



A COMPUTERIZED SEISMIC DATA  
ACQUISITION AND PROCESSING SYSTEM AND ITS APPLICATIONS

by

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## SUMMARY

The South Australian seismic network, operated by the Physics Department of the University of Adelaide, has grown steadily from its original three stations in 1963 to twelve in 1979. The network now extends to the South-East of the State (to monitor seismic activity possibly associated with volcanism in the region), and the density of the network has been increased around the northern tip of Spencer Gulf (to study the microseismicity of the seismically active Adelaide Geosyncline adjacent to this important industrial area). Recording in the latter region has been augmented by microearthquake surveys performed in the area using an additional seven stations comprised of portable equipment. The surveys, reported in this thesis, prompted the main aim of the investigation; viz, to re-evaluate the entire earthquake location and magnitude determination procedures used in South Australia in view of the greatly increased volume of data now involved.

The re-evaluation has resulted in the development of a computerized seismic data system, based around a Data General Nova minicomputer, including dual floppy disks and a fast printing terminal, with additional peripherals developed as part of the project. Software comprises an integrated, interactive system of seismic analysis routines covering all of the data processing needs of the network, from performing station calibrations and maintaining up-to-date station data, through the determination of locations and magnitudes of local earthquakes and the needs of microearthquake survey data processing, to the retrieval and display of earthquake statistics from an archived data base. In developing the routines,

some new location methods were employed, and a duration-based magnitude scale was developed and incorporated.

The computerized data processing system extends to the acquisition of digital seismic data in the field, using a microprocessor-controlled digital seismic event recorder designed as part of the system. The event recorder is battery powered, recording data on digital cassette tape. The software maintains maximum dynamic range by controlling the amplifier gain. Events are selected tentatively on the basis of amplitude, and are confirmed by tests based on total signal duration and principal frequency component before any data are committed to tape. Cassettes can be read directly into the Nova computer, digitized waveforms can be displayed, and phases interactively selected and submitted for processing by the analysis routines. The computerized system (with the exception of the event recorder itself) has been used in the analysis of all local earthquakes and microearthquake surveys in South Australia since the beginning of 1978.

## STATEMENT

This thesis describes work performed by the author at the Physics Department of the University of Adelaide. Except where due reference is made in the text, the thesis contains no work carried out, written or published by another person, nor accepted for any other degree or diploma in any educational institution.

Richard T. Parham

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The Director and Council of Salisbury College of Advanced Education are owed a debt of gratitude for making it possible for me to undertake these investigations whilst employed as a lecturer at the college, and especially for the 12 months study leave allowed me. Additional acknowledgements relating to specific aspects of the investigation appear in the text.



## CHAPTER 1: INSTRUMENTATION AND COMPUTERIZATION

### 1.1 The South Australian Seismic Network

The then province of South Australia was proclaimed on 28th December 1836, and before it was one year old the newly-arrived settlers in Adelaide had experienced an earthquake. McCue (1975) discusses this and other earthquakes reported in South Australia prior and subsequent to the installation of the first seismograph at the Adelaide Astronomical Observatory in 1908. Fifty years later, in 1958, the University of Adelaide set up a 3-component Benioff system at Mt. Bonython near Adelaide, which became a World Wide Standard Seismograph Network station (ADE), still operated by the University, in 1962. The equipment made redundant at Mt. Bonython was used to establish a station at Hallett (HTT), 150 km North. With the opening in 1963 of an additional station at Cleve (CLV), on Eyre Peninsula, the first tripartite seismic network was operational in South Australia. HTT and CLV employ short-period vertical-component Benioff seismometers only, and originally used photographic recording as at ADE. This was changed to ink recording in 1974 (HTT) and 1975 (CLV).

Several additional stations were opened subsequently, some of which were later closed or relocated. At the time of commencement of the present study (1975), the stations of the South Australian seismic network were as shown in Table 1.1.

Earthquakes have been located since 1963 using a standard least-squares minimization procedure (Bolt, 1960; Bullen, 1963; etc.) from a hand-plotted provisional location. The computer program (White, 1967) ran in a batch environment, generally processing one month's events at a time, using arrival times punched onto cards,



TABLE 1.1

## THE SOUTH AUSTRALIAN SEISMIC NETWORK IN 1975

STATION	COMMENCEMENT	LATITUDE	LONGITUDE	ELEVATION (m)	SEISMOMETER(S)	COMMENTS
Adelaide (ADE)	1958	-34.967	138.714	655	3 SP Benioff 3 LP Sprengnether	WWSSN station
Hallett (HTT)	1962	-33.431	138.922	708	1 SP(Z) Benioff	
Cleve (CLV)	1963	-33.691	136.496	238	1 SP(Z) Benioff	
Umberatana (UMB)	1967	-30.240	139.128	610	1 SP(Z) Willmore	
Partacoona (PNA)	1969	-32.006	138.165	180	1 SP(Z) Willmore	
Woomera (WSA)	1973	-31.144	136.805	180	1 SP(Z) Geotech	Moved from Island Lagoon (ILN)
Adelaide-Telemetry (ADT)	1974	-34.967	138.714	655	1 SP(Z) Willmore	See section 1.2
Hawk's Nest (HKN)	1975	-30.012	135.186	209	1 SP(Z) Kinematics	See section 1.2

along with station data applicable at the time of the events. Up to six phases (P1, PR, Pn, S1, SR, and Sn) could be accommodated for each station. This was later extended to nine by Stewart (1972a) who regarded three particular S to P converted phases as also being significant.

The crustal model used throughout consisted of a single-layered, homogeneous crust over a half-space. A review of crustal structure determinations up to 1975 is given by Shackelford (1978). The coefficients in White's original program were those of Doyle and Everingham (1964). They were slightly modified subsequently by White to those of Table 1.2, which are still in use.

TABLE 1.2  
SOUTH AUSTRALIAN CRUSTAL MODEL COEFFICIENTS

WAVE VELOCITIES (km/s)				MOHO DEPTH (km)
Crust		Upper Mantle		
P	S	P	S	
6.23	3.58	8.05	4.60	38

Magnitudes have been quoted for South Australian local earthquakes since the first locations were determined in 1963. Parham (1977a) has reviewed the development of this aspect. The first scales (White, 1968) were based on the conversion of amplitudes measured at ADE, HTT and CLV to equivalent Wood-Anderson amplitudes, with empirical distance-dependent terms in Richter-type formulae (Richter, 1935, 1958). Since 1969, magnitudes have been based on the 'new local scale', denoted MN (Stewart, 1975). This contains terms representing average source spectrum and frequency-dependent absorption in addition to geometrical attenuation, and involves a

measurement of principal period component in addition to amplitude. MN is still determined but is becoming less important with the introduction (see Chapter 3) of the more convenient and consistent duration-based magnitude MD.

The network and attendant computational procedures outlined above have enabled the overall pattern of seismicity of South Australia, certainly with respect to the Adelaide Geosyncline, to be determined (Sutton and White, 1968; Doyle, Everingham and Sutton, 1968; Stewart, Slade and Sutton, 1973; for example). Tectonic interpretations of the seismicity have also been undertaken, primarily by Stewart (1972b, 1976a, 1976b; Stewart and Mount, 1972; for example) and to a lesser extent more recently by McCue and Sutton (1979).

The University seismology group has recently made a number of changes to the network. These have occurred in parallel with the present study, and have a direct bearing on it. They are discussed briefly in the following two sections.

## 1.2 Recent Expansion of the Network

Five new stations have been opened in the South Australian network since 1977. Three, at Endilloe (EDO), Roopena (RPA) and Nectar Brook (NBK), increase the density of stations around the northern tip of Spencer Gulf\*, and the other two, at Willalooka (WKA) and Mt. Gambier (MGR), extend the network into the South-East of the state. Previously the most southerly station was ADE at Mt. Bonython.

The increased density of stations in the Spencer Gulf region follows a pilot study undertaken with portable instruments in 1977 by Parham and Sutton. This was reported upon by Parham (1977b) and is

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\* See state map of South Australia (Figure 1.1).

dealt with in detail in Chapter 4. The long-term goal is the determination of the microseismicity of the region, particularly in view of its industrial importance to the state.

The opening of stations in the South-East of the state was prompted by the continuing occurrence of a small but significant number of earthquakes in the region, and its known volcanic history (Sutton, McCue and Bugeja, 1977). Prior to the installation of the new stations, the region was well outside the South Australian network, although the opening in 1972 of the Bureau of Mineral Resources station at Bellfield (BFD) in the Victorian Grampians eased the situation somewhat. It is interesting to note that the largest earthquake in the state since the proclamation of 1836 occurred in this region (in 1897).

In 1974, the Bureau of Mineral Resources opened a station at Stephen's Creek (STK), near Broken Hill in New South Wales. Like BFD, this station has been of benefit in locating South Australian earthquakes, particularly in this case in the Flinders Ranges region.

Radio telemetry between seismometer and recorder was used for the first time in South Australia at NBK, with the seismometer at Nectar Brook in the Flinders Ranges and the recorder at the Environmental Research Station at Chinaman's Creek on the coast near Redcliff Point, 13 km away. Radio telemetry was again employed at MGR with the recorder at the Mines Department office in Mt. Gambier and the seismometer at The Bluff, 19 km away.

Telemetry by leased telephone line had been used before in South Australia. From 1974, data from Mt. Bonython have been telemetered to a pen recorder at the University of Adelaide in the city. A seismometer separate from the WWSSN instruments is used, thereby establishing essentially a parallel station, denoted ADT. (Time and

calibration pulses derive from the WWSSN facilities.) This arrangement gives an immediate visual indication at the University of any seismic activity near the population centre of Adelaide.

In 1975, when the seismometer installed at the Mirikata tracking station on the Woomera Rocket Range two years previously was moved to a quieter site at Hawk's Nest, 10 km away, line telemetry was again used to transmit the data to the recorder at Mirikata. In 1980, with the closure of the tracking station, the data were rerouted 240 km to Woomera. A 3 km telephone line also formed part of WKA when it was installed in 1979.

Details of the five new stations are presented in Table 1.3. The complete South Australian network, as at the end of 1980, is shown in Figure 1.1, along with the neighbouring stations BFD and STK.

### 1.3 Portable Stations

The permanent network described above has also recently been supplemented with seven sets of portable equipment, five owned by the University and one each by the South Australian Institute of Technology and Salisbury College of Advanced Education. Each set comprises a Kinematics Ranger seismometer and PS1A portable recorder. Spare battery packs and drums, battery chargers, portable radios and time-pulse amplifiers provide support facilities to enable a complete portable network to be set up in a region. The equipment was first used on a large scale by Shackelford (1978) to record quarry blasts from Leigh Creek, Iron Baron and Kanmantoo as a further study of crustal structure in South Australia.

One additional portable station may be set up using an early model of a slow-speed tape recorder, built by the University to a design developed by the Australian National University (Muirhead and

TABLE 1.3

## ADDITIONS TO THE SOUTH AUSTRALIAN SEISMIC NETWORK SINCE 1975

STATION	COMMENCEMENT	LATITUDE	LONGITUDE	ELEVATION (m)	SEISMOMETER(S)	COMMENTS
Roopena (RPA)	1977	-32.725	137.403	95	1 SP(Z) Kinematics	
Endilloe (EDO)	1977	-32.322	138.048	300	1 SP(Z) Kinematics	
Willalooka (WKA)	1979	-36.417	140.321	40	1 SP(Z) Kinematics	
Nectar Brook (NBK)	1979	-32.701	137.983	180	1 SP(Z) Kinematics	
Mt. Gambier (MGR)	1980	-37.728	140.571	190	1 SP(Z) Kinematics	

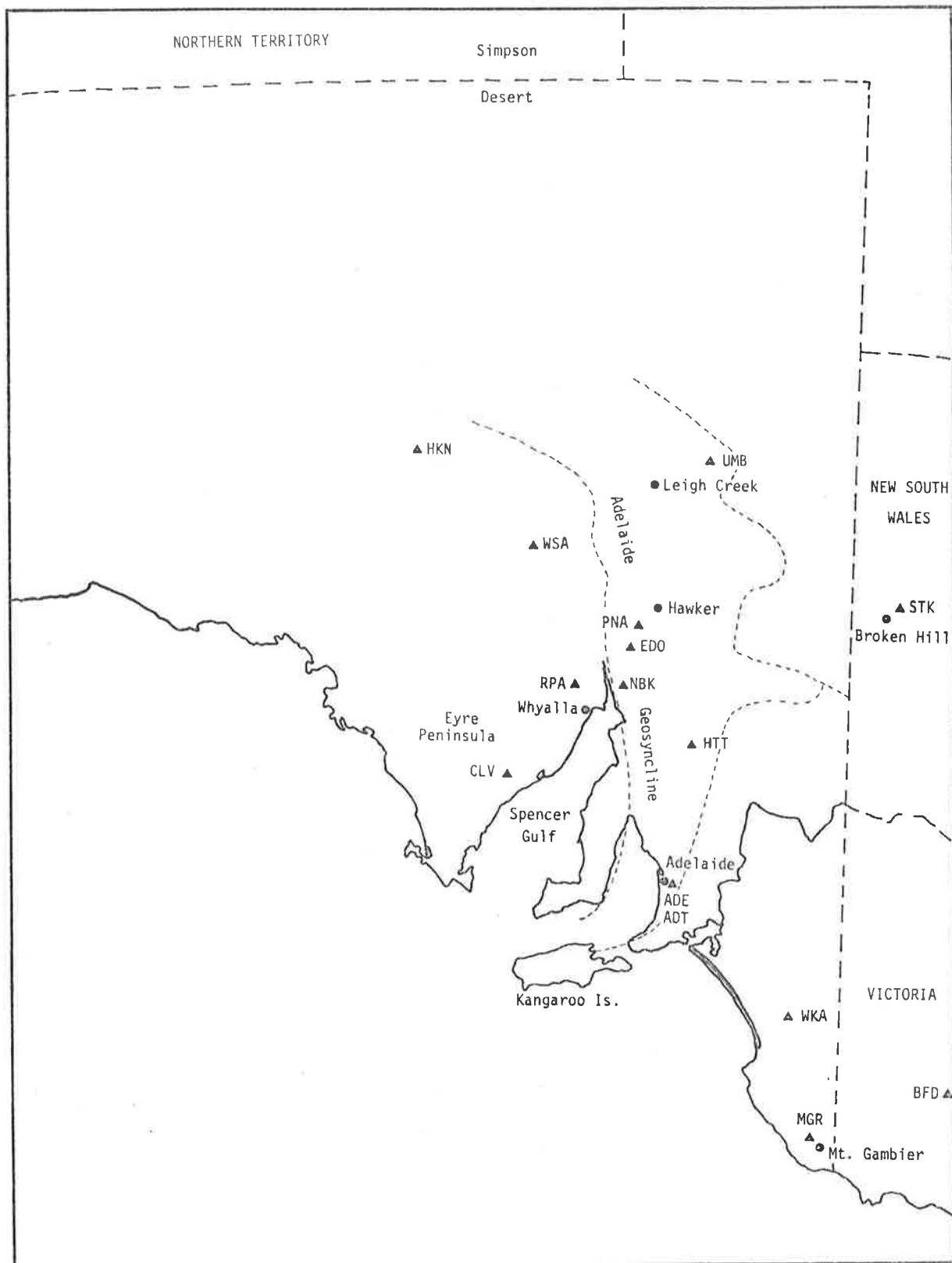


FIGURE 1.1

THE SOUTH AUSTRALIAN SEISMIC NETWORK AND ADJACENT STATIONS IN 1980.  
 (Also shown are the locations of the main places referred to in the text.)

Simpson, 1972). This unit records four channels, comprising internal clock and radio time pulses and high and low gain seismic data, on conventional reel-to-reel analogue magnetic tape at a very low speed. When replayed at conventional speeds, events can be recognized audibly and displayed on a multi-channel ultraviolet recorder.

The tape recorder was used at Nectar Brook and in the South-East as an interim measure while the permanent stations were being constructed. It was also used, along with the Kinometrics portable instruments, in the 1977 pilot Flinders Ranges microearthquake survey. In each case a recorder was needed which would operate for a long period of time unattended. When this is not a major factor, as in a second microearthquake survey in the more accessible Adelaide Hills by Sutton in 1978, and another more compact survey in the Flinders Ranges in 1979, the Kinometrics instruments are used exclusively. Subsequent to the construction of the tape recorder by the University, a more advanced six-channel recorder has been developed and used extensively by A.N.U.

These portable facilities add a further eight stations to the number which could be in operation at any time as part of the South Australian network, bringing the total to 21 stations (or 23 if BFD and STK are included). This represents a very large increase in the data processing load since 1963 when the computational procedures were designed. The data processing problem is compounded by the fact that when a dense portable network is set up in an active area, events which would be too small to be recorded at sufficient permanent stations to enable them to be located, may nevertheless be recorded on sufficient portable stations to enable a location to be carried out. Further, since the number of events increases exponentially with decreasing magnitude (Gutenberg and Richter, 1944, 1954; Lomnitz-Adler



and Lomnitz, 1979), the data processing load from a microearthquake survey becomes acute. As an illustration, the 1977 Flinders Ranges survey resulted in 70 locatable events being recorded over a three-week period, compared with 49 and 51 for the entire previous two years (1975 and 1976 respectively) in the permanent network. The same was found in the northern Spencer Gulf region with the permanent network when the new stations were opened in that region. The number of earthquakes located per month rose from an average of 4 per month for the first 10 months of 1977 to 15 in November and 20 in December, the first two months of operation of EDO and RPA.

These facts implied that if the expanded network were to function satisfactorily, and parallel microearthquake surveys were also to be carried out in localized areas, then a major concomitant expansion of the data handling aspect of the network would be necessary. This was a primary goal for much of the work carried out in the present investigation.

#### 1.4 Some Seismic Data Processing Methods Employed Elsewhere

Many other networks have been faced with a similar need to re-evaluate the data processing aspects of their operation in recent years. An examination of a selection of these and the solutions adopted is useful for comparison with the South Australian system.

The University of California at Berkeley, which operates a seismic network in northern California, is developing a computerized seismic data system, the eventual operation of which is outlined in their Final Technical Report (Bolt, McEvelly and Johnson, 1977). Data from all stations are telemetered by line to a central site where they are multiplexed and recorded continuously onto multi-channel analogue magnetic tape, along with a centrally-derived time code. Each tape

contains a single day's recording from all stations in the network.

A second tape drive is used to replay the previous day's recording for computer analysis. Under interactive software control, data are digitized and transferred to temporary storage on magnetic disk, from where they may be subsequently retrieved and displayed on a graphics screen, the relevant seismic information extracted, and the information used to locate and determine the magnitude of each event. Data pertinent to each event are written onto digital magnetic tape for archiving. The interactive software itself is almost exclusively written in a high-level language (FORTRAN).

A somewhat similar system is in operation in Edinburgh at the Institute of Geological Sciences (Houliston, 1975). Data are again recorded in analogue form on multi-channel magnetic tape. During playback, the data are temporarily transposed onto a continuously overwritten tape loop. When an event has been transferred to the loop, the playback tape is stopped and the loop repeatedly examined. The event can either be transferred to a multi-channel pen recorder, possibly via filters, or digitized for analysis at the Edinburgh Regional Computing Centre, where a suite of analysis programs has been written. Digital data can be saved on digital magnetic tape as at Berkeley.

Computerized techniques have been applied as an integral part of the Seismic Research Observatories of the WWSSN (Peterson et al., 1976; Peterson and Orsini, 1976). Besides being written as conventional seismograms, data from the three broad-band bore-hole seismometers at each SRO station are continuously digitized and presented to an on-site minicomputer which is programmed to detect events and write them (only) onto digital magnetic tape.

Being an industry-compatible medium, digital event tapes from

the SRO's, like the archive tapes from Berkeley and Edinburgh, can be read by any computer with a tape drive. Recently, computer networks have provided an alternative method of transferring large volumes of data between computers. SRO data, for example, are transferred via the Advanced Research Projects Agency Network (Arpanet) in the United States between Albuquerque, New Mexico, where the tapes are read, Cambridge, Massachusetts, where the data are stored on a mass on-line memory system, and Alexandria, Virginia, and elsewhere, where they are analysed (Dorin and Eastlake, 1978). Real-time seismic array data, telemetered by line and satellite to Alexandria, are also sent via Arpanet to the mass storage system at Cambridge and thence elsewhere for analysis.

At the Seismic Data Analysis Centre in Alexandria, an interactive seismic processing system is in operation which has been developed by Texas Instruments Inc. (Sun and Shaub, 1978). Data from various sources and in various formats are converted to a standard form and buffered onto disk prior to the execution of the analysis software which is itself modular and disk-based with inter-module communication via disk data files. Digital seismic waveforms are displayed on the screen of a graphics console, with interaction provided for by means of a light pen and keyboard. The package, which is written in FORTRAN except for some device drivers which are in assembly language, provides interactive event detection, earthquake parameter determination and spectral analysis amongst its procedures.

A number of factors emerge from a consideration of these representative systems:

1. More efficient processing of seismic data is provided by involving the computer in as many stages of the acquisition and analysis process as possible. This requires the conversion of

data to digital form at an early stage.

2. Notwithstanding, conventional analogue recording is retained in addition to digital methods wherever possible.
3. Seismic analysis software involves interactive rather than batch processing, so that the judgement and experience of the seismologist complement the speed and computational capability of the computer.
4. A high-level language is used for software wherever possible. Although less efficient, this is more amenable to on-going maintenance and does not preclude non-specialist programmers from contributing software to the system.
5. A graphics capability is necessary for the display of digitized seismic data.
6. A method for archiving results of analyses in machine-readable form is essential.
7. Maximum flexibility in input format, methods of analysis, and output format is desirable.
8. Software is modular and preferably disk-resident, being swapped into main memory as needed. Temporary data are also stored on disk.
9. Transferability of data with other computers is highly desirable.

Although the South Australian computerized seismic data system was developed in parallel with some of the above systems, and therefore knowledge of them was not possessed at the time, nevertheless the above considerations are essentially those used as a basis for the design. In view of the limited financial resources available, however, one further consideration must be added, viz:

10. The system is the least expensive able to perform satisfactorily subject to the previous considerations.

### 1.5 The South Australian Seismic Data Acquisition and Processing System

The South Australian seismic data system has been developed in two phases. The aim of the first was to provide faster, more reliable, interactive analysis of conventional seismograms from existing permanent and portable stations. In the case of the stations of the permanent state network, the analysis essentially comprises location and magnitude determination of all South Australian local earthquakes previously processed by hand-plotting of provisional location followed by batch revision. Separate analysis, with no previous counterpart, is performed for data from portable stations involved in microearthquake surveys. In either case, the results of the calculations are stored off-line for subsequent compilation of earthquake statistics.

The aim of the second phase was to provide for the input of seismic data in digital form, and the merging of these data with data from conventional seismograms for analysis and archiving as in the first phase.

The handling of digital data approaches more closely that of the Seismic Research Observatories rather than that at Berkeley or Edinburgh. A microprocessor-based field unit, designed as part of the system, provides on-site event detection of incoming data. Events are recorded on digital cassette tape, which is subsequently transferred to the central computer. Details of the event recorders are contained in Chapter 6.

The central computer facility is shown in Figure 1.2. Its hardware consists of the following components:

1. A 16-bit minicomputer with the maximum 64 Kbytes of unmapped memory, real-time clock, and power-fail/auto-restart option.

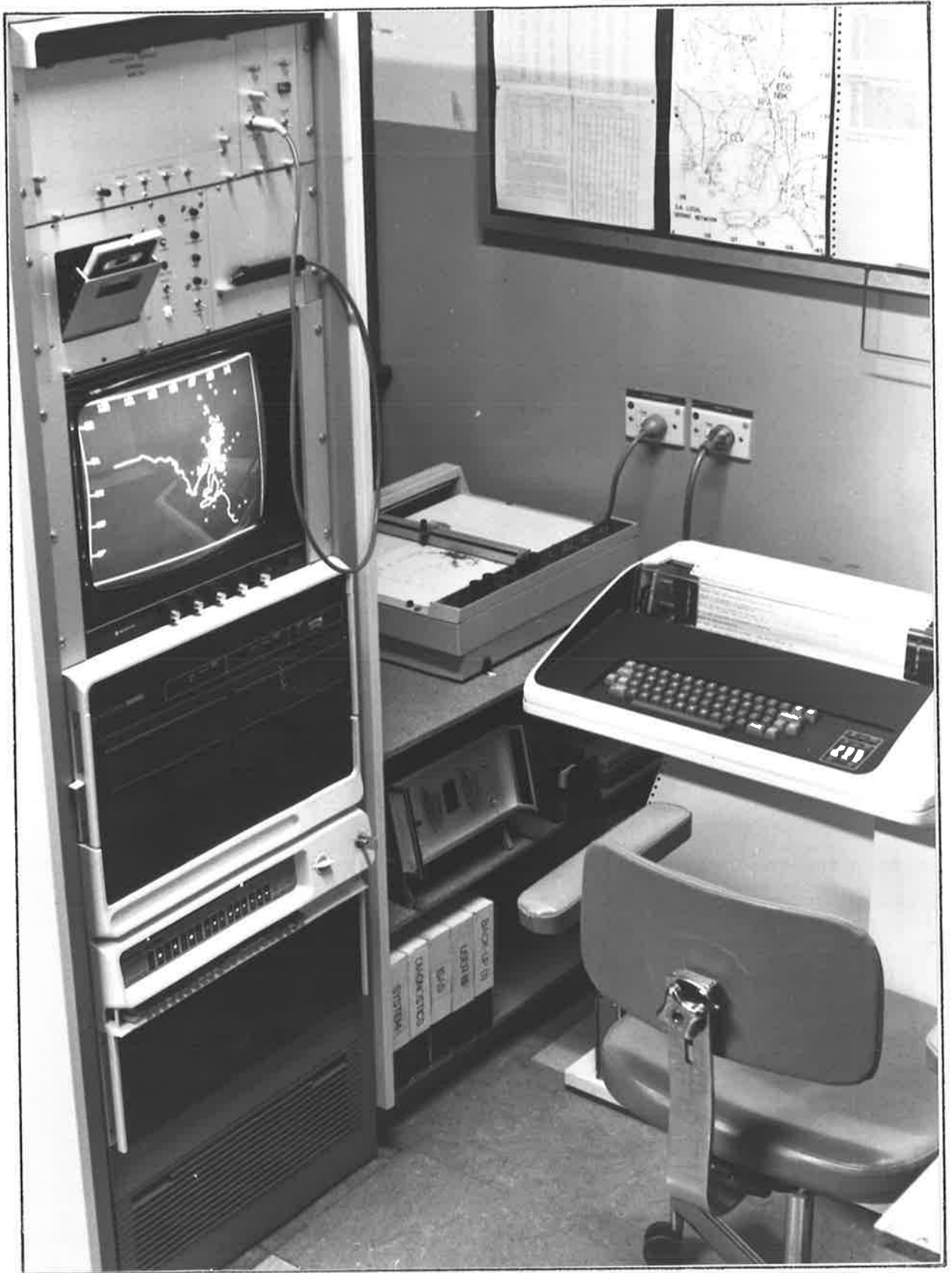


FIGURE 1.2

THE CENTRAL-SITE COMPUTER OF THE SOUTH AUSTRALIAN COMPUTERIZED SEISMIC DATA SYSTEM.

2. Dual 308 Kbyte, 8 inch floppy disk subsystem.
3. A 60 character per second, 132 column printing terminal.
4. A digital cassette tape reader.
5. A microprocessor-controlled graphics unit with screen and plotter output and interactive light-pen input.
6. An EPROM programmer.

The first three components are commercial items purchased from Data General Corporation, the minicomputer being a Nova 3. The remainder were all developed locally and built especially for the system. They are discussed in later chapters.

The software for the central computer consists of the following:

1. A disk-based operating system.
2. Text, binary and disk editors.
3. Assembler, relocatable linking loader, and debugger.
4. FORTRAN compiler.
5. BASIC interpreter.
6. Diagnostic routines and diagnostic operating system.
7. Cross-assemblers for microprocessor-controlled devices.
8. Drivers for EPROM programmer, cassette reader and graphics unit.
9. Interactive seismic processing software.

Software in the first six categories was obtained commercially from the computer manufacturers, the operating system being Data General DOS (Disk Operating System). FORTRAN and BASIC are the only high-level languages supported by Data General for DOS. The cross-assemblers were converted locally from software designed for other machines. One was written in FORTRAN and the other in assembly language. The device drivers were all written especially for the system. Assembly language was used, of necessity, with the exception of the EPROM programmer driver which was able to be written in

FORTRAN. The cross-assemblers and drivers are discussed in later chapters.

The major item of software is the seismic processing package itself, denoted ISAS (Interactive Seismic Analysis System). In a relatively slow and limited-capacity floppy disk environment, FORTRAN compilation, involving use of editor, compiler, assembler, loader, run-time libraries and debugger, is unsuitable for such a large and intricate piece of software. Instead, BASIC, the other high-level language supported by DOS, was used. This is interpretive and incorporates its own editor, requiring no disk-consuming support utilities and no time-consuming compilation, assembly and loading phases. Execution times are necessarily longer, but this is generally of no consequence. The language, being more modern than FORTRAN, was also designed from the outset to facilitate interactive input/output (especially of alphabetic information), a prime requisite of ISAS.

A major disadvantage of an interpretive language is that comment text is memory-resident during execution. For very large programs, such as those comprising ISAS, the memory overheads involved with detailed program comments are prohibitive, and a self-documenting listing is impractical. For this reason an overview of the logic design is incorporated in subsequent chapters. Operation of the software and its maintenance is covered in separate manuals (Parham 1980a, 1980b). The following is a general discussion of the overall structure of ISAS.

## 1.6 ISAS

ISAS is a modular, disk-based system of interrelated programs. The software is command-structured, with each command corresponding to an independent, identifiable operation such as opening a new station



in the network or determining a provisional location. Related commands are grouped into subsystems, only one of which is memory-resident at a given time. The subsystems and their areas of responsibility are shown in Table 1.4.

Code for each subsystem consists of a root portion and a set of overlays. The root portion contains the subsystem executive and a pool of subroutines common to all commands in the subsystem. The overlays contain the command code itself, the number of commands present in each overlay depending on the complexity of the commands. Table 1.4 shows the number of commands and overlays present in each subsystem. The overlay structure is transparent to the seismologist using the system, apart from time delays while overlay swapping takes place. A subsystem with overlay in position consumes (along with the operating system, language interpreter and data buffers) all available memory. Commands within any given subsystem enable a swap to be made to any other subsystem.

All commands are fully interactive and the commands themselves are order-independent, giving the seismologist almost unlimited flexibility of operation. Data are passed between commands by a series of disk-based data files which may be written to, read from and displayed in a variety of ways. Ultimately the data are transferred off-line for storage. To facilitate this, one of the two on-line floppy disks is temporarily released from the system to enable an archive disk to be placed on-line. After the transfer, the original disk is returned. An unlimited number of archive disks can be generated and accessed in this way.

The floppy disks forming the ISAS archives are transportable between all Data General computers operating under DOS (or the related RDOS) and possessing a floppy disk drive. One such machine is

TABLE 1.4  
ISAS SUBSYSTEMS

SUBSYSTEM	NAME	FUNCTION	COMMANDS	OVERLAYS
Network Data Management Subsystem	NETWK	Maintains data files of all seismic recording stations in the network	18	2
Cassette Data Management Subsystem	CASET	Interfaces ISAS to the seismic event recorders	14	1
Local Earthquake Subsystem	LOCAL	Performs analyses associated with local earthquakes	17	4
Microearthquake Subsystem	MICRO	Performs analyses associated with microearthquakes	15	2
Earthquake Statistics Subsystem	STATS	Compiles and displays statistics on earthquakes	15	1

interfaced to the main University computer, a Control Data Corporation Cyber 173, giving ISAS access to a large main-frame machine if necessary. Via the Cyber, digital magnetic tapes can be written or read (and cards or paper-tape punched or read), thereby ensuring considerable transferability of data between ISAS and computers elsewhere.

ISAS has been used to locate all South Australian local earthquakes using data from conventional seismograms since the beginning of 1978. Results of analyses of all previous events have also been placed on ISAS-format archive disks to enable them to be used by ISAS for the compilation of earthquake statistics. Data from the second and third microearthquake surveys referred to earlier were analysed by ISAS, and the results of the first study have also been added to the ISAS archives. The second phase of the computerized system, involving the input of data in digital form from event recorders, was realized at the end of 1980, thereby completing the system as originally designed.

## CHAPTER 2: NETWORK DATA MANAGEMENT

### 2.1 The Purpose of the ISAS Network Data Management Subsystem

The determination of earthquake focal coordinates from data recorded by a set of geographically distributed seismic recording stations requires information about the stations themselves in addition to the seismic data; specifically the location of each of the stations. Magnitude (MN) determination similarly requires a knowledge of the gain of each station as a function of frequency. Station location does not usually change; but minor site adjustments, equipment alterations and replacements, and amplifier gain changes usually affect the response curve of a station. The number of such changes to South Australian stations in the past has at times been significant. Apart from recalibrations resulting from equipment adjustments, the generally accepted practice of recalibrating stations nominally once per year results in an average of at least one recalibration per month for the South Australian network. While many recalibrations show negligible change in station characteristics for the purpose of magnitude calculations, nevertheless it is common for one recalibration every other month or so to require station data to be updated.

The monthly batch revision program LEQREV (White, 1967) read a set of data cards containing the current values of all station parameters in the network, prior to commencing its locations and magnitude determinations. If new data applied for one or more stations during the month, the batch run had to be repeated for each segment of the month, with the correct station data for each segment. In addition, if past events were required to be reworked, data

pertinent to every station at the time of the event had to be manually reassembled. Past events occurring over a wide time interval were generally unable to be batch-processed in the way in which the program was designed because some of the station data had possibly changed during the time interval.

The assembly of correct station data for every station involved in the analysis of any event since the network commenced and up to the present time is performed automatically by ISAS. The analysis subsystems LOCAL and MICRO invisibly use the station list and event date and time supplied to compile the network data pertinent to each event. The data are selected from a set of network disk data files. Subsystem NETWK is responsible for creating the files, updating them with valid data, displaying all or parts of them, archiving them when they become too large, and managing the resulting archives. The subsystem also performs the calculations involved with a station calibration, displaying the response curve graphically and updating the data on disk.

## 2.2 Network File Organization

A given ISAS network file contains a complete chronological history of every station whose data are used by ISAS, including portable stations and some stations outside South Australia, over a well-defined period of time. The separate files are non-overlapping in time and as a group span the history of the network without a break. One network file in particular, the current network file, spans a time range continuing to the present. This is the only file to which new data may be added. The current network file is always on-line for immediate access. One of the remaining network files may also be on-line at any given time. This particular file is termed the

archive network file. The rest, including a copy of the archive network file, are stored off-line on archive disks.

The analysis subsystems LOCAL and MICRO initially direct their search for station data to the current network file. If the event is out of range of this file, they automatically access the archive network file. Subsystem NETWK enables the archive network file to be replaced on-line by any other network file from the archive disks, to ensure that any event in the past can be reworked.

The network files themselves are all identical in structure. They are sequential files containing a file header followed by a variable number of variable-length records. Table 2.1 shows the file format.\* The file header contains the time range spanned by the data in the file. Each record following the file header contains the information corresponding to a single entry for a single station in the file. Each entry is one of seven different types, corresponding to the seven distinct categories of station data shown in Table 2.2. When a new station is opened in the network, entries corresponding to all categories are written into the file; thereafter, any given category can be updated by adding a new file entry for that category. Subsystem NETWK ensures that all entries for a given station are in strict chronological order, although no such restriction is imposed on entries corresponding to different stations.

Each network file has associated with it a small sequential file consisting of a succession of 3-character strings giving the names of all stations represented in the corresponding network file.

---

\* All dates/times are internally stored in ISAS in the form of ASCII character strings as shown in Table 2.1. Two such dates/times can then be conveniently tested to determine their temporal order by performing a left-to-right character-wise comparison.

TABLE 2.1  
ISAS NETWORK FILE STRUCTURE

INFORMATION	DATA TYPE	INTERNAL FILE FORMAT
FILE HEADER		
File commencement date/time	ASCII string	YYYYMMDDHHmm ~~~~~ year day minute month hour
File conclusion date/time	ASCII string	YYYYMMDDHHmm OR (if not concluded) 'present'
STATION DATA RECORDS		
Header portion		
Date/time of entry	ASCII string	YYYYMMDDHHmm
Station, person and station characteristic	ASCII string	C S S S I I I ~~~~~ ↖ stn person's code initials characteristics code for variable portion
Variable portion		
Station data	4-byte floating point numeric	Dependent on characteristics code as in Table 2.2

TABLE 2.2  
STATION DATA

CHARACTERISTICS CODE	NO. ITEMS	DATA
0	3	Geographic latitude*, longitude*, elevation
1	1	Travel-time correction
2	2	Seismometer mass, motor constant
3	7	Calibration curve coefficients
4	1	MN station correction
5	3	MD coefficients
6	1	Length of calibration pulse

\* stored internally relative to preset origin (30°S, 130°W for South Australia)

### 2.3 THE ISAS Network Data Management Subsystem

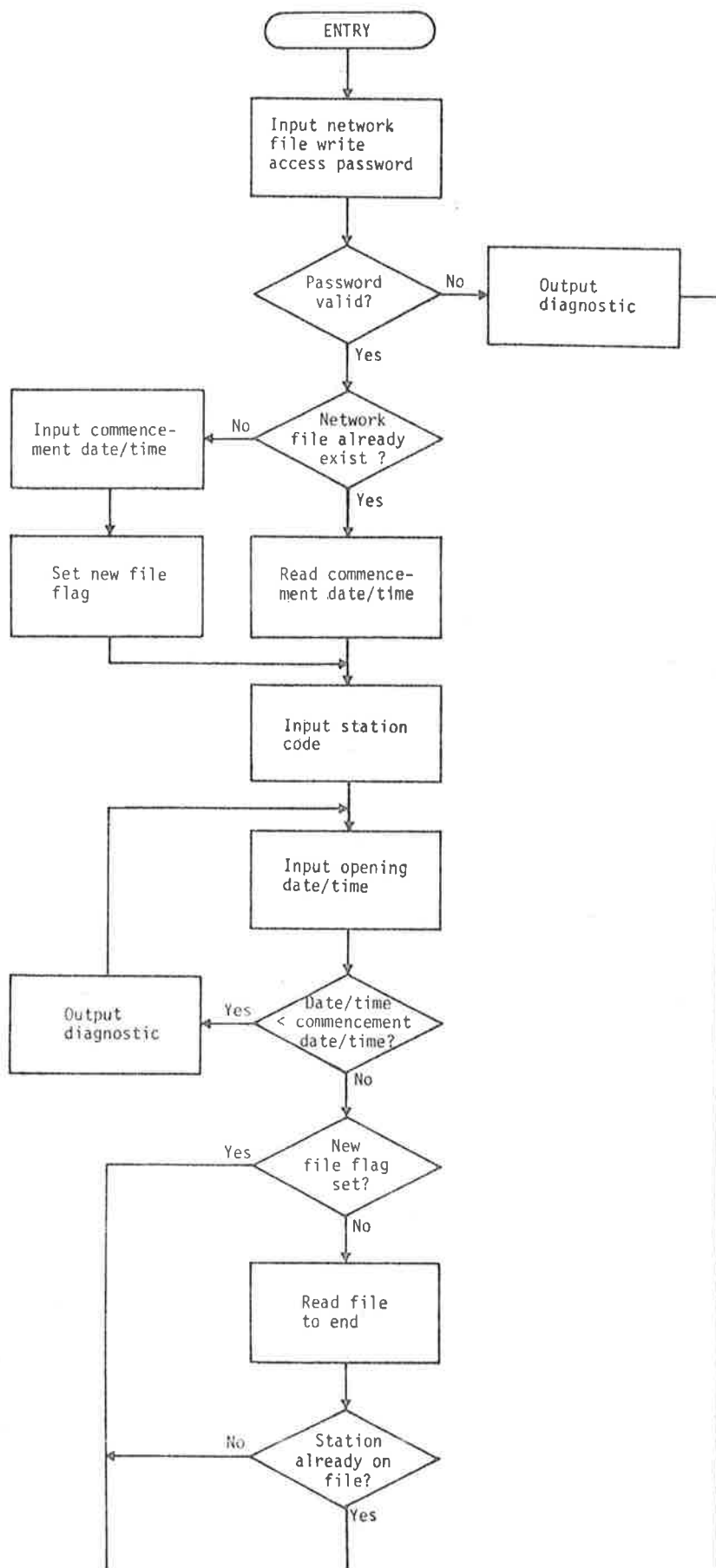
Table 2.3 contains a list of all commands present in the ISAS Network Data Management Subsystem (NETWK), and their actions. The commands fall into three main classes: those which write data to the current network file, those which display data from the current or archive network file, and those involved with the network file archives.

Program descriptions have recently begun to appear in terms of a generalized Pascal-like 'program design language' (e.g. Linger, Mills and Witt, 1979). However, since this is not yet in widespread use generally, the more familiar flow-chart representation will be used here (and the level of detail mostly confined to the broad concepts). Figures 2.1 and 2.2 present flow-charts for commands in the first category stated above, with the exception of CALIB, an extended command to be considered separately in the next section. The flow charts serve to illustrate the manner in which the integrity of the data in the files is maintained. A password (part of which is the person's initials) is required to gain write access to the file, the



TABLE 2.3  
COMMANDS IN SUBSYSTEM NETWK

COMMAND	ACTION
HELP	Display commands and their actions.
OPEN	Open a new station in the network.
CLOSE	Close an existing station in the network.
UPDATE	Update a station characteristic.
CALIB	Calibrate a station.
UNCAL	Remove a previous station calibration.
DISP	Display file for a station.
FILE	Display entire network file.
LIST	Display list of stations on file.
RANGE	Display network file range.
ARCHIVE	Archive the current network file and start a new file.
LOAD	Load a network file from an archive disk.
NETS	Display list of network files and their ranges for a given archive disk.
CASET	Transfer to Cassette Data Management Subsystem
LOCAL	Transfer to Local Earthquake Subsystem.
MICRO	Transfer to Microearthquake Subsystem.
STATS	Transfer to Earthquake Statistics Subsystem.
LOGOFF	Log-off from system.



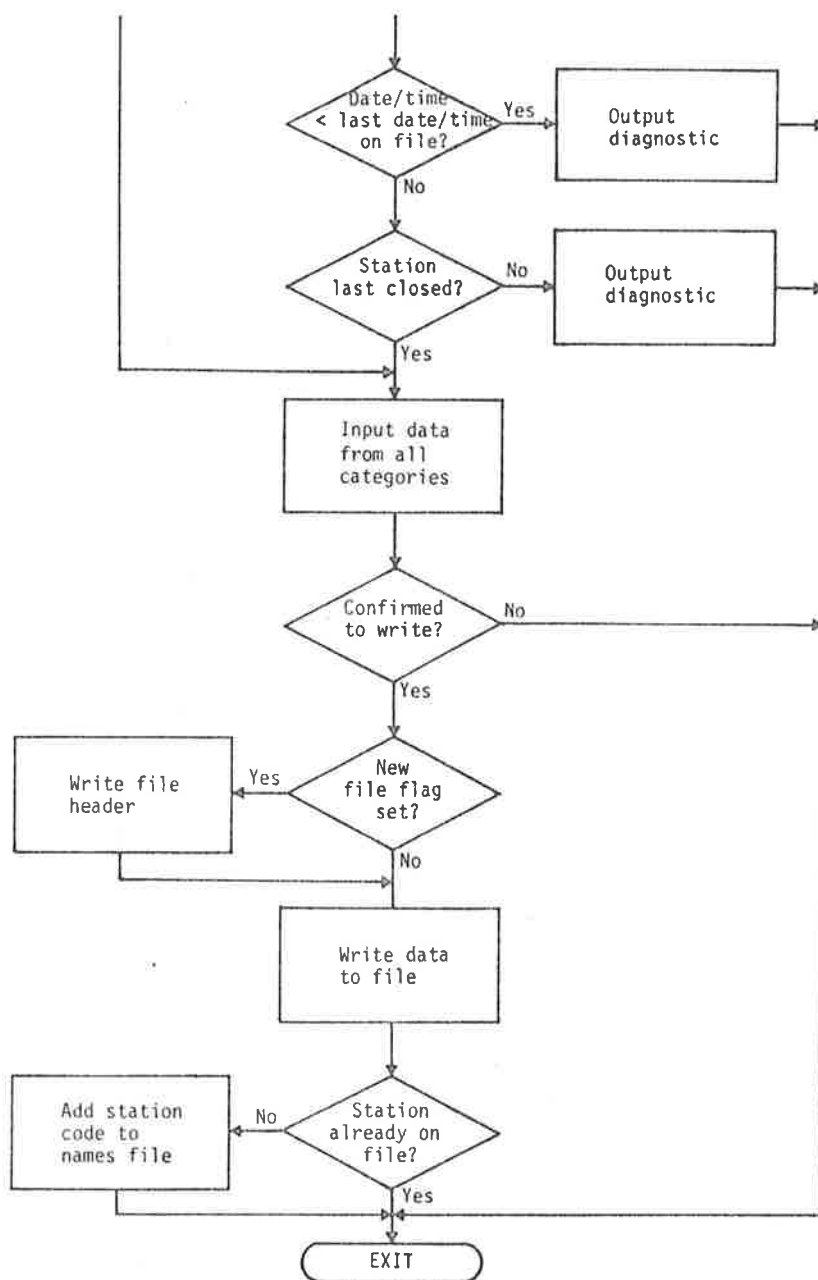


FIGURE 2.1  
OPEN COMMAND LOGIC.

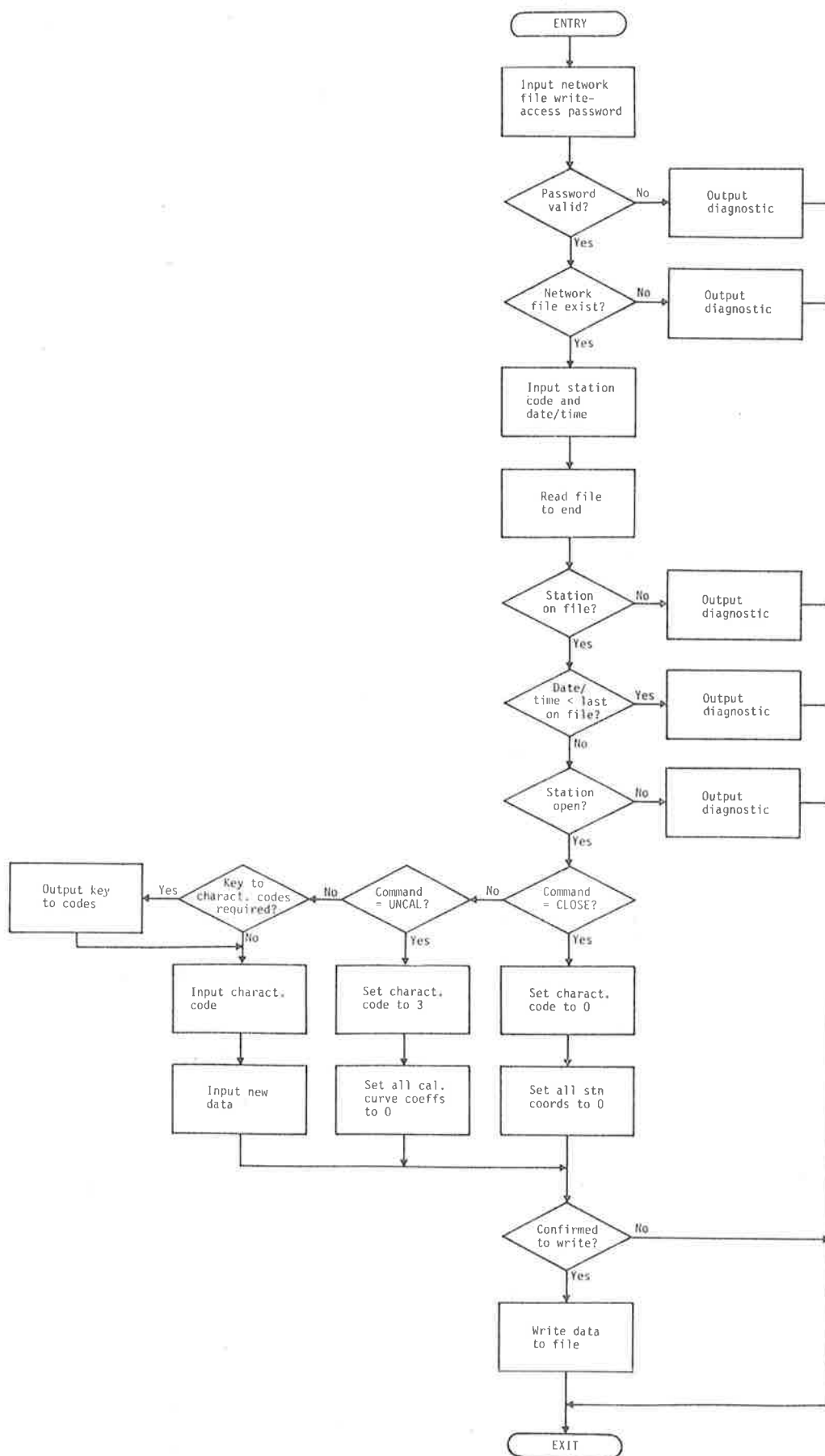


FIGURE 2.2

CLOSE, UPDATE, UNCAL COMMAND LOGIC.

validity of the proposed operation is checked (and also, not shown, that of all input data where feasible), and final confirmation is required before the data are actually written to the file. Figure 2.2 also illustrates the fact that although commands are independent and generally separately coded, in some cases very similar commands share common code with an internal branch. In this case, a closed station is represented on file by a set of station coordinates all equal to zero (a combination rejected in the OPEN and UPDATE commands) and an uncalibrated station by a set of all zero calibration curve coefficients. The manner of use of the OPEN and UPDATE commands is illustrated in Figure 2.3.

The commands in the second category, viz, those which display data from the current or archive network file, are all straightforward. RANGE displays the commencement and conclusion dates/times of the current or archive network file, as determined from the file header. LIST displays the contents of the auxiliary names file of the current or archive network file. DISP and FILE share common code, and display the current or archive file contents, the former command selecting only records corresponding to a required station. Since station records are in chronological order, a station history is displayed. FILE displays the entire network file in the order in which it was created. The manner of use of commands RANGE, LIST and DISP is illustrated in Figure 2.4.

The third group of commands in subsystem NETWK involves the ISAS archives. ISAS archive disks may contain archived network files or archived events. These may not be mixed on the same archive disk, however. All archive disks, irrespective of type, contain a sequential index file, the structure of which is shown in Table 2.4. The file header, created when the disk is first used to write archive

20/04/1981 15:08 [NETWK] COMMAND: OPEN

PASSWORD: \_-RTP

STATION CODE: CLU

DATE (DD/MM/YYYY) AND TIME (HH:MM): 26/10/1963,00:00

STATION NOT ON FILE.

STATION CHARACTERISTICS (ENTER 0 FOR EACH VALUE NOT DETERMINED):

0. GEOG. LATITUDE (-VE FOR S), LONGITUDE, AND ELEVATION (IN m) OF STATION: -33.6911,136.4955,238

1. TRAVEL TIME CORRECTION: 0

2. SEISMOMETER MASS (IN kg) AND MOTOR CONSTANT (IN N/A): 107.5,2.01

3. 7 CALIBRATION CURVE COEFFICIENTS: 0,0,0,0,0,0,0

4. STATION CORRECTION FOR MN DETERMINATIONS: .54

5. 3 MD COEFFICIENTS: -.286,1.393,2.968E-4

6. LENGTH (IN mm) OF NOMINAL CALIBRATION PULSE: 21

READY TO TRANSFER TO FILE. PROCEED (P) OR ABORT (A)? P

TRANSFER COMPLETED.

20/04/1981 15:11 [NETWK] COMMAND: UPDATE

PASSWORD: \_-RTP

STATION CODE: ADE

DATE (DD/MM/YYYY) AND TIME (HH:MM): 01/01/1980,00:00

STATION ON FILE AND OPENED.

DO YOU WANT KEY TO CHARACTERISTICS PRINTED (Y OR N)? Y

KEY: 0 = Station coordinates (geog lat, long, elevn)  
1 = Travel time correction  
2 = Seismometer mass, motor constant  
3 = Calibration curve coefficients

4 = MN station correction  
5 = MD coefficients  
6 = Length of calibration pulse

CHARACTERISTICS CODE: 5

3 MD COEFFICIENTS: -.061,1.412,2.859E-4

READY TO TRANSFER TO FILE. PROCEED (P) OR ABORT (A)? P

TRANSFER COMPLETED.

