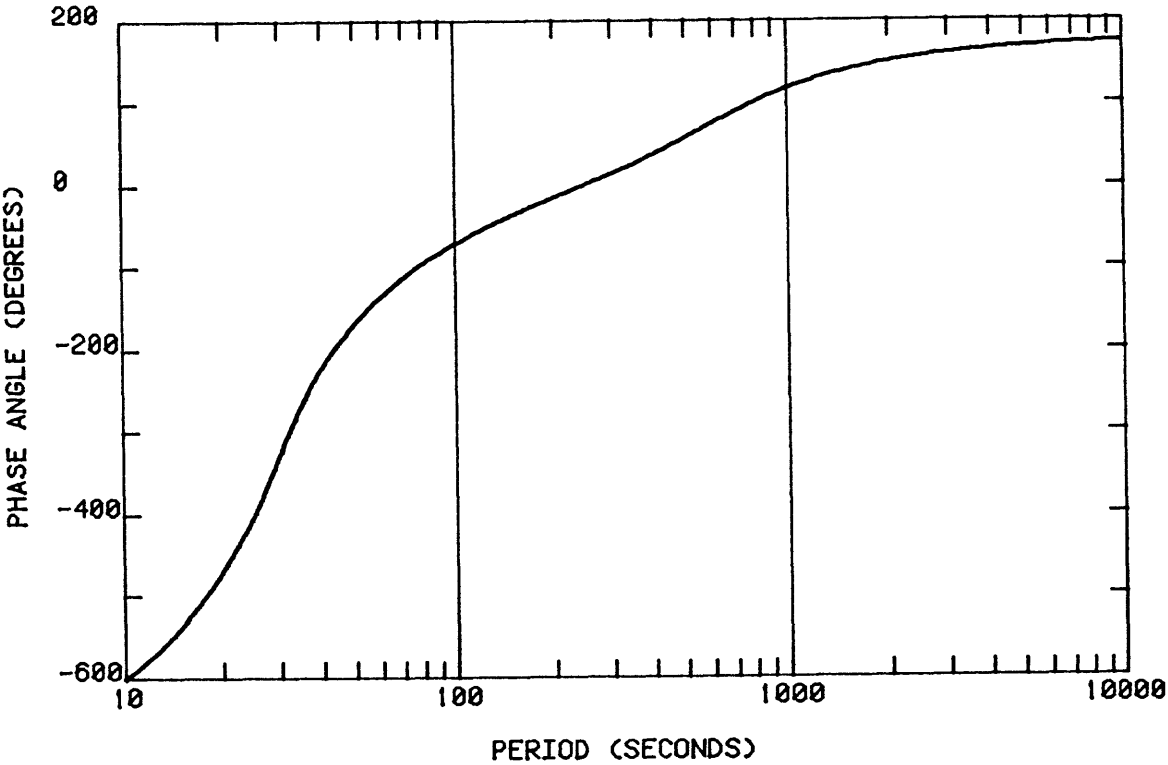


Figure 4.21. Amplitude and phase responses of the LP channel output of the STS sensor system computed from the transfer function. Points on the amplitude curve are average measured values.

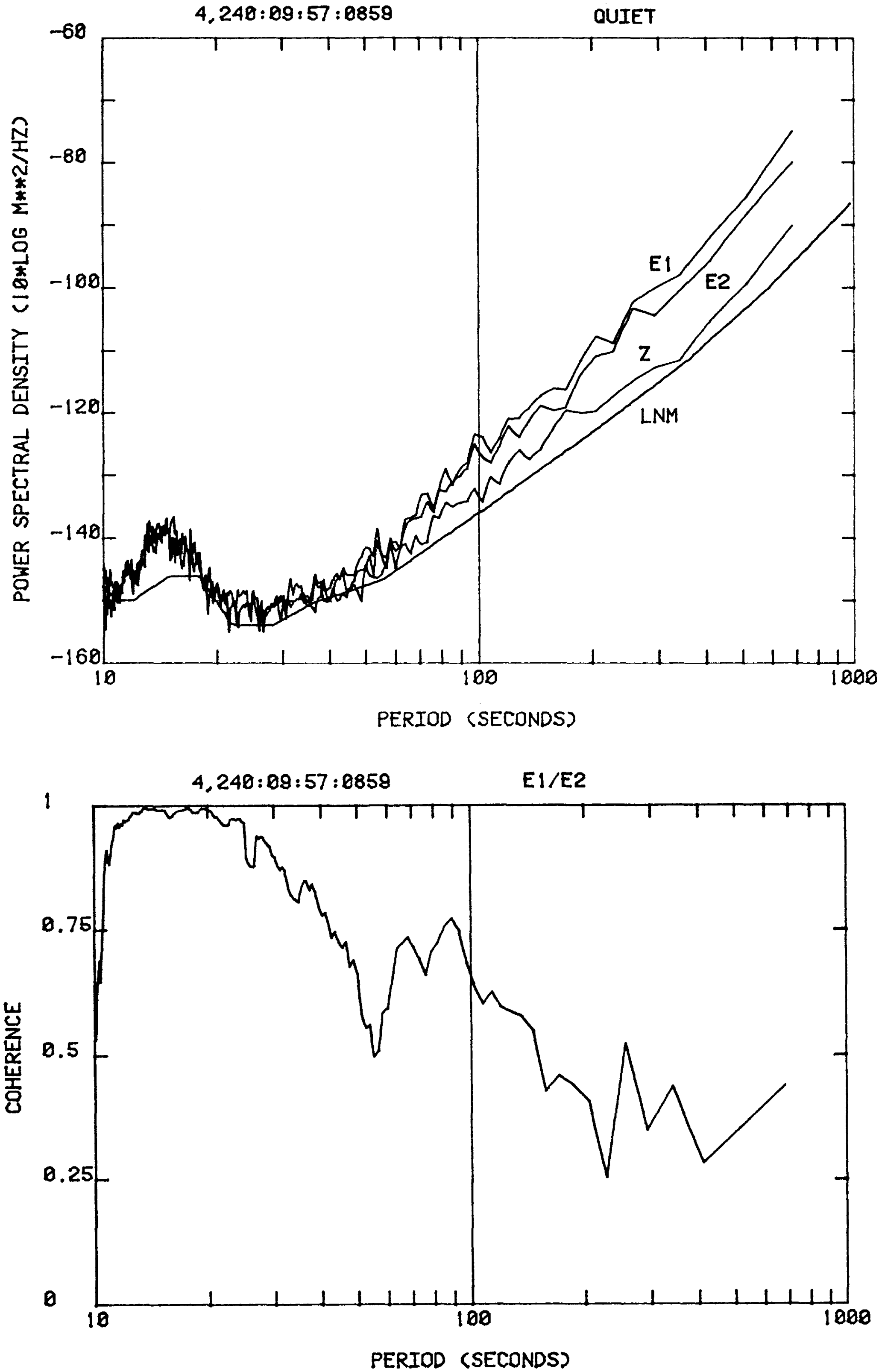


Figure 4.22. Power spectral densities (above) computed from LP signals taken from three STS components during a quiet period in the ASL vault and coherence (below) between horizontal-component signals.

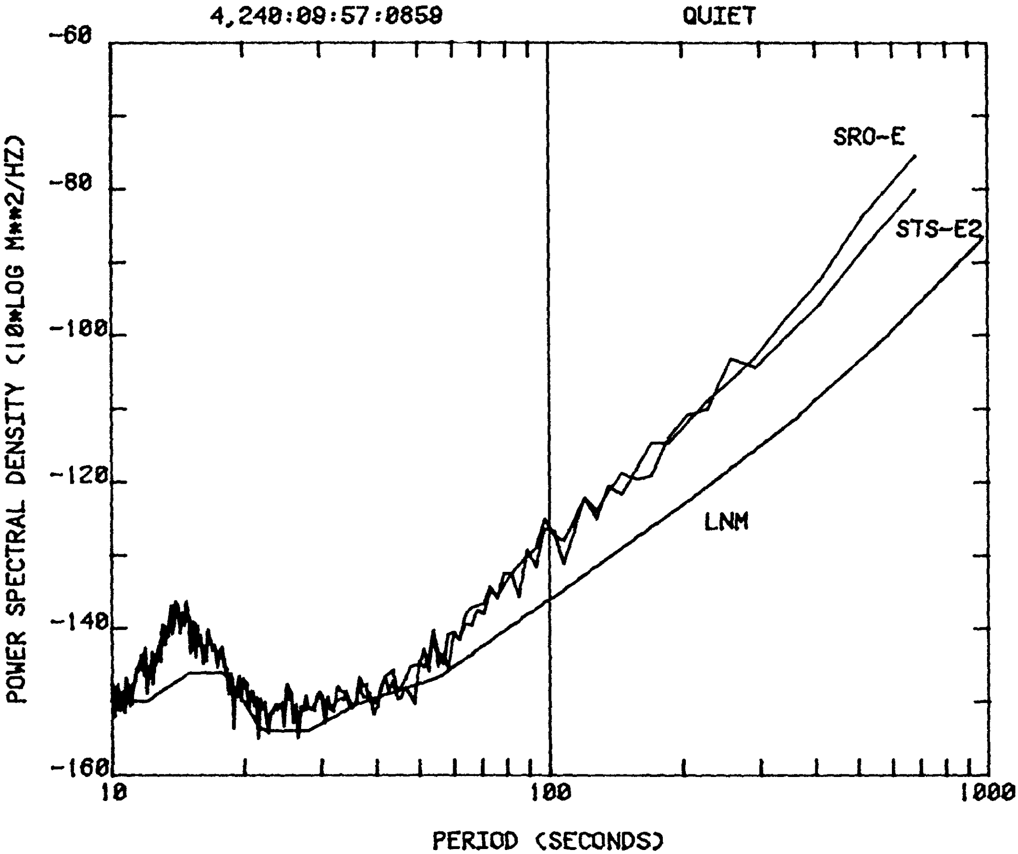
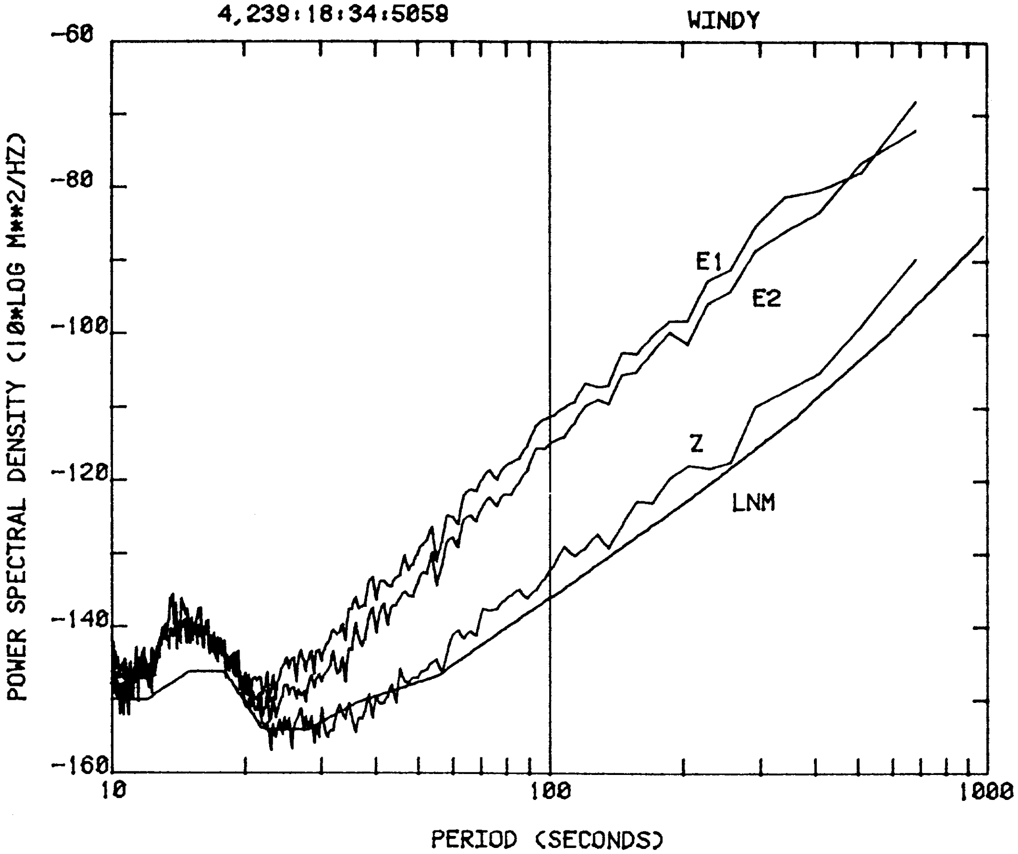


Figure 4.23. A comparison of power spectral densities computed from simultaneous STS and SRO horizontal-component long-period signals during a wind-free period.



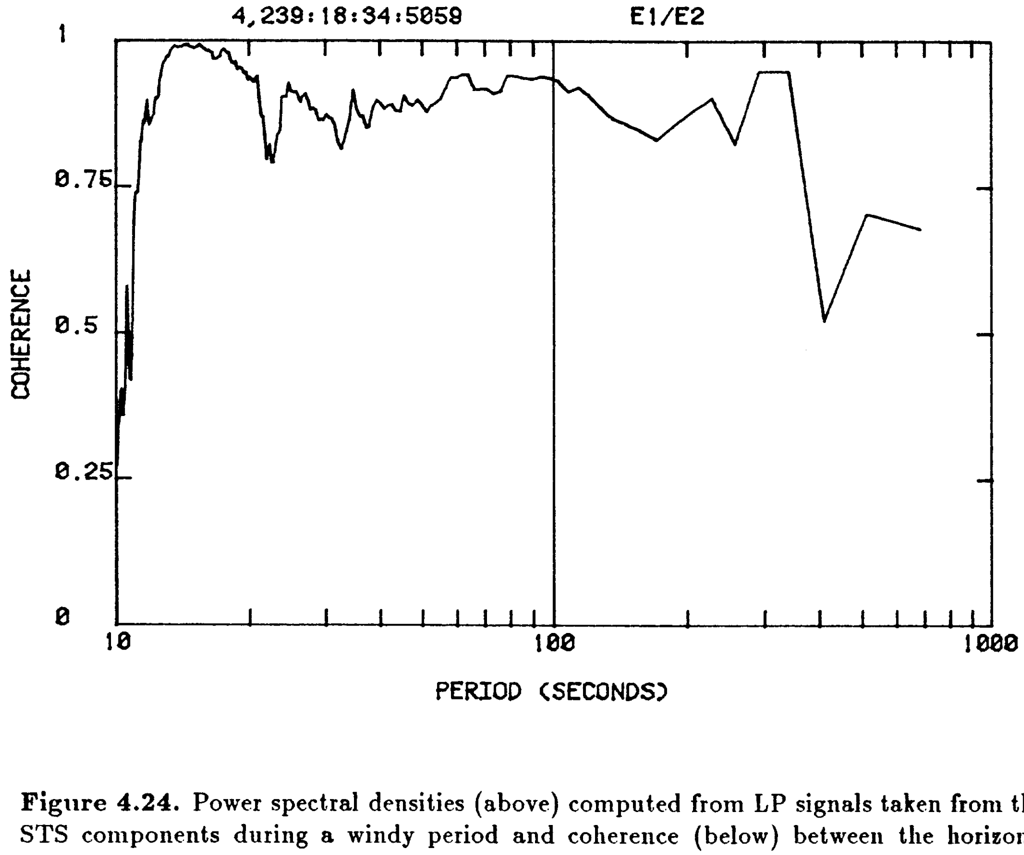


Figure 4.24. Power spectral densities (above) computed from LP signals taken from three STS components during a windy period and coherence (below) between the horizontal-component signals.

