Micro–Earthquake Data Processing and Analysis System (MEPAS), a Software for Geothermal Applications

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ABSTRACT

NEDO has developed MEPAS, a software for exploration of geothermal reservoir. MEPAS has bcen developed as a tool for geologists to analyze earthquakes and find fractures by comparing earthquakes with other exploration data. 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. Using these functions, the user can extract possible fracture planes suggested by hypocenters and examine relation between earthquakes and geological structure. At the Kakkonda field some fracture planes were extracted.

1. Introduction

Micro–Earthquake Data Processing and Analysis System (MEPAS) is a special software designed for geothermal exploration. In this paper, functions of MEPAS are introduced and some examples of application are shown.

MEPAS was developed as a part of a project entitled “ Development of exploration techniques for fractured reservoir" which was conducted by New Energy and Industrial Technology Development Organization (NEDO) from FY 1990 to FY 1993. NEDO is a sub–governmental agency whose projects are 100% funded by Ministry of International Trade and Industry. Research aud development of the software has been entrusted to Japan Metals and Chemicals Co., Ltd. (JMC), which is one of the major geothermal developers in Japan.

2. Goal of the project

In many geothermal fields microearthquakes are often occumng. Microearthquake monitoring is a promising technique to explore geothermal reservoirs (Sugihara and Tosha,1988; Ito and Sugihara,1988; Tosha et al.1993 etc.). Detection of underground fractures is very important for geothermal reservoir exploration and microearthquakes are good indicators for the existence of fractures. As earthquakes in a geothermal field often occur due to pressure change of geothermal fluid in the reservoir. existence of microearthquake sometimes indicate existence of geothermal reservoir directly. Many developing geothermal fields have a small microearthquake monitoring system hut is not fully used for geothermal exploration. One reason is that geothermal geologists are usually not trained in seismic analysis. They usually asked service company for data processing and analysis, For the purpose of exploring geothermal reservoir, results of earthquake analysis must he compared with other exploration data. This process is not always easy especially in studying 3D distribution and time distribution between hypocenters and other exploration data unless aided in by computer. In this project we developed a computer program of microearthquake data processing and analysis for geothermal geologists. MEPAS 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.

3. Hardware and software

Before the start of software development we considered it important for this system to he widely accepted. This system uses available hardware and software, and employs inexpensive operating environment. So UNIX workstation and common languages were selected. Operating environment is shown in Table 1. MEPAS employs graphical user interface (GUI) for easy operation. MEPAS consists of modules of functions for the purpose of easy improvement and conversion to other UNIX workstations.

The structure of MEPAS is shown in Figure 1. MEPAS is divided into raw–data processing part, amval–time determination part, hypocenter determination and other analysis part, and 3D plot and geological interpretation part. The former three parts are used for seismological data processing. Each part consists of automatic and manual analysis programs. Users can select fully automatic processing. We have provided a series of practical manual utilities for higher accuracy analysis and for special cases which automatic analysis can not deal with. The geological interpretation part aims to help users compare earthquake and geological data to image and investigate geothermal structures. This part involves mainly manual operation applications.

Although MEPAS has various kinds of functions, mainly for geothermal applications are described in this paper.

Table 1 Operating environment of MEPAS

Hardware	
computer	UNIX workstation (SUN SPARC station 2)
memory	about 100MB: including virtual storage (146MB: main memory 16MB, virtual storage 130MB)
others	hard disc: MEPAS install 50MB, data field 50MB (2.6GB) cartridge magnetic tape unit color display mouse
OS	UNIX (SunOS Ver.4.1.3)
Window	X-Window Vir.11 Release 5 :free software (Open Windows Ver.3)
Languages	C FORTRAN77
Graphic library	X-lib: attached to X-Window Vir.11 Release 5
Environment during development is shown in ( ).	

