Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

RECENT RESERVOIR STUDIES OF THE OLKARIA GEOTHERMAL FIELD, KENYA

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Keywords: Olkaria, Interference, Micro-Seismicity

ABSTRACT

Pressure interference tests and induced micro-seismicity have been used to determine the permeability structure of the Olkaria North East reservoir. Interference tests between wells OW-719 and OW-701 have indicated the presence of a high transmissivity (kh ~18 – 22.4 d-m) east-west zone. The presence of this zone (possibly the Olkaria fault) has been confirmed by the fast spread of a seismic cloud (0.6 m/hr) in the NE-SW direction. Lack of induced micro-seismicity 200 m east of well OW-719 at depths below 1400 m has suggested that a dyke-intruded fault exists there. Lack of pressure response at well OW-R3 has provided an indication that this well could be isolated from OW-719.

1.0 INTRODUCTION

The Olkaria Geothermal field is situated in the eastern sector of the great Rift Valley and is located about 125 km north west of Nairobi, the capital city of Kenya (Figure 1). The field is divided into five sectors namely East, North East, West, Central and Domes.

Active geothermal exploration work in Olkaria started in 1970. In 1973, the first deep exploration well was drilled to a depth of 1003 m. A second exploration well drilled about 3.5 km to the north of the first well led to the discovery of a two phase reservoir. Using the information from this well (OW-02), other offset wells OW-03, OW-04 and OW-05 were drilled within 250 m distance from it.

Subsequent investigation of the area (Olkaria-East) led to the commissioning of the first 15 MWe power plant in 1981 and two others in 1982 and 1985 giving the total current capacity of 45 MWe. 33 wells have been drilled in this sector, seven of which are make-up wells. A total of 30 wells have been drilled in the Olkaria-NE sector and discharge tests of these wells have proven a steam equivalent of 78 MWe. Already a design has been made for a 2 x 32 MWe plant whose construction is planned. Other sectors are still under exploration.

As part of the effort to understand and characterise the reservoir from which the Olkaria N.E wells tap their fluid, interference tests and micro-seismic monitoring programmes were formulated and carried out with well OW-719 as the discharging well. Pressure drawdown was monitored in wells OW-701, OW-707, OW-728 and OW-R3 (Ofwona, 1998). Seismic monitoring based on six stations spread to cover an area of about 4 km^2 was centered on well OW-719 (Simiyu, 1999). Pressure data was acquired by use of both quartz pressure transducer-capillary tubing filled with nitrogen gas as well as mechanical Kuster pressure gauge. Seismic data was acquired by use of REFTEK instruments. Timing and location of the instruments was done by use of GPS.

This paper presents the results obtained from these two tests and tries to identify the main permeability structures controlling fluid movement in this part of the greater Olkaria geothermal field.

2.0 AN OVERVIEW OF THE OLKARIA NORTH-EAST SECTOR

2.1 Geological Structure

Figure 1 shows the main geological structures of the Olkaria geothermal field. The field is associated with the Olkaria volcanic centre and the reservoir is considered to be bounded by arcuate faults forming a ring or a caldera structure (Naylor, 1972). The heat source for the geothermal fluids in the area is consequently related to this volcano. N-S and E-W trending faults and fractures are prominent in the area with other inferred faults striking almost NW-SE. The northeast sector is at an elevation of about 2000 m.a.s.l and is underlain by pyroclastics and tuffs, ryholites, trachytes and basalts (Figure 2). From the top to 1400 m.a.s.l the field is composed mainly of acid volcanics; below these, the dominant rocks are trachytes with regular thin basaltic flows. The permeability in this sector is mainly associated with fractures, contact zones between lava units and porous pyroclastics and tuffs.

2.2 Temperature distribution

Figure 3 shows temperature profiles for wells OW-719, OW-701, OW-707 and OW-R3 taken during shut-in. From the temperature profiles, it is observed that these wells tap fluids at 260 °C – 290 °C. Planar view of formation temperature distribution across the entire Olkaria field at 750 m.a.s.l (Figure 4) indicates that the majority of wells in Olkaria N.E have temperatures between 250 °C – 290 °C at this elevation.

