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AN UPDATE ON MEPAS, A SOFTWARE PACKAGE FOR RESERVOIR MASS AND HEAT FLOW CHARACTERIZATION IN GEOTHERMAL RESERVOIRS USING MICRO-EARTHQUAKE DATA

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ABSTRACT

MEPAS, a micro-earthquake analysis package, is being updated as a tool for geothermal engineers to analyze earthquakes as a mean of forecasting mass and heat flows in geothermal reservoirs. MEPAS consists of a seismic data processing part and a geological analysis part. The geological analysis part features 3D display, time and space distribution display, fracture plane extraction program, 3D focal mechanism display, display of probability of hypocenter location, etc. These functions will be useful to evaluate the behavior of geothermal reservoirs in the early stage of exploitation (and to explore new reservoir around the existing reservoir). We are improving MEPAS, especially the functions of automatic hypocenter determination and the database modules. Also, MEPAS has been converted from UNIX to Windows NT.

1. INTRODUCTION

Both minimizing the decrease in power generation and increasing overall output are very important tasks for geothermal energy development. Therefore, technology for identifying the physical and hydrological changes that occur in the reservoir during production is required.

Pressure, temperature and phase changes of geothermal fluid which may occur when geothermal fluid is withdrawn from or reinjected into geothermal reservoirs, may cause changes in micro-earthquake distribution and velocity structures. Micro-earthquakes often occur due to pressure change of geothermal fluid in a reservoir. Detection of underground fractures is very important for geothermal reservoir exploration and micro-earthquakes are good indicators of the existence of fractures in some fields. So micro-earthquake monitoring is a promising technique to explore some geothermal reservoirs (e.g. Sugihara and Tosha, 1988; Ito and Sugihara, 1988a, b; Tosha et al., 1993). It is an important task to develop effective observation and analysis system for micro-earthquakes and to develop exploration technique for monitoring changes in reservoir conditions. The New Energy and Industrial Technology Development Organization (NEDO) launched an R&D project "Development of Technology for Reservoir Mass and Heat Flow Characterization" in 1997. We improve and update the Micro-Earthquake data Processing and Analysis System (MEPAS) as a part of this project.

2. OUTLINE OF MEPAS

MEPAS is a software package designed for geothermal exploration using micro-earthquake data (Miyazaki et al, 1995).

Many geothermal fields have small micro-earthquake monitoring systems but these micro-earthquake data are not fully used for geothermal exploration. One reason is that geothermal exploration engineers are usually not trained in seismic analysis. They usually ask a Service Company for data processing and analysis. For the purpose of exploring geothermal reservoirs, results from micro-earthquake analysis must be compared with other exploration data. MEPAS was developed as a computer program of micro-earthquake data processing and analysis for geothermal exploration engineers and was designed on the assumption that earthquake observation data are acquired by existing observation and recording system, and therefore does not include a data-acquisition system.

We feel we especially need the real time processing and the database modules of MEPAS. Real time processing consists of the fully automatic selection of local earthquakes, arrival time detection and hypocenter calculation. The database function of MEPAS will be improved that users may use and display any desired set of earthquake data easily from the database. Finally, these improvements will cut down the time, the cost and the workload for processing data.

3. HARDWARE AND SOFTWARE

MEPAS was initially developed as a UNIX base application, and has been converted to Windows NT (Table 1). Windows NT is reliable and its user interface is popular. We adapt

Oracle8 as the database management system and "win" format (Urabe and Tsukada, 1992) as the wave data format.
The structure of MEPAS is shown in Figure 1. MEPAS is divided into two subsystems, Real Time Processing System (MEPAS-R) and Offline Fully Functional Processing System (MEPAS-F). MEPAS-R is an additional function in the current version. This system reports micro-earthquake hypocenters and magnitudes automatically in real time. MEPAS-F consists of both manual and fully automatic processing functions. Using these functions, user can analyze micro-earthquake data in detail. Database function links these two systems so that user may manage MEPAS-R/F data with ease.

