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An Update on the Stable Isotopes Geochemistry of Mahanagdong Field, Leyte, Philippines

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ABSTRACT

The use of stable isotopes as natural tracers in a geothermal system has long been established to be highly essential from exploration up to the production stage of the resource. Stable isotopes are considered as conservative geochemical indicators as they do not participate in the different reactions taking place in the reservoir. Therefore the changes in the isotopic data can be used to trace the movement of the different fluids in the reservoir through time. Regular monitoring of deuterium and oxygen-18 in production wells, surface waters and thermal areas is an important part of resource management in the Leyte Geothermal Production Field. During the expansion in the Mahanagdong Field, the deuterium and oxygen-18 data from the newly-drilled production wells have greatly changed our understanding and perception of the geothermal field. Correlating the deuterium and oxygen-18 data with the physical and geochemical parameters of the field reinforced the identification of a new location of the upflow, as well as, being instrumental in pinpointing the different reservoir processes affecting the field.

1. MAHANAGDONG GEOTHERMAL FIELD

The Greater Tongonan Geothermal Field in Leyte, Philippines is divided into two geothermal systems – the Tongonan Geothermal Field in the north and the Mahanagdong Geothermal Field in the south (Fig 1). The impermeable Mamban block lies between the two systems that, despite their proximity to one another, have developed into different geothermal systems (Gonzalez, et al., 2005).

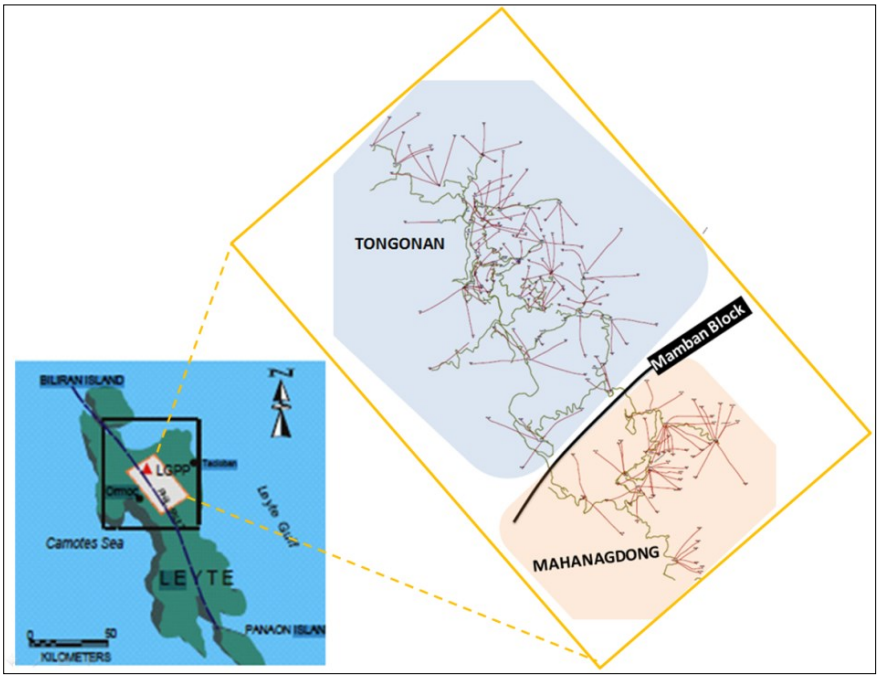

Figure 1: Location of the Greater Tongonan Geothermal Field in the island of Leyte, Philippines.

Different resource assessments conducted have confirmed that Tongonan and Mahanagdong each have their separate, individual upflow and outflow areas. In the studies of Dacillo & Salonga (2004) and previous update of Dacoag (2015), isotopic geochemistry has been an invaluable tool in supporting the distinction of the hydrothermal systems of Tongonan and Mahangdong. This paper will build up on the evaluation conducted by Dacoag in 2015, but will focus only on the Mahanagdong Geothermal Field and how the new isotopic geochemical data extracted from the expansion areas has helped in improving the understanding and management of the field.

