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PARAMETRIC STUDY OF GRAVITY CHANGE ACCOMPANYING GEOTHERMAL RESERVOIR CHANGE CALCULATED BY NUMERICAL SIMULATION

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ABSTRACT

We conducted feasibility studies of gravity monitoring based upon reservoir simulation.

At first, actual field data (although slightly modified) were used for constructing the conceptual model of a geothermal reservoir, particularly for shallow geothermal reservoir case study. Then the possibility of gravity monitoring was confirmed.

Secondly, in order to study the possibility of this for deep geothermal reservoir, we constructed simplified models for deep reservoir. Three models were prepared for our feasibility studies. These simulations showed us that we could also get fairly positive results, if we apply a very sensitive and stable gravity monitoring system.

As a next step, we will investigate gravity monitoring systems according to our feasibility studies.

1. INTRODUCTION

The Microgravity monitoring has been successfully applied in several geothermal areas such as Wairakei in New Zealand (Allis and Hunt, 1986), Takigami in Japan (Motoyama et al., 1992), and so on. If measurement is made inside and outside a field, the Microgravity changes might suggest zone where something must occur inside the field or its vicinity according to production and injection.

In this paper, we investigated the Microgravity changes relating to both deep reservoir which is deeper than approximate 3,000 meters, and shallow reservoir which is less than approximate 1,000 meters.

2. METHOD

2.1 Methodology

We prepared both shallow reservoir model and deep one, then we evaluated the gravity changes at surface and in borehole due to production and injection. Fig. 1 shows the procedure of calculation of gravity changes.

2.2 Reservoir Simulator and Way of Calculation of Gravity Changes

The TOUGH (Pruess, 1987) was used for our reservoir simulation and the Talwani method (Plouff, 1976) was applied for the calculation of gravity changes.

In our study, density changes were calculated at each block using changes of steam quality, vapor density, and liquid density at each block for reservoir simulation on TOUGH. Density changes are computed by the following equation.

$$\Delta\rho = \{ (sq_2 \times \rho s_2 + lq_2 \times \rho l_2) - (sq_1 \times \rho s_1 + lq_1 \times \rho l_1) \} \times \phi$$

$\Delta\rho$:Density change sq :Steam quality
lq :Lequid quality ρs :Density of steam
ρl :Density of lequid ϕ :Porosity
Subscript1:Natural state Subscript2:After operation
$sq, lq, \rho s, \rho l$ are calcurated by TOUGH.

3. OUTLINE OF SIMULATIONS

3.1 Shallow Reservoir Model

(1) Natural state of shallow reservoir

Grid model for shallow reservoir is shown in Fig. 2. To construct this model actual field data such as borehole temperature and borehole pressure are referred to. Natural state simulations of 63 thousand years employ this conceptual model.

(2) Performance prediction simulation

Production corresponding to 10 MW is assumed for more than 20 years in the limited small area. Locations of production wells and injection ones at Layer–5 are presumed as shown in Fig. 3. Blocks for production and injection are located in Layer–3 and Layer–4, and all of separated water from steam shall be injected into the reservoir. Conditions of performance are as follows.

Production steam rate: 120 ton/hour (constant rate)
Separator pressure: 0.345 MPa
Enthalpy of injection water: 530 kJ/kg

(3) Gravity changes

Fig. 4 shows distribution of pressure, temperature, and steam quality of Layer–5 (depth of 100–300 meters) at the natural state and after 15 years of production and injection. Fig. 5 shows distribution of pressure changes, temperature ones, steam quality ones, and gravity ones of Layer–5 after 2.5 and 15 years of production. Changes of these parameters increase with change with time of 2.5 and 15 years of production.

Gravity increases at injection zone and decreases at production zone. These gravity changes correspond very well to the steam quality changes. At injection zone, steam quality decreases due to injection water, and distribution of gravity changes also agrees to high permeable zone as shown in Fig. 3.

3.2 Deep Reservoir Model

(1) Natural state of deep reservoir

Very simple model is introduced for this study, because we don't have enough data for deep reservoir yet.

Fig. 6 shows grid model for deep reservoir. In this model Layer–4 (depth of 1,500–2,000 meters) is impermeable and splits the shallow reservoir (Layer–5 and Layer–6) and the deep one (Layer–1, Layer–2, and Layer–3).

