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Determination of Negative Density Changes in the Kamojang Geothermal Field Using TimeLapse Microgravity Analysis Keywords: time-lapse microgravity, stripping filter, density changes ABSTRACT Ground deformations and gravity changes were mesured inorder to study density distribution changes caused by theproduction and re-injection into the Kamojang geothennalreservoir. In the last two years (2006-2007) we conductedtwo elevation measurements, in July 2006 and July 2007. Inaddition, we carried out three microgravity surveys, in June2006, November 2006 and July 2007. The gravity stationswere located at 88 benchmarks to cover the survey area.From those three maps we have already made two timelapse microgravity anomaly change maps, covering theperiods of June-November 2006 and June 2006-July 2007.

Gravity effects due to density change in the reservoir(caused by production/re-injection) were obtained bycorrecting the measured gravity anomalies of thegravitational effect to vertical ground movements(subsidence) and ground water level changes. Gravityanomaly measured on the surface due to elevation changehas a positive value for elevation lowering (subsidence) andthe gravity change is approximately 3 pGal for 1 cmelevation change. Gravity anomaly related to dynamicgroundwater was corrected by a stripping filter. By usinginversion methods, a map of density distribution changeshas been produced during this period. 1 .

INTRODUCTION Applications of the gravity method are carried out formonitoring purposes. Multiple studies have been performed,for example for monitoring EOR at oil and gas fields(Santoso, et al, 2004; Hare, et al. 1999), and geothermalfields (Allis and Hunt, 1986; Fujimitsu et al, 2000). Gravitywas also monitored in the Kamojang geothermal field.Results of time lapse gravity surveys for 5 periods (1984,1988, 1992, and 1999) by Pertamina Geotermal indicatethat the negative gravity anomaly from 1984 to 1999 isaround -250 pGal at the center of production; whilst thesubsidence maximum is at 0.2 m.

Gravity monitoring in geothermal fields is used to predictthe distribution of density change in the reservoir and/orbehavior of a two-phase zone as a result of production andreinjection of geothermal fluid. Gravity anomaly changesbetween two surveys result from changing ground surfaceand subsurface as well (Santoso, dkk, 2006). Changes ofgravity in the subsurface are due to changing groundwaterlevel, and saturation of fluid in reservoir. Therefore, themicrogravity anomaly in the reservoir needs to be correctedto account for subsidence and lowering of groundwaterlevel. Corrected gravity due to subsidence can be done directly ifelevation changes are known from leveling or GPS surveys.

Gravity corrections for groundwater level change can bedone with the stripping filter method. This paper analyzes the distribution of density changes inthe Kamojang geothermal field using time-lapsemicrogravity anomaly period of June 2006 to July 2007.Modified filter stripping was used to separate gravityanomaly near surface (groundwater level) from that in thereservoir. 2. METHOD AND DATA 2.1 Time-Lapse Microgravity Survey and GPS During period of 2006-2007, we conducted time lapsegravity surveys 3 times that were June 2006, November2006 and July 2007, using a digital Lacoste & Romberg G-1158 gravimeter.

The numbers of benchmarks used for thesurveys were 88 with the same looping to get gravimeterdrifts that were relatively similar. Tidal correction wasmeasured directly by the Lacoste & Romberg G-508gravimeter, which was read continuously at the base. The elevation of 26 benchmarks was measured using GPS (Trimble 4000 LS) with measurement duration of 5-6 hours at every point. Stripping Filter To separate gravity anomalies from shallow-subsurface (groundwater level change) and deep (geothermal reservoir), we applied filter stripping, modified from Cordell (1985) and Aina (1994).

Gravity anomaly caused the mass density changes in the horizontal direction can be written as, / If an anomaly observed on the surface stems from changes in the shallow-subsurface and the deep-subsurface, then the total anomaly can be written as, g(x, y)= gs(x, y)+ g <1(x, y) (2) where subscripts s and d denote shallow and deep. Equations (1) and (2) in the wave number domain can be written: / And G(u,v)=G,(u,v)+GjUi,v) (4) where u is wave number coordinate, G(u) is Fourier transform (TF) from g(x), Gs(u) is TF from gs(x), Gd(u) is TF from gd(x), tj = hbs-frs and td = hM-htd is prism thickness. The continuity equation (3) can be written for shallow and deep sources separately, i.e.: / Equations (5) and (6) give an important basis design for the desired filter stripping.

Filter stripping for a shallow anomaly spectrum can be written: / Substituting equations (5) and (6) to equation (7) is: / Where / Equation (8) is filter stripping which a form identical to the equation presented by Cordell (1985) and Aina (1994). Flere a is comparison density, p thickness comparison (t) and £, it is the difference in depth between the shallow and deep layers. 3. RESULTS AND DISCUSSION 3.1 Subsidence and Groundwater Level Changes in the Survey Area To determine change of gravity, each gravity stationcollected data with high accuracy (leveling or GPS), i.e. onthe order of mm. Figure 1 as measured by GPS in June2006 and July 2007.