4. REAL TIME PROCESSING SYSTEM

It is useful to know micro-earthquake hypocenters and magnitudes in real time. It is important to know the relationship between micro-earthquake and any kinds of events in geothermal reservoirs. MEPAS-R can notify the relationship.
A flow chart of MEPAS-R is shown in Figure 2. A time chart of real time processing system of MEPAS-R is shown in Figure 3. MEPAS-R keeps on watching the contents of a monitoring PC's Hard Disk at regular intervals. When new micro-earthquake data is recorded on, MEPAS-R copy the micro-earthquake data from the monitoring PC to another PC, then starts processing. Micro-earthquake monitoring is not stopped by any trouble with MEPAS-R, because the analyzing PC is independent from the monitoring PC.
An example of real time processing module of MEPAS-R is shown Figure 4. When new micro-earthquake data are recorded, MEPAS-R starts the selection of local earthquakes. If the micro-earthquake is regarded as local, this system automatically picks up arrival-times. Hypocenters and magnitudes are calculated automatically. These processing results are shown on the display screen and recorded in the database.

4.1 Automatic Selection of Local Earthquake

Seismographs record not only local micro-earthquakes occurred inside the geothermal field but also distant earthquakes. Distant earthquakes are not necessary for the real time processing. Thus MEPAS has a function to screen local earthquakes before the automatic arrival-time picking. Distant earthquakes usually have lower frequency content. MEPAS judges distant earthquake by a digital frequency filter. As threshold frequency may depend on the field, it must be decided before analysis. For this purpose MEPAS has a frequency analysis function. Digital filter is used only to judge wave frequency; original waveform is used for data processing and analysis after that.

4.2 Automatic Arrival Time Detection

Automatic detection of P-wave and S-wave arrival times utilizes on multi-dimensional AR (autoregressive) model and AIC (Akaike Information Criterion) as described by Yokota et al (1981). When the amplitude is too small or first arrival is not clear, automatic detection sometimes fails. Thus the system has an automatic redetection function which searches for an arrival time within a narrow time interval that is predicted from travel time estimated from an initial hypocenter calculation. This process makes auto-detection more reliable.

4.3 Hypocenter Calculation

Hypocenters are calculated by the standard least square techniques using a horizontal layered velocity structure.

5. OFFLINE PROCESSING SYSTEM

MEPAS-F includes some manual processing functions, for example, manual selection of local earthquake, manual arrival time picking, etc. Moreover, this system has all of the automatic processing functions. For example, a user can display waveforms with the result of automatic arrival time picking, and modify arrival times manually. Also, when users analyze micro-earthquake data in detail for the purpose of exploring geothermal reservoirs, they can use 3D plot and geological interpretation part.

5.1 Manual Selection of Local Earthquake

An example of manual selection of local earthquake module is shown in Figure 5. Using this function, users can sort out local earthquakes, distant earthquakes and noises using the mouse. In addition, the files that contain 2 or more micro-earthquakes can be divided to several files.
Frequency Analysis and Frequency Filtering are also supported. These are useful to determine parameters for the automatic selection program, which uses filtering on waveforms.

5.2 Manual Arrival Time Determination

An example of the manual arrival time determination module is shown in Figure 6. Using this function, a user can determine P-wave and S-wave arrival times. Also, this function has three support functions, such as the synthetic waveform display, the particle motion display and the wadati diagram display.

The program displays synthetic waveforms synthesized from 3-component wave records in order to look at the waveform from any direction. The program can display particle motion using 3-component wave records. We will also update to use the 4-component.

5.3 Hypocenter Calculation

An example of Manual Hypocenter Calculation module is shown in Figure 7.

a. One-Dimensional Velocity Structure Inversion Program

This program is used for the calculation of a horizontal layered velocity structure by inversion. The method employs an algorithm of Crosson (1976a,b).

b. Relative Hypocenter Calculation Program

When many earthquakes occurred in a small area in a short time, this program is useful for the calculation of relative difference of each hypocenter by the master event method.

c. Detectability Evaluation Program

This program can calculate the distribution of detectability in the network area. The minimum detectable magnitude is calculated by comparing expected amplitude of the observatories with their trigger levels.

d. Evaluation of Accuracy of Hypocenter Location

This program can simulate standard error of calculated hypocenter from errors of origin time, velocity structure, and observatory positions.