Average temperature of this model is 340°C after the natural state simulation of 63 thousand years.

(2) Performance prediction simulation

The following three deep reservoir types were examined.

Model A : No boundary between production zone and injection zone.
Model B (1): Boundary between production zone and injection zone.
Model B (2): Boundary, but different shape.

Fig. 7 shows distribution of permeability at Layer–1, Layer–2, and Layer–3 in deep reservoir model. This figure also shows locations of production wells and injection ones producing or injecting at Layer–2. All of separated water shall be injected into the reservoir as shallow model. Conditions of performance are as follows.

Production steam rate: 500 ton/hour
Separator pressure: 0.345 MPa
Enthalpy of injection water: 530 kJ/kg

(3) Gravity changes

Fig. 8 shows distribution of pressure changes, temperature ones, steam quality ones, and gravity ones at Layer–3 in deep reservoir model after 15 years of production.

Gravity changes are minus at production zone and its distribution is good coincident with the distribution of steam quality at Layer–3. Consequently we consider that the pressure of reservoir decreases dramatically due to expansion of two phase zone. Furthermore this distribution is also controlled by the boundary of reservoir at Layer–3. Refer to Fig. 7 about the distribution of permeability at Layer–3.

Temperature decreases at the area of injection zone due to injection water, and also at the area of production zone due to pressure draw down. Although density at injection zone ascends, it is difficult to see effect of these changes on gravity data.

4. CONCLUSION

We summarize the conclusion as follows.

a) The Microgravity changes depend upon expansion or reduction of two phase zone distribution by production and injection.

b) In our simulation, maximum changes are 50 micro gal at surface and more than this in borehole. Therefore, it is necessary to develop a very high accuracy Microgravity measurement system for successful monitoring.
c) In addition to high accuracy measurement, high density measurement is also essential to eliminate short period gravity changes in space because of shallow reservoir or ground water level.

ACKNOWLEDGEMENTS

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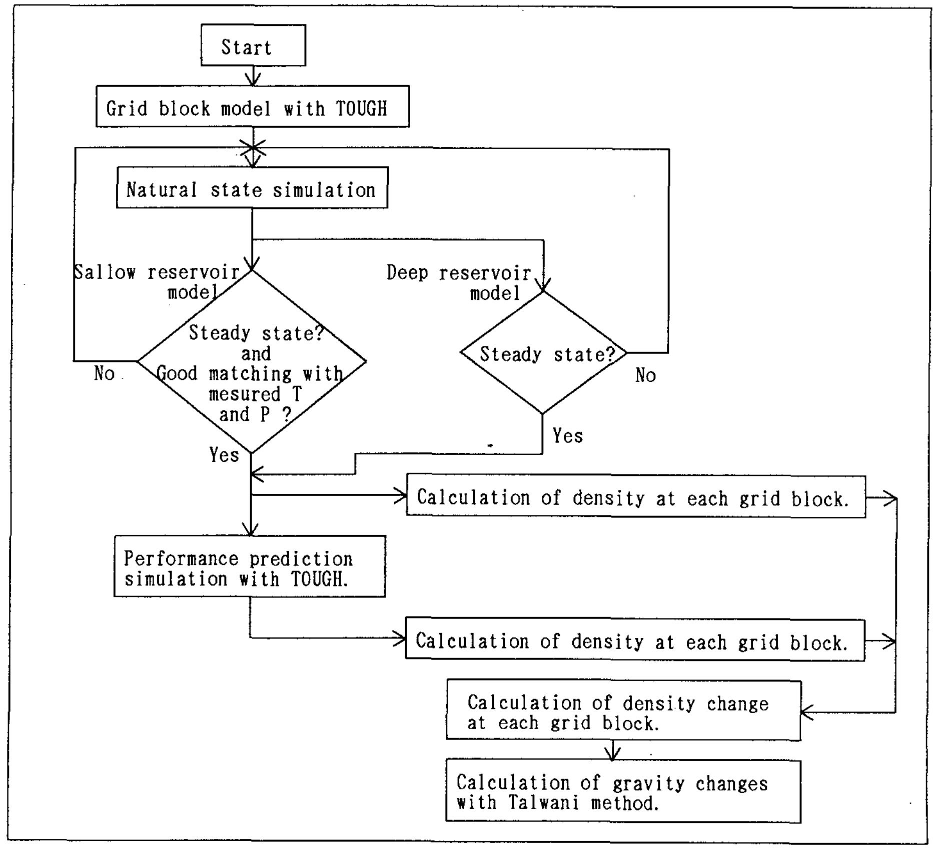

Fig. 1 Flow chart of calculation of gravity changes.