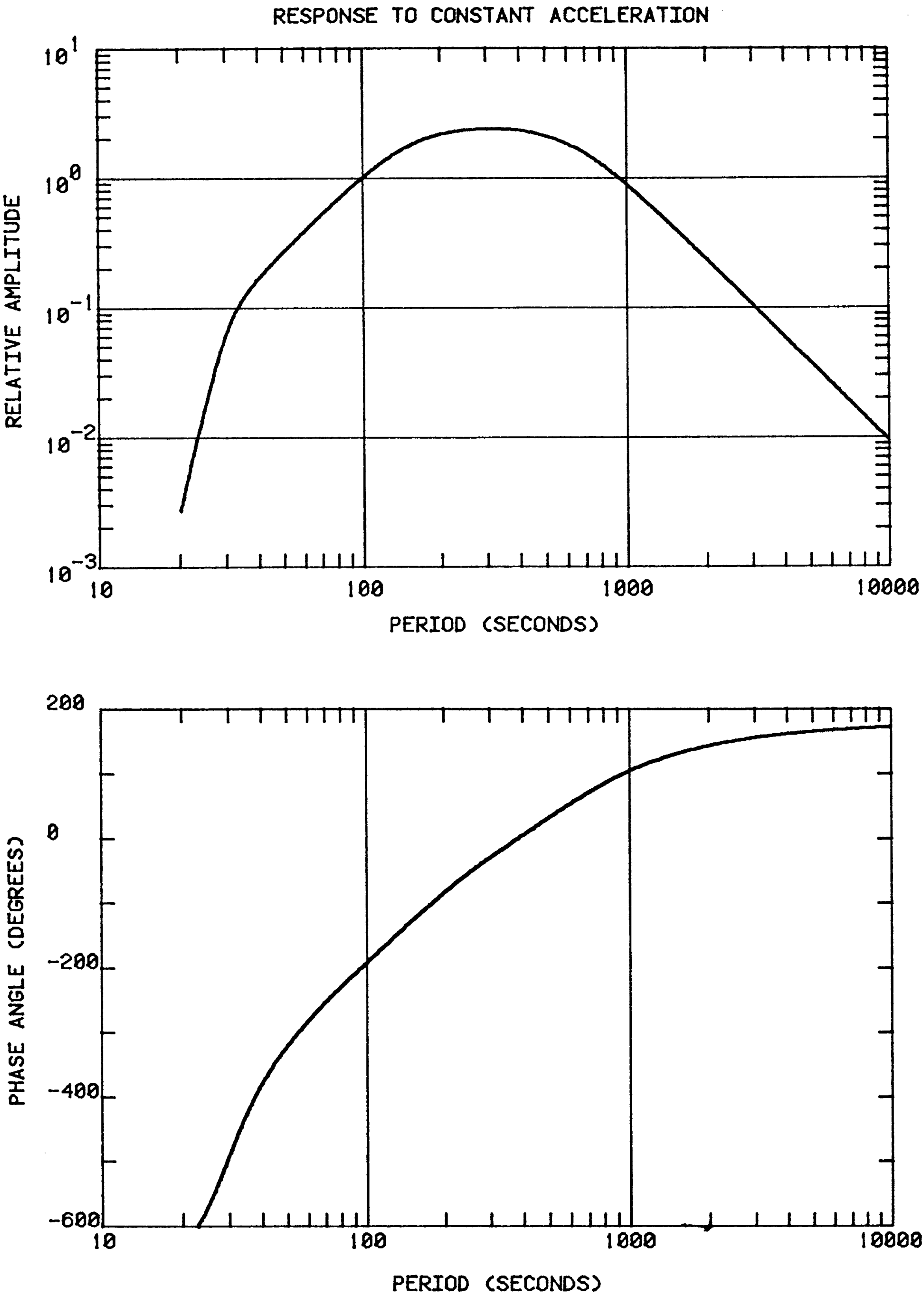


Figure 4.25. Amplitude and phase responses of the VLP channel output of the STS sensor system computed from the transfer function.

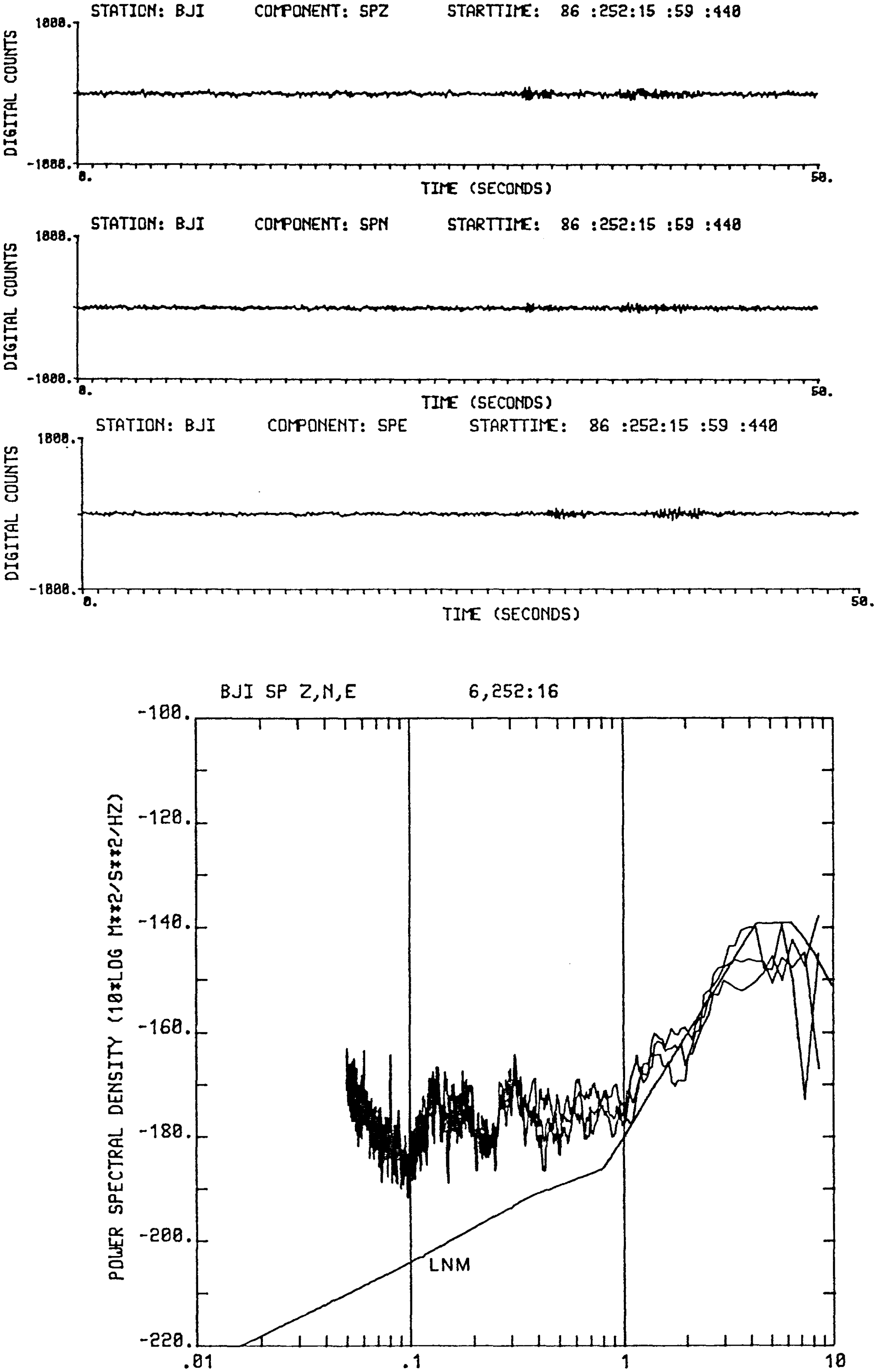


Figure 4.26. Sample data segments and associated noise power from the SP channels recorded at the Baijatuan Station. The DJ-1 short-period seismometers are installed in a borehole at a depth of 170 meters.

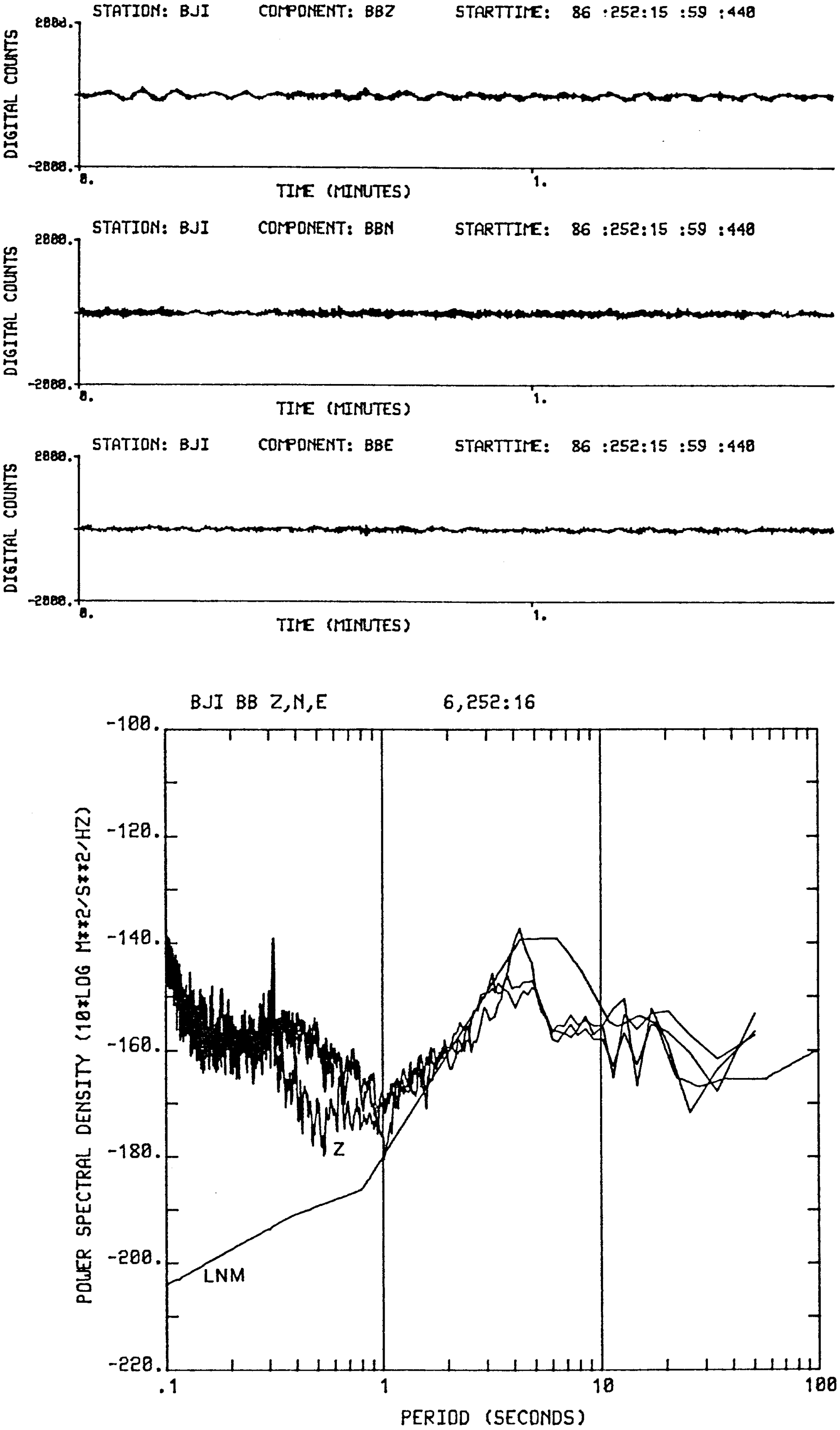


Figure 4.27. Sample data segments and associated noise power from the BB channels recorded at the Baijatuan Station.

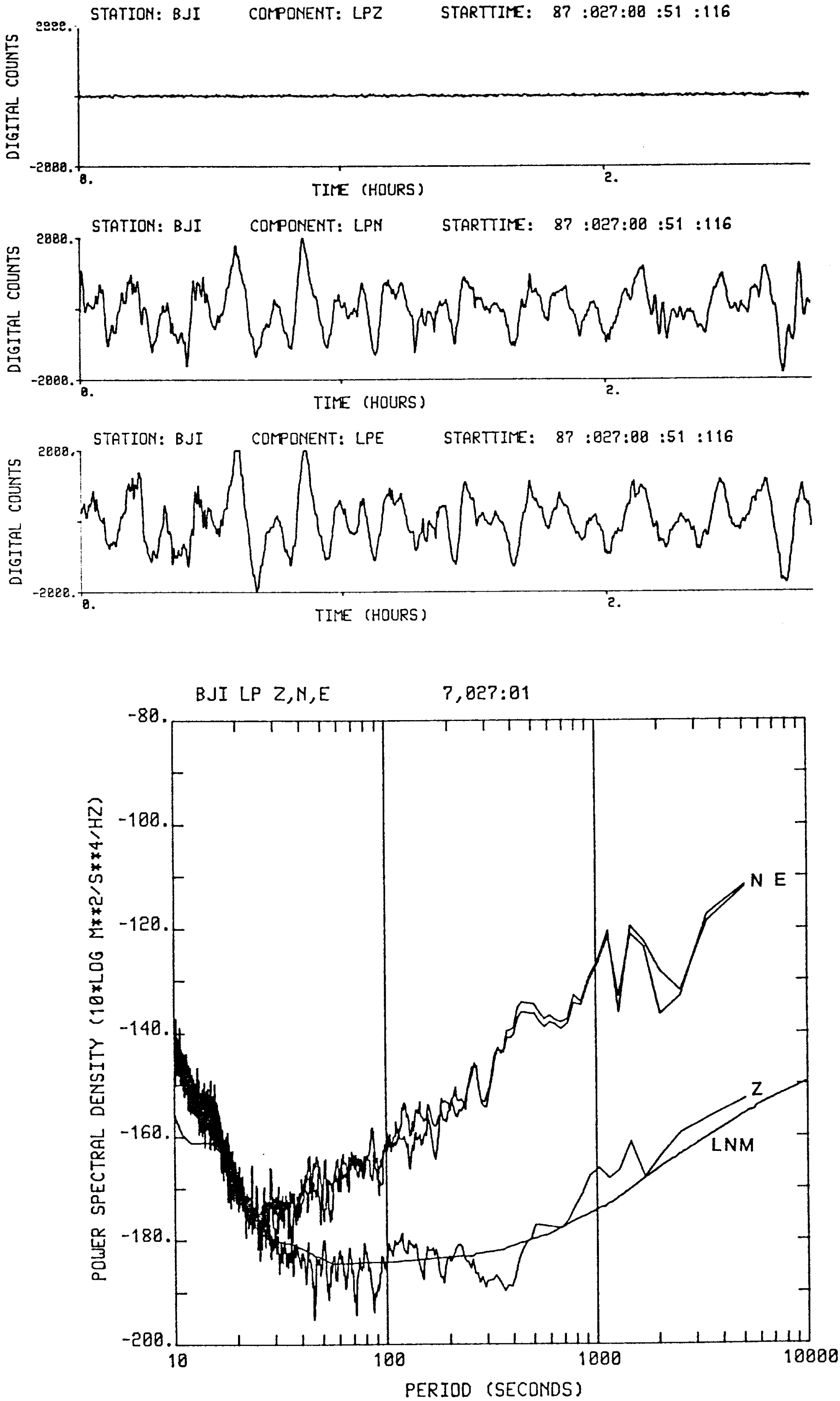


Figure 4.28. Sample data segments and associated noise power from the LP channels recorded at the Baijatuan Station.

