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Improvement of the reservoir model using the well-based data and geophysical exploration data in the Wasabizawa field, Japan

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ABSTRACT

The Wasabizawa geothermal power plant in Akita prefecture, Japan has been in operation since May 2019 with a generation capacity of approximately 46 MW. Many geophysical surveys have been conducted prior to the beginning of the operation, and some geophysical data such as time-lapse gravity and self-potential are periodically observed during ongoing operation at the field. A three-dimensional numerical model of the reservoir developed prior to the beginning of the operation has been improved mainly based on the data of the new-drilled wells to be matched to the logging data and previous pressure transient tests.

In this study, we conduct a production-reinjection history matching simulation which incorporates the operation history using the improved model, and compare the results with the data of the produced fluid, pressure histories of the observation wells, and the results of the previous and the latest geophysical surveys. While the improved model shows the better matching in the overall data, some discrepancies still remain. We attempt to further improve the model based onto the self-potential monitoring data. The results indicate that minor geological structures of the caprock could affect the fluid flow in the reservoir, and geophysical monitoring data can provide 2D and 3D information of reservoir behavior and be useful to improve the reservoir model.

1. INTRODUCTION

The Wasabizawa and Akinomiya geothermal area, which are adjacently located in Akita Prefecture, northern part of Honshu Island of Japan (Figure 1), were prospected since geothermal development promotional surveys supported by The Japanese New Energy and Industrial Technology Development Organization (NEDO) (so-called "C" surveys) in 1990s and the early 2000s (NEDO, 1998; NEDO, 2001, Inoue et al. (2000), Suzuki et al. (2000), Kurozumi et al. (2000)). After feasibility studies, drilling of exploratory wells, a production test and environmental impact assessment, the Wasabizawa geothermal power plant has been in operation since May 2019 with a generation capacity of approximately 46 MW operated by Yuzawa Geothermal Power Corporation (YGP) which is jointly established by J-Power, Mitsubishi Materials Corporation (MMC), and Mitsubishi Gas Chemical Company, Inc. (MGC).

To contribute to the assessment of the sustainability of the power generation and the management of the geothermal reservoir, AIST and J-Power are carrying out the collaborative research on the numerical prediction of the reservoir behavior with the operation of power plant, geophysical monitoring such as gravity and self-potential (SP), and the improvement of the reservoir model based on those monitoring data. A three-dimensional numerical model of the reservoir developed prior to the beginning of the operation (Nakanishi et al., 2017; Model2017) has been improved mainly based on the data of the new-drilled wells to be matched to the logging data and the previous pressure transient tests (Kano et al., 2023; Model2023). In this study, we conduct a production-reinjection history matching simulation which incorporates the operation history using the Model2023 and investigate the matching of the simulated results to the well-based and geophysical monitoring data.

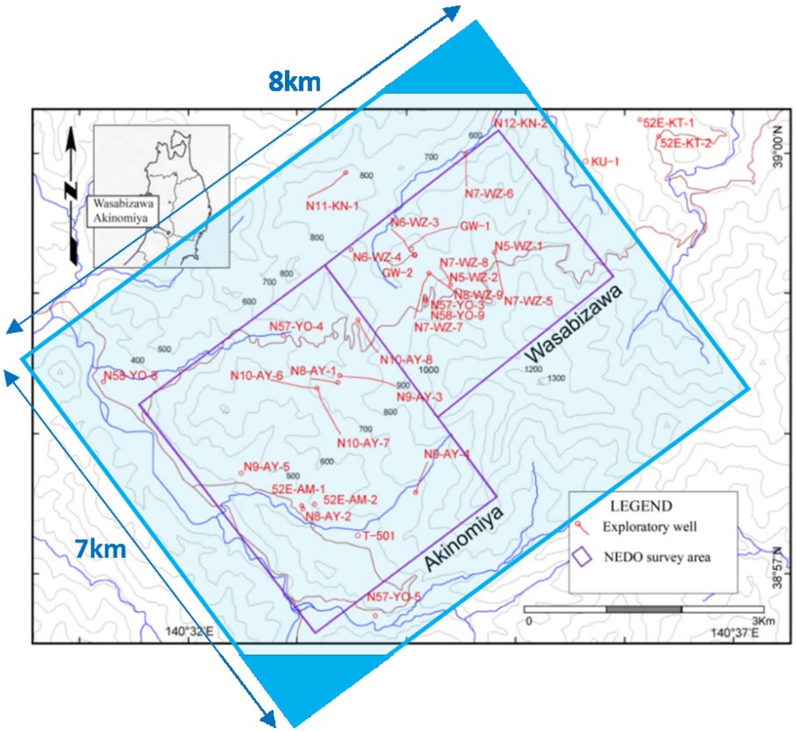

Figure 1: Exploratory well locations in the Wasabizawa-Akinomiya geothermal field.and the model domain modified after Nakanishi et al. (2017).