FIGURE 2.3

THE USE OF COMMANDS OPEN AND UPDATE TO OPEN A NEW STATION IN THE NETWORK AND TO UPDATE A STATION CHARACTERISTIC RESPECTIVELY. (In this and subsequent examples of computer interactive output, underlined characters were typed by the seismologist at the console.)

20/04/1981 14:05 [NETWK] COMMAND: RANGE

CURRENT (C) OR ARCHIVE (A) NETWORK FILE? A

NETWORK FILE RANGE: 02/07/1958 00:00 to 31/12/1979 23:59

20/04/1981 14:05 [NETWK] COMMAND: RANGE

CURRENT (C) OR ARCHIVE (A) NETWORK FILE? C

NETWORK FILE RANGE: 01/01/1980 00:00 to present

20/04/1981 14:05 [NETWK] COMMAND: LIST

CURRENT (C) OR ARCHIVE (A) NETWORK FILE? A

STATIONS ON FILE:

ADE HTT TOO CLU UMB PNA ILN ASP ODO BFD WSA MTA STK ADT HKN end lsp mck nbk sck coo cui nbt RPA ELO lpa scc stg mla job cnw rya  
pua cpj EDO WLK NBK 99m sta stx bta mgt spk ypa mgs uue

20/04/1981 14:05 [NETWK] COMMAND: LIST

CURRENT (C) OR ARCHIVE (A) NETWORK FILE? C

STATIONS ON FILE:

ADE HTT TOO CLU UMB PNA ASP BFD WSA STK ADT HKN RPA EDO NBK WKA rdk MGR

20/04/1981 14:06 [NETWK] COMMAND: DISP

STATION CODE: WSA

CURRENT (C) OR ARCHIVE (A) NETWORK FILE? A

DATE	TIME	STN	BY	
26/04/1973	00:00	WSA	RTP	Geog latitude = -31.1444 Longitude = 136.8047 Elevation = 180 m
26/04/1973	00:00	WSA	RTP	Travel time correction = +0.00
26/04/1973	00:00	WSA	RTP	Seismometer mass = 5.00 kg Motor constant = 0.200 N/A
26/04/1973	00:00	WSA	RTP	Station uncalibrated.
26/04/1973	00:00	WSA	RTP	MN station correction = 0.00
26/04/1973	00:00	WSA	RTP	MD coeffs: 0.000 0.000 0.000E+00
26/04/1973	00:00	WSA	RTP	Length of calibration pulse = 0.0 mm
19/05/1976	00:00	WSA	RTP	Cal. curve coeffs: 4.039E+00 1.917E+00 1.558E+00 -1.203E+01 2.416E+01 -2.343E+01 8.345E+00
19/05/1976	00:00	WSA	RTP	MN station correction = -0.10
19/05/1976	00:00	WSA	RTP	MD coeffs: -0.983 1.617 2.300E-04

FIGURE 2.4

THE USE OF COMMANDS RANGE, LIST AND DISP TO DISPLAY NETWORK INFORMATION.

TABLE 2.4

## ISAS ARCHIVE DISK INDEX FILE STRUCTURE

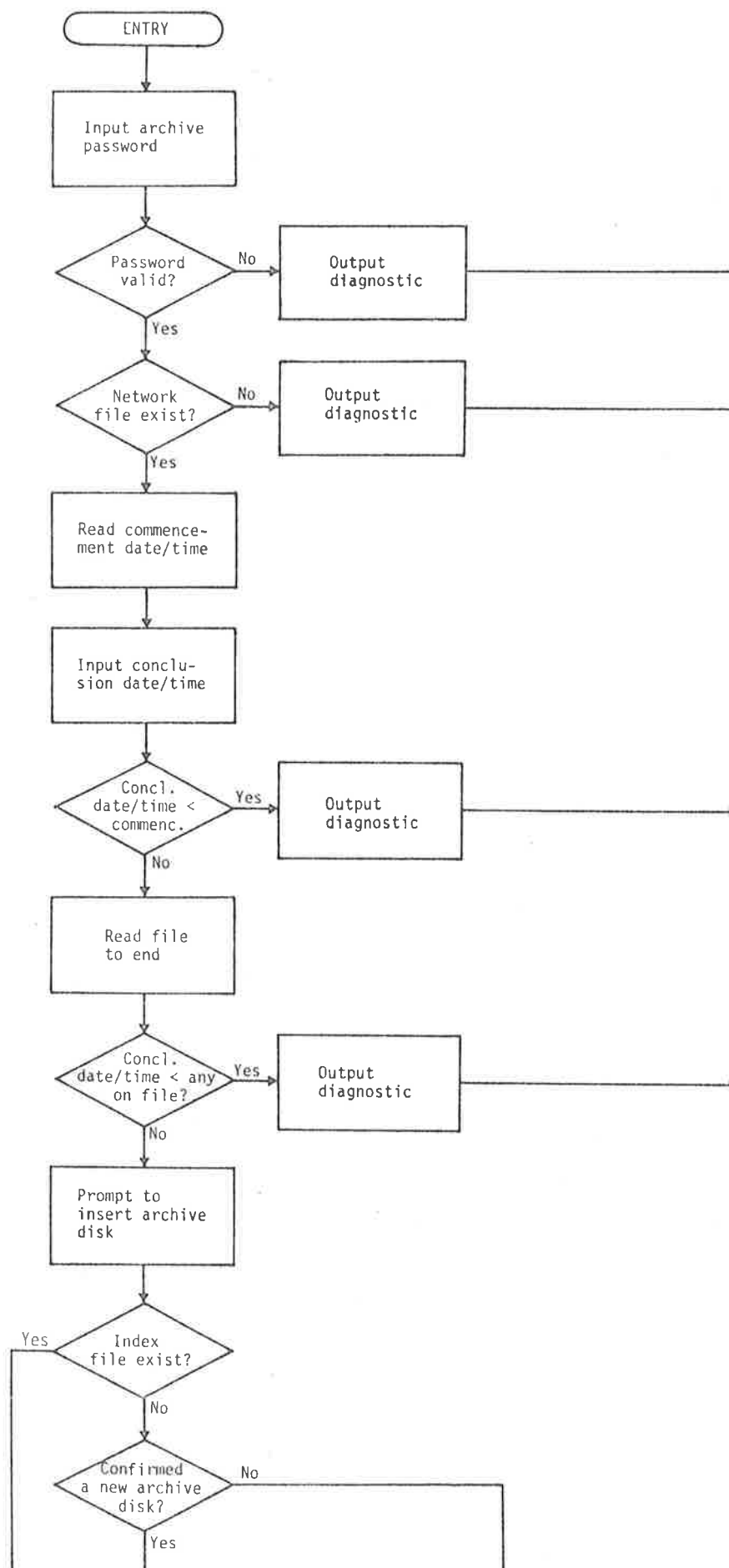
INFORMATION	DATA TYPE	INTERNAL FILE FORMAT
FILE HEADER		
Archive disk type (T)	4-byte floating point numeric	T < 0: NETWORK FILE ARCHIVE DISK  T  = no. network files on disk T > 0: EVENT ARCHIVE DISK T = next available free record in event file
PER FILE - NETWORK FILE ARCHIVE DISK		
File commencement date/time	ASCII string	YYYYMMDDHHmm (as in Table 2.1)
File conclusion date/time	ASCII string	YYYYMMDDHHmm (as in Table 2.1)
PER EVENT - EVENT ARCHIVE DISK		
Event reference number	ASCII string	1 to 7 alphanumeric characters or symbols
Starting record number in event file	4-byte floating point numeric	



data, provides the mechanism for determining the archive disk type in future accesses. For a network file archive disk, index file records following the header contain the commencement and conclusion dates and times of all network files stored on the disk. The archived network files themselves are in exactly the same format as the on-line files; only the filenames are changed to ensure that each file is unique: whereas the filenames of the on-line current and archive network files are NETWKC and NETWKA (with auxiliary names files NAMESC and NAMESA), the archived files are NETWK1, NETWK2, etc. (and NAMES1, NAMES2, etc.) in the order of their archiving.

Command NETS in subsystem NETWK reads and displays the index file for a given network file archive disk, showing the network file number and range of each file stored on the disk. In the LOAD command, the seismologist specifies a file number, after which the on-line archive file NETWKA is deleted and the requested file is copied from the archive disk and renamed NETWKA.

A file transfer in the opposite direction occurs in the ARCHIVE command. In this case, however, validation checking is required, as can be seen in the flow-chart of Figure 2.5, to ensure that the current network file conclusion date specified is consistent with the data on the file and that the file does not overlap any already archived. Once NETWKC is copied to the archive disk, NETWKA is deleted and NETWKC is renamed NETWKA. If the seismologist wishes to start a new NETWKC, the commencement date supplied is also checked against the archive disk index file to ensure no overlap. The command then allows any number of stations to be carried from NETWKA into NETWKC. For each requested station, the latest data are copied into the new file, with the date and time changed to the commencement date and time of the file so as to ensure that no data lie outside the file



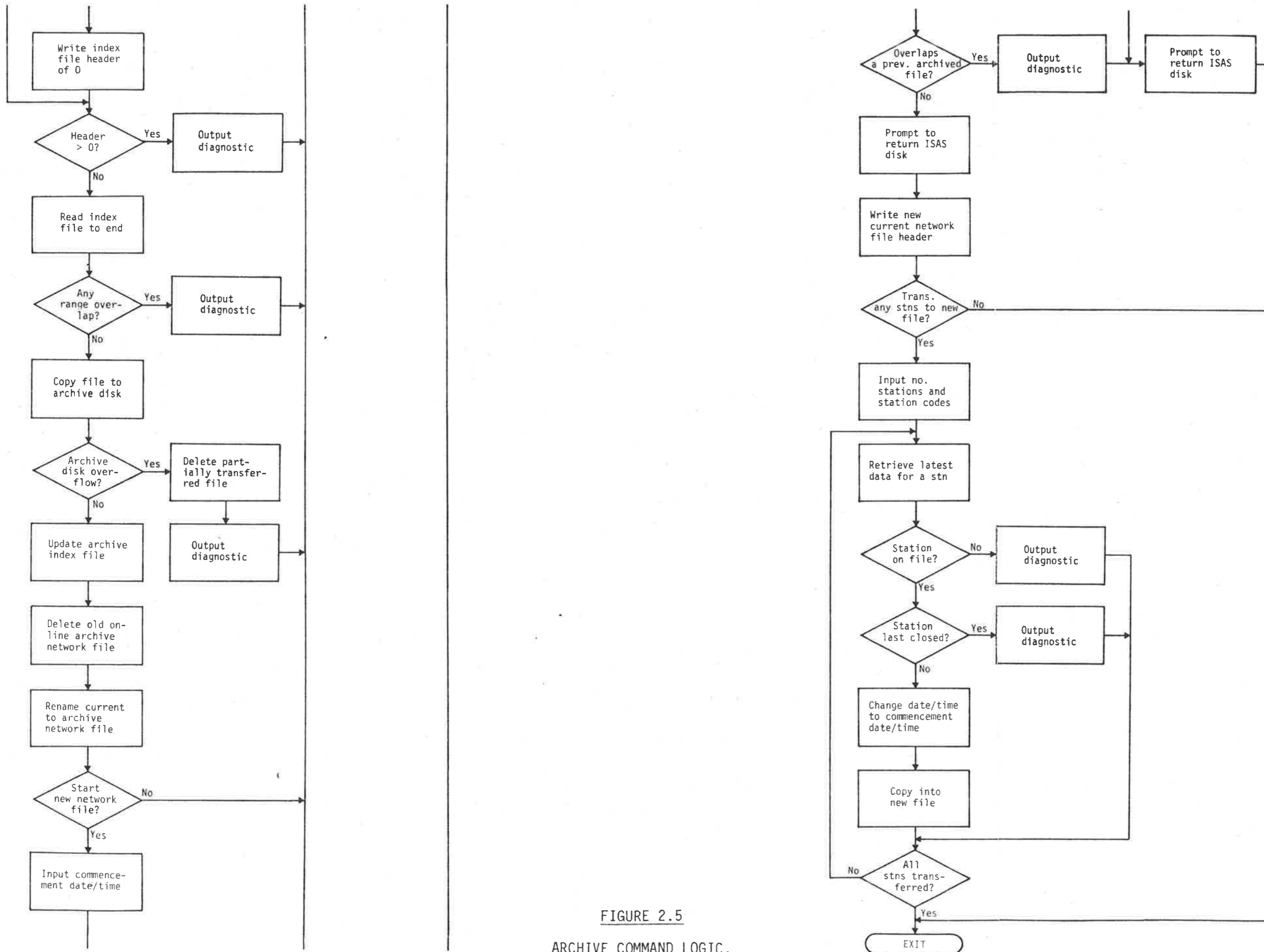


FIGURE 2.5  
ARCHIVE COMMAND LOGIC.

range. The NAMES files are transferred, renamed and updated in the obvious manner along with the main NETWK files themselves. The manner of use of the commands ARCHIVE, NETS and LOAD is illustrated in Figure 2.6.

#### 2.4 Station Calibrations

South Australian stations are presently calibrated, as they have always been, using a whole-system harmonic drive method involving a constant-current, variable-frequency, sinusoidal signal generator and seismometer calibration coil. In the case of stations using Willmore Mk II seismometers without calibration coils (see Table 1.1), a calibration coil was designed and fitted (Stewart and Sutton, 1967). The theory of the calibration method was originally described by Murphy et al. (1954) and Chakrabarty et al. (1964), and has been reviewed more recently in the Manual of Seismological Observatory Practice (Willmore (ed.), 1979).

The event recorders (Chapter 6) are presently calibrated by the same method as the stations, with a software peak detector and digital readout taking the place of the chart record. Whole-system impulse methods (for example, Mitchell and Landisman, 1969; Berg and Chesley, 1976) or a random binary signal method (Berger et al., 1979) are well-suited to the event recorders, however, and warrant further investigation in future models of the device.

For the determination of MN, the maximum peak-to-peak amplitude of ground motion amongst the S waves and corresponding principal frequency component are required (Stewart, 1975). With a modification of LEQREV, Stewart determined the ground amplitude from the trace amplitude and period, by obtaining and entering for each station seven coefficients representing the sixth-order least squares polynomial fit

```

20/04/1981 14:08 [NETWK] COMMAND: ARCHIVE
PASSWORD: -RTP
CONCLUSION DATE (DD/MM/YYYY) AND TIME (HH:MM): 31/03/1981,23:59
*** INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' ***
DO YOU WANT TO START A NEW CURRENT NETWORK FILE (Y OR N)? Y
COMMENCEMENT DATE (DD/MM/YYYY) AND TIME (HH:MM): 01/04/1981,00:00
*** RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' ***
DO YOU WANT TO CARRY OVER ANY STATIONS FROM THE OLD TO THE NEW CURRENT NETWORK FILE (Y OR N)? Y
NUMBER OF STATIONS: 15
STATION CODES, ONE AT A TIME AS REQUESTED:
1. AOE 2. HTT 3. CLU 4. UMB 5. PMA 6. BFD 7. WSA 8. STK 9. ADT 10. HKN 11. RPA 12. EDD 13. NBK 14. WKA 15. MGR
NEW CURRENT NETWORK FILE CREATED.

20/04/1981 14:13 [NETWK] COMMAND: NETS
*** INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' ***
FILE      COMMENCEMENT      CONCLUSION
1      02/07/1958 00:00      31/12/1979 23:59
2      01/01/1980 00:00      31/03/1981 23:59
*** RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' ***

20/04/1981 14:14 [NETWK] COMMAND: LOAD
*** INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' ***
FILE NUMBER: 1
*** RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' ***

```

FIGURE 2.6

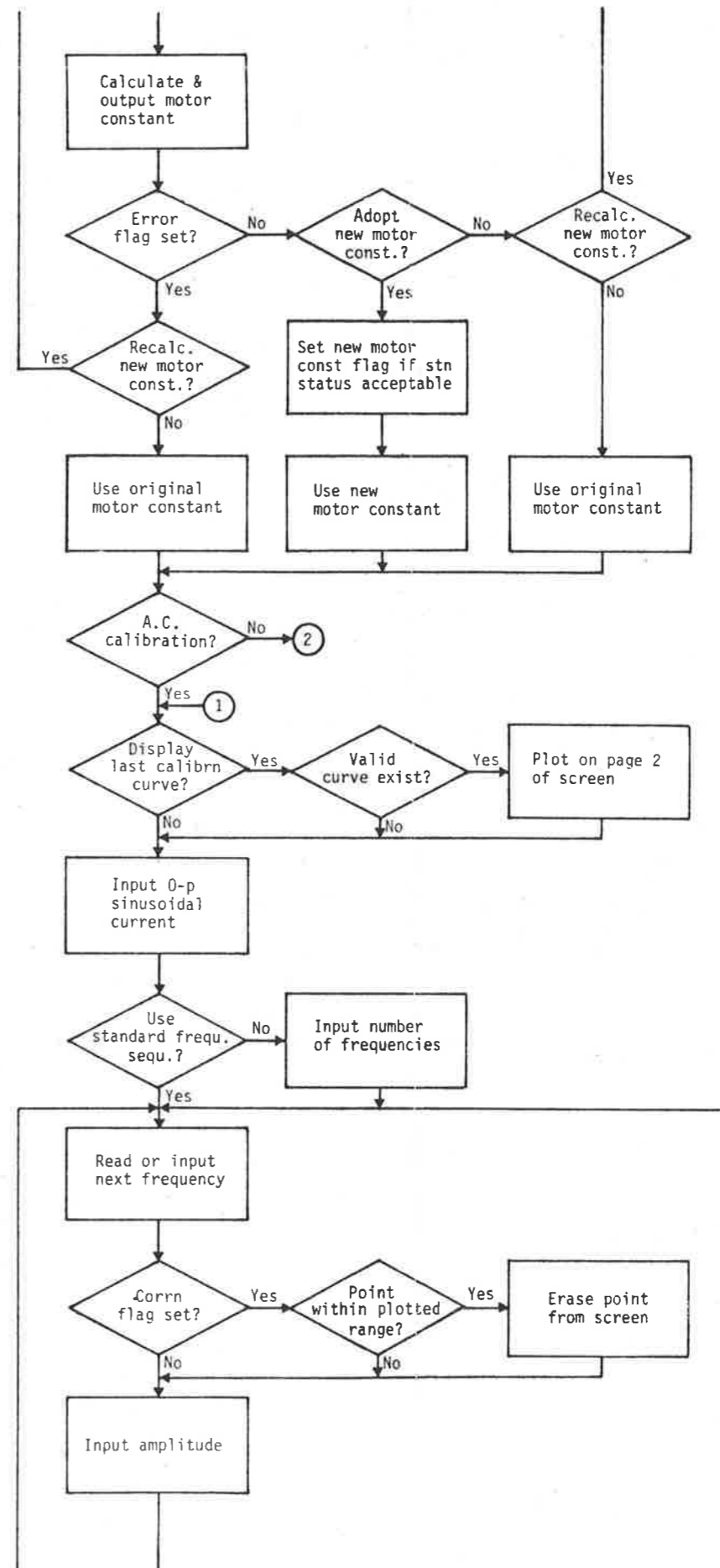
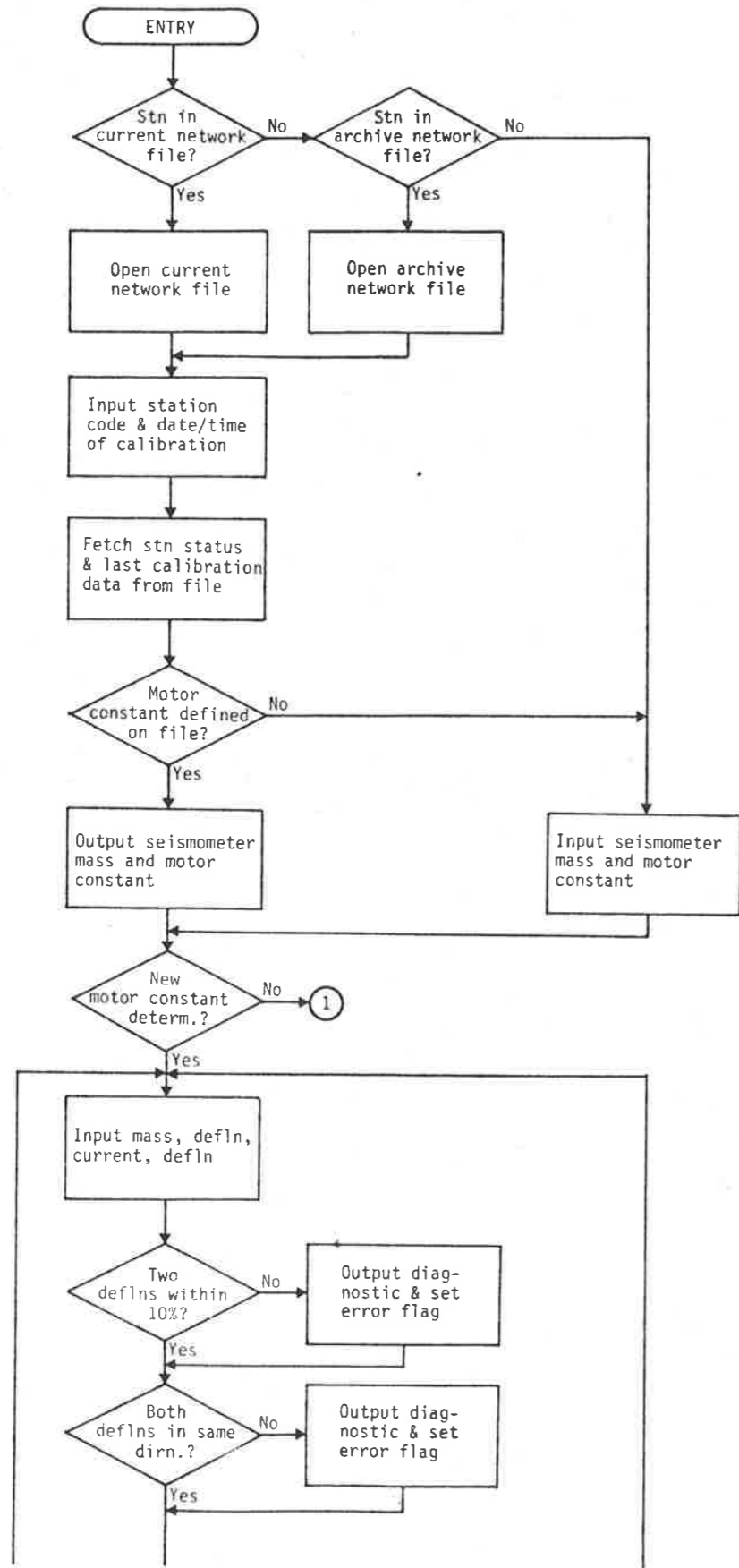
THE USE OF COMMANDS ARCHIVE, NETS AND LOAD IN HANDLING THE ISAS NETWORK FILE ARCHIVES.

to log (gain) vs log (frequency) over the interval, [1.0, 10.0] Hz, the logarithms being to the base ten. No reason was given by Stewart for the choice of a sixth-order polynomial, and tests on sample events during the preliminary stages of ISAS showed that for most stations a lower-order fit (certainly a fourth-order) would suffice. HTT alone, with a tendency towards a double-peaked curve (see Figure 2.10), required a sixth-order fit, being the next even order above the minimum able to reproduce the required number of inflections. Rather than experimenting with equipment adjustments in order to modify the response characteristics of HTT to conform more closely to those of other stations, ISAS was written to fit a sixth-order polynomial also.\*

Command CALIB on request determines the seven calibration curve coefficients representing the sixth-order polynomial, after the amplitudes and frequencies have been entered and the corresponding gains and velocity sensitivities interactively displayed. A new motor constant determination can be carried out prior to the A.C. calibration, or the motor constant can be supplied or read from file. Updated motor constant and coefficients are written to file on request, provided the operation satisfies the validity criteria. The full command logic is shown in Figure 2.7 and a typical calibration is shown in Figure 2.8.

---

\* The solution of the least squares normal equations for a sixth-order polynomial, involving a system of seven linear equations in seven unknowns, was achieved despite the limited (6 to 7 digit floating point) precision of the Nova computer, by coding a Choleski factorization routine (Ralston and Wilf (ed.), 1967) as part of ISAS, and by using string arithmetic to accumulate the inner products. (String arithmetic enables up to 18 digits of precision by performing arithmetic operations on ASCII number strings rather than on 4-byte floating-point variables). Comparison of results with those from the main University Cyber computer using 15-digit single precision arithmetic verified the technique.



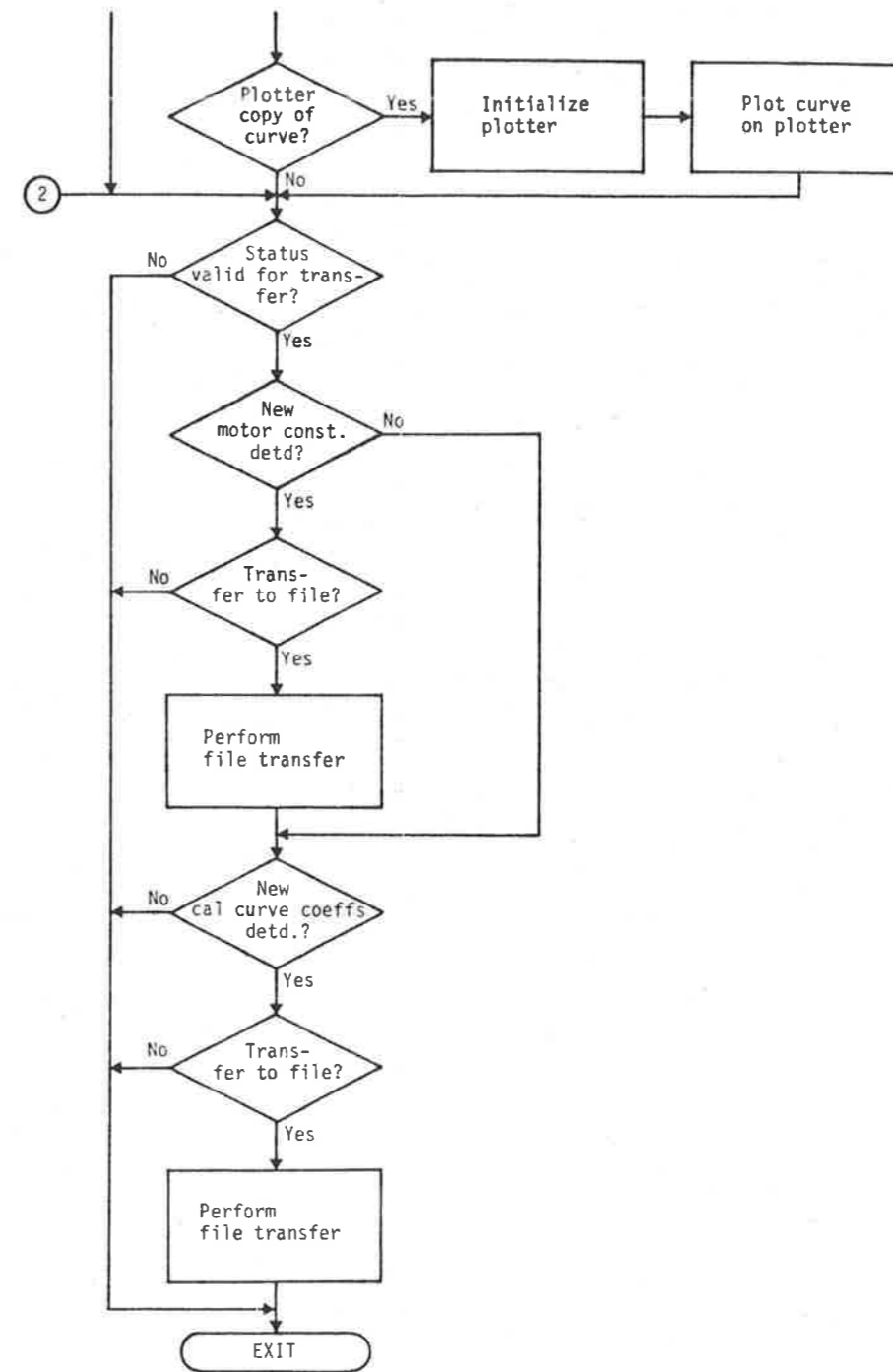
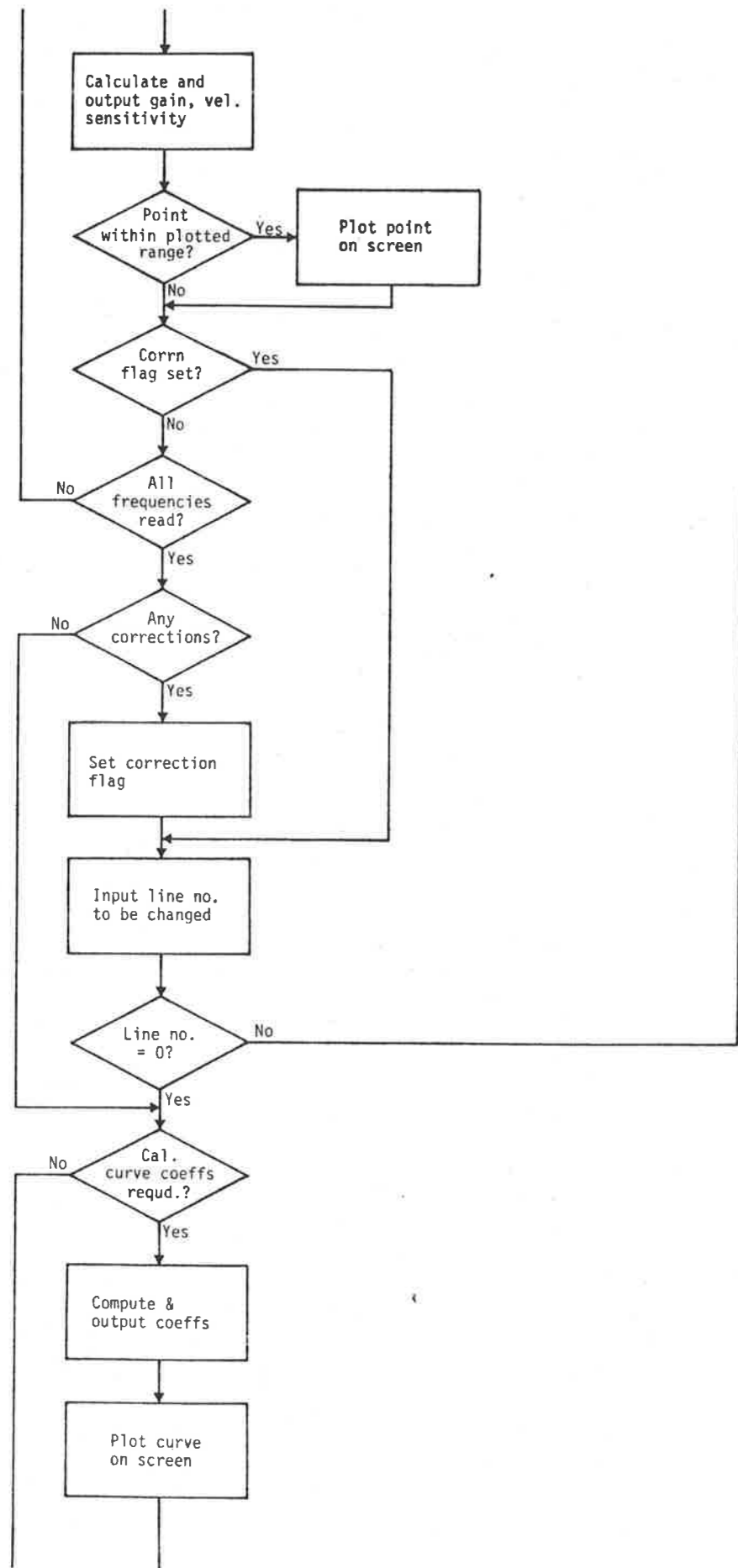


FIGURE 2.7  
CALIB COMMAND LOGIC.



20/04/1981 16:01 [NETWORK] COMMAND: CALIB

CURRENT (C) OR ARCHIVE (A) NETWORK FILE, OR NEITHER (N)? C

STATION CODE: HII

DATE (DD/MM/YYYY) AND TIME (HH:MM): 24/05/1980,05:40

STATION ON FILE AND OPENED.

NETWORK FILE DATA AVAILABLE FOR USE:

DATE TIME STN BY  
18/09/1975 00:00 HTT RTP Seismometer mass = 107.50 kg Motor constant = 1.770 N/A

NEW MOTOR CONSTANT DETERMINATION (Y OR N)? Y

MASS LIFTED (IN g): .2

FIRST DEFLECTION DUE TO THIS MASS LIFT (IN mm): 29.3

CURRENT PULSE (IN mA): 1

FIRST DEFLECTION DUE TO THIS CURRENT PULSE (IN mm): 27.1

ARE BOTH DEFLECTIONS IN THE SAME (S) OR OPPOSITE (O) DIRECTION? S

MOTOR CONSTANT = 1.813 N/A

DO YOU WISH TO ADOPT THIS VALUE (A), RECALCULATE A NEW VALUE (R), OR USE ORIGINAL VALUE (U)? A

A.C. CALIBRATION (Y OR N)? Y

DO YOU WANT LAST CALIBRATION CURVE MADE AVAILABLE (Y OR N)? Y

To view, TEMPORARILY lower special function switch 'D' to superimpose, TEMPORARILY lower 'C' and 'D'

0-P VALUE OF SINUSOIDAL CURRENT (IN mA): 5

STANDARD FREQUENCY SEQUENCE (Y OR N)? Y

ENTER DATA IN THE FOLLOWING TABLE, TERMINATING EACH NUMBER WITH THE 'RETURN' KEY:

NO.	FREQ. (Hz)	P-P AMP. (mm)	PER. (s)	GAIN	V-SENS.
1	.1	<u>2.8</u>	10.00	6.555E+01	1.043E+02
2	.12	<u>3.4</u>	8.33	1.146E+02	1.520E+02
3	.15	<u>3.9</u>	6.67	2.054E+02	2.180E+02
4	.18	<u>4.3</u>	5.56	3.262E+02	2.884E+02
5	.2	<u>4.9</u>	5.00	4.588E+02	3.651E+02
6	.25	<u>6.2</u>	4.00	9.072E+02	5.775E+02
7	.3	<u>6.7</u>	3.33	1.412E+03	7.489E+02
8	.35	<u>8.4</u>	2.86	2.409E+03	1.095E+03
9	.4	<u>8.9</u>	2.50	3.334E+03	1.326E+03
10	.5	<u>12.5</u>	2.00	7.316E+03	2.329E+03
11	.6	<u>17.1</u>	1.67	1.441E+04	3.823E+03
12	.7	<u>91.3</u>	1.43	1.047E+05	2.381E+04
13	.8	<u>23.3</u>	1.25	3.491E+04	6.945E+03
14	1	<u>32.6</u>	1.00	7.632E+04	1.215E+04

15	1.2	:46.2	0.83	1.557E+05	2.066E+04
16	1.5	:73.7	0.67	3.882E+05	4.119E+04
17	1.8	:78.8	0.56	5.977E+05	5.285E+04
18	2	:65.5	0.50	6.134E+05	4.881E+04
19	2.5	:37.4	0.40	5.472E+05	3.484E+04
20	3	:25.5	0.33	5.373E+05	2.850E+04
21	3.5	:19.3	0.29	5.535E+05	2.517E+04
22	4	:15	0.25	5.619E+05	2.236E+04
23	5	:10	0.20	5.853E+05	1.863E+04
24	6	:7.3	0.17	6.152E+05	1.632E+04
25	7	:5.7	0.14	6.539E+05	1.487E+04
26	8	:3.5	0.13	5.244E+05	1.043E+04
27	10	:2.1	0.10	4.916E+05	7.824E+03

◁(a)

◁(b)

DO YOU WANT TO CHANGE ANY VALUES (Y OR N)? Y  
 ENTER DATA IN THE FOLLOWING TABLE, USING NO. 0 TO END:

NO.	FREQ. (Hz)	P-P AMP. (mm)	PER. (s)	GAIN	V-SENS.
:12	7	:19.3	1.43	2.214E+04	5.034E+03
:0					

◁(c)

DO YOU WANT CALIBRATION CURVE DETERMINED (Y OR N)? Y ◁(d)

COEFFICIENTS OF 6th ORDER POLYNOMIAL ON [1.10] Hz ARE:  
 4.850E+00 6.293E+00 -1.411E+01 1.147E+01 -4.024E+00 5.839E+00 -4.648E+00

DO YOU WANT PLOTTER COPY OF CALIBRATION (Y OR N)? Y

+++ INITIALIZE PLOTTER, THEN PRESS 'RETURN' +++

DO YOU WANT TO TRANSFER NEW MOTOR CONSTANT TO FILE (Y OR N)? Y  
 DO YOU WANT TO TRANSFER NEW COEFFICIENTS TO FILE (Y OR N)? Y

PASSWORD: -RTP

READY TO TRANSFER TO FILE. PROCEED (P) OR ABORT (A)? P  
 TRANSFER COMPLETED.

FIGURE 2.8

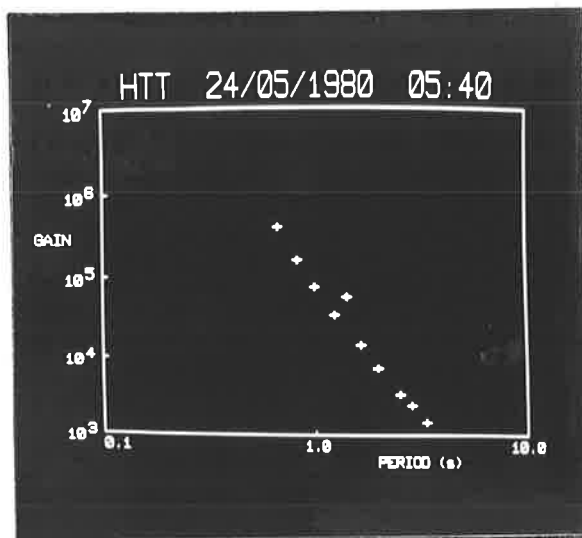
THE USE OF COMMAND CALIB TO PERFORM A STATION CALIBRATION. (See Figure 2.9 for the graphics display corresponding to (a), (b), (c) and (d).)

Not obvious from the printed output is the fact that the data are also displayed graphically on the system television monitor throughout. The screen displays at times corresponding to (a), (b), (c) and (d) in Figure 2.8 are shown in the corresponding portions of Figure 2.9. Final plotter hard-copy is shown in Figure 2.10. The graphics material in each case was produced by the unit designed as part of the computerized system.

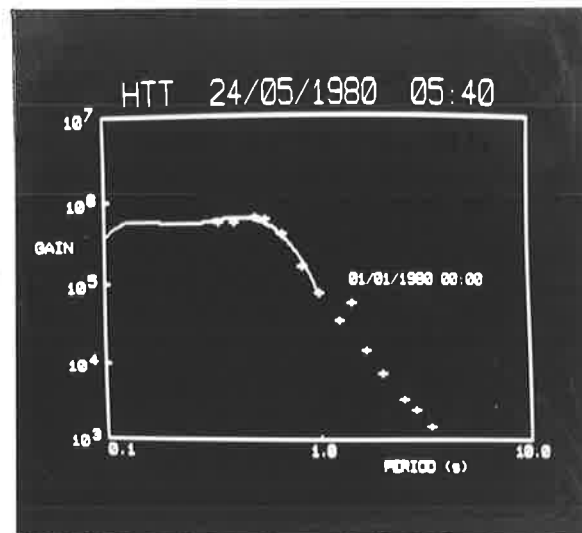
## 2.5 Interactive Graphics Unit

A graphics capability, as has already been noted in Chapter 1, is necessary for the interpretation of digitized seismic waveforms from the event recorders. The display of calibration data and (see Chapter 5) epicentre distribution maps is a secondary, although important, consideration. The event recorders are designed to achieve auto-ranging based on the ambient noise level, and as a result of this optimization use only 8 bits per sample in the recorded data. This requires a vertical resolution of 256 points when displayed graphically. A convenient horizontal graphical resolution of 512 points provides a display window of 10 seconds at the nominal event recorder data rate of 50 samples per second. Interactive selection of phases from the displayed data is required, and could be achieved using a light-pen or controllable cursor. Hard copy of the displayed trace is also necessary.

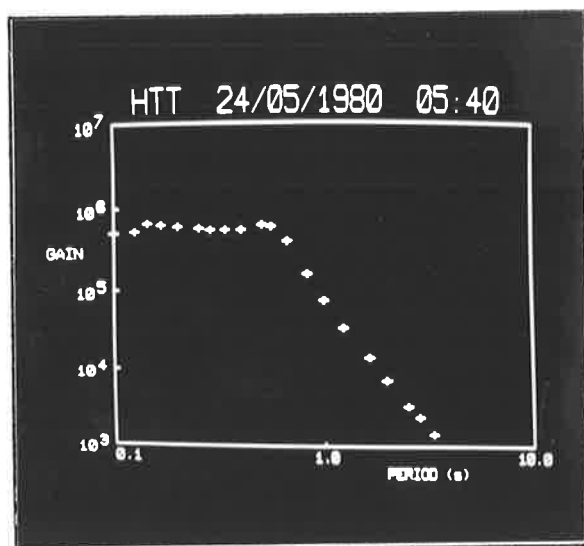
Commercial units satisfying all of the above requirements were at the time either of inferior performance or else prohibitively expensive. A unit meeting all of the specifications was, however, being designed by the Electrical Engineering Department of the University (Ackland et al., 1977) and after negotiation was adopted for the present project. The unit uses charge-coupled devices



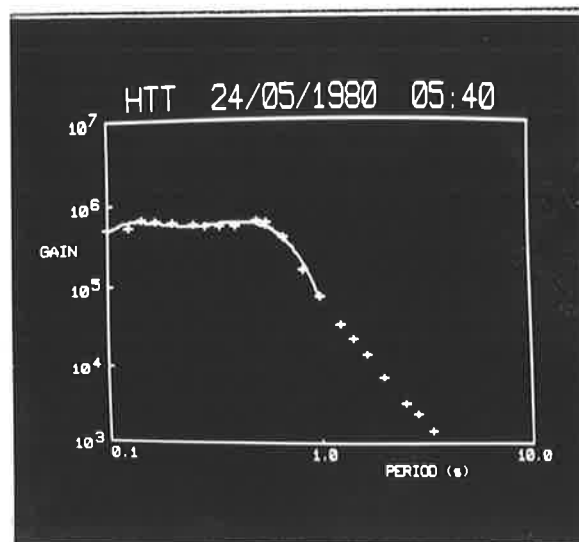
(a) Points are plotted as determined.



(b) The last calibration curve can be superimposed at any time for comparison.



(c) Erroneous points can be erased and corrected.



(d) The fitted 6th order polynomial over [1,10] Hz is displayed.

FIGURE 2.9

TELEVISION GRAPHICS DISPLAY CORRESPONDING TO (a), (b), (c) AND (d) IN FIGURE 2.8.

HTT 24/05/1980 05:40

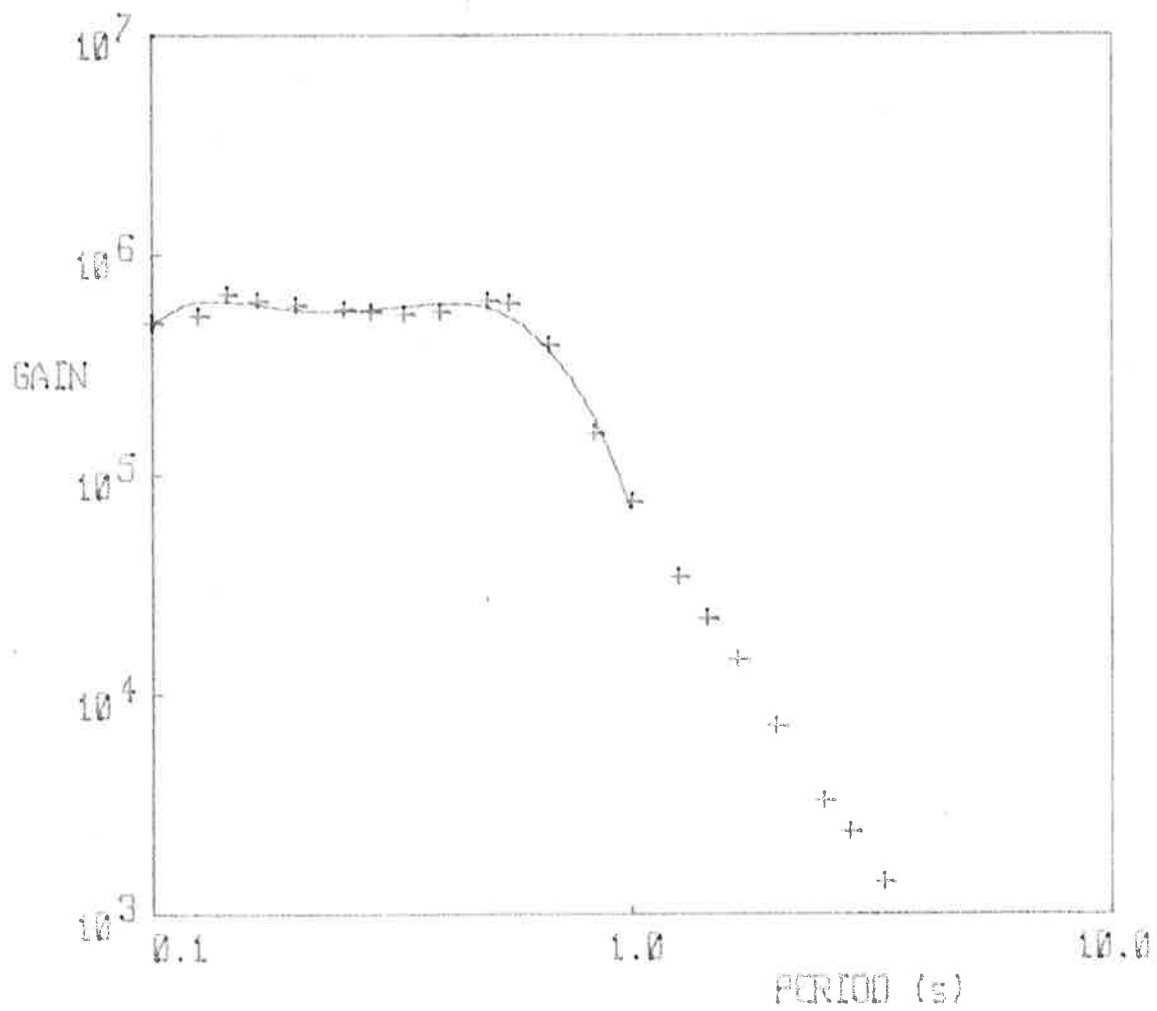


FIGURE 2.10

PLOTTER HARDCOPY OF THE CALIBRATION OF FIGURES 2.8 AND 2.9, PRODUCED BY THE COMPUTERIZED DATA SYSTEM GRAPHICS UNIT.

(256K x 1 bit CCD memory) to store and refresh a 512 x 512 point interlaced scan television image, or two 256 x 512 point non-interlaced scan images. Output in either case is conventional composite video, enabling an ordinary television monitor to be used with the unit. Alternatively, output can be directed to a pair of digital to analogue converters in order to drive a conventional laboratory XY recorder. A photo-transistor light-pen, used in conjunction with an internally-generated short-duration white raster, provides interactive input, and a keyboard can also be added if required. Communication with the host computer is via a standard 20 mA serial line.

The graphics unit is microprocessor-controlled, employing an Intel 8080 microprocessor with 4K of 2708 ROM and 2K of RAM. The self-documenting software to drive the unit was written by Mr P. Perry of Salisbury College of Advanced Education and the author. The former was responsible for the logic design and the major part of the coding and debugging, while the latter was responsible for the character generation, the completion of the debugging, and the user manual (Parham, 1979).

The software interfaces the host computer to the graphics unit in such a way that the host computer can regard the graphics unit merely as a terminal, the graphics functions being activated by ASCII control codes transmitted by the host computer. The full capabilities of the graphics unit from the user programmer's point of view can be ascertained from the user manual.

In the absence of a microprocessor development system, programming and debugging the software for the graphics unit could have been a lengthy if not impossible task. The same is true of the microprocessor-controlled event recorders. This was anticipated,

however, and the Data General Nova computer was used in both instances to emulate aspects of a development system, as outlined below.

## 2.6 Nova-based Microprocessor Development System

As detailed in Chapter 6, the event recorders are based on the CMOS Intersil IM6100 microprocessor, which uses the instruction set of the PDP8/E minicomputer. The software executes from CMOS RAM, loaded from Intel 2758 (1K) or 2716 (2K) ROMs. Since, as previously noted, the graphics unit operates from Intel 2708 (1K) ROMs using the Intel 8080 microprocessor, the development system must be able to handle two types of microprocessor code and three types of ROM.

A standard Data General text editor is used to enter and edit 8080 or PDP8 assembly language text, saving it as a disk file. A cross-assembler for the required microprocessor subsequently parses the file (twice) and creates a new disk file containing the object code for the target microprocessor. Finally, the object code is converted to ROM images and used to program the appropriate type of ROM.

Nova assembly language source code for an 8080 cross-assembler was obtained from the Defence Research Centre, Salisbury, and was substantially rewritten to operate under DOS. Output from the cross-assembler is in standard Intel hex format. A PDP8 cross-assembler, written in FORTRAN, was purchased commercially and was also modified substantially to suit the Nova operating environment. Output in this case is in standard PDP8 BIN format.

The EPROM programmer was designed by Mr. I. Davidson of Salisbury College of Advanced Education (hardware) and the author (software). The programmer is interfaced to the Nova by a 20 mA serial line (temporarily taking the place of the graphics unit),

thereby obviating the necessity for a complicated interface to the Nova. At the baud rate of 1200 bits per second used for the graphics unit/EPROM programmer, the read time for a 1K ROM is less than 10 seconds. Programming times for a 2708 depend upon the number of write cycles performed. Each write cycle takes the same time as a read operation, and typically 6 to 10 cycles are required. A 2758 or 2716 needs only one programming cycle but requires a 50 ms programming pulse per memory location, necessitating a software delay between bytes transferred. The effect of this delay is to extend the cycle time to approximately one minute per 1K locations.

The software to drive the EPROM programmer contains 15 commands, the actions of which can be seen in Table 2.5. Output from either of the cross-assemblers is read from disk and held in a memory buffer in ROM-image form, prior to being used to program a ROM. The ROM can be previously erase-tested and subsequently verified, with a detailed map of faulty locations optionally printed in either case.

The software enables the ROM buffer to be listed, saved on disk, read from disk, or read from the ROM itself. In the last case, if the buffer is subsequently transferred to another ROM, a copy of the original can be made. When saved on disk, ROM buffers can be split or combined, in order to reformat data between 1 K and 2K ROMs. (The SEROS command of Table 2.5 is used when programming the event recorders: the cross-assembler output contains executable RAM addresses, which must be relocated to ROM for subsequent loading into RAM in the recorder. The SEROS command performs the address translation.)

The final component in the Nova-based development system is an ultraviolet EPROM eraser. This is a commercial item which erases up to eight EPROMs in approximately 30 minutes.



TABLE 2.5  
EPROM PROGRAMMER COMMANDS

COMMAND	ACTION
HELP	Display commands and their actions.
RESET	Reset ROM and/or listing files and/or ROM buffer size and/or number of lines for brief listings.
PDP8	Read PDP8 CROSS-ASSEMBLER output into ROM buffer.
8080	Read 8080 CROSS-ASSEMBLER output into ROM buffer.
READ	Read ROM contents into ROM buffer.
LIST	List contents of ROM buffer.
PROGRAM	Program ROM with data in ROM buffer.
VERIFY	Verify ROM contents against ROM buffer.
TEST	Erase-test ROM.
SAVE	Save ROM buffer on disk.
LOAD	Load a previously SAVED ROM buffer from disk.
COMBINE	Combine two 1K disk ROM buffers into one 2K disk ROM buffer.
SPLIT	Split one 2K disk ROM buffer into two 1K disk ROM buffers.
SEROS	Adjust addresses in SEROS.XF for ROM.
RETURN	Return to the operating system.