3. RESULTS

3.1 Pressure Interference

Between September 1997 to April 1998, pressure interference test experiments were carried out at Olkaria North East. Well OW-719, with an average total mass flow of 145 t/hr of fluid, was fully opened for discharge on 1/10/97 and pressure drawdown monitored in the nearby shut-in wells OW-701, OW-728, OW-707 and OW-R3. Three observation wells (OW-701, OW-728 and OW-707) were equipped with downhole pressure gauges of the capillary tube-quartz transducer type and one observation well (OW-R3) was equipped with the mechanical Kuster gauge type. Before well OW-719 was discharged, static pressures were monitored in all the observation wells except

OW-R3. The duration varied from 10 to 20 days. Well OW-719 was shut-in on 31/1/98 and pressure build-up was monitored in the observation wells.

Pressure response at well OW-701

Well OW-701 is 286.4 m from well OW-719. The well was drilled to 1803 m and cased at 647 m. It has permeable zones at 800-1200 m and 1800 – 2000 m. The pressure tool was positioned at 1050 m and the response is as shown in Figure 5. This well showed an instantaneous response to discharge and shut-in of well OW-719. After 1600 hours of discharging well OW-719, a sudden unexplained pressure build-up that persisted for about 600 hours occurred in this well.

The drawdown part of the response was very steady but the build-up part was quite noisy. Pressure build-up was therefore not analysed. Assuming an infinite acting system and using the Theis model, semi-log analysis (Earlougher, 1977) of pressure drawdown data gave a transmissivity (kh) value of 22.4 d-m assuming liquid reservoir at 260 °C. Curve-matching the drawdown data with the exponential integral solution (Figure 6) gave a transmissivity value of 18 dm. Storativity values obtained from semi-log analysis of pressure drawdown and curve matching were 2.9 x 10^{-8} m/Pa and 7.5 x 10^{-8} m/Pa, respectively.

Pressure response at well OW-728

Well OW-728 is 334.8 m from well OW-719. The well was drilled to 1605 m and cased at 504 m. Its major feed zones exist at 800 – 1400 m and 1800 – 1900 m. The pressure tool was positioned at 1244 m and the response is as shown on Figure 7. Pressure build-up was not monitored in this well due to problems with the pressure tool. The response from this well was also very noisy even though a declining trend could be observed. It was therefore not analysed.

Pressure response at well OW-707

Well OW-707 is 572.9 m from well OW-719. The well was drilled to 1797 m and cased at 620 m. Its major feed zones exist at 900 – 1000 m and 1200 – 1400 m. The pressure tool was positioned at 1400 m and the response is as shown on Figure 8. There was a lot of data scatter and so it was not easy to analyse the data.

Pressure response at well OW-R3

Well OW-R3 is 953.6 m from well OW-719. It was drilled to 2200 m and cased at 705 m. Its major feed zones exist at 800 – 1200 m and 1300 – 1500 m. The pressure tool was positioned at 1300 m and the response is as shown on Figure 9. There was no marked drawdown or build-up observed.

3.2 Induced Micro-Seismicity

Details of this work are contained in Simiyu, (1999). The results of this work showed that 2515 events were detected out of which about 2203 were located. Figure 10 shows the location of the instruments used to record the seismic events and epicentre distribution around the discharging well, while Figure 11 shows the seismic cloud spread with time. It was observed that there was a broad seismic cloud expansion in the NE direction implying a major fluid flow in the SW direction. The cloud spread was faster in the NE direction and slower in the NW direction with a restricted spread to the SW and SE implying a possibility of hydrologic control. The vertical section of hypo-centre distribution around the discharging well. (Figure 12) showed that the zone between 1300 –1400 m had the fastest spread rate of 0.65 m/hr. At about 200 m to the east of well OW-719, the events revealed a steep structure interpreted as a normal fault with a throw to the east. On the eastern part of the fault, the seismic cloud was centred at about 1400 m. The zone between 1600 –1700 m showed a smooth spread of seismic cloud on both sides to a distance of 200 m. However at that point the spread was abruptly stopped at an area coincident with the interpreted fault, affecting the shallow events. Since there were no events on the eastern side as opposed to the shallow zone, this structure was interpreted as a dyke-intruded fault.

