TOUGH APPLICATIONS TO ANALYSIS OF THE PRESSURE TRANSIENT DATA OF VERKHNE-MUTNOVSKY SITE, MUTNOVSKY GEOTHERMAL FIELD, KAMCHATKA.

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ABSTRACT

Pressure monitoring data in well #30 (capillary tubing system installed at 950 m depth) cover the time period from Sept. 1995 until Oct. 1997 and revealed two types of pressure responses in the Mutnovsky geothermal reservoir (two phase conditions, 250-270°C):

1. Slow pressure changes synchronized with flow tests of wells 049N, 048 and 055 , and reinjection to well 024N.
2. Fast pressure changes with large amplitude pressure oscillations (pressure variations more than 6 σ (mean square deviation)) synchronized with earthquakes. There were two such pressure anomalies during a one year observation period (Sept. 1996 - Sept.1997) in undisturbed conditions.

A 3D numerical model of the Mutnovsky geothermal reservoir based on the TOUGH2 computer code (Kiryukhin, 1996) was used to explain the first type of pressure response mentioned above. An extended model is under development to explain the second type of pressure response (with fracture properties as controlling parameters).

CHARACTERISTICS AND PRODUCTION ZONE DISTRIBUTION IN GEOTHERMAL RESERVOIR

According to flow test data of production wells we can assume that a north-east (NE) trending production zone controls the upper feed zones of wells 055, 048, 30, 037, and also the Verkhne-Mutnovsky natural steam manifestations. This zone has a NE strike and a 60° SE dip. The upper production intervals of wells 049N, 047, 024N and 30 occur on an east-northeast (ENE) trending production zone with east-southeast (ESE) dip of 60°. Traces of production zones mentioned above at elevation of -250 masl are shown in Fig. 1.

FEATURES OF OBSERVATION WELL #30

Pressure monitoring well #30, where a capillary tubing system was installed at a depth of 950 m, has the following features:

a. Small steam flow rate of 10-30 g/s is used to maintain operating conditions a in wooden shack, where recording equipment for the capillary tubing system is installed.

b. Downhole pressures recorded at a depth of 950 m are rather sensitive to the steam flow rate at the wellhead. For example, pressure build-up was 0.3 bars in 1 hr when the steam flow rate dropped from 25 g/s to zero after the valve was closed (October 10-th , 1997). The well productivity index was estimated as no more than 0.083 kg/s*bar.

c. Gas composition of steam discharged from the wellhead is as follows: CO_2-77.2%, H_2S-17.4%, N_2-2.1%, H_2-1.6%, $Ar+O_2$-1.2%, CH_4-0.5%. Mass gas concentration was estimated as 7.1 g/kg (Nov. 1996).

TOUGH2 APPLICATIONS TO PRESSURE TRANSIENT DATA ANALYSIS (FLOW TESTS)

3D Model Application to Long -Term Flow-Tests from Well 049N

Analysis of long-term pressure transient data during flow tests of well 049N (Nov.27,1995-May.7,1996) was made using the existing 3D model of the Mutnovsky geothermal field (Kiryukhin, 1996) with some modifications. Rock compressibility C was used as a calibration parameter. $C=3*10^{-8}$ Pa^{-1} gives a satisfactory match for the pressure draw-down period, while the pressure build-up data are shifted upward relative to the model predictions (Fig.2). This 0.1-0.15 bars increase in well #30 is explained by a valve change after the winter time period (as mentioned above, well #30 pressure is very sensitive to the wellhead valve position).

An analysis of long-term pressure transient data during flow tests of well 049N (Nov.27, 1995-May.7,1996) was done using the inversion program DIAGNS of S-Cubed. The estimated parameters of the reservoir are: permeability-thickness 4.8 D*m, storativity - 7.2 10^{-7} m/Pa, and initial undisturbed pressure 46.1 bars (Y.Yano, 1997).