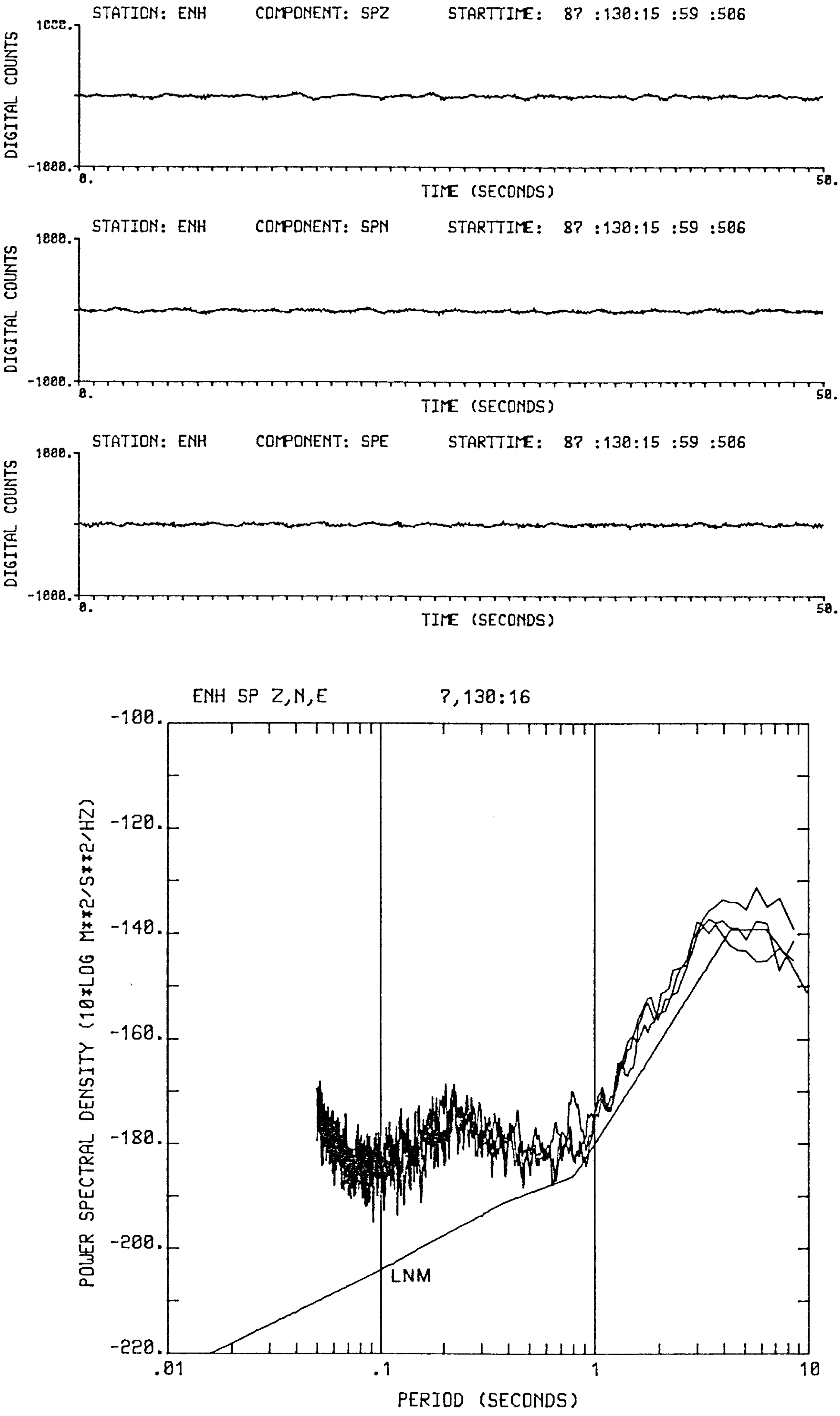


Figure 4.29. Sample data segments and associated noise power from the SP channels recorded at the Enshi Station.

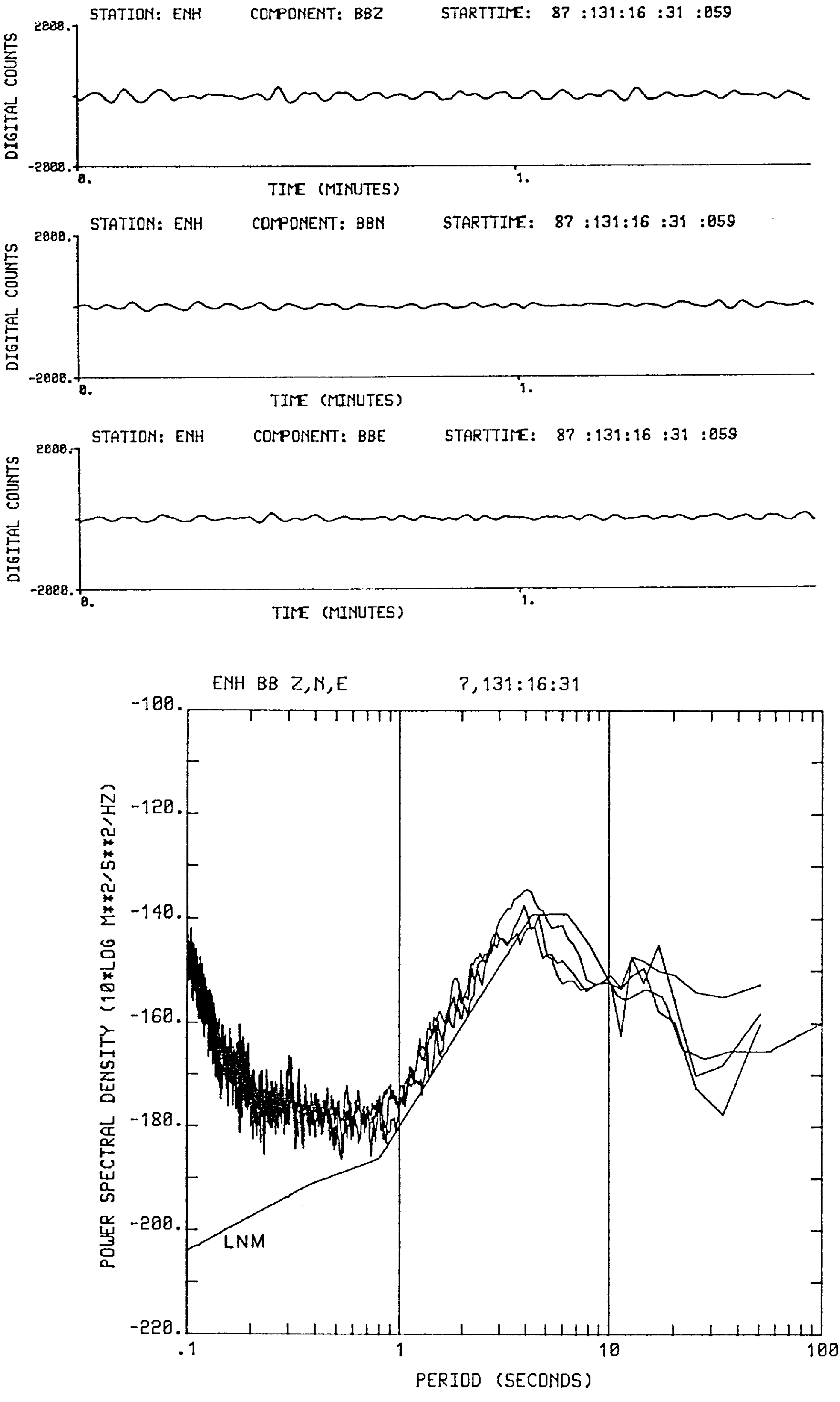


Figure 4.30. Sample data segments and associated noise power from the BB channels recorded at the Enshi Station.

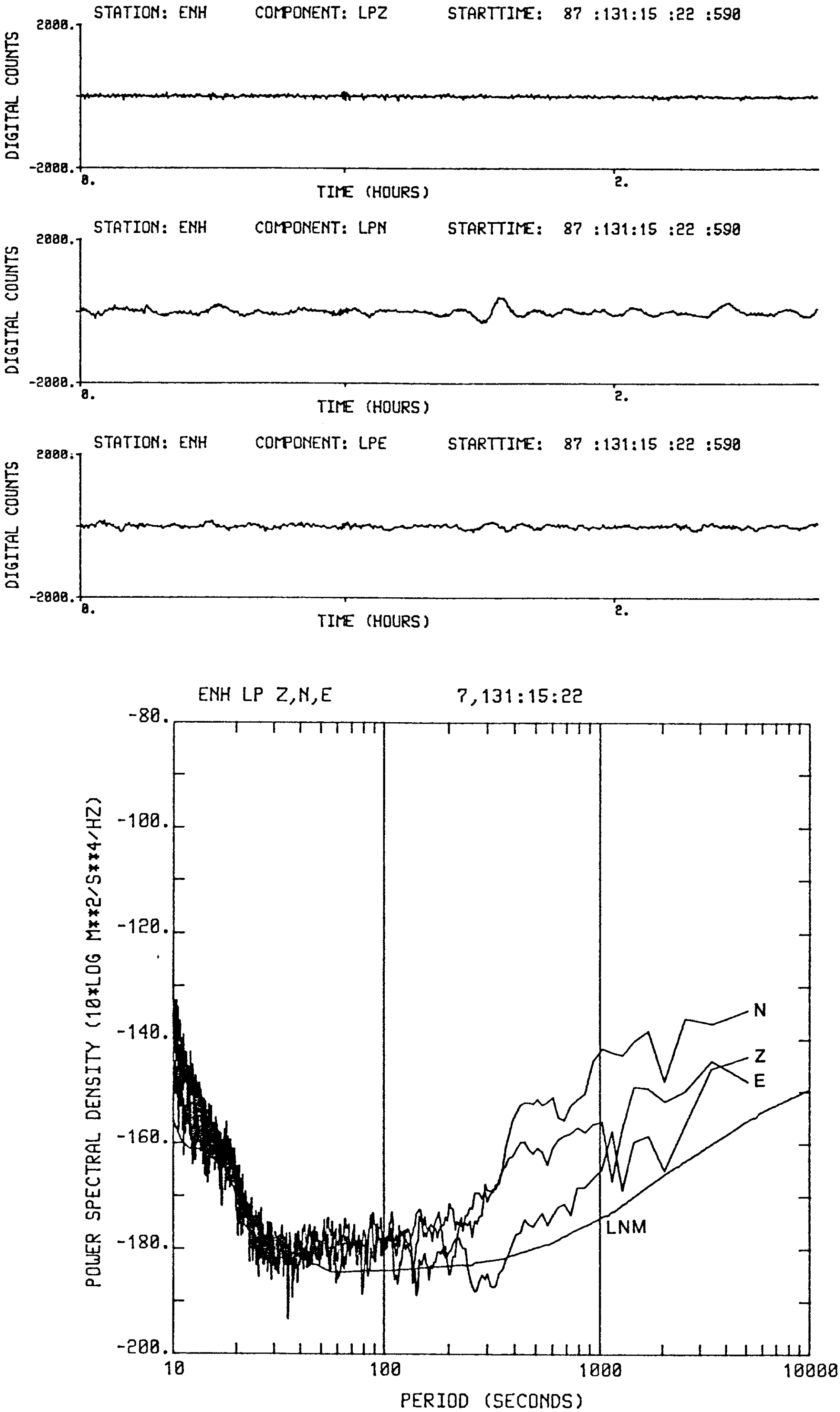


Figure 4.31. Sample data segments and associated noise power from the LP channels recorded at the Enshi Station.

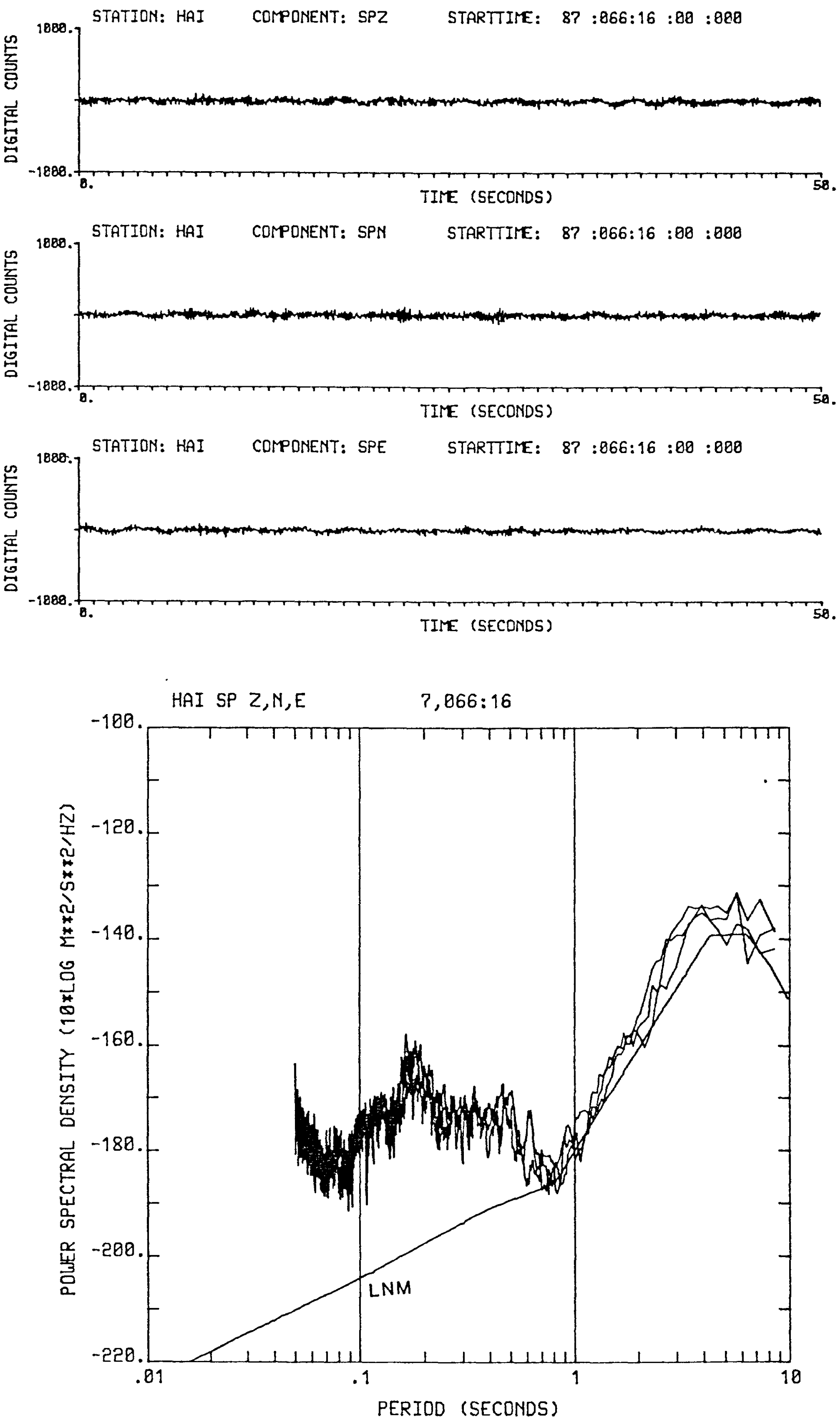


Figure 4.32. Sample data segments and associated noise power from the SP channels recorded at the Hailar Station.