The combination of components outlined above enables the microprocessor-controlled devices designed as part of the South Australian computerized seismic data system to be programmed quickly and conveniently in mnemonic source code form. The use of the Nova in emulating aspects of an expensive development system also serves to illustrate the manner in which criterion 10 of the last chapter (page 13) is implemented in practice.

### CHAPTER 3: LOCAL EARTHQUAKE ANALYSIS

#### 3.1 Previous South Australian Practice

Until recently, the methods used to locate local earthquakes in South Australia were influenced largely by the relatively small number of recording stations and the consequent need to extract the maximum amount of information from every record. Methods have always involved the determination of a provisional solution and its subsequent computer revision.

The provisional solution is essentially determined by the method described by Richter (1958) and involves measurement of at least one S-P interval in order to determine the corresponding P travel time and hence event origin time. Thence, the distance to each station is found from the travel time of the first P arrival at each station. From the set of distances, the epicentre was found previously either by consulting tables giving the distance to each station for a grid of possible epicentres, or alternatively by using a map and drawing arcs centred on each station or moving a template containing concentric distance circles.

Adequate depth control has always been a major concern. Since depth has no effect on origin times calculated from S1-P1 and negligible effect on those calculated from Sn-Pn (unlike S1-Pn and Sn-P1), White (1967) used the method of assigning the provisional depth so as to bring the origin time calculated from S1-Pn into agreement with that determined from either S1-P1 or Sn-Pn. The travel times of several prominent phases for a station were then marked on a strip which was subsequently moved over a set of travel time curves for various phases and depths, in order to determine the epicen-

tral distance for the station. This enabled several phases to be taken into account and provided a check on the depth, which White stated could not be changed by more than 5 km without producing inconsistencies.

White's method subsequently fell into disuse in favour of assuming a depth (usually 10 km), determining distances to stations based on the assumed depth, and then revising the assumption if the distances proved inconsistent when fitting the epicentre. This method was used up until the introduction of ISAS.

The computer revision of the provisional solution (White, 1967) uses Geiger's method of least squares (Geiger, 1912) with data for the reference spheroid from Bomford (1962), in which one geocentric degree is taken as 111.2 km for South Australia. Ellipticity corrections of the type described by Jeffreys (1935) are not employed for local earthquake revision, but the flattening of the earth is taken into account when converting from geographic ( $\phi$ ) to geocentric ( $\psi$ ) latitude, according to the relation,  $\tan \psi = 0.993272 \tan \phi$ . Station corrections for sedimentary layers are not employed, although the possibility was investigated by Stewart (1972a). Phases are weighted because of the small number of stations and the need to use phases after the first. Iterations are stopped when the standard error of the residuals fails to decrease by at least 0.002 s over the value from the previous iteration, or after five iterations.

The computer program incorporating the revision (LEQREV), as written by White, used the six phases P1, PR, Pn, S1, SR and Sn. An algorithm internal to the program associated each observed arrival time with a particular phase at the commencement of the revision. This was necessary because of the batch nature of the program, but it denied the seismologist any control over the selection, and frequently resulted in more than one arrival being assigned to the same phase.

Such an algorithm was omitted by the author in ISAS in favour of interactive phase identification.

In an attempt to increase the amount of information able to be used from each seismogram and also to improve the depth control, Stewart (1972a) added three further phases to LEQREV, assumed to occur with significant amplitude based on theoretical amplitude versus distance curves produced by White (1969). The phases were the S to P converted Moho reflection (SMP), the S to P converted surface reflection subsequently Moho-reflected (sPR), and the S to P converted surface reflection subsequently striking the Moho at the critical angle and propagating as a head wave (sPn). However, as Stewart himself notes, White's theoretical amplitudes are not entirely borne out in practice: SR and sPR are predicted to have greater amplitude than S1 for distances greater than  $0.7^{\circ}$ , but in fact S1 has the greatest amplitude in about 80% of cases at HTT and CLV. Further, LEQREV has a tendency to assign Pn phases incorrectly to sPn, especially for shallow events. Misinterpretation of Stewart's converted phases is particularly noticeable in the very common  $1^{\circ}$  to  $2^{\circ}$  range due to travel time crossover points. These problems, and the availability of data from more stations than previously, resulted in Stewart's phases being dropped in ISAS.

### 3.2 Some Alternative Earthquake Location Procedures

Many earthquake location programs have been reported in the literature, especially shortly after computers first came into widespread use (e.g., Flinn, 1960; Bolt, 1960; Nordquist, 1962; Cleary and Doyle, 1962; Engdahl and Gunst, 1966). Most programs are based on least squares iterations in the time domain. Many, like LEQREV, use four independent parameters (origin time, epicentral latitude and

longitude, and depth), although as mentioned by many authors (e.g., Flinn, 1965; James et al., 1969; Lomnitz, 1980), a three-parameter solution with origin time or depth independently determined, reduces the uncertainty in both by reducing their compensatory tendency. Stewart (1972a) has already evaluated this approach in the South Australian situation and pointed out its difficulties. A number of additional shortcomings in programs based on Geiger's original method have been raised by Buland (1976).

Lomnitz (1977) has recently suggested performing revision (for teleseisms) in the spacial domain rather than the time domain, the quoted advantage being a linear set of equations of condition, with consequent simplification and speed improvement. Although the approach has been challenged (Smith, 1978; Lomnitz, 1978), it warrants further investigation in the future to determine its potential for use with local earthquakes.

Perhaps the most widely used program for local earthquake revision is HYP071 (Lee and Lahr, 1975). This program uses Geiger's method, but incorporates stepwise multiple linear regression (Draper and Smith, 1966) instead of simple linear regression. Amplitude and duration magnitude can also be determined and a first motion pattern can be plotted (using an equal-area projection on the lower focal hemisphere). The model used is flexible in that multiple horizontal layers of specified thickness and with specified P velocities may be stipulated, and station variations may be taken into account. However, S velocities in the model may not be assigned independently, being determined by a single stipulated P to S velocity ratio. Only one P and optionally one S phase (the first arrivals) may be used for each station. Overall, the flexibility of the program is impressive but is better suited to larger networks and was not considered further for use in South Australia.

HYP071, like LEQREV and the previously referred to programs, is batch orientated. Some interactive programs have recently appeared in the literature (e.g., Garza et al, 1977 and 1979). For the reasons stated in Chapter 1, ISAS was designed from the outset to be fully interactive. Its principal local earthquake routines are a provisional location procedure, replacing the previous manual determination, and a revision procedure, based loosely on its predecessor, LEQREV. Additional routines determine amplitude and duration magnitudes, enable entry of direction of first motion data, and provide data management and archiving support. These routines are available as commands within the Local Earthquake Subsystem (LOCAL) of ISAS.

### 3.3 The ISAS Local Earthquake Subsystem

The commands of subsystem LOCAL are shown in Table 3.1. PROV, REVISE, MAGD and MAGN are the principal seismic analysis routines, and these are discussed in later sections, along with FIRST.

LOCAL, as presently constructed, deals exclusively with crustal models of the type generally accepted for South Australia; viz, a uniform single-layered crust over a half-space; although Shackelford (1978) has recently presented some evidence for a more complicated structure. Model parameters, consisting of the model number, P and S wave velocities in the crust and upper mantle, and the depth to the Moho, are internally read from a small sequential disk data file, in the format shown in Table 3.2, when the subsystem is first entered. Currently, the model coefficients are those of Table 1.2 and the model number is 1.

TABLE 3.1  
COMMANDS IN SUBSYSTEM LOCAL

COMMAND	ACTION
HELP	Display commands and their actions.
PROV	Determine provisional location.
REVISE	Revise provisional location.
MAGD	Determine MD magnitude.
MAGN	Determine MN magnitude.
FIRST	Enter first motion data into a temporary file.
ARCHIVE	Display a temporary file and optionally transfer to an archive disk.
LOAD	Load an event from an archive disk into a temporary file.
TEMP	Display event numbers in temporary file and optionally delete events.
RENUM	Renumber an event in a temporary file.
MODEL	Display single layer model coefficients and optionally change temporarily or permanently.
RESTORE	Restore permanent single layer model coefficients after a temporary change.
NETWK	Transfer to Network Data Management Subsystem.
CASET	Transfer to Cassette Data Management Subsystem.
MICRO	Transfer to Microearthquake Subsystem.
STATS	Transfer to Earthquake Statistics Subsystem.
LOGOFF	Log-off from system.



TABLE 3.2  
ISAS MODEL FILE STRUCTURE

INFORMATION	DATA TYPE
Model number	4-byte floating point numeric
P velocity in crust (km/s)	" "
S velocity in crust (km/s)	" "
P velocity in upper mantle (km/s)	" "
S velocity in upper mantle (km/s)	" "
Depth to Moho (km)	" "

If a seismologist at the interactive console wishes to experiment with different model coefficients, or if a new set of coefficients is to permanently replace the old, the MODEL command in subsystem LOCAL is executed. This displays the current model coefficients and enables them to be replaced either temporarily or permanently. If a temporary replacement is requested, only the values held in memory are changed: when the subsystem is next entered, the permanent values are again read from disk. A permanent replacement changes the values in memory and also writes the new values to the disk file (incrementing the model number) so that the new values will subsequently be read on entry to LOCAL. A password is required if the latter mode of replacement is requested.

To ensure that archived events can always be subsequently reworked and the same results reproduced from the same data, the number of the model originally used is archived along with the event data for every earthquake. Events analysed with a temporary model cannot be archived. (The system is always aware that a temporary

model is in use since the MODEL command internally changes the model number to zero when the coefficients are temporarily changed.) The RESTORE command returns to the permanent model after a temporary change, by rereading the disk data file.

In keeping with the stated aim in Chapter 1 (page 13) of maximum flexibility, the four analysis commands in LOCAL are all independent: MAGD for example can be executed in isolation if a magnitude is required for an otherwise located event, or all four commands can be invoked in turn to fully analyse a new event. Since all commands require network data, and some commands require data produced by other commands (e.g., the magnitude commands require epicentral distances and the revision command requires a provisional location), a system of temporary files exists, to which the results may be written at the end of each command for possible use by subsequent commands, and to which all network data pertinent to an event may also be written after the network files have been accessed, thereby avoiding the need to repeatedly read the (sometimes lengthy) network files to accumulate the same station data for each command in turn.

Five temporary files exist (with filenames TEMP1 to TEMP5), each able to accommodate a single event. They are sequential files having the structure shown in Table 3.3. At the conclusion of the first command for a new event, if the seismologist requests the results to be saved in a temporary file, each file is tested in turn and the first free file is used to store the data. A message is printed indicating which file is used, after which an event reference number is requested by the system. This is hereafter associated with the event, eventually being archived with it and subsequently used to reference the event from the archives. At the commencement of subsequent commands for the event, input can be requested from the

TABLE 3.3  
ISAS TEMPORARY FILE STRUCTURE

INFORMATION	DATA TYPE	INTERNAL FILE FORMAT
Event reference number Base date and time	ASCII string "	1 to 7 characters YYYYMMDDHHmm ~~~~~ year    day   minute month   hour
Provisional origin time Provisional geog. latitude Provisional longitude Provisional depth Std err. prov. residuals No. stations No. seismogram stations	4-byte floating point numeric " " " " " "	
Station codes First motions	ASCII string "	3 characters per station 1 character per station
Mean MD magnitude No. stations contrib. to MD Std dev. MD Mean MN magnitude No. stations contrib. to MN Std dev. MN Revised origin time Std err. rev. origin time Revised geog. latitude Std err. rev. geog. latitude Revised longitude Std err. rev. longitude Revised depth Std err. rev. depth No. phases used Std. err. rev. residuals Model number	4-byte floating point numeric " " " " " " " " " " " " " " " "	

TABLE 3.3 (contd)

Provisional P arrival times Provisional S arrival times Durations Epicentral distances (in km) Azimuths	4-byte floating point numeric " " "	No. stations x 1 array " " " "
Station data	4-byte floating floating numeric	No. stations x 18 array (18 values as in Table 2.2 valid at base date/time from network files)
Amplitudes (in mm) Periods	4-byte floating point numeric "	No. stations x 1 array "
Magnitudes	4-byte floating point numeric	No. stations x 2 array (First col. MD, second MN)
Revision arrival times & errors	4-byte floating point numeric	No. stations x 12 array (Arr. time & error for P1, PR, Pn, S1, SR, Sn in turn)

temporary file containing the data. All previous results and previously assembled network data then become available to the new command, and results of the command can on request be added to the temporary file at the conclusion of the command. By means of the five temporary files, five earthquakes can be at various stages of progression through the different commands at any time.

The TEMP command in subsystem LOCAL displays a summary of the status of each temporary file, indicating whether or not it is free. If a file is occupied, the reference number of the event is displayed and the option is given of deleting it, thereby making the file available for a new event. The reference number of the event in a temporary file can be changed using the RENUM command. Both of these commands are straight-forward and no comment on their coding is necessary.

After an earthquake has been located, its magnitude determined, direction of first motion recorded, and all results accumulated in a temporary file, the data are normally transferred off-line to an archive disk. Command ARCHIVE firstly displays the detailed contents of a requested temporary file (with the exception of the network data) for verification and confirmation to transfer. (The command is also used when a detailed examination of the contents of a temporary file is required, in which case confirmation to transfer the event to an archive disk is denied.) Following confirmation and supply of a valid password, on request up to 20 characters of text describing locations at which the earthquake was felt may be added to the data, or the event may be tagged as a quarry blast (the latter enabling the event to be rejected in subsystem STATS if required). The non-network data are then transferred to an archive disk, after which the temporary file is deleted on request.

Once placed on an archive disk, the event can be used by subsystem STATS for the accumulation of earthquake statistics (see Chapter 5). Any event on an archive disk can also be reloaded into a LOCAL temporary file (provided it was originally archived from subsystem LOCAL) by means of the LOAD command, in order to be reworked. LOAD searches for a free temporary file, reads the data for the requested event from the archive disk, accesses the network files for network data applicable at the date and time of the event, and then writes all information to the temporary file. If the current model number differs from that archived with the event, an informative diagnostic, quoting both model numbers, is printed. The manner of use of each of the commands discussed above is shown in Figure 3.1.

The structure of the ISAS temporary files is designed to facilitate rapid interchange of data between disk and memory, with data grouped on file as in memory, by variable rather than by station. The structure of the ISAS event archive disks is determined by totally different constraints, however, and in consequence is quite different. Since an event archive file can be extremely large, containing data for perhaps many hundreds of earthquakes, a random file structure is necessary in order to locate any given event efficiently. To take into account the widely differing amounts of data held for different earthquakes, depending on the number of stations recording them, a small record size, equal to 48 bytes, is used and events are built up on the basis of a varying number of records, as shown in Table 3.4. In particular, each earthquake comprises three 48-byte random records plus two additional records per station.

The number of the first random record in the file for any given event is contained in the archive disk index file shown in Table 2.4.

20/04/1981 11:02 [LOCAL] COMMAND: MODEL

PRESENT MODEL COEFFICIENTS: 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)  
DO YOU WANT TO CHANGE THESE COEFFICIENTS (Y OR N)? Y

NEW MODEL COEFFICIENTS (P1,S1,P2,S2,H): 5.85,3.47,8.05,4.6,38  
TEMPORARY (T) OR PERMANENT (P) CHANGE? T

20/04/1981 11:05 [LOCAL] COMMAND: RESTORE

PERMANENT MODEL RESTORED.

20/04/1981 11:05 [LOCAL] COMMAND: TEMP

FILE	EVENT	
1	304/80	DELETE (Y OR N)? <u>Y</u> DELETED.
2	287/8	DELETE (Y OR N)? <u>N</u>
3	221/80	DELETE (Y OR N)? <u>N</u>
4	free	
5	free	

20/04/1981 11:06 [LOCAL] COMMAND: RENUM

TEMPORARY FILE NUMBER (1 TO 5): 2  
EVENT 287/8 TO BECOME (UP TO 7 CHARACTERS): 287/80  
TRANSFER COMPLETED.

20/04/1981 11:07 [LOCAL] COMMAND: TEMP

FILE	EVENT	
1	free	
2	287/80	DELETE (Y OR N)? <u>N</u>
3	221/80	DELETE (Y OR N)? <u>N</u>
4	free	
5	free	

20/04/1981 11:07 [LOCAL] COMMAND: LOAD

TEMPORARY FILE 1 WILL BE USED.  
REFERENCE NUMBER OF REQUIRED EVENT: 10/80

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

ARCHIVE DATA ASSEMBLED. COMMENCING NETWORK FILE SEARCH.  
TRANSFER COMPLETED.

20/04/1981 11:08 [LOCAL] COMMAND: ARCHIVE

TEMPORARY FILE NUMBER (1 TO 5): 3

EVENT REF NO: 221/80

BASE DATE & TIME: 08/09/1980 10:35

PROVISIONAL Geos latitude = -32.75 Longitude = 138.33 Depth = 24 km  
Origin time = 47.4 s SE res = 4.1E-02 s

MODEL: 1

REVISED Geos latitude = -32.764 (SE=9.6E-03) Longitude = 138.329 (SE=1.3E-02) Depth = 25.9 km (SE=1.1E+00)  
Origin time = 47.05 s (SE=1.5E-01) SE res = 3.7E-01 s No phases = 16

Mean MD = 1.9 (SD=4.4E-02) No stations = 4 Mean MN = 2.0 (SD=2.0E-01) No stations = 3

STN	DIST	AZM	(P)	(S)	DURM	MD	AMP	PER	MN	1st	P1	ERR	PR	ERR	Pn	ERR	S1	ERR	SR	ERR	Sn	ERR
EDD	56	332	57.0	64.1	69.0	1.9	23.5	0.20	1.9	+	57.0	0.2	59.4	0.3			64.1	0.2	68.6	0.3		
HTT	92	143	63.0	73.5	69.0	1.9	11.4	0.20	1.8	+	63.0	0.3					73.5	0.3			75.7	0.3
NSK	33	282	54.0	59.0	68.0	1.9				0	54.0	0.2	56.7	0.3			59.0	0.2				
PNA	85	350	61.4	71.3	108.0	1.9				+	61.4	0.2					71.3	0.3				
RPA	87	273	62.0	71.9			29.0	0.20	2.2	N	62.0	0.3			63.0	0.2	71.9	0.3			74.1	0.3

TRANSFER TO ARCHIVE DISKETTE (Y OR N)? Y

PASSWORD: -RMD

WAS THE EVENT EITHER REPORTED FELT OR A QUARRY BLAST (Y OR N)? N

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

DELETE TEMPORARY FILE (Y OR N)? Y

DELETED.

FIGURE 3.1

THE MODEL, RESTORE, TEMP, RENUM, LOAD AND ARCHIVE COMMANDS OF SUBSYSTEM LOCAL.



TABLE 3.4

## ISAS EVENT ARCHIVE FILE STRUCTURE (Subsystem LOCAL)

INFORMATION	DATA TYPE	INTERNAL FILE FORMAT
RECORD ZERO		
Reserved for future use		
RECORD #1 PER EVENT - ALL SUBSYSTEMS		
No. stations, subsystem, and event reference number	ASCII string	<p>NNSRRRRRRR</p> <p>no. ref. no. stns</p> <p>SUBSYSTEM: 0 = pre-ISAS 1 = LOCAL 2 = MICRO (3 = REGNL)</p>
Base date and time	"	YYYYMMDDHHmm (as in Table 3.3)
Provisional origin time (LOCAL), mean origin time (MICRO)	4-byte floating point numeric	
Provisional geog. latitude (LOCAL), geog. latitude (MICRO)	"	
Provisional longitude (LOCAL), longitude (MICRO)	"	
Provisional depth (LOCAL), mean depth (MICRO)	"	
Std err. prov. residuals (LOCAL), 0 (MICRO)	"	
Mean MD	"	

TABLE 3.4 (contd)

RECORD #2 PER EVENT - LOCAL		
Mean MN	"	
No. stations MD, MN	"	(no. MD) + (no. MN)/100
Revised origin time	"	
Std err. rev. origin time	"	
Revised geog. latitude	"	
Std err. rev. geog. latitude	"	
Revised longitude	"	
Std err. rev. longitude	"	
Revised depth	"	
Std err. rev. depth	"	
No. phases, model no.	"	(no. phases) + (model no.)/100
Std err. rev. residuals	"	
RECORD #3 PER EVENT - LOCAL		
Std dev. MD	"	
Std dev. MN	"	
0		
0		
0		
0		
} Reserved for future use		
Initials of person archiving, locations felt or quarry blast	ASCII string	3 characters, then 1-20 characters or "Q/B"
RECORD #1 PER STATION - LOCAL		
Station code	ASCII string	3 characters
Duration	4-byte floating point numeric	
Amplitude (in mm)	"	
Period	"	
First motion	ASCII string	1 character
Provisional P arrival time	4-byte floating point numeric	
Provisional S arrival time	"	
Epicentral distance (in km)	"	
Azimuth	"	
MD	"	
MN	"	
0 (Reserved for future use)	"	
Future expansion flag	ASCII string	1 character, presently "0"

TABLE 3.4 (contd)

RECORD #2 PER STATION - LOCAL		
P1 arrival time	4-byte floating	
error in P1	point numeric	
PR arrival time	"	
error in PR	"	
Pn arrival time	"	
error in Pn	"	
S1 arrival time	"	
error in S1	"	
SR arrival time	"	
error in SR	"	
Sn arrival time	"	
error in Sn	"	

When a new event is added to an archive disk, the next free record is obtained from the file header of the index file. After the event data have been added to the archive file and an entry for the event created in the index file, the file header is updated in preparation for the next event to be archived.

### 3.4 Provisional Location

The manual determination of the provisional solution outlined in an earlier section is replaced in ISAS by an interactive numerical procedure within the framework of command PROV in subsystem LOCAL. Raw input data consist of the arrival times of the first P and S phases at each station where known, the values being either entered interactively at the console (if read from seismograms), read automatically from the cassette file (if read from event recorder cassettes - see Chapter 6), or accessed from a temporary file (if loaded from an archive disk for reworking, or transferred from subsystem MICRO - see Chapter 4). At least three P times and one S time are required.

The seismologist may elect either to supply or alternatively to have calculated the origin time and/or hypocentral coordinates, the former option generally being invoked if the arrival times are to be checked against known quantities. The origin time is calculated from the P and S arrival times of a single station and their assumed phase type (P1 or Pn and S1 or Sn), supplied by the seismologist, using the S-P interval and crustal model. Standard formulae are used (e.g., Garland, 1979). From the origin time and the arrival times of all phases, a set of travel times is determined.

The hypocentre is located by performing a three-dimensional binary search over a region of roughly equal extent in latitude and longitude and covering the state by default, but able to be changed from the interactive console. The depth variable changes least rapidly. It is initialized by dividing the distance from the surface to the Moho into two equal intervals and then selecting a depth equal to the mid-point of the upper interval. A two-dimensional search is performed at this depth, and this is repeated at a depth equal to the mid-point of the lower interval. One of the two is subsequently discarded, the remaining interval halved, and two further searches are performed. This is continued until the dimension of the interval is reduced to some nominal value, presently set internally to one kilometre.

The two-dimensional search is performed in the manner of Figure 3.2. The hypocentre is assumed at the centre of each of the four subregions (at the fixed depth) in turn. Three of these are subsequently rejected, the fourth further subdivided, and four further tests performed. This is continued until the dimensions of both sides of the sub-regions are reduced to some nominal value, again presently set internally to one kilometre.

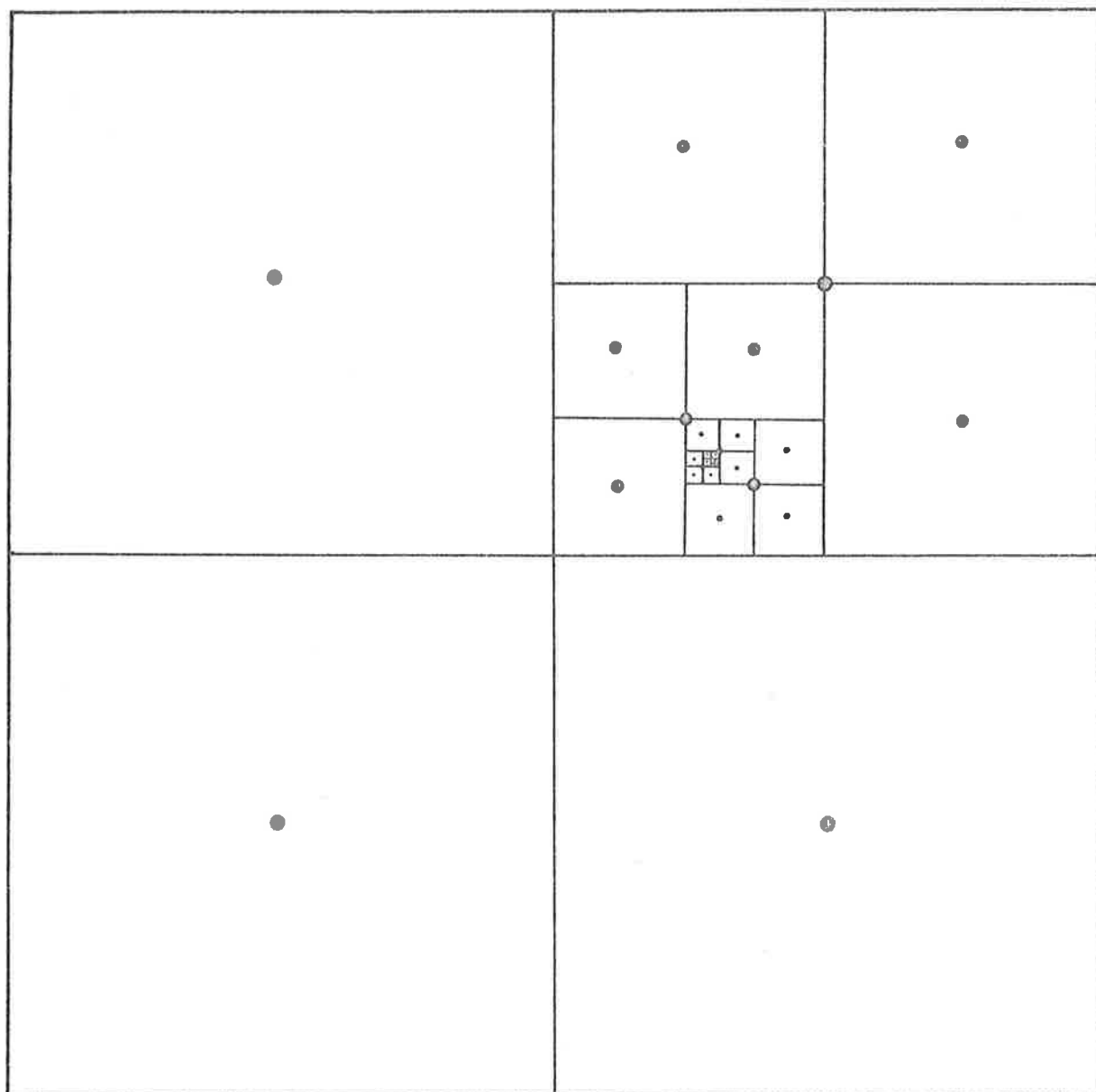


FIGURE 3.2

THE TWO-DIMENSIONAL SEARCH PERFORMED BY PROV.

For the default search region, 11 cycles are required to reduce the size to one kilometre in the two-dimensional search and 6 in the depth search. In practice, however, once the first two-dimensional search is performed, an approximate epicentre is known and it is unnecessary to return to the outermost level for subsequent two-dimensional searches. This greatly reduces the total number of nodes required to be tested during the entire search.

The test performed at each node consists of determining the computed travel time of the first arrival at each station, based on the assumed nodal hypocentre and the single-layer model coefficients in use. First P phases only are considered, with the exception of the station (if any) providing the origin time, for which the first S phase is also used. The (observed minus calculated) travel time residual is determined for each arrival, and the sum of the squares of all residuals computed. The node for which this is a minimum is the one selected in every case.

The procedure is well suited to computer execution, being highly structured and repetitive. The basic algorithm also remains the same irrespective of the complexity of the actual travel time calculations with regard to the nature of the model and the number of corrections applied. It has been used as part of the routine location of all South Australian local earthquakes using ISAS since the beginning of 1978.

Figure 3.3 shows a typical local earthquake provisional solution being determined by PROV. The nature of the printed results can be seen, as can the manner in which results are entered into a temporary file. The example also serves to illustrate the flexibility of the interactive approach adopted, in that the seismologist, on examination of a provisional solution, can change one or more arrival times,

20/04/1981 10:30 [LOCAL] COMMAND: PROU

DATA FROM CASSETTE (C), SEISMOGRAM (S), CASSETTE AND SEISMOGRAM (A) OR TEMPORARY FILE (T)? S

BASE DATE (DD/MM/YYYY) AND TIME (HH:MM): 08/09/1980,10:35

NUMBER OF STATIONS WITH SEISMOGRAM OBSERVATIONS: 5

ENTER DATA IN THE FOLLOWING TABLE, TERMINATING EACH NUMBER WITH THE 'RETURN' KEY AND ENTERING '-' FOR MISSING DATA:

NO.	STN	P (s)	S (s)
1	EDO	57	64.1
2	HTT	63	83.5
3	NBK	54	59
4	PBA	61.4	71.3
5	RPA	62	71.9

DO YOU WANT TO CHANGE ANY VALUES (Y OR N)? Y

ENTER DATA IN THE FOLLOWING TABLE, USING NO. 0 TO END:

NO.	STN	P (s)	S (s)
4	PNA	61.4	71.3
0			

CALCULATE (C) OR SUPPLY (S) HYPOCENTRAL COORDINATES? C

DEFAULT EPICENTRE SEARCH REGION: Geog latitude -39 to -28 Longitude 129 to 142

DO YOU WANT TO CHANGE THESE LIMITS (Y OR N)? N

CALCULATE (C) OR SUPPLY (S) ORIGIN TIME? C

STATION TO BE USED IN DETERMINING ORIGIN TIME: NBK

ASSUMPTION: P1/S1 (1), P1/Sn (2), Pn/S1 (3), or Pn/Sn (4)? 1

MODEL 1: Single layer, 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)

PROVISIONAL SOLUTION: Geog latitude = -32.75 Longitude = 138.33 Depth = 27 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.2 s

STN	DIST	AZM	PH	ARR.TIME	OBS.TT	CALC.TT	RES	PH	ARR.TIME	OBS.TT	CALC.TT	RES
EDO	54	331	P1	57.0	9.8	9.7	0.0	S1	64.1	16.9	16.9	-0.0 *
HTT	94	144	P1	63.0	15.8	15.7	0.1	S1	83.5	36.3	27.3	-9.0 *
NBK	33	279	P1	54.0	6.8	6.8	-0.0	S1	59.0	11.8	11.8	-0.1
PNA	84	349	P1	61.4	14.2	14.1	0.0	S1	71.3	24.1	24.6	-0.5 *
RPA	87	271	P1	62.0	14.8	14.6	0.2	S1	71.9	24.7	25.3	-0.7 *

SE RES = 9.4E-02 s (\* excluded, not used)

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? Y

DO YOU WANT TO SAVE THE LAST SOLUTION (Y OR N)? Y

TO RESTORE, SPECIFY SAVED SOLUTION NUMBER 1.

DO YOU WANT TO CHANGE ANY ARRIVAL TIMES (Y OR N)? Y  
 IN THE FOLLOWING, TO REMOVE AN ARRIVAL, SPECIFY '-' FOR NEW TIME. TO END, SPECIFY '-' FOR STATION CODE.  
 STN: HTT P OR S? S NEW VALUE: 73.5  
 STN: -

CALCULATE (C) OR SUPPLY (S) HYPOCENTRAL COORDINATES? C

DEFAULT EPICENTRE SEARCH REGION: Geog latitude -39 to -28 Longitude 129 to 142  
 DO YOU WANT TO CHANGE THESE LIMITS (Y OR N)? N

CALCULATE (C) OR SUPPLY (S) ORIGIN TIME? C

STATION TO BE USED IN DETERMINING ORIGIN TIME: EDO  
 ASSUMPTION: P1/S1 (1), P1/Sn (2), Pn/S1 (3), or Pn/Sn (4)? 1

MODEL 1: Single layer, 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)

PROVISIONAL SOLUTION: Geog latitude = -32.75 Longitude = 138.33 Depth = 24 km  
 Base date and time = 08/09/1980 10:35 Origin time = 47.4 s

STN	DIST	AZM	PH	ARR.TIME	OBS.TT	CALC.TT	RES	PH	ARR.TIME	OBS.TT	CALC.TT	RES
EDO	54	330	P1	57.0	9.6	9.6	0.0	S1	64.1	16.7	16.7	0.0
HTT	93	144	P1	63.0	15.6	15.5	0.1	S1	73.5	26.1	27.0	-0.9 *
NBK	33	279	P1	54.0	6.6	6.6	-0.1	S1	59.0	11.6	11.6	0.0 *
PNA	84	349	P1	61.4	14.0	14.0	-0.0	S1	71.3	23.9	24.4	-0.5 *
RPA	87	271	P1	62.0	14.6	14.5	0.0	S1	71.9	24.5	25.3	-0.8 *

SE RES = 4.1E-02 s (\* excluded, not used)

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? N

DO YOU WANT TO ENTER RESULTS INTO TEMPORARY FILE (Y OR N)? Y  
 CURRENT SOLUTION (C) OR SAVED SOLUTION NUMBER: C  
 TEMPORARY FILE 3 WILL BE USED. REFERENCE NUMBER OF EVENT (UP TO 7 CHARACTERS): 221/80  
 TRANSFER COMPLETED.

FIGURE 3.3

THE USE OF COMMAND PROV TO DETERMINE A PROVISIONAL EARTHQUAKE LOCATION.



and/or the station and/or the phase assumptions used to determine the origin time, and perform additional calculations. Up to five solutions can be held (in disk buffers), and any one (or the last solution, still in memory) can be eventually written to the temporary file at the conclusion of the command, for subsequent revision.

The internal command logic for PROV is shown in the flow-chart of Figure 3.4, the elements of which are as presented in this section. The discussion of the manner in which PROV (and other ISAS commands) deals with cassette data from the event recorders is deferred until Chapter 6.

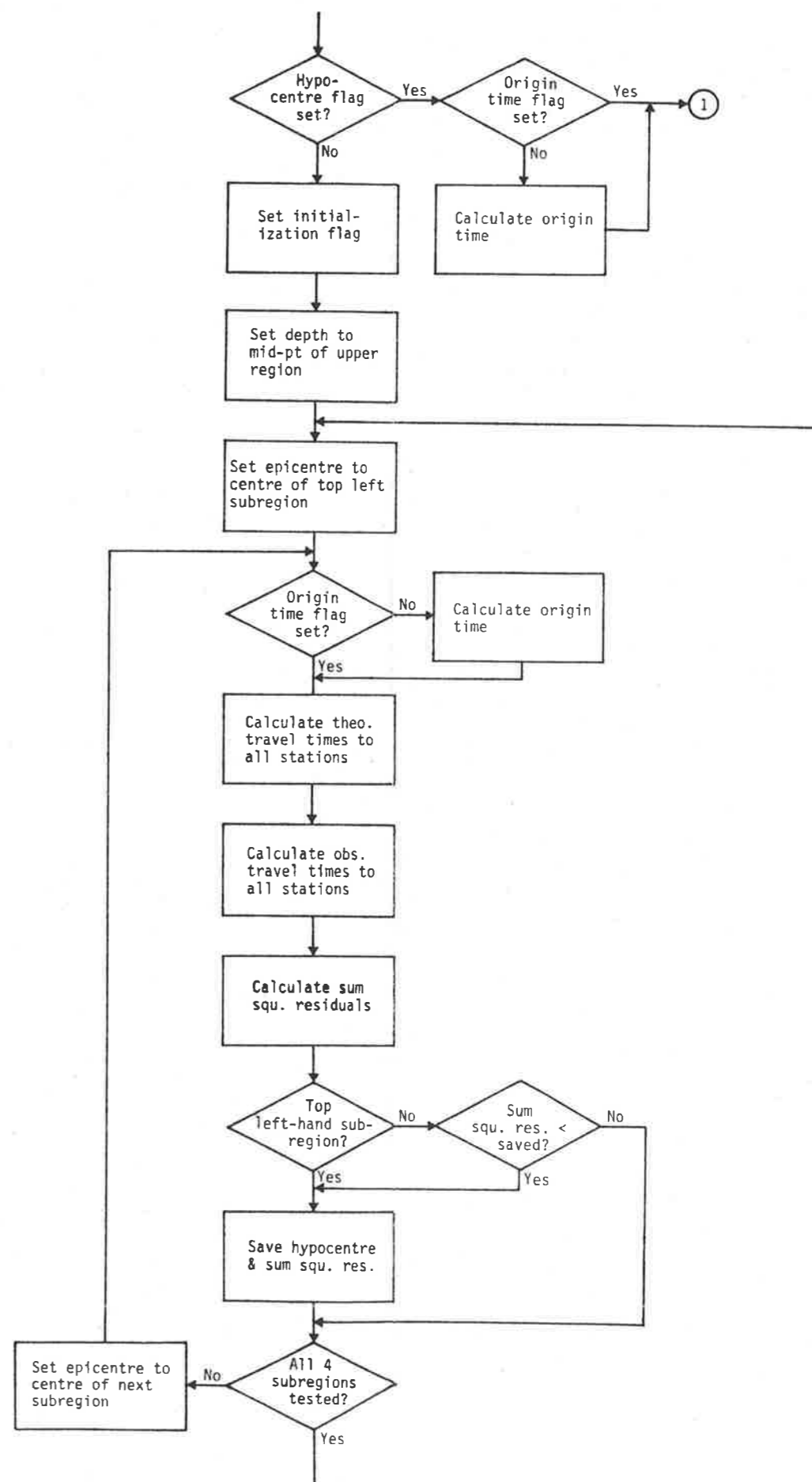
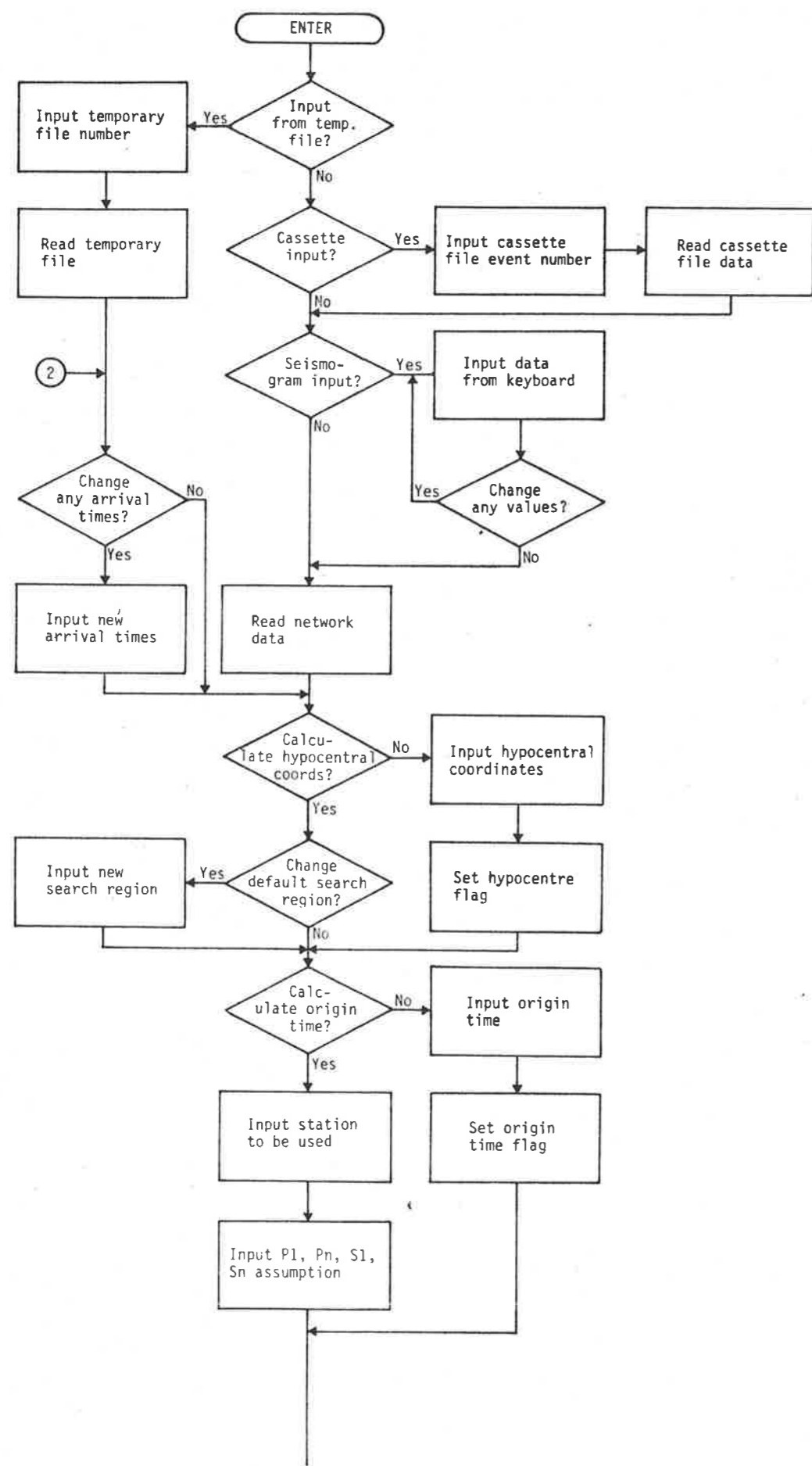
### 3.5 Revision of the Provisional Location

The hypocentre determined by PROV is confined to a finite, albeit large, set of fixed nodal coordinates defining the search grid. In addition, it is derived from a limited subset of the total available data, comprising essentially the first arrivals. It is therefore regarded as provisional and is further refined using the REVISE procedure in subsystem LOCAL of ISAS.

REVISE employs standard least squares revision (e.g., Bullen, 1963), involving the determination of additive corrections  $x_1/\cos \psi$ ,  $x_2$ ,  $x_3$  and  $x_4$  to the longitude, geocentric latitude ( $\psi$ ), focal depth ( $h$ ) and origin time, based on the equation of condition:

$$-(x_1 \sin \alpha + x_2 \cos \alpha) \frac{\partial T}{\partial \Delta} + x_3 \frac{\partial T}{\partial h} + x_4 - \mu = \epsilon$$

in which  $\alpha$  is the azimuth,  $\Delta$  the angular epicentral distance,  $\mu$  the (observed minus calculated) travel time residual,  $\epsilon$  the error in the observed travel time, and  $T$  the travel time itself. Weighting of observations is used (Bolt, 1960), the weighting function being  $0.04/e^2$  (White, 1967), where  $e$  is the error in the arrival time



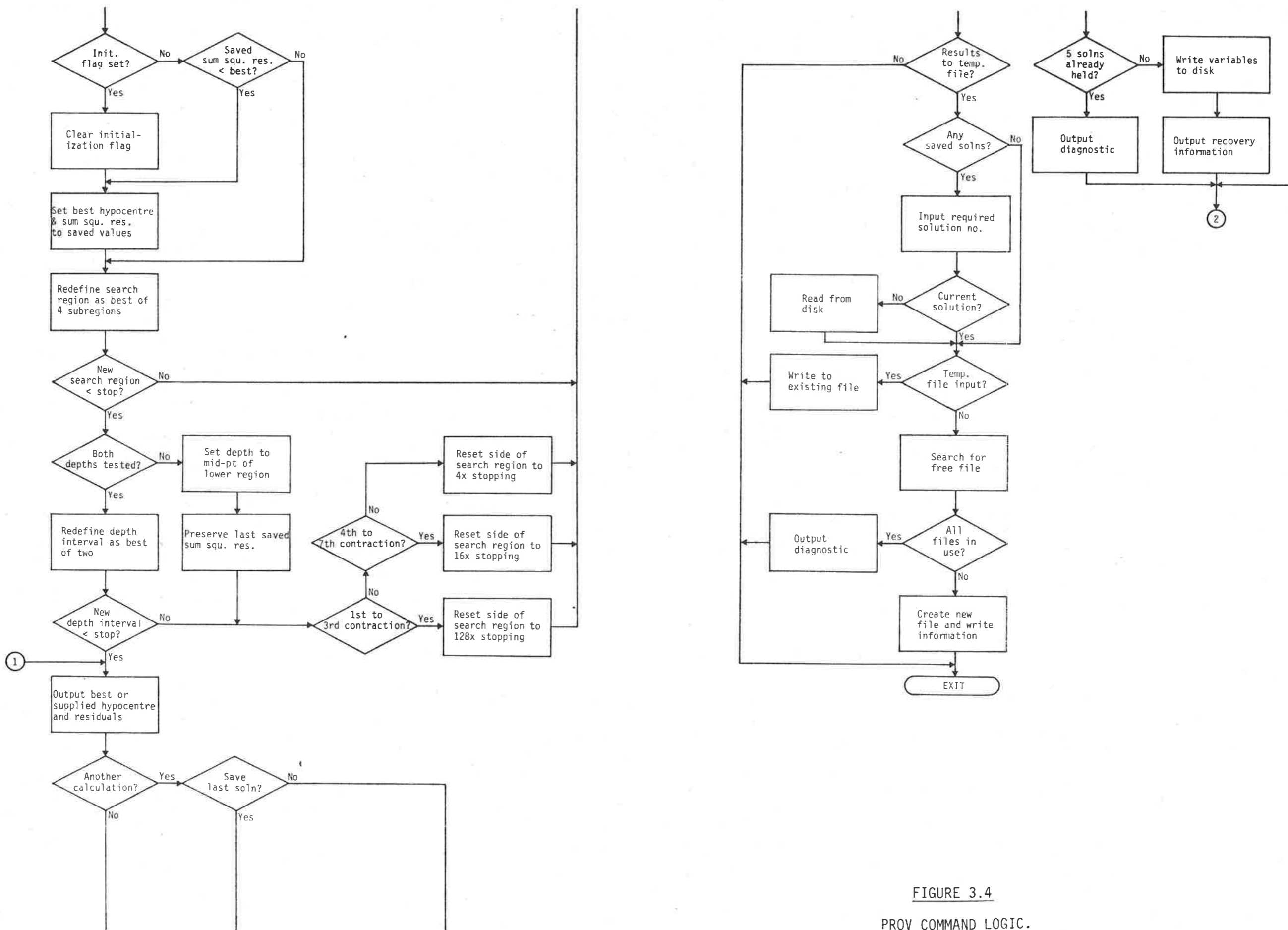


FIGURE 3.4  
PROV COMMAND LOGIC.

estimated from the records. Stopping conditions are the same as described earlier for LEQREV. The REVISE command in ISAS differs markedly from LEQREV, however, in the allocation of arrival times to theoretical phases. Prior to the commencement of the first iteration, the calculated arrival times of the six phases, P1, PR, Pn, S1, SR and Sn, at each of the stations recording the earthquake are printed, based on the provisional solution. The observed arrival times are then entered interactively from the keyboard, and allocated to phases at the discretion of the seismologist. This is shown in Figure 3.5, using the same earthquake as in Figure 3.3.

Figure 3.5 also serves to illustrate the manner in which data stored in a temporary file at the conclusion of PROV are made available at the commencement of REVISE. Alternatively, a provisional solution and set of recording stations could have been supplied from the keyboard without using a temporary file, or in the case of a previously revised event stored in a temporary file, the revision arrival times could also have been read from the temporary file, in which case only changes would need to have been entered from the keyboard. In all, 16 combinations of input and output modes are provided in REVISE.

As in the case of PROV, the option is available at the end of a calculation of repeating it with modified data, in this case arrival times and/or provisional solution. If the latter is changed, a new table of theoretical arrival times is printed. Because a provisional solution can be assigned by the seismologist independently of any model, either in PROV or REVISE, the model number stored in the temporary file is always zero, corresponding to a temporary model, until a (model-dependent) revision has been performed. (This implies that an event cannot be archived until it is revised, because of the

20/04/1981 10:44 [LOCAL] COMMAND: REVISE

PROVISIONAL DATA FROM KEYBOARD (K) OR TEMPORARY FILE (T)? I  
REVISION ARRIVAL TIMES FROM CASSETTE (C), SEISMOGRAM (S), CASSETTE AND SEISMOGRAM (A) OR TEMPORARY FILE (T)? S

TEMPORARY FILE NUMBER (1 TO 5): 3

REL TO 08/09/1980 10:35. CALCULATED ARRIVAL TIMES OF PHASES ARE:

STN	NO.	P1	NO.	PR	NO.	Pn	NO.	S1	NO.	SR	NO.	Sn
EDD	1	57.0	2	59.5	3	-	4	64.1	5	68.4	6	-
HTT	7	62.9	8	64.6	9	64.3	10	74.4	11	77.3	12	76.9
NBK	13	54.1	14	57.3	15	-	16	59.0	17	64.6	18	-
PNA	19	61.4	20	63.2	21	63.1	22	71.8	23	75.0	24	74.7
RPA	25	62.0	26	63.7	27	63.5	28	72.7	29	75.8	30	75.5

ENTER DATA IN THE FOLLOWING TABLE, SEPARATING NUMBERS WITH THE 'RETURN' KEY AND USING NO. 0 TO END.  
NOTE: To change a previous line, retype the line; to delete entirely, specify '-' for arrival time.  
A 'P' or 'S' may be typed instead of an arrival time to use provisional time from temporary file.

NO.	ARR. TIME	ERROR
1	P	2
2	59.4	2
4	S	2
5	68.6	7
7	P	2
10	S	3
13	P	2
14	56.7	3
16	S	2
19	P	2
22	S	2
25	P	2
27	63	2
28	S	2
0		

INVALID ERROR VALUE - REPEAT: 3

REJECT PHASES WITH LARGE RESIDUALS (R) OR USE ALL PHASES (A)? R

SUM WT = 9.56 NO PH = 14 SE RES = 3.6E-01 s

MODEL 1: Single layer, 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)

REVISED SOLUTION 1: Geog latitude = -32.759 Longitude = 138.334 Depth = 25.0 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.13 s

STN	DIST	AZM	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES
				OBS	ERR	CALC	OBS	CALC	OBS			ERR	CALC	OBS	ERR	CALC	OBS			ERR	CALC	OBS	ERR	CALC	OBS	
EDD	55	331	P1	57.0	0.2	56.9	9.9	9.8	0.1	PR	59.4	0.3	59.3	12.3	12.1	0.1	Pn	-	-	0.0	Sn	-	-	0.0		
			S1	64.1	0.2	64.1	17.0	17.0	-0.0		SR	68.6	0.3	68.2	21.5	21.1		0.4	-	-		0.0				
HTT	93	144	P1	63.0	0.3	62.5	15.9	15.4	0.5	PR	64.1	-	17.0	-	-	Pn	63.9	-	16.8	Sn	76.3	-	29.2			
			S1	73.5	0.3	73.9	26.4	26.8	-0.4		SR	76.7	-	29.6	-		-	76.3	-		29.2					
NBK	34	281	P1	54.0	0.2	53.9	6.9	6.7	0.1	PR	56.7	0.3	57.0	9.6	9.8	-0.3	Pn	-	-	0.0	Sn	-	-	0.0		
			S1	59.0	0.2	58.8	11.9	11.7	0.2		SR	64.2	-	17.1	-	-		-	-	0.0						
PNA	85	349	P1	61.4	0.2	61.4	14.3	14.2	0.0	PR	63.1	-	15.9	-	-	Pn	62.9	-	15.8	Sn	74.6	-	27.5			
			S1	71.3	0.3	71.9	24.2	24.8	-0.6		SR	74.9	-	27.7	-		-	74.6	-		27.5					
RPA	87	272	P1	62.0	0.3	61.7	14.9	14.6	0.3	PR	63.4	-	16.2	-	-	Pn	63.0	0.2	63.2	15.9	16.0	-0.2	Sn	75.1	-	27.9
			S1	71.9	0.3	72.5	24.8	25.4	-0.6		SR	75.4	-	28.3	-		-	75.1	-	27.9						

SUM WT = 9.56 NO PH = 14 SE RES = 3.3E-01 s SE LAT = 8.7E-03 SE LONG = 1.3E-02 SE DEPTH = 1.1E+00 km SE OT = 1.6E-01 s

REVISED SOLUTION 2: Geog latitude = -32.759 Longitude = 138.334 Depth = 25.0 km  
 Base date and time = 08/09/1980 10:35 Origin time = 47.13 s

STN	DIST	AZM	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES
				OBS	ERR	CALC	OBS	CALC	OBS			ERR	CALC	OBS	ERR	CALC	OBS			ERR	CALC	OBS	ERR	CALC	OBS	
EDD	55	331	P1	57.0	0.2	56.9	9.9	9.8	0.1	PR	59.4	0.3	59.3	12.3	12.1	0.1	Pn	-	-	0.0	Sn	-	-	0.0		
			S1	64.1	0.2	64.1	17.0	17.0	-0.0		SR	68.6	0.3	68.2	21.5	21.1		0.4	-	-		0.0				
HTT	92	144	P1	63.0	0.3	62.5	15.9	15.4	0.5	PR	64.1	-	17.0	-	-	Pn	63.9	-	16.8	Sn	76.3	-	29.2			
			S1	73.5	0.3	73.9	26.4	26.8	-0.4		SR	76.7	-	29.6	-		-	76.3	-		29.2					
NBK	33	281	P1	54.0	0.2	53.8	6.9	6.7	0.2	PR	56.7	0.3	56.9	9.6	9.8	-0.2	Pn	-	-	0.0	Sn	-	-	0.0		
			S1	59.0	0.2	58.8	11.9	11.7	0.2		SR	64.2	-	17.1	-	-		-	-	0.0						
PNA	85	349	P1	61.4	0.2	61.4	14.3	14.2	0.0	PR	63.1	-	15.9	-	-	Pn	62.9	-	15.8	Sn	74.6	-	27.5			
			S1	71.3	0.3	71.9	24.2	24.8	-0.6		SR	74.9	-	27.7	-		-	74.6	-		27.5					
RPA	87	272	P1	62.0	0.3	61.7	14.9	14.6	0.3	PR	63.4	-	16.2	-	-	Pn	63.0	0.2	63.2	15.9	16.0	-0.2	Sn	75.1	-	27.9
			S1	71.9	0.3	72.5	24.8	25.4	-0.6		SR	75.4	-	28.3	-		-	75.1	-	27.9						

SUM WT = 9.56 NO PH = 14 SE RES = 3.3E-01 s SE LAT = 8.8E-03 SE LONG = 1.3E-02 SE DEPTH = 1.1E+00 km SE OT = 1.6E-01 s

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? Y  
 DO YOU WANT TO SAVE THE LAST SOLUTION (Y OR N)? Y  
 TO RESTORE, SPECIFY SAVED SOLUTION NUMBER 1.