5.4 Focal Mechanism Analysis

This program can analyze nodal planes automatically by focal sphere analysis (Figure 8).

5.5 3D Plot and Geological Interpretation

In order to analyze the relations between micro-earthquake hypocenters and the geothermal reservoir, it is necessary not only to display hypocenters with other exploration data and to analyze characteristics of hypocentral region, but also to display hypocenters simply. MEPAS has 3D Plot and Geological Interoperation functions as a support tool of such a applied analysis.

a. 3-Dimensional Display (Figure 9)

Information such as location of hypocenters, well geology, location of lost circulation during drilling, fault planes, strata planes and topography, etc. are displayed in a screen and can be 3-dimensionaly rotated around three axes. Display can zoom in and out. Plan view and cross section are also available.

b. Time Distribution Display (Figure 10)

The program can display origin time of earthquakes with the time history of some events such as change of geothermal production rate, shut-in of production wells, change of injection rate, etc.

c. Time and Space Distribution Display (Figure 11)

When a production well was shut-in, hypocenters spread around the vicinity of the well, and this phenomenon is useful to calculate permeability of the reservoir (Ito and Sugihara, 1988b). To analyze this phenomenon MEPAS has a function to display time and space distribution of earthquakes.

d. Contour Line Diagram on a Schmidt Projection (Figure 12)

This program displays poles of nodal planes by Schmidt projection and draw contour lines based on densities of poles.

e. Hypocenter Display in a Plan view and a Cross Section (Figure 13)

Micro-earthquake hypocenters and magnitude are shown in a plan view and a cross section as a basic form of a micro-earthquake analysis display.

f. Frequency-magnitude relationship (Figure 14)

The frequency-magnitude relationship uses the maximum likelihood method for calculation of b-value.

6. CONCLUDING AND REMARKS

We believe improved MEPAS is useful for data processing and analysis of micro-earthquake data in many geothermal fields.

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Table 1. Operating environments of both former and new MEPAS

	Former MEPAS	New MEPAS
Hardware	UNIX Workstation	Personal Computer (DOS/V)
Operating System	UNIX SunOS Ver.4.1.3	Windows NT Workstation 4.0
Program Languages	C (Display part)	Visual Basic 5.0, Visual C++ (Display part)
	FORTRAN77 (Processing part)	FORTRAN77 (Processing part)
Database	--	Oracle8
Graphic Library	X-Window Ver.11 Release 5, X-lib	OpenGL