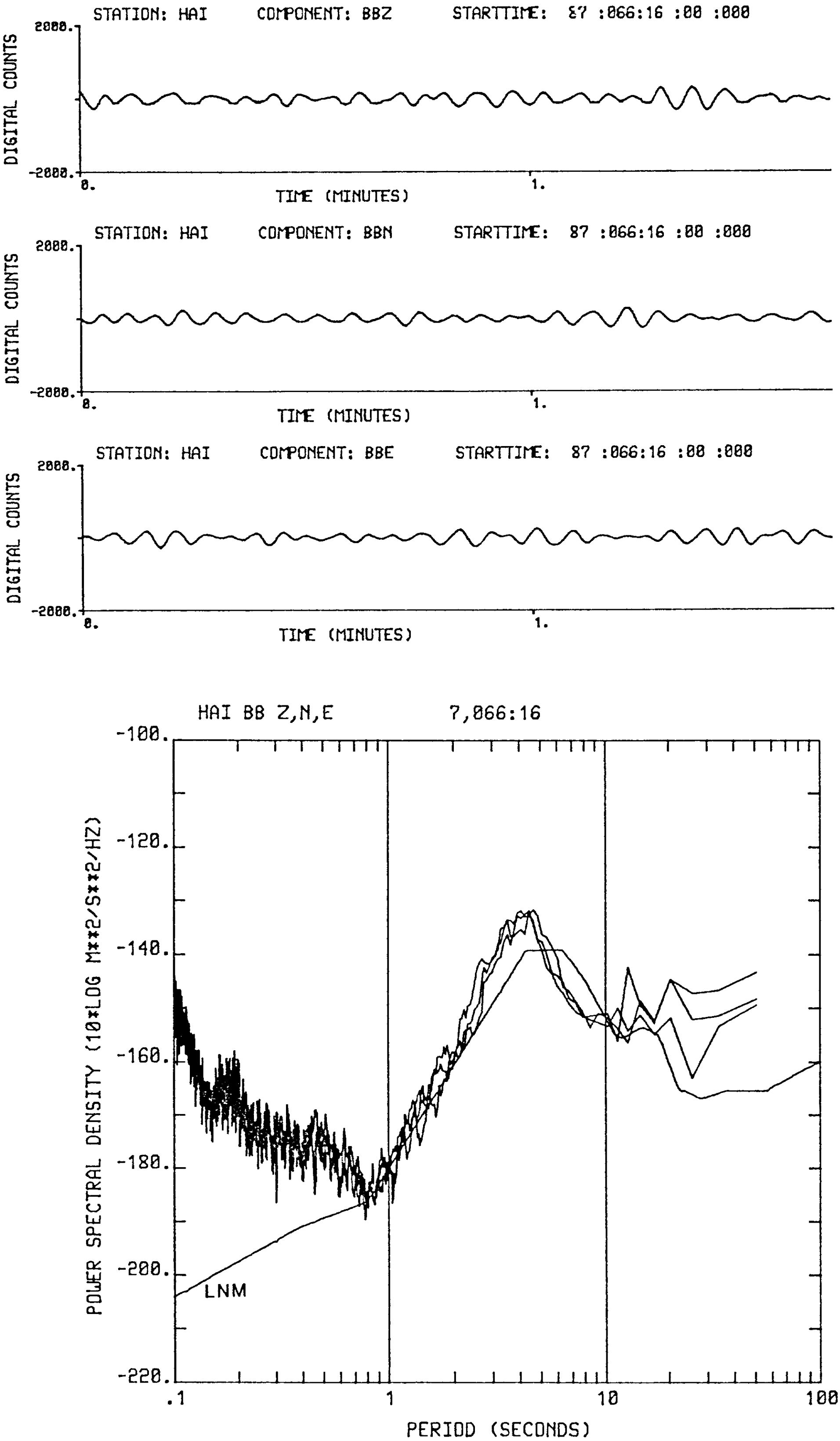


Figure 4.33. Sample data segments and associated noise power from the BB channels recorded at the Hailar Station.

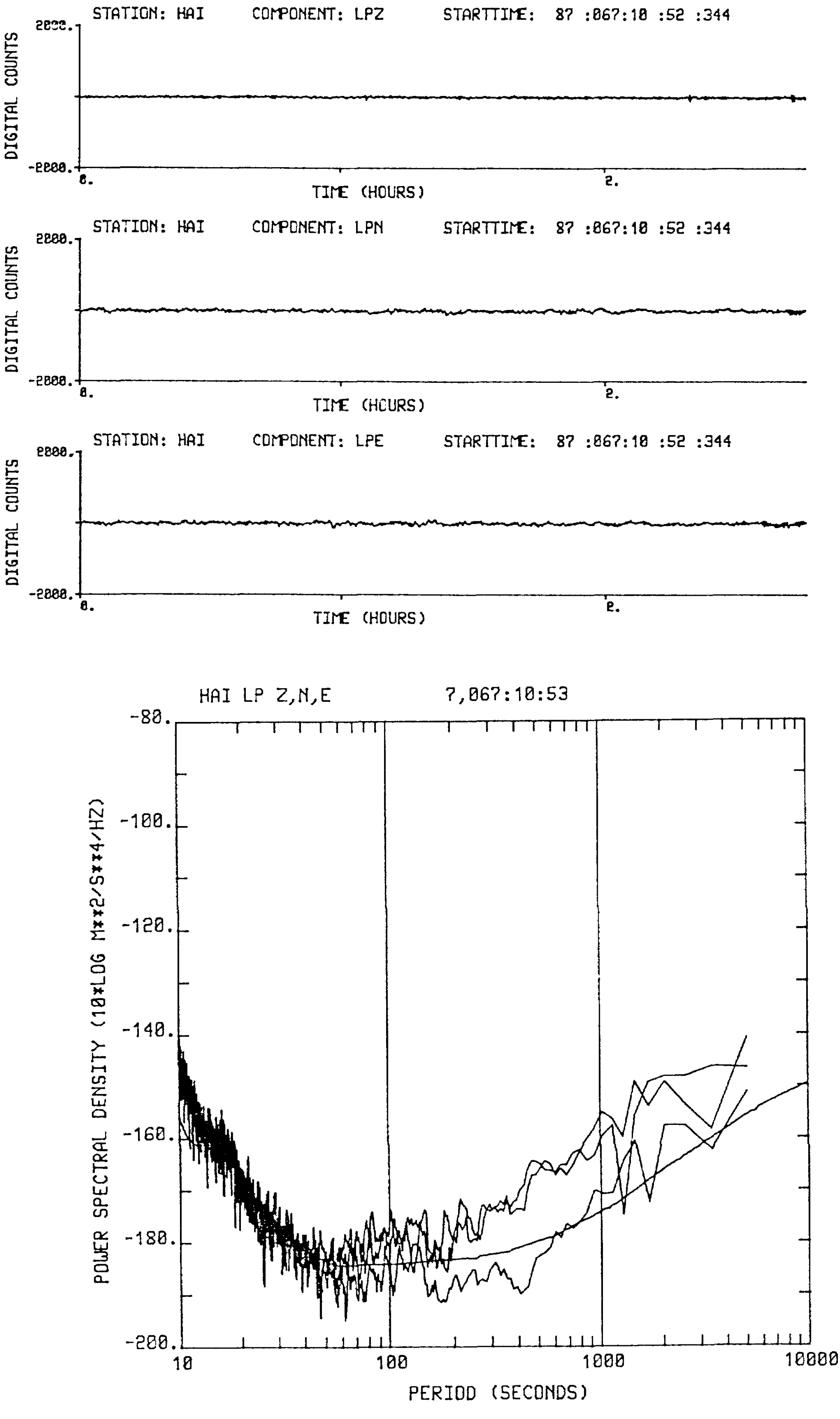


Figure 4.34. Sample data segments and associated noise power from the LP channels recorded at the Hailar Station.

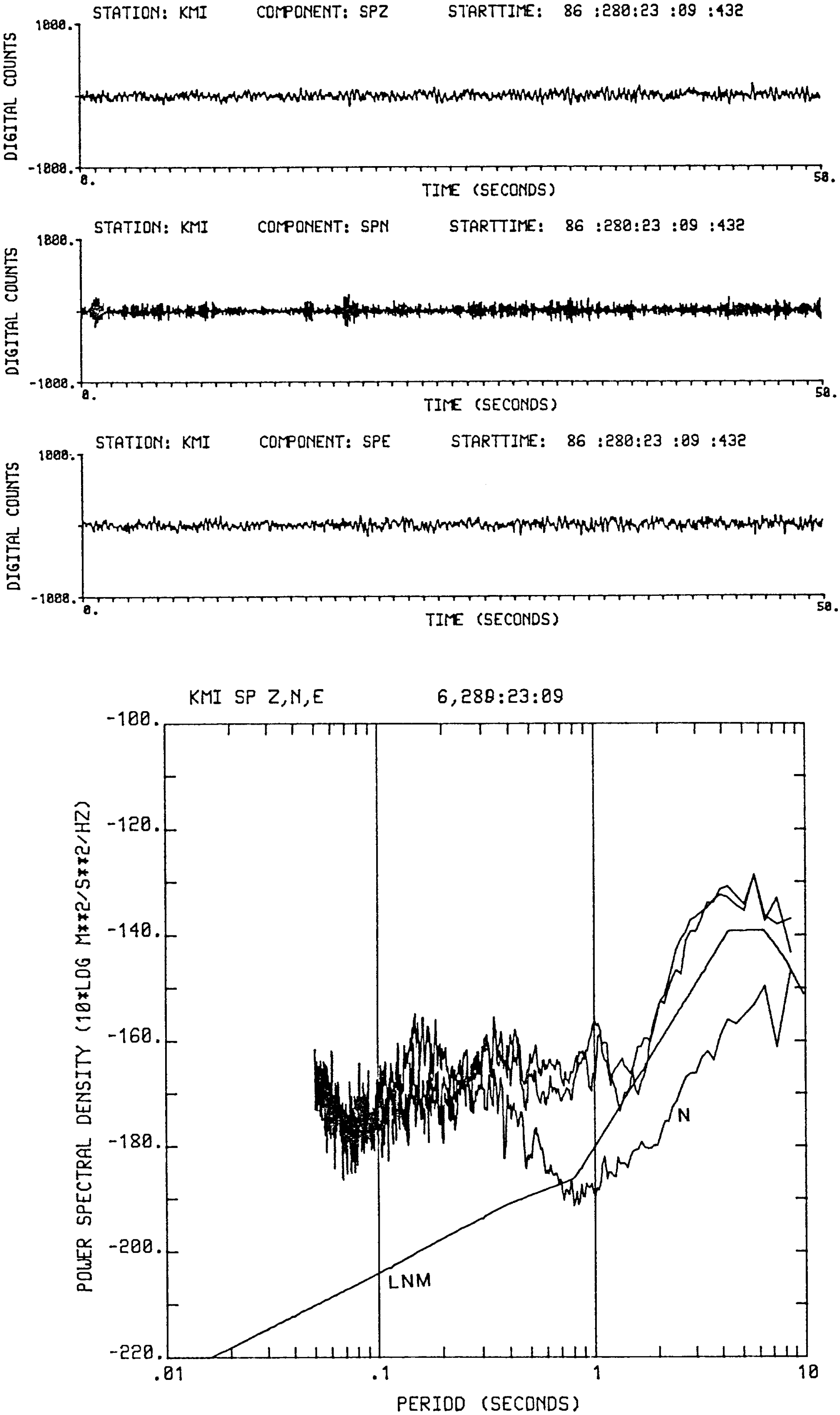


Figure 4.35. Sample data segments and associated noise power from the SP channels recorded at the Kunming Station. The north component was not operating properly during the installation test but has since been replaced.

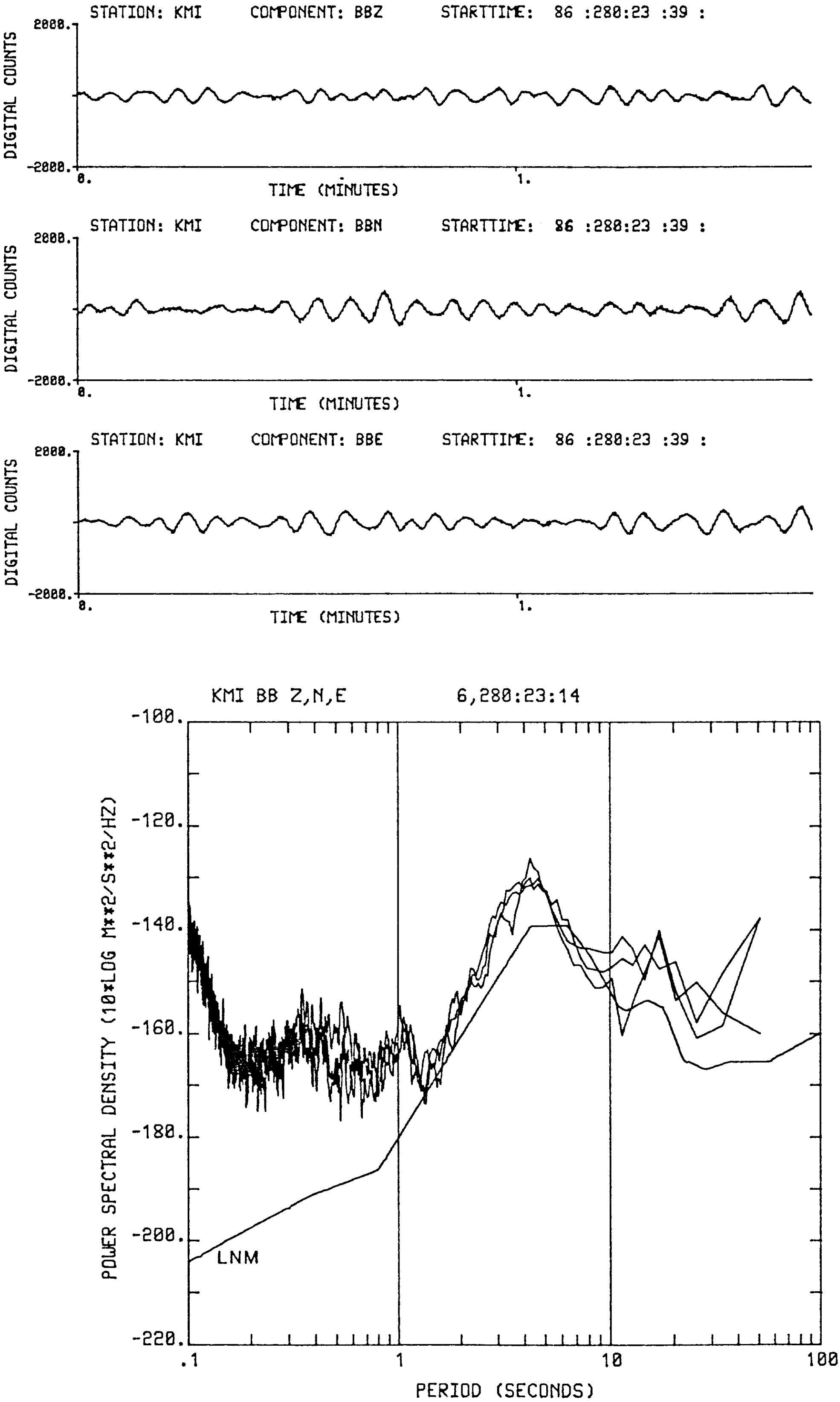


Figure 4.36. Sample data segments and associated noise power from the BB channels recorded at the Kunming Station.