3D+2D Model Application to Short-Term Flow-Tests from Well 048

There was no satisfactory match obtained using the 3-D model (Kiryukhin, 1996) (Fig.3). Therefore a high-permeability feature following the observed trend of the production zone (N-East production zone, Fig.1) was implemented in the 3-D model. This was accomplished by adding a 2-D sub-grid consisting of 91 elements with 236 m * 191 m denoted as FFK J, where K = 1,...,9 corresponding to the X- position (local X axis was chosen along NE direction), J = 1,...,9 corresponding to Y-position (local Y axis chosen along subvertical fracture dip of 60° SE). All elements of the 2D grid were connected to corresponding elements of the former 3D model grid (main-grid): A276, A287, A298, A2A9, A377, A388, A399, A467, A478, A489, A4910. For example, elements FFK J (K=1,2,3; J =7,8,9) were connected to element A46 7 of 3D model grid , ..., elements FFK J (K=7,8,9; J =1,2,3) were connected to element A2A 9 of 3D model grid. Domain FFF 1 with specified rock properties was assigned to 2D sub-grid elements. As a result a 3D+2D model was developed. The following parameters of the "FFF 1" fracture zone in the 3D+2D model were adjusted to match observed and modeled pressure response: porosity 0.5, compressibility 4 10^{-6} Pa^{-1}, permeability 120 D, thickness 0.6 m (Fig.3).

3D+2D model Application to Long-Term Flow Test from Well 055

The 3D model previously used gives no satisfactory match (Fig.4). So the 3D+2D model described above was used to match observed data. The "FFF 1" fracture parameters obtained are: porosity=0.5, compressibility 10^{-6} Pa^{-1}, permeability 4 D and thickness 1 m (Fig.4).

3D+2D Model Application to Short-Term Flow Tests from Wells 049, 055 and Reinjection in Well 024N

The 3D model previously used gives no satisfactory match (Fig.5). So, implementation of a 2D production zone (east-northeast production zone, Fig.1) in the 3D model was performed.To do this an additional 2D sub-grid consisting of 36 elements 183 m * 191 m denoted as GGK J where K=1,....,6 corresponding to the X-position (local X axis chosen along ENE direction) , J=1, ... 6 (local Y-axis chosen along subvertical fracture dip of 60° SSE). All elements of the 2D grid were connected to corresponding elements of the former 3D model grid (main grid): A387, A398, A497 and A498. For example, elements GGK J (K=1,2,3; J=1,2,3) were connected to element A387 of the 3D model grid, etc. Domain "GGG 1" with specified rock properties was assigned to 2D sub-grid elements.The following parameters of the "GGG1" fracture in 3D+2D model were adjusted to match observed and modeled pressure response: porosity 0.5, compressibility 10^{-7} Pa^{-1}, permeability 1000 D and thickness 0.25 m (Fig.5).

PRESSURE ANOMALIES RELATED TO EARTHQUAKES

At least four pressure anomalies during no-flow periods were detected in well #30 that were clearly related to earthquakes. Two of them have pressure variations of more than 6 σ (mean square deviation):

a. Pressure drawdown of 0.1 bars and, after a seismic event, pressure oscillations of up to 0.85 bars during a time interval of 28 hours (time period = 1.5 hours) - synchronized with an earthquake of magnitude M=4.5, at a distance of D= 82 km,

b. Pressure drawdown of 0.15 bars and, after a seismic event, pressure oscillations of up to 0.95 bars during a time interval of 26 hours (time period = 0.5-1.0 hours) - synchronized with an earthquake of M=4.1, D=112 km. (See Figs.6 and 7).

CONCLUSIONS

1.TOUGH2 application to analysis of observed pressure data at the Verkhne-Mutnovsky site, Mutnovsky geothermal field, during long-term and short-term flow tests has revealed the fractured nature of the geothermal reservoir, and corresponding hydrodynamic properties of the production zones were estimated.

2.Significant pressure perturbations in the reservoir were recorded following seismic activity at distances from 82 - 112 km. An extended TOUGH2 model is being developed to determine the underlying mechanisms.

Acknowledgements

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References:

1. Kiryukhin A.V. (1996) Modeling Studies: the Dachny Geothermal Reservoir , Kamchatka, Russia // Geothermics, Vol.25, No.1, p.63-90.

2. Kiryukhin A.V.,Yano Y.,Nakao S.,Ishido T., Lesnykh M.D., Polyakov A.Y., Zorin D.G. (1997) Analysis of Pressure Transient Data of Verkhne-Mutnovsky Site, Mutnovsky Geothermal Field , Kamchatka, Russia // Proc. 22-nd Stanford Geoth. Res. Eng. Workshop.

3. Pruess K. (1991) TOUGH2 - A General Purpose Numerical Simulator for Multiphase Fluid and Heat Flow , Lawrence Berkeley Laboratory Report LBL-29400, Berkeley , CA, 102 pp.