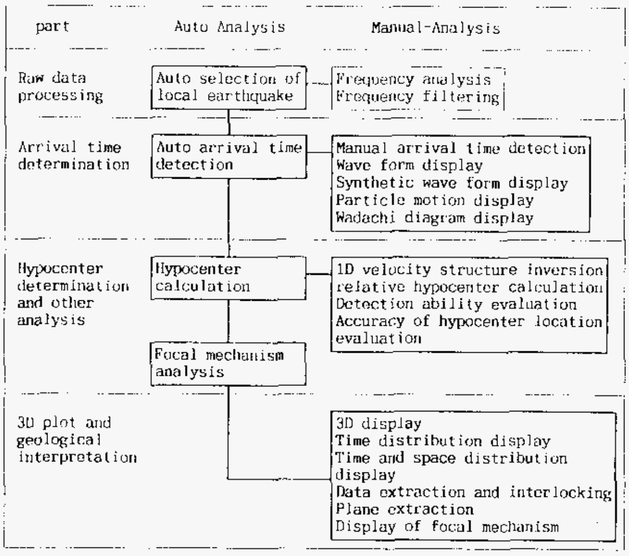


Figure 1 Flow chart of analysis and module structure of MEPAS

4. Raw data processing part

Raw data proccssing part is used for preparing data for later processing. In order to analyze various kinds of earthquake data acquired from different acquisition system, MEPAS employs a standardized data format.

4.1 Automatic selection of local earthquake

Scismographs record not only local microearthquakes that occur inside the geothermal field but also distant earthquakes. Distant earthquakes are not required for geothermal exploration and give unnecessary load for automatic data processing. Thus MEPAS has a function to eliminate distant earthquakes before automatic amval–time picking. Distant hypocenten usually have lower frequency content. MEPAS judges distant earthquake by digital frequency filter. As threshold frequency may depend on the field, it must he decided in advance. For this purpose MEPAS has a frequency analysis function. Digital filter is used only to judge wave frequency, original wave form is used for data processing and analysis after that.

5. Arrival time determination part

5.1 Automatic arrival–time detection

Automatic detection of P– and S–wave arrival times utilizes multi–dimensional AR (autoregressive) model and AIC (Akaike Information Criterion) as described by Yokota et.al.(1981). When wave amplitude is too small or wave form 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. This is predicted from travel time estimated from tentative hypocenter calculation. This process makes autodetection more reliable.

5.2 Manual arrival–time detection

MEPAS has a function of computer–aided manual detection. The program displays wave forms with the results of autodetection that can be modified manually. The program displays synthetic wave forms synthesized from 3–component wave rewrds in order to observe wave form from any direction. The program displays particle motion using 3–component wave records (Figure 2).

6. Hypocenter determination and other analysis part

6.1 Hypocenter calculation

Hypocenter calculation utilizes a method that calculates travel time with horizontal layered velocity structure (improved based on Shibuya and Horie, 1977), and solve them iterativly using damped least squares as described by Gciger(1910).

6.2 Hypocenter calculation support program

a. One–dimensional velocity structure inversion program

This program calculates a horizontal layered velocity structure by inversion. The method uses an algorithm of Crosson(1976a,b).

b. Relative hypocenter calculation program

When many earthquakes occurred in a small area, this program calculates relative difference of each hypocenter by master event method.

c. Detection ability evaluation program

This program calculates the minimum detectable magnitude at any place. The minimum magnitude is calculated by comparing an observed amplitude with a trigger level.

d. Evaluation of accuracy of hypocenter location

This program simulates standard error of calculated hypocenter from that of origin time and velocity structure.

Figure 3 shows an example of display of detection ability evaluation and evaluation of accuracy of hypocenter location. When a new earthquake monitor system is to be constructed or an additional seismograph is to be set at a new location, user can evaluate where the best location is to set seismograph(s) by this program.

6.3 Earthquake mechanism analysis program

This program analyze nodal planes automatically by focal sphere analysis.

7. Accuracy of seismological analysis of MEPAS

In order to check accuracy of seismological analysis of MEPAS, a test run has been carried out using a set of data observed at Western part of Nagano in 1986. This observation was conducted by a group incorporating outstanding observation organizations in Japan (The group for the seismological research in western Nagano Prefecture, 1989). The objective of this observation was earthquake swarm occurred shallower than 10km. The observation network's excellent number of seismographs and accuracy of hypocenters is generally recognized.

7.1 Accuracy of arrival–time detection

Sampling frequency was 150Hz, and 12 hit binary Scale was used in A/D conversion in this observation.