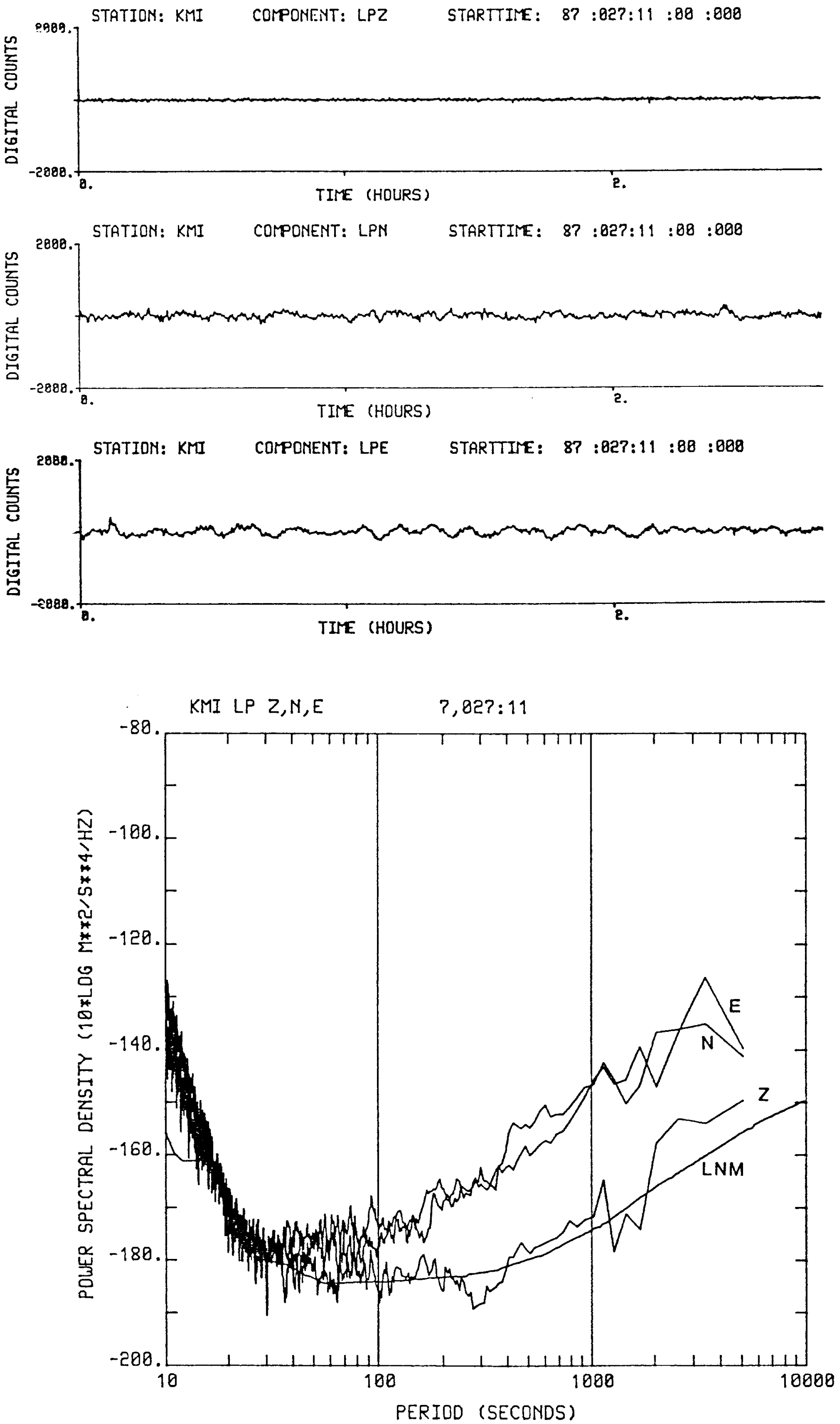
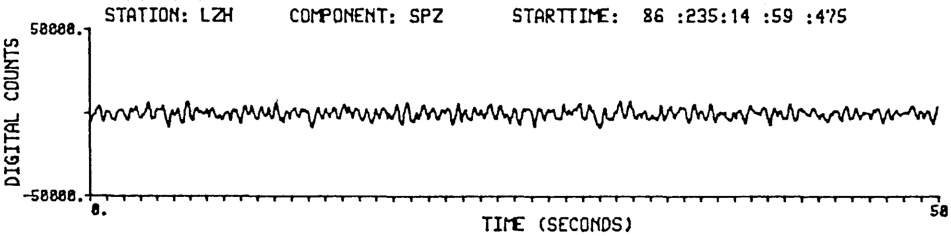


Figure 4.37. Sample data segments and associated noise power from the LP channels recorded at the Kunming Station.



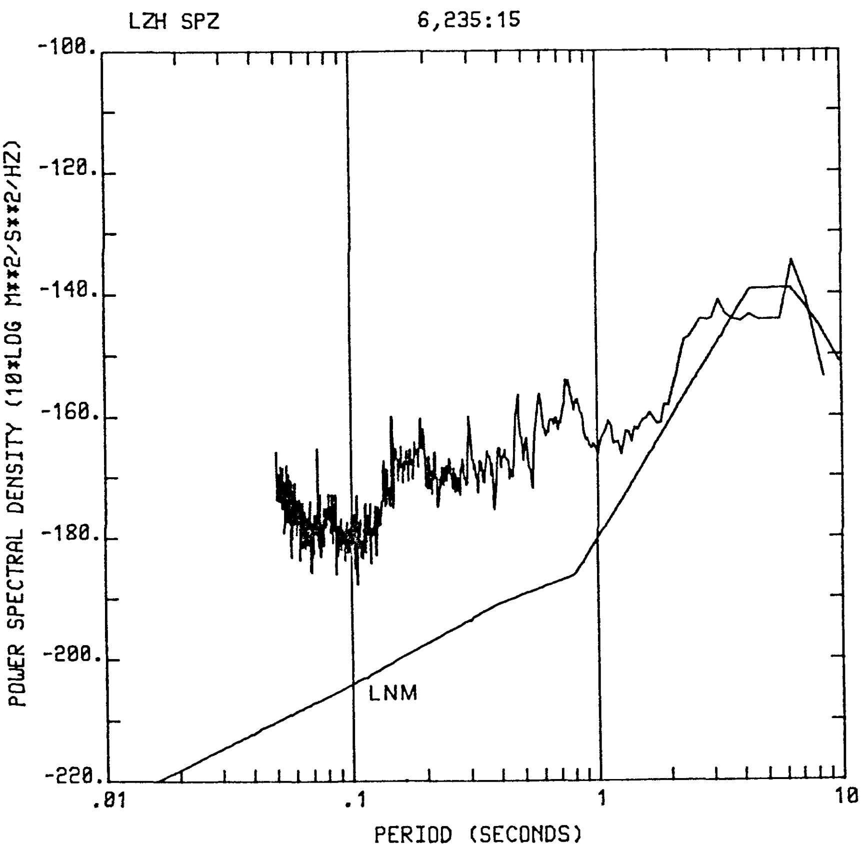


Figure 4.38. Sample data segments and associated noise power from the SPZ channel recorded at the Lanzhou Station. The SP signals are derived from an SRO-type borehole seismometer. Horizontal-component recording has been added since these test Sample data were recorded.

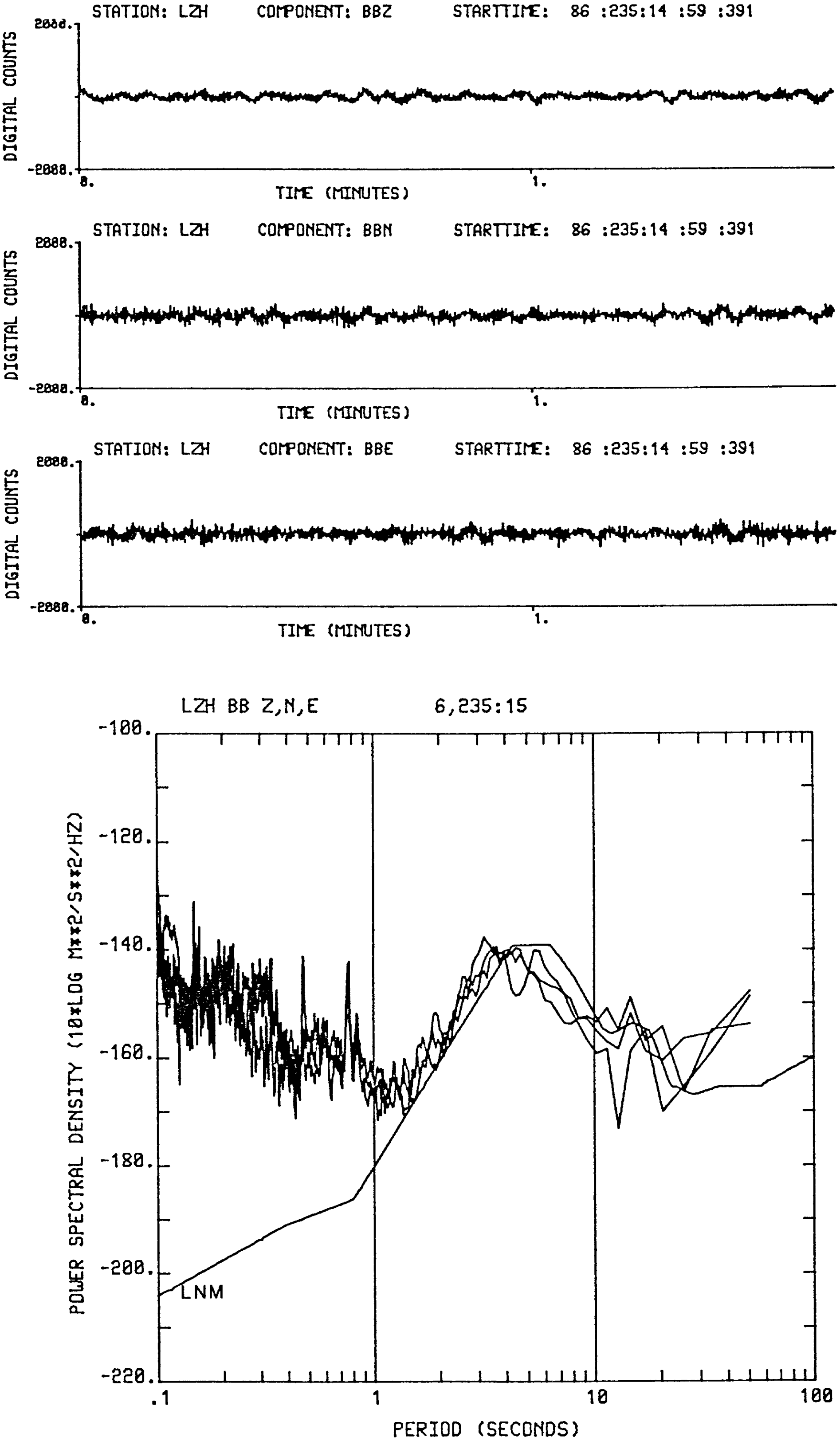


Figure 4.30. Sample data segments and associated noise power from the STS BB channels recorded at the Lanzhou Station.

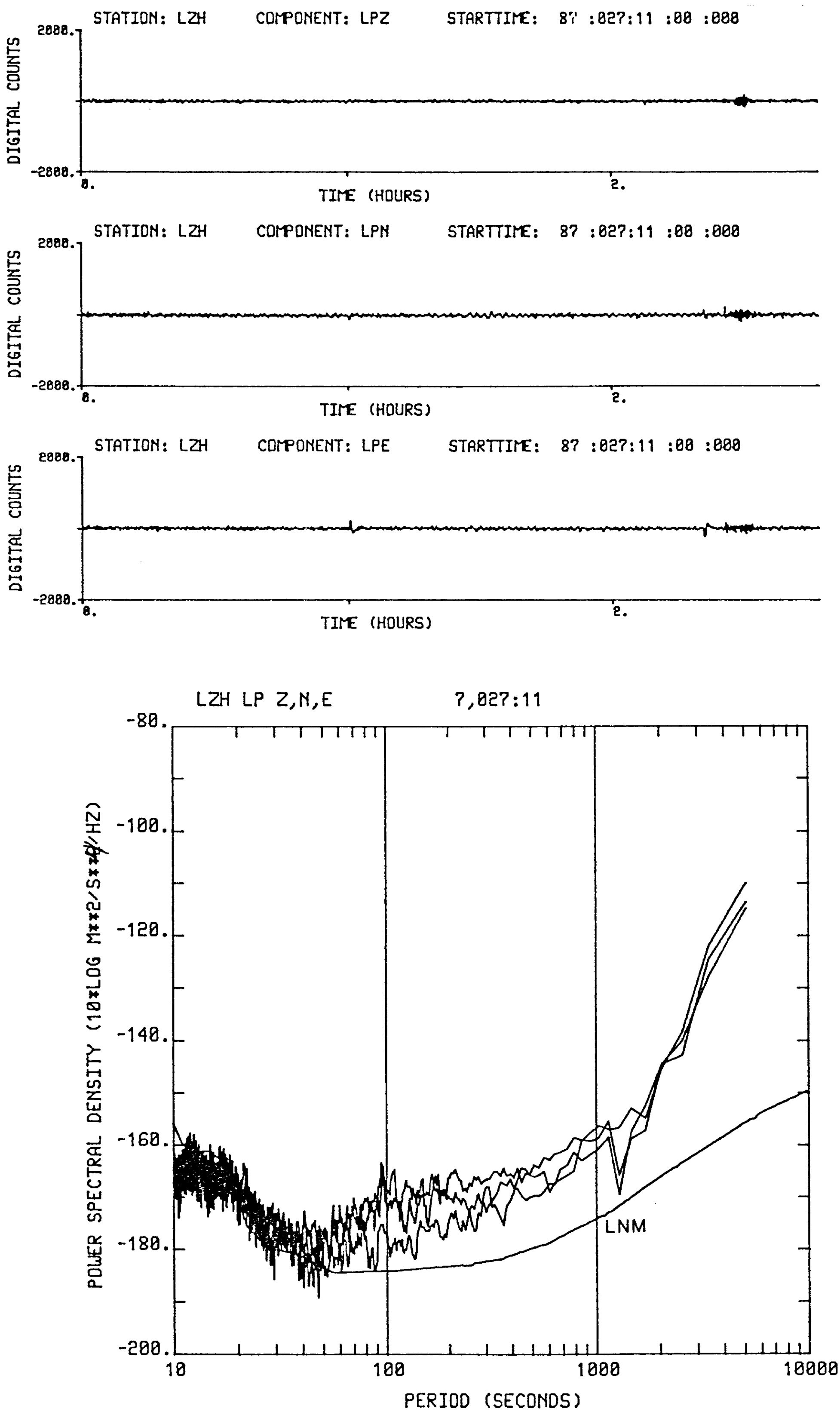


Figure 4.40. Sample data segments and associated noise power from the LP channels of the SRO-type borehole seismometer recorded at the Lanzhou Station.