Fig.1 Verkhne-Mutnovsky Site Mutnovsky Geothermal Field, Temperature Distribution , Production Zone and Wells Location , Grid Corresponding to 3D Model (Kiryukhin, 1996) -250 masl

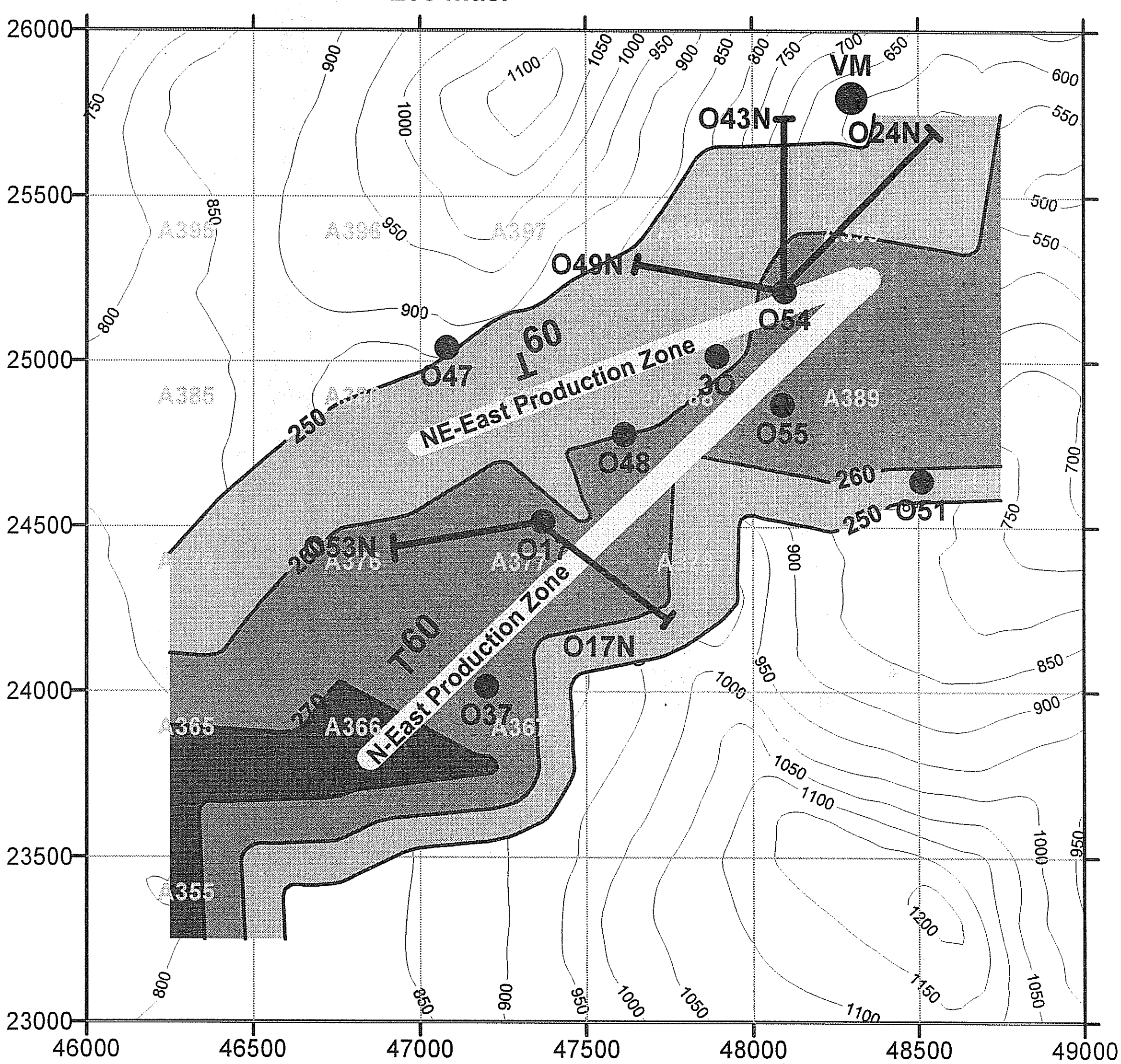

Fig.2 Pressure Match in Well #30 During Long Term Flow Tests from Well 049N (27 Nov. 1995 - 7 May 1996).
Dashed line - Pressure Monitoring Data (running average,21)

