A MICROEARTHQUAKE OBSERVATION SYSTEM WITH PORTABLE DIGITAL EVENT RECORDERS: PRINCIPLES AND APPLICATIONS

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INTRODUCTION

The Geological Survey of Japan's microearthquake study program is intended to determine the geophysical properties of the fracture and fault systems which constitute known reservoir of hot water and/or steam and to systematize the study of microearthquakes as a geophysical investigating tool for geothermal area. Detailed studies of microearthquakes can reveal the spatial extent of the geothermal reservoir by establishing the epicenter distribution. Variations in seismic wave travel time may be related to anomalies in the spatial distribution of seismic velocities. Low velocity regions may be due to the presence of highly fractured zones in geothermal areas. Spatial and temporal variations in induced earthquake epicenters allow an estimation of permeability around a injection well (Ito and Sugihara, 1988). The above studies require only the arrival time of first seismic motion as recorded by each seismometer. On the other hand Sugihara and Tosha (1988) identified microearthquake source processes in the geothermal area by an analysis of the shape of the seismic wave. The waveform itself is important in this later study. Shear wave splitting is observed when rocks under seismic stations are anisotropic in the propagation of shear wave. The anisotropy is caused by aligned microcracks (Crampin, 1978). This analysis requires a great dynamic range record because of the use of the first movement. An example of the shear wave splitting will be discussed later.

Since December 1982, a digital acquisition system with seven 3-component seismometers has been operating in the Takinoue geothermal area (which contains the Kakkonda geothermal power plant) Iwate Prefecture in Japan (Ito and Sugihara, 1987). The microearthquake data acquired by the system reveal the fundamental characteristics of the earthquake in the geothermal area. Design work is in progress on a portable version of this data acquisition system.

In 1985, 1986, and 1988, we recorded numerous microearthquakes which took place in the Takinoue geothermal area. The seismic data are recorded not only in the seven permanent stations but also temporal stations. The field experiments were designed to provide improved hypocenter locations and compressional and shear wave velocity structures. Another objective was to identify any shortcomings in the portable acquisition system. After the experiment the system have been improved both in hardware and in software to overcome the shortcomings.

RECORDING SYSTEM IN GEOTHERMAL AREA

Recent technological advances in microprocessors and integrated circuits allowed the development of portable seismic recording systems. This progress has provided system components to permit low power consumption, great dynamic range, and broad bandwidth compared to the previous ones. Even with the severe constraints upon space and power consumption required for ocean-bottom applications, some digital recording systems are now installed (McDonald et al., 1977; Prothero, 1977; Kasahara et al., 1985). All of these systems are controlled by microprocessors.

Since microprocessor control became possible, degrees of flexibility in system design have increased substantially compared with earlier hardwired units. The microprocessor permits software control of the various system hardware components based on parameters provided through online data or data keyed-in by an operator. Land-based digital recording systems use much the same architectures as those installed undersea applications, but there are a few differences arising from different environmental requirements. The general architectures of land-based digital recording systems is discussed by Borcherdt et al.(1985).

The elastic energy released by microearthquakes in geothermal areas is usually so small that high-gained amplifiers and very sensitive seismograph are required for their detection. Since the microearthquakes epicenters occur within a restricted area and must be located precisely for purposed of analysis, the seismic network in the study must be closely spaced and the average distance between seismometers. The microearthquakes with high frequency spectrum requires high accuracy of time determination and a broad range of frequency spectrum in the recording device.

HARDWARE MODULES

Hardware modules which perform the various system functions were designed to permit future technological upgrading. All modules (except the data-storage device and the operator interface devices) are configured on cards of uniform size and are interconnected by means of a 100-pin bus. Block diagram of hardware architecture in Fig. 1 shows the relationship of hardware modules in the system.