4.0 DISCUSSION

The high transmissivity values obtained at OW-701 showed that wells OW-701 and OW-719 are located in a high permeability zone. The fact that no pressure response was observed in well OW-R3 could suggest that this well could either be in a different reservoir or is separated from well OW-719 by a sealing fault. The storativity values obtained are relatively low and suggest that these wells tap fluids from a liquid-dominated reservoir. The predominance of noisy data could be a result of multi-feed zones existing in these wells.

Seismic monitoring shows that a barrier exists to the east of well OW-719. This barrier has been interpreted to be a dyke-intruded fault. The fact that there was a fast spread of seismic cloud in the NE direction confirms a high permeability zone in this direction. This could possibly be the Olkaria fault zone (Figure 1)

5.0 CONCLUSIONS

1. Both interference tests and induced micro-seismicity monitoring have been invaluable in delineating the permeability structure of the Olkaria North East reservoir and more tests of this nature should be encouraged in this field.

2. Interference tests between wells OW-719 and OW-701 have indicated the presence of a high transmissivity (18 – 22.4 d-m) zone aligned west to east. Low storativity (2.9 – 7.5 x 10^{-8} m/Pa) could imply a liquid-dominated reservoir.

3. Tests between wells OW-719 and OW-R3 indicate that these two wells could be separated by a sealing structure.

4. Induced micro-seismic monitoring shows fast spreading of the seismic cloud (0.6 m/hr) in the NE-SW direction, indicating fluid movement from this direction and a high permeability zone.

ACKNOWLEDGNENTS

I am greatly indebted to Olkaria reservoir engineering and geophysics staff for their thoroughness in carrying out the interference tests and seismic work. Without their effort, no data could have been available for this work. I also thank Dr. Simiyu for his major contribution to this paper.

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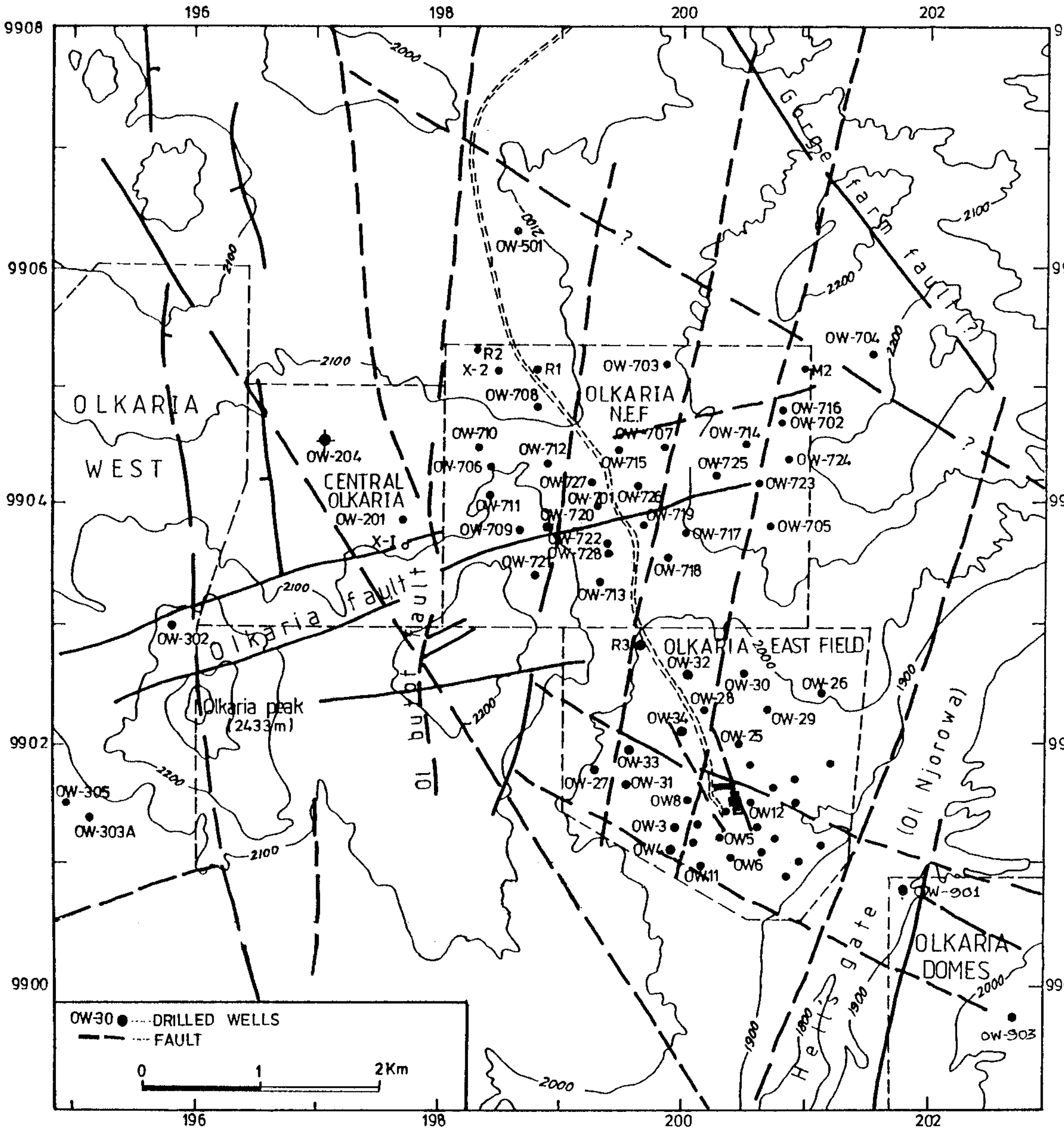