The Mahanagdong Geothermal Field is further divided into two sectors: A and B. Mahanagdong-A consists of production pads AB, AC and AD and reinjection pads AA and AF. Pad AE has low permeability and the wells are not utilized. The wells in these pads cater to powerplant A (Figure 3). Mahanagdong-B consists of production pads BA, BB and BC and reinjection pads BD and BE, and all of them cater to powerplant B. Baseline isotopic data in Mahanagdong has been collected since the exploration stage in the 1980s and until the production stage from 1997-2002 from surface waters, thermal areas and 18 production wells in pads AB, AC

AD and BA. Sample collection resumed in 2010 when in-house isotope analysis was re-established (Dacoag, 2015). Isotopic data from 2010-2011 included 3 wells additional wells in pad BA, and 3 more wells in new pad BB. The samples collected in 2016-2017 included 3 additional wells in pad BB and the 2 wells in new pad BC. Pads BB and BC are the expansion areas.

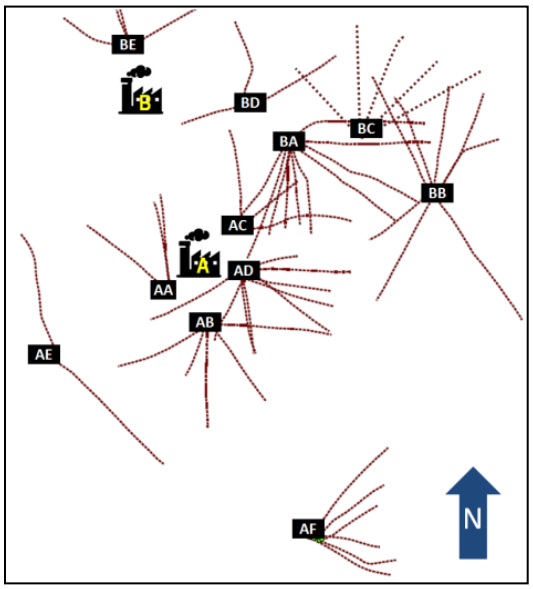

Figure 2: Pad and well track lay-out of Mahanagdong

2. ISOTOPE SAMPLING AND ANALYSIS

Monitoring of deuterium and oxygen-18 isotopes are an important part of the reservoir management in the Leyte Geothermal Production Field. Biannual sampling – during wet and dry season – is done for all production wells, reinjection lines, surface waters and thermal areas. Sampling in production wells are done via a twin-cyclone separator wherein the two-phase discharge from the production wells are separated into liquid and vapor phase and collected separately, with the vapor component being condensed via cooling coil (Figure 3). Liquid samples are collected from reinjection lines, surface waters and thermal springs. For steaming grounds an inverted funnel set-up is used in order to collect and condense the vapor samples (Figure 3). From 1994 to 2006 a mass spectrometer was used to analyze deuterium and oxygen-18 isotope samples (Lagura, 2012). After the instrument broke down, it was replaced with a liquid water isotope analyzer in 2010 which is still currently in use. Three international isotope standards – SLAP, GISP and VSMOW – are used as primary standards.



Figure 3: Twin-cyclone separator used in sampling production wells with a two-phase discharge (left). Inverted funnel set-up used for fumaroles (right).

3. SURFACE WATERS AND THERMAL AREAS

There are 5 bodies of water providing meteoric water recharge to Mahanagdong, namely – Cabadiangan River, Gungob Dam, Hanipolong Creek, Mamban River and Mantugop River. There are also 3 different sites of thermal areas (hot springs) surrounding the field – the Mahanagdong, Paril and Hanipolong Thermal Areas. Geochemical and isotopic samples are taken from these locations annually in order to monitor the effects of the continuous increase of mass extraction in the reservoir.