A 8-bit microprocessor (CPU-1) serves as the central module of the system, provides the hardware modules with software control, and executes software algorithms for detecting seismological events. Another microprocessor (CPU-2) is used to control a 1/4" cassette magnetic tape device with a capacity of 15 Mbyte on a 555-ft tape. The data buffer or pre-event memory module of 204 KByte RAM provides interim data storage for the cassette tape.

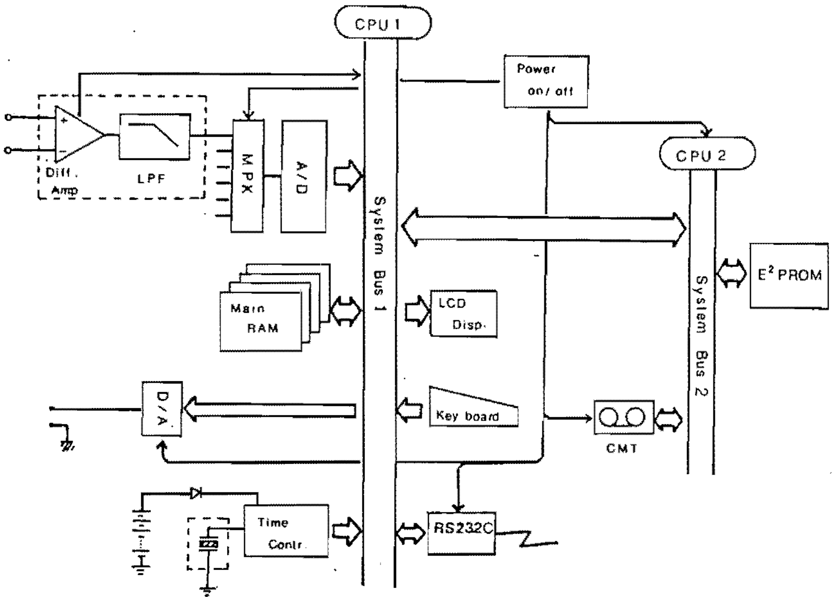

Figure 1. Simplified hardware circuit diagram. Two 8-bit microprocessors control the other hardware modules. Optional devices (including CPU-2 and the mass storage device) are shut down by CPU-1 when not in use.

The amplifiers in signal condition modules present a compromise between system noise reduction and power consumption requirements. Separate cards for each input channel contain circuitry for amplifier-transient protection and balanced input for reducing the common-mode signal. High pass and low pass filters are provided to remove DC offset and avoid an aliasing effect of digitization, respectively. The present configuration provides for up to six independent input channels.

The performance characteristics of the A/D (analog/digital) conversion module play a significant role in a determining the bandwidth, dynamic range, and resolution of recorded signals. A 16-bit CMOS A/D conversion module (Analog Devices, DAS1159) was initially selectedfor implementation in the recording unit. If desired, this unit may be easily replaced by a 12-bit CMOS module.

The time control module presently incorporated in the system includes a 3.2768 MHz oven controlled crystal oscillator (OCXO) as the internal time standard. A JJY radio receiver and associated decoding electronics for automatic recording of the difference between the internal time standard and the JJY reference signal will be installed in the new system. Time information (year, month, day, hour, minute, and second) is processed by a clock CPU (Ricoh, RP-5C01). The clock CPU, crystal oscillator, and associated electronics circuits will operate for about 10 hours on battery power without an external power supply.

The existing playback program permits the operator to rewind the tape, optionally to skip some files, and to select either analog or digital playback output. The analog output can be obtained in real time using BNC and Bendix waterproof connectors. The D/A conversion module permits the system to be used as an analog data playback either in the field or in the laboratory. The digital wave data are transferred to a host system via RS-232C device with header informations such as various system diagnostics, unit identification, preamp gain, triggering parameters, and so on.