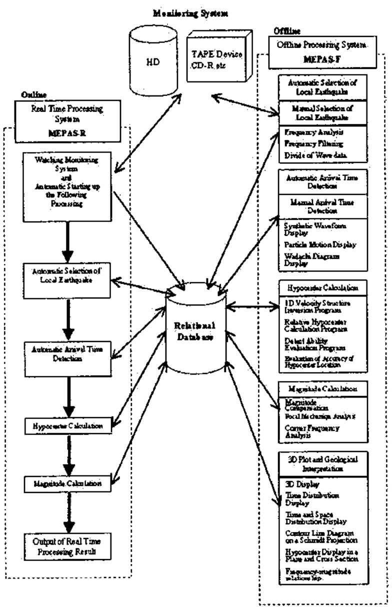

Figure 1. The structure of MEPAS

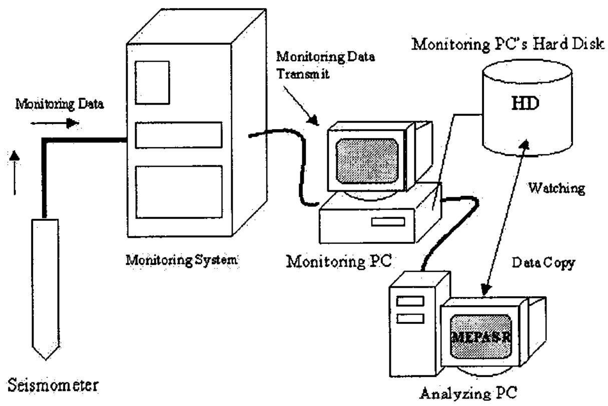

Figure 2. A schema of real time processing system of MEPAS-R

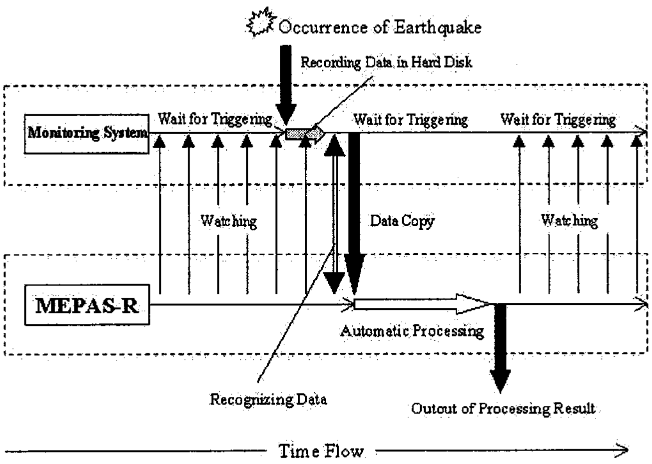

Figure 3. A time chart of real time processing system of MEPAS-R

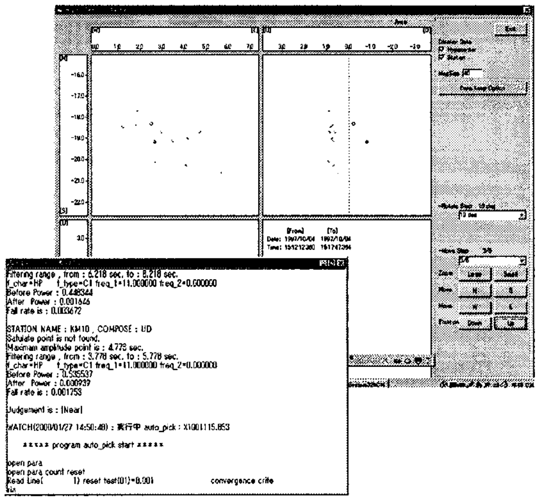

Figure 4. An example of real time processing module of MEPAS-R

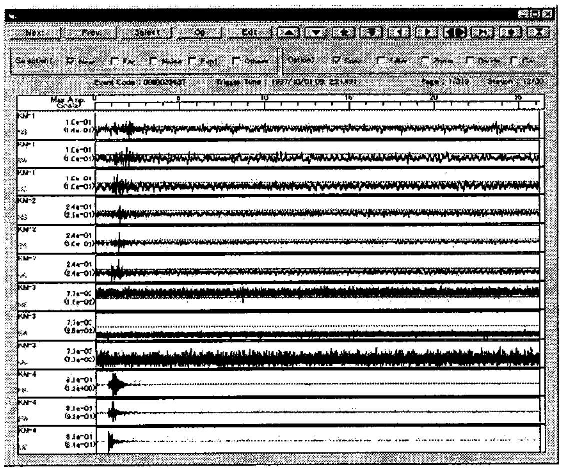

Figure 5. An example of Manual Selection of Local Earthquake module (MEPAS-F)

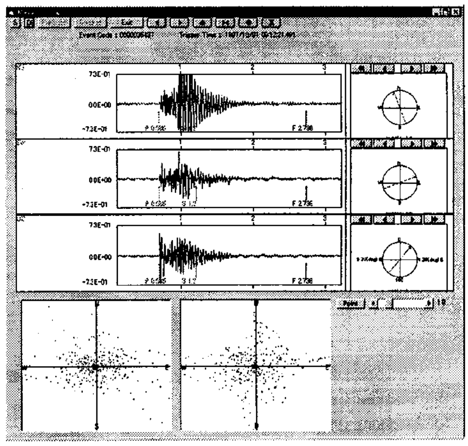

Figure 6. An example of Manual Arrival Time Determination module (MEPAS-F)