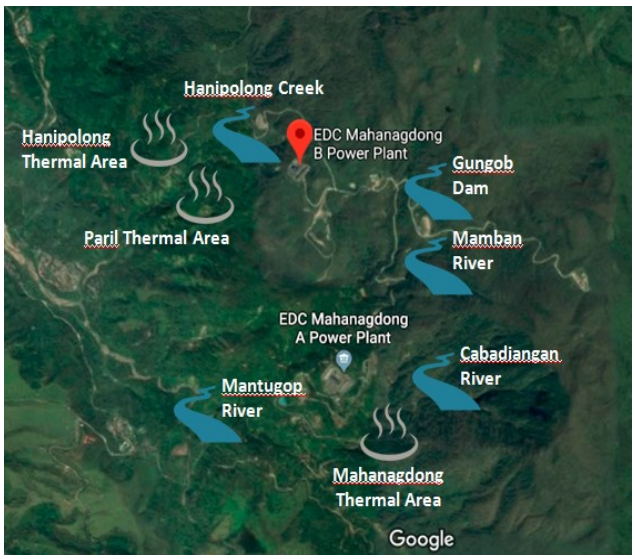

Figure 4: Location of thermal areas and surface waters in Mahanagdong.

The data of the surface waters together with the collected rainwater data in Leyte plots along the updated Philippine Meteoric Water Line (Salonga, 2015), as shown in Figure 5, while the data from the thermal areas shift towards the right as expected from springs with input from geothermal fluids. Getting the slope of the meteoric water indices (MWI) of the different hot springs against the MWL yields two different types of springs present. Chloride-sulfate (Cl-SO_4) springs are more enriched in oxygen-18 with slopes ranging from 2-2.5 which indicate contributions from the geothermal reservoir (Dacillo & Salonga, 2004). Acid-SO_4 springs with slopes from 4.5-5 are more enriched with H-2 due to surface evaporation (Dacillo & Salonga, 2004). However, in correlating this with the chemistry of these springs, an anomaly can be found in Hanipulong HS #19 which has a pH=2-3 as compared to Paril HS #28 and Hanipulong HS #18 that have neutral pH ranges of 5-6 (Table 1). Based also on the sulfate concentrations, Hanipulong HS #19 also shares the high sulfate content of the acid-SO_4 springs (Table 1).