Areas experiencing subsidence areparallel to the SW-NE direction with Citepus fault andKendang fault. Maximum subsidence is 6 cm, which is thesouth part around the rim-structure. The largest inflation (6cm) was measured in the North field. Transformation ofgravity as result of subsidence every 1 cm is around 3,08pGal. Changes in groundwater level were calculated using localrainfall based on equation of Akasaka and Nakanishi(2000), as seen in Figure 2. The change in groundwaterlevel for the period of June 2006 to November 2006 was -1,502 m; whilst during the period from June 2006 to July2007 it was +0,396 m.

Based on previous studies andmeasured ground water level from wells it is on average 5to 10 m, and the depth of geothermal reservoir around 700m (Kamah et al., 2005). 3.2 Time-lapse Microgravity Anomaly, Stripping Filter and Inversion A survey monitoring gravity changes needs to be conductedwith high accuracy. In addition, the survey must be donewith similar sequence (looping) so that every gravity stationin each period has the approximately equal drift. Tidal correction was applied using measured tidal variations fromthe base.

Three gravity observations were conducted toobtain two microgravity anomaly data sets from June '06 toNovember '06 and June '06 to July '07. Both microgravityanomalies are corrected to account for subsidence in eachperiod. The result is an estimate of the change indistribution of density in the subsurface. The gravityanomaly in the subsurface consists of a shallow anomaly(groundwater level change) and a deep anomaly (change ofdistribution of geothermal reservoir density). These twoanomalies were separated using filter stripping. Filter stripping performed by multiplying the gravitysubsurface spectrum with the filter spectmm built fromshallow and deep layer parameters (groundwater levelchange).

These were estimated from geological data, welldata and other geophysical data. The filter strippingparameters are density change (a), thickness comparison (P)and depth difference (4) between the shallow layer and deeplayer (Equation (8)). The results show a change of shallowlayer density (Aps) 0,3 gr/cm3, deep layer density in (Apd)0,018 gr/cm3; an average depth of 5m for the shallow layerand 700m for the deep layer (reservoir). Filter strippingminimizes the gravity effects of the shallow layer andmaximizes the gravity effects of the deep layer.Microgravity anomaly changes in time, which result fromchanges in distribution density in the geothermal reservoirs,Figure 3 and Figure 4. These were obtained using the filter.The research area is dominated by negative gravityanomaly, with the maximum negative gravity anomalylocated in the western and northern parts of the field. Figure4 shows gravity change over a one year period, withnegative gravity anomaly equal to -80 pGal.

The distribution of density change in the reservoir is foundusing inversion methods. A field model is built with 16cells in the x-axis direction, 17 cells in the y-axis directionwith a grid of 250 m x 250 m, and 9 cells in z-axis directionof with 4 layers. Modeling was applied using the softwareGrav3D version 20 of UBC-GEOPHYSICAL InversionFacility, University of British Columbia. Figures 5 and 6 are maps of density change at a depth of 1100 m for the periods of June '06 to November '06 and June '06 to July '07. CONCLUSION Gravity monitoring at the Kamojang geothennal field hasbeen carried out 5 times since the year 1984.

In this studythe change of gravity was measured over a period of oneyear, utilizing correction methods based on GPS data andthe filter stripping method to separate gravity anomalycaused by shallow subsurface variations from deepreservoir variations. This way we could estimate thedistribution of reservoir density using a data collected overa relatively short period. The stripping filter can separate mierogravity anomalies, asa result of reservoir mass decrease due to extraction ofvapor and/or addition of reservoir mass from reinjection ofgeothennal brine, from gravity anomalies resulting fromlowering of the water table. Subsidence (dry-out) is shownby negative microgravity time-lapse anomaly (-) andadditional mass of injection water in the reservoir(recharge) is shown by positive microgravity time-lapseanomaly (+).

Negative microgravity time-lapse anomaly (-)is interpreted as negative change in density anomaly (-) andpositive microgravity time-lapse anomaly (+) is interpretedas positive change in density. Filtering result shows that negative gravity anomaly isrelated to production wells. Based on time-lapse anomalymicrogravity maps from the period of June 06 to July 07,negative concentration anomalies are located in the westernfield, i.e. around rim structures. This can be related toactivity of production wells (KMJ-22, KMJ-28, KMJ-37,KMJ-41, KMJ-42, KMJ-27 andKMJ-65) in the area. Basedon a 3D cross sectional map at depth of 1100 m (+400 ma.sl.), this area is represented by negative density from -0.02 up to -0.04 gram/cm3. This also proves that injectionamounts through injection well KMJ-35, and KMJ-46 in thearea is not effective.

Positive anomaly is represented byaccumulation of injection water from injection well and oraccumulation of water meteoric flowing through faults.Existence of fluid flow in the reservoir is clarified withresults of > analysis tracer injection and microearthquake(MEQ).

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