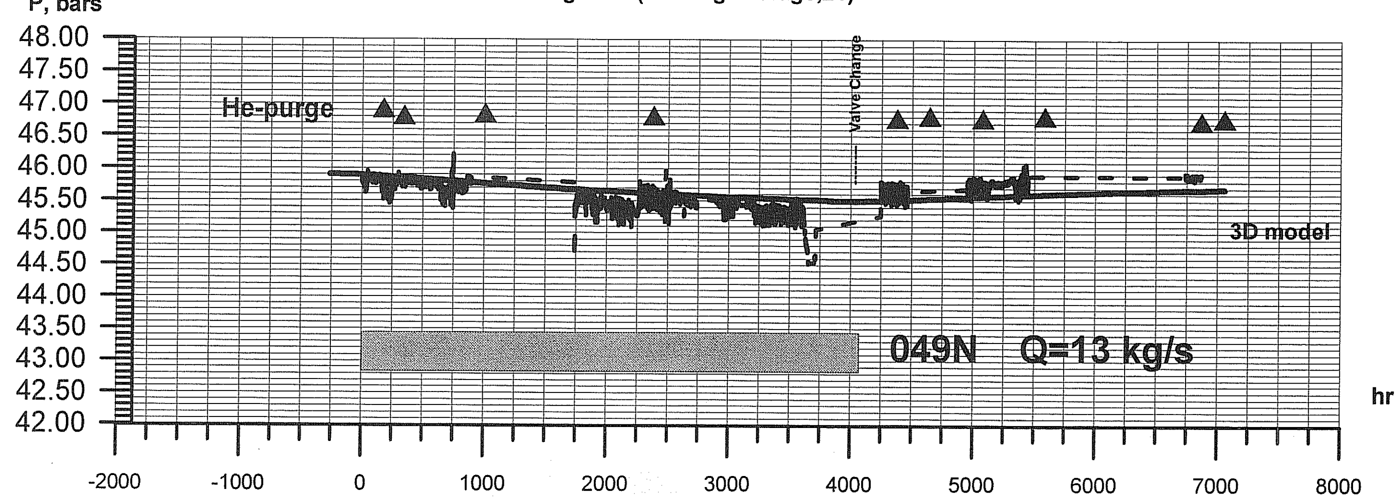

Fig.3 Pressure Match in Well #30 During Short Term Flow Tests from well 048 (Sept.14 - 15 ,1996)
Dashed Line - Pressure Monitoring Data (running average,21)

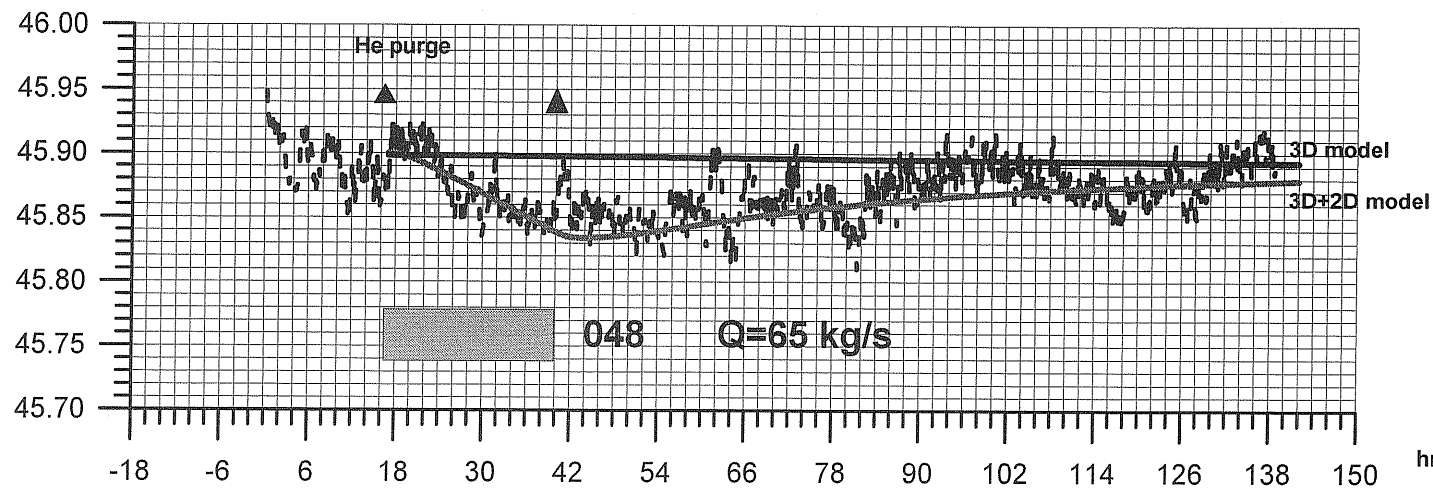

Fig.4 Pressure Match in Well #30 During Long Term Flow Tests from Well 055 (from 9 Dec. 1997). Dashed line - Pressure Monitoring Data (running average 21)