2. MODEL SETUP

2.1 Conceptual model

The Mt. Yamabushi and Mt. Takamatsu volcanoes which locate southeastern part of the site is believed to be the principal heat source for the geothermal system in this area. The volcanic stratigraphy may be subdivided into six major formations. The reservoir consists of the fracture network in the basement rocks (***Bm***) composed of granite and metamorphic rocks in Paleogene. Doroyu formation (***Dy***) composed of sandstone, conglomerate and andesite lava in the early Miocene period, the Ootoritanisawa formation (***Ot***) composed of tuff and tuffaceous sand, Mt. Torake (***Tw***) / Minase River formation (***Mn***) composed of tuff or tuff breccia in the Late Triassic Period, and the topmost Mt. Takamatsu volcanic rocks (***Tk***) composed of dacite or pyroxene andesite lava in the Quaternary overlie it (Sasaki et al., 2018).

Over 30 exploratory wells and geophysical surveys in the area revealed that the caprock appears to extend down to depths corresponding to between +200 m ASL and -200 m ASL ("above sea level") vertical elevation, below which the convection-dominated reservoir is found at temperatures between 280°C and 290°C. Temperature distribution, results of pressure interference tests, and chemical logging data suggest that the Akinomiya-Wasabizawa reservoir appears to be hydrologically disjoint from the nearby resource supplying the power station at Uenotai, which is located northeast of these area. The reservoir mainly exists between two relatively impermeable zones, is isolated from the Akinomiya hot spring area in the southwest side and the Kawarage fumarole in the northeast side (Nakanishi et al., 2021).

Based on this conceptual model, a numerical reservoir model was built to evaluate the electrical capacity of the field and to design optimum exploitation strategies (Nakanishi et al., 2017).

2.2 Numerical model

2.2.1 Grid constructure

Numerical model has an area of 7 km × 8 km and a vertical extent from -2.5 km ASL up to +1.05 km (total 3.55 km) as shown in Figure 2. The x-axis (northeast direction) and the y-axis (northwest direction) are subdivided into 24 and 22 grid blocks respectively, of which size is from 300 m at minimum to 600 m at maximum. The z-axis in vertical direction is subdivided into 23 layers with thickness of 100 m above -0.5 km ASL and coarser below. The geometrical centers of topmost cells are set to be located just below the "water table depth" which reflects the highly irregular topography and locates around 150 m below the local actual ground surface.