SOFTWARE

The microcomputer-based system can be easily modified for the future technological upgrading in hardware components. Software programs between the operator and the system are frequently modified for the improvement of the operation. The operator interface as well as hardware modules are under the control on the CPU-1 served in the central module. The interface programs consists of five main mode and several subprograms shown in Fig. 2. The operator first select among five main menus and the chooses a function to be performed form an associated submenu. In order to operate the system correctly, the operator can adjust the system parameters such as choice of trigger algorithm, short and long time duration necessary for STA/LTA trigger algorithm, pre-event buffering time, and so on. These parameters are set in PARAMETER mode and save in a non-volatile RAM as default parameters.

We can select among three trigger algorithms (STA/LTA, threshold level, and external TTL pulse trigger algorithms). The STA/LTA method uses a ratio of short-term and long-term averages (Prothero, 1980). A quarter-second summation is used in place of data at each point. Short and long term averages are calculated as described by Kasahara et al.(1985). The threshold level trigger algorithm simply generates a trigger pulse if a present threshold level is exceeded. Figure 2 illustrates the various basic program modes and the available functions.

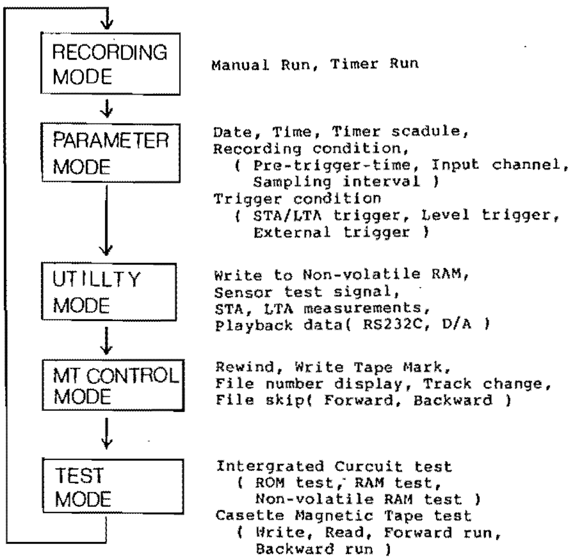

Figure 2. Software architecture. The operator first selects the proper mode and chooses the suitable subprogram.

AN EXAMPLE OF A MICROEARTHQUAKE STUDY

Shear-wave splitting studies can provide information about fracture system structure. Stress-induced microcracks in rock are system atically oriented spatially; such cracks will result in anisotropic seismic wave propagation. Shear wave propagating through rocks containing these aligned cracks will split into two or more components with different velocity and polarization (Crampin, 1978). Hence, it is possible to estimate the orientation of the aligned microcracks from the polarization of split shear waves (e.g. Booth and Crampin, 1985).

Figure 3 shows a typical example of polarized shear wave. The top figure is simultaneous seismic wave traces (of one second) recorded in the EW and NS component of seismometer. The arrival of shear wave is clearly recognized on the NS component. The bottom four figures are particle-motion plots in the horizontal plane during successive 50 millisecond intervals. These plots correspond to the middle portion of the seismic wave histories shown above, as indicated on the bottom of the top figure (A, B, C, and D). The direction of initial shear wave was determined to be N15W as shown on plot B. Figure 4 shows rose diagrams of the initial shear-wave polarization orientations. Each rose diagram is plotted at the location of the corresponding 3-component seismic station. In this figure the shear wave splitting orientations which were founded in a previous study (Kaneshima et al., 1988) are also shown (stations 5 and 6).

These principal orientations are evident in Figure 4. The first is NW-SE, typified by results form station L. This direction is subparallel to that of the major reservoir axis as determined by the spatial distribution of microearthquake epicenters (Figure 5). It is also subparallel to the strike directions of intrusive porphylites and of a highly fractured area near station L (Doi et al., 1988). A conjugate NE-SW trend is found at stations A and E. The third principle direction is the E-W direction (station 6). Multiple trends are evident at the remaining stations (stations B and 5), which may be due to temporal variations in the stress field. Additional measurements are needed to resolve the matter.