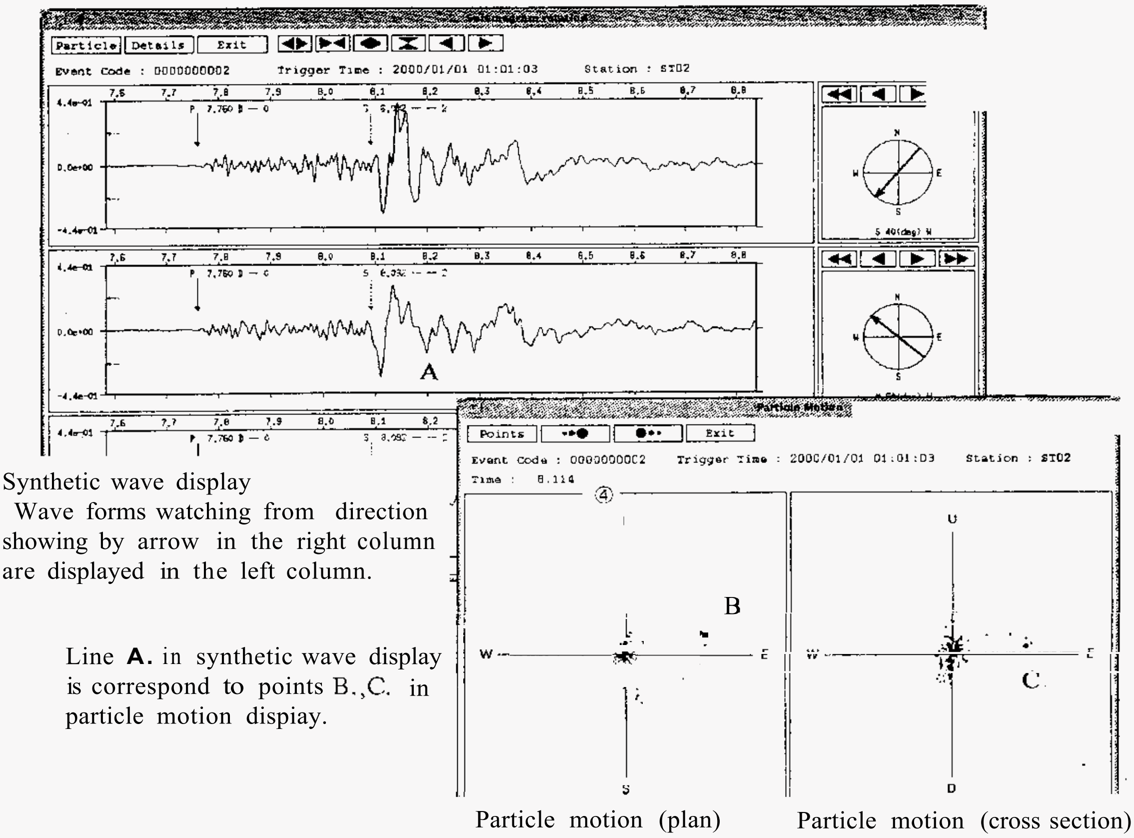


Fig.2 An example of display showing manual arrival time detection

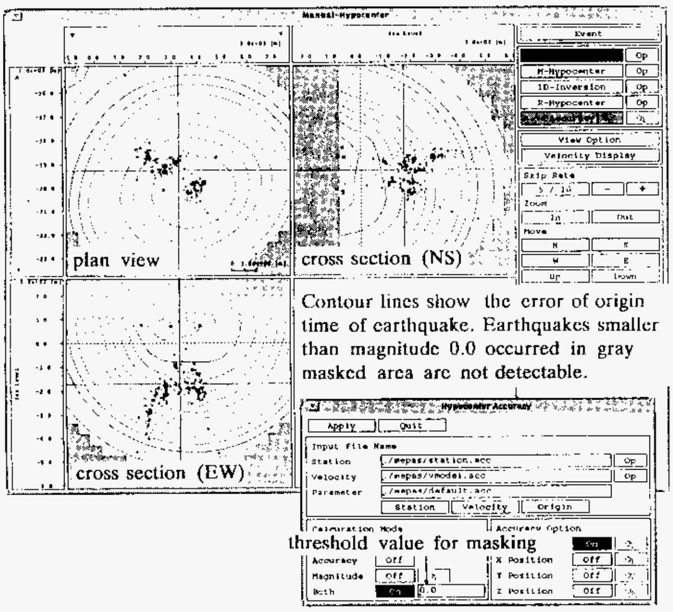


Fig.3 An example of evaluation of accuracy of hypocenter, with detection ability evaluation

Results oi automatic arrival time detection by MEPAS was as follows. About 29% of events are within 0.005 second of difference between the results of the group and that of MEPAS, and 61% are within 0.015 second. Considering the sampling frequency, 61% of the automatic detection are within *3* samples, so accuracy **of** detection of MEPAS is enough for practical use.