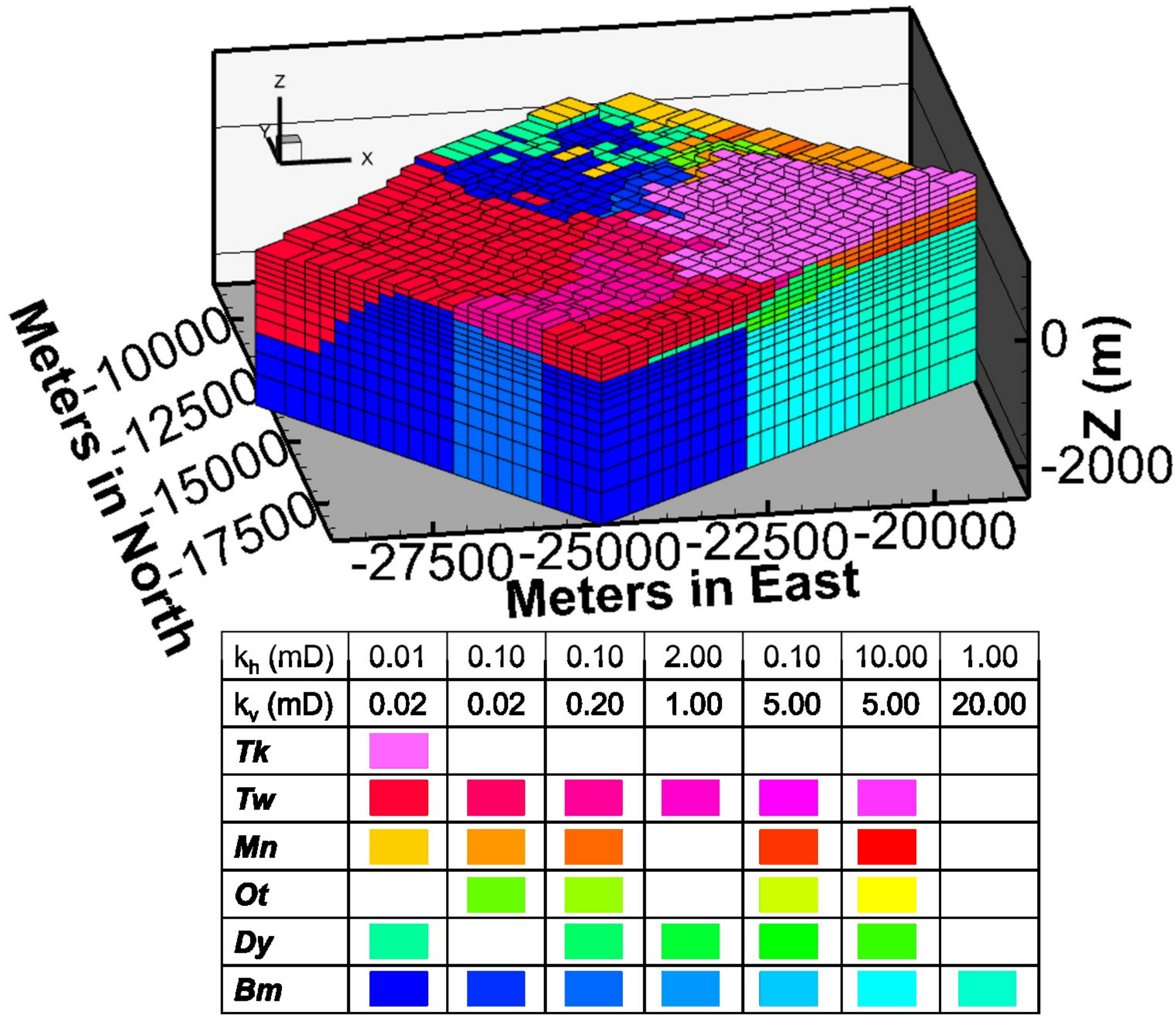

Figure 2: Grid constructure and rock phase distribution in the Model2023.

2.2.2 Boundary conditions

In the Model2017, the all lateral boundaries are impermeable and insulated (Nakanishi et al., 2017). Low permeable zone is widely distributed in the northwestern and southwestern part of the area, and the area appears to be hydrologically disjoint from the other geothermal area to the northeast as mentioned in the section 2.1. The southeastern boundary is jointed to Mt. Yamabushi and Mt. Takamattsu volcanoes while it is also imposed to impermeable condition in the model for the conservative prediction of the production. Model2023 also adopts these conditions in the natural state calculation to be matched to the new drilled logging-data and the previous pressure transient tests. In this study, we conduct production-reinjection simulation with these conservative conditions.

Fixed-pressure condition is imposed to the topmost boundary to allow the downward recharge and upward discharge (cf: hot spring). Inflow fluid consists of cold meteoric water (H_2O) for the available volume which corresponds to precipitation percolation, and additional atmospheric air (N_2) to maintain the grid block pressure. In actual, the downward recharge never exceeds the limit of percolation during the calculations in this study.

Impermeable condition and fixed conductive heat flux are imposed most part of the bottom boundary. The value of the heat conductive flux is set to decrease progressively around the Mt. Takamatsu volcano located in the southeastern corner of the model (Figure 3). At the deep part of the Mt. Takamatsu indicated as an orange-colored part in Figure 3, a uniform fixed fluid mass flux that totals 11 kg/s with temperature of 325 °C is imposed.

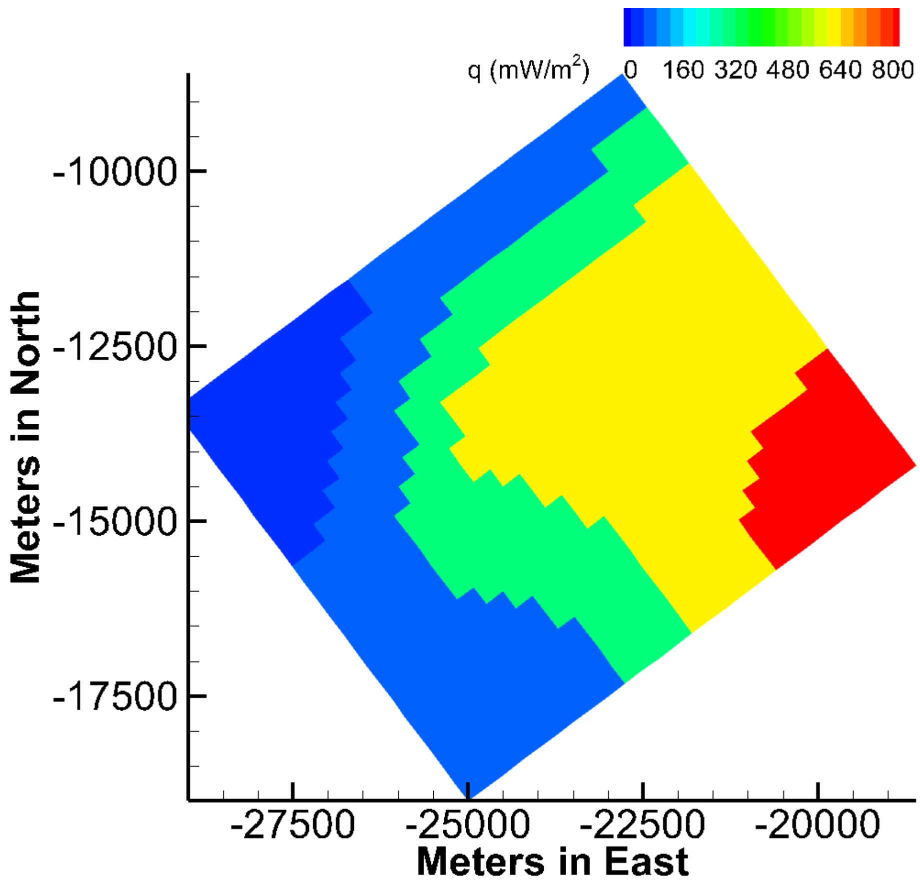

Figure 3: Heat flux distribution at the bottom of the model.