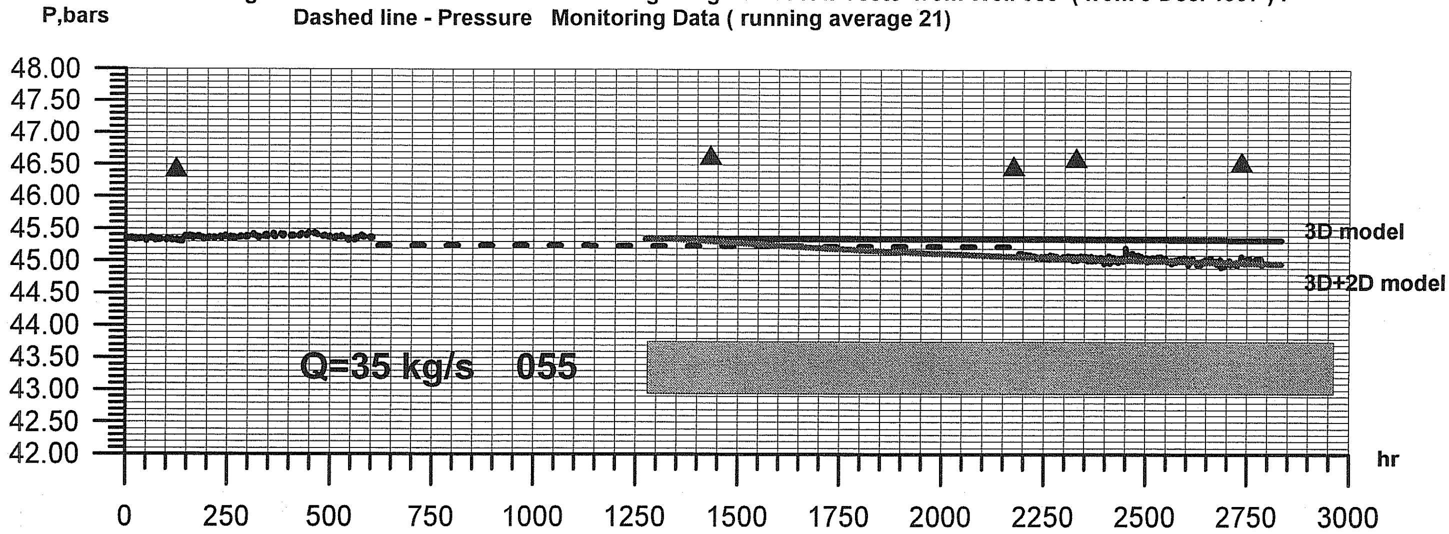

Fig.5 Pressure Match in Well #30 During Flow Tests from wells 049N & 055 , Aug. - Sept. 1997 Dashed Line - Pressure Monitoring Data (running average 21)