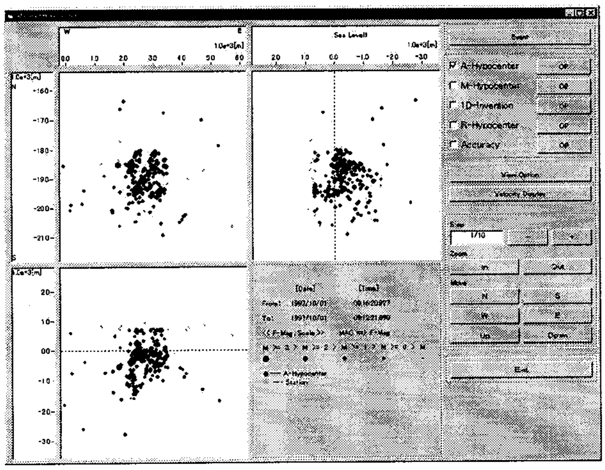

Figure 7. An example of Manual Hypocenter Calculation module (MEPAS-F)

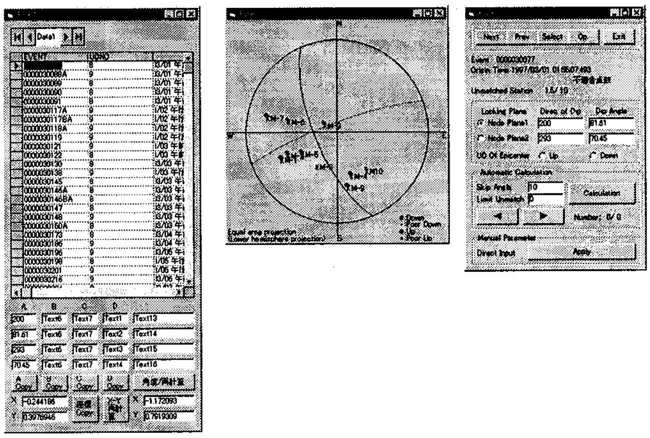

Figure 8. An example of Focal Mechanism Analysis (MEPAS-F)

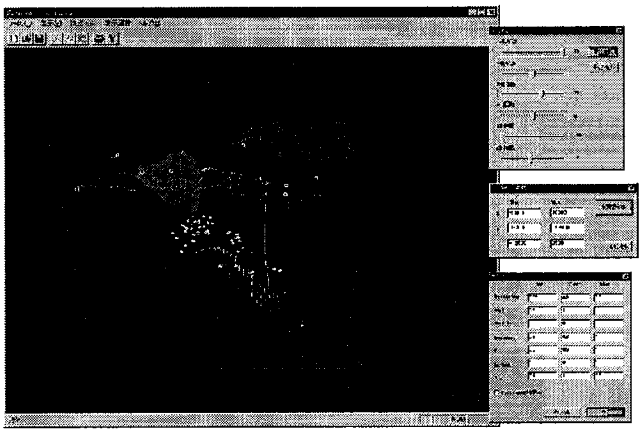

Figure 9. An example of 3-Dimensional Display (MEPAS-F)

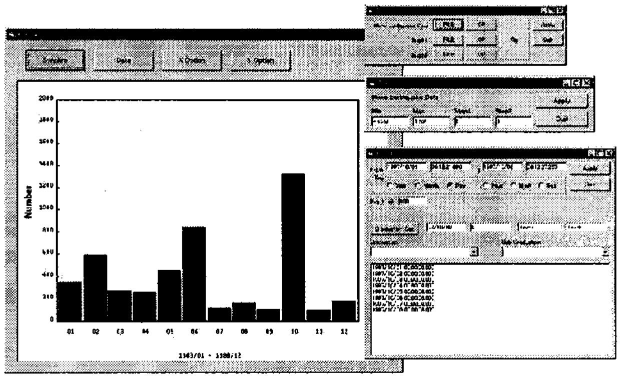

Figure 10. An example of Time Distribution Display (MEPAS-F)