2.2.3 Geological model

Figure 4 shows the planes of the numerical model domain where one of the feed points of the production wells is located and their rock phase distribution in the Model2023. Six major formations are subdivided into 28 phases in the regard of permeabilities as shown in the legend in Figure 2. Other rock properties based on measured data for each formation are shown in Table 1.

Pale blue and deep blue part indicate the high-permeable reservoir and the adjacent low-permeable area, respectively. To reproduce the hydrological and thermal behavior in the fractured reservoir, "MINC" double porosity model (Pritchet, 1997) was adopted in the model. The rock medium is represented with thermal conductive impermeable matrix and fracture conduits.

It is noted that most of the documented wells were completed to bottom-hole elevations lying between -0.3 km and -0.9 km ASL, so that there is less information on the exterior depth. Lateral heterogeneity is also left to be uncertain while some geophysical data were referred to.

Table 1: Bulk properties of the major geological formation in the numerical model.

Formation	Grain density (kg/m^3)	Overall porosity (-)	Grain heat capacity (J/kg-°C)	Thermal conductivity (W/m-°C)
Tk	2,300	0.14	1,000	1.7
Tw	2,500	0.07	1,000	2.1
Ot	2,500	0.07	1,000	2.1
Mn	2,600	0.06	1,000	2.4
Dy	2,600	0.02	1,000	2.4
Bm	2,700	0.02	1,000	2.4

WA (WZ), WB, and WC indicate the production bases and AA (AY) and AB indicate the reinjection bases. Black-colored bases are where originally drilled wells during the "C" surveys are located, and blue-colored bases are newly constructed for the power plant.

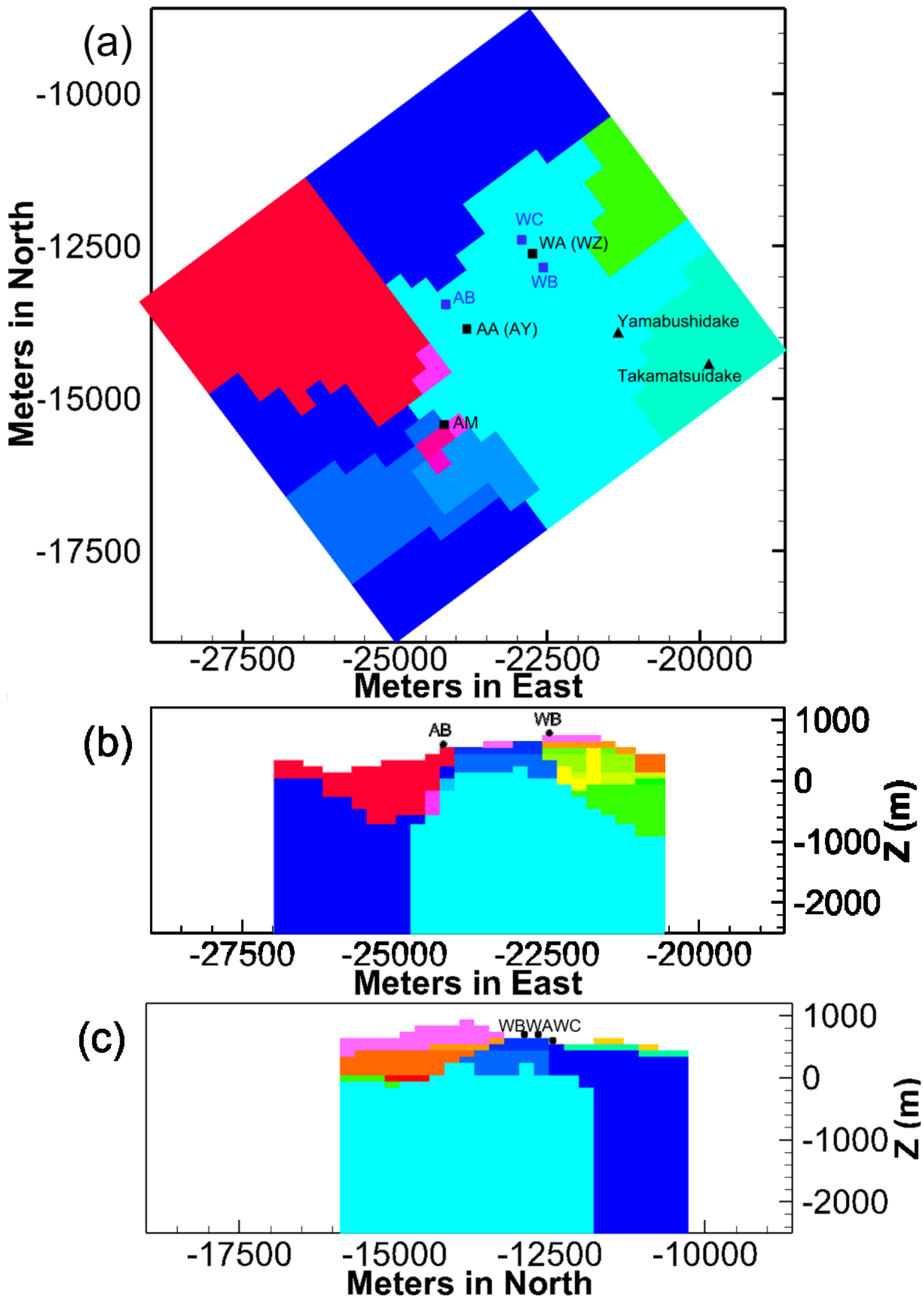

Figure 4: Rock phase distribution and specified locations at the plane of (a) k = 8 and (b) j = 12 and (c) i = 17 in the Model2023. The rock phase legend is referred to Figure 2.