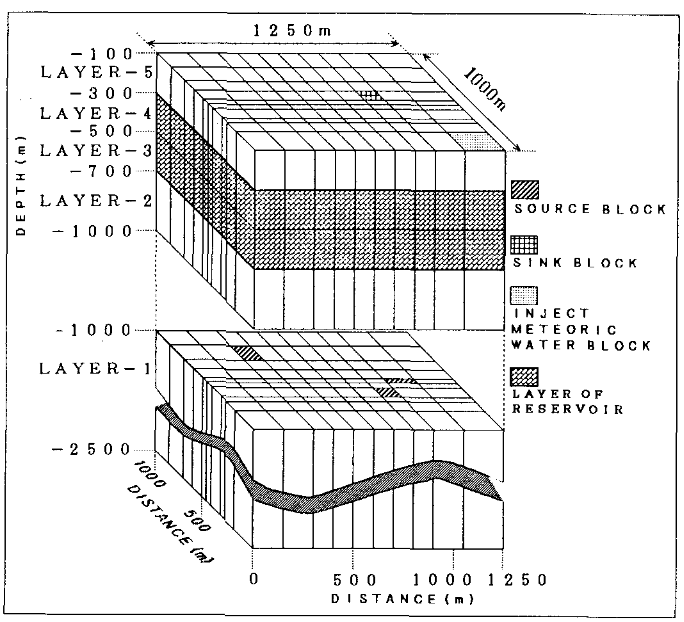

Fig. 2 Grid model for shallow reservoir.

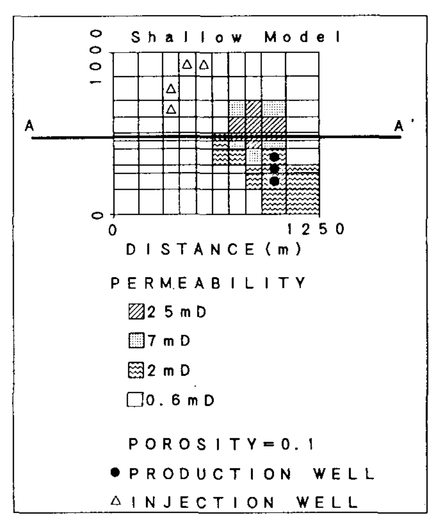

Fig. 3 Well location and distribution of permeability at Layer-5 in shallow reservoir model.