1.2 Detection of polarity

22 records out of a total of *23* records of seismographs coincide with the results of the group, so MEPAS can detect polarity with enough accuracy for practical use.

1.3 Velocity structure analysis

Hypocenter calculation by MEPAS using velocity structure obtained by 1D inversion velocity structure analysis got almost the same results as those of the group.

8. 3D plot and geological interpretation part

8.1 display program

a. 3-dimensional display (Figure **4)**

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

b. Time distribution display

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.

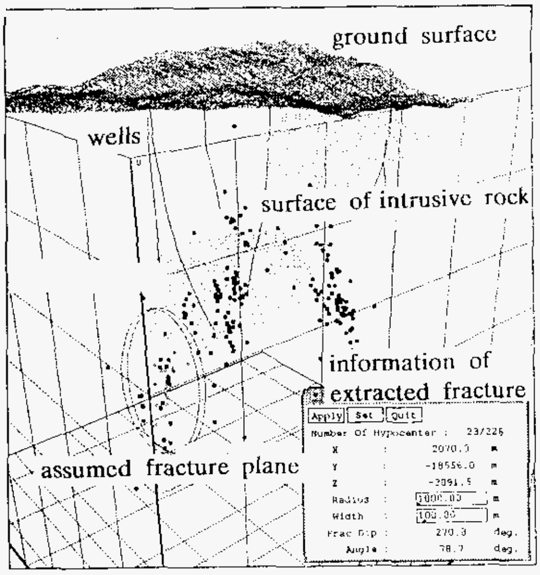
c. Time and space distribution display

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 iunction to display time and space distribution oi earthquakes.

d. Database program

MEPAS has a database program to store earthquake and exploration data for the display programs.

8.2 Data cxtraction and interlocking display



Hypocenters, ground surface, strata surface, trajectory of wells and assumed fracturr plane are displayed.

Fig.4 An example of 3 dimensional display

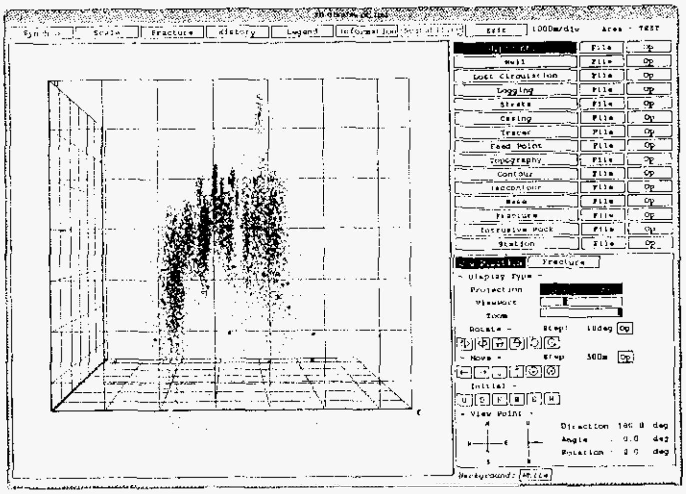


Fig.5 **An** example **of** display showing probability of hypocenter location

MEPAS can specify and extract some liypocenters or data group and display on other display programs.

8.3 Plane extraction program

MEPAS has a function to extract a plane on which hypocenters distribute. On 3D display, a set of closely located parallel discs represent supposed fracture plane. Location. direction and space of discs are controllable. When user finds a group of hypocenters which are located on a plane, the user can move the discs to fit these hypocenters. Hypocenters located between discs are shown by reverse calor, to make it easy to judge whether the discs are fitting or not. After the position of the discs are set, location, strike and dip of the discs are displayed (cf. Figure **4).**

8.4 Display of focal mechanism on 3D display

Focal mechanisms can he displayed at each hypocenter on the 3D display. This makes it easy to find groups of hypocenters having the same focal mechanism (*cf.* Figure 7).