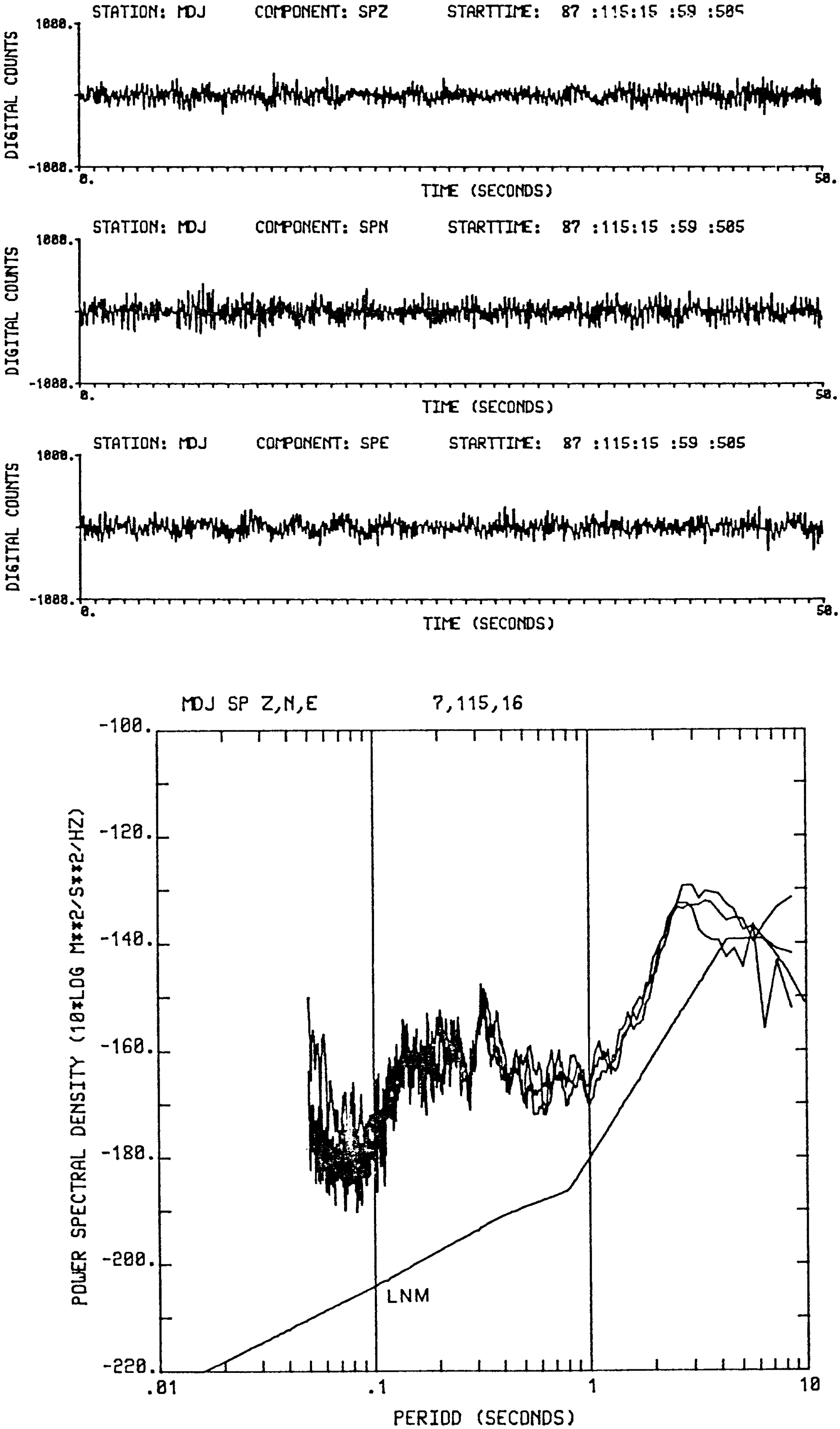


Figure 4.41. Sample data segments and associated noise power from the SP channels recorded at the Mudanjiang Station.

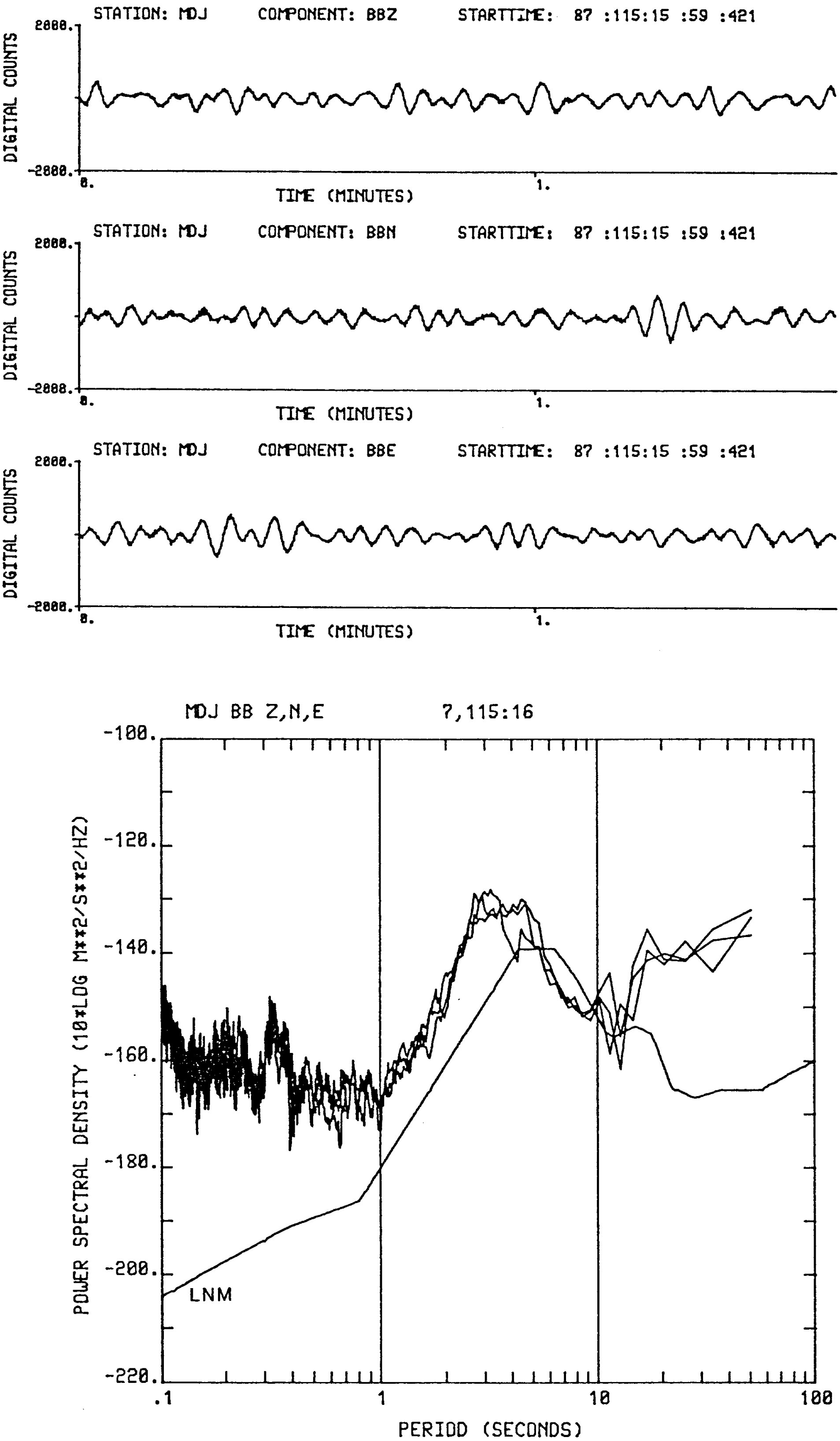


Figure 4.42. Sample data segments and associated noise power from the BB channels recorded at the Mudanjiang Station.

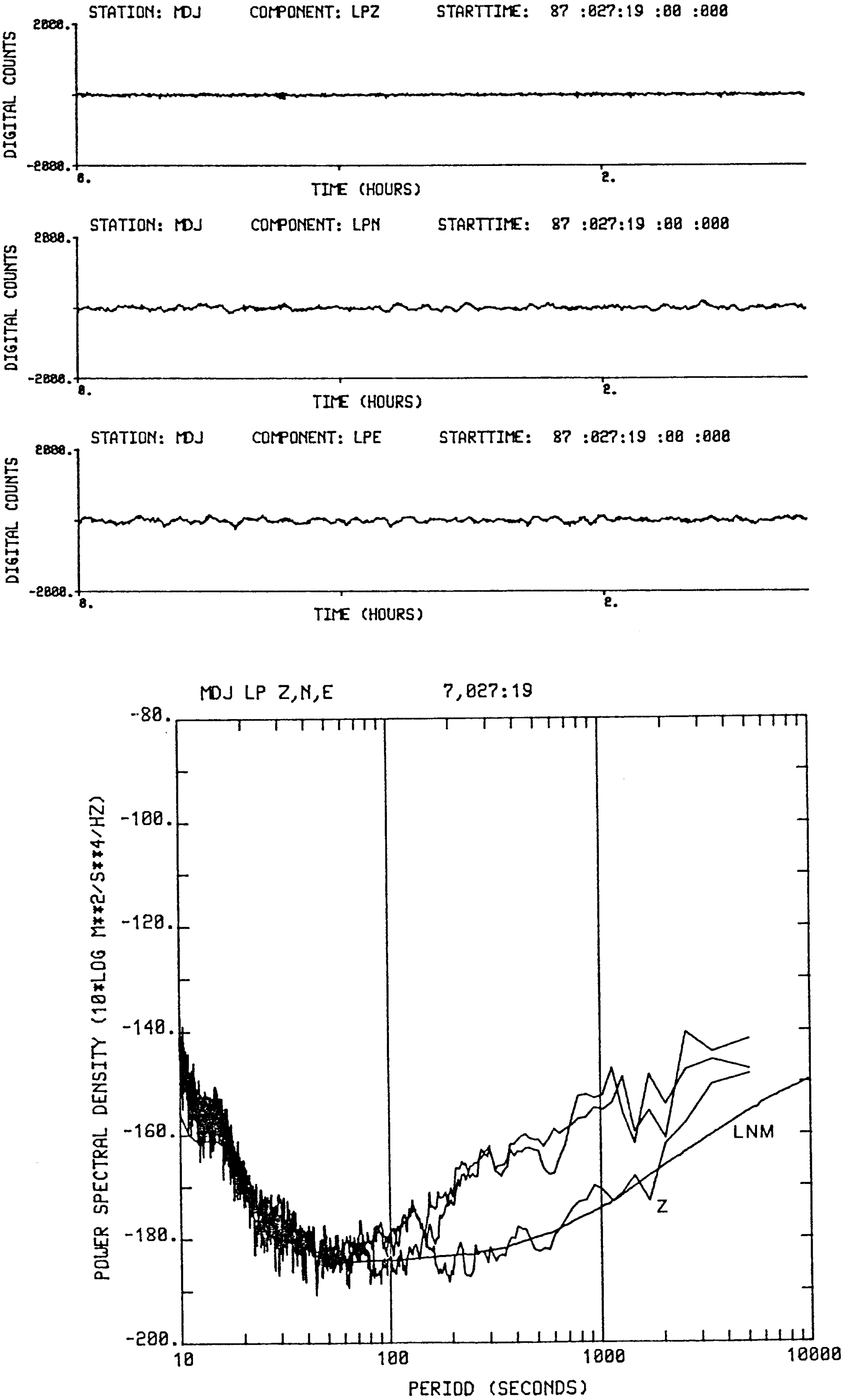


Figure 4.43. Sample data segments and associated noise power from the LP channels recorded at the Mudanjiang Station.

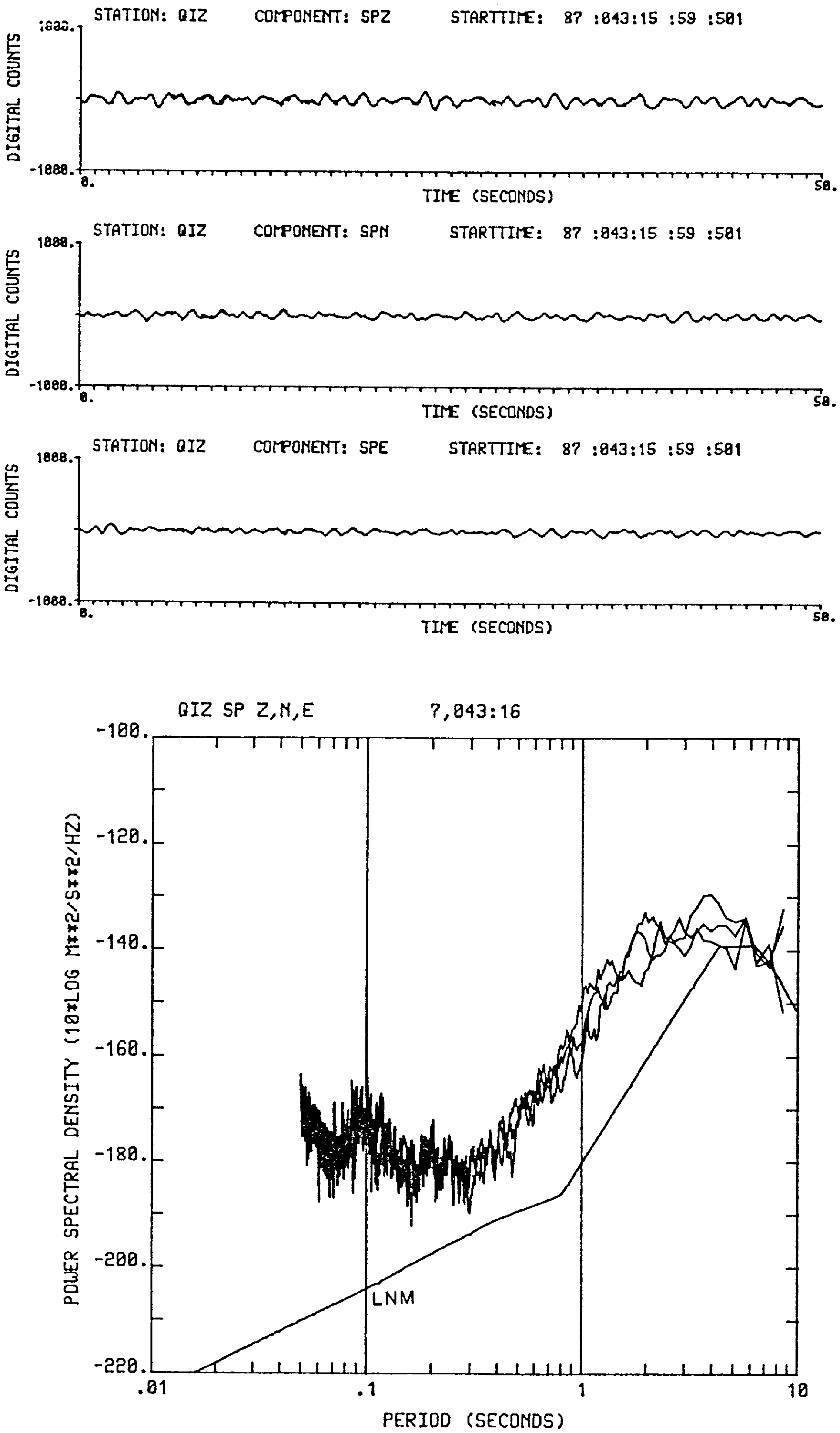


Figure 4.44. Sample data segments and associated noise power from the SP channels recorded at the Qiongzhong Station.