Figure 1. Olkaria geothermal field – well location and structural map

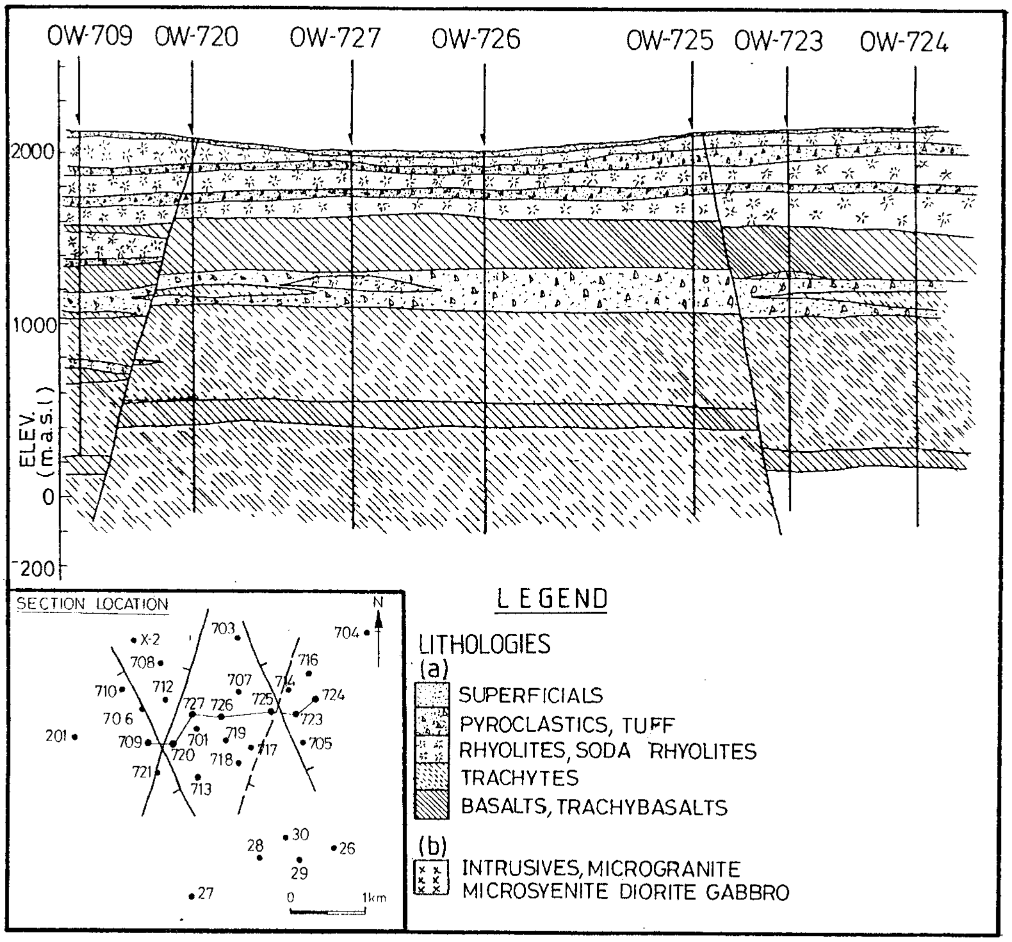

Figure 2. An E –W lithologic section of Olkaria north east

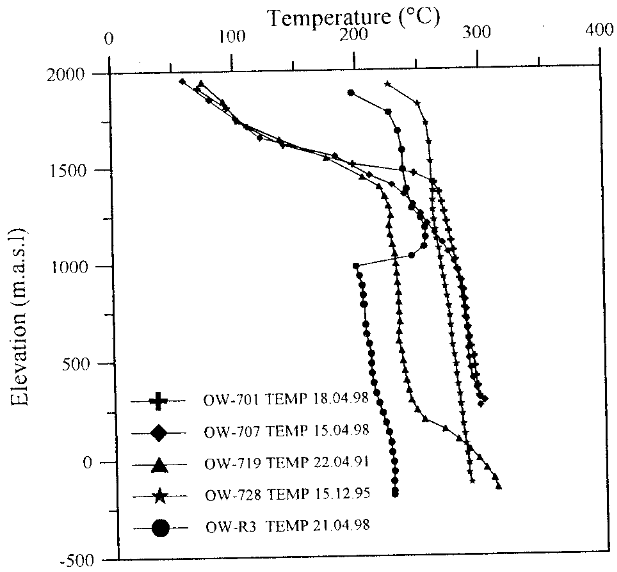

Figure 3. Downhole temperatures

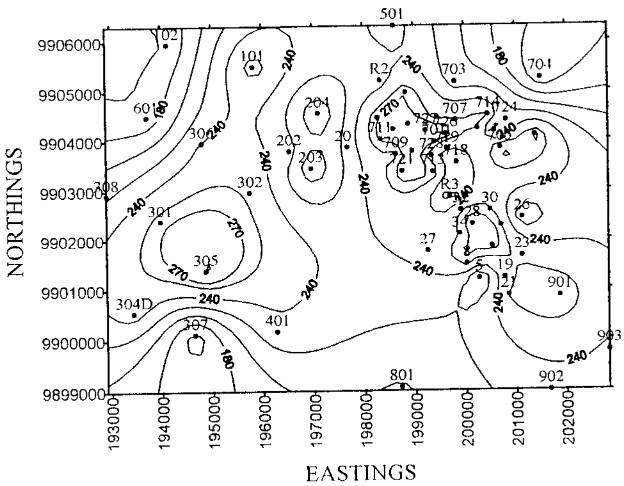