3. SIMUATION RESULTS AND MATCHING

3.1 Natural state simulation

Simulations are conducted using STAR reservoir simulator (Pritchett, 1995). We calculate 200,000 years to obtain the natural steady state. Figure 5 shows the temperature matching of the Model2017 and the improved Model2023 to the some new-drilled production well profiles. Reservoir model was modified from Model2017 to Model2023 on the bottom surface of the caprock mainly based on the temperature conductive-advective profile.

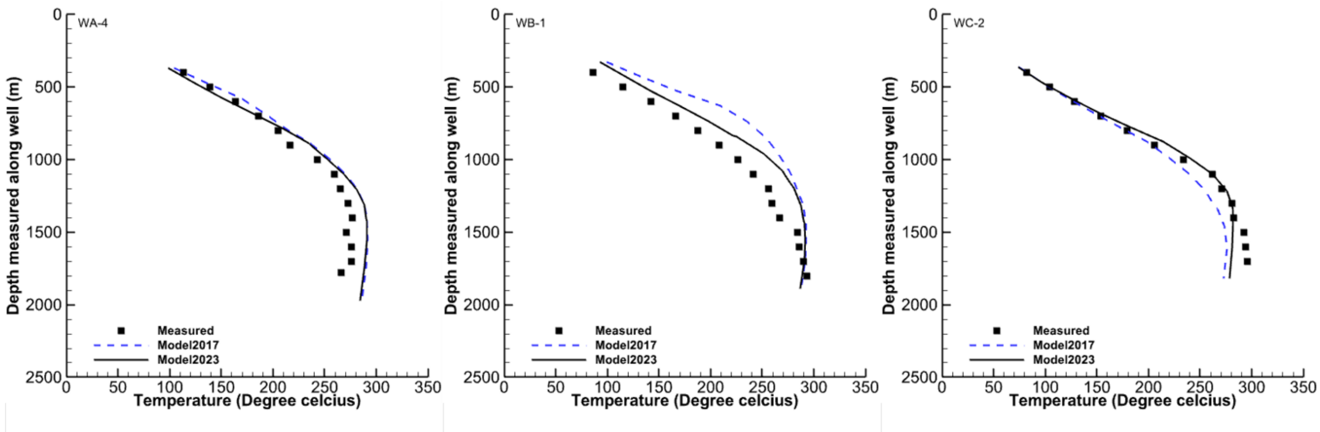

Figure 5: Temperature profiles along some of the major production wells.

3.2 Production-reinjection simulation comparison to monitoring data

The Wasabizawa geothermal power plant is a double-flash plant designed to generate 260 t/h of steam and 690 t/h of hot water with a capacity of approximately 46 MW. It is currently operated at approximately 43 MW output. Time histories of power output and reinjection rate of each well for 5.5 years from January 1st 2019 to June 30th 2024 are used as the input data for history matching.

3.2.1 Production fluid

Figure 6 shows the time histories of the sums of production rate and the enthalpy of produced fluid from each production well. Total fluid rate and the ratio of hot water/steam are mostly in good agreement with the actual result, while the simulation cannot address the production interruption of the specific well so that sometimes the hot water/steam ratio does not match between them. All wells produce hot-water dominant fluid in the simulation, while reported are wellbore flash in the WA-3 and that the WB-2 is steam-dominant and in intermittently operation. These discrepancies indicate that the present model still needs the improvement for the distribution of the two-phase zone.