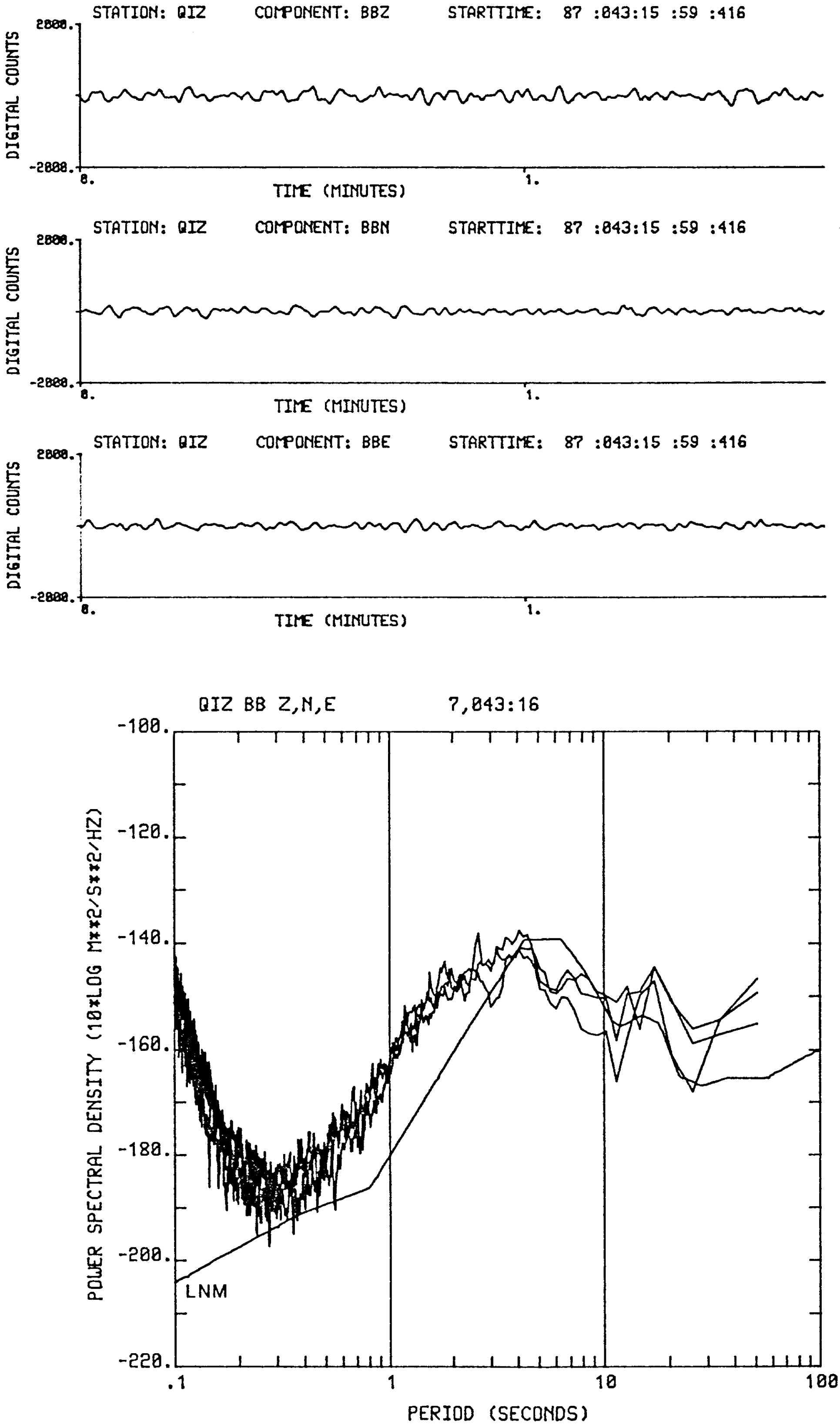


Figure 4.45. Sample data segments and associated noise power from the BB channels recorded at the Qiongzhong Station.

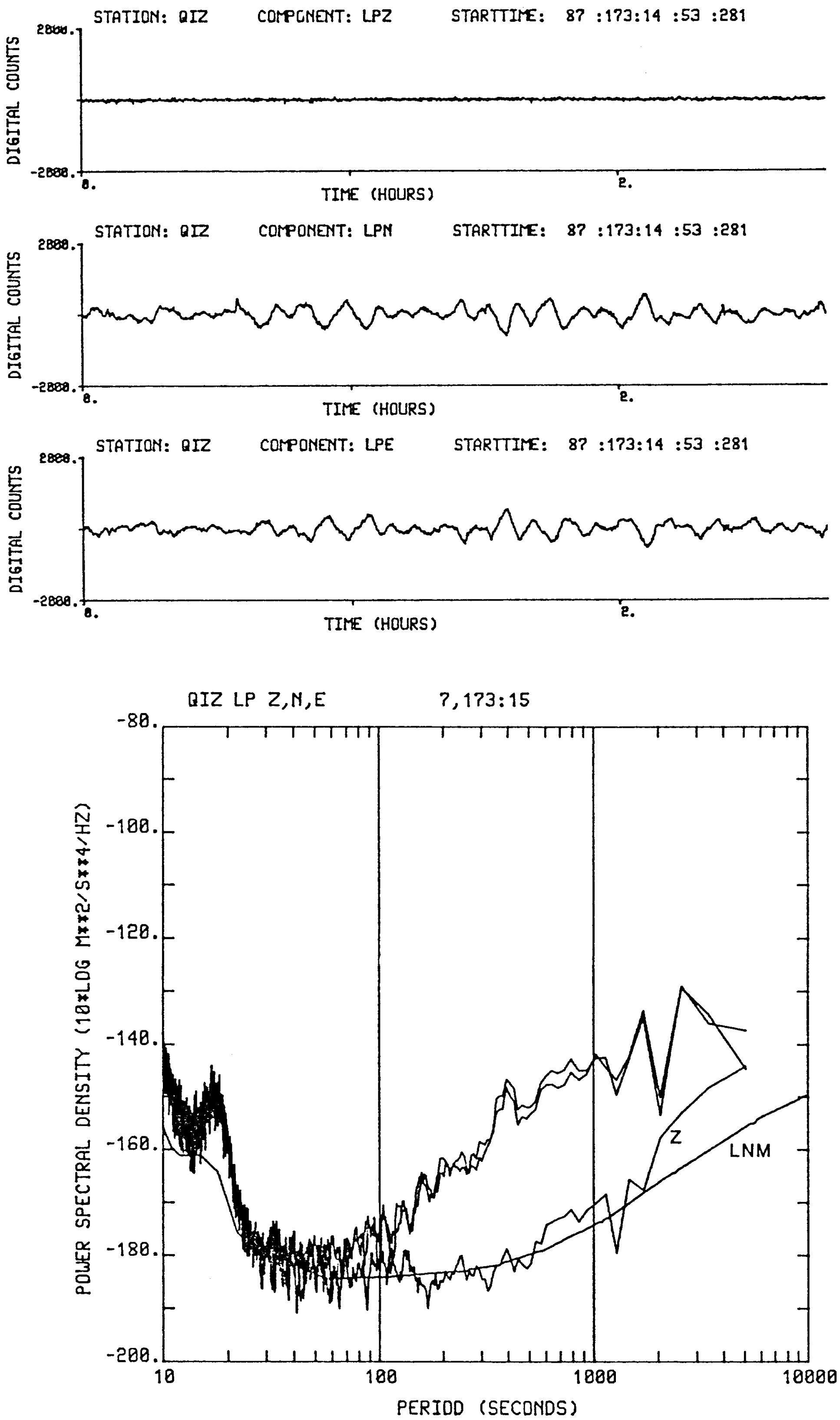


Figure 4.46. Sample data segments and associated noise power from the LP channels recorded at the Qiongzhong Station.

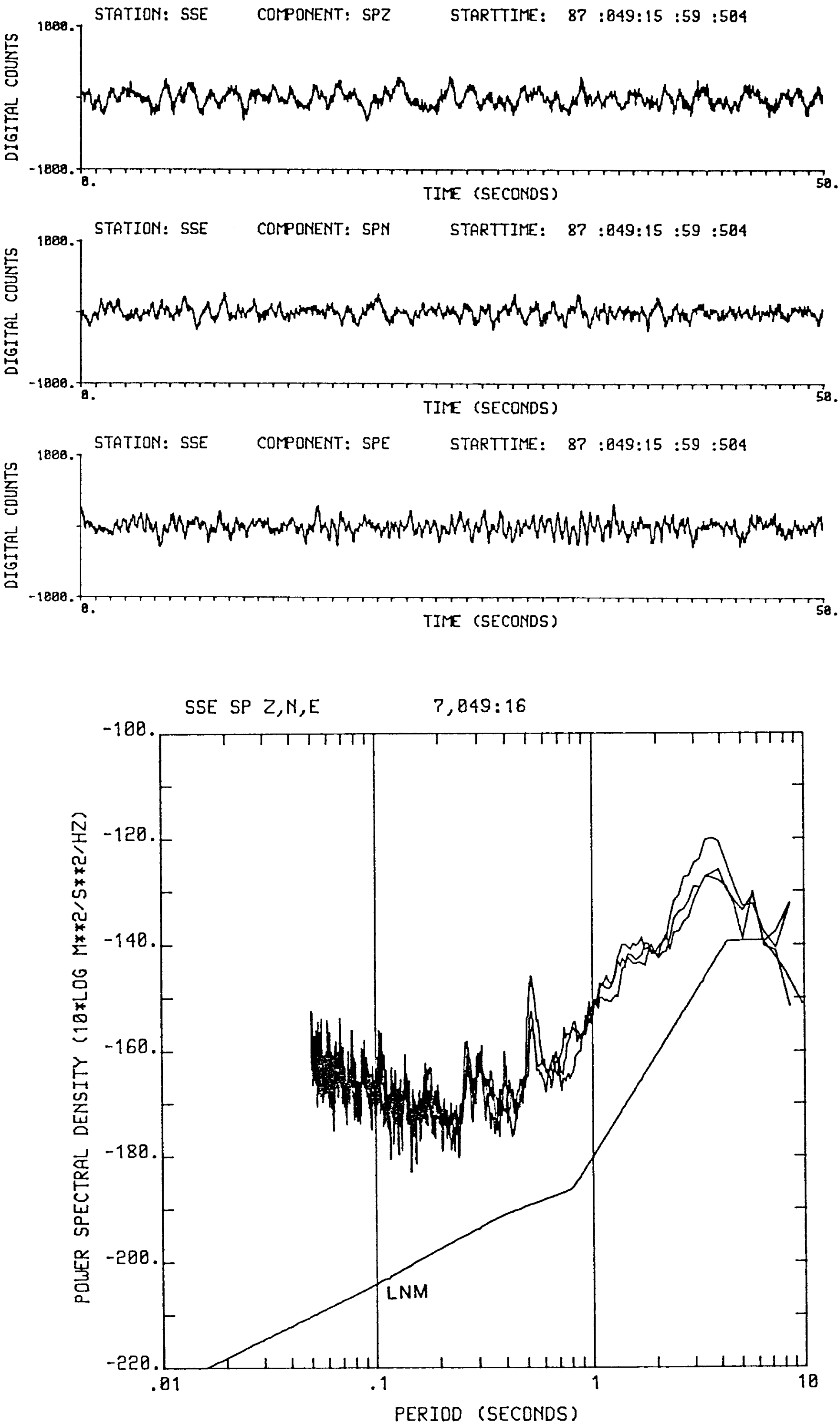


Figure 4.47. Sample data segments and associated noise power from the SP channels recorded at the Sheshan Station.

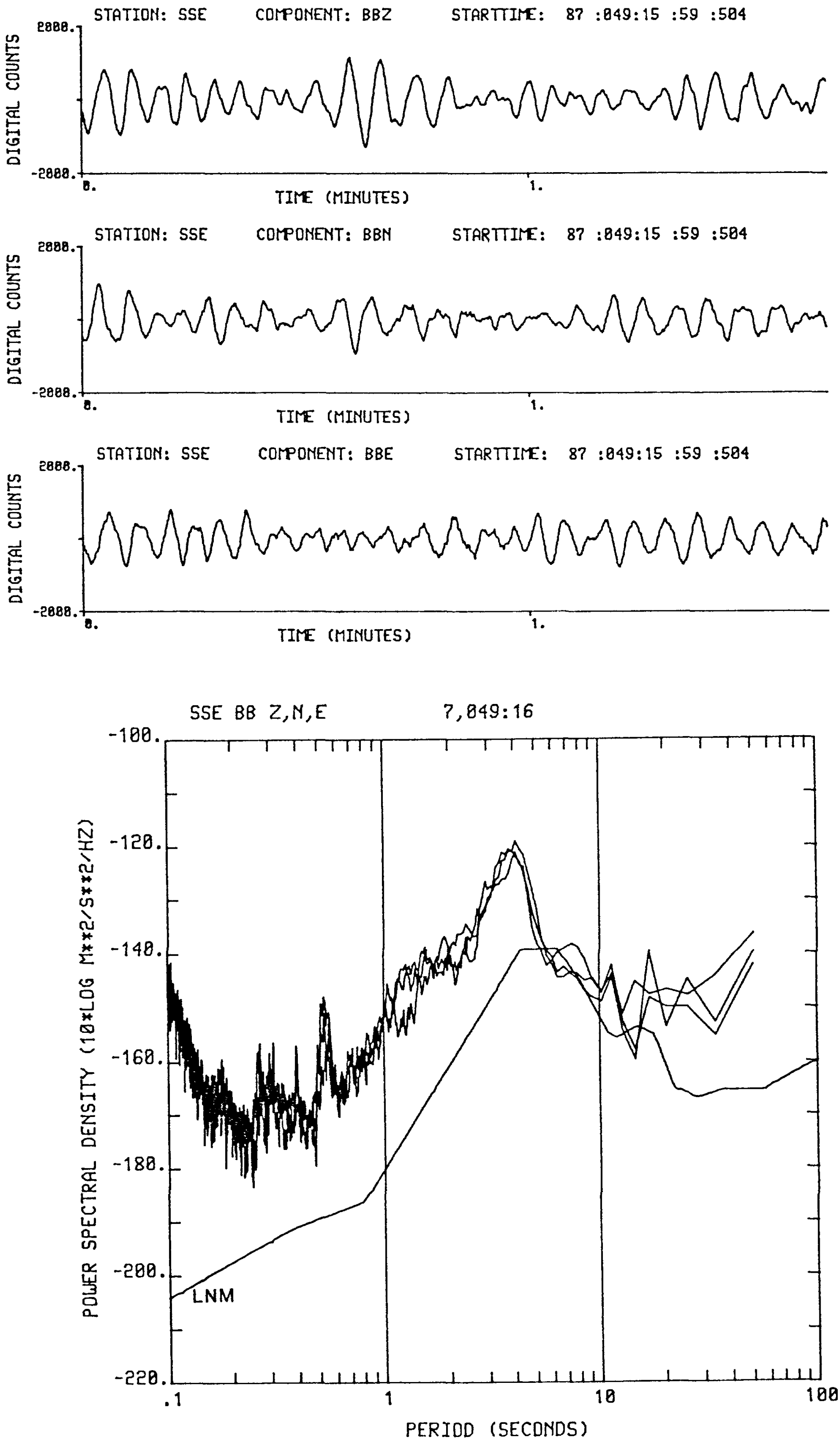


Figure 4.48. Sample data segments and associated noise power from the BB channels recorded at the Sheshan Station.