8.5 Contour line diagram on a Schmidt projection

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

8.6 Display of probability of hypocenter location

This program displays errors of hypocenter locations estimated in the hypocenter calculation. Hypocenters are displayed by a constant number of dots inside an ellipsoid, and size **of** the ellipsoid is in proportion to degree of the error of the hypocenter−location in E−W, N–S and depth axes, respectively. By this method, a hypocenter with small error appears as a deep−color compact cloud and that of large error appears as a light−color thin cloud (Figure *5).* User can understand reliability of hypocenter location at a glance.

9. Application of MEPAS to geothermal exploration

Some examples of finding relation between microearthquakes and geothermal reservoir is shown in the following.

9.1 Comparison of hypocenter locations with exploration data (c.f. Figure **4)**

This example is a 3 dimensional display showing hypocenters and the shape of an intrusive **rock.** Most of the hypocenters of microearthquakes are shallower than the upper surface of the intrusive hody. The distribution of hypocenters gives a good indication of the shape of the intrusive body. In the Kakkonda field in Northeast Japan, there is a good geothermal reservoir on the **upper** surface of a new granitic intrusive body and the shape of the intrusive body is thought to hit a good indicator of the reservoir.

9.2 Estimation of fracture

At the Kakkonda field, some production wells drilled to the cloud of microearthquakes distributed as lines or planes have good flow rates. Microearthquakes located on lines or planes have a possibility of occurring on the same fracture plane, especially when they have the same focal mechanism, and becomes a good indicator of a fracture. Here we show an example of estimating fractures at the Kakkonda field (Figure 6).

At the Kakkonda field, there is a group of microearthqnakes occurring at the north--west and deeper part of the reservoir, that show planar distribution, These microearthquakes were extracted on the cross−section display for farther analysis. The b−value is 0.9060. Contour diagram of pole of the nodal planes shows they have nodal planes approximately concordant with the direction of their distribution. Fracture plane estimated from their distribution was extracted by the plane extraction program. Direction of dip of the extracted plane is 251 degrees from north and inclination is 87 degrees. This direction is approximately the same as the direction of hypocenter distribution. Thus these microearthquakes have a possibility of occurring on the same fracture plane or on a group of the parallel fracture planes.

Y.3 An example of continually occurred earthquake

Figure 7 shows wave form of 6 microearthquakes observed at the Kakkonda field, and hypocenter locations expressed by focal spheres on 3D display. They occurred successively. Hypocenters were calculated by relative hypocenter calculation program. The shallower **5** hypocenters not only fall on a Line but **also** have the same focal mechanisms, and their