DO YOU WANT TO CHANGE PROVISIONAL SOLUTION (Y OR N)? N

DO YOU WANT TO CHANGE ANY ARRIVAL TIMES (Y OR N)? Y

ENTER NEW DATA IN THE FOLLOWING TABLE, SEPARATING NUMBERS WITH THE 'RETURN' KEY AND USING NO. 0 TO END.  
NOTE: To change a previous line, retype the line; to delete entirely, specify '-' for arrival time.  
A 'P' or 'S' may be typed instead of an arrival time to use provisional time from temporary file.

NO.	ARR. TIME	ERROR
<u>12</u>	<u>75.7</u>	<u>.3</u>
<u>30</u>	<u>74.1</u>	<u>.3</u>
<u>0</u>		

REJECT PHASES WITH LARGE RESIDUALS (R) OR USE ALL PHASES (A)? R

SUM WT = 10.44 NO PH = 16 SE RES = 5.1E-01 s

MODEL 1: Single layer, 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)

REVISED SOLUTION 1: Geog latitude = -32.763 Longitude = 138.330 Depth = 26.0 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.05 s

STN	DIST	AZM	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES					
				OBS	ERR	CALC	OBS	CALC	OBS			ERR	CALC	OBS	CALC	OBS	ERR		CALC				
EDO	56	332	P1	57.0	0.2	56.9	9.9	9.9	0.1	PR	59.4	0.3	59.1	12.3	12.0	0.3	Pn	-	0.0				
			S1	64.1	0.2	64.2	17.0	17.2	-0.1	SR	68.6	0.3	68.0	21.5	21.0	0.6	Sn	-	0.0				
HTT	92	143	P1	63.0	0.3	62.5	15.9	15.4	0.5	PR			64.0		16.9		Pn		63.7	16.6			
			S1	73.5	0.3	73.9	26.4	26.8	-0.4	SR			76.5		29.4		Sn	75.7	0.3	76.0	28.6	29.0	-0.3
NBK	33	282	P1	54.0	0.2	53.8	6.9	6.8	0.2	PR	56.7	0.3	56.7	9.6	9.7	-0.0	Pn	-	0.0				
			S1	59.0	0.2	58.9	11.9	11.8	0.1	SR			63.9		16.8		Sn	-	0.0				
PNA	85	349	P1	61.4	0.2	61.4	14.3	14.3	0.0	PR			63.0		15.9		Pn		62.8	15.7			
			S1	71.3	0.3	72.0	24.2	25.0	-0.7	SR			74.7		27.7		Sn		74.4	27.4			
RPA	87	273	P1	62.0	0.3	61.6	14.9	14.6	0.4	PR			63.2		16.1		Pn	63.0	0.2	62.9	15.9	15.9	0.1
			S1	71.9	0.3	72.4	24.8	25.4	-0.5	SR			75.1		28.0		Sn	74.1	0.3	74.7	27.0	27.7	-0.6

SUM WT = 10.44 NO PH = 16 SE RES = 3.7E-01 s SE LAT = 9.5E-03 SE LONG = 1.3E-02 SE DEPTH = 1.1E+00 km SE DT = 1.5E-01 s

REVISED SOLUTION 2: Geog latitude = -32.764 Longitude = 138.329 Depth = 25.9 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.05 s

STN	DIST	AZM	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES
				OBS	ERR	CALC	OBS	CALC	OBS			ERR	CALC	OBS	ERR	CALC	OBS			ERR	CALC	OBS	ERR	CALC	OBS	
EDD	56	332	P1	57.0	0.2	56.9	10.0	9.9	0.1	PR	59.4	0.3	59.1	12.4	12.0	0.3	Pn	-	-	0.0						
			S1	64.1	0.2	64.2	17.1	17.2	-0.1	SR	68.6	0.3	68.0	21.6	21.0	0.6	Sn	-	-	0.0						
HTT	92	143	P1	63.0	0.3	62.5	16.0	15.4	0.5	PR			64.0		16.9		Pn		63.7		16.6					
			S1	73.5	0.3	73.9	26.5	26.8	-0.4	SR			76.5		29.4		Sn	75.7	0.3	76.0	28.7	29.0	-0.3			
NBK	33	202	P1	54.0	0.2	53.8	7.0	6.0	0.2	PR	56.7	0.3	56.7	9.7	9.7	-0.0	Pn	-	-	0.0						
			S1	59.0	0.2	58.8	12.0	11.8	0.2	SR			63.9		16.8		Sn	-	-	0.0						
PNA	85	350	P1	61.4	0.2	61.4	14.4	14.3	0.0	PR			63.0		15.9		Pn		62.8		15.7					
			S1	71.3	0.3	72.0	24.3	25.0	-0.7	SR			74.7		27.7		Sn		74.4		27.4					
RPA	87	273	P1	62.0	0.3	61.6	15.0	14.6	0.4	PR			63.2		16.1		Pn	63.0	0.2	62.9	16.0	15.9	0.1			
			S1	71.9	0.3	72.4	24.9	25.3	-0.5	SR			75.1		28.0		Sn	74.1	0.3	74.7	27.1	27.7	-0.6			

SUM WT = 10.44    NO PH = 16    SE RES = 3.7E-01 s    SE LAT = 9.6E-03    SE LONG = 1.3E-02    SE DEPTH = 1.1E+00 km    SE QT = 1.5E-01 s

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? N

DO YOU WANT TO ENTER RESULTS INTO TEMPORARY FILE (Y OR N)? Y  
 CURRENT SOLUTION (C) OR SAVED SOLUTION NUMBER: C  
 TRANSFER COMPLETED.

FIGURE 3.5

THE USE OF COMMAND REVISE IN THE REVISION OF A PROVISIONAL LOCATION.



lock on temporary models.) As with PROV, five complete calculations may be held pending the final decision as to which to accept for writing to the temporary file at the conclusion of the command.

Each least squares calculation performed by REVISE may proceed in either of two modes. In the first, all phases entered are used in the calculation; in the second, phases may be internally rejected from an iteration, based on the magnitude of their residuals. In this mode, for inclusion in the first iteration, residuals must be less than two seconds; for subsequent iterations, less than twice the standard error of the residuals from the previous iteration. This and the other aspects of REVISE discussed above appear in its flow-chart, Figure 3.6.

Stewart (1972a) compared the original 6-phase LEQREV with his 9-phase version containing the three converted phases. His data have been brought together in tabular form and are presented, along with those corresponding to the first year of operation of ISAS, in Table 3.5. Despite the improvement achieved by Stewart, the ISAS solutions exhibit even lower standard errors without using converted phases. These results can be explained in part by the increased number of stations in recent years and their improved azimuthal distribution relative to the main seismic areas of the state. However, in view of the importance of a good provisional solution to the operation of least squares revision (Flinn, 1965), the effect of the PROV procedure in ISAS is likely to be significant. The removal of automatic phase allocation has eliminated another known source of error and inconsistency due to misidentifications, which became especially troublesome with the addition of the extra phases by Stewart. Finally, past investigators have tended to concentrate on theoretical methods for improving locations, forgetful that in the

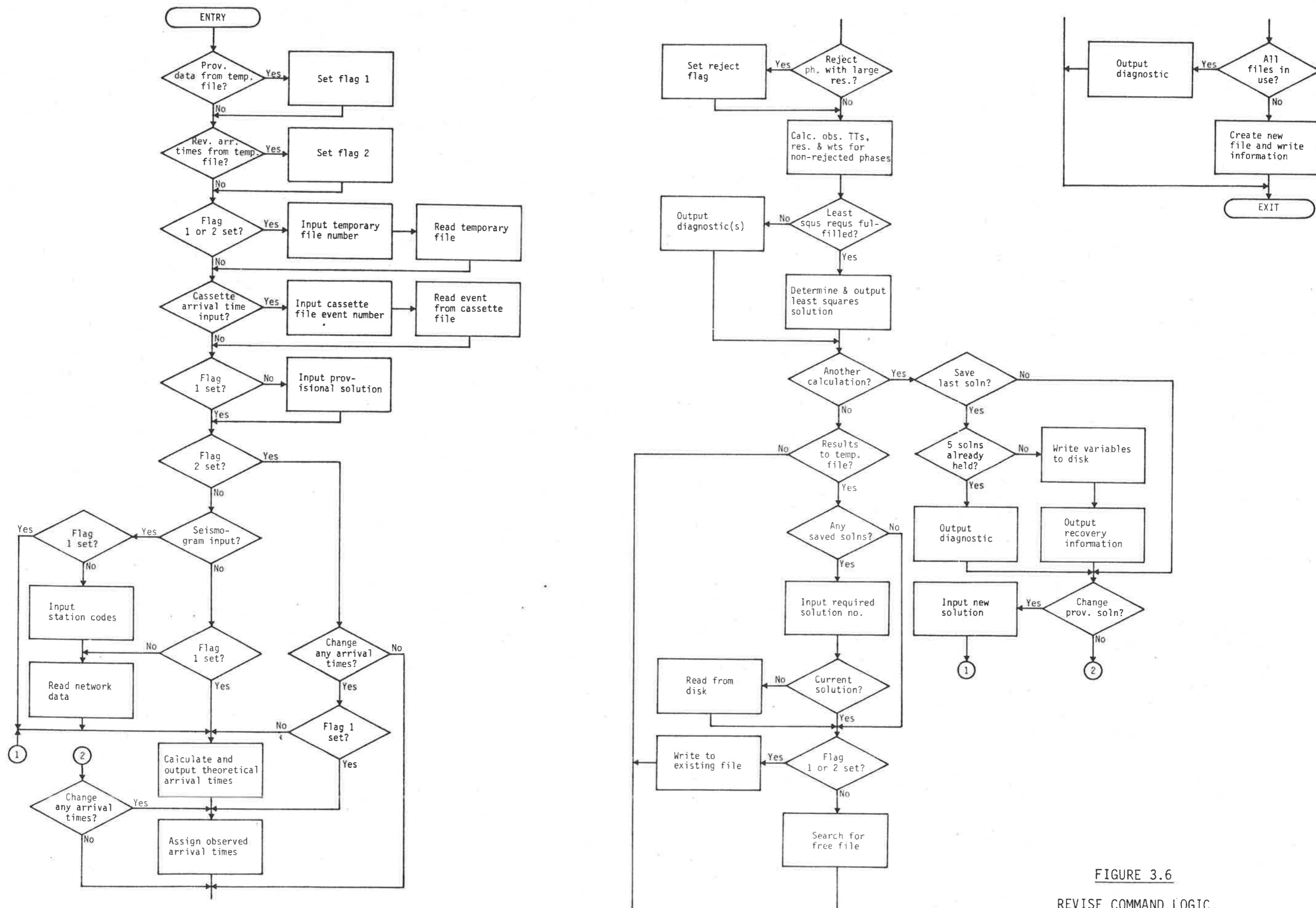


FIGURE 3.6  
REVISE COMMAND LOGIC.

TABLE 3.5

COMPARISON OF ACCURACY OF CALCULATED HYPOCENTRES FROM ISAS AND LEQREV

LOCATION METHOD	YEAR	NO. EVENTS	MEAN NO. STATIONS PER EVENT	MEAN NO. PHASES PER EVENT	MEAN S.E. GEOG. LAT.	MEAN S.E. LONG.	MEAN S.E. DEPTH
6-PHASE LEQREV	1969	82	3.5	7.1	0.071 <sup>o</sup>	0.073 <sup>o</sup>	8.3 km
9-PHASE LEQREV	1970	66	4.3	9.0	0.038 <sup>o</sup>	0.057 <sup>o</sup>	4.2 km
6-PHASE ISAS (PROV/REVISE)	1978	174	5.3	11.5	0.024 <sup>o</sup>	0.040 <sup>o</sup>	3.1 km

majority of cases their methods are implemented by often less skilled and dedicated data processing staff. The greater care required in the reading of seismograms and the need to scrutinize output more carefully for misidentified phases, for example, probably militated against the greater success of converted phases in LEQREV. One of the major strengths of ISAS is its extreme ease of use and the fact that, being interactive, effects of actions can be seen immediately and corrected if necessary while still fresh in the mind. The elimination of the long and tedious hand determination of the provisional solution also leaves more time for investigating alternative phase allocations and interpretations.

A discussion of the significance of the standard errors and their dependence on the model used has been given by White (1967). Since the model is unchanged, no further comment need be made on this aspect.

### 3.6 Magnitude

The first magnitudes determined for South Australian local earthquakes (in 1963) were obtained (White, 1968) by converting amplitudes derived from the Benioff seismometers at ADE, HTT and CLV to equivalent Wood-Anderson amplitudes, and substituting in Richter's formula (Richter, 1935), derived for such instruments and for southern California. The magnitudes so determined were found to increase with distance. A distance-dependent correction (and station corrections) were found, and the resulting formula was used for magnitude determinations from 1963 to 1966. During that period, magnitude residuals were analysed by White using a modification of the "time term" method originally developed for refraction surveys (Scheidegger and Willmore, 1957; Willmore and Bancroft, 1960), as a result of which

a revised formula was obtained (White, 1968) which was used for magnitude determinations from 1967 to 1969. In 1969, White's scale was replaced by the "new local scale" MN (Stewart, 1975), which is still in use. MN is based on a theoretical examination of the energy radiated from a seismic source, and contains terms representing average source spectrum, geometrical attenuation and frequency-dependent absorption. The formula is:

$$MN = 4.85 + \log A_g + 0.84 \log \Delta + 0.0003f\Delta / 2.3 \\ - 2.89 \log f + 2.45 (\log f)^2 + c$$

in which  $\Delta$  is the epicentral distance in km,  $A_g$  is the peak-to-peak maximum vertical ground amplitude amongst the S waves,  $f$  is the corresponding frequency,  $c$  is a station correction and all logarithms are to the base ten. The standard error of one observation based on this formula is quoted as 0.24, and the relationship between MN and local Richter magnitude ML is given as  $ML = 1.33 MN - 0.73$  (Stewart, 1972a).

Subsequent to the introduction of MN and prior to the commencement of the present study, significant changes in the South Australian network occurred: ILN (Island Lagoon) was closed in April 1973 and the equipment shifted to WSA, 25 km west (ref. Figure 1.1), MTA (Mirikata) was opened in June 1973 and shifted to HKN, 10 km south, in August 1975, ADT (ADE telemetered to Adelaide University) commenced operation in May 1974, all new equipment was installed at UMB in November 1974, and HTT and CLV were converted from photographic to pen recording in September 1974 and April 1975 respectively. This investigation therefore commenced by recalibrating all stations and monitoring MN values in order to determine updated station corrections. The mean magnitude residual was obtained for each station using the 55 earthquakes occurring from the time all stations

were recalibrated (November 1975) until the end of 1976. These were used to bring magnitudes from new or modified stations into coincidence with those from the only unmodified station, ADE (PNA not previously having been used for magnitude determinations), thereby ensuring that the scale was not shifted in absolute terms. With the new station corrections, the standard error of a single observation over the monitoring period was 0.21. Table 3.6 shows the station corrections determined as above, together with corrections for several new stations which were determined in the same manner at the beginning of 1980.

MN is determined for an event in ISAS using the command MAGN, the manner of use of which is shown in Figure 3.7 using the same earthquake as previously. Input is again from temporary file, although a list of stations could alternatively have been supplied for an isolated magnitude determination. In the table, any data already known from the temporary file are used (and printed); otherwise appropriate values are requested. The calibration pulse length supplied for each station is checked against the applicable nominal value read from the network files, and a warning is issued if the two differ by more than 20%. The ground amplitude  $A_g$  used in the MN formula is determined from the supplied amplitude and period, and the seven calibration curve coefficients for each station (Chapter 2).

For a new station, for which a station correction is not known, amplitudes are entered as negative, which ensures that magnitudes calculated for the station do not contribute to the means. The station magnitudes are still archived with each event, however, and after sufficient have accumulated, a command in subsystem STATS (Chapter 5) is used to compare the station

TABLE 3.6  
MN STATION CORRECTIONS

STATION	CORRECTION
ADE	0
HTT	0.70
CLV	0.54
UMB	0.66
PNA	0.64
WSA	-0.10
HKN	0.24
BFD	0.69
STK	0.57
ADT	0.10
RPA	0.74
EDO	0.65
NBK	0.63

magnitude with the mean for each event, and so determine the mean residual and hence the station correction. Once determined, the station correction is entered into the current network file, and the station is then able to be used as a contributor to the mean magnitude for subsequent earthquakes. This method was used for the new stations in Table 3.6, and is still in progress for the other new stations of Table 1.3.

A discussion of MN with respect to factors contributing to the standard error of one observation has been given by Stewart (1975),

20/04/1981 10:58 [LOCAL] COMMAND: MAGN

DATA FROM SEISMOGRAM (S) OR TEMPORARY FILE (T)? I  
TEMPORARY FILE NUMBER (1 TO 5): 3

ENTER DATA IN THE FOLLOWING TABLE (IF REQUESTED), TERMINATING EACH NUMBER WITH THE 'RETURN' KEY  
AND ENTERING 0 FOR EACH VALUE NOT DETERMINED.

NOTE: Enter an amplitude as negative if not to be included in the mean.

STN	PULSE (mm)	P-P (mm)	PER (s)	DIST (km)	MN
EDD	: <u>20</u>	: <u>23.5</u>	: <u>1.2</u>	56	1.9
HTT	: <u>13</u>	: <u>11.4</u>	: <u>1.2</u>	92	1.8
NEK	: <u>14</u>	: <u>0</u>			
PNA	: <u>24</u>	: <u>0</u>			
RPA	: <u>20.5</u>	: <u>29</u>	: <u>1.2</u>	87	2.2
					-----
MEAN:					2.0
SD:					2.0E-01

DO YOU WANT TO ENTER RESULTS INTO TEMPORARY FILE (Y OR N)? Y  
TRANSFER COMPLETED.

FIGURE 3.7

THE USE OF COMMAND MAGN TO DETERMINE SOUTH AUSTRALIAN 'NEW LOCAL MAGNITUDE',  
MN.



who stated that the standard error approached the theoretical limit provided by anisotropy in the source radiation pattern and variations in local geology (Duda and Nuttli, 1974; Duda, 1978). A breakdown of the MN formula by term and by variable using a sample of the 1976 data by the author, however, showed that errors in the frequency, which enters into several of the terms in MN, can cause significant errors in the computed magnitude, the errors increasing with decreasing frequency. For example, Table 3.7 shows the effect on MN of an error

TABLE 3.7  
EFFECT ON MN OF ERRORS IN THE PERIOD

PERIOD	NO. OBS	ERROR	MEAN ERROR IN MN
0.4 s	20	-0.1 s	-0.12
		+0.1 s	+0.18
0.5 s	23	-0.1 s	-0.15
		+0.1 s	+0.21

of 0.1 s in period for the two most common periods, 0.4 and 0.5 s. In view of the difficulty in reading periods of this order accurately from seismograms, the above must be regarded as a serious contributor to the observed variability in MN. A magnitude scale which is not as sensitive to source radiation anisotropy and geological inhomogeneity, and at the same time does not place great demands on measurement accuracy may be expected to produce more consistent magnitudes. A duration-based scale is the most promising in this regard. It is also very convenient for use with the event recorders since they already determine total signal duration as one of the triggering parameters,

whereas maximum amplitude is sometimes unreadable for large or close events due to signal saturation, a problem shared with conventional seismographs. In consequence of the above considerations, a duration-based magnitude scale was developed for South Australia, using the same earthquakes as used for the determination of revised station corrections for MN. The scale has been in routine use alongside MN since the beginning of 1977.

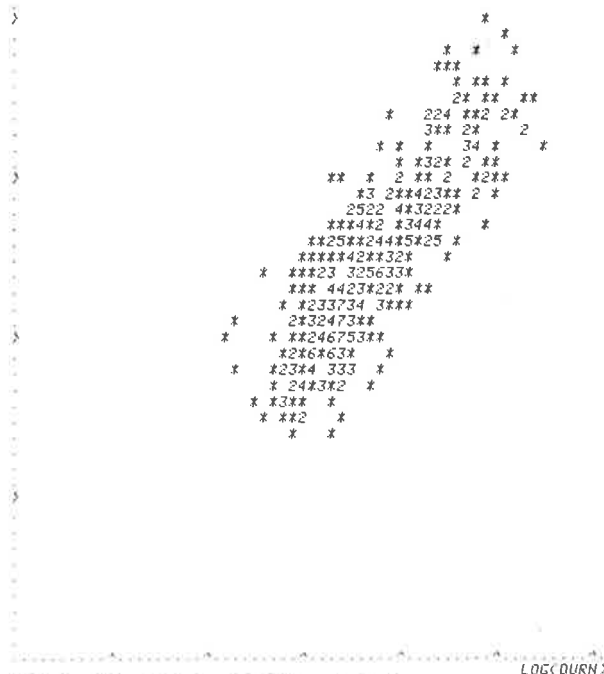
Signal duration as a basis for magnitude determinations was first used by Bisztricsany (1958), who used the duration of the surface waves only to determine the magnitudes of teleseisms. Total signal duration has been more commonly used subsequently, and the method was reported applied to local earthquakes in Sakhalin (Solov'ev, 1965), Honshu (Tsumura, 1967), Puget Sound (Crosson, 1972), central California (Lee et al., 1972), southern California (Real and Teng, 1973) and in the central United States (Herrmann, 1975). Preliminary results from a survey conducted by the Working Group on Magnitude Determination of Near Earthquakes set up by the International Association of Seismology and Physics of the Earth's Interior (IASPEI) for North, Central and South America (Lee and Wetmiller, 1976) showed that by 1976, 27 of the 52 networks involved in the survey were using duration either solely or in conjunction with other magnitude scales. Preliminary results for Australia and South-east Asia (Sutton, pers. comm.) showed no networks in these regions using a duration-based magnitude scale at the time, although some have since begun to do so (e.g., Cuthbertson, 1977). Final reports of the IASPEI survey have since been published (Lee and Wetmiller, 1978; Adams, 1977) and include data for other parts of the world, in which a further 11 networks reported using duration as a basis for local magnitude determinations. The method must therefore

now be regarded as firmly established.

Duration magnitude formulae in the majority of cases involve as their principal term,  $\log \tau$ , where the logarithm is to the base ten and  $\tau$  is the total duration of the disturbance measured on a seismogram from the initial onset to some predefined termination point, usually either the point at which the signal last exceeds a certain peak-to-peak level on a certain type of instrument, or else the time at which the amplitude of the signal becomes equal to that of the background noise (and hence the signal to noise ratio becomes unity). The first definition is less subjective and to a degree independent of fluctuations in the microseismic background, whereas the second is independent of the particular seismograph and of instrumental gain changes. In investigating a scale for South Australian local earthquakes, both methods were used for comparison, the termination signal level for the first method being 2 mm. The event recorders, however, being autoranging based on the mean noise level, effectively use the second method. An event recorder seismic waveform is deemed complete when 256 contiguous samples (5.12 seconds of data) lie below 4 times the mean computed noise level. (See Chapter 6.) Irrespective of the method used to measure  $\tau$ , scattergrams of  $\log \tau$  versus an otherwise determined local magnitude show that the two quantities exhibit a generally high linear correlation. For example, Figure 3.8 shows four such plots for the 1976 South Australian data referred to earlier, combined with data for 1977. (The combined data were used for a re-evaluation of the duration magnitude scale at the end of its first year of operation.) The first two diagrams display all data, irrespective of station, for durations measured to the 2 mm and background levels respectively. Corresponding (Pearson product-moment) correlation coefficients are 0.83 and

430 TOTAL OBSERVATIONS : r = 0.828

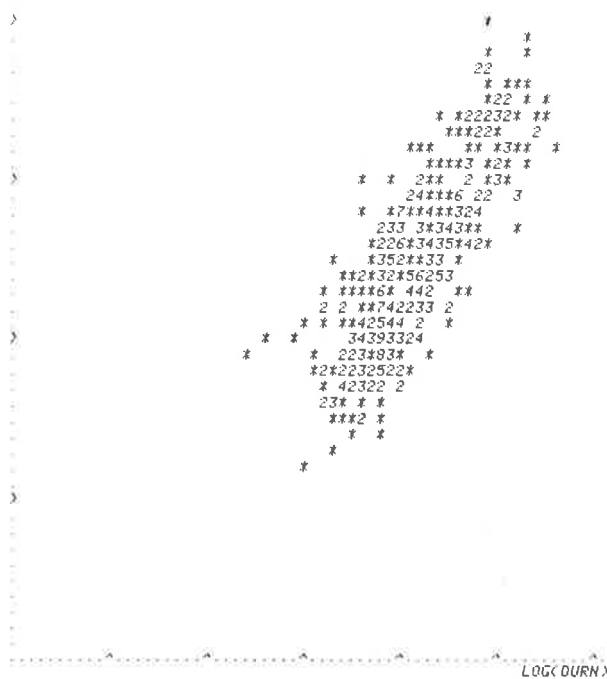
MN



(a) Combined data at the 2 mm cutoff level.

435 TOTAL OBSERVATIONS : r = 0.805

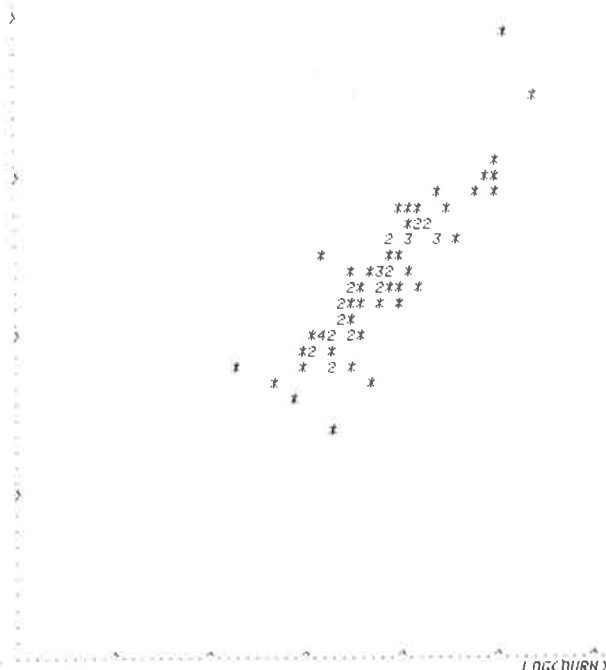
MN



(b) Combined data at the back-ground level.

77 OBSERVATIONS FOR HTT : r = 0.889

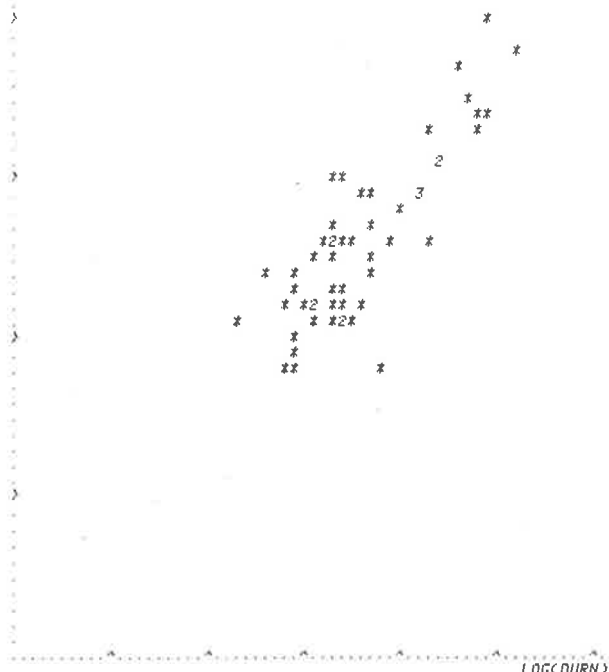
MN



(c) Data for HTT at the 2 mm cutoff level.

54 OBSERVATIONS FOR CLV : r = 0.838

MN



(d) Data for CLV at the 2 mm cutoff level.

FIGURE 3.8

SCATTERGRAMS OF MN VERSUS LOG (DURATION) FOR DATA TO THE END OF 1977. (Numerals indicate the number of coincident points.)

0.81. Individual station plots show the same relationship, with all stations exhibiting correlations within the range 0.7 to 0.9. The second two scattergrams of Figure 3.8 show examples of station plots. In all cases, duration is plotted against the MN value determined from the same seismogram.

Some workers (e.g., Real and Teng, 1973; Herrmann, 1975) have reported a 'knee' in scattergrams such as those of Figure 3.8. This has also been observed in the Oroville, California region by Bakun and Lindh (1977); and has been treated either by fitting two separate  $\log \tau$  segments to the data (Herrmann, 1975; Bakun and Lindh, 1977) or by introducing an additional  $(\log \tau)^2$  term (Real and Teng, 1973). In the latter case, the quadratic term is found to render the linear term insignificant. While no deviation from a linear trend is apparent in the South Australian data, nevertheless scales incorporating second-order duration terms were investigated, amongst others, as discussed below.

In addition to the duration term, most formulae also involve a distance term, usually epicentral distance  $\Delta$ , but sometimes hypocentral distance  $(\Delta^2 + h^2)^{1/2}$ , where  $h$  is the focal depth and  $\Delta$  and  $h$  are both in km. Some formulae separate  $\Delta$  and  $h$  as two independent terms. In all cases, contributions from terms other than the duration term are found to be small, and to a first approximation can be neglected. Suteau and Whitcomb (1979) use a formula without any distance terms, but introduce distance implicitly by measuring durations from the earthquake origin time.

In the South Australian study, six formulae were investigated, as follows:

$$MD = a_0 + a_1 \log \tau \quad (1)$$

$$MD = a_0 + a_1 \log \tau + a_2 \Delta \quad (2)$$

$$MD = a_0 + a_1 \log \tau + a_2 \Delta + a_3 h \quad (3)$$

$$MD = a_0 + a_1 \log \tau + a_2 (\Delta^2 + h^2)^{1/2} \quad (4)$$

$$MD = a_0 + a_1 (\log \tau)^2 + a_2 \Delta \quad (5)$$

$$MD = a_0 + a_1 \log \tau + a_2 (\log \tau)^2 + a_3 \Delta \quad (6)$$

where  $a_0$ ,  $a_1$ ,  $a_2$ , and  $a_3$  are coefficients to be determined, and MD is the duration magnitude. The coefficients were found in each case by stepwise multiple linear regression (Ralston and Wilf (ed.), 1960), the dependent variable being the mean value of MN for each event. The resulting duration magnitude scale therefore corresponds on average with MN over the range of the regression. A separate analysis was performed and a separate set of coefficients obtained for each station, in addition to a combined network regression for each formula.

Results of the analyses can be conveniently summarized by the method used by Real and Teng (1973) of determining three standard deviations per station, in this instance:

$$\sigma_1 = \left[ \frac{1}{N-1} \sum_{i=1}^N (MD - \overline{MD})_i^2 \right]^{1/2}$$

$$\sigma_2 = \left[ \frac{1}{N-1} \sum_{i=1}^N (MN - \overline{MN})_i^2 \right]^{1/2}$$

$$\sigma_3 = \left[ \frac{1}{N-1} \sum_{i=1}^N (MD - \overline{MN})_i^2 \right]^{1/2}$$

where N is the number of events. The mean values of  $\sigma_1$ ,  $\sigma_2$  and

$\sigma_3$  over all stations are presented in Table 3.8 for each of the formulae tested and each of the duration measurement methods used. Values reported by Real and Teng (1973) for southern California are included for comparison.

TABLE 3.8  
EVALUATION OF SIX DURATION MAGNITUDE FORMULAE AND  
TWO DURATION MEASUREMENT METHODS, USING DATA TO THE END OF 1977

NETWORK	FORMULA	2 mm			BACKGROUND		
		$\sigma_1$	$\sigma_2$	$\sigma_3$	$\sigma_1$	$\sigma_2$	$\sigma_3$
South Australian	(1)	0.10	0.20	0.17	0.12	0.19	0.18
	(2)	0.09	"	0.16	0.11	"	0.17
	(3)	0.09	"	0.15	0.10	"	0.16
	(4)	0.09	"	0.16	0.11	"	0.17
	(5)	0.09	"	0.16	0.10	"	0.16
	(6)	0.09	"	0.15	0.10	"	0.16
CIT (Real & Teng)	(6)	-	-	-	0.10	0.27	0.20
BHSN (Real & Teng)	(6)	-	-	-	0.06	"	0.19

Irrespective of the particular duration magnitude formula used, the variability amongst station estimates of MD for an event is about half that of MN, with measurements to the 2 mm cutoff level being marginally more consistent than those to the background level. Apart from the simplest formula, involving the  $\log \tau$  term alone, no particular MD formula is significantly better or worse than any other, supporting the findings of small distance dependence in other studies

and the lack of any noticeable deviation from linearity in the scattergrams.

A strength of the stepwise method of multiple linear regression is that it enables independent variables to be added to the regression in a controlled way, one at a time, with statistical tests at each step to determine the proportion of variance in the dependent variable already accounted for by previously included variables, to be accounted for by the new variable, and whether or not the improvement is statistically significant. In the particular method used in this study, variables were added to the regression in order of the magnitude of their contribution to the variance of the dependent variable, as determined by their respective  $F$  values at each step. In the case of formula (3), for example, the  $\log \tau$  term was always the first to be included, accounting for typically 0.78 to 0.90 of the variance, depending on the station and the measurement method. The  $\Delta$  variable was almost always included next, typically accounting for 0.02 to 0.04 of the variance, which was overall statistically significant at the 99% level. The contribution to the variance due to the final variable  $h$  was too small to be measured in nearly every case, or if measurable was not statistically significant. (In the case of the exceptional stations for which  $h$  entered the regression before  $\Delta$ , neither variable was statistically significant.) The conclusion to be drawn from this example is that a duration magnitude formula for South Australia should not exclude the distance term (except as a first approximation) but an additional depth term is not warranted. (Depth also appears as part of the hypocentral distance term in formula (4), from which it cannot be separated for statistical analysis as above. However, it seems highly unlikely that formula (4) represents an improvement over formula (3) in view of the data of Table 3.8.)



An examination of the statistical aspects of the method in the case of formula (6) showed that neither the linear nor the second-order  $\log \tau$  term in the formula consistently entered the regression first. Whichever term did enter first, however, accounted for 0.78 to 0.90 of the variance and rendered the other term insignificant. This being the case, the simpler linear term alone was adopted for use, and the South Australian duration magnitude scale is therefore based on the formula:

$$MD = a_0 + a_1 \log \tau + a_2 \Delta$$

This formula is in fact the one most commonly used elsewhere, according to the above-mentioned IASPEI survey, by other networks around the world employing a duration-based magnitude scale. It is also interesting to note that Cuthbertson (1977), using non-linear least squares (e.g., Sadler, 1975) to determine the value of the exponent of  $\log \tau$ , obtained values between 1.0 and 1.7 for stations in Victoria.

As a result of the review at the end of 1977, and coinciding with the introduction of ISAS at the beginning of 1978, the background level was adopted for subsequent duration measurements. Although slightly less consistent than the alternative 2 mm level (Table 3.8), background measurements do not involve corrections whenever the gain of a station changes (since signal and noise change by the same amount) and are directly related to the quantity determined under software control in the event recorders. The 1:1 signal-to-noise ratio embodied in the background level is also more "natural" and consequently aesthetically more satisfying.

The data used in the 1976 and 1977 evaluations covered all months of the year, providing a uniform sample of all levels of weather-related background microseisms. The majority of the data was

in the distance range  $0.5^{\circ}$  to  $3.5^{\circ}$ , and MN magnitude range 1.5 to 4.0, with corresponding background-level durations extending broadly from 40 to 400 seconds. To avoid regression extrapolation errors, MD should be regarded as being limited to these ranges. Bakun and Lindh (1977) and Suteau and Whitcomb (1979) have cautioned against the use of duration for magnitude determinations of very small earthquakes (say with durations less than about 10 seconds), as the coda is not sufficiently differentiated from the S wave arrival. Also, MN was developed and studied for distances to  $5^{\circ}$  only, thereby placing a corresponding limit on MD by way of the regression, although the very small distance dependence in MD means that the duration magnitude scale may well be able to be extended beyond the range of MN. Indeed, Nersesov et al. (1976) have used a duration-based scale with distances as large as 3000 km in the U.S.S.R. The continuing accumulation of data from the interstate stations BFD and STK (Figure 1.1) will eventually enable these stations to be included in the South Australian magnitude scales, at which time the distance ranges of both MD and MN can be re-evaluated, and their relationship with interstate magnitude scales also clarified.

To take advantage of the ever-increasing data base, at the beginning of 1980 the MD coefficients were recalculated using the data accumulated from earthquakes to the end of 1979. The coefficients so determined are shown in Table 3.9. Unlike some networks, which use a single network formula, possibly with station corrections, in South Australia the large aperture of the network, with attendant variations in local geology, and the range of equipment in use at the various stations has meant that individual station coefficients are more appropriate. In ISAS the coefficients are stored in the network files as part of the station data (Table 2.2).

TABLE 3.9

COEFFICIENTS IN  $MD = a_0 + a_1 \log \tau + a_2 \Delta$  ( $\Delta$  IN KM)  
FOR SOUTH AUSTRALIAN STATIONS, USING DATA TO THE END OF 1979

STATION	NO. OBS.	$a_0$	$a_1$	STD ERROR	$a_2$	STD ERROR
ADE	26	-0.06	1.41	0.13	0.0003	0.0004
HTT	211	-0.94	1.54	0.05	0.0006	0.0001
CLV	73	-0.29	1.39	0.05	0.0003	0.0001
UMB	50	-1.41	1.80	0.10	0.0000	0.0002
PNA	342	-1.63	1.71	0.05	0.0008	0.0001
WSA	85	-1.12	1.62	0.10	0.0011	0.0004
HKN	32	-2.80	2.33	0.19	0.0002	0.0002
ADT	35	-0.49	1.52	0.13	0.0003	0.0002
RPA	280	-1.20	1.63	0.04	0.0005	0.0001
EDO	166	-1.23	1.67	0.05	0.0007	0.0002
NBK	80	-1.06	1.58	0.08	0.0005	0.0002

Duration magnitudes are determined by the ISAS command MAGD, the manner of use of which is shown in Figure 3.9 for the same earthquake as previously. For cassette-recording stations using the event recorders, the durations determined by the recorders are automatically made available and used by the command, whether entered directly or via a temporary file. Distances, for temporary file input, are also used automatically if already determined. Remaining information is requested from the keyboard, as MD is interactively calculated and displayed for each station in turn. Results may be added to the temporary file at the conclusion of the command on request.

20/04/1981 10:56 [LOCAL] COMMAND: MAGD

DATA FROM CASSETTE (C), SEISMOGRAM (S), CASSETTE AND SEISMOGRAM (A) OR TEMPORARY FILE (T)? I  
TEMPORARY FILE NUMBER (1 TO 5): 3

ENTER DATA IN THE FOLLOWING TABLE (IF REQUESTED), TERMINATING EACH NUMBER WITH THE 'RETURN' KEY  
AND ENTERING 0 FOR EACH VALUE NOT DETERMINED:

STN	DURN ( $\pm$ )	DIST (km)	MD
EDD	<u>69</u>	56	1.9
HTT	<u>69</u>	92	1.9
NBK	<u>68</u>	33	1.9
PNA	<u>108</u>	85	1.9
RPA	<u>0</u>		
-----			
MEAN:			1.9
SD:			4.4E-02

DO YOU WANT TO ENTER RESULTS INTO TEMPORARY FILE (Y OR N)? Y  
TRANSFER COMPLETED.

FIGURE 3.9

THE USE OF COMMAND MAGD TO DETERMINE SOUTH AUSTRALIAN DURATION MAGNITUDE,  
MD.



For a new station, for which MD coefficients are not known, durations are entered normally. The lack of coefficients for the station prevents the undetermined values influencing the means, but the durations are still archived with the events. After sufficient events have accumulated, a command in subsystem STATS (Chapter 5) is used to perform the stepwise multiple linear regression for durations and distances corresponding to the station against the mean value of MN for each event, from which the duration magnitude coefficients can be read and subsequently entered into the current network file. The station can thereafter be used in the determination of duration magnitudes. This procedure was in fact followed in the 1980 update of station coefficients presented in Table 3.9.

A number of workers have investigated the theoretical basis for the observed properties of duration-based magnitude scales. Aki (1969) proposed the theory that the later part of the coda of local earthquakes is composed of back-scattered surface waves due to lateral inhomogeneities in the shallow crust, showing that this implies durations which are nearly independent of epicentral distance. Aki and Chouet (1975) have expanded upon this, and suggested alternative theories for the coda in terms of scattered body waves and also as a diffusion process. The data, however, appear to favour scattered surface waves under normal conditions (e.g., Suteau and Whitcomb, 1979; Herrmann, 1980).

Herrmann (1975) showed that a duration magnitude formula of the form  $q \log \tau + r$  ( $q$  and  $r$  constants) follows as a result of a  $t^{-q}$  coda envelope, and suggested a typical  $q$  value of 1.5. A comparison with Table 3.9 shows that the  $\log \tau$  coefficient for South Australian stations lies in the range 1.4 to 1.8, with the exception of HKN whose higher value is perhaps more typical of values generally reported

elsewhere. Herrmann (1975) attributes such differences to geographical dependences for the scattering process, although instrumental response is also significant (Bakun and Lindh, 1977). Indeed, the non-linearity sometimes observed in scattergrams such as Figure 3.8 has been attributed to the source spectrum corner frequency passing through the peak instrumental response (Herrmann, 1975; Bakun and Lindh, 1977), although Herrmann (1980) has suggested an alternative explanation in terms of changes in the coda shape due to dispersion by the Earth's Q filter.

### 3.7 Direction of First Motion

Direction of first motion data are gathered by ISAS but are not used at present in the determination of fault plane solutions due to the relatively small number of stations and the fact that fewer than 10% of events are recorded by all stations. Stewart and Denham (1974) combined data from South Australian stations with those from interstate stations to produce a fault plane solution for the first accurately-located earthquake in the Simpson Desert in Central Australia in 1972. Since that time, only three fault plane solutions have been published for South Australian events (McCue and Sutton, 1979). These correspond to earthquakes occurring in 1977, one of which was recorded within the 7-station portable network in the Flinders Ranges (as well as being recorded by the permanent stations) during the first microearthquake survey mentioned in Chapters 1 and 4. The paucity of fault plane solutions is not to imply that focal mechanisms have not been investigated in South Australia: Stewart used the azimuthal distribution of MN residuals as a means of studying tectonic stresses, particularly for the Flinders-Mt. Lofty Ranges (Stewart and Mount, 1972). Composite fault plane solutions (Aki,

1966; Mendiguren, 1980) also provide an alternative which could prove useful in the South Australian situation.

Direction of first motion data are added to the information held in a temporary file in ISAS using the command FIRST, the manner of use of which is shown in Figure 3.10 for the same earthquake as previously. For cassette-recording stations using the event recorders, the direction of first motion is entered into the temporary file automatically when the cassette is read; the value is therefore merely displayed. For the remainder of the stations, the directions of first motion are requested from the keyboard. With the increasing number of stations in the state network, the time is approaching where it will be feasible to extend this command to produce a first motion plot, such as is done in HYP071 (Lee and Lahr, 1975), from which the fault plane and auxiliary plane can be added by hand. Computer programs have been written to produce the final fault plane solution from direction of first motion data (e.g., Kasahara, 1963; Julian, 1978) and these warrant closer examination, although the machine time required may well exceed the time taken to add the two planes by hand, with only a dubious increase in accuracy. Composite fault plane solutions would have to be provided within the framework of subsystem STATS (Chapter 5) since data would be required from several earthquakes. Such a command would be able to utilize the currently-archived first motion data. Only the direction of P wave first motion is presently recorded, although if the direction of S wave first motion were required to be added in future, the archive file structure of ISAS (Table 3.4) could accommodate it, either within its existing record structure or as part of a new record, by way of a "future expansion flag" included with each set of station data but at present never set. A similar situation exists with the header records

20/04/1981 11:00 [LOCAL] COMMAND: FIRST

TEMPORARY FILE NUMBER (1 TO 5): 3

DO YOU WANT KEY TO SYMBOLS PRINTED (Y OR N)? Y

KEY:     U = first motion clear and up     D = first motion clear and down  
          + = first motion poor and up     - = first motion poor and down  
                          N = first motion not readable

ENTER DATA IN THE FOLLOWING TABLE (IF REQUESTED):

STN	1st MOTN	
EDD	: ±	
HTT	: ±	INVALID SYMBOL - REPEAT: ±
NBK	: <u>0</u>	
PNA	: ±	
RPA	: <u>N</u>	

READY TO TRANSFER TO TEMPORARY FILE. PROCEED (P) OR ABORT (A)? P  
TRANSFER COMPLETED.

FIGURE 3.10

THE USE OF COMMAND FIRST TO ENTER DIRECTION OF FIRST MOTION DATA INTO A TEMPORARY FILE.



of each event if the strike and dip of the fault plane and auxiliary plane are required to be added to the archived data in future.

The direction of first motion data of Figure 3.10, along with the provisional and revised locations of Figures 3.3 and 3.5, and MN and MD magnitudes of Figures 3.7 and 3.9, can be seen in the detailed temporary file display of Figure 3.1, which applies for the same event. After all commands have been executed to the satisfaction of the seismologist, the event is normally transferred off-line to an archive disk, and the temporary file made available for use with a new local earthquake.

## CHAPTER 4: MICROEARTHQUAKE SURVEYS AND ANALYSIS

### 4.1 First Flinders Ranges Microearthquake Survey

The area around the northern tip of Spencer Gulf in South Australia (Figure 4.1) is important to the state because of its high level of industrial development. However, the region borders the southern Flinders Ranges, which is part of the seismically active Adelaide Geosyncline, and it is therefore an area of non-negligible seismic risk. Because of this, a detailed examination of the seismicity of the region was seen to be important, and in fact prompted much of the funding of the present research. The eventual aim of the study is to locate and map active faults, and to quantify the seismic risk in the area.

To achieve the goals stated above, monitoring over a long period of time by a localized network in the region is required. This is now in progress and was the reason for opening the new stations RPA, EDO and NBK (Table 1.3, Figure 1.1). As a guide to the placement of these stations, and to gain an early indication of the likely activity to be expected, a 25 day pilot study was carried out in April-May 1977 using 7 portable stations, the locations of which are shown in Figure 4.1. Studies have been made of the optimum placement of seismic stations for a small localized network such as the above (e.g., Underwood, 1967; Uhrhammer, 1980). The locations shown in Figure 4.1, however, were largely a result of the practical considerations of accessibility, isolation from potential noise sources, and availability of suitable foundation rock for the seismometers. Site coordinates were determined to within 100 metres using 1:50 000 maps.

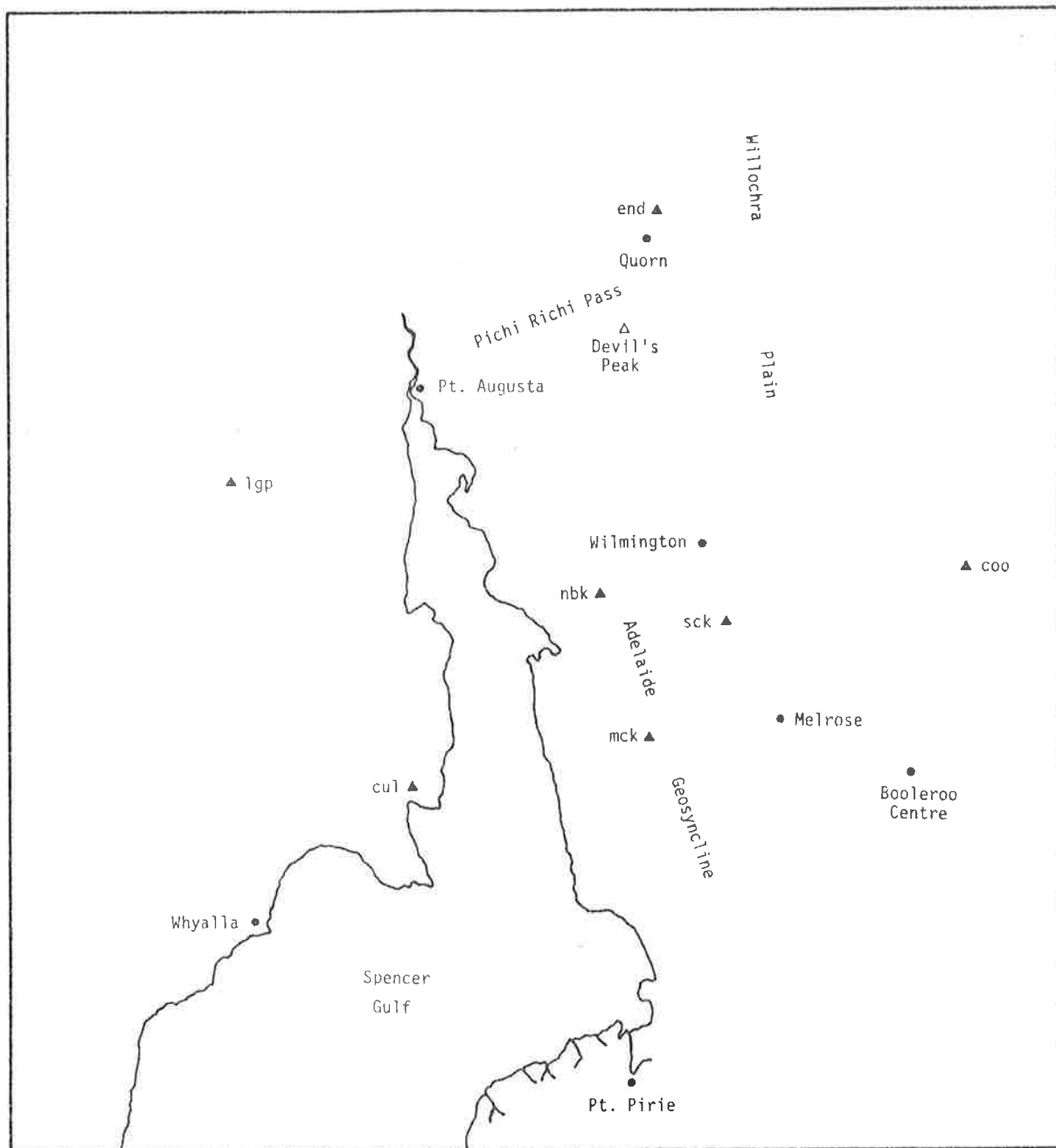


FIGURE 4.1

THE NORTHERN SPENCER GULF REGION OF SOUTH AUSTRALIA, SHOWING THE LOCATIONS OF THE PORTABLE STATIONS USED IN THE FIRST FLINDERS RANGES MICROEARTHQUAKE SURVEY, APRIL-MAY 1977. (Also shown are the locations of the main places referred to in the text.)