Figure 4. Temperature contours at 750 m.a.s.l

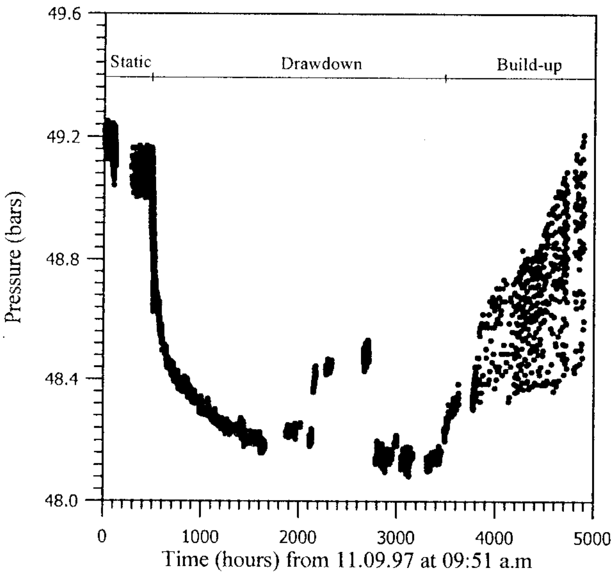

Figure 5. Pressure response at well OW-701

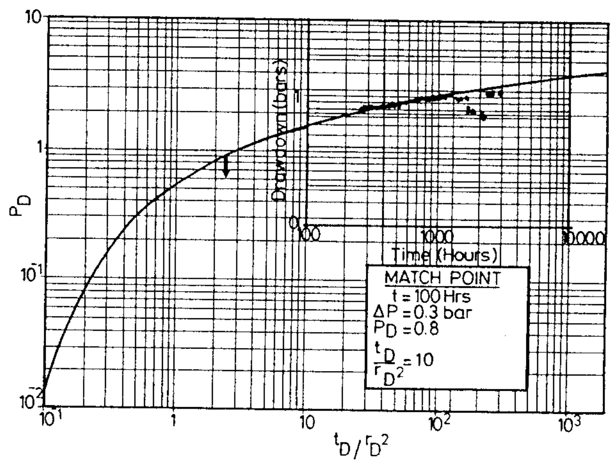

Figure 6. Curve matching well OW-701 data with infinite acting curve

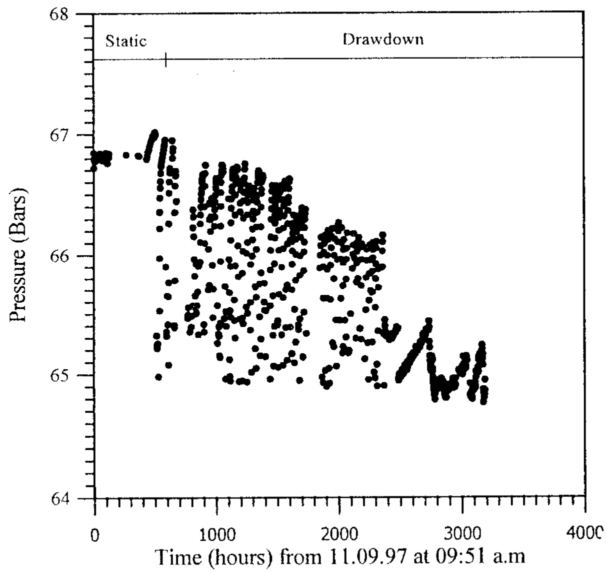