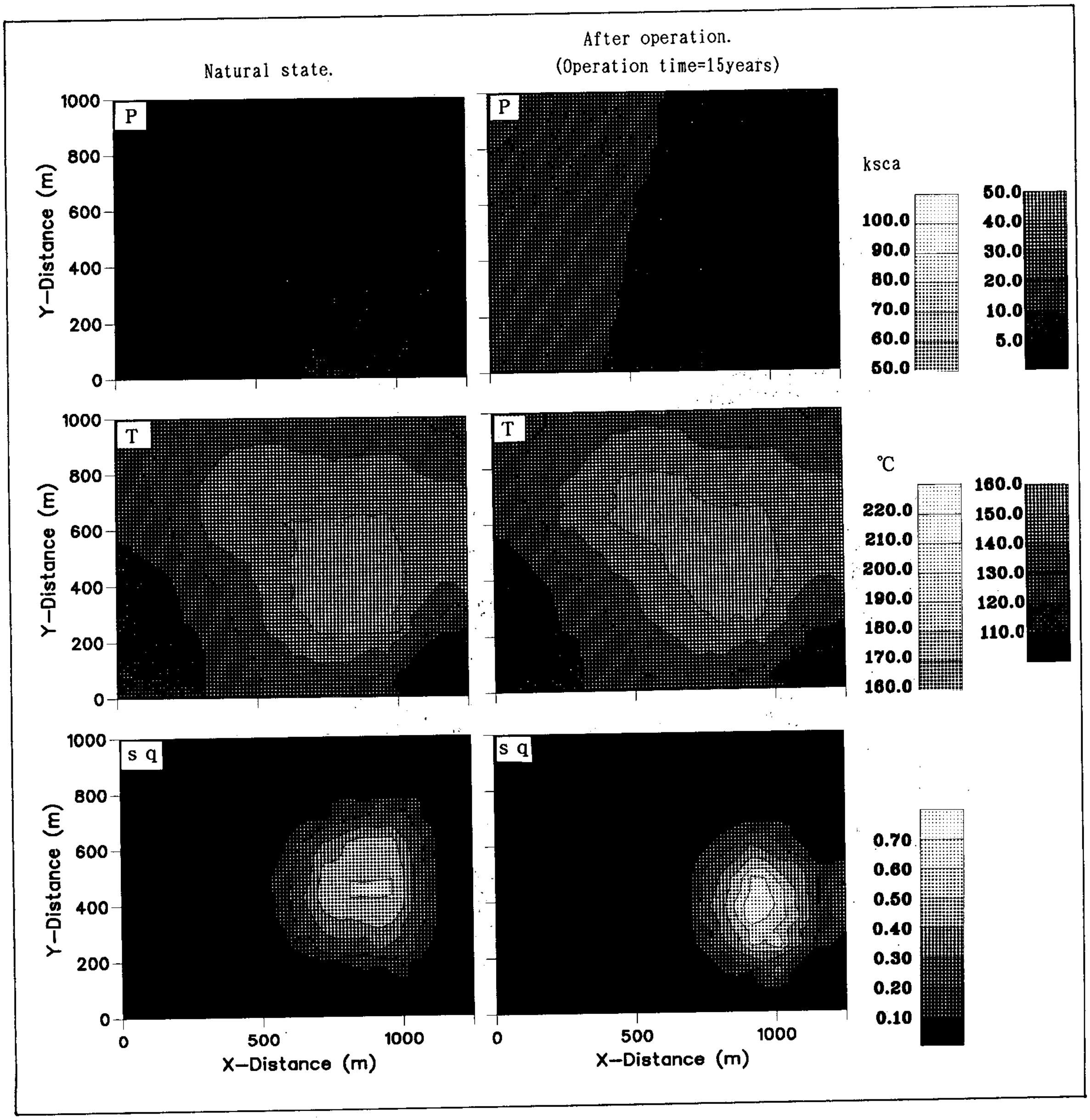

Fig. 4 Distribution of pressure (P), temperature (T), and steam quality (sq) at Layer−5 for shallow reservoir model. Figures of left side are the distribution of natural state and right side ones are the distribution after 15 years of production.