With the exception of cul, all stations were equipped with identical Kinometrics Ranger SS-1 seismometers with 1 s period, and Kinometrics PS-1A seismographs. The seismometers were placed in covered holes wherever possible, and the seismographs and external batteries were contained in locked metal boxes with heat shields, or in small tents. Figure 4.2 shows the arrangements at some of the stations. The slow-speed tape recorder (Chapter 1) was employed at cul due to the relative isolation of the site and the fact that the tape recorder can operate for several weeks unattended. For the remainder of the network, each station was visited daily to change the record, insert calibration pulses, check the clock, and change batteries as needed; representing over 300 km of travel daily. Members of the University seismology group manned the network in pairs for a few days at a time, with teams commuting between Adelaide and the network base at Endilloe (end, Figure 4.1) by light aircraft.

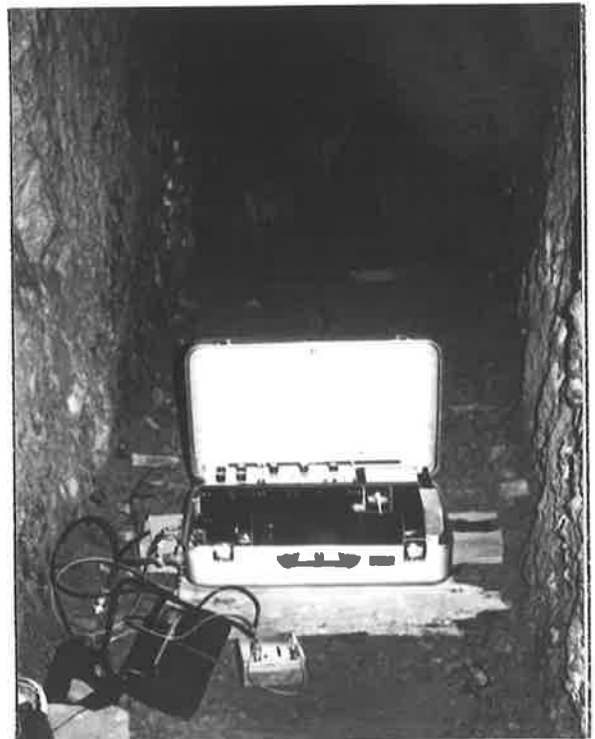
All stations using Kinometrics seismographs operated for most of the time using PS-1A internal filter #4 (Figure 4.3), being the most appropriate for typical microearthquake frequencies. For comparison, however, the stations were operated using the #2 filter (Figure 4.3) for a few days. Response using this filter corresponds approximately to that of the permanent stations in the state network. (An exception was nbk which, due to the proximity of a transmission line from the Port Augusta power station, was operated exclusively with filter #2 to avoid 50 Hz interference.) The equipment functioned satisfactorily over the 25 day period with the exception of a problem with the internal clock in the tape recorder at cul which resulted in that station not being used for events after the first.



(a) Covered, above-ground seismometer (foreground) and tent containing the recorder at lgp; also employed at end.



(b) Heat-shielded seismograph box used at mck, nbk, and coo.



(c) Locked, disused mine used to house equipment at sck.

FIGURE 4.2

ARRANGEMENT OF SOME PORTABLE STATIONS IN THE FIRST FLINDERS RANGES MICRO-EARTHQUAKE SURVEY.

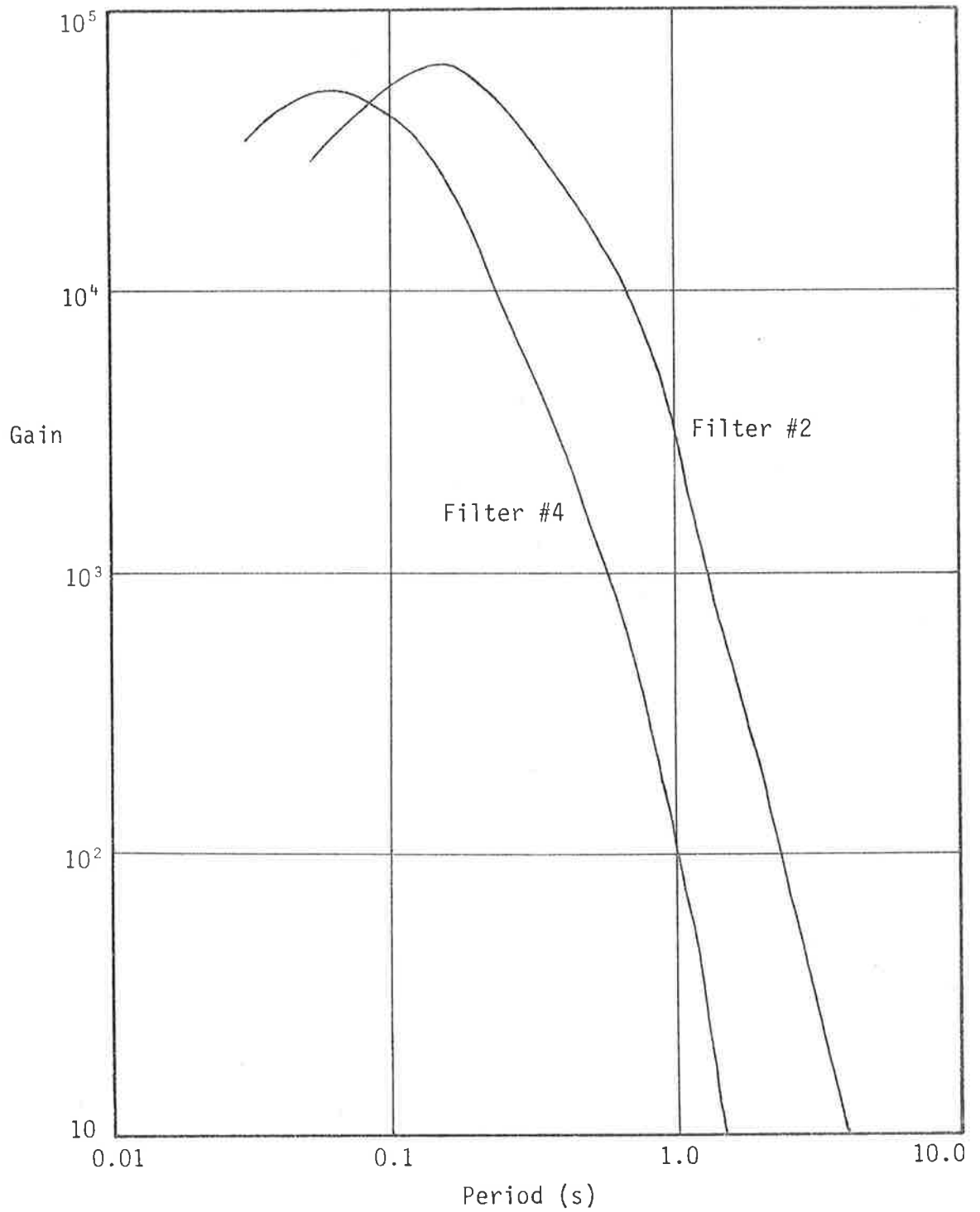


FIGURE 4.3

RESPONSE CURVES FOR KINEMATRICS PORTABLE STATIONS end, lgp, mck, nbk, sck AND coo. (The curves apply for a PS-1A amplifier attenuation of 44 dB.)

TABLE 4.1  
 DISTRIBUTION OF RECORDED EVENTS BY STATION  
 IN THE FIRST FLINDERS RANGES MICROEARTHQUAKE SURVEY

STATION	NO. POTENTIALLY LOCATABLE EVENTS	NO. UNLOCATABLE EVENTS
end	57	75
lgp	54	12
mck	58	23
nbk	67	15
sck	57	16
coo	59	107

During the recording period, 70 potentially locatable events (recorded at 3 or more stations) were observed. Table 4.1 shows the distribution of these events by station, and also the further number of events recorded at only the station concerned (or at most one other station). 53 of the 70 potentially locatable events were in fact located, the remaining 17 being eliminated either because one or more records were too noisy to enable sufficient phases to be read, or alternatively because the event was too far outside the network to be reliably located. A fast, direct location algorithm was devised, which was subsequently incorporated as the central command in the ISAS Microearthquake Subsystem. It is discussed in the next section of this chapter. The geographical distribution of located events is presented, together with that of events subsequently located by the new permanent stations in the region, in the next chapter.

The first event recorded during the monitoring period was in fact felt around Quorn (by, amongst others, the author and his supervisor, who were manning the network at the time), and was also recorded by

all stations in the permanent state network. It had a magnitude (MD) of 3.4 and was one of the three earthquakes mentioned in the last chapter whose fault plane solution was plotted by McCue and Sutton (1979). Many of the located events of the following few days were attributable to aftershocks of this earthquake. The large number of unlocated events in Table 4.1 for nearby station end represents an extension of the aftershock sequence into the smaller magnitude range (as inferred from the S-P times and temporal relationship with the main shock). The other station with an abnormally large number of small earthquakes in its vicinity, as seen in Table 4.1, is coo. The events occurred uniformly throughout the recording period and their S-P times correspond to distances of 16 to 29 km from coo. Their origin is unknown.

An approximate duration magnitude scale was established for the portable network by comparing durations and distances in the portable network with MN values from nearby PNA (Figure 1.1), for 16 earthquakes which were recorded by both PNA and stations in the portable network. The technique of stepwise multiple linear regression (Chapter 3) was again employed. In this case, however, due to the small amount of data, a single network formula only was obtained, rather than individual station formulae as obtained for the permanent stations. This is justified in this case considering the limited geographical extent of the portable network and the fact that all stations used identical seismometers and recorders. The resulting formula is:

$$MD = -1.72 + 1.87 \log \tau + 0.0013\Delta$$

in which  $\Delta$  is the epicentral distance in kilometres and  $\tau$  is the duration in seconds from initial onset to the background cutoff level (Chapter 3). Standard errors for the duration and distance



coefficients in the above formula are 0.5 and 0.002 respectively. These are larger than the corresponding errors for the permanent stations (Table 3.9), reflecting the smaller amount of data used in the analysis. The error in the distance coefficient is such that the distance term could be justifiably ignored entirely. In practice, however, the formula breaks down at very small distances, as it does for very small magnitudes (Bakun and Lindh, 1977; Suteau and Whitcomb, 1979), due to the lack of a clearly delineated coda of back-scattered surface waves. When applied to 52 of the 53 located events in the survey (the coda of one being lost in the following event), the above formula resulted in magnitudes with a standard error of one observation of 0.23; higher than that obtained in the permanent network for MD but still of the same order as that obtained for MN.

A complicating factor in obtaining a magnitude scale for the portable network was the filter change during the recording period. Ideally, separate formulae should have been obtained for each filter, in view of the dependence of signal duration on system response (e.g., Herrmann, 1980). In this case, however, insufficient data were available to enable such a breakdown. Nevertheless, a comparison of durations from nbk, which used filter #2 exclusively, with those from the other stations, which operated predominantly with filter #4, showed that the former were not systematically above nor below the latter, and suggested that a single formula is justified despite the slightly different frequency windows.

The 25 days of recording with the portable network resulted in 50% more potentially locatable earthquakes than actually located for the entire previous year with the permanent state network. The location methods in use at the time (manual determination of provisional location and batch computer revision) were very slow and

inappropriate for use in microearthquake surveys. Consequently, a fast method, making use of the restricted geographical extent of the portable network, was devised, and is discussed below.

#### 4.2 Microearthquake Location Method

Because a microearthquake survey generally involves a network operating in a region of limited geographic extent, spherical geometry and ellipticity corrections used with local earthquake solutions can be dispensed with and the solution instead performed using rectangular coordinates. This results in a significant computational simplification. Another consequence of using a localized network, with the added assumption of a homogeneous isotropic crust, is that the first P and S wave arrivals can be taken to be the direct waves, having travelled in a straight line from hypocentre to station. This further simplifies the analysis. In the method developed for the South Australian surveys, an over-determined linear system of equations is obtained, which is solved by standard (linear) least squares techniques. The method (see below) determines the (assumed constant) crustal P and S wave velocities along with the hypocentral coordinates, and can therefore be used in a region of unknown crustal structure, provided the assumptions implicit in the method can be justified. Other methods for jointly determining crustal structure and focal coordinates have appeared in the literature (e.g., Aki and Lee, 1976; Crosson, 1976; Mitchell and Hashim, 1977; Hileman, 1979; Pavlis and Booker, 1980). These typically determine a more general crustal structure, including depths to discontinuities, at the expense of the speed and simplicity which was the primary motivation for the method described here.

If P and S denote the arrival times of P1 and S1 respectively at a station distant  $\Delta$  from an earthquake hypocentre,  $v_p$  and  $v_s$  are the corresponding crustal velocities, and 0 is the origin time of the earthquake, then:

$$P-0 = \Delta/v_p \quad \text{and} \quad S-0 = \Delta/v_s \quad (1)$$

from which:

$$0 = P - (S-P)/(v_p/v_s - 1) \quad (2)$$

This expression is used to determine the origin time of an event for each station reporting both a P and S arrival, from which the mean origin time is found. This is used to compute travel times for all phases.

The value of  $v_p/v_s$  in (2) is found from a preliminary examination of many events. Rearranging (2) and combining with (1):

$$S-P = (v_p/v_s - 1)P + b \quad (3)$$

$$\text{where} \quad b = (1 - v_p/v_s)0 \quad (4)$$

showing that if S-P intervals for a given event are plotted against P arrival times, a value of  $v_p/v_s$  can be obtained from the slope of the resulting straight line. Repeating over many events enables a mean value to be computed, which is then used in (2).

If stations i and j have rectangular coordinates  $(x_i, y_i, z_i)$  and  $(x_j, y_j, z_j)$  respectively relative to sea level at some point of latitude and longitude taken as the origin, and if  $t_i = P_i-0$  and  $t_j = P_j-0$  are the travel times of P1 to stations i and j respectively, then:

$$v_p^2 t_i^2 = (x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2$$

and

$$v_p^2 t_j^2 = (x_j - x)^2 + (y_j - y)^2 + (z_j - z)^2$$

where  $(x, y, z)$  are the rectangular coordinates of the hypocentre.

Subtracting and simplifying:

$$(t_i^2 - t_j^2)v_p^2 = (x_i^2 - x_j^2) + (y_i^2 - y_j^2) + (z_i^2 - z_j^2) \\ - 2(x_i - x_j)x - 2(y_i - y_j)y - 2(z_i - z_j)z$$

The process of subtracting eliminates non-linear terms in the variables  $x$ ,  $y$ ,  $z$  and  $v_p^2$ . However, it leads to an ill-conditioned system of equations, since  $z_i \approx z_j$  and both are in any case much smaller than the corresponding  $x$  and  $y$  coordinates. The problem can be overcome to a good approximation by taking the stations to be the same height above sea level. This eliminates the variable  $z$  entirely, necessitating an independent depth determination, and produces the following system of equations:

$$a_{ij}x + b_{ij}y + c_{ij}v_p^2 + d_{ij} = 0$$

where:

$$a_{ij} = 2(x_i - x_j)$$

$$b_{ij} = 2(y_i - y_j)$$

$$c_{ij} = t_i^2 - t_j^2$$

and

$$d_{ij} = -(x_i^2 - x_j^2) - (y_i^2 - y_j^2)$$

By considering every combination of stations  $i$  and  $j$  recording the earthquake, an over-determined system of linear equations in  $x$ ,  $y$  and  $v_p^2$  is obtained, provided at least four stations are involved. This system is solved for the epicentral coordinates and crustal  $P$  wave velocity using conventional least squares theory.

Standard errors for  $x$ ,  $y$  and  $v_p^2$  can be found as for any least squares solution. However, the assumption of normality on which standard errors are based breaks down when the square root is taken to obtain  $v_p$ . Hence the standard error of  $v_p$  is only approximate. (An analytically correct procedure would be to determine say a 95% confidence interval for  $v_p^2$  and then transform the interval to  $v_p$ . However, this is unnecessarily cumbersome, and the practice of

approximating standard errors has long been used in earthquake location, whether knowingly or otherwise.)

The depth of focus is determined for each station separately by considering the right-angled triangle formed in a vertical plane by the focus, the epicentre and the station (assumed at the same height above sea level as the epicentre). In this triangle the surface distance is obtained from the known station and epicentral coordinates, and the slant distance is obtained from the P wave velocity and travel time. Hence the depth can be easily computed. From the separate depths determined for each station, the mean depth is found. With the hypocentre known, the distances along the direct wave paths to each station and the travel times of the S1 phase to each station enable a set of values for  $v_S$  to be obtained, from which the mean is found.

For the above method to be applied, an event must have been recorded by four or more stations. At least four P phases are required and at least one S phase. From the collective P and S velocities determined by the method, the means can be found and used as constants in the application of the same equations to determine hypocentres (only) for events recorded by three stations.

For the data of the first Flinders Ranges microearthquake survey, the mean value of  $v_P/v_S$  was computed over 37 events to be 1.689, with a standard error of the mean of 0.008. This ratio was used to locate 32 events satisfying the condition for a combined hypocentre and velocity determination. The mean velocities over 28 events (4 events well outside the network being neglected) were found to be 5.85 km/s for  $v_P$  and 3.47 km/s for  $v_S$ , with standard errors of the means of 0.03 and 0.02 km/s respectively. These velocities are lower than the currently-used crustal velocities for South Australia of

6.23 km/s and 3.58 km/s respectively (Table 1.2). Similar lower velocities were also found in the Adelaide Geosyncline for quarry blast data by Shackelford (1978), who has discussed their interpretation in detail. The mean velocities were used to locate the remaining 16 of the 53 located events.

The mean latitude and longitude standard errors over the 28 events mentioned above are  $0.006^{\circ}$  (600 m) and  $0.005^{\circ}$  (500 m) respectively, which are not surprisingly well below the equivalent values of  $0.024^{\circ}$  and  $0.040^{\circ}$  respectively for the state network (Table 3.5). The mean of the standard deviations in the depth parameter is 1.6 km, and this may be taken as an indication of the accuracy of the depth determination, although considerable variation exists from one event to another, as summarized by the associated standard deviation of 2.1 km.

The analysis of the data from the 25 days of recording during the first Flinders Ranges microearthquake survey occupied the subsequent four (man-) months, and provided not only a guide to the placement of the new permanent stations in the region but also a clear indication of the increased volume of data to be expected from an increase in the density of the state network in the area. Such data-processing considerations led directly to the development of ISAS, the location method discussed above forming the nucleus of the Microearthquake Subsystem.

#### 4.3 The ISAS Microearthquake Subsystem

The commands of subsystem MICRO are shown in Table 4.2. The principal command, incorporating the location method of the previous section, is SOLVE. This is discussed in the next section. Other commands provide support for SOLVE: CREATE and DELETE enable a small

TABLE 4.2  
COMMANDS IN SUBSYSTEM MICRO

COMMAND	ACTION
HELP	Display commands and their actions.
CONS	Set operational constants for subsequent commands.
CREATE	Create a temporary network file.
DELETE	Delete temporary network file.
SOLVE	Locate and determine magnitude of a microearthquake.
SIZE	Display number of events in holding file.
EVENTS	Display event numbers in holding file and number of events.
RESET	Reset holding file.
MEAN	Determine mean velocities from holding file.
ARCHIVE	Transfer holding file to an archive disk.
NETWK	Transfer to Network Data Management Subsystem.
CASET	Transfer to Cassette Data Management Subsystem.
LOCAL	Transfer to Local Earthquake Subsystem.
STATS	Transfer to Earthquake Statistics Subsystem.
LOGOFF	Log-off from system.

temporary network file to be created and deleted respectively, containing only those stations involved in a microearthquake survey and only over the period of interest. The use of such a file reduces file search times in SOLVE considerably when successive earthquakes involve essentially the same station data. SIZE, EVENTS, RESET and ARCHIVE are responsible for the management of a microearthquake data file called the holding file, which has the capacity to store raw data and results of SOLVE for all events involved in a microearthquake survey, with random retrieval and update of data for reworking any event. SIZE displays the number of events currently in the holding file, as does EVENTS, which additionally displays the event reference number (by which an event is retrieved) for each earthquake in the file. RESET, on receipt of an appropriate password, deletes the holding file, making it available for a new microearthquake survey. This can also be accomplished by the ARCHIVE command, but in this case all events in the holding file are firstly transferred to an archive disk (which is the principal function of the command). The way in which these commands are used can be seen in Figures 4.4 and 4.5.

The data structure of the temporary network file is identical to that of the current and archive permanent network files, NETWKC and NETWKA, and the network files on an archive disk, NETWK1, NETWK2, etc. (Table 2.1). The temporary file is distinguished solely by its filename, NETWKT, and its lack of an attendant NAMES file. It cannot be displayed, archived, or otherwise accessed apart from within SOLVE for which it was designed.

The data structure of the holding file is identical to that of an event archive disk, and it can be thought of as an on-line extension of the ISAS event archives. An index file is present, with the same format as that of an archive disk index file (Table 2.4). This



21/04/1981 22:27 [MICRO] COMMAND: RESET

PASSWORD: \_RTP

CONTENTS OF FILE WILL BE LOST. PROCEED (P) OR ABORT (A)? P  
HOLDING FILE RESET.

21/04/1981 22:28 [MICRO] COMMAND: DELETE

TEMPORARY NETWORK FILE DELETED.

21/04/1981 22:28 [MICRO] COMMAND: CREATE

NUMBER OF STATIONS (UP TO 20): 7

STATION CODES, ONE AT A TIME AS REQUESTED:

1. end 2. lsp 3. mck 4. nbk 5. sck 6. coo 7. cul

COMMENCEMENT DATE (DD/MM/YYYY) AND TIME (HH:MM): 16/04/1977,08:30

CURRENT (C) OR ARCHIVE (A) NETWORK FILE? A

DO YOU WANT TO SPECIFY A CONCLUSION DATE (Y OR N)? Y

CONCLUSION DATE (DD/MM/YYYY) AND TIME (HH:MM): 08/05/1977,23:30

TEMPORARY NETWORK FILE CREATED.

FIGURE 4.4

THE USE OF COMMAND RESET TO RESET THE HOLDING FILE, AND OF COMMANDS CREATE AND DELETE TO CREATE AND DELETE A TEMPORARY NETWORK FILE, RESPECTIVELY.

21/04/1981 22:54 [MICROJ] COMMAND: SIZE

HOLDING FILE CONTAINS 53 EVENTS.

21/04/1981 22:55 [MICROJ] COMMAND: EVENTS

EVENTS IN HOLDING FILE:

3/M2	4/M2	6/M2	7/M2	8/M2	9/M2	12/M2	14/M2	15/M2	16/M2	18/M2	22/M2	23/M2
24/M2	25/M2	26/M2	5/M2	28/M2	29/M2	30/M2	32/M2	33/M2	34/M2	35/M2	38/M2	39/M2
42/M2	43/M2	44/M2	45/M2	46/M2	47/M2	48/M2	51/M2	54/M2	55/M2	17/M2	41/M2	49/M2
20/M2	1/M2	2/M2	10/M2	19/M2	27/M2	36/M2	37/M2	52/M2	53/M2	50/M2	13/M2	11/M2
31/M2												

(53 EVENTS)

21/04/1981 22:56 [MICROJ] COMMAND: ARCHIVE

PASSWORD: -RTP

DO YOU WANT TO TRANSFER HOLDING FILE CONSTANTS (H) OR PRESENT CONSTANTS (P)? P

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

RESET HOLDING FILE (Y OR N)? Y

HOLDING FILE RESET.

FIGURE 4.5

THE USE OF COMMANDS SIZE AND EVENTS TO DETERMINE THE STATUS OF THE HOLDING FILE, AND OF COMMAND ARCHIVE TO TRANSFER THE HOLDING FILE TO AN ARCHIVE DISK.

enables any event to be found randomly, given its reference number, and also indicates where the next event is to be placed in the file. SIZE and EVENTS determine the number of events in the holding file by reading the index file and counting the entries. EVENTS additionally displays each event reference number in the file as it is read.

The holding file itself consists of 48-byte random records, compatible with those from subsystem LOCAL shown in Table 3.4. In fact, on an event archive disk, events archived from subsystem MICRO may be freely mixed with those from subsystem LOCAL; the first record is identical in either case and contains the subsystem identification (Table 3.4) which enables the remaining records (which do differ) to be correctly read. The data structure for MICRO events on an archive disk, and for all events in the holding file, is shown in Table 4.3. Each event consists of three records (as does each LOCAL event) with a single additional record per station (compared with two per station for LOCAL events).

SOLVE uses several constants in the determination of an earthquake hypocentre. For 3-station events, the crustal P and S wave velocities are required, while for all events the crustal P to S wave velocity ratio is needed. Default values for these quantities are read from the model file (Table 3.2), the ratio being computed from the separate velocities. Since the model coefficients in the file can be changed in subsystem LOCAL by means of the MODEL command (Chapter 3), it follows that a permanent model change also alters the default values in subsystem MICRO. In addition to the above model parameters, SOLVE requires a latitude and longitude origin, which should be near the centre of the localized network, and latitude and longitude degrees to kilometres conversion factors applicable near the origin. Default values for these parameters, corresponding to the

TABLE 4.3

ISAS EVENT ARCHIVE FILE STRUCTURE (Subsystem MICRO)  
AND HOLDING FILE STRUCTURE

INFORMATION	DATA TYPE	INTERNAL FILE FORMAT
See Table 3.4 for Record zero, and for Record #1 per event		
RECORD #2 PER EVENT - MICRO		
Std dev. origin time Std err. geog. latitude Std err. longitude Std err. depth No. stns MD, depth Std dev. MD Crustal P velocity (vp) Std. err. vp Crustal S velocity (vs) Std dev. vs No. stns vs, origin time vp/vs constant	4-byte floating point numeric " " " " " " " " " "	    $(\text{no. MD}) + (\text{no. depth})/100$    $(\text{no. vs}) +$ $(\text{no. origin time})/100$
RECORD #3 PER EVENT - MICRO		
vp constant vs constant Lat. origin constant Long. origin constant Lat. to km conv. constant Long. to km conv. constant	4-byte floating point numeric " " " "	
Initials of person archiving, locations felt or quarry blast	ASCII string	3 characters, then 1-20 characters or "Q/B"

TABLE 4.3 (contd)

PER STATION - MICRO (ONE RECORD)		
Station code	ASCII string	3 characters
Duration	4-byte floating point numeric	
0 } Reserved for future use	"	
0 }	"	
First motion	ASCII string	1 character
P arrival time	4-byte floating point numeric	
S arrival time	"	
Epicentral distance (in km)	"	
Azimuth	"	
MD	"	
0 } Reserved for future use	"	
0 }	"	
Future expansion flag	ASCII string	1 character, presently "0"

Flinders Ranges region of South Australia, apply on entry to the subsystem. Command CONS, as shown in Figure 4.6, displays the default values of all of the above constants, as well as their present values. New values may be entered as required. The resulting values remain in force for all subsequent commands until the seismologist again changes them, exits from MICRO, or logs off. In the last two cases, the default values again apply on re-entry to MICRO. As can be seen in Table 4.3, the values of all constants used in the location of an event are stored in the holding file and on the archive disks with each event, in order to ensure reproducibility of results when reworking old events.

Command MEAN, as shown in Figure 4.7, determines the mean P and S wave velocities in the holding file from the individual values computed as part of the location of events recorded by four or more stations. The usefulness of the command can be shown by outlining the complete process of using MICRO to analyse data from a microearthquake

```
21/04/1981 22:21 [MICRO] COMMAND: CONS
```

```
IN THE FOLLOWING, ENTER 'D' TO CHANGE TO DEFAULT VALUE, 'P' TO RETAIN PRESENT VALUE, OR ENTER NEW VALUE.  
A 'C' MAY BE ENTERED FOR v(P1)/v(S1) TO CALCULATE FROM v(P1) AND v(S1).
```

CONSTANT	DEF. VALUE	PRES. VALUE	NEW VALUE
Lat. origin	-32.5	-32.5	P
Long. origin	138	138	P
Lat. to km	110.893	110.893	P
Long. to km	93.9763	93.9763	P
v(P1)	6.23	6.23	5.85
v(S1)	3.58	3.58	3.47
v(P1)/v(S1)	1.74022	1.74022	1.6986

FIGURE 4.6

THE USE OF COMMAND CONS TO CHANGE OPERATIONAL CONSTANTS IN SUBSYSTEM MICRO.

```
21/04/1981 20:55 [MICRO] COMMAND: MEAN
```

	v(P1)	v(S1)	
MEAN	5.19168	3.13645	<41 VALUES>
SD	4.4E-01	3.4E-01	
SE	6.8E-02	5.3E-02	

```
DO YOU WANT TO CHANGE PRESENT v(P1), v(S1) TO MEAN VALUES (Y OR N)? Y  
COMPLETED.
```

FIGURE 4.7

THE USE OF COMMAND MEAN TO DETERMINE THE MEAN P AND S WAVE VELOCITIES FROM DATA IN THE HOLDING FILE.

survey in a region of unknown crustal structure. Prior to invoking MICRO, a value of the P to S wave velocity ratio is found for each event, from the relationship between S-P time and P arrival time, as indicated in the last section (see equations (3) and (4)). The mean over many (or all) earthquakes in the survey is then entered using the CONS command, along with an appropriate latitude and longitude origin, and latitude and longitude degrees to kilometres conversion factors (e.g., from Richter, 1958). Individual P and S wave velocities are left at their default values. SOLVE is next used to locate all events recorded by four or more stations, the corresponding P and S wave velocities also being determined for each such event. All data and results are saved in the holding file. When all four-or-more-station events have been satisfactorily located, command MEAN is executed to determine the mean P and S wave velocities from the individual values in the holding file. (Any 3-station events in the file are ignored by MEAN.) The newly determined means are adopted as the new values of the corresponding constants, either using the CONS command or immediately from within MEAN (Figure 4.7). Using the mean velocities, the three-station events (which require velocities to be supplied) are located using SOLVE and saved in the holding file. The analysis is completed by executing the ARCHIVE command, to transfer all events off-line onto an archive disk and then reset the holding file.

A subtle factor in executing ARCHIVE is that the events in the holding file recorded by four or more stations still have the default rather than the mean velocities associated with them in the holding file. ARCHIVE therefore on request allows the current values of all constants to be archived with each earthquake rather than the holding file values (see Figure 4.5). The CONS command is used to ensure that the current values of all constants are the appropriate ones prior to executing ARCHIVE.

The above process locates all events able to be located in a microearthquake survey, without prior knowledge of the seismic velocities. The central command in the process, SOLVE, is discussed below.

#### 4.4 SOLVE

The location algorithm employed by this command is that presented previously: this section concentrates on other aspects of the command. Figure 4.8 shows SOLVE in use with one of the events in the first Flinders Ranges microearthquake survey. In addition to locating the earthquake, the command also computes the duration magnitude and provides for the entry of direction of first motion data, in the same manner as in the equivalent separate commands in subsystem LOCAL. Figure 4.8 also illustrates the flexibility of input to the command, with the data able to be derived from a combination of seismograms and event recorder cassettes, from the holding file or an archive disk, or from a temporary file from subsystem LOCAL. The last option provides for the transfer of events from LOCAL if an earthquake in the process of being analysed by that subsystem is seen to satisfy the assumptions of the location method employed by SOLVE and to be possibly better located by it. In the case of input from an archive disk, the current constants can be optionally replaced by those stored on the archive disk with the event (an implied CONS command).

Up to five solutions can be saved by SOLVE, in addition to the last, for adoption as the final solution at the end of the command, in the same manner as in PROV and REVISE in subsystem LOCAL. At the end of the command, results can be entered into the holding file, saved on an archive disk, or written to a LOCAL temporary file. In the last case, if the input data were from a temporary file, the results are



21/04/1981 23:17 [MICRO] COMMAND: SOLVE

DATA FROM CASSETTE (C), SEISMOGRAM (S), CASSETTE AND SEISMOGRAM (A), HOLDING FILE (H), ARCHIVE DISKETTE (D)  
OR [LOCAL] TEMPORARY FILE (T)? S

BASE DATE (DD/MM/YYYY) AND TIME (HH:MM): 16/04/1977,18:29

NUMBER OF STATIONS WITH SEISMOGRAM OBSERVATIONS: 4

ENTER DATA IN THE FOLLOWING TABLE, TERMINATING EACH NUMBER WITH THE 'RETURN' KEY AND ENTERING '-' FOR MISSING DATA.

NOTE: Enter missing first motions as N (not readable). Other codes are U,D (clear) and +,- (poor).

NO.	STN	P (s)	S (s)	DURN (s)	1st MOTN
1	end	5.8	7.7	50	N
2	lsp	12	-	-	N
3	mck	12.8	9.6	-	N
3	mck	12.8	19.6	-	N
4	coo	12.4	-	332	-

S TIME MUST BE GREATER THAN P TIME - IGNORED.

DO YOU WANT TO CHANGE ANY VALUES (Y OR N)? N

NETWORK DATA FROM PERMANENT (P) OR TEMPORARY (T) NETWORK FILE? I

CONSTANTS:  $v(P1)/v(S1) = 1.6986$   $v(P1) = 6.23$  km/s  $v(S1) = 3.58$  km/s  
Lat. origin = -32.5 Long. origin = 138 Lat. to km = 110.893 Long. to km = 93.9763

SOLUTION: Base date and time = 16/04/1977 18:29  
Geog latitude = -32.341 (SE=1.5E-07) Longitude = 138.006 (SE=4.4E-08)  
 $v(P1) = 5.93$  km/s (SE=4.4E-03)

STN	DIST	AZM	1st MOTN	OR TIME	P ARR.TIME	S ARR.TIME	v(S1)	DEPTH	DURN	MO
end	5.0	56	N	3.0	5.8	7.7	3.55	15.6	50.0	1.5
lsp	51.0	237	N		12.0			15.7		
mck	56.0	177	N	2.9	12.8	19.6	3.50	15.8		
coo	53.5	134	-		12.4			15.5	332.0	3.1
MEAN:				3.0			3.52	15.6		2.3
SD:				8.2E-02			3.2E-02	1.2E-01		1.1E+00

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? Y

DO YOU WANT TO SAVE THE LAST SOLUTION (Y OR N)? Y  
TO RESTORE, SPECIFY SAVED SOLUTION NUMBER 1.

IN THE FOLLOWING, P = P ARR.TIME, S = S ARR.TIME, D = DURN, F = 1st MOTN.  
TO REMOVE A VALUE, SPECIFY '-' FOR NEW VALUE (OR 'N' IF A 1st MOTN). TO END, SPECIFY '-' FOR STATION CODE.

STN: coo P,S,D OR F? D NEW VALUE: 32  
STN: coo P,S,D OR F? F NEW VALUE: N  
STN: -

CONSTANTS:  $v(P1)/v(S1) = 1.6886$      $v(P1) = 6.23 \text{ km/s}$      $v(S1) = 3.58 \text{ km/s}$   
 Lat. origin = -32.5    Long. origin = 138    Lat. to km = 110.893    Long. to km = 93.9763

SOLUTION: Base date and time = 16/04/1977 18:29  
 Geog latitude = -32.341 (SE=1.5E-07)    Longitude = 138.006 (SE=4.4E-08)  
 $v(P1) = 5.93 \text{ km/s}$  (SE=4.4E-03)

STN	DIST	AZM	1st MOTN	OR TIME	P ARR TIME	S ARR TIME	$v(S1)$	DEPTH	DURN	MD
end	5.0	56	N	3.0	5.8	7.7	3.55	15.6	50.0	1.5
l9f	51.0	237	N		12.0			15.7		
mck	56.0	177	N	2.9	12.8	19.6	3.50	15.8		
coo	53.5	134	N		12.4			15.5	32.0	1.2
MEAN:				3.0			3.52	15.6		1.3
SD:				8.2E-02			3.2E-02	1.2E-01		2.1E-01

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? N

RESULTS TO HOLDING FILE (H), ARCHIVE DISKETTE (D), [LOCAL] TEMPORARY FILE (T) OR NONE (N)? H  
 CURRENT SOLUTION (C) OR SAVED SOLUTION NUMBER: C

REFERENCE NUMBER OF EVENT (UP TO 7 CHARACTERS): 2/M1  
 WAS THE EVENT EITHER REPORTED FELT OR A QUARRY BLAST (Y OR N)? N  
 HOLDING FILE EMPTY. NEW FILE WILL BE COMMENCED.  
 TRANSFER COMPLETED.

FIGURE 4.8

THE USE OF COMMAND SOLVE IN LOCATING AND DETERMINING THE MAGNITUDE OF A MICROEARTHQUAKE IN THE FIRST FLINDERS RANGES SURVEY.

written to the existing file; otherwise a free file is sought, and if found the file structure (Table 3.3) is created for the event. In either case, the single P and S arrivals for each station are written into the temporary file as if they were entered by PROV in subsystem LOCAL, and the solution from SOLVE is written as if it were a provisional solution from PROV. This enables a microearthquake, in the process of being analysed by MICRO, to be transferred to LOCAL for input to PROV with temporary file specified, or for input directly to REVISE with provisional solution on temporary file specified. This ensures complete transferability of events between the two subsystems.

The SOLVE command logic is shown in Figure 4.9. The algorithm is switched into one of two modes by the number of phases present. If at least four P phases and at least one S phase are present, velocities and hypocentre are determined; if three P phases and at least one S phase are present,  $v_p$  is taken as a constant (at the currently-defined value) rather than a variable and the epicentral coordinates alone are found. The origin time and depth are determined as before, but no value is computed for  $v_s$ . If the number of P phases falls below three, or no S phase is present, no solution is possible.

The location method central to SOLVE was tested against synthetic data and known quarry blasts prior to use in a stand-alone program to process the data from the first Flinders Ranges microearthquake survey in 1977. SOLVE itself, and ISAS in general, did not come into being until the following year. Since then, solutions from SOLVE have also been checked against those from PROV and REVISE in subsystem LOCAL, and MICRO has been used in the analysis of data from two subsequent microearthquake surveys.

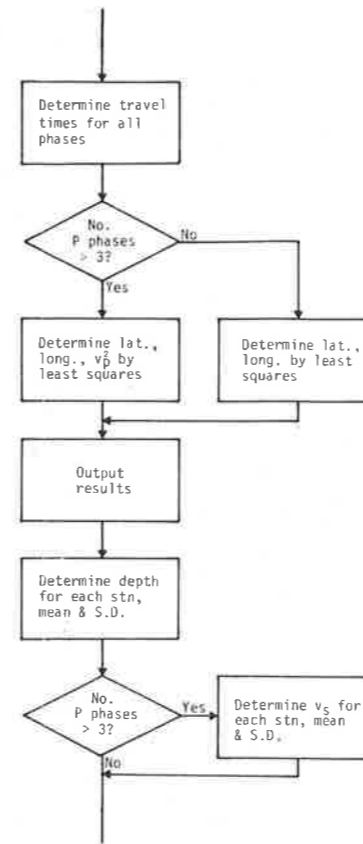
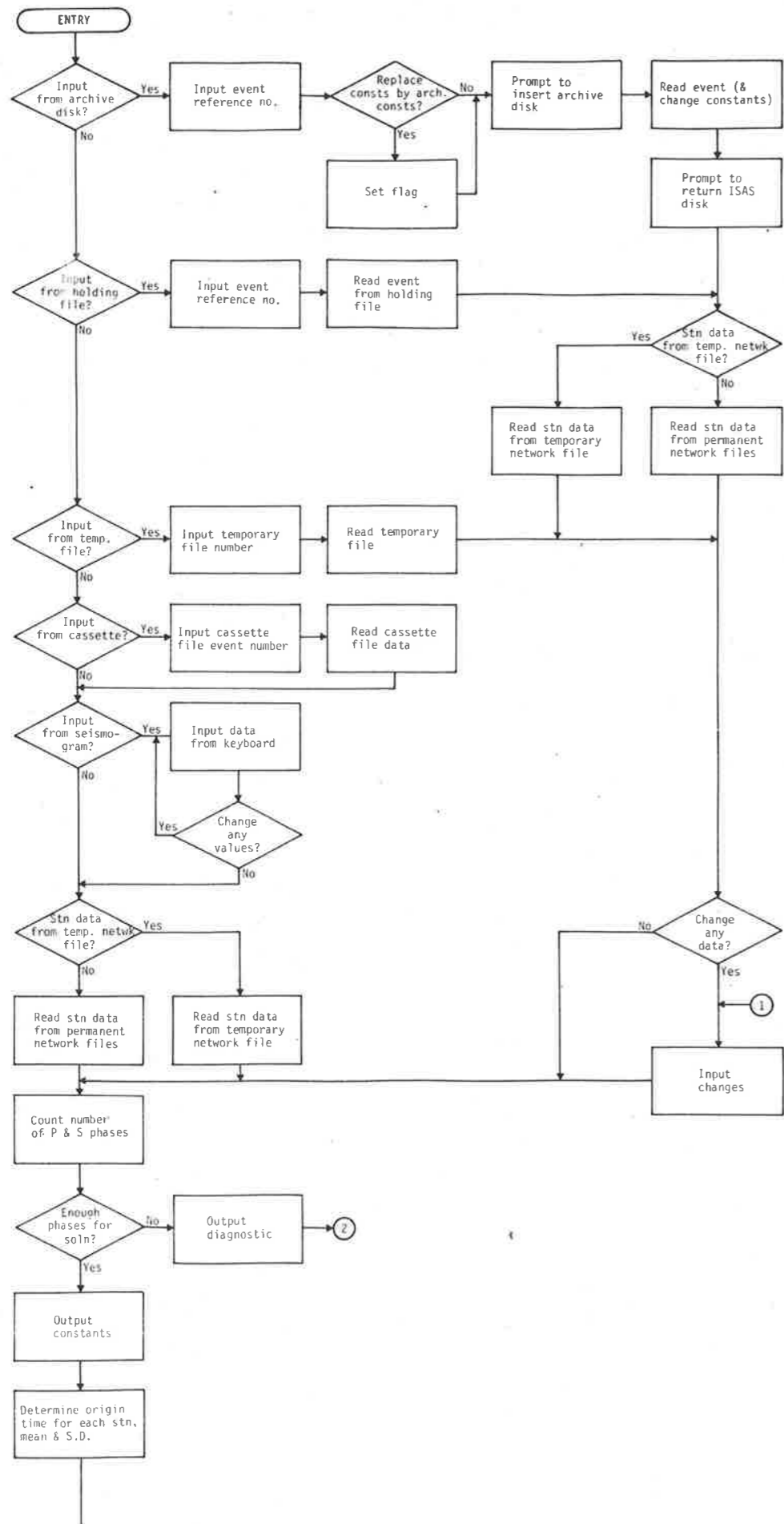
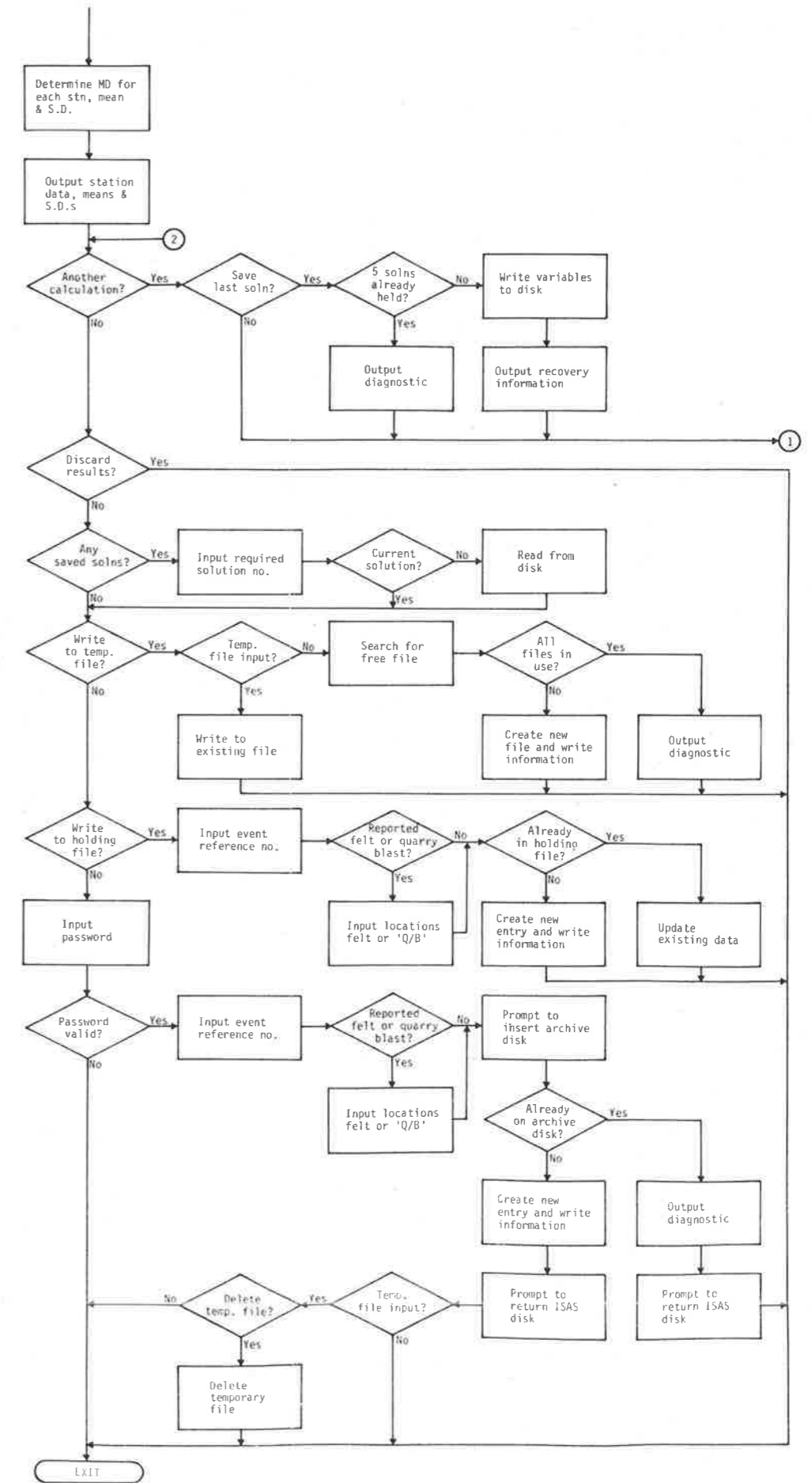


FIGURE 4.9  
SOLVE COMMAND LOGIC.



#### 4.5 Adelaide Hills and second Flinders Ranges Microearthquake Surveys

The region around the northern tip of Spencer Gulf was, and continues to be, studied in detail because of its industrial importance and its proximity to a seismically active area. The region around the South Australian capital, Adelaide, has begun to be investigated for similar reasons, being a city approaching one million inhabitants and the only Australian capital city to be classified as category 1 seismic risk, according to the SAA Earthquake Code, Australian Standard 2121-1979 (see also McCue, 1973, 1975, 1978). For 25 days in March-April 1978, a network of portable stations (Figure 4.10) was operated in the Adelaide Hills by the University seismology group in a similar preliminary investigation to that performed in the Flinders Ranges region. In this case, however, as was expected from many years of observation at ADE, the level of activity was significantly lower: of the 53 located events, only 27 were earthquakes, the remainder being attributed to blasts from one of several quarries in the region. Subsystem MICRO was used in the analysis of the data, but the involvement of the author in this survey was minimal and it would be inappropriate here to discuss the results further.

In October-November 1979 another portable network (Figure 4.11) was set up in the Flinders Ranges region and operated by the University seismology group for 30 days. This network was more restricted in extent than that of the 1977 survey, concentrating on the eastern site of the gulf where the majority of the activity is known to occur. One portable station, coo, was in the same location as for the earlier survey, while end and nbk became the sites of the new permanent stations EDO and NBK respectively. New permanent station RPA is not far from the previous portable station, lgp.

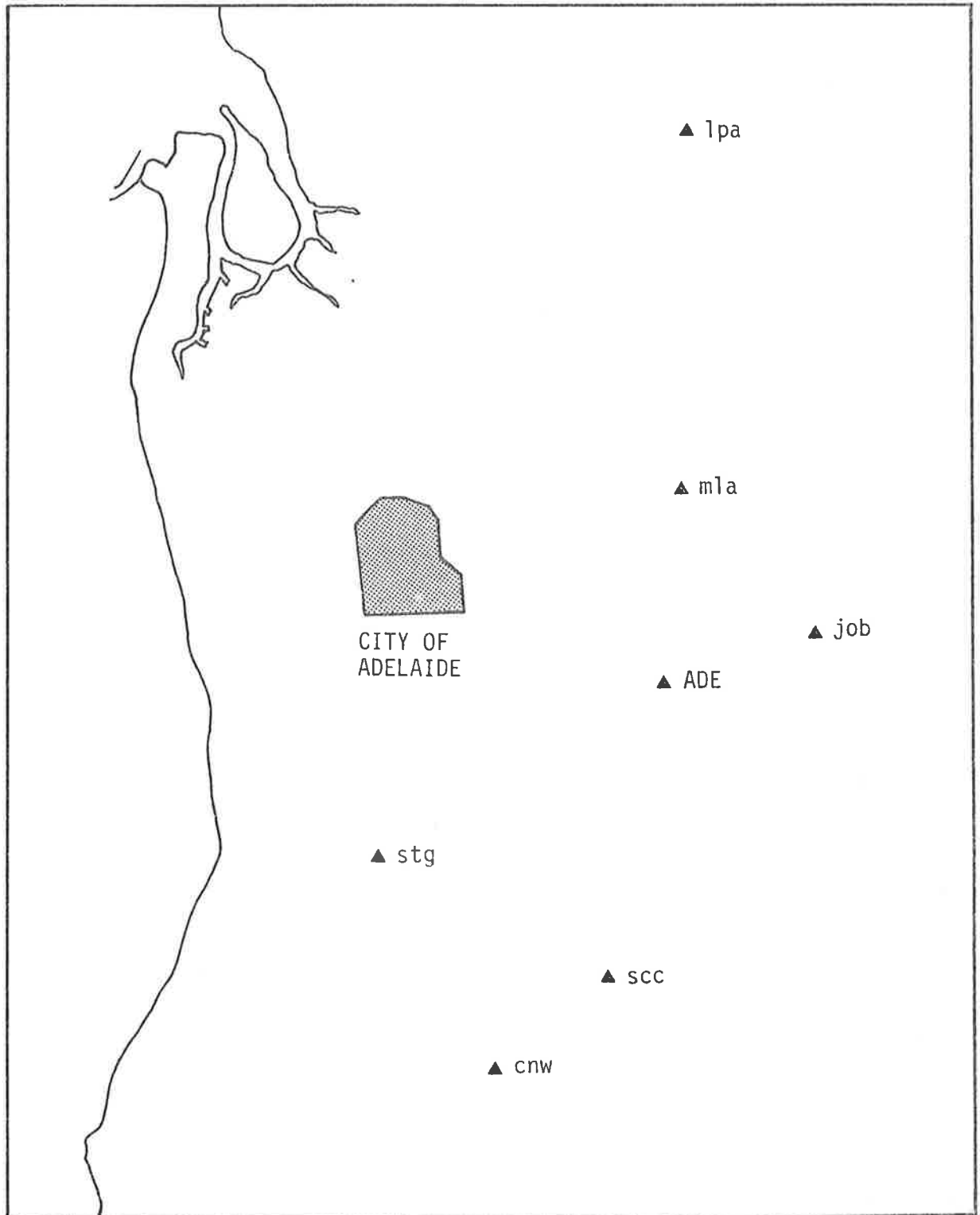


FIGURE 4.10

STATION LOCATIONS FOR THE ADELAIDE HILLS MICROEARTHQUAKE SURVEY, MARCH-APRIL 1978.