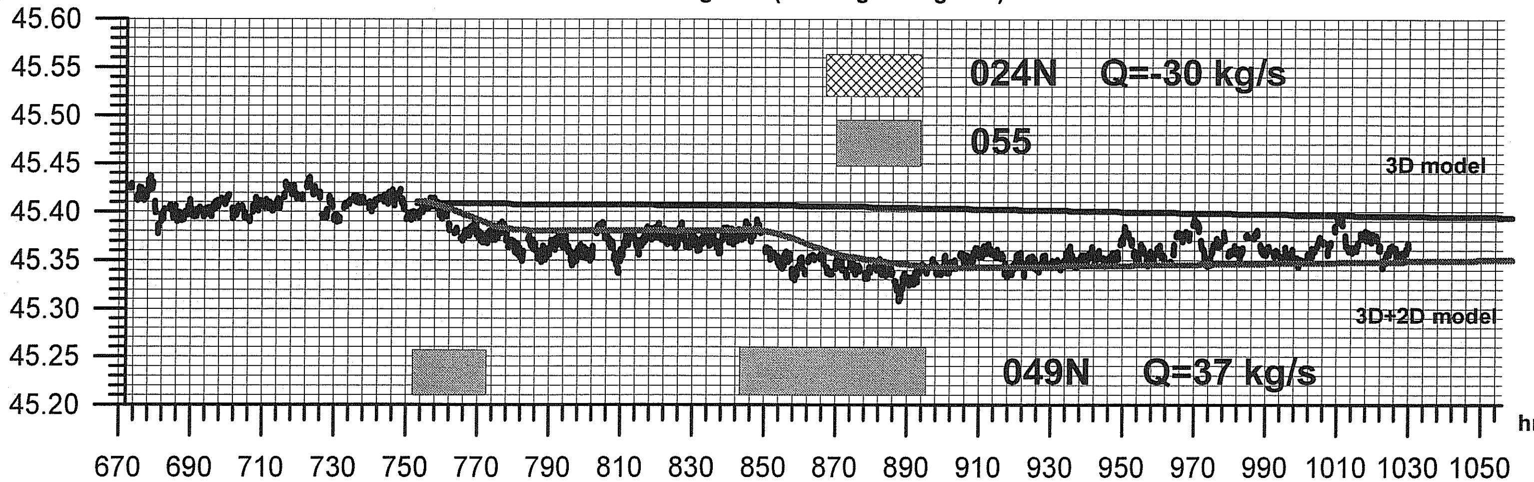

Fig.6 Pressure Variations in Well #30 Related to Earthquake

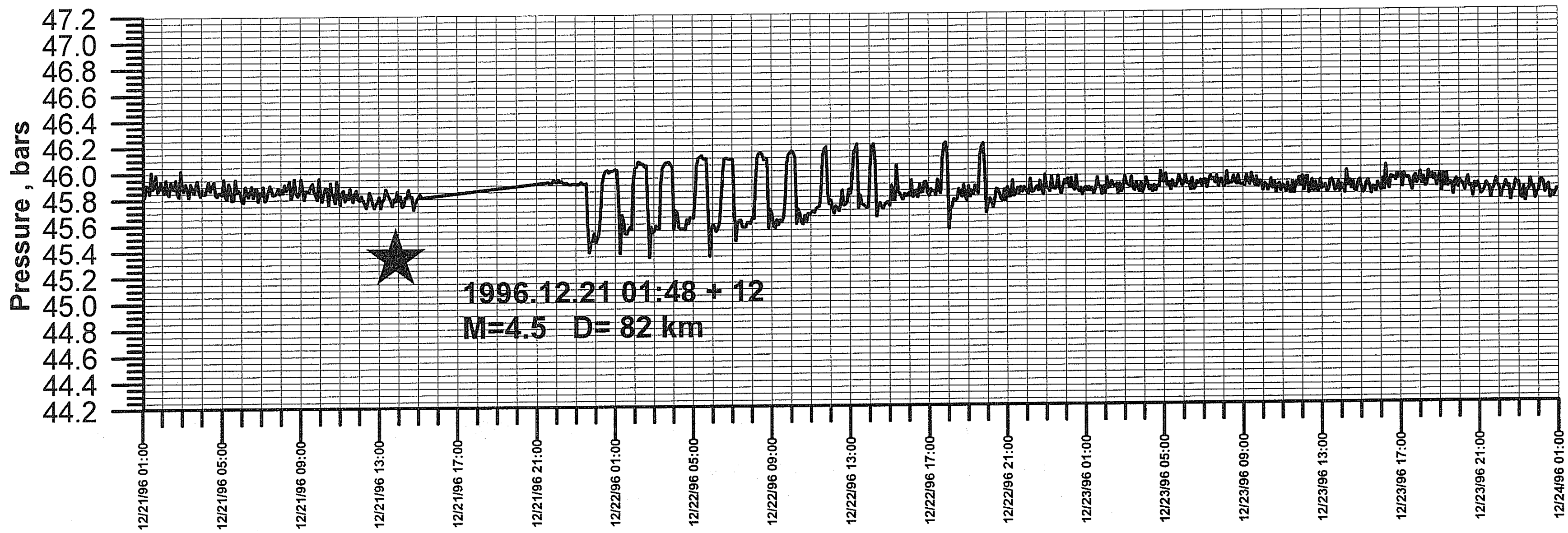

Fig.7 Pressure Variations in Well #30 Related to Earthquake