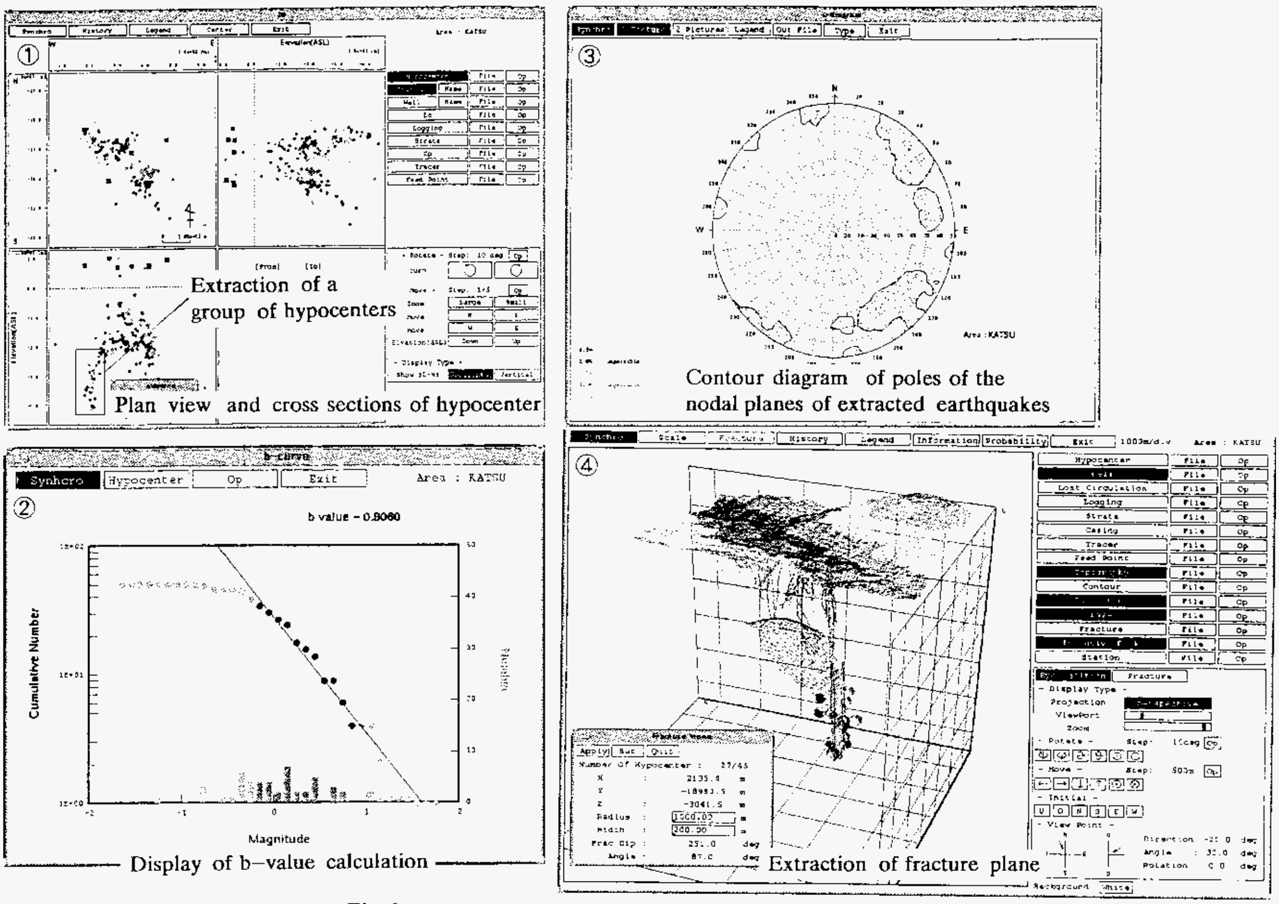


Fig.6 An example *of* estimation of fracture

nodal planes have almost the same direction as the line of hypocenter distribution. Thus these microearthquakes are thought to occur on the same fracture plane.

10. Concluding remarks

As MEPAS was developed from funding from the national budget, it is going to he released to public use through NEDO. MEPAS also is being used in the project " Deep−seated geothermal resources survey" which is being conducted by NEDO. **This** project is to drill a 4000m class survey well to study deep geothermal reservoir at the Kakkonda field. In this project, NEDO is observing microearthquakes now and preparing additional network of observation. MEPAS is being used for data processing and analysis, and a lot of fruits are expected.

Acknowledgment

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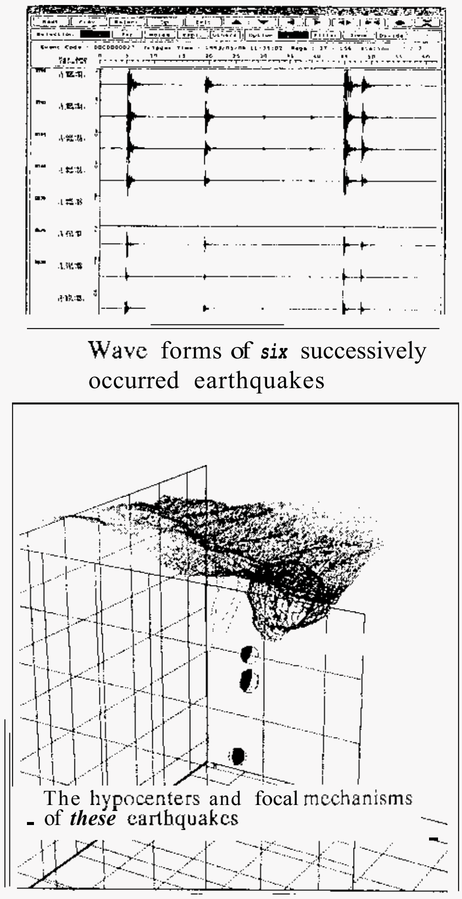

Fig.7 An example of successively occurred earthquakes

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