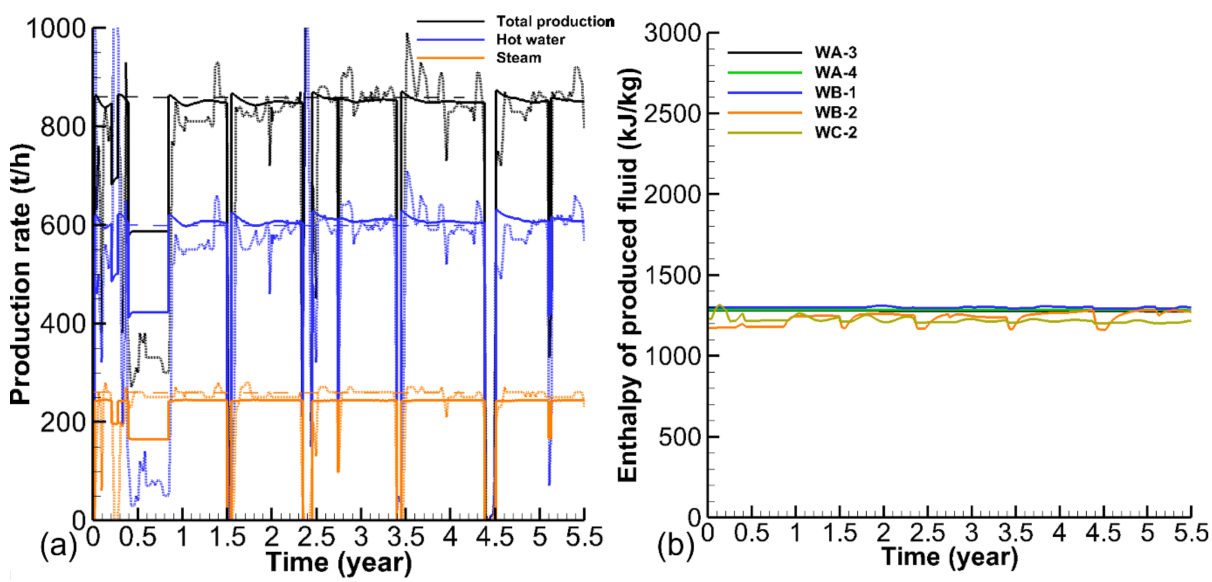

Figure 6: Time histories of (a) production rate (Solid lines indicate the simulated results and dashed lines indicate the weekly-averaged records.) and (b) enthalpy of produced fluid at each well.

3.2.2 Pressure histories

Figure 7 shows the time histories of the pressure at the observation wells.

For the GW-1 in the production area of WC, the trend in gradual decrease of the pressure is in good agreement while the response at the timing of the production interruption is still large in the simulation. For the WZ-8 in the production area of WB, the decrease trend in the simulation continues longer than the observation, however, the matching is improved compared to the previous Model2017. For the OGC-3 in the reinjection area of AB, the pressure increase and the response due to the reinjection in the simulation are much larger than the observation, however, the trend of remaining at the constant level is in good agreement and the trend in the response is improved. The all matching of the Model2023 were improved from the previous Model2017, although some discrepancies are left, which are thought to be related to the distribution of the two-phase zone and the local permeability in the vicinity of the reinjection wells.