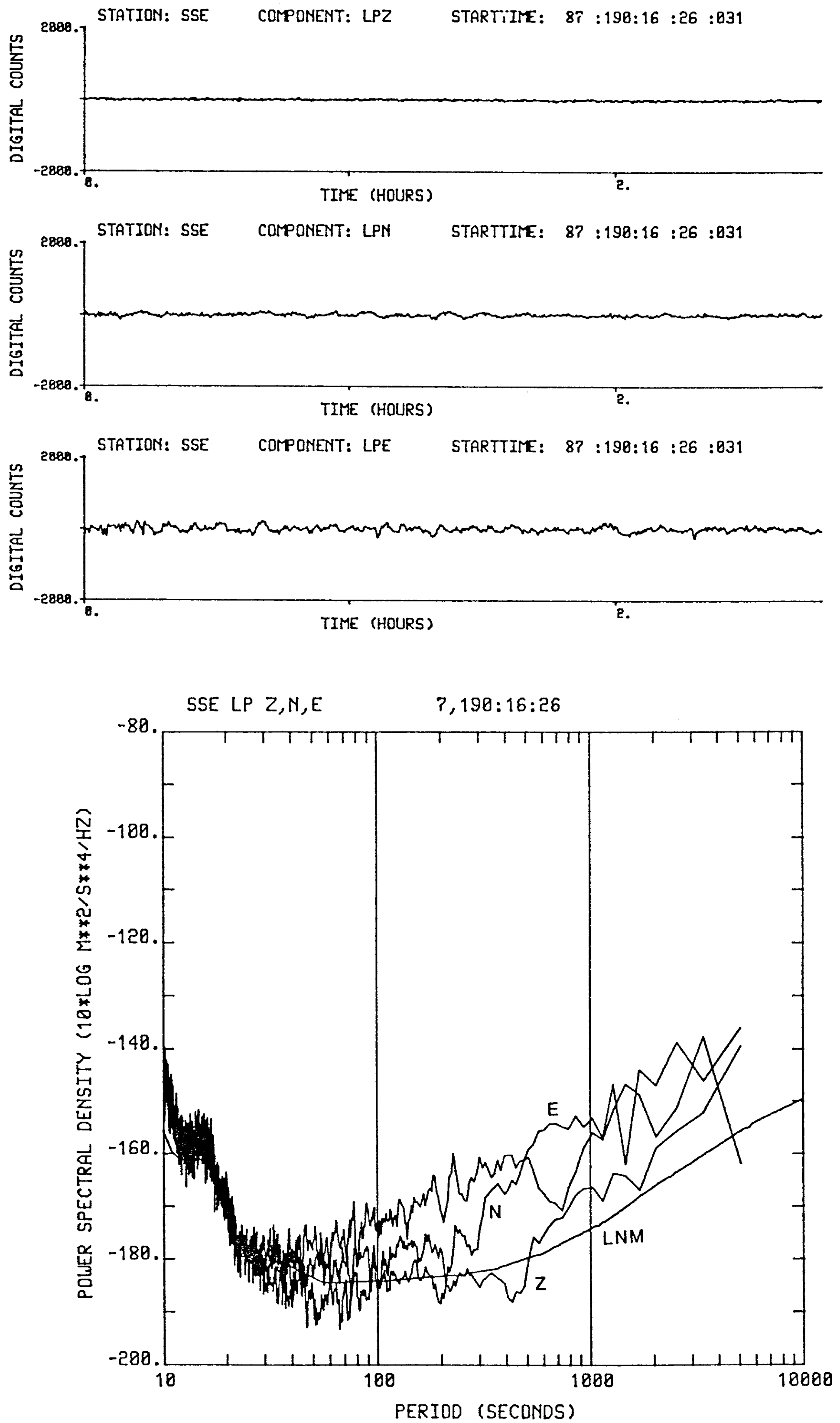


Figure 4.49. Sample data segments and associated noise power from the LP channels recorded at the Sheshan Station.

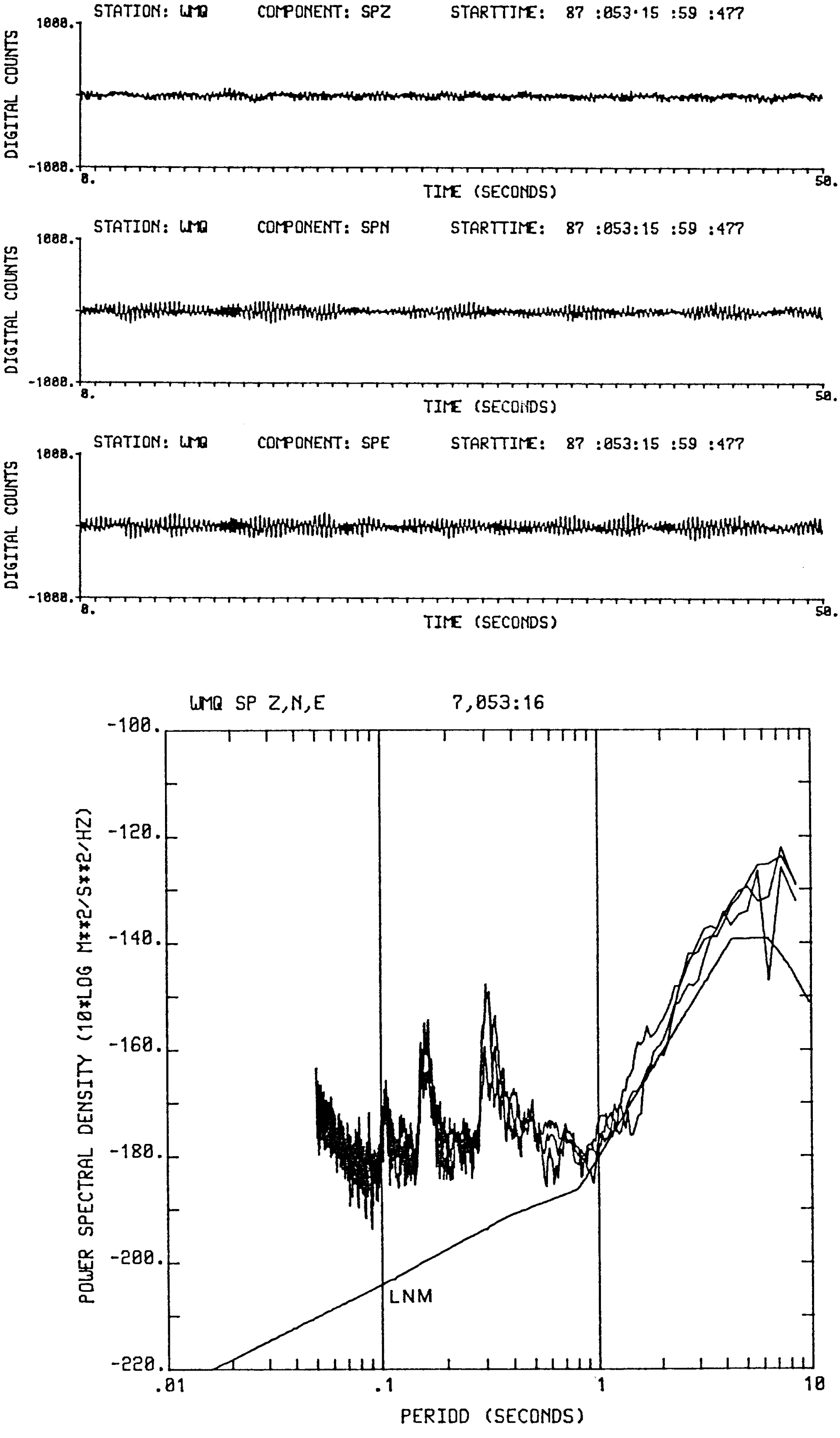


Figure 4.50. Sample data segments and associated noise power from the SP channels recorded at the Urumqi Station.

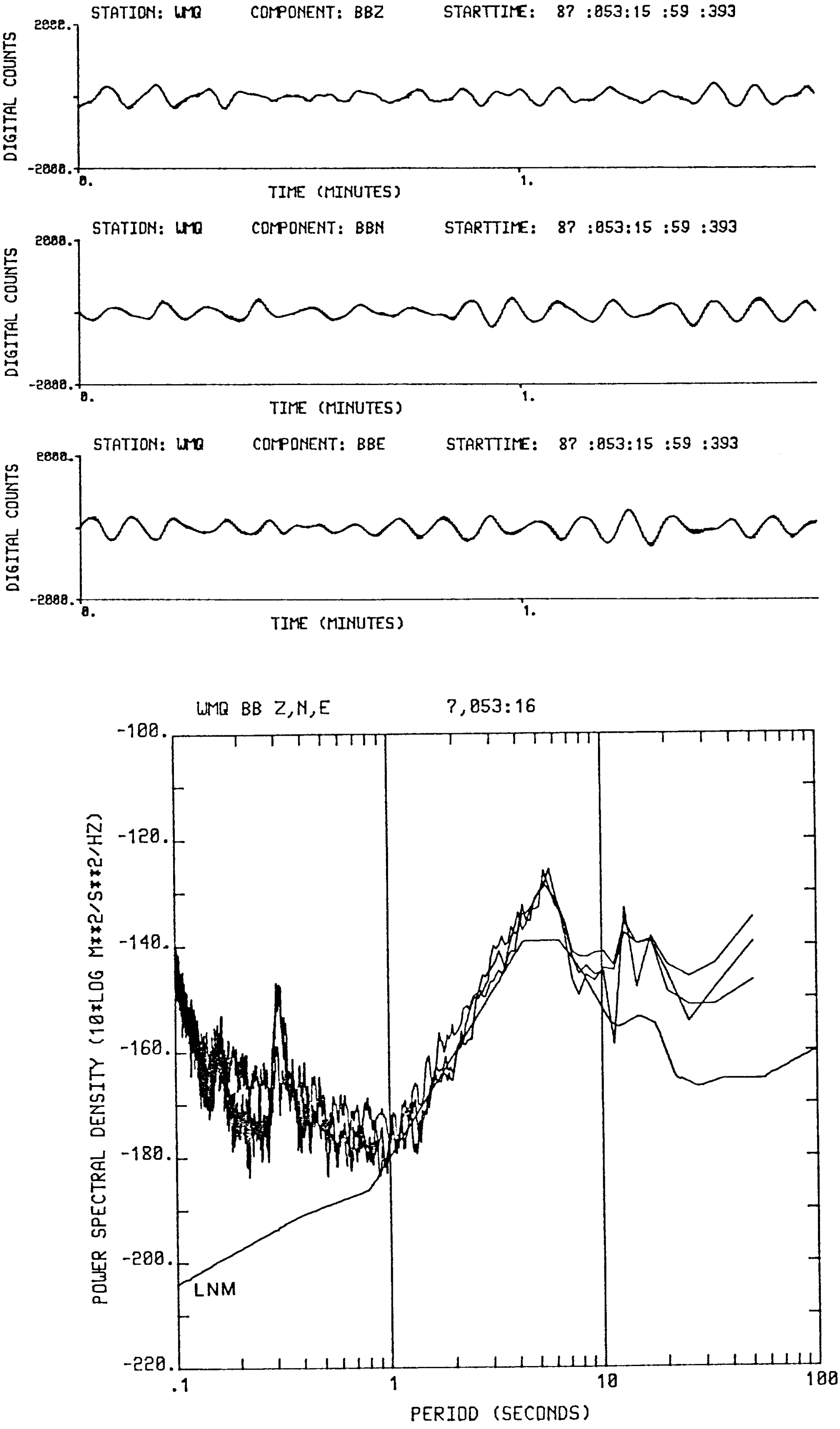


Figure 4.51. Sample data segments and associated noise power from the BB channels recorded at the Urumqi Station.

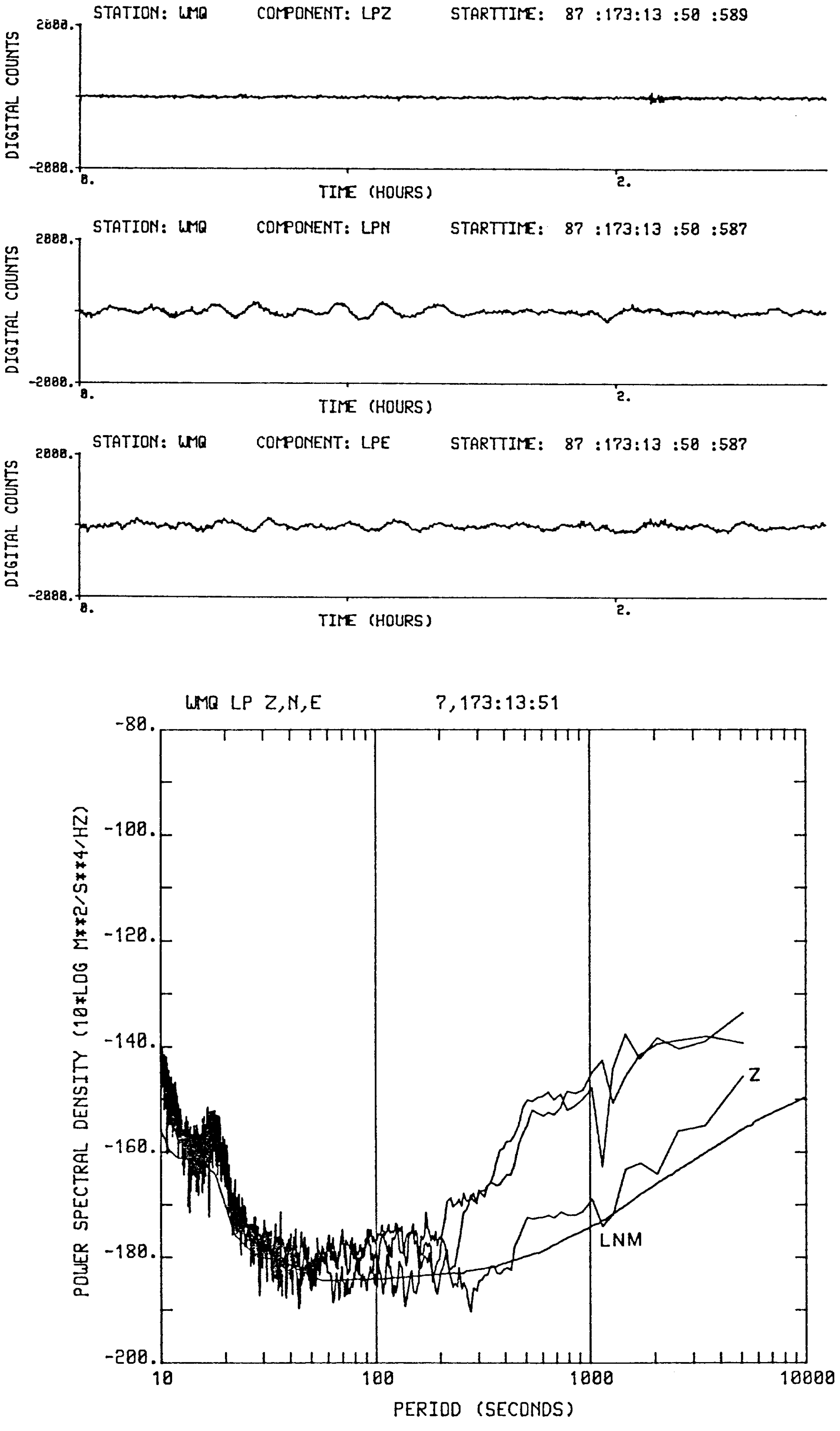


Figure 4.52. Sample data segments and associated noise power from the LP channels recorded at the Urumqi Station.

5 FUTURE PLANS FOR THE NETWORK

The CDSN is not only an operational facility, it represents an important framework for future development. Planning for improvements and additions is already underway.

In order to provide better coverage of southwestern China, specifically the Qinghai-Tibetan plateau, three additional stations are planned. The three new stations will be located at Lhasa in the Xizang Autonomous Region, at Hotan in the Xinjiang Uygur Autonomous Region, and at Golmud in Qinghai Province. This extended network configuration will consummate the large-scale plan for the digital network.

Existing CDSN equipment will be improved and perfected. There will be continued efforts to lower detection thresholds and improve the event detector, the bandwidth of the STS seismometers may be extended by incorporating a modification that has recently become available from the manufacturer, the efficiency of station power and equipment will be improved, and playback systems for checking data quality at the stations will be developed.

Programs for assembling network-day tapes will be improved, and automated procedures for calibration monitoring will be developed. Data retrieval and analysis programs will also be developed for extracting and processing event data needed for determining earthquake parameters.

The CDSN digital data will be fully utilized in cooperative studies of seismicity, crustal structure, source mechanisms, and for other fundamental and applied research having the ultimate goal of progress in the field of earthquake prediction.

The continued development of the CDSN and the effective utilization of the data are the important new program goals now that the installation phase of the CDSN program is finished.

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