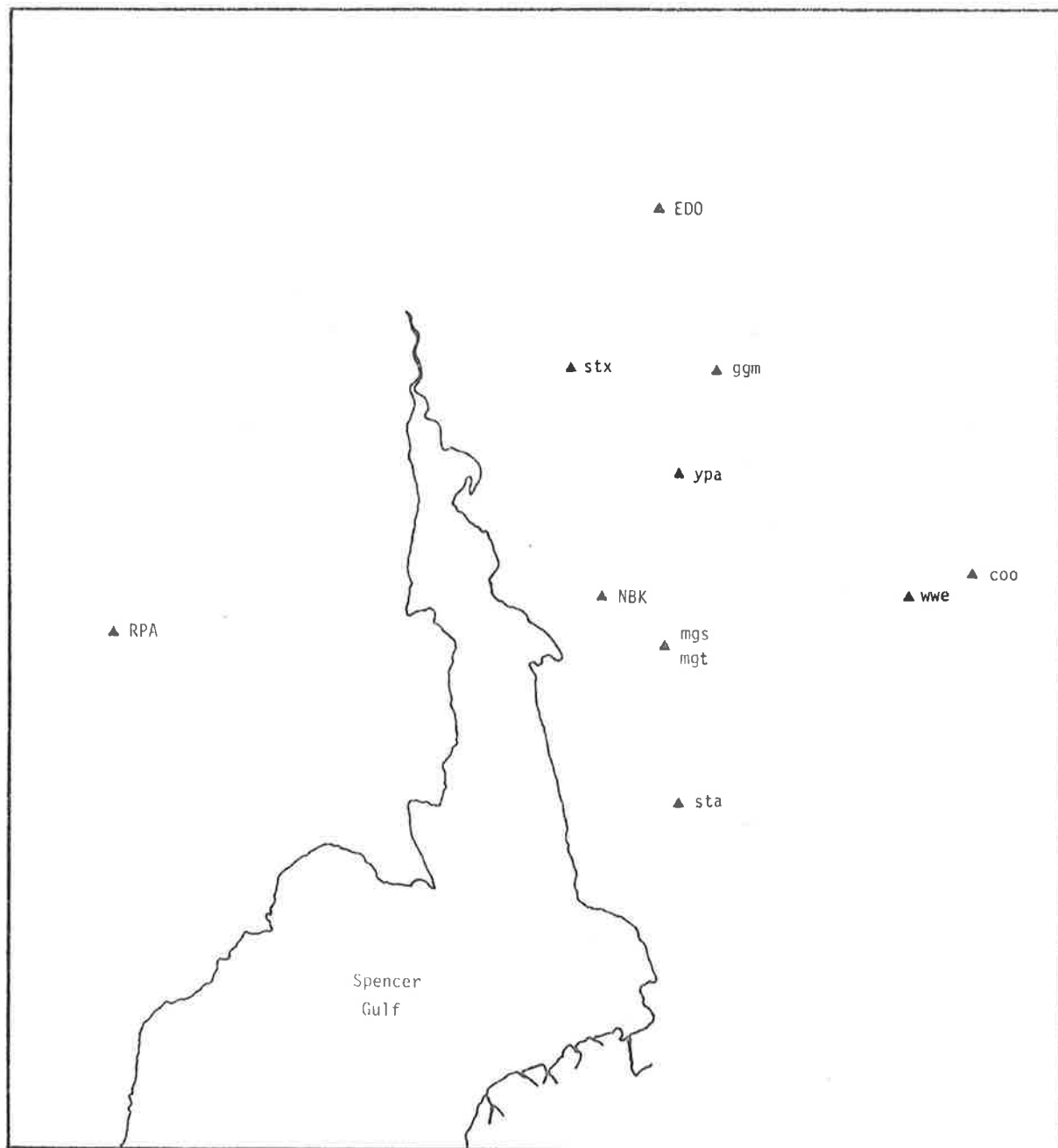


FIGURE 4.11

STATION LOCATIONS FOR THE SECOND FLINDERS RANGES MICROEARTHQUAKE SURVEY, OCTOBER-NOVEMBER 1979.

Results of this survey, which like the last involved the author only in a peripheral manner, were still being processed by subsystem MICRO at the time of writing.

Although the first (1977) Flinders Ranges microearthquake survey predated ISAS, nevertheless all data and results of that survey were subsequently formatted to conform to the ISAS archive file structure for events from subsystem MICRO (Table 4.3), and were copied onto an ISAS archive disk. Hence the events of the 1977 study can be accessed and displayed (along with the data from the new permanent stations in the region) by the ISAS Earthquake Statistics Subsystem, which forms the subject of the next chapter.



## CHAPTER 5: EARTHQUAKE STATISTICS

### 5.1 The ISAS Earthquake Statistics Subsystem

Very rarely do earthquakes occur in South Australia with sufficient magnitude to warrant study in more detail than that outlined in the previous two chapters. Mostly, interest centres on the patterns evident from examinations of large numbers of events. Given this, a subsystem in ISAS is devoted to the retrieval and display of information held in the ISAS archive files. The ISAS Earthquake Statistics Subsystem (STATS) contains commands, as shown in Table 5.1, to facilitate studies of seismicity and seismic risk, retrieve detailed data on individual earthquakes, determine statistical station parameters for return to the network files (Chapter 2), and generally provide data management of the ISAS archives.

Commands DISK, SIZE and EVENTS, in performing the actions shown in Table 5.1, access only the index file (Table 2.4) on a given archive disk, and DISK in particular reads only the file header. The usable file space on a floppy disk is calculated as being able to accommodate 6000 48-byte records in an archive event file (allowing space on the disk for the index file, operating system disk directory, and disk identification and bootstrap blocks). The record number to be used for the next event in the event file is always accessible as the index file header. DISK prints this value, and the difference between 6000 and the value. The archiving routines in subsystems LOCAL and MICRO monitor the index file header and reject further archiving requests when the value exceeds 6000, at which time a new archive disk must be commenced.

TABLE 5.1  
COMMANDS IN SUBSYSTEM STATS

COMMAND	ACTION
HELP	Display commands and their actions.
DISP	Display summary statistics for events satisfying a specified set of conditions on several archive disks.
NUMBER	Display number of events satisfying a specified set of conditions on several archive disks.
FILE	Display summary statistics for all events on a given archive disk.
DATA	Display all data for given events on an archive disk.
DISK	Display disk space used and remaining on a given archive disk.
SIZE	Display number of events on a given archive disk.
EVENTS	Display ref. numbers of all events on a given archive disk and number of events.
MNCOR	Determine MN station correction for a station using specified data.
MDCOEFS	Determine MD coefficients for a station using specified data.
NETWK	Transfer to Network Data Management Subsystem.
CASET	Transfer to Cassette Data Management Subsystem.
LOCAL	Transfer to Local Earthquake Subsystem.
MICRO	Transfer to Microearthquake Subsystem.
LOGOFF	Log-off from system.

SIZE and EVENTS read the entire index file. The former merely counts the entries and thereby determines the number of events on the disk, whereas the latter also displays the event reference numbers as they are read. Both commands display the number of events on the disk. The two commands operate on an archive index file in exactly the same manner as the correspondingly-named commands in MICRO operate on the holding file index. The manner of use of commands DISK, SIZE and EVENTS can be seen in Figure 5.1.

The actual number of events (as opposed to the number of records) able to be accommodated on an archive disk depends on the number of stations recording each event and on whether the event was archived from subsystem LOCAL or MICRO. Experience has shown an average expectation to be about 450 earthquakes per floppy disk.

All past events located since the initial South Australian tripartite network became operational in 1963 (Chapter 1) have been transferred to an ISAS archive disk by the University seismology group, using an auxiliary computer program written by the author to reformat the data so as to conform to the ISAS archive file structure for local earthquakes (Table 3.4). Historical earthquakes in South Australia prior to 1963 (see for example Sutton and White, 1968; McCue, 1975) have also been added to the file, as far as possible. Archived pre-ISAS events (with the exception of those used in the magnitude studies of Chapter 3) contain no station data and in consequence all 910 such earthquakes are accommodated on a single archive disk.

19/04/1981 11:13 [STATS] COMMAND: SIZE

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

ARCHIVE DISKETTE CONTAINS 323 EVENTS.

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

19/04/1981 11:13 [STATS] COMMAND: EVENTS

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

EVENTS ON ARCHIVE DISKETTE:

260/79	261/79	262/79	263/79	264/79	265/79	266/79	267/79	268/79	269/79	270/79	271/79	272/79
273/79	274/79	275/79	276/79	277/79	278/79	279/79	13H/79	48H/79	1/80	2/80	3/80	4/80
5/80	6/80	7/80	8/80	9/80	10/80	11/80	12/80	13/80	14/80	15/80	16/80	17/80
18/80	19/80	20/80	21/80	22/80	23/80	24/80	25/80	27/80	28/80	29/80	30/80	31/80
32/80	33/80	34/80	35/80	36/80	37/80	38/80	39/80	40/80	41/80	42/80	43/80	44/80
45/80	46/80	47/80	48/80	49/80	50/80	51/80	52/80	53/80	54/80	55/80	56/80	48H/80
57/80	58/80	59/80	60/80	61/80	62/80	63/80	64/80	65/80	66/80	67/80	68/80	69/80
70/80	71/80	72/80	73/80	74/80	75/80	76/80	77/80	78/80	79/80	80/80	81/80	82/80
83/80	84/80	85/80	86/80	87/80	88/80	89/80	90/80	91/80	92/80	93/80	94/80	95/80
96/80	97/80	98/80	99/80	100/80	101/80	102/80	103/80	104/80	105/80	106/80	107/80	108/80
109/80	110/80	112/80	113/80	114/80	115/80	116/80	117/80	118/80	119/80	120/80	121/80	122/80
123/80	124/80	125/80	126/80	127/80	128/80	129/80	130/80	131/80	132/80	133/80	134/80	135/80
136/80	137/80	138/80	139/80	140/80	141/80	142/80	143/80	144/80	145/80	146/80	147/80	148/80
149/80	150/80	151/80	152/80	153/80	154/80	155/80	156/80	157/80	158/80	159/80	160/80	161/80

267/80	268/80	269/80	270/80	271/80	272/80	273/80	274/80	275/80	276/80	277/80	278/80	279/80
280/80	281/80	282/80	283/80	284/80	285/80	286/80	287/80	288/80	289/80	290/80	291/80	292/80
293/80	294/80	295/80	296/80	297/80	298/80	299/80	300/80	301/80	302/80	303/80		

(323 EVENTS)

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

19/04/1981 11:15 [STATS] COMMAND: DISK

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

NUMBER OF 48-BYTE RECORDS USED = 4280

NUMBER REMAINING = 1720

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

FIGURE 5.1

THE USE OF COMMANDS SIZE, EVENTS AND DISK IN DETERMINING THE STATUS OF AN ARCHIVE DISK.

## 5.2 Seismicity

Commands DISP and NUMBER (and to a lesser extent DATA and FILE) in subsystem STATS aid in the accumulation of data for studies of seismicity and seismic risk. All of these commands access the main event file (Tables 3.4 and 4.3), being directed to the first record of each event in turn by the archive disk index file (Table 2.4). All commands except DATA examine only the first three records in the archive file for each event, ignoring the station data. DATA, on the other hand, reads all data for one or more events selected by reference number on an archive disk, displaying the information in the manner of the ARCHIVE command in subsystem LOCAL (Figure 3.1) or in a related manner for events archived from subsystem MICRO. Figure 5.2 shows the method of use of the command and its output. FILE reads the 3-record header in the event file for every event on a given archive disk, and displays the data in a summary table as shown in Figure 5.3.

DISP and NUMBER are more powerful commands which enable data to be accumulated over any number of event archive disks, and which permit events to be selected on the basis of any combination of the following:

1. Time interval (as determined by specified commencement and conclusion dates and times).
2. Epicentral region (as determined by specified latitude and longitude limits).
3. Depth range.
4. Magnitude range.
5. Particular subsystem only.
6. Felt events only.

In addition, events tagged as quarry blasts by LOCAL or MICRO can be ignored if required.

20/04/1981 11:15 [ESTATS] COMMAND: DATA

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

EVENT REF NO: 221/80 BASE DATE & TIME: 08/09/1980 10:35 SUBSYSTEM: LOCAL BY: RMD

PROVISIONAL Geos latitude = -32.75 Longitude = 138.33 Depth = 24 km MODEL: 1  
Orisin time = 47.4 s SE res = 4.1E-02 s

REVISED Geos latitude = -32.764 (SE=9.6E-03) Longitude = 138.329 (SE=1.3E-02) Depth = 25.9 km (SE=1.1E+00)  
Orisin time = 47.05 s (SE=1.5E-01) SE res = 3.7E-01 s No phases = 16

Mean MD = 1.9 (SD=4.4E-02) No stations = 4 Mean MH = 2.0 (SD=2.0E-01) No stations = 3

STN	DIST	AZM	(P)	(S)	DURN	MD	AMP	PER	MN	1st	P1	ERR	PR	ERR	Pn	ERR	S1	ERR	SR	ERR	Sn	ERR
EDO	56	332	57.0	64.1	69.0	1.9	23.5	0.20	1.9	+	57.0	0.2	59.4	0.3			64.1	0.2	68.6	0.3		
HTT	92	143	63.0	73.5	69.0	1.9	11.4	0.20	1.8	+	63.0	0.3					73.5	0.3			75.7	0.3
NBK	33	282	54.0	59.0	68.0	1.9				D	54.0	0.2	56.7	0.3			59.0	0.2				
PNA	85	350	61.4	71.3	108.0	1.9				+	61.4	0.2					71.3	0.3				
RPA	87	273	62.0	71.9			29.0	0.20	2.2	N	62.0	0.3			63.0	0.2	71.9	0.3			74.1	0.3

NOT REPORTED FELT.

ANOTHER EVENT FROM THIS ARCHIVE DISKETTE (Y OR N)? Y

EVENT REF NO: 227/80 BASE DATE & TIME: 17/09/1980 23:13 SUBSYSTEM: MICRO BY: RMD

CONSTANTS: v(P1)/v(S1) = 1.74022 v(P1) = 6.23 km/s v(S1) = 3.58 km/s  
Lat. orisin = -32.5 Long. orisin = 138 Lat. to km = 110.893 Long. to km = 93.9763

Geos latitude = -32.773 (SE=3.7E-06) Longitude = 138.250 (SE=4.7E-06)  
Mean depth = 5.6 km (SD=8.5E-02) No stations = 4 Mean orisin time = 21.8 s (SD=1.8E-01) No stations = 2

v(P1) = 6.24 km/s (SE=1.7E-02) Mean v(S1) = 3.57 km/s (SD=4.3E-02) No stations = 2

Mean MD = 1.6 (SD=9.2E-02) No stations = 4

STN	DIST	AZM	P ARR TIME	S ARR.TIME	DURN	MD	1st
EDO	53.5	339	30.4		57.0	1.7	D
NBK	26.4	288	26.1	29.4	49.0	1.6	+
PNA	85.4	355	35.5		65.0	1.5	U
RPA	79.8	274	34.6	44.0	45.0	1.5	+

NOT REPORTED FELT.

ANOTHER EVENT FROM THIS ARCHIVE DISKETTE (Y OR N)? N

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

FIGURE 5.2

THE USE OF COMMAND DATA TO DISPLAY ALL DATA FOR GIVEN EVENTS ON A GIVEN ARCHIVE DISK.

19/04/1981 11:54 [STATS] COMMAND: FILE

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

REF.NO.	BASE DATE & TIME	SUBS.	BY	MODEL NO.	STNS	GEOG. LAT SE	LONG SE	DEPTH SE/SD NO	DR. TIME SE/SD NO	MEAN MD SD NO	MEAN MN SD NO	SE RES NO. PH.	v(P1) SE	v(S1) SD NO
1/78	01/01/1978 18:36	LOCAL	RTP	1	3	-32.209 4.8E-02	136.245 3.4E-02	21.4 8.9E-01	3.2 3.2E-01	2.0 3.7E-02 2	2.0 2.9E-03 2	1.7E-01 5		
2/78	09/01/1978 23:04	MICRO	RTP		3	-32.112 4.1E-07	137.127 5.9E-07	0.0 0.0E+00 3	23.2 6.5E-01 2	1.4 0.0E+00 1				
3/78	10/01/1978 04:34	LOCAL	RTP	1	3	-30.482 7.6E-02	138.727 2.6E-01	0.0 1.3E+01	12.2 1.3E+00	1.9 1.1E-01 2	1.8 7.0E-02 2	8.1E-01 6		
4/78	13/01/1978 00:43	LOCAL	RTP	1	3	-30.473 1.4E-01	138.960 3.4E-01	0.0 1.2E+01	-22.1 1.6E+00	1.8 0.0E+00 1	1.8 0.0E+00 1	7.6E-01 8		
5/78	17/01/1978 01:08	LOCAL	DJS	1	4	-32.679 4.9E-02	138.470 8.4E-02	0.0 1.9E+03	36.9 1.6E+00	1.6 1.7E-01 3	1.5 2.3E-01 3	1.9E+00 7		
6/78	17/01/1978 01:45	LOCAL	DJS	1	6	-32.025 6.3E-02	138.960 7.0E-02	0.0 9.2E+00	10.2 1.3E+00	2.6 5.4E-02 5	2.6 1.7E-01 5	1.4E+00 12		
7/78	24/01/1978 05:38	LOCAL	DJS	1	4	-32.025 4.5E-03	138.707 5.5E-03	6.1 5.0E-01	33.4 8.6E-02	2.0 7.7E-02 4	1.9 9.2E-02 4	7.6E-02 6		
8/78	29/01/1978 20:34	MICRO	RMD		4	-33.065 4.7E-07	138.226 4.2E-07	24.1 3.0E-01 4	15.7 7.4E-01 4	1.7 1.4E-01 4			6.26 8.3E-03	3.60 7.7E-02 4

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

FIGURE 5.3

THE USE OF COMMAND FILE TO DISPLAY SUMMARY DATA FOR ALL EVENTS ON A GIVEN ARCHIVE DISK.

NUMBER merely displays the number of events satisfying the prescribed conditions. Figure 5.4 demonstrates the use of this command to determine the number of earthquakes of magnitude 2.0 or greater occurring in the lesser South Australian seismic region of eastern Eyre Peninsula (see Figures 1.1 and 5.5) since the beginning of 1970. (In determining whether or not an event is within a specified magnitude range, the mean of MD and MN for the event is used if both are present, otherwise one or the other is used unless neither is present, in which case the event is rejected.) The result obtained in Figure 5.4 is referred to later in this section.

DISP displays some information for each event selected. It can be instructed to produce a tabular listing of the summary data for each event, in exactly the same format as that used with the FILE command, or it can produce an epicentral plot, either on the television monitor or the graph plotter, or finally it can produce both a table and a plot. In the case of the epicentral plot, symbols coded to the magnitude of each event are used, as described in the ISAS User's Manual (Parham, 1980a). A simple rectangular projection is used, with default latitude and longitude degrees to kilometres conversion factors the same as those used in subsystem MICRO, but able to be changed on request. The plot is automatically scaled, based on the latitude and longitude limits requested. If limits are not specified, internal limits, corresponding to the whole of South Australia, are applied. An outline of the coast of South Australia (including Kangaroo Island) may be added to the plot on request. This is derived from a data file obtained via the University Geography Department from the Division of National Mapping of the Australian Government Department of National Resources. The file originally contained the entire coastline of Australia, including off-shore



19/04/1981 11:58 [STATS] COMMAND: NUMBER

DO YOU WANT KEY TO DATA CATEGORIES PRINTED (Y OR N)? Y

T = time interval            D = depth range            F = felt events only  
E = epicentral region       M = magnitude range       S = single subsystem only  
                                 Q = ignore quarry blasts

CATEGORY CODES (NOT separated by commas; eg, TEM): METQ

MINIMUM AND MAXIMUM MAGNITUDES: 2.9

MINIMUM AND MAXIMUM LATITUDES: -35. -32.5

MINIMUM AND MAXIMUM LONGITUDES: 135. 137.5

LOWER LIMIT DATE (DD/MM/YYYY) AND TIME (HH:MM): 01/01/1970.00:00

UPPER LIMIT DATE (DD/MM/YYYY) AND TIME (HH:MM): 31/12/1980.23:59

NUMBER OF ARCHIVE DISKETTES: 3

(Interchange archive diskettes when terminal buzzer sounds twice, then press 'return'.)

\*\*\* INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' \*\*\*

NUMBER OF EVENTS = 60

\*\*\* RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' \*\*\*

FIGURE 5.4

THE USE OF COMMAND NUMBER TO DETERMINE THE NUMBER OF EVENTS SATISFYING  
PRESCRIBED CONDITIONS.

islands, digitized to half-kilometre resolution. To economize on disk space and plotting time, this was reduced by the author to South Australia only, all islands except Kangaroo Island were removed, and the resolution halved. Nevertheless, some 3257 coordinate pairs must be read and processed each time a coastline plot is requested. (The COAST file format consists of pairs of 32-bit floating point numeric coordinates, using the conventions that southern latitudes are negative and longitudes are offset by  $-100^{\circ}$ . The pair 0,0 indicates the start of coastline coordinates and 0,2 the start of island coordinates. 0,1 indicated the start of a state boundary on the original file.)

Figure 5.5 shows the command DISP used to obtain an epicentral plot for the entire state of South Australia, containing every earthquake on file from the earliest historic (in 1898) to the last event in 1980 (but excluding microearthquake survey data). The corresponding plot, including coastal outline, is shown in Figure 5.6. The plot reiterates the well established pattern of seismicity in South Australia, with the major part of the seismic activity corresponding to the Adelaide Geosyncline from Leigh Creek in the north to Kangaroo Island in the south, and with greatest concentration around Hawker in the Flinders Ranges (see also Figure 1.1). Eyre Peninsula, particularly the eastern portion, and the south-east of the state are additional regions of lower seismic activity.

South Australian seismicity has been discussed in many papers and publications (e.g., Sutton and White, 1968; Stewart, Slade and Sutton, 1973; McCue, 1975). In particular, the parameters  $a$  and  $b$  in the relation:

$$\log N = a - b ML \quad (1)$$

(where  $\log N$  is the base-10 logarithm of the annual number of

```
19/04/1981 12:13 [STATS] COMMAND: DISP  
DO YOU WANT KEY TO DATA CATEGORIES PRINTED (Y OR N)? N  
CATEGORY CODES (NOT separated by commas; eg, TEM): 0  
TABULAR (T) OR GRAPHICS (G) DISPLAY, OR BOTH (B)? G  
SCREEN (S) OR PLOTTER (P) GRAPHICS? P  
DEFAULT RECTANGULAR PROJECTION CONSTANTS (REL TO -32.5, 138): 110.893 (lat to km), 93.9763 (long to km)  
DO YOU WANT TO CHANGE THESE VALUES (Y OR N)? N  
DO YOU WANT ERROR BARS ON EPICENTRES (Y OR N)? N  
NUMBER OF ARCHIVE DISKETTES: 3  
(Interchange archive diskettes when terminal buzzer sounds twice, then press 'return'.)  
*** INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' ***  
+++ INITIALIZE PLOTTER, THEN PRESS 'RETURN' +++  
*** RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' ***  
DO YOU WANT TO ADD COASTAL OUTLINE TO DISPLAY (Y OR N)? Y
```

FIGURE 5.5

THE USE OF COMMAND DISP TO PRODUCE THE EPICENTRAL PLOT OF FIGURE 5.6.

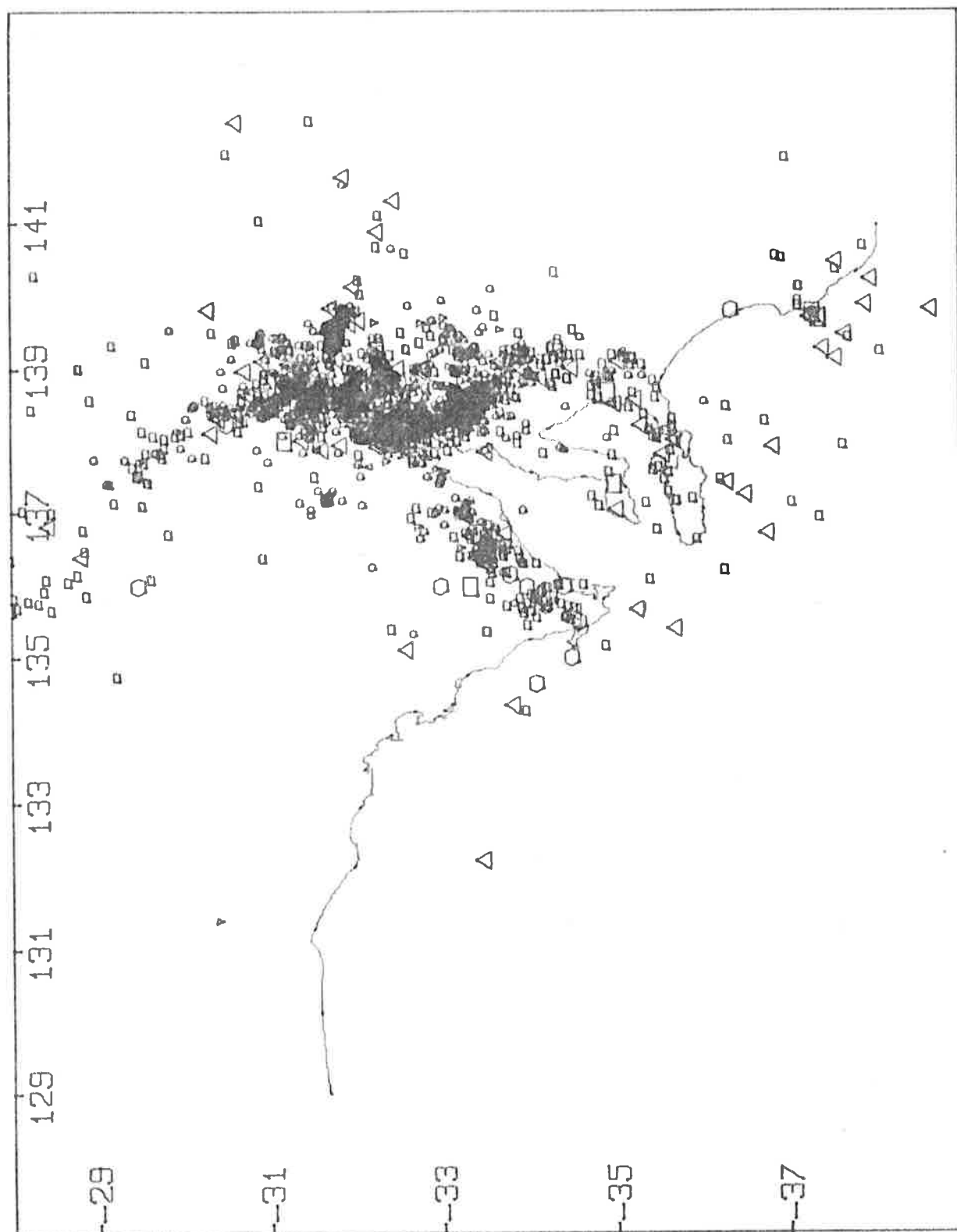


FIGURE 5.6

EPICENTRES FOR ALL SOUTH AUSTRALIAN EARTHQUAKES IN THE ISAS ARCHIVES FROM 1898 TO 1980 (MICROEARTHQUAKE SURVEY DATA EXCLUDED).

earthquakes with local Richter magnitude greater than or equal to ML (Gutenberg and Richter, 1944, 1954)) have been determined by the above South Australian authors. Sutton and White (1968) used the data from about 80 earthquakes of  $ML > 2.4$  occurring between 1963 and 1968 to obtain the relation:

$$\log N = 2.3(\pm 0.3) - 0.56(\pm 0.05) ML$$

for the whole of South Australia. Quoting the statement by Sanford and Singh (1968) that the number of earthquakes involved in such analyses needs to be at least 150 for statistical reliability, Stewart, Slade and Sutton (1973) used the 215 earthquakes of  $ML \geq 1.9$  occurring between 1967 and 1971 to revise the above formula in favour of the following:

$$\log N = 3.50(\pm 0.29) - 0.89(\pm 0.06) ML$$

again applying to the whole state. McCue (1975) has since determined separate relations for the Adelaide Geosyncline; e.g.,

$$\log N = 2.96(\pm 0.04) - 0.70(\pm 0.01) ML \quad (2)$$

for earthquakes of  $ML \geq 2.1$  occurring between 1963 and 1973; and has also suggested a tentative relation for Eyre Peninsula over the same time interval; viz,

$$\log N = 2.06 - 0.73 ML$$

The NUMBER command in ISAS can be used to compile the data for the determination of earthquake recurrence relations such as the above. In connection with this, the result embodied in Figure 5.4 demonstrates that there are still statistically too few earthquakes in the Eyre Peninsula region for a reliable recurrence relation to be determined. Such is not the case for the Adelaide Geosyncline over the interval 1978 to 1980 (inclusive), however, and the NUMBER command was used to determine (following Stewart, 1972a) the number of earthquakes in magnitude intervals of 0.3 commencing at  $MN=2.0$ , in

order to obtain a recent recurrence relation for this region for comparison with McCue (1975). For the purpose of the command, the Adelaide Geosyncline was taken to be the region between  $-36^{\circ}$  and  $-30^{\circ}$  latitude and  $137.5^{\circ}$  and  $140^{\circ}$  longitude. Magnitudes were converted to ML using the relation of Stewart (1972a) quoted in Chapter 3. The data appear graphically in Figure 5.7, along with those of McCue (1975) corresponding to equation (2) above. The 1978-1980 recurrence relation derived from the above data by standard linear regression techniques is:

$$\log N = 3.89(\pm 0.16) - 1.08(\pm 0.05) ML$$

Given that the coefficient  $b$  in equation (1) represents the ratio of small to large earthquakes (while the coefficient  $a$  measures the overall level of seismicity for regions of comparable  $b$ ), the relation for 1978-1980 shows that the balance of activity in the Adelaide Geosyncline has shifted in favour of a greater relative number of smaller earthquakes compared with the 1963-1973 data. In fact, in the recent data, there were no events above  $MN=3.8$  and only one above  $MN=3.5$ . Significant time (as well as regional) variations in  $b$  have been observed in other countries and there is some evidence for  $b$  variations as precursors to large earthquakes (e.g., Fiedler, 1974; Robinson, 1979; Smith, 1981). With the convenience now offered by ISAS, time variations in  $b$  in the Adelaide Geosyncline can easily be monitored in future.

A second epicentre plot from command DISP is shown in Figure 5.8, corresponding to that portion of the Adelaide Geosyncline adjacent to the northern tip of Spencer Gulf (Figures 4.1 and 4.11) and showing the distribution of epicentres from the first Flinders Ranges microearthquake survey in 1977 combined with epicentres located in the region since the new stations RPA, EDO and NBK opened in late

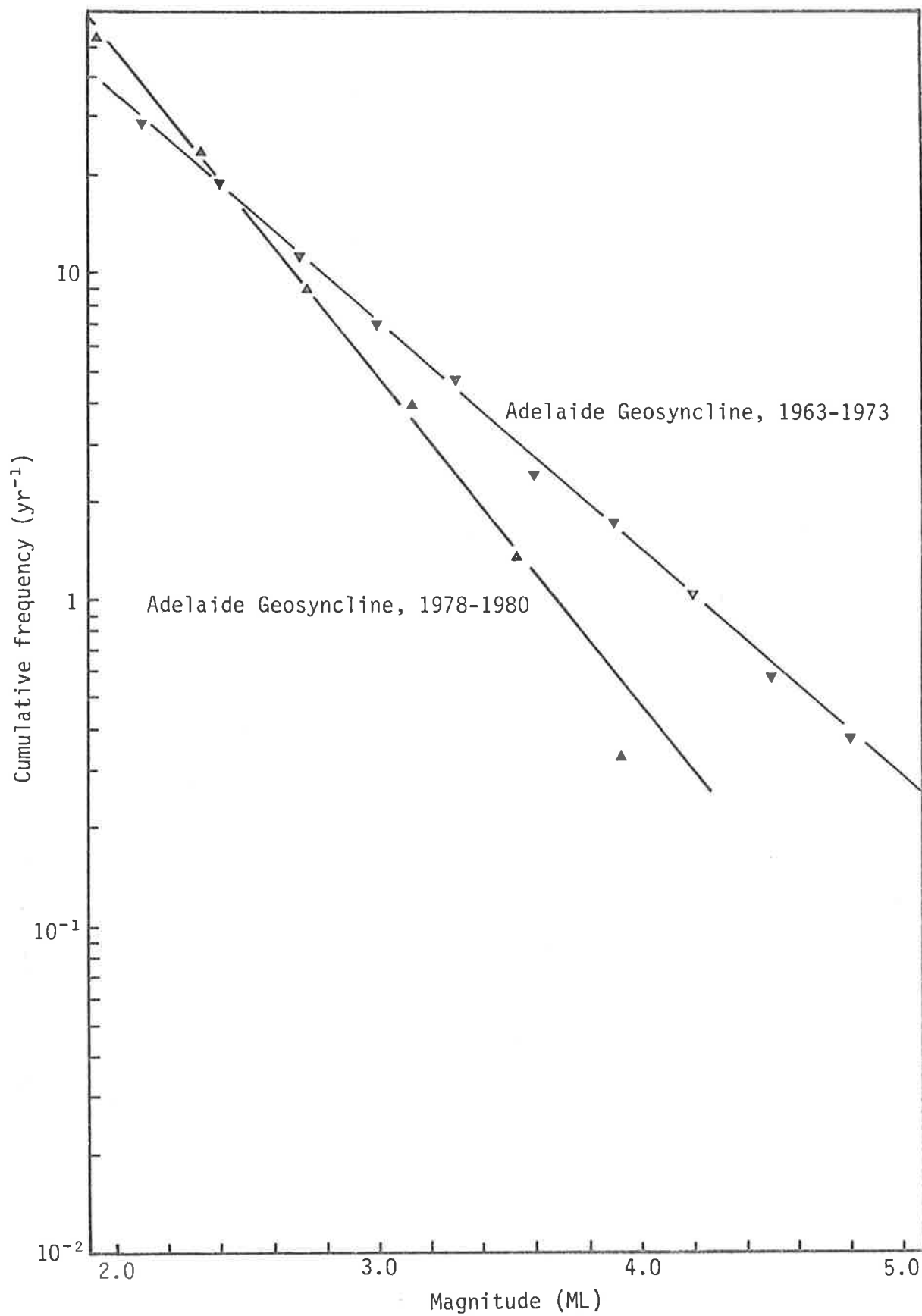


FIGURE 5.7

THE ANNUAL CUMULATIVE NUMBER OF EVENTS OF MAGNITUDE  $\geq$  ML VERSUS ML FOR THE ADELAIDE GEOSYNCLINE FOR 1963-1973 (McCUE) AND 1978-1980.

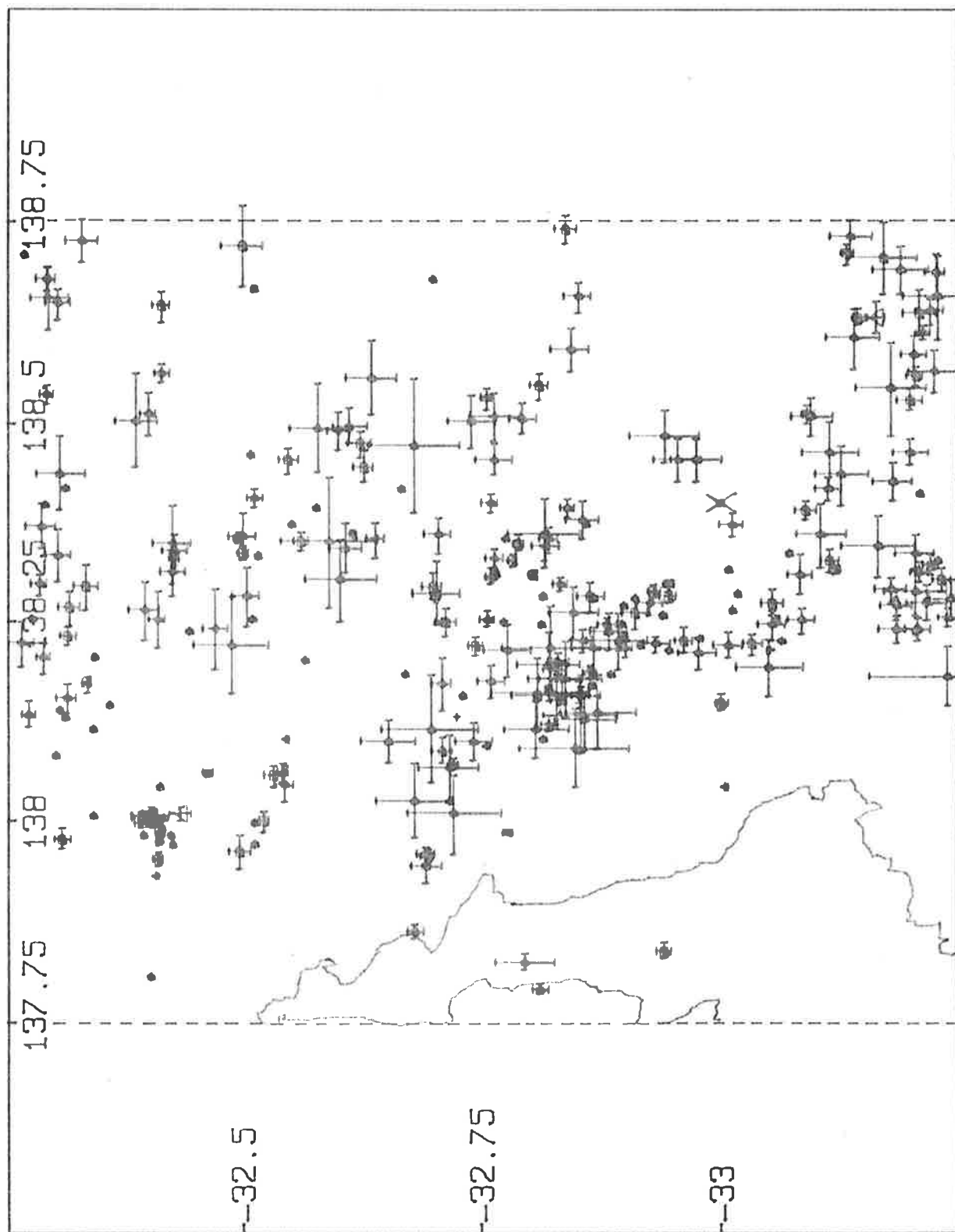


FIGURE 5.8

EPICENTRES IN THE ADELAIDE GEOSYNCLINE ADJACENT TO THE NORTHERN TIP OF SPENCER GULF FOR THE FIRST FLINDERS RANGES MICROEARTHQUAKE SURVEY AND SINCE THE OPENING OF RPA, EDO AND NBK IN THE REGION. (See text for explanation of error bars.)



1977 (RPA, EDO) and 1979 (NBK). The limits specified for Figure 5.8 were  $-33.25^{\circ}$  to  $-32.25^{\circ}$  latitude and  $137.75^{\circ}$  to  $138.75^{\circ}$  longitude. The plot also invokes the option (Figure 5.5) of plotting epicentres with associated error bars, representing one standard error in latitude and longitude on either side of the epicentre symbol. (The diagonals corresponding to the event at latitude  $-33^{\circ}$  indicate unknown standard errors.)

The epicentral distribution of Figure 5.8 can be correlated with geographic and geological features of the area. The relatively aseismic strip parallel with and adjacent to the gulf corresponds to the flat coastal plains, which end abruptly at the foothills of the Flinders Ranges in the east, delineated sharply by the concentration of epicentres in Figure 5.8. The most active part of the Flinders Ranges in this region at present is seen to be that between latitudes  $-32.75^{\circ}$  and  $-33^{\circ}$ , corresponding to the area around the town of Melrose (Figure 4.1) and Mt. Remarkable National Park to the north and west. The isolated group of earthquakes above the gulf at about longitude  $138^{\circ}$  corresponds to the felt (MD=3.4) event and its aftershocks referred to in the last chapter. These events occurred in the vicinity of Devil's Peak in the Pichi Richi Pass (Figure 4.1), where Mines Department 1:250 000 geological maps show the presence of an extensive system of faults. Apart from these events and a small number of other isolated earthquakes, the Flinders Ranges in this region are curiously quiet at present. Immediately to the east of the above event and its aftershocks lies the Willochra Plain, which is another relatively aseismic area. The concentrated region of seismic activity around Melrose appears at present in its northern extent to be diverted to the east of the Willochra Plain. Detailed data for the region are still being gathered by the new permanent stations in the

area, and the results of the second study with portable instruments are yet to be added. After another year or two of recording, a comprehensive analysis of the accumulated data for this area can be carried out, with the view to locating and mapping active faults and determining the detailed seismic risk zones in the area.

### 5.3 Station Statistics

The two remaining instances in ISAS in which data are required from many archived events, are for the determination of MN station corrections and MD coefficients. Both were mentioned in Chapter 3: in the first case, (MN) magnitudes for a given station are compared with mean (MN) magnitudes over many events and the mean residual is determined; in the second case, logarithms of the durations for a given station and corresponding epicentral distances are compared with the mean (MN) magnitude over many events and a stepwise multiple linear regression (Ralston and Wilf (ed.), 1960) is performed to determine the coefficients  $a_0$ ,  $a_1$  and  $a_2$  in the best-fit relation:

$$MN = a_0 + a_1 \log \tau + a_2 \Delta$$

(see Chapter 3). The events to be used in either analysis can be selected on the same basis as that used in the DISP and NUMBER commands of the last section. Indeed, much of the internal code is common to all four commands (and to the FILE command).

The manner of use of command MNCOR is illustrated in Figure 5.9 where the station correction for NBK (Table 3.6) is determined. Figure 5.10 similarly shows the use of command MDCOEF5 in determining the duration magnitude coefficients for NBK (Table 3.9). The results of the commands in either case are normally entered into the network file using the UPDATE command of subsystem NETWK.

```

19/04/1981 15:06 [STATSJ] COMMAND: MNCOR
DO YOU WANT KEY TO DATA CATEGORIES PRINTED (Y OR N)? N
CATEGORY CODES (NOT separated by commas; eg, TEM): TQ
LOWER LIMIT DATE (DD/MM/YYYY) AND TIME (HH:MM): 16/05/1979,02:00
UPPER LIMIT DATE (DD/MM/YYYY) AND TIME (HH:MM): 31/12/1979,23:59
NUMBER OF ARCHIVE DISKETTES: 2
(Interchange archive diskettes when terminal buzzer sounds twice, then press 'return'.)
STATION CODE: NBK
NEGATIVE (N), POSITIVE (P), OR ALL (A) AMPLITUDES? N
*** INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' ***
NUMBER OF EVENTS = 65
MEAN RESIDUAL (STATION MN - MEAN MN) = -.627337
MN STATION CORRECTION FOR NBK = 0.63
*** RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' ***

```

FIGURE 5.9

THE USE OF COMMAND MNCOR TO DETERMINE AN MN STATION CORRECTION.

```

19/04/1981 15:22 [STATSJ] COMMAND: MDCOEFS
DO YOU WANT KEY TO DATA CATEGORIES PRINTED (Y OR N)? N
CATEGORY CODES (NOT separated by commas; eg, TEM): TQ
LOWER LIMIT DATE (DD/MM/YYYY) AND TIME (HH:MM): 16/05/1979,02:00
UPPER LIMIT DATE (DD/MM/YYYY) AND TIME (HH:MM): 31/12/1979,23:59
NUMBER OF ARCHIVE DISKETTES: 2
(Interchange archive diskettes when terminal buzzer sounds twice, then press 'return'.)
STATION CODE: NBK
*** INSERT ARCHIVE DISKETTE IN DRIVE 1, THEN PRESS 'RETURN' ***
*** RETURN ISAS DISKETTE TO DRIVE 1, THEN PRESS 'RETURN' ***
VARIABLE DEFINITIONS:
log(durn) = X1
distance = X2
mean MN = X3 = Y

```

CRITICAL F VALUES (IN,OUT): .0001,0

NUMBER OF EVENTS = 80

INITIAL CORRELATIONS:

	X1	X2
X2	0.467	
X3	0.928	0.507

STANDARD ERROR OF Y = 4.8E-01

CYCLE No. 1

Variable 1 entering at F level 485.71

COEFFICIENTS OF REGRESSION:

VARIABLE	COEFFICIENT	STD ERROR
X1	1.65776E+00	7.5E-02
const	-1.13813E+00	

STANDARD ERROR OF Y = 1.8E-01

CYCLE No. 2

Variable 2 entering at F level 4.05353

COEFFICIENTS OF REGRESSION:

VARIABLE	COEFFICIENT	STD ERROR
X1	1.57935E+00	8.3E-02
X2	4.86016E-04	2.4E-04
const	-1.05688E+00	

STANDARD ERROR OF Y = 1.8E-01

CYCLE No. 3

Analysis completed

MD COEFFICIENTS FOR NBK = -1.05688 1.57935 4.86016E-04

FIGURE 5.10

THE USE OF COMMAND MD COEFS TO DETERMINE MD COEFFICIENTS FOR A STATION.

In conclusion, subsystem STATS represents the final stage in earthquake processing using ISAS, whereby the results obtained by other subsystems can be combined in various ways and made available for interpretation or as just discussed, for feedback to earlier stages of ISAS in order to improve aspects of the analysis for subsequent events. The remaining chapter of this thesis discusses the first stage of earthquake processing in the case of the event recorders; in which the seismic data are scrutinized in the field under software control, events are selected and recorded, and the resulting data ultimately made available to ISAS for use by its analysis subsystems.

## CHAPTER 6: DIGITAL SEISMIC EVENT RECORDING AND PROCESSING

### 6.1 A Digital Seismic Event Recorder

The rationale for a digital recording system for South Australia was presented in Chapter 1. Continuous digital recording, however, is prohibitively expensive, requiring about 10 times the magnetic tape used for an FM record of equivalent bandwidth and about 100 times the tape used for a directly recorded signal (Willmore (ed.), 1979). For this reason, almost every digital seismic recording system ultimately stores digitized events only, either transcribed from an intermediate continuous analogue tape or alternatively recorded in digital form directly using a recorder triggered by the events. The latter approach was the one adopted in South Australia.

A problem with event-triggered recorders is that, for earthquakes, the portion of the waveform which triggers the recorder is sometimes not the initial P wave onset but the relatively more energetic S wave, resulting in the loss of important information unless steps are taken to ensure that the part of the input data stream immediately preceding the trigger is recorded along with the subsequent data. This implies that a short-term buffer memory of some sort is required. Early event recorders (e.g., Omote et al., 1955) used a tape loop as a means of continually saving the previous few seconds of data. Such loops deteriorated quickly, however, as a result of the large number of passes over the record and playback heads. An alternative approach, consisting of a long tape which was repeatedly rewound (Choudhury and Hourii, 1973), resulted in periods of time when the recorder could not be used, while the tape was

rewinding. Both systems were heavily mechanical, posing problems of long-term reliability in the field. A significant improvement was obtained with the use of semiconductor memory in the form of shift registers, which achieved the same result as a tape loop but without any moving parts or tape deterioration. Several event recorders using this method are described in the literature (e.g., Ambuter and Solomon, 1974; Prothero, 1974, 1976). When confronted with the problem in South Australia in 1976, at a time when microprocessors had just begun to be readily available, the decision was made to employ random-access memory (RAM) for the short-term signal buffer memory and to develop a microprocessor-controlled digital event recorder.

The chief advantage of a microprocessor-based recorder, as with any other microprocessor-controlled device, is that the hardware is reduced to its simplest form and the complexity is shifted to the associated software, which is generally less expensive to produce, less time and labour intensive, and more easily modified, both during the design and testing phases and when later changes must be made. As an illustration, previous event recorders often employed electronic integrators with long and short time constants in order to derive the long term average (LTA) and short term average (STA) of the incoming signal. A hardware comparator triggered the device whenever the STA/LTA ratio exceeded a certain value. With a microprocessor-controlled recorder, all of the above functions can be performed by software; and the triggering algorithm can be changed subsequently in favour of a totally different (perhaps significantly more sophisticated) algorithm at a later date without a single wiring change. Testimony to the advantages of a microprocessor-based design is the fact that, during the period when the South Australian unit was being developed, almost every commercial manufacturer of seismic

equipment announced plans for microprocessor-controlled event recorders. Most of these are now available and have been readily adopted by seismologists (e.g., Brune et al., 1980). In addition, several (if not many) other research groups are also developing, or have developed, similar devices (e.g., Prothero, 1980).

Figure 6.1 shows the South Australian digital seismic event recorder. Its specifications (to follow) reflect the primary use for which it was designed: as part of a portable network for microearthquake studies. The hardware components of the device are outlined in the next section; the software is discussed in the two sections following.

## 6.2 Hardware Aspects of the Event Recorder

Because the event recorder is required to operate for many days unattended and generally away from mains power, low power consumption was a primary design objective. The unit consumes approximately 0.3 W, enabling its two internal 6 V, 8 Ah batteries to power the unit for approximately 12 days, or external 24 Ah batteries to power it for approximately 36 days, although tape capacity is generally the limiting factor in the latter case. The low power consumption was achieved by the use of CMOS devices. The only CMOS microprocessors available in 1976 (as at the time of writing) were the RCA COSMAC and the Intersil IM6100. The latter was adopted on software considerations, emulating as it does the instruction set of the PDP8/E minicomputer. The Data General Nova architecture and instruction set owe their origin to the earlier and more restrictive PDP8/E. The similarity in philosophy and the author's familiarity with the former made the transition to the latter straightforward. The availability of a PDP8 cross-assembler for the Nova (Chapter 2) further contributed



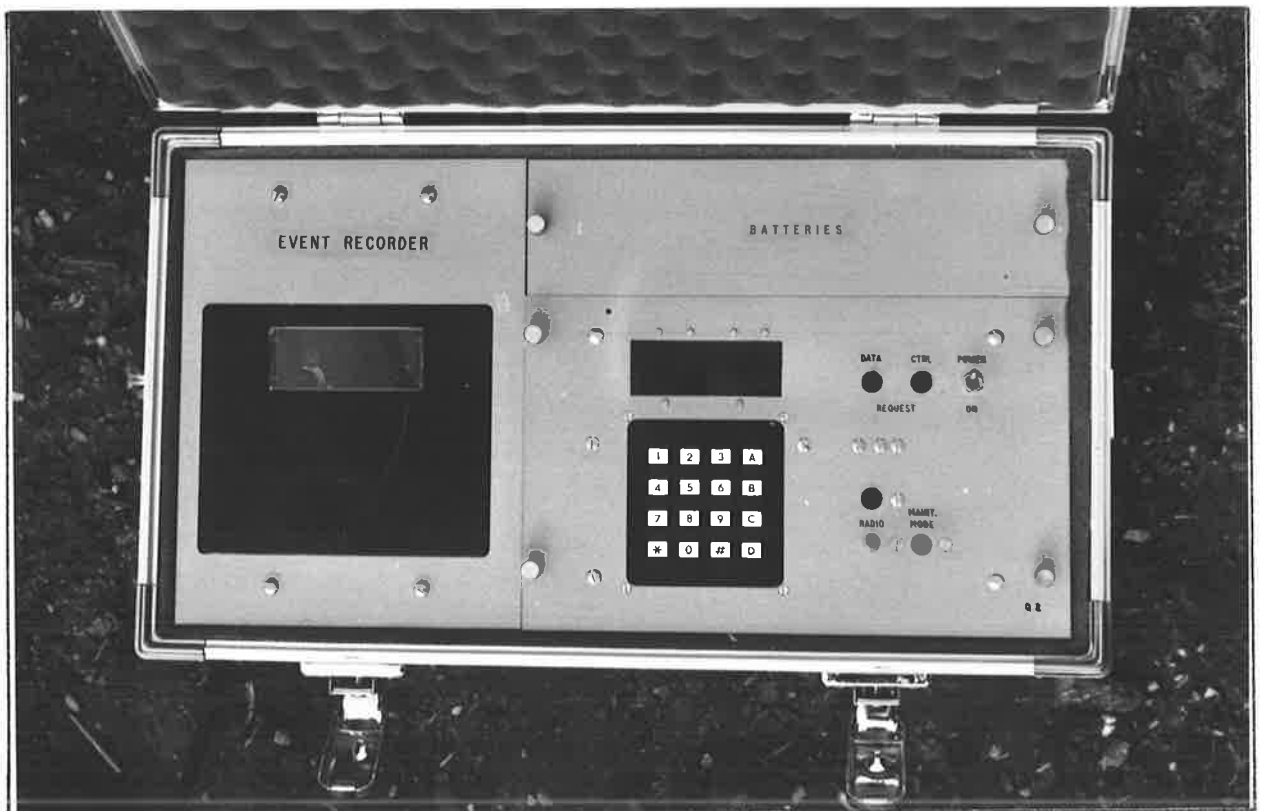


FIGURE 6.1

THE MICROPROCESSOR-CONTROLLED DIGITAL SEISMIC EVENT RECORDER DEVELOPED AS PART OF THE SOUTH AUSTRALIAN SEISMIC DATA SYSTEM.

to the choice. Prothero (1980) and other Australian seismologists have also more recently adopted this device.