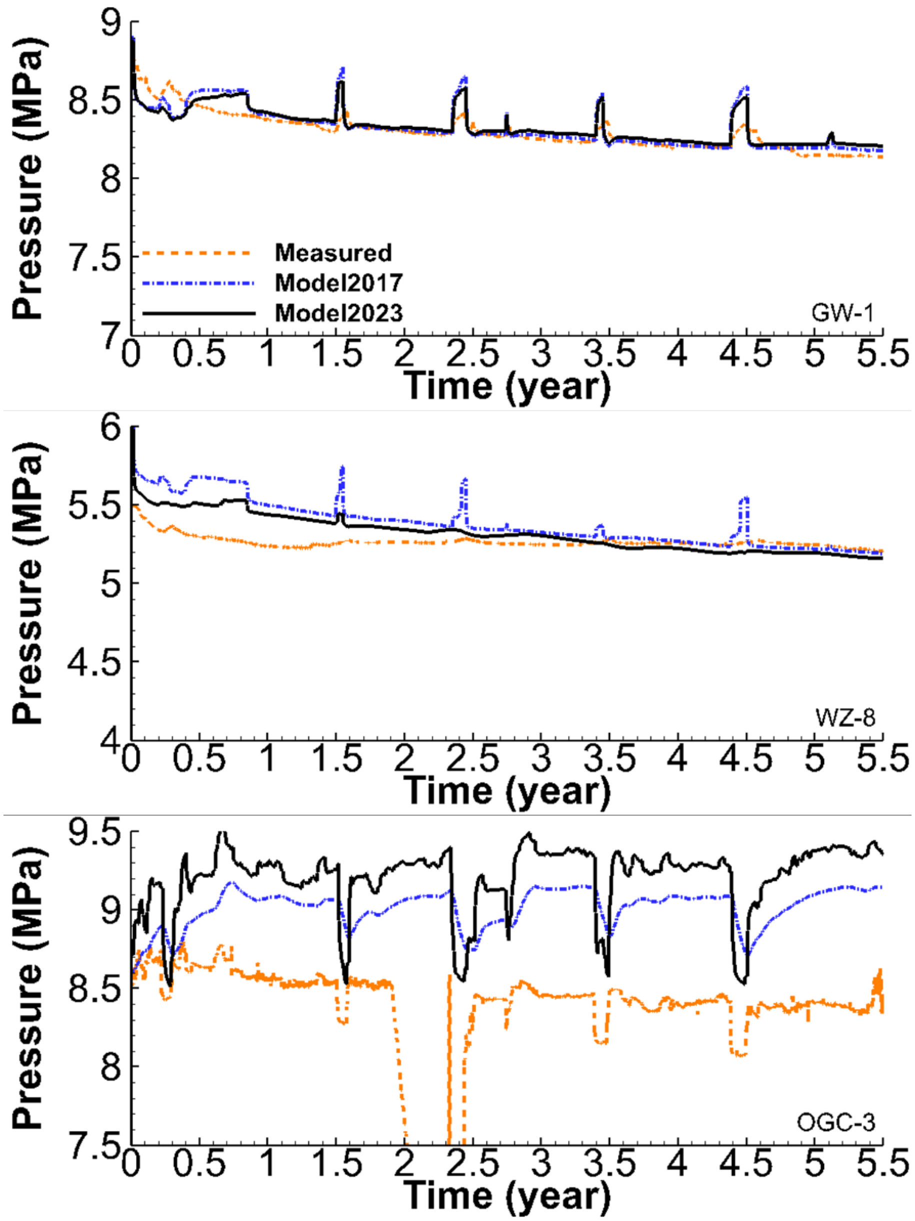

Figure 7: Time histories of pressure at observation wells.

3.2.3 Geophysical data

AIST and J-Power have been conducting repeated geophysical surveys before and during the operation of the geothermal power plant to monitor the reservoir behavior affected by the operation of the geothermal power plant (Horikawa et al., 2024). Figure 8 shows the map of the measurement points of the gravity and SP measuring line along prefectural road 310 onto the bottom plane of STAR model.

Figure 9 shows the relative sea level (RSL) and the self-potential (SP) profile along the measurement line. The effect of the elevation is well reproduced by the model, however, convex profile around the production area which is thought to be due to the upward geothermal flow is not. This discrepancy may be attributed to minor geological structures of the caprock.

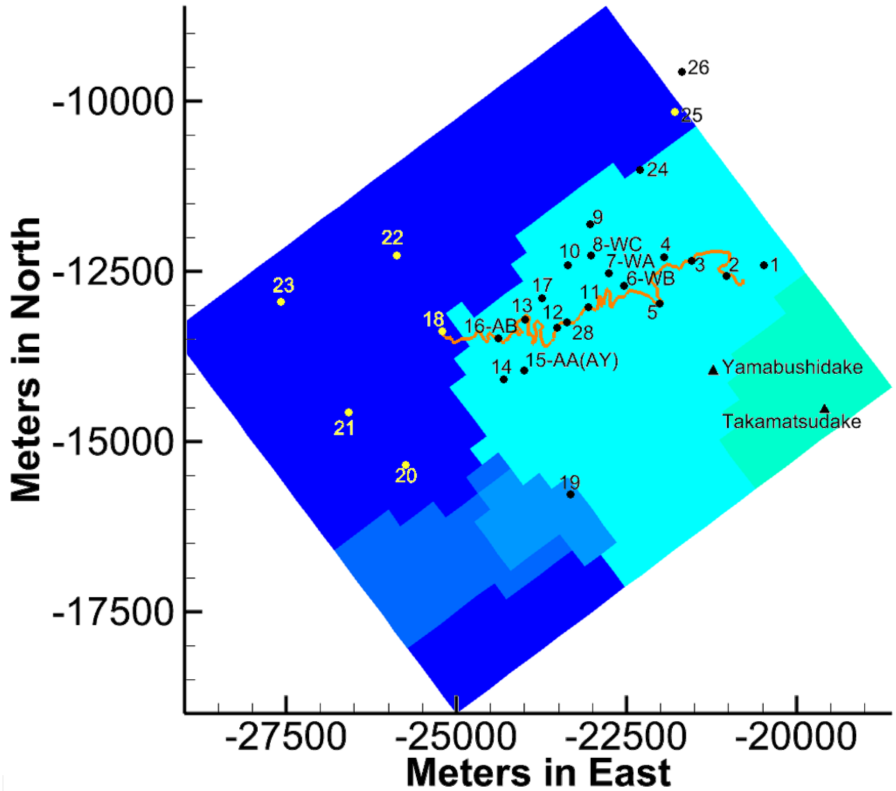

Figure 8: The map of the measurement points of the gravity (numbered dot) and SP measurement line (orange) onto the bottom plane of STAR model.