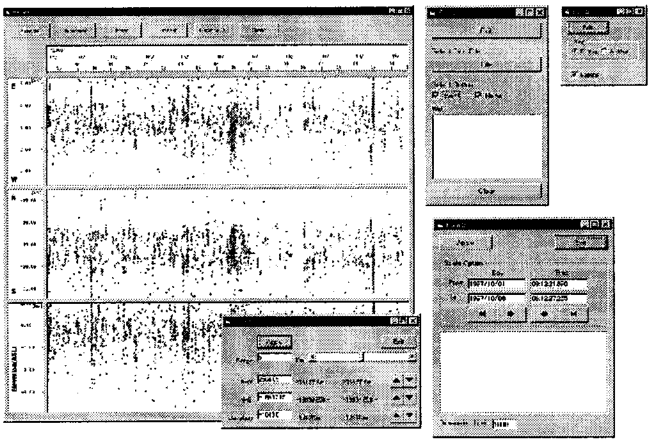

Figure 11. An example of Time and Space Distribution Display (MEPAS-F)

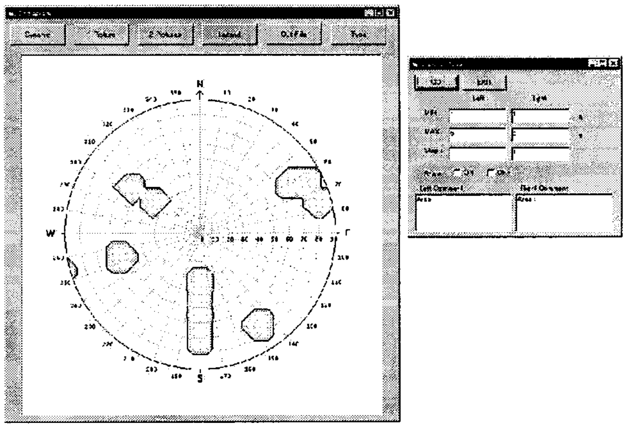

Figure 12. An example of Counter Line Diagram on a Schmidt Projection (MEPAS-F)

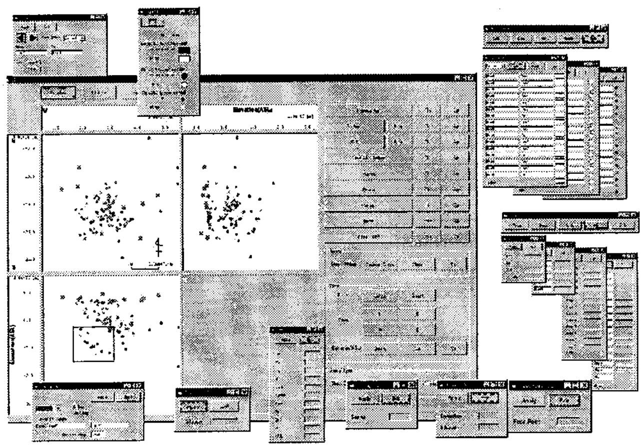

Figure 13. An example of Hypocenter Display in a Plane and a Cross Section (MEPAS-F)

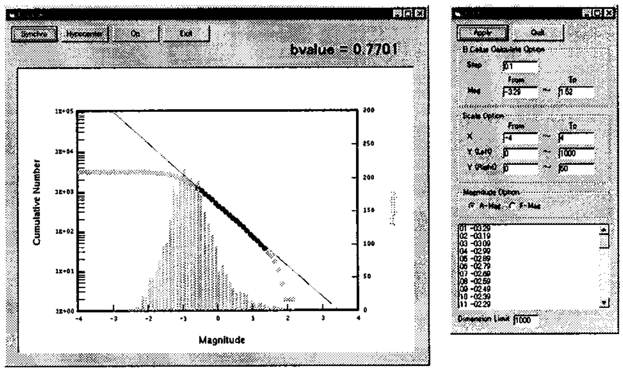

Figure 14. An example of Frequency-Magnitude relationship (MEPAS-F)