CMOS read/write memory (RAM) is employed, amounting to the maximum unmapped 4K, in the form of 12 MB8404E 4K x 1 bit devices. The analogue to digital converter is a semi-integrated sample-and-hold successive-approximation design, developed in the absence of availability of a fully integrated CMOS A/D converter at the time.

The microprocessor clock frequency was chosen so that by suitable frequency division it also forms the system real-time clock, initiating analogue to digital conversions at a rate of 50 samples per second, which was considered an optimal balance between the need to record high frequencies for microearthquake studies, on the one hand, and the constraints of tape consumption (necessitating more frequent station visits) and decrease in processing time between samples, on the other. In order to minimize current consumption, a relatively low clock frequency of 1.6384 MHz is used, which nevertheless enables the software to complete all processing in a small fraction of the time between samples. This gives a valuable margin for the incorporation of more sophisticated signal processing techniques in future versions of the software. At present the margin is used to achieve further current economies by forcing the processor to enter a low-power wait state at the end of processing, until reactivated by the hardware with the arrival of the next datum by the analogue to digital converter. A Plessey SL680C crystal oscillator maintaining circuit is used to stabilize the clock crystal against temperature drift, the quoted accuracy being 0.1 ppm per  $^{\circ}\text{C}$  over the interval  $-20^{\circ}\text{C}$  to  $80^{\circ}\text{C}$ . The real-time clock can be started and stopped under software control by gating the input to the frequency divider after the microprocessor clock signal has been derived. An external radio and time pulse

amplifier (previously used in conjunction with the Kinometrics PS-1A portable seismographs) enable synchronized starts with radio time pulses and subsequent determinations of clock error, using a radio input on the event recorder connected to one bit of a status port (see later).

Microprocessor code is generally executed from read only memory (ROM), using RAM only for data and temporaries. Because the Intersil device is based on a minicomputer, which typically executes code from RAM, it is not ideally suited to ROM execution. In particular, the return address in a subroutine call is stored in the first location of the subroutine, which requires an indirect entry through RAM if the subroutine is contained in ROM. Because of this and two other disadvantages of ROM execution, viz, that locations cannot be changed for in-unit debugging and that the only CMOS read only memories available at the time involved expensive mask programming, the event recorder software was designed for execution completely in RAM, after being placed there on power-up from conventional (MOS) ROMs by a loader incorporated in the software. To achieve this, the upper 2K of memory in the recorder is software-switchable between RAM and ROM, with the ROM selected on power-up. The ROM loader transfers the remainder of the code to the lower 2K of RAM and subsequently transfers control to it. The upper 2K is then switched from ROM to RAM, to become the data storage area. Thus the current-consuming ROM is only powered for a few tens of milliseconds when the event recorder is first switched on. Two Intel 2716 EPROMs are used in parallel to provide the required 2K of 12-bit words (or alternatively four Intel 2758 EPROMs can be used).

The event recorder amplifiers provide for a fixed gain of 54 dB and an additional gain of between 0 and 48 dB which is software-

controllable in 6 dB steps. The software adjusts the gain dynamically so as to maintain the background noise level between predefined limits. This autoranging facility ensures that the dynamic range of the recorder is not compromised by too large a noise level in the data, and has enabled 8-bit resolution to be used with very satisfactory results rather than the more usual 12-bit resolution, thereby allowing 50% more events to be recorded on a given amount of tape. An anti-aliasing filter is incorporated in the amplifiers, providing 18 dB per octave attenuation at a corner frequency of 25 Hz.

Interaction between the event recorder and the operator is provided by means of a 16-key keypad and a set of four 7-segment displays. The 16 keys consist of the digits 0 to 9, the letters A to D (which the software interprets as control keys) and keys labelled # and \* (which the software interprets as numeric entry and clear keys respectively). The 7-segment displays are at present of the LED type although they are operated in a scanning mode to allow for easy conversion to liquid crystals in the future. The software display driver provides for both decimal conversion (for normal use) and octal conversion (for memory locations when debugging). Auxiliary LEDs provide prompts when the software requires data or a control key, and an indication that the recorder is waiting for a radio time pulse to start the clock.

Events are recorded on digital cassettes using a Digideck PI71W write-only cassette drive with CMOS interface, obtained commercially from International Computer Products Inc. The unit provides for 9-bit data, recorded serially on one track of the tape with framing pulses recorded on a second track, the two tracks together occupying the full width of the tape. The event recorder uses eight of the nine bits for data and the software encodes even parity in the ninth bit. The PI71W

is capable of asynchronous or block synchronous operation. The latter, although involving considerably more complex software, is used with the event recorder because it approximately doubles the packing density on tape. The software blocks the data into 128-byte blocks preceded by a header byte (see later). The cassette unit can sense whether a cassette is in place, is write-protected, and is on clear leader, and corresponding status signals are made available to the software as further bits in the status port mentioned above.

The recording density of the cassette unit can be set from 200 to 600 bits per inch. At 550 bits per inch using block synchronous recording, a 300 foot cassette accommodates approximately 200 000 data bytes, or approximately one hour of recording at 50 samples per second. Error rates are quoted as less than 1 in  $10^6$  bits (or 1 in  $10^7$  for 'improved environments').

The cassette unit, as well as the keyboard, the displays, and the analogue subsystem, does not use interrupts, being instead serviced adequately by software polling. The interrupt system is employed, however, to activate a software debugger from a recessed 'maintenance mode' button on the front panel. The debugger is discussed along with the remainder of the software in the following two sections. By dedicating the interrupt system to this function, the debugger can be relied upon to be available at all times (barring a catastrophic failure such as the debugger being overwritten). This has proved indispensable in the systematic checking and debugging of the first unit.

The translation of the design concepts outlined above into operational circuits was performed by Mr I.C. Davidson, Technical Officer (Electronics) of Salisbury College of Advanced Education, whose considerable expertise in the area is gratefully acknowledged.

The software was written by the author and is discussed in detail below.

### 6.3 SEROS

The Seismic Event Recorder Operating Software (SEROS) consists of the following components: loader, initializer, main program - normal-running phase, main program - tape-writing phase, debugger, diagnostics, and calibrator. It is written in PDP8 assembly language and was entered, edited, assembled, programmed into ROMs and verified using the Nova-based development system discussed in Chapter 2.

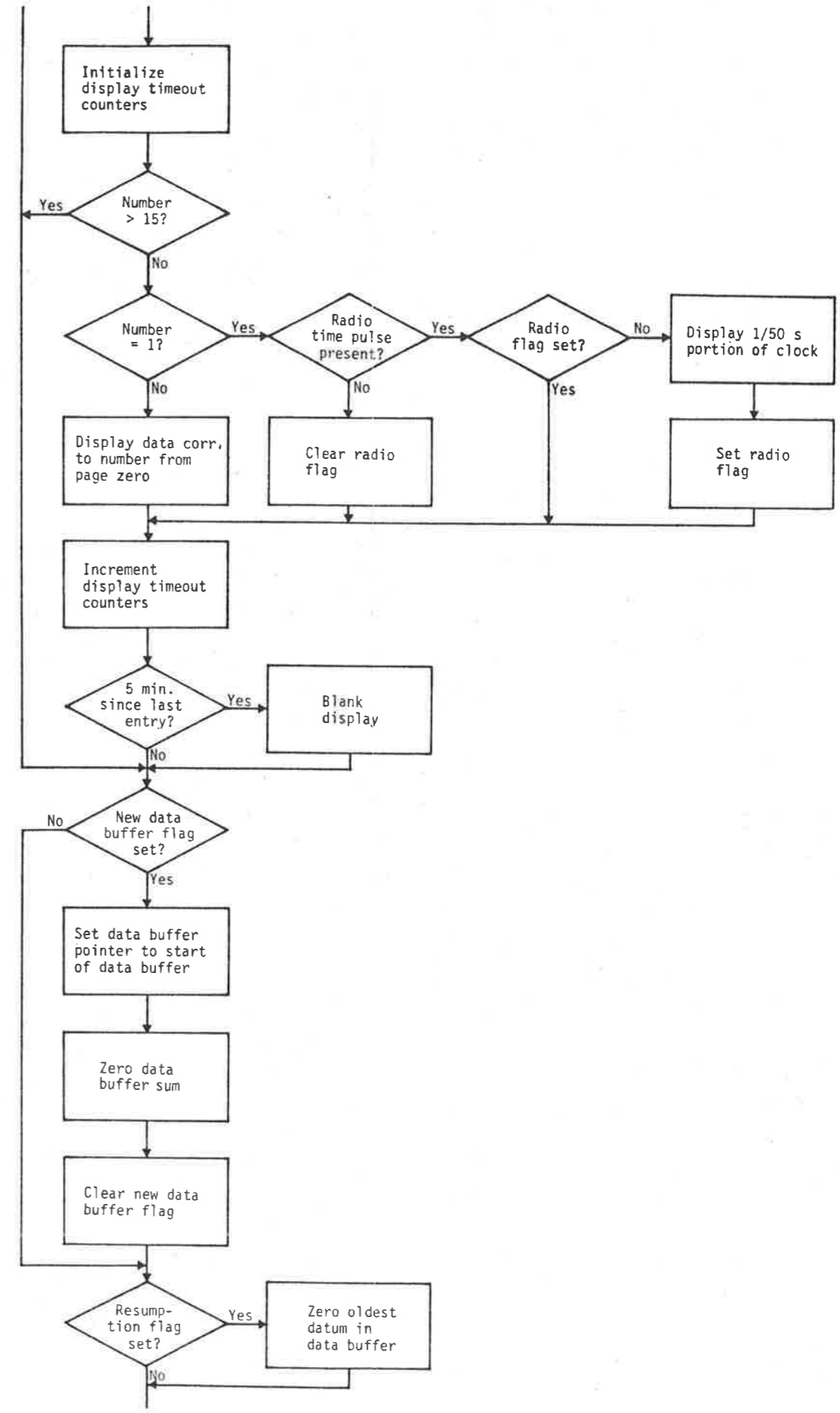
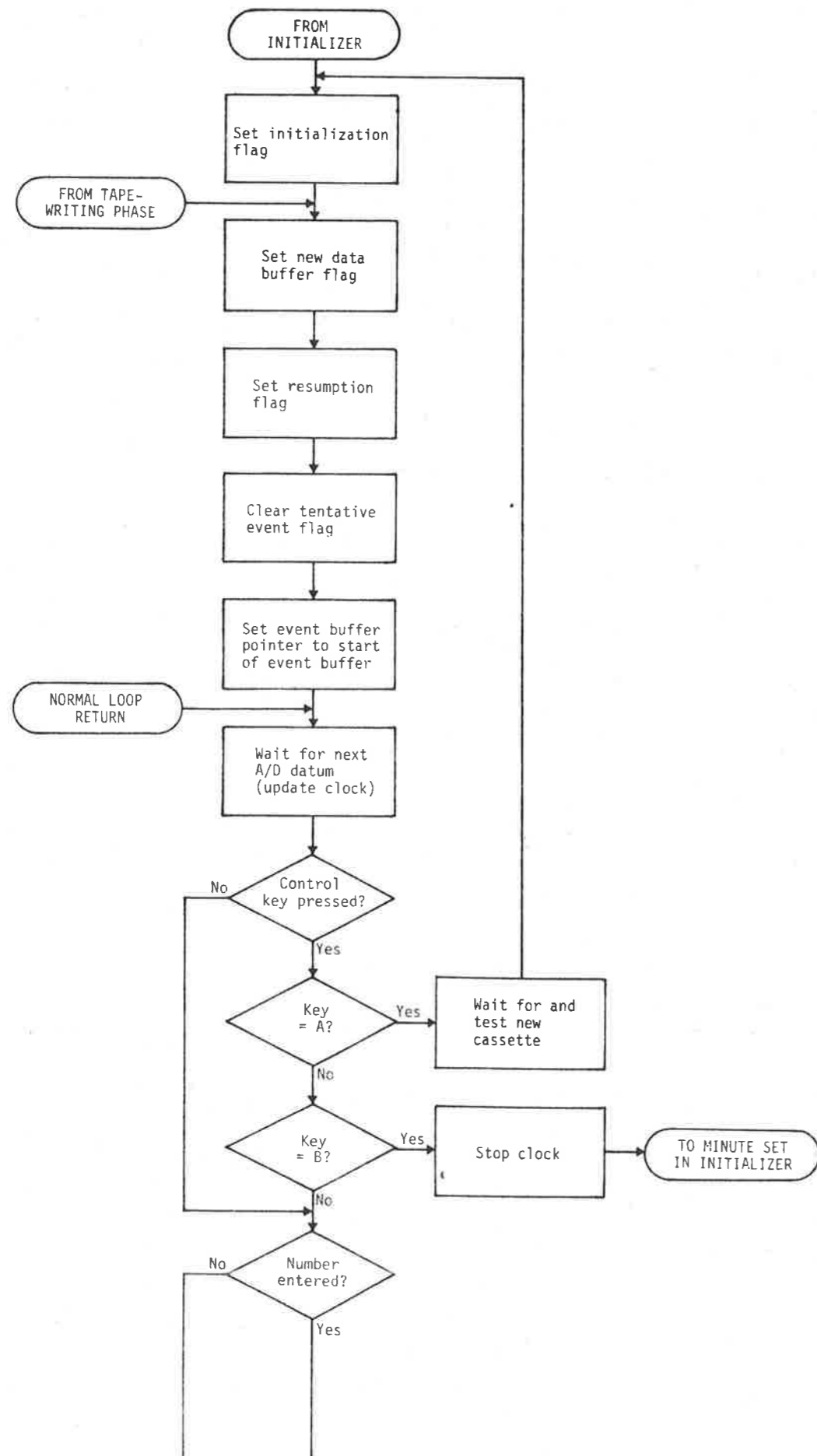
The loader is the only routine executed from ROM. It is executed on power-up and copies a block of data, containing a known number of words, from ROM, starting at the lowest ROM address (4000 octal), into RAM, starting at address zero in page zero. An adjacent block in ROM, comprising a fixed number of words of program code, is then copied into RAM, starting at the first normal address (200 octal). Following the transfer of the second block, control is passed to the loaded software at address 200, which is the starting address of the initializer.

The first action of the initializer is to switch the upper 2K of memory to RAM, removing power from the ROM. The initial amplifier gain, corresponding to the midpoint of its range, is then set. This is followed by a call to a subroutine to test the preparedness of the cassette to receive data, and then to advance the tape to load point, ready to record the first event. Calls to a keyboard subroutine follow, in which the day, hour and minute at which the clock is to be started are entered from the keyboard, the last two being checked for valid data. The final action performed by the initializer is to start the clock. Four options are provided, in response to the four control

keys on the keyboard. The first advances the clock one minute, the second displays the current minute, the third attempts to start the clock in synchronization with the next radio minute pulse, and the final option starts the clock immediately. Once the clock is started, SEROS enters the normal-running phase of the main program.

The main program interacts with a number of data storage areas, primarily in the upper 2K of memory. The signal buffer memory in SEROS is a 256 word (2 page) block of RAM referred to as the data buffer, commencing at location 4000 (octal). Each successive datum from the analogue to digital converter is stored in the data buffer, with the next location to be used pointed to by a data buffer pointer in page zero. The data buffer is a circular buffer with the oldest datum being continually overwritten, thereby ensuring that (at 50 samples per second) the last 5.12 seconds of data are always preserved. Under conditions to be discussed later, as each new datum enters the data buffer, its absolute value is added to the sum of those already in the buffer. Each time the buffer wraps around, the mean absolute value is computed and stored in another data area called the mean pool, and the sum is cleared. The mean pool is also a circular buffer, immediately preceding the data buffer in memory, holding the means of the previous 32 data buffers, with the next location to be used pointed to by a mean pool pointer in page zero. By maintaining a running average of the 32 means in the mean pool, the noise level is effectively computed over the last  $32 \times 5.12 = 163.84$  seconds, or 2.73 minutes of data. A third data area, a 14 page event buffer, immediately following the data buffer in memory, will be discussed later.

Figures 6.2 and 6.3 show the flowchart of the SEROS main program in its normal-running phase. The logic presented in the diagrams is





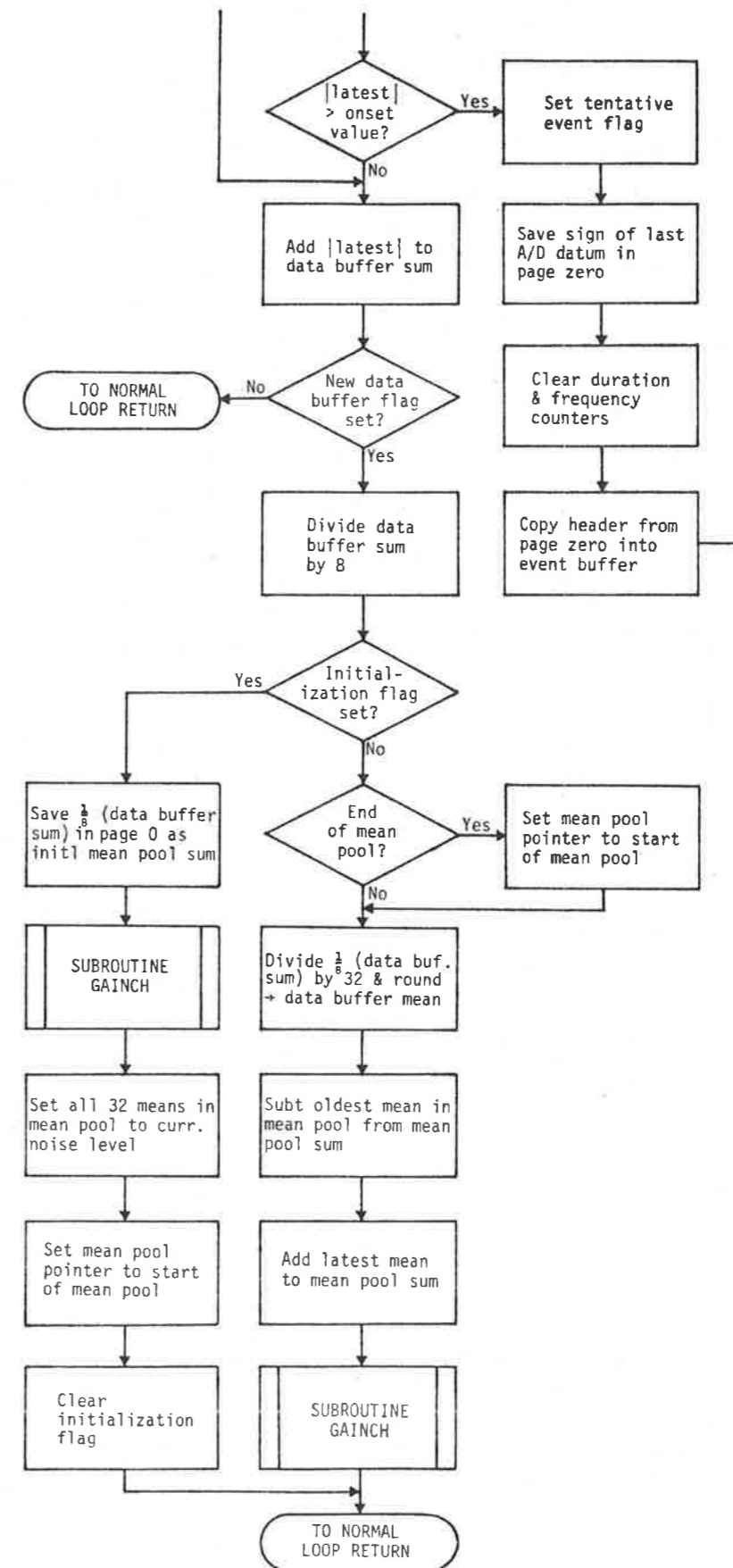
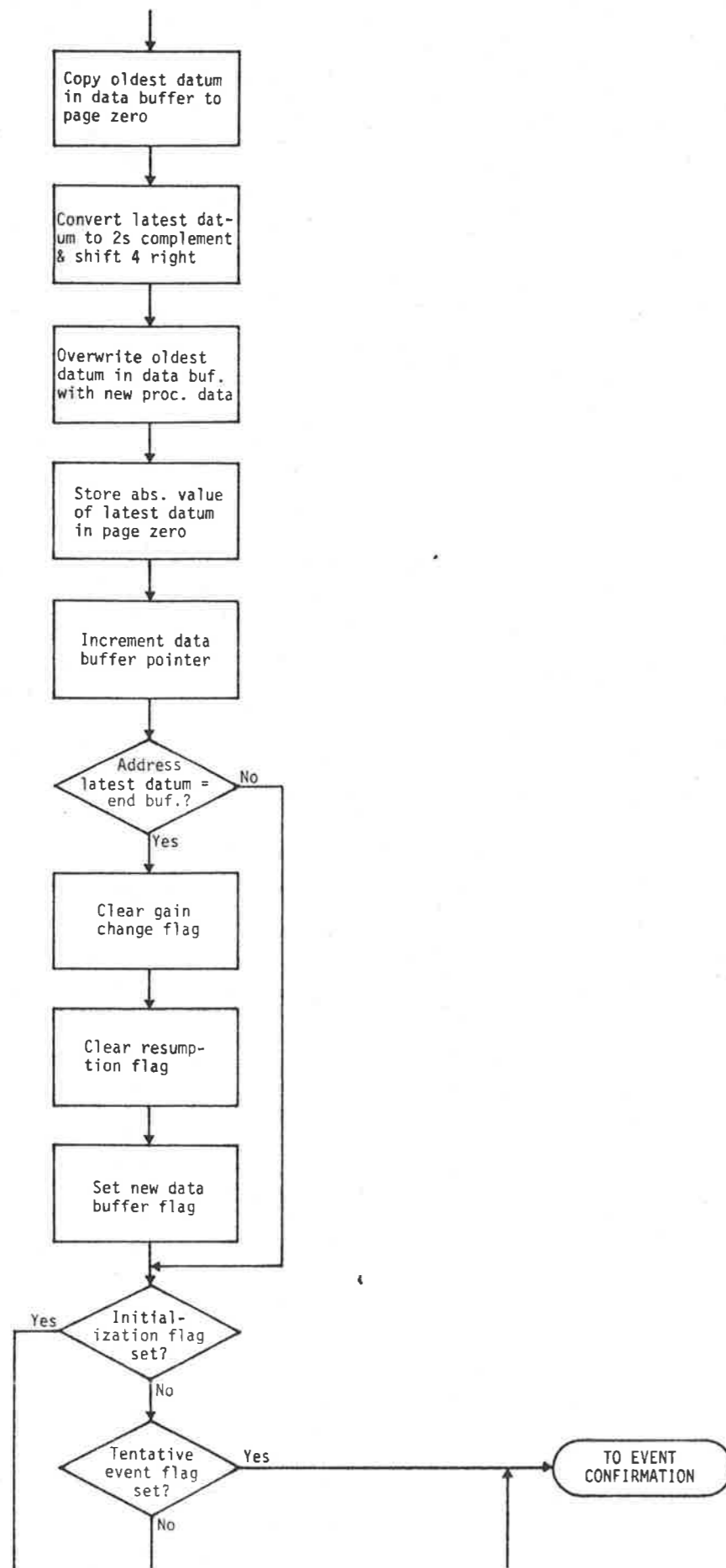


FIGURE 6.2

LOGIC FOR THE SEROS MAIN PROGRAM (NORMAL-RUNNING PHASE).

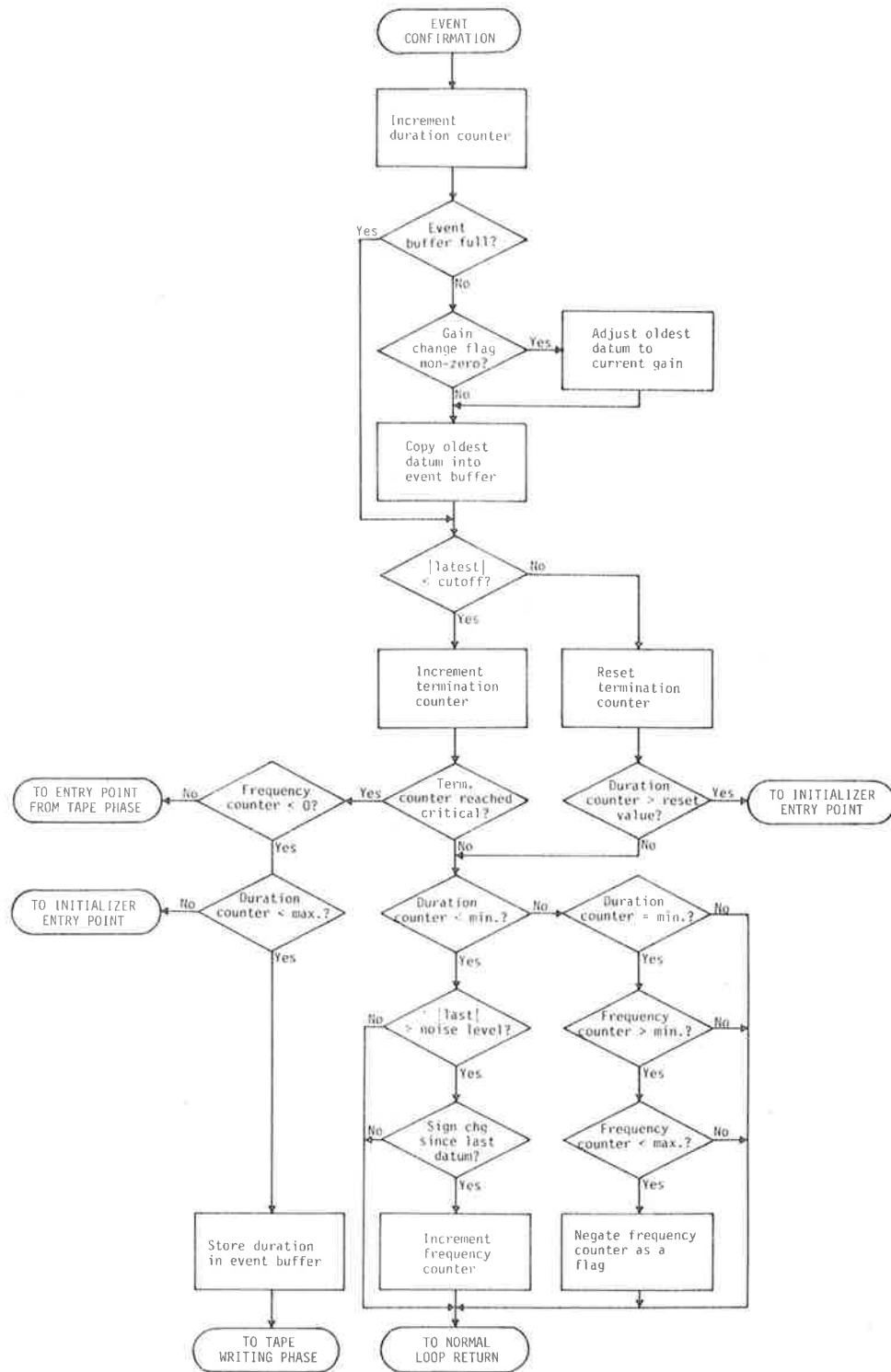


FIGURE 6.3

EVENT CONFIRMATION LOGIC OF THE SEROS MAIN PROGRAM (NORMAL-RUNNING PHASE).

repeated with each successive datum from the analogue to digital converter, and therefore 50 times each second. On entry from the initializer, an initialization flag is set, indicating that the noise level has not yet been determined. Until a noise level has been established (and the initialization flag cleared) no events can be detected. Other flags appearing in the flowcharts are:

1. New data buffer flag: set each time the datum entered into the data buffer occupies the highest memory address in the buffer.
2. Resumption flag: set for the duration of the first complete data buffer following any break in the data stream into the buffer.
3. Tentative event flag: set when the latest datum is deemed to indicate a possible event onset; cleared when the event has either been cancelled, or confirmed and written onto tape.
4. Radio flag: set when the radio time pulse is first detected; cleared when first absent.
5. Gain change flag: 0 if no gain change occurred at the end of the last data buffer, +1 if the gain was increased by 6 dB, -1 if the gain was decreased by 6 dB.

The logic loop of Figure 6.2 commences when a new datum is available from the analogue to digital converter. The first action performed is the determination of whether or not a control key has been pressed on the keyboard. Key A can be pressed to request a cassette change, and key B to request a clock resynchronization. In either case, a branch occurs in order to satisfy the request; otherwise a check is performed for the presence of a number entered on the keyboard. Numbers from 1 to 15 indicate requests for status information, as shown in Table 6.1. All except a clock error request involve simply transmitting the status information in page zero to the display (with possibly some reformatting). The clock error is

TABLE 6.1  
STATUS INFORMATION AVAILABLE UNDER SEROS

CODE	STATUS
1	Clock error (current 1/50 second)
2	Current second
3	Current minute
4	Current hour
5	Current day
6	Amplifier attenuation (in dB)
7	ROM identification
8	Current noise level
9	Tentative event (flag)
10	Initialization (flag)
11	Number of events on tape
12	Tape status 0 = functional 1 = tape full 2 = error when writing gap 3 = error when writing block
13	Events missed (due to nonzero tape status)
14	Day tape status became nonzero
15	Hour tape status became nonzero

displayed by transmitting the 1/50 second portion of the internal software clock at the time when the radio second pulse is first detected.

After operator status requests have been serviced, the new datum from the analogue to digital converter is processed, as shown in Figure 6.2. The datum is saved in the data buffer, overwriting the oldest datum, which is first transferred to page zero in preparation for writing into the event buffer should a tentative event be flagged. If the initialization flag is not set and a tentative event has not already been flagged, the latest datum is tested for a possible event onset. Sophisticated event detection algorithms have been designed (e.g., Veith, 1978); however, provided sufficiently thorough confirmatory tests are carried out, it is sufficient to simply flag a tentative event, as done in SEROS, when the absolute value of a datum exceeds a convenient multiple of the noise level, in this case eight times. If the test is positive, the tentative event flag is set, and the confirmation routine (Figure 6.3) is initialized and subsequently entered. If the test is negative, the absolute value of the latest datum is added to the sum of the absolute values of all previous entries in the current data buffer. When the data buffer contains its full 256 words, the sum is (eventually) divided by 256 to obtain the absolute mean of the buffer. (These operations are carried out, of necessity, in double precision.)

At the end of the first data buffer, the buffer mean is taken as the initial noise level. This is copied through the 32 word mean pool, and 32 times the noise level is set as the initial mean pool sum. Prior to returning to the start of the data buffer to commence the second buffer, the initialization flag is cleared to enable event detection to begin.

At the end of subsequent data buffers, the buffer mean is entered into the mean pool in place of the oldest entry, and the mean pool sum is updated by subtracting the oldest mean from the previous value of the mean pool sum, and adding the newest mean. The updated mean pool sum is then divided by 32 to obtain the updated noise level.

During the first 32 data buffers, the effect of the above procedure is to progressively improve the initial estimate of the noise level as each of the original 32 identical means in the mean pool is overwritten by the mean of the latest data buffer. Thus 2.73 minutes must elapse after the recorder is started before the noise level has reached its most reliable value, although an event could be detected any time after the first 5.12 seconds.

Also at the end of every data buffer, the amplifier gain comes under scrutiny via a call to the automatic gain changing subroutine (Figure 6.4). The mean pool sum is compared with upper and lower acceptable bounds. If found to be outside these bounds, a change of one setting (6 dB, or one bit shift in the data) is forced on the amplifier gain. The gain change flag is set appropriately (see above) to communicate the change to other parts of the program. If a gain change is made, the noise level, mean pool sum, and every mean in the mean pool are adjusted to the values appropriate for the new gain.

The confirmation routine (Figure 6.3) must endeavour to determine whether the onset which caused the tentative event flag to be set was due (in the present configuration) to a genuine local earthquake, and not a teleseism, quarry blast, animal, wind gust, machine or other man-made disturbance, or an electrical transient. Seismograms produced by some of these sources may require close examination by an experienced seismologist in order to distinguish the trace from that produced by a local earthquake. In such cases it would be unrealistic

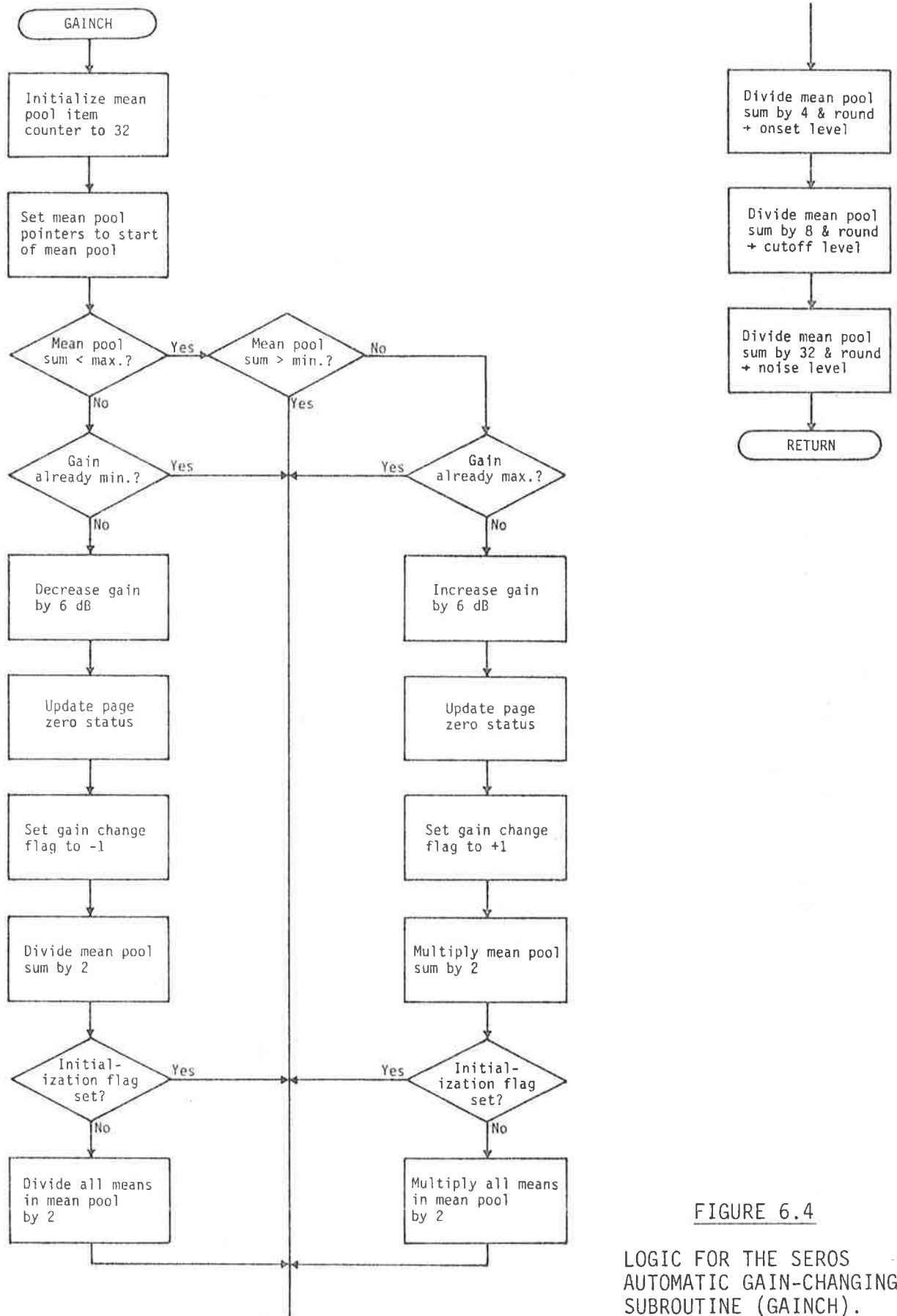


FIGURE 6.4

LOGIC FOR THE SEROS AUTOMATIC GAIN-CHANGING SUBROUTINE (GAINCH).

to expect an automatic selection algorithm to successfully distinguish them. Nevertheless, a large majority of false triggers can be eliminated by basing confirmation jointly on the total duration of the event and its principal frequency component. This ensures that the disturbance is oscillatory and prolonged, thereby rejecting electrical transients. By imposing upper and lower limits on each variable, animal disturbances and teleseisms can be eliminated in the majority of cases. Prolonged cultural noise (e.g., trucks on roads, trains, etc.), and quarry blasts, on the other hand, are very difficult to reject. The limits on the total duration are presently 15 seconds to 12 minutes, and on the principal frequency component, 2 to 10 Hz. A consequence of the adopted confirmation procedure is the need to hold an event in memory until it is over, before initiating any tape motion. This is the purpose of the event buffer referred to earlier.

As part of the initialization of the confirmation routine for each new event, the current day, hour, minute, second, 1/50 second, amplifier attenuation and ROM identification number are copied from page zero into the event buffer. These, along with the event duration computed subsequently, form a header for the event when (or if) eventually written onto tape. Thereafter, with each new datum entering the data buffer, the oldest datum in the buffer is transferred into the event buffer, thereby preserving 5.12 s of pre-onset signal. The time corresponding to any datum can be determined by assigning 1/50 s intervals from the 256th datum whose time is contained in the header. The event buffer occupies 14 pages of memory, sufficient (at 50 samples per second) for approximately 35 seconds of data. Since all phases of interest in a local earthquake normally occur within this time, considerable tape savings are achieved by not writing the coda of larger events. (The total



duration is nevertheless recorded as part of the event header.)

A situation which must be taken into account is that in which the amplifier gain was changed at the end of the last data buffer before the one in which the onset was detected. (This can be ascertained by an examination of the gain change flag.) In such cases, samples at the old gain are converted to values they would have had at the new gain before being copied into the event buffer. In every case, all gain changes and noise level determinations are frozen until the tentative event has either been cancelled or alternatively written to tape, after which a new data buffer is commenced with the resumption flag set.

If the event is found to be of duration greater than the maximum acceptable value, at its conclusion the initialization flag is set in order to force a completely new noise level determination. Otherwise, the running average of the mean pool is resumed at the conclusion of the event. The confirmation routine is also able to prematurely terminate an event, again with the initialization flag set, if it is still in progress after a very long time, presently set at approximately one hour. (This acts as a fail-safe mechanism should the background noise level build up markedly during the period when it is not being updated while a large teleseism is being received.)

The duration of an event is found by clearing a counter as part of the initialization of the confirmation routine, and then incrementing it with each new datum received. The count therefore becomes the number of 1/50 second intervals comprising the event. The event is deemed to be over when 256 contiguous samples have absolute values below four times the mean noise level (or approximately twice the peak noise level).

The principal frequency component is found by clearing another counter as part of the initialization of the confirmation routine, and then counting the number of times the signal crosses the noise level with opposite sign in a time interval commencing with the initial onset and concluding at the lower acceptable duration limit. In this way, as soon as the onset becomes eligible for event status on the basis of duration, it is also known whether or not it qualifies on the basis of principal frequency component. This produces very efficient code.

If the event is confirmed, control passes from the normal-running phase to the tape-writing phase of the main program. During this phase, new data are accepted solely for the purpose of updating the clock. The event buffer is flushed at maximum speed onto cassette tape in synchronous blocks of 128 data bytes preceded by one header byte per block. The header byte contains the number of blocks comprising the event less the number already written. As stated previously, all bytes are 8 bits with even parity computed and written as a ninth bit. A one-byte gap is written between blocks to enable the tape to be stopped by ISAS during play-back without loss of data while the block is transferred to disk (see later). A whole number of blocks is always written. This number is 14 if the event filled the event buffer; otherwise a lesser number may be written, with the last block padded out with zeros if necessary. The page zero event count status is incremented with each event transferred to tape.

During tape transfer operations, tests are conducted for clear leader, indicating the end of tape, and for failure to receive control signals from the deck within specified timeout periods, indicating a jammed cassette or deck malfunction. If a test fails, the tape status in page zero is updated to reflect the fault, and the current day and

hour are saved as additional status information (Table 6.1). The tape status is tested each time the tape-writing phase is entered. If a fault is found to have occurred, rather than attempting to write the event, the page-zero non-recorded event count status is incremented and control returns immediately to the normal-running phase.

The above software components are all logically related, and operate as a unit. The remaining routines; viz, the debugger, diagnostics and calibrator; are logically disjoint from the above and can be executed only after the event recorder has been placed in 'maintenance mode' via a recessed front panel button.

#### 6.4 Event Recorder Maintenance Mode

Pressing the recessed 'maintenance mode' button on the front panel initiates a hardware interrupt, and control is immediately transferred to the debugger. Using the debugger, any memory location can be examined and optionally modified. The processor registers are saved in page zero on entry, where they may be examined also, and optionally modified. They are reloaded from page zero on exit from the debugger, which can be instructed to resume execution at any desired address by depositing the restart address at location zero. Although it can be initially entered only by an interrupt, the debugger can be used to deposit break-points in the software for subsequent controlled execution of sections of code. In this manner, the entire software package was originally tested and debugged, and faults were able to be traced either to the software or to the hardware, with surprising ease. In this regard, a number of diagnostic routines, executable from the debugger and following it in memory, proved extremely useful. One diagnostic deposits a binary count through the event buffer as a preliminary to testing the

tape-writing phase of the software, and the cassette hardware. Others facilitate the adjustment of the amplifiers. Additional short routines were written as needed and deposited using the debugger in free memory while the unit was running. One particular routine executable from the debugger is the system calibrator. This comprises a software peak detector to provide a digital readout of the maximum D.C. pulse deflection or A.C. amplitude when the seismometer calibration coil is driven by an external calibration unit. It also enables the programmable gain amplifier to be set manually to a suitable gain from the front panel, and enables the direction of 'pen' motion to be read following deflection of the seismometer mass in a known direction. The operation of the calibrator, along with that of the event recorder in general, is contained in the User's Manual (Parham, 1980c).

The software discussed in this and the last sections, and the hardware discussed in section 6.2, were tested against continuous analogue pen-recording seismographs at ADE and HTT. Attempts to induce false triggers by stamping the ground or other movements were unsuccessful in every case. The degree of immunity to other noise sources, and the number of unrecorded genuine events, will be established as experience with the recorders increases over the next few years. One event recorder is currently operational and a further three are presently under construction. A sample event is shown in the next section.

#### 6.5 The ISAS Cassette Data Management Subsystem

Of the examples of computerized data systems discussed in Chapter 1, those involving telemetry to a central site (e.g., Bolt et al., 1977; Houlston, 1975) offer the advantage that the

association of traces from different stations for the same event is straightforward, being all recorded in parallel on a multichannel medium. In South Australia, the large distances involved render telemetry of all data to a central site prohibitively expensive. Consequently, a method must be provided for regrouping data by event, ready for analysis, rather than by station, as received on cassettes. Subsystem CASET performs the transformation, also reducing the data from complete events (including those of no interest) to a set of arrival times and other data able to be used directly by the ISAS analysis subsystems, LOCAL and MICRO. At the same time, it enables a hard-copy of the original waveform to be saved with phase identifications labelled. The subsystem therefore forms the link between the event recorders and the central computer.

Data are passed from the Cassette Data Management Subsystem to the remainder of ISAS by means of a disk data file called the cassette file, the structure of which is shown in Table 6.2. The file is initially configured for a given maximum number of cassette-recording stations and a given maximum number of phases per station. The values of these parameters are stored in the file header and they determine the random record structure of the file. Records are 16 bytes in length and all data for a given event are stored in contiguous records. As each cassette is read, data pertaining to each event in turn are directed to the appropriate records containing the event by virtue of the random file structure. The data consist of the station code, cassette identification characters, direction of first motion, event duration, event sequence number on tape, a set of phase arrival times and corresponding errors, and for the first station reporting each event only, the base date and time (relative to which the arrival times in seconds are measured). Data entry is effected using the

TABLE 6.2

## ISAS CASSETTE FILE STRUCTURE

INFORMATION	DATA TYPE	INTERNAL FILE FORMAT
FILE HEADER		
Number of stations per event, phases per station Number of events on file Number of free events Initials of person who reset file	4-byte floating point numeric " " ASCII string	(stations per event) + (phases per stn)/100  3 characters
HEADER PER EVENT		
Base date and time  Unused	ASCII string  "	YYYYMMDDHHmm year    day    minute month    hour 2 characters
PER STATION PER EVENT		
Station code, cassette ID, direction of first motion  Event number on cassette Duration	ASCII string  4-byte floating point numeric "	SSSCCF stn    direction of code    1st motion cas ID
Arrival time, error	4-byte floating point numeric	Two sets per record. Number of records = (phases per station)/2

ENTER command, as discussed in the next section. The complete command set for subsystem CASET is presented in Table 6.3.

The RESET command, shown in Figure 6.5, is used initially to configure the cassette file in the manner discussed above, and subsequently if it is desired to change the configuration. The latter necessarily destroys any data stored in the file, and is normally carried out only after all data have been processed. A password is required in order to execute the command.

DISP and FILE display data for a selected event and for all events in the cassette file, respectively. The format used in each case is the same and is shown in Figure 6.5 for the DISP command. Events are referenced in the cassette file by number, in order of their position in the file. The cassette file event number is also used to access cassette file data in subsystems LOCAL and MICRO (see later).

When all cassette data for a given event have been assembled and passed to one of the analysis subsystems, the cassette file space occupied by the data can be freed for use with a new event. Command FREE internally writes a null string as the header of the event, which allows ENTER to reclaim the file space for a new event (and causes FILE to omit the event in its listing). The cassette file header (Table 6.2) maintains a count of the current number of events stored in the cassette file and the number of these which are currently free. The FREE command updates this status. The file parameter and status information stored in the cassette file header can be displayed using the PARAM command. If the actual file numbers of the currently free events are required (for use in the ENTER command, for example), the EVENTS command can be executed, which reads the header record of each event in the cassette file in turn and prints the sequence number

TABLE 6.3  
COMMANDS IN SUBSYSTEM CASET

COMMAND	ACTION
HELP	Display commands and their actions.
ENTER	Enter data from a cassette into cassette file.
PARAM	Display cassette file parameters and current status.
RESET	Reset cassette file.
DISP	Display data for one event in cassette file.
FILE	Display entire cassette file.
FREE	Free an event in cassette file.
EVENTS	Display numbers of free events in cassette file.
ADJUST	Adjust arrival times for an event in cassette file.
NETWK	Transfer to Network Data Management Subsystem.
LOCAL	Transfer to Local Earthquake Subsystem.
MICRO	Transfer to Microearthquake Subsystem.
STATS	Transfer to Earthquake Statistics Subsystem.
LOGOFF	Log-off from system.



23/04/1981 20:43 [CASET] COMMAND: DISP

CASSETTE FILE EVENT NUMBER: 6

EV.NO.	BASE DATE & TIME	STN	CAS.ID	EV.ID	1st	MOTH	DURN	PH.NO.	ARR.TIME	ERR	PH.NO.	ARR.TIME	ERR
6	24/09/1980 08:30	ADE	S1B	10	+		45.2	1	6.5	0.2	2	13.3	0.3
								3	8.2	0.3	4	9.7	0.3
		EDD	S1A	25	-		38.5	1	-7.3	0.2	2	-5.1	0.3
								3	-6.5	0.3	4	-3.2	0.3
								5	-6.8	0.3	6	-2.8	0.3
		NBK	S1F	38	0		35.8	1	-5.8	0.2	2	-1.9	0.2
								3	-6.3	0.3	4	-0.6	0.3
								5	-1.2	0.3			

23/04/1981 20:51 [CASET] COMMAND: ADJUST

CASSETTE FILE EVENT NUMBER: 6

BASE DATE AND TIME = 24/09/1980 08:30

NEW BASE DATE (00/MM/YYYY) AND TIME (HH:MM): 24/09/1980,08:29

SECONDS TO BE ADDED TO ALL ARRIVAL TIMES: 60

COMPLETED.

23/04/1981 20:53 [CASET] COMMAND: RESET

PASSWORD: -RTP

MAXIMUM NUMBER OF CASSETTE-RECORDING STATIONS PER EVENT: 3

MAXIMUM NUMBER OF PHASES PER STATION: 8

CONTENTS OF FILE WILL BE LOST. PROCEED (P) OR ABORT (A)? P  
CASSETTE FILE RESET.

FIGURE 6.5

THE USE OF COMMANDS DISP, ADJUST AND RESET IN SUBSYSTEM CASET. (Output from command FILE is similar to that from DISP.)

of the event if it encounters the null string indicating a free event.

The manner of use of commands FREE, PARAM and EVENTS can be seen in Figure 6.6. The central command in the subsystem, ENTER, is discussed below, after which brief mention is made of the remaining command, ADJUST.

## 6.6 ENTER

The transition from cassette tape to specific data in the cassette file takes place in the ENTER command via an intermediate disk data file capable of holding one complete digitized event. The file is written sequentially block for block as the corresponding cassette data blocks are read; and is then accessed randomly in order to display on the graphics screen sections of the waveform for interactive phase selection using a light pen. Once the data are in standard 32-bit floating point format on a standard disk file, ordinary language commands can be issued to process them. However, being a non-standard device, the cassette reader requires a custom-designed hardware interface to the Nova and a specially written device driver incorporated into the operating system, in order to convert the 9-bit integer data on tape to 32-bit floating point format, and to write it to disk.

The Digideck PI71W CMOS write-only cassette unit was used in the event recorders primarily because an interface to the Nova for the compatible PI70 read/write unit had already been designed by the Mawson Institute for Antarctic Research of the University (Brimble, 1975). A unit based on their design was built for the system. The cassette reader device driver was designed by the author and written in assembly language. It makes an entry in the operating system device interrupt vector table and subsequently starts and

23/04/1981 20:34 [CASET] COMMAND: FREE

CASSETTE FILE EVENT NUMBER: 15

BASE DATE AND TIME = 03/03/1980 00:02

EVENT WILL BE LOST. PROCEED (P) OR ABORT (A)? P  
EVENT FREE.

23/04/1981 20:35 [CASET] COMMAND: PARAM

CASSETTE FILE RESET BY RTP.

MAXIMUM NUMBER OF CASSETTE-RECORDING STATIONS PER EVENT = 4

MAXIMUM NUMBER OF PHASES PER STATION = 8

CURRENTLY:

18 TOTAL EVENTS, 5 FREE EVENTS

23/04/1981 20:36 [CASET] COMMAND: EVENTS

NUMBERS OF FREE EVENTS:

7 9 10 11 15

FIGURE 6.6

THE USE OF COMMANDS FREE, PARAM AND EVENTS IN SUBSYSTEM CASET.

services the device at the interrupt level, filling an internal one-block buffer and processing it at the program level in order to check parity and float the data. When the buffer is full at the interrupt level, tape motion is halted, and when fully processed, the operating system is called upon to transfer the block to disk. This is then repeated for subsequent blocks. The block header byte of the first block contains the number of blocks comprising the event (see section 6.3). If a parity error is detected in this byte, the header byte of the second block is used to establish the block count. If this is also faulty, reading terminates at the end of the second block and an error code is returned. Block header bytes are removed from the data prior to writing to disk. Parity errors in any of the 128 data bytes in a block result in the out-of-range value 200 (decimal) being substituted for the datum. This is used to trigger remedial action in ISAS, depending on the circumstances (see later).

The structure of the disk data file is shown in Table 6.4 and corresponds directly to the order in which the data were recorded on the original cassette by the event recorder. ISAS, in reading the file, internally adjusts for the offsets shown, and also calculates the event duration from the low and high order portions of the recorded duration counter.