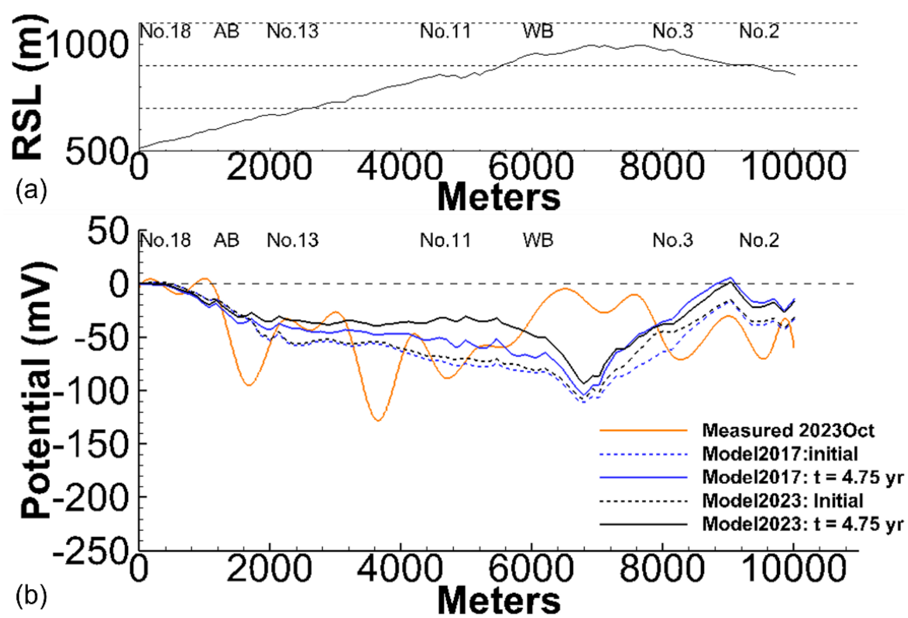

Figure 9: The relative sea level and (b) SP profile along the measurement line indicated in Figure 8.

4. IMPROVEMENT OF THE RESREVOIR MODEL

One of the possible causes of the discrepancy in SP convex profile around the production area is the minor geological structure of the caprock. The structure may also contribute to the distribution of two-phase zone. Figure 10 shows the trial model (Model-SP) in which the basement of the caprock is modified to encourage the geothermal fluid to migrate upward to shallower depth. Compared to Figure 4 (b), yellow-colored high-permeable zone in the vicinity of the production base and the high elevation area is extended to shallower part. This modification is adopted not to worse the temperature profile matching around the area. Figure 11 shows its new resultant SP profile. Convex profile between 6,000 m and 8,000 m is still smaller than the measurement, however, it shows some improvement.

This result suggests that minor geological structures of the caprock could affect the fluid flow in the reservoir, and geophysical monitoring data such as SP can provides 2D and 3D information of fluid dynamics and be useful to improve the reservoir model.

It is noted, however, that this trial Model-SP still has problems in the matching to the other data left and further improvement is expected in together other monitoring data such as pressure and gravity.

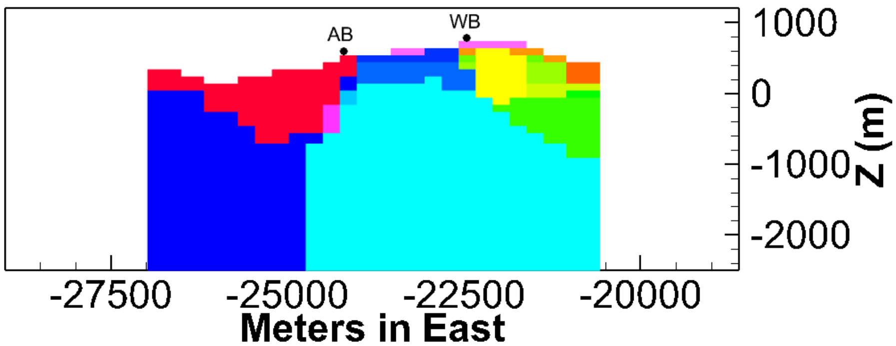

Figure 10: Rock phase distribution and specified locations at the plane of j = 12 and in the Model-SP. The rock phase legend is referred to Figure 2.

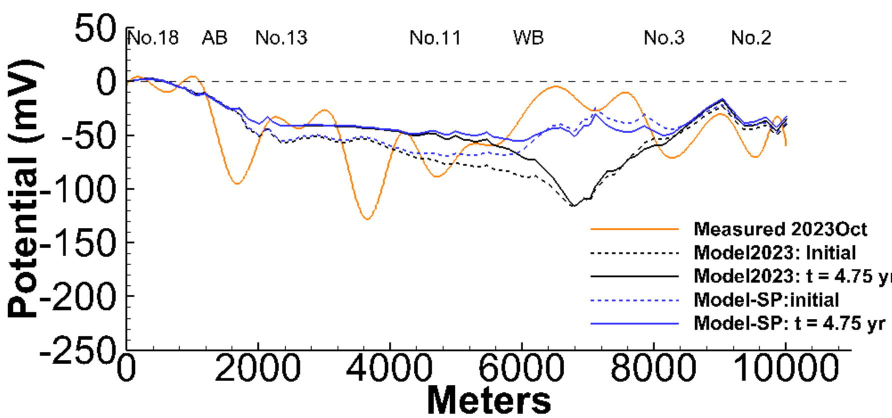

Figure 11: SP profile along the measurement line indicated in Figure 8 with the Model-SP.

5. CONCLUSION

In this study, targeted in the Wasabizawa-Akinomiya geothermal area and the power plant operation, we conduct a production-reinjection history matching simulation which incorporates the operation history using the improved model based upon the well-based data, then compare the results with the data of the produced fluid, pressure histories of the observation wells, and the results of the previous and the latest geophysical surveys. Simulated results show the better matching in most of the observation data, while some discrepancies are left. Trial model improvement based onto the geophysical data suggests that minor geological structures of the caprock could affect the fluid flow in the reservoir, and geophysical monitoring data such as SP can provides 2D and 3D information of fluid dynamics and be useful to improve the reservoir model.

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