Shear wave splitting depends on the alignments of cracks located just below the seismic station. The initial shear wave directions vary from station to station although a weak spatial correlation may be perceived. The shear wave splitting direction, however, provides useful information concerning microcrack alignments. It is moreover possible to compute crack density from time-delays in the split shear wave (time difference between T1 and T2 ; see, Fig. 3). It will be necessary to

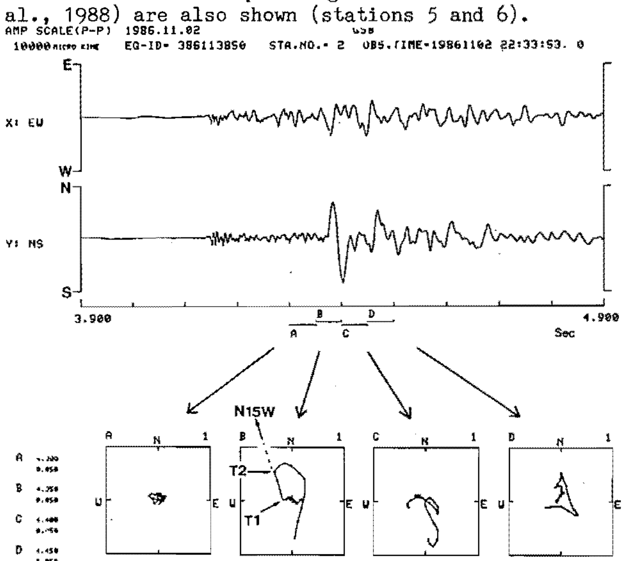

Figure 3. An example of a wave recorded in the Takinoue geothermal area. The top figure represents E-W and N-S components of the seismic wave traces. The bottom figure shows particle motion in the horizontal plane. Initial shear wave arrived at time T1 and later phase of shear wave came at time T2. The aligned microcracks density under the station can be estimated from time dif ference between T1 and T2.

deploy many 3-component seismic stations incorporating data recorders with great dynamic range and broad bandwidth to define the detailed microcrack alignment distribution in the area under investigation. Our newly developed digital event recorders are suitable for field experiments of this type.

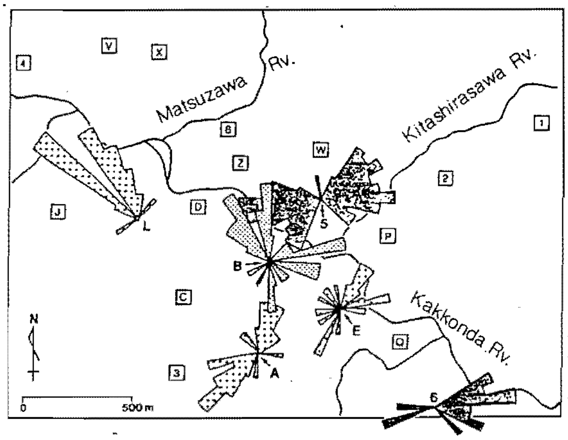

Figure 4. Directions of initial shear wave motion plotted on the hypocenter map.

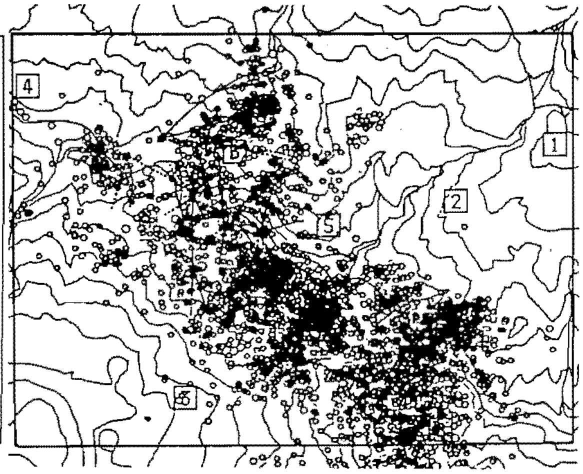

Figure 5. The spatial distribution of the microearthquake hypocenter in Takinoue geothermal area from April 1, 1987 to March 31, 1988.

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