Figure 7. Pressure response at well OW-728

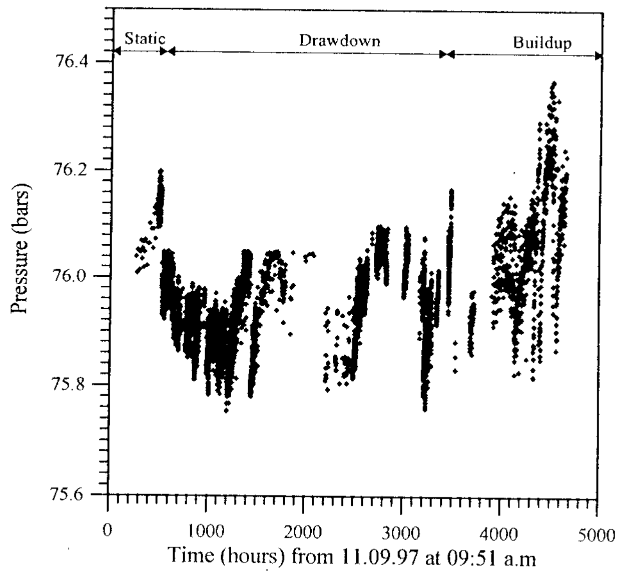

Figure 8. Pressure response at well OW-707

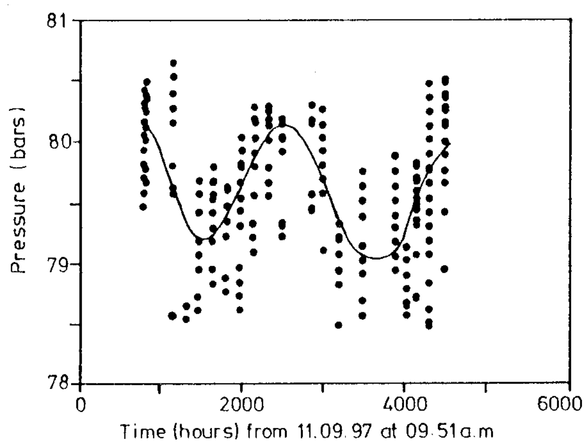

Figure 9. Pressure response at well OW-R3

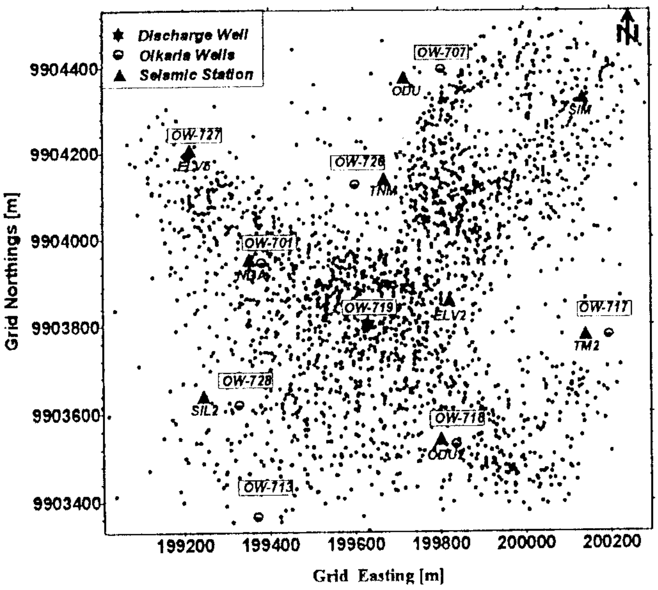