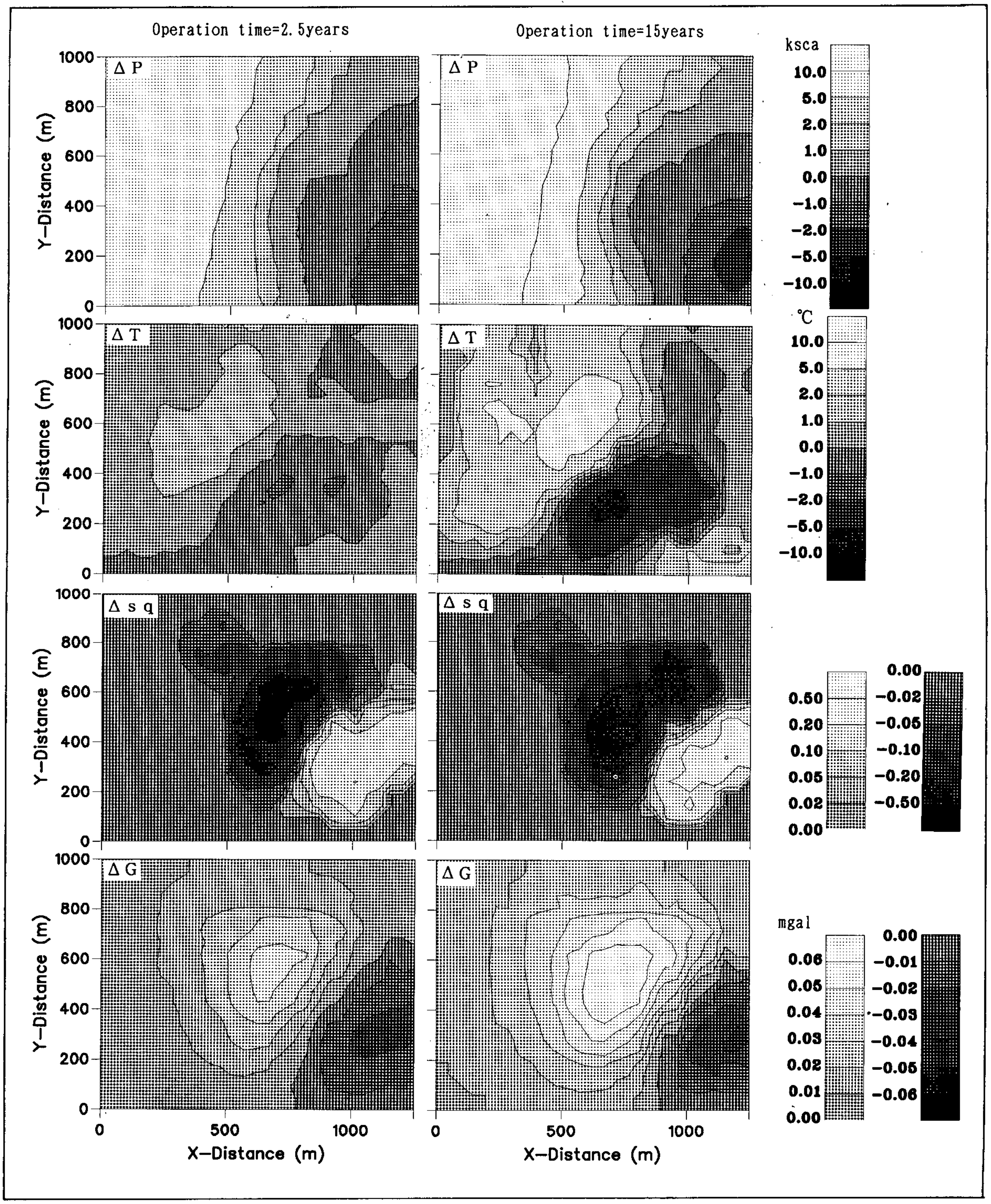

Fig. 5 Distribution of pressure changes (ΔP), temperature changes (ΔT), steam quality changes (Δsq), and gravity changes (ΔG) at Layer–5 for shallow reservoir model after 2.5 and 15 years of production.

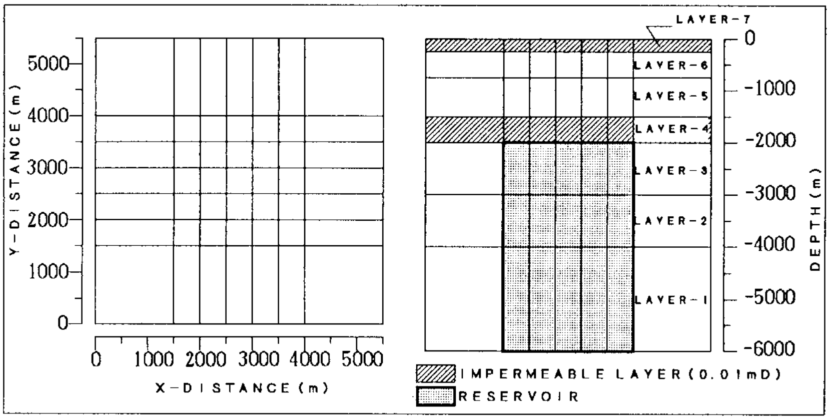

Fig. 6 Grid model for deep reservoir.

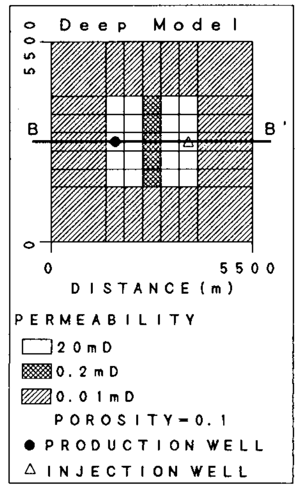

Fig. 7 Well location and distribution of permeability at Layer–1, Layer–2, and Layer–3 in deep reservoir model.