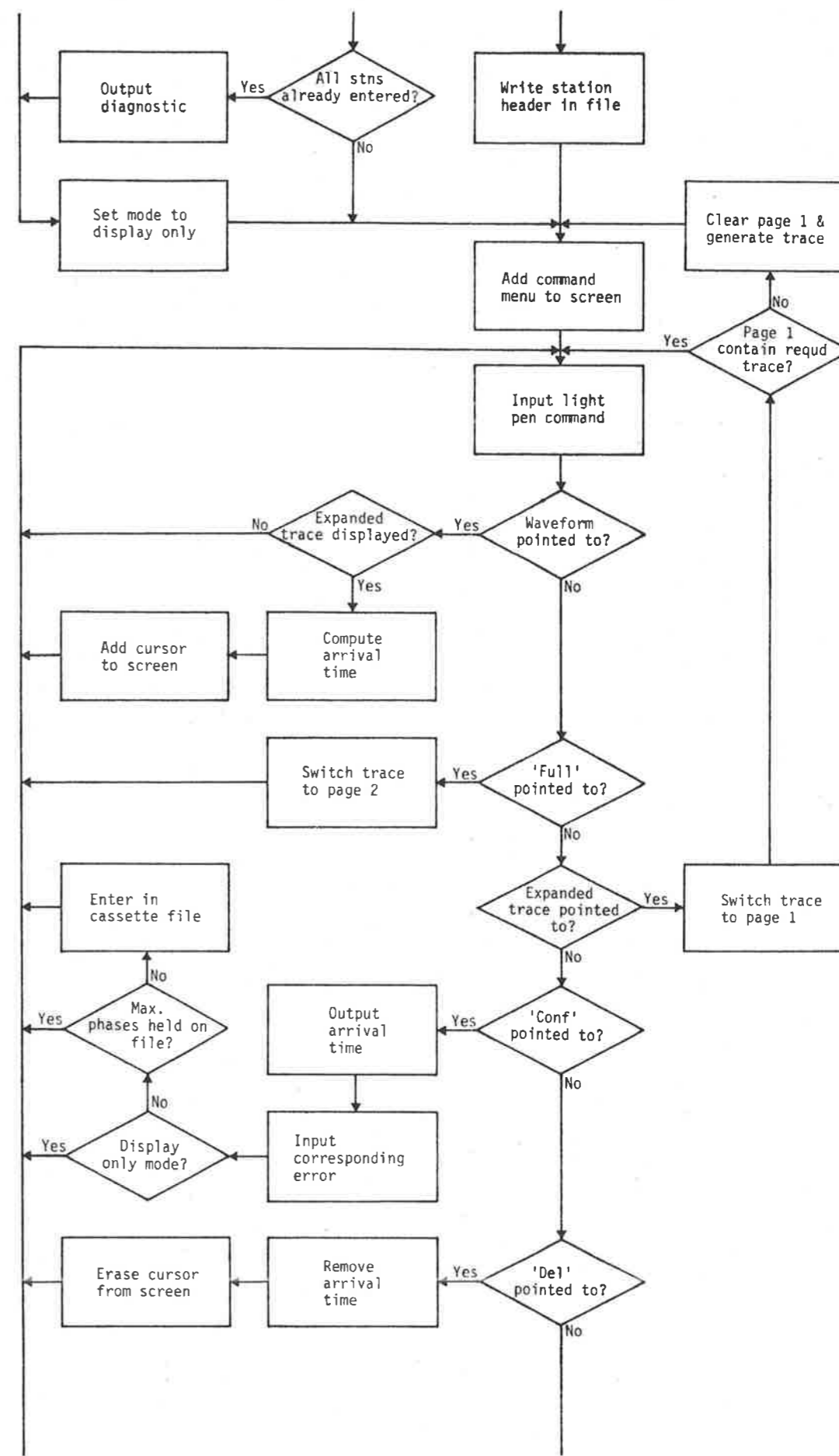
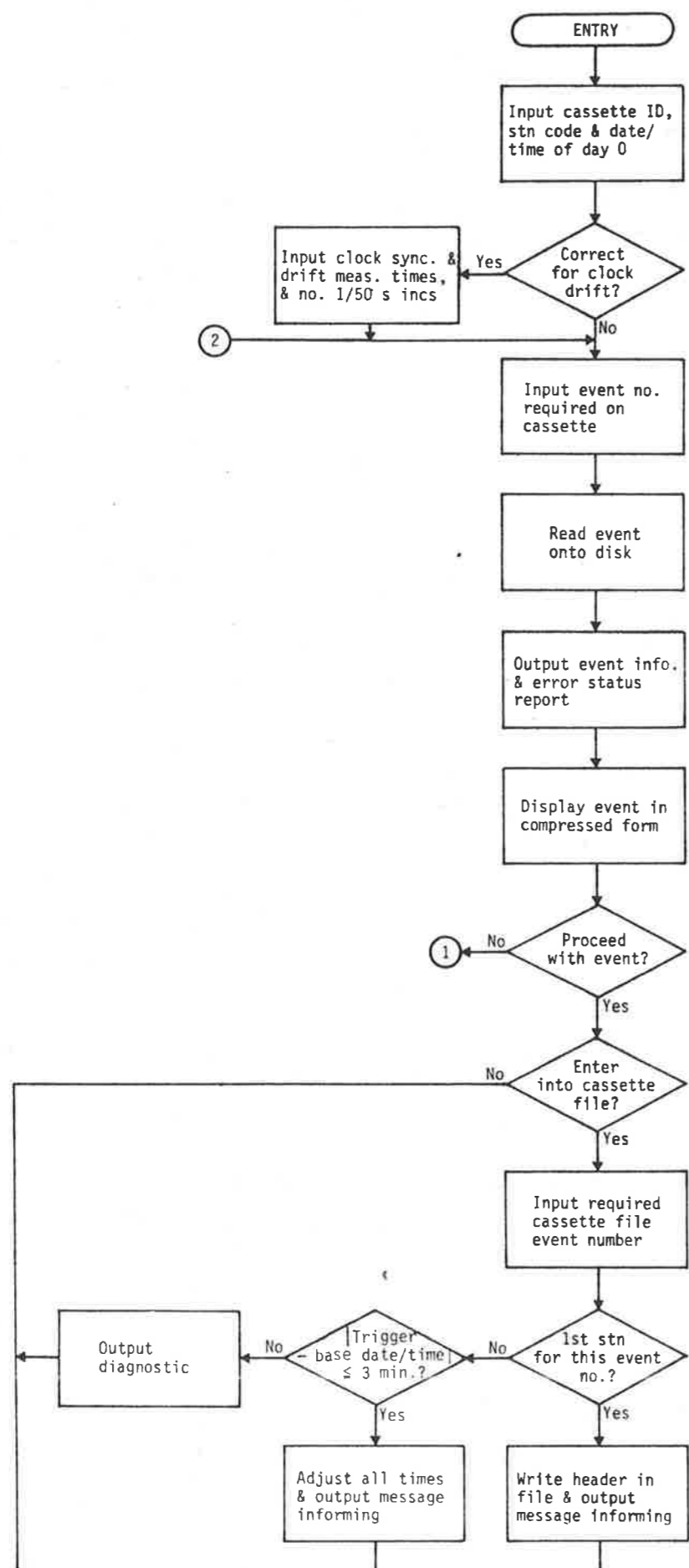
Figure 6.7 shows a simplified flowchart for the ENTER command. The command is intended to process all events in turn on a given event recorder cassette, and commences by requesting the station code and cassette identification. If required, clock drift in the event recorder can be taken into account. This involves entering the day number and hour corresponding to the time of the original synchronization and the subsequent drift measurement, and the number of 1/50 s increments to be added to the event recorder clock at the

TABLE 6.4  
 STRUCTURE OF THE TEMPORARY DISK FILE CREATED  
 WHEN AN EVENT IS READ FROM CASSETTE

INFORMATION	DATA TYPE	INTERNAL FILE FORMAT
1/50 s portion of trigger time	4-byte floating point numeric	Offset by -50
Second portion of trigger time	"	Offset by -60
Minute portion of trigger time	"	Offset by -60
Hour portion of trigger time	"	Offset by -24
Day of trigger	"	
Amplifier attenuation (in dB)	"	
ROM identification number	"	
Event Duration, low order (L)	"	If $L < 0$ then $L \leftarrow L + 256$
Event duration, high order (H)	"	Duration (in s) = $(256 * H + L) / 50$
Data at 1/50 s intervals	"	

Note: Trigger time corresponds to the 256th datum from the commencement of the data portion of the file.

time of the drift measurement in order to read the correct time. (The last value can be easily determined in the field using the clock error status readout of Table 6.1.) Assuming a uniform drift rate, the drift per hour is internally determined and applied invisibly to all subsequent event arrival times. The required event on the cassette (usually the next) is read into the temporary disk file as discussed previously. The trigger date and time, amplifier attenuation, ROM identification and event duration read from the file (Table 6.4) are printed, the first computed using an internal calendar from the day number and previously supplied date corresponding to day zero.



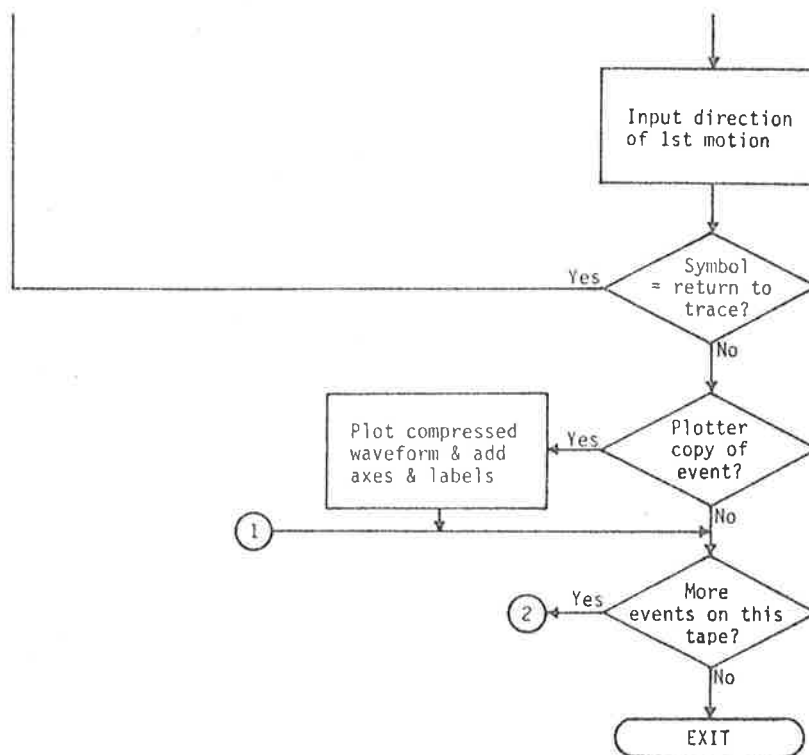


FIGURE 6.7

ENTER COMMAND LOGIC.

The waveform of the complete event is displayed on the system television monitor in a compressed form, as a means of displaying up to the maximum  $(14 \times 128) - 9 = 1727$  event data points within the 512 pixel horizontal resolution of the graphics unit. To achieve this compression, the mean of every four samples is computed and plotted. A parity error in one of the four samples (as indicated by the presence of the otherwise impossible value 200) causes the remaining three samples to be used; two parity errors causes the remaining two to be used; and more than two errors results in a gap in the trace. (In fact, present early indications are that parity errors are very rare, in keeping with the quoted Digideck error rate mentioned earlier.)

With the event displayed for examination, the seismologist can

decide whether to skip the event or to proceed further. If the latter, he/she can also elect only to display phase arrival times or to additionally enter them into the cassette file. When cassette file entry is requested, a cassette file event number must be supplied. If one or more previous cassettes have already been read for the event (as ascertained from the trigger dates and times), the cassette file number supplied is that used with the previous cassettes; if not, a currently free cassette file number is supplied. In the latter case, the trigger date and time is written in the event header (Table 6.2) as the event date and time; in the former, the trigger date and time is compared with the base date and time on file. If the two differ by more than three minutes, a diagnostic is issued and display-only mode is forced; if not, arrival times (in seconds) are adjusted so as to be correct relative to the file base date and time. A message informing of the nature of the adjustment is printed.

The preceding steps, and those to follow, are illustrated in Figures 6.8, 6.9 and 6.10, which show an event from an event recorder cassette being processed using the ENTER command. In the case shown, the arrival times are being entered into the cassette file and data are the first entered for the particular event. An informative message appears as stated above, after which a command menu is drawn on the television screen (Figure 6.9). Further processing is directed from the screen using the light pen as follows:

1. If the pen is pointed at the 'Full' command, the full (compressed) trace as shown in Figure 6.9(a) is returned to the screen. (As stated in Chapter 2, the graphics unit can operate with two independent pages. In this instance, the full trace is kept permanently on the second page for immediate return without need for regeneration.)



30/06/1981 23:09 [CASSET] COMMAND: ENTER

CASSETTE ID: S18

STATION CODE: ADL

DATE (DD/MM/YYYY) CORRESPONDING TO DAY 0 ON TAPE: 13/06/1981

DO YOU WANT TO CORRECT TIMES FOR CLOCK DRIFT (Y OR N)? Y

CLOCK SYNC. DAY NO. AND HOUR: 0.5 DRIFT MEAS. DAY NO. AND HOUR: 2.7 DRIFT (IN 1/50 s) TO BE ADDED: 3

--- INITIALIZE CASSETTE UNIT, THEN PRESS 'RETURN' ---

NEXT EVENT ON TAPE (N) OR EVENT ID NO: 4

EVENT ID NO. 4 TRIGGER DATE AND TIME = 13/06/1981 06:00 ROM ID = 1 ATTENUATION = 24 dB DURATION = 108.3 s  
ERROR SUMMARY: 0 single errors, 0 double errors, 0 aborted points,  
0 total errors, 1780 total samples.

PROCEED WITH THIS EVENT (P) OR IGNORE (I)? P

ENTER INTO CASSETTE FILE (E) OR DISPLAY ONLY (D)? E

CASSETTE FILE EVENT NUMBER: 10

NEW EVENT - TRIGGER DATE AND TIME WILL BECOME BASE DATE AND TIME.

PHASE NO. ARR. TIME ERROR

1	43.5	+1.1
2	55.8	+1.2
3	45.3	+1.3
4	46.1	+1.3
5	48.1	+1.3
6	43.7	+1.3
7	52.7	+1.4
8	61.5	+1.4

MAXIMUM NUMBER OF PHASES NOW ON FILE - HENCEFORTH DISPLAYING ONLY.

9	58.0	+1.5
10	71.4	+1.5

FIRST MOTION (U,D if clear; +,- if poor; N if not readable; R if return to trace): -

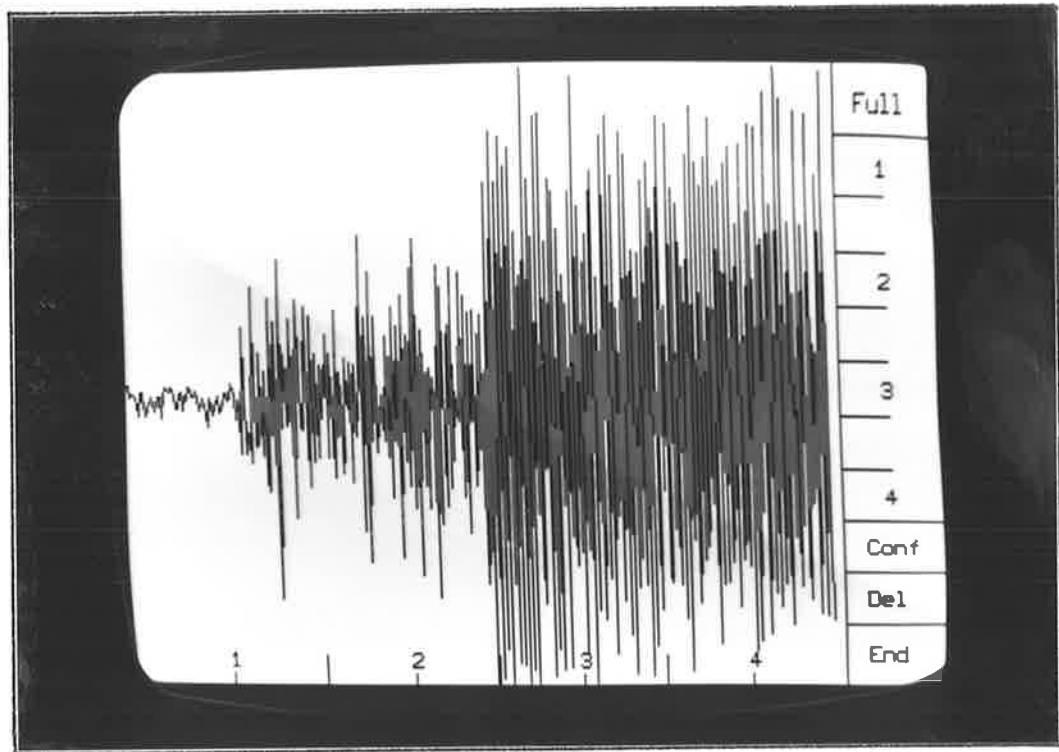
DO YOU WANT PLOTTER COPY OF WAVEFORM (Y OR N)? Y

+++ INITIALIZE PLOTTER, THEN PRESS 'RETURN' +++

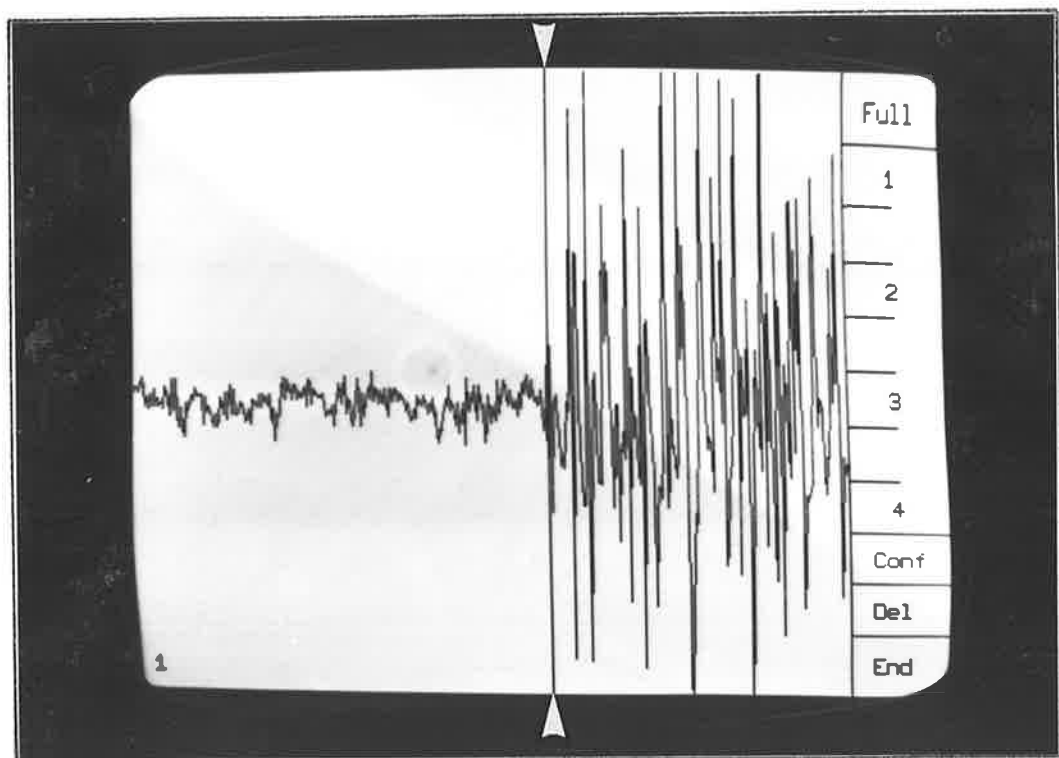
ANOTHER EVENT ON THIS TAPE (Y OR N)? N

FIGURE 6.8

THE USE OF COMMAND ENTER TO READ AND PROCESS AN EVENT FROM AN EVENT RECORDER CASSETTE.



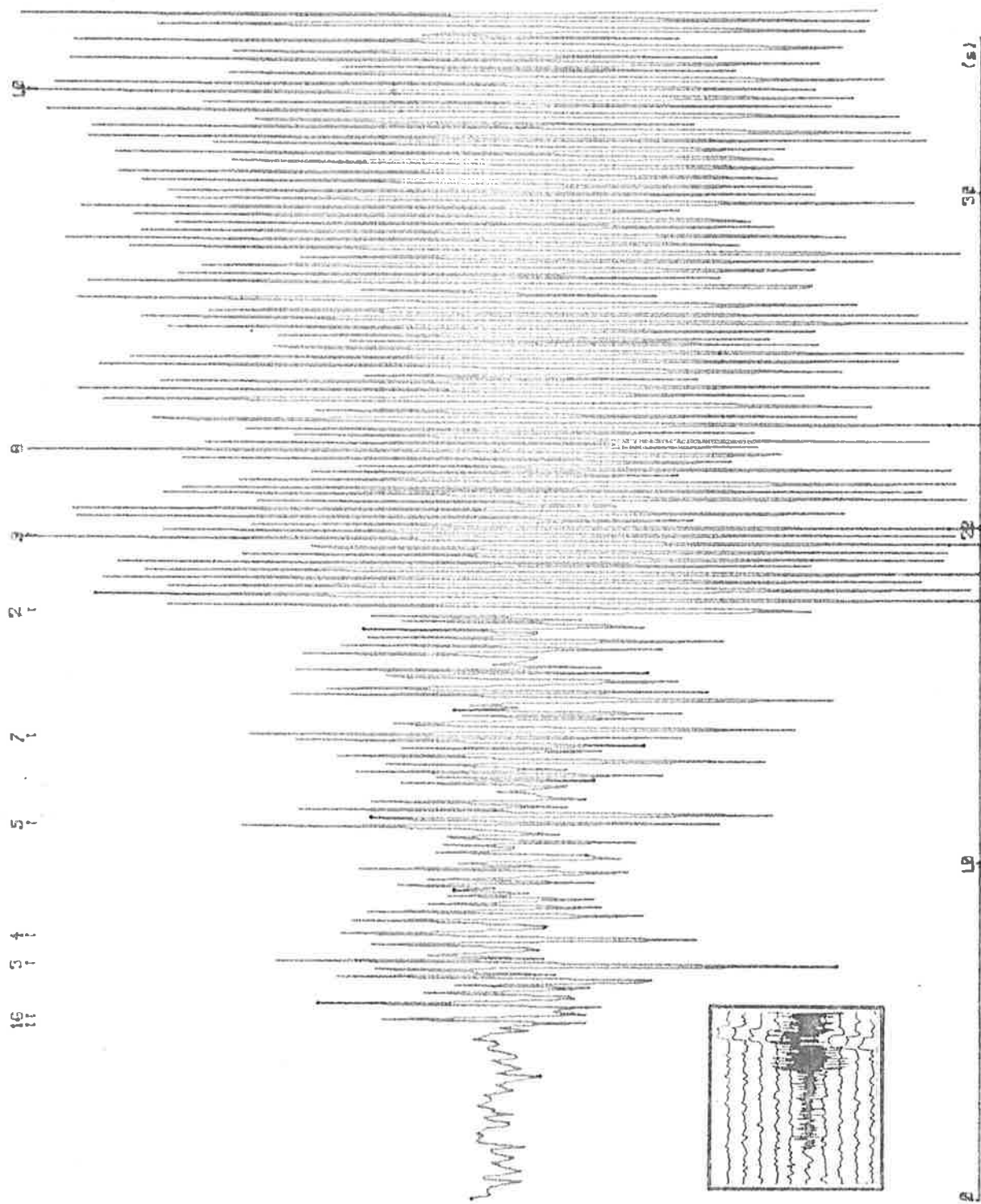
(a) Full trace (compressed by a factor of four).



(b) Portion of the trace at full resolution, with cursor indicating a phase identification.

FIGURE 6.9

EXAMPLES OF GRAPHICS DISPLAY OUTPUT CORRESPONDING TO THE EVENT OF FIGURE 6.8.



ADE 13/06/1981 06:00 (0 = 38.3 s)

FIGURE 6.10

PLOTTER HARDCOPY OF THE EVENT SHOWN IN FIGURES 6.8 AND 6.9. (Numbered markers indicate phase identifications. Inset shows the same event recorded conventionally.)

2. If the pen is pointed at one of the numbered or blank boxes in the command menu, a portion of the waveform is displayed at full resolution, in which one horizontal pixel displacement corresponds to one sample interval on the original tape. (Parity errors in this case always result in a gap in the trace.) The portions displayed for boxes labelled 1 to 4 are indicated along the bottom of the full trace in Figure 6.9(a). The blank boxes generate the last half of the previous-numbered portion of the waveform and the first half of the next. An example is shown in Figure 6.9(b) (in which the vertical cursor was generated subsequently, as in 3 below). A number in the bottom left-hand corner of the screen identifies the portion of the trace displayed.
3. If the pen is pointed at a phase displayed at full resolution, a vertical cursor is drawn through the point on the screen (Figure 6.9(b)) and the arrival time of the phase (possibly corrected for clock drift) is internally calculated.
4. If the pen is pointed at the 'Del' command, the cursor is erased and the arrival time cancelled.
5. If the pen is pointed at the 'Conf' command, it is assumed that the cursor is positioned correctly and the seismologist wishes to confirm the phase for arrival time display and (if applicable) entry into the cassette file. The arrival time is printed as shown in Figure 6.8, after which an error estimate is requested from the seismologist, who replies with a time in seconds as in the REVISE command of subsystem LOCAL (Chapter 3).

The above are executed repeatedly until,

6. If the pen is pointed at the 'End' command, the interactive phase selection portion of the command is concluded and execution passes to the entry of the direction of first motion.

The effect of one of the possible replies to the direction of first motion request is to re-enter light pen input mode. This reply is issued if the direction was not previously noted. Otherwise an appropriate code is entered, as in command FIRST of subsystem LOCAL (Chapter 3). Execution then passes to the final phase, in which the compressed trace may be drawn on the system plotter, as in Figure 6.10. The scale along the base of such a plot indicates time in seconds relative to the origin time displayed along the side of the plot. The phases identified during the execution of the command are labelled along the top of the plot, with numbers corresponding to those in the arrival times table (Figure 6.8).

Because the trigger date and time of the first station is used to establish the base date and time of an event, it is possible, if that station is disproportionately close to or distant from the earthquake, for the resulting base date and time to have an inconvenient value for the remainder of the stations. Under these circumstances, all arrival times for the event in the cassette file may be adjusted using the ADJUST command in subsystem CASET, the manner of use of which is illustrated in Figure 6.5. The command can also be used to compensate for a parity error in the event header on tape (which results in zero being substituted in the file in place of the value) if the correct value can be inferred.

As a result of the procedures discussed in this section, hard-copy seismograms of events recorded on event recorder cassettes may be obtained and phase arrival times filed in a form able to be used directly by other subsystems in ISAS. The latter aspect is discussed in the next section.

## 6.7 Cassette Data Processing in Subsystems LOCAL and MICRO

The handling of cassette file data by the ISAS subsystems is largely automatic. Figure 6.11 shows the manner in which a provisional solution proceeds when some data derive from the cassette file and the remainder from conventional seismograms. Subsequent to supplying the cassette file event number, the first two phases in the file for each cassette station are automatically used for the determination of the provisional solution. It is assumed, therefore, that during the ENTER command the first P and S arrivals are entered as phases 1 and 2. The base date and time is also read from the file, and communicated to the seismologist for verification and to indicate that phase arrival times to be entered for conventional stations must be relative to the same base. At the conclusion of the calculation, when the seismologist has the option of repeating the location with different arrival times, alternative cassette file phases may be indicated by entering their phase numbers (preceded by a # symbol to distinguish them from arrival times). If a temporary file is generated at the conclusion of the command, duration and direction of first motion data from the cassette file are also entered into the temporary file together with the information used in PROV.

REVISE in Subsystem LOCAL operates in a similar manner, as shown in Figure 6.12 for the same earthquake as in Figure 6.11. Following the display of phase arrival times, phases from the cassette file can be assigned by entering their phase numbers preceded by # symbols. It is not necessary to enter the associated error estimates since these are already known from the cassette file.

The duration magnitude command and direction of first motion command, shown in Figure 6.13 for the same earthquake as previously, further illustrate the automatic nature of cassette data treatment.

23/04/1981 23:38 [LOCAL] COMMAND: PROU

DATA FROM CASSETTE (C), SEISMOGRAM (S), CASSETTE AND SEISMOGRAM (A) OR TEMPORARY FILE (T)? A

CASSETTE FILE EVENT NUMBER: 1

BASE DATE AND TIME = 08/09/1980 10:35

NUMBER OF STATIONS WITH SEISMOGRAM OBSERVATIONS: 2

ENTER DATA IN THE FOLLOWING TABLE, TERMINATING EACH NUMBER WITH THE 'RETURN' KEY AND ENTERING '-' FOR MISSING DATA:

NO.	STN	P (s)	S (s)
1	<u>PNA</u>	<u>61.4</u>	<u>71.3</u>
2	<u>RPA</u>	<u>62.0</u>	<u>71.9</u>

DO YOU WANT TO CHANGE ANY VALUES (Y OR N)? N

CALCULATE (C) OR SUPPLY (S) HYPOCENTRAL COORDINATES? C

DEFAULT EPICENTRE SEARCH REGION: Geog latitude -39 to -28 Longitude 129 to 142

DO YOU WANT TO CHANGE THESE LIMITS (Y OR N)? N

CALCULATE (C) OR SUPPLY (S) ORIGIN TIME? C

STATION TO BE USED IN DETERMINING ORIGIN TIME: EDD

ASSUMPTION: P1/S1 (1), P1/Sn (2), Pn/S1 (3), or Pn/Sn (4)? 1

MODEL 1: Single layer, 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)

PROVISIONAL SOLUTION: Geog latitude = -32.75 Longitude = 138.33 Depth = 24 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.4 s

STN	DIST	AZM	PH	ARR TIME	OBS TT	CALC TT	RES	PH	ARR TIME	OBS TT	CALC TT	RES
EDD	54	330	P1	57.0	9.6	9.6	0.0	S1	64.1	16.7	16.7	0.0
HTT	93	144	P1	63.0	15.6	15.5	0.1	S1	73.5	26.1	27.0	-0.9 *
NBK	33	279	P1	54.0	6.6	6.6	-0.1	S1	59.0	11.6	11.6	0.0 *
PNA	84	349	P1	61.4	14.0	14.0	-0.0	S1	71.3	23.9	24.4	-0.5 *
RPA	87	271	P1	62.0	14.6	14.5	0.0	S1	71.9	24.5	25.3	-0.8 *

SE RES = 4.1E-02 s (\* excluded, not used)

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? Y

DO YOU WANT TO SAVE THE LAST SOLUTION (Y OR N)? Y

TO RESTORE, SPECIFY SAVED SOLUTION NUMBER 1.

DO YOU WANT TO CHANGE ANY ARRIVAL TIMES (Y OR N)? Y

IN THE FOLLOWING, TO REMOVE AN ARRIVAL, SPECIFY '-' FOR NEW TIME. TO END, SPECIFY '-' FOR STATION CODE.

NOTE: To use an arrival time from cassette file, specify '#' followed by phase number.

STN: HTT P OR S? S NEW VALUE: #3  
STN: PNA P OR S? S NEW VALUE: #4 NOT A CASSETTE STATION - IGNORED.  
STN: =

CALCULATE (C) OR SUPPLY (S) HYPOCENTRAL COORDINATES? C

DEFAULT EPICENTRE SEARCH REGION: Geog latitude -39 to -28 Longitude 129 to 142  
DO YOU WANT TO CHANGE THESE LIMITS (Y OR N)? N

CALCULATE (C) OR SUPPLY (S) ORIGIN TIME? C

STATION TO BE USED IN DETERMINING ORIGIN TIME: EDQ  
ASSUMPTION: P1/S1 (1), P1/Sn (2), Pn/S1 (3), or Pn/Sn (4)? 1

MODEL 1: Single layer, 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)

PROVISIONAL SOLUTION: Geog latitude = -32.75 Longitude = 138.33 Depth = 24 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.4 s

STN	DIST	AZM	PH	ARR.TIME	OBS.TT	CALC.TT	RES	PH	ARR.TIME	OBS.TT	CALC.TT	RES
EDQ	54	330	P1	57.0	9.6	9.6	0.0	S1	64.1	16.7	16.7	0.0
HTT	93	144	P1	63.0	15.6	15.5	0.1	S1	75.7	28.3	27.0	1.3 *
NEK	33	279	P1	54.0	6.6	6.6	-0.1	S1	59.0	11.6	11.6	0.0 *
PNA	84	349	P1	61.4	14.0	14.0	-0.0	S1	71.3	23.9	24.4	-0.5 *
RPA	87	271	P1	62.0	14.6	14.5	0.0	S1	71.9	24.5	25.3	-0.8 *

SE RES = 4.1E-02 s (\* excluded, not used)

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? N

DO YOU WANT TO ENTER RESULTS INTO TEMPORARY FILE (Y OR N)? Y

CURRENT SOLUTION (C) OR SAVED SOLUTION NUMBER: 1

TEMPORARY FILE 2 WILL BE USED. REFERENCE NUMBER OF EVENT (UP TO 7 CHARACTERS): 221/80

TRANSFER COMPLETED.

FIGURE 6.11

DETERMINATION OF A PROVISIONAL LOCATION IN WHICH DATA FOR SOME STATIONS ARE DERIVED FROM THE CASSETTE FILE AND THE REMAINDER ARE ENTERED MANUALLY FROM SEISMOGRAMS. (For illustration, the earthquake is the same as used in Chapter 3.)



23/04/1981 23:48 [LOCAL] COMMAND: REVISE

PROVISIONAL DATA FROM KEYBOARD (K) OR TEMPORARY FILE (T)? T  
REVISION ARRIVAL TIMES FROM CASSETTE (C), SEISMOGRAM (S), CASSETTE AND SEISMOGRAM (A) OR TEMPORARY FILE (T)? A

TEMPORARY FILE NUMBER (1 TO 5): 2

CASSETTE FILE EVENT NUMBER: 1

REL TO 08/09/1980 10:35, CALCULATED ARRIVAL TIMES OF PHASES ARE:

STN	NO.	P1	NO.	PR	NO.	Pn	NO.	S1	NO.	SR	NO.	Sn
EDD	1	57.0	2	59.5	3	-	4	64.1	5	68.4	6	-
HTT	7	62.9	8	64.6	9	64.3	10	74.4	11	77.3	12	76.9
NBK	13	54.1	14	57.3	15	-	16	59.0	17	64.6	18	-
PNA	19	61.4	20	63.2	21	63.1	22	71.8	23	75.0	24	74.7
RPA	25	62.0	26	63.7	27	63.5	28	72.7	29	75.8	30	75.5

ENTER DATA IN THE FOLLOWING TABLE, SEPARATING NUMBERS WITH THE 'RETURN' KEY AND USING NO. 0 TO END.

NOTE: To change a previous line, retype the line; to delete entirely, specify '-' for arrival time.  
A 'P' or 'S' may be typed instead of an arrival time to use provisional time from temporary file.  
To use an arrival time from cassette file, specify '#' followed by phase number.

NO.	ARR. TIME	ERROR
<u>1</u>	<u>#1</u>	
<u>2</u>	<u>#3</u>	
<u>4</u>	<u>#2</u>	
<u>5</u>	<u>#4</u>	
<u>7</u>	<u>#1</u>	
<u>10</u>	<u>#2</u>	
<u>13</u>	<u>#1</u>	
<u>14</u>	<u>#3</u>	
<u>16</u>	<u>#2</u>	
<u>19</u>	<u>P</u>	<u>.2</u>
<u>22</u>	<u>S</u>	<u>.3</u>
<u>25</u>	<u>P</u>	<u>.3</u>
<u>27</u>	<u>63.0</u>	<u>.2</u>
<u>28</u>	<u>S</u>	<u>.3</u>
<u>0</u>		

REJECT PHASES WITH LARGE RESIDUALS (R) OR USE ALL PHASES (A)? R

SUM WT = 9.56 NO PH = 14 SE RES = 3.6E-01 s

MODEL 1: Single layer, 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)

REVISED SOLUTION 1: Geog latitude = -32.759 Longitude = 138.334 Depth = 25.0 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.13 s

STN	DIST	AZM	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES
				OBS	ERR	CALC	OBS	CALC	OBS			ERR	CALC	OBS	CALC	OBS	ERR			CALC	OBS	CALC	OBS	ERR	CALC	
EDD	55	331	P1	57.0	0.2	56.9	9.9	9.8	0.1	PR	59.4	0.3	59.3	12.3	12.1	0.1	Pn	-	-	0.0	Sn	-	-	0.0		
			S1	64.1	0.2	64.1	17.0	17.0	-0.0		SR	68.6	0.3	68.2	21.5	21.1		0.4	-	-		0.0				
HTT	93	144	P1	63.0	0.3	62.5	15.9	15.4	0.5	PR			64.1		17.0	Pn		63.9	16.8	Sn		76.3	29.2			
			S1	73.5	0.3	73.9	26.4	26.8	-0.4		SR			76.7			29.6	-	-		0.0					
NBK	34	281	P1	54.0	0.2	53.9	6.9	6.7	0.1	PR	56.7	0.3	57.0	9.6	9.8	-0.3	Pn	-	-	0.0	Sn	-	-	0.0		
			S1	59.0	0.2	58.8	11.9	11.7	0.2		SR			64.2		17.1		-	-	0.0						
PNA	85	349	P1	61.4	0.2	61.4	14.3	14.2	0.0	PR			63.1		15.9	Pn		62.9	15.8	Sn		74.6	27.5			
			S1	71.3	0.3	71.9	24.2	24.8	-0.6		SR			74.9			27.7	-	-		0.0					
RPA	87	272	P1	62.0	0.3	61.7	14.9	14.6	0.3	PR			63.4		16.2	Pn	63.0	0.2	63.2	15.9	16.0	-0.2	Sn	75.1	27.9	
			S1	71.9	0.3	72.5	24.8	25.4	-0.6		SR			75.4			28.3	-	-	0.0						

SUM WT = 9.56 NO PH = 14 SE RES = 3.3E-01 s SE LAT = 8.7E-03 SE LONG = 1.3E-02 SE DEPTH = 1.1E+00 km SE OT = 1.6E-01 s

REVISED SOLUTION 2: Geos latitude = -32.759 Longitude = 138.334 Depth = 25.0 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.13 s

STN	DIST	AZM	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES	PH	ARRIVAL-TIMES			TRAVEL-TIMES			RES
				OBS	ERR	CALC	OBS	CALC	OBS			ERR	CALC	OBS	CALC	OBS	ERR			CALC	OBS	CALC	OBS	ERR	CALC	
EDD	55	331	P1	57.0	0.2	56.9	9.9	9.8	0.1	PR	59.4	0.3	59.3	12.3	12.1	0.1	Pn	-	-	0.0	Sn	-	-	0.0		
			S1	64.1	0.2	64.1	17.0	17.0	-0.0		SR	68.6	0.3	68.2	21.5	21.1		0.4	-	-		0.0				
HTT	92	144	P1	63.0	0.3	62.5	15.9	15.4	0.5	PR			64.1		17.0	Pn		63.9	16.8	Sn		76.3	29.2			
			S1	73.5	0.3	73.9	26.4	26.8	-0.4		SR			76.7			29.6	-	-		0.0					
NBK	33	281	P1	54.0	0.2	53.8	6.9	6.7	0.2	PR	56.7	0.3	56.9	9.6	9.8	-0.2	Pn	-	-	0.0	Sn	-	-	0.0		
			S1	59.0	0.2	58.8	11.9	11.7	0.2		SR			64.2		17.1		-	-	0.0						
PNA	85	349	P1	61.4	0.2	61.4	14.3	14.2	0.0	PR			63.1		15.9	Pn		62.9	15.8	Sn		74.6	27.5			
			S1	71.3	0.3	71.9	24.2	24.8	-0.6		SR			74.9			27.7	-	-		0.0					
RPA	87	272	P1	62.0	0.3	61.7	14.9	14.6	0.3	PR			63.4		16.2	Pn	63.0	0.2	63.2	15.9	16.0	-0.2	Sn	75.1	27.9	
			S1	71.9	0.3	72.5	24.8	25.4	-0.6		SR			75.4			28.3	-	-	0.0						

SUM WT = 9.56 NO PH = 14 SE RES = 3.3E-01 s SE LAT = 8.8E-03 SE LONG = 1.3E-02 SE DEPTH = 1.1E+00 km SE OT = 1.6E-01 s

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? Y  
DO YOU WANT TO SAVE THE LAST SOLUTION (Y OR N)? Y  
TO RESTORE, SPECIFY SAVED SOLUTION NUMBER 1.

DO YOU WANT TO CHANGE PROVISIONAL SOLUTION (Y OR N)? N

DO YOU WANT TO CHANGE ANY ARRIVAL TIMES (Y OR N)? Y

ENTER NEW DATA IN THE FOLLOWING TABLE, SEPARATING NUMBERS WITH THE 'RETURN' KEY AND USING NO. 0 TO END.  
NOTE: To change a previous line, retype the line; to delete entirely, specify '-' for arrival time.  
A 'P' or 'S' may be typed instead of an arrival time to use provisional time from temporary file.  
To use an arrival time from cassette file, specify '#' followed by phase number.

NO.	ARR. TIME	ERROR
:5	:#4	
:11	:#6	
:17	:#4	
:0		

PHASE NOT PRESENT FOR THIS STATION - IGNORED.

REJECT PHASES WITH LARGE RESIDUALS (R) OR USE ALL PHASES (A)? R

SUM WT = 9 81 NO PH = 15 SE RES = 3.6E-01 s

MODEL 1: Single layer, 6.23 (P1), 3.58 (S1), 8.05 (P2), 4.6 (S2), 38 (H)

REVISED SOLUTION 1: Geog latitude = -32.758 Longitude = 138.332 Depth = 24.9 km  
Base date and time = 08/09/1980 10:35 Origin time = 47.16 s

SUM WT = 9 81 NO PH = 15 SE RES = 3.2E-01 s SE LAT = 8.5E-03 SE LONG = 1.2E-02 SE DEPTH = 1.0E+00 km SE OT = 1.4E-01 s

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? N

DO YOU WANT TO ENTER RESULTS INTO TEMPORARY FILE (Y OR N)? Y

CURRENT SOLUTION (C) OR SAVED SOLUTION NUMBER: 1

TRANSFER COMPLETED.

FIGURE 6.12

REVISION OF THE PROVISIONAL LOCATION OF FIGURE 6.11, USING A COMBINATION OF DATA FROM THE CASSETTE FILE AND FROM SEISMOGRAMS.

24/04/1981 00:00 [LOCAL] COMMAND: MAGD

DATA FROM CASSETTE (C), SEISMOGRAM (S), CASSETTE AND SEISMOGRAM (A) OR TEMPORARY FILE (T)? T  
TEMPORARY FILE NUMBER (1 TO 5): 2

ENTER DATA IN THE FOLLOWING TABLE (IF REQUESTED), TERMINATING EACH NUMBER WITH THE 'RETURN' KEY  
AND ENTERING 0 FOR EACH VALUE NOT DETERMINED:

STN	DURN (s)	DIST (km)	MD
EDQ	69	55	1.9
HTT	69	92	1.9
NBK	68	33	1.9
PNA	:108	85	1.9
RPA	:0		

-----  
MEAN: 1.9  
SD: 4.4E-02

DO YOU WANT TO ENTER RESULTS INTO TEMPORARY FILE (Y OR N)? Y  
TRANSFER COMPLETED.

24/04/1981 00:02 [LOCAL] COMMAND: FIRST

TEMPORARY FILE NUMBER (1 TO 5): 2

DO YOU WANT KEY TO SYMBOLS PRINTED (Y OR N)? N

ENTER DATA IN THE FOLLOWING TABLE (IF REQUESTED):

STN	1st MOTN
EDQ	+
HTT	+
NBK	0
PNA	:+
RPA	:H

READY TO TRANSFER TO TEMPORARY FILE. PROCEED (P) OR ABORT (A)? P  
TRANSFER COMPLETED.

FIGURE 6.13

DETERMINATION OF DURATION MAGNITUDE (MD) AND ENTRY OF DIRECTION OF FIRST MOTION DATA FOR THE EVENT OF FIGURES 6.11 AND 6.12, IN WHICH DATA FOR SOME STATIONS DERIVE FROM THE CASSETTE FILE AND THE REMAINDER FROM SEISMOGRAMS.

The durations and first motions, normally requested for conventional stations, have already been read from the cassette file for the event recording stations and are instead displayed and automatically used as if just entered. (MN magnitude has not been implemented for the event recorders.)

Subsystem MICRO is involved with event recorder data processing in command SOLVE. The treatment is entirely consistent with that in subsystem LOCAL, and can be seen in Figure 6.14 in which data again derive partially from the cassette file and partially by keyboard entry from seismograms. Subsequent to specifying the cassette file event number, the first two phase arrival times, the durations, and the directions of first motion for each event recording station are read from the cassette file and automatically used in the solution. Seismogram data can then be entered relative to the cassette file base date and time, which is printed for verification and reference. Alternative cassette file phases can be substituted following the calculation by specifying their phase numbers preceded by # symbols.

In each of the above cases, if cassette data only were specified, the commands would contract by omitting all requests for seismogram data. The internal command logic of PROV, REVISE and SOLVE can be seen in the flowcharts of Figures 3.4, 3.6 and 4.9 respectively, and the seismological aspects of all commands shown in this section are discussed in the appropriate sections of Chapters 3 and 4.

## 6.8 Future Directions

Given the present rate of advance of semiconductor technology, the long-term possibilities for the event recorders cannot be predicted. However, some short-term goals and improvements can be foreseen. For example, the availability of monolithic CMOS 16-channel

24/04/1981 00:07 [MICRO] COMMAND: SOLVE

DATA FROM CASSETTE (C), SEISMOGRAM (S), CASSETTE AND SEISMOGRAM (A), HOLDING FILE (H), ARCHIVE DISKETTE (D)  
OR [LOCAL] TEMPORARY FILE (T)? A

CASSETTE FILE EVENT NUMBER: 4  
BASE DATE AND TIME = 17/09/1980 23:13

NUMBER OF STATIONS WITH SEISMOGRAM OBSERVATIONS: 2  
ENTER DATA IN THE FOLLOWING TABLE, TERMINATING EACH NUMBER WITH THE 'RETURN' KEY AND ENTERING '-' FOR MISSING DATA.  
NOTE: Enter missing first motions as N (not readable). Other codes are U,D (clear) and +,- (poor).

NO.	STN	P (s)	S (s)	DURN (s)	1st MOTN
1	<u>PNA</u>	<u>35.5</u>	<u>-</u>	<u>65</u>	<u>U</u>
2	<u>RFA</u>				
2	<u>EDO</u>	<u>30.4</u>	<u>-</u>	<u>57</u>	<u>D</u>

STATION ALREADY PRESENT - IGNORED.

DO YOU WANT TO CHANGE ANY VALUES (Y OR N)? N

NETWORK DATA FROM PERMANENT (P) OR TEMPORARY (T) NETWORK FILE? P

CONSTANTS:  $v(P1)/v(S1) = 1.74022$   $v(P1) = 6.23$  km/s  $v(S1) = 3.58$  km/s  
Lat. origin = -32.5 Long. origin = 138 Lat. to km = 110.893 Long. to km = 93.9763

SOLUTION: Base date and time = 17/09/1980 23:13  
Geog latitude = -32.773 (SE=3.9E-06) Longitude = 138.251 (SE=4.9E-06)  
 $v(P1) = 6.24$  km/s (SE=1.7E-02)

STN	DIST	AZM	1st MOTN	OR TIME	P ARR.TIME	S ARR.TIME	v(S1)	DEPTH	DURN	MD
NBK	26.4	288	+	21.6	26.1	29.4	3.54	5.6	49.0	1.6
RFA	79.8	274	+	21.9	34.6	44.0	3.60	5.7	45.0	1.5
PNA	85.4	355	U		35.5			5.6	65.0	1.5
EDO	53.5	339	D		30.4			5.5	57.0	1.7
MEAN:				21.8			3.57	5.6		1.6
SD:				1.8E-01			4.3E-02	8.3E-02		9.2E-02

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? Y  
DO YOU WANT TO SAVE THE LAST SOLUTION (Y OR N)? Y  
TO RESTORE, SPECIFY SAVED SOLUTION NUMBER 1.

IN THE FOLLOWING, P = P ARR.TIME, S = S ARR.TIME, D = DURN, F = 1st MOTN.  
TO REMOVE A VALUE, SPECIFY '-' FOR NEW VALUE (OR 'N' IF A 1st MOTN). TO END, SPECIFY '-' FOR STATION CODE.  
NOTE: To use an arrival time from cassette file, specify '#' followed by phase number.

STN: NBK P,S,D OR F? S NEW VALUE: #4  
STN: -

CONSTANTS:  $v(P1)/v(S1) = 1.74822$   $v(P1) = 6.23 \text{ km/s}$   $v(S1) = 3.58 \text{ km/s}$   
 Lat. origin = -32.5 Long. origin = 138 Lat. to km = 110.893 Long. to km = 93.9763

SOLUTION: Base date and time = 17/09/1980 23:13  
 Geog latitude = -32.796 (SE=3.9E-06) Longitude = 138.281 (SE=5.0E-06)  
 $v(P1) = 6.07 \text{ km/s}$  (SE=1.6E-02)

STN	DIST	AZM	1st MOTN	OR TIME	P ARR TIME	S ARR TIME	v(S1)	DEPTH	DURN	MO
NRK	29.9	291	+	19.8	26.1	30.8	3.21	11.3	49.0	1.6
RPA	82.8	275	+	21.9	34.6	44.0	3.61	11.4	45.0	1.5
PNA	88.3	353	U		35.5			11.3	65.0	1.5
EDD	57.0	337	D		38.4			11.2	57.0	1.7
MEAN:				20.8			3.41	11.3		1.6
SD:				1.5E+00			2.8E-01	8.5E-02		9.2E-02

ANOTHER CALCULATION FOR THIS EVENT (Y OR N)? N

RESULTS TO HOLDING FILE (H), ARCHIVE DISKETTE (D), [LOCAL] TEMPORARY FILE (T) OR NONE (N)? I  
 CURRENT SOLUTION (C) OR SAVED SOLUTION NUMBER: 1  
 TEMPORARY FILE 3 WILL BE USED. REFERENCE NUMBER OF EVENT (UP TO 7 CHARACTERS): 227/80  
 TRANSFER COMPLETED.

24/04/1981 00:12 [MICRO] COMMAND: LOGOFF

ISAS LOGGED OFF.

FIGURE 6.14

MICROEARTHQUAKE LOCATION AND MAGNITUDE DETERMINATION USING DATA FOR SOME STATIONS FROM THE CASSETTE FILE AND THE REMAINDER FROM SEISMOGRAMS.

analogue to digital converters since the South Australian design was completed means that in future models a wider range of analogue inputs could be provided: temperature could be sensed and the data used to provide more accurate crystal compensation; battery voltage could be checked and an orderly shutdown performed (including the transfer of a status report to non-volatile magnetic tape) if the voltage fell below a minimum; and a three-component or telemetered central recorder could be designed using multiple seismic input channels. Other hardware improvements consist of the replacement of LED displays with liquid crystals, the incorporation of solar cells and dual cassette units for longer running times, and perhaps eventually the replacement of cassettes with bubble-memory devices, although this would require substantial modifications to the Nova as well as the event recorders and is also likely to be financially unrealistic for some time.

Principal software modifications, apart from those necessitated by hardware changes, include the development of Version 2 of SEROS, to be orientated towards use in permanent stations, which are serviced daily. Under these conditions, tape economies are less important and event codas can be recorded. This would then prompt the development of spectral analysis and digital filtering routines for ISAS (e.g., as in Sun and Shaub, 1978). It may also be desirable to remove the teleseism rejection measures in Version 2. The version of SEROS in use with a particular cassette is accessible to the ENTER command (and future signal processing commands) in ISAS via the ROM identification status read from tape. This can internally switch the routine into any special processing modes if required. Another software modification is the recording on tape of system calibration data. This could be extended, with additional hardware, to the automatic recording of a system calibration pulse at programmed intervals. Such



a pulse could be processed by ISAS (e.g., as in Mitchell and Landisman, 1969, or Berg and Chesley, 1976) to elicit the system characteristics.

Several other additions to ISAS have already been discussed in Chapter 3: incorporation of fault plane and composite fault plane solutions, investigation of spacial-domain (and other) revision algorithms, and incorporation of multi-layered models (especially the composite model of Shackleford, 1978). An entirely new Regional Earthquake Subsystem (REGNL) is also planned for ISAS, drawing upon work commenced in South Australia by White (1967) and subsequently extended by Kamprod (1970). Provision already exists in the ISAS event archive file structure (see Table 3.4) for events from subsystem REGNL to be combined with those from LOCAL and MICRO; and subsystem STATS was written towards the eventual incorporation of regional events. Finally, the facility mentioned in Chapter 1 to transfer data between the Data General Nova and the main University Control Data Cyber 173 (and thence via magnetic tape between the Cyber and other computers) has only become available as of February 1981. To use the facility, a transfer routine will have to be incorporated into ISAS in order to assemble the data required to be transferred, and reformat it to a suitable form for the transfer. The possibilities which will be opened up by this transfer mechanism will no doubt be endless.

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