Figure 10. Map showing seismic recording stations and epicentre distribution

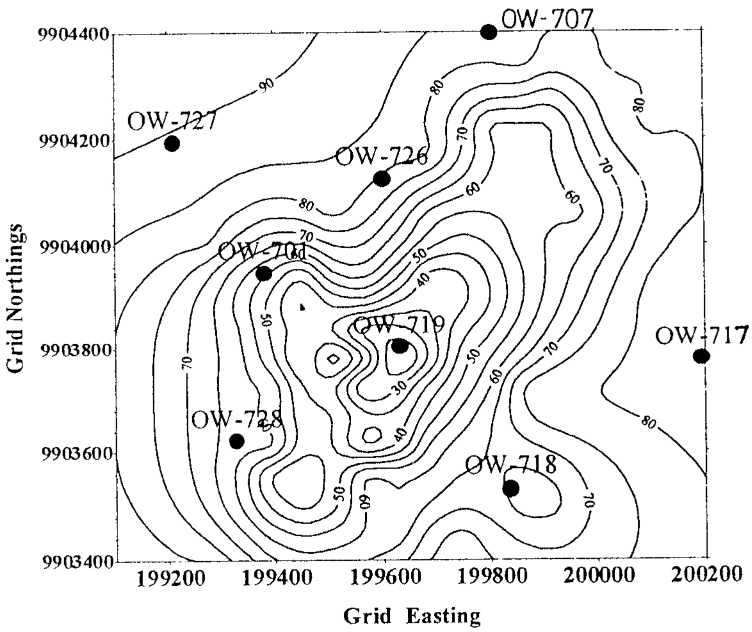

Figure 11. Contour map of micro – seismic spread with time

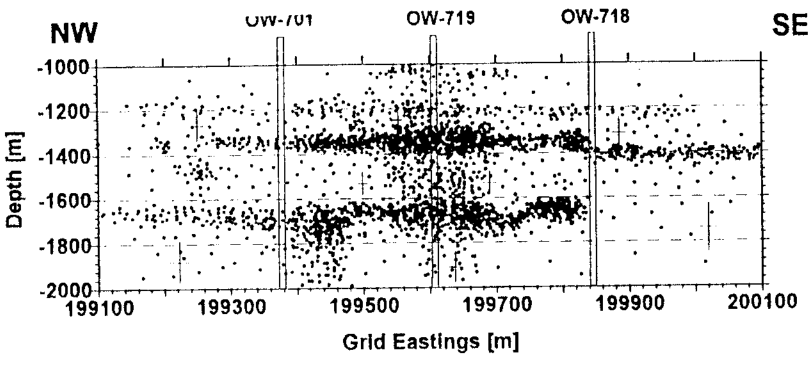

Figure 12. NW – SE sectional view of hypo – centre distribution