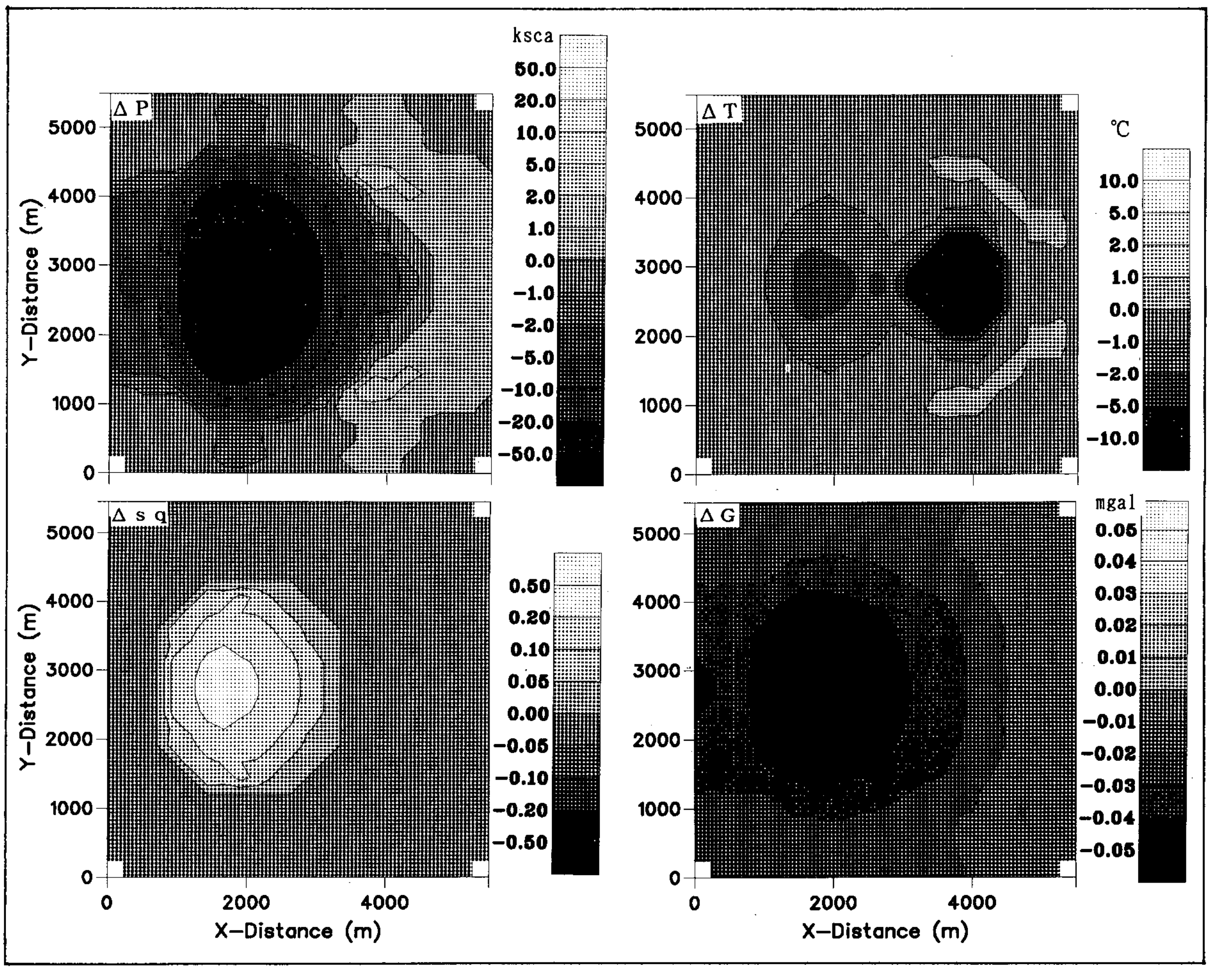

Fig. 8 Distribution of pressure changes (ΔP), temperature changes (ΔT), steam quality changes (Δsq), and gravity changes (ΔG) at Layer–3 for deep reservoir model after 15 years of production.