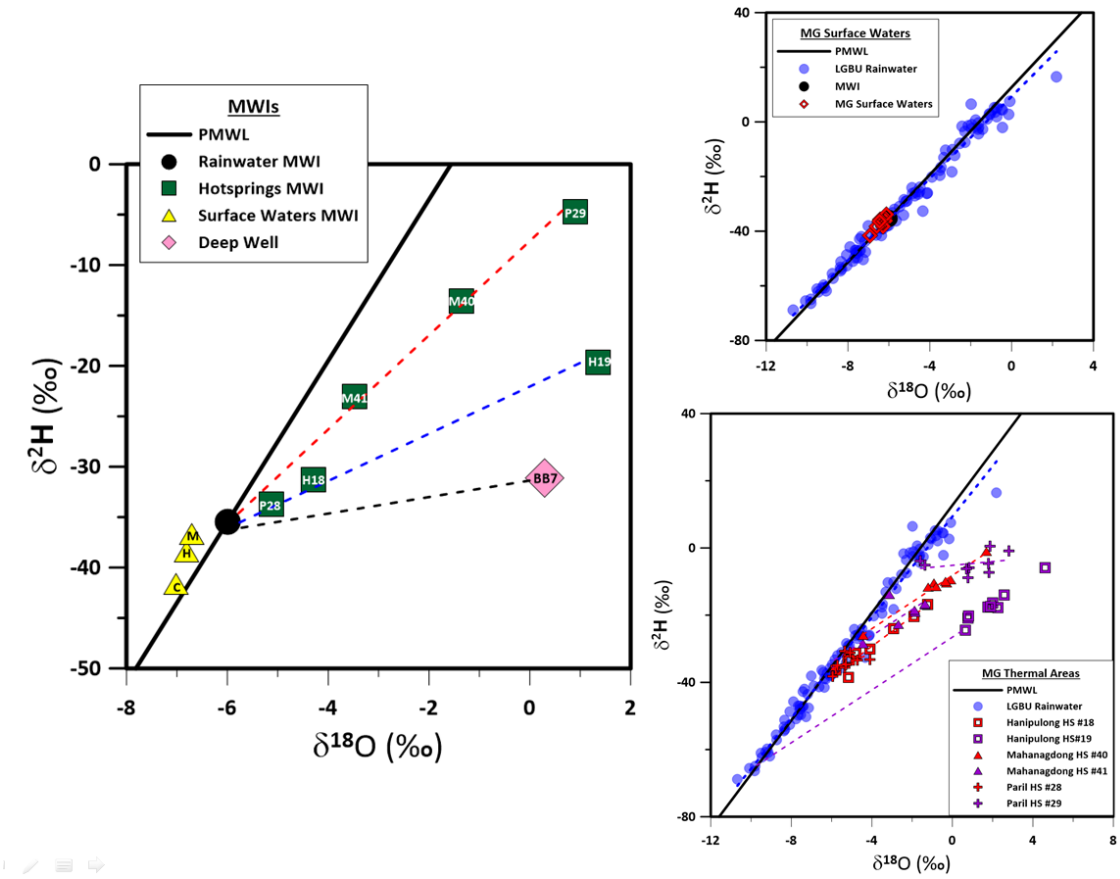

Figure 5: Isotope plots of Mahanagdong thermal areas and surface waters against the Philippine Meteoric Water Line.

Table 1. Meteoric water index and chemistry of the thermal areas in Mahanagdong.

THERMAL AREA	O-MWI	H-MWI	Slope	pH	Cl (ppm)	SO4 (ppm)
Hanipulong HS #18	-4.29	-31.30	2.44	5.37	21.7	162
Hanipulong HS #19	1.36	-19.68	2.15	3.21	<5.00	942
Paril HS #28	-5.13	-33.77	1.96	6.43	<5.00	172
Paril HS #29	0.91	-4.72	4.46	4.09	<5.00	1357
Mahanagdong HS #40	-1.35	-13.56	4.71	2.73	<5.00	1767
Mahanagdong HS #41	-3.48	-23.07	4.97	2.42	<5.00	1876

Rainwater O-MWI= -5.99 and H-MWI = -35.45.

4. DEEP WELLS

It can be observed in the stable isotope data of the deep wells in Figure 6 that through time, the additional data coming from the new wells in the expansion areas of the field revealed waters that were more enriched in O^{18}, thus pinpointing a new location of the upflow. In the 1990s, when there were only 3 production pads: AB, AC and AD. The upflow was interpreted to be located within AC-1 and AC-3 as these wells had the hottest downhole temperature of 300°C and T_{QTZ} of 290°C. This was also supported by the isotope data with these wells have the most enriched O^{18} fluids (Daco-ag, 2012). In 2011, the area within wells BB-1/BB-4/BA-9 had the highest downhole field temperatures of 290°C-300°C compared to well AC-1 which decreased to 250°C (Andrino, et al, 2012). This is corroborated by geochemical data of BA-9 having T_{QTZ} ranging from 290-320°C and isotopic data that showed BA-9, having the most enriched OXYGEN-18. Downhole temperature surveys in 2016-2017 still shows that the area around BB-1/BB-4/BA-10 has the highest downhole field temperatures of 300°C-310°C (Almanzor, et al, 2017). Based on the isotope data collected at this period, it was observed that the additional wells drilled in Pads BB and BC have more enriched oxygen-18 compared to the other wells, with BB-7 as the most enriched. Comparing the % geothermal fluids with respect to the isotopic composition of andesitic waters by Giggenbach of the 3 most enriched wells through time, yield BA-9 in 2011 as the highest with 47% geothermal fluids, followed by BB-7 in 2016 at 38% and AC-1 in the 1990s with 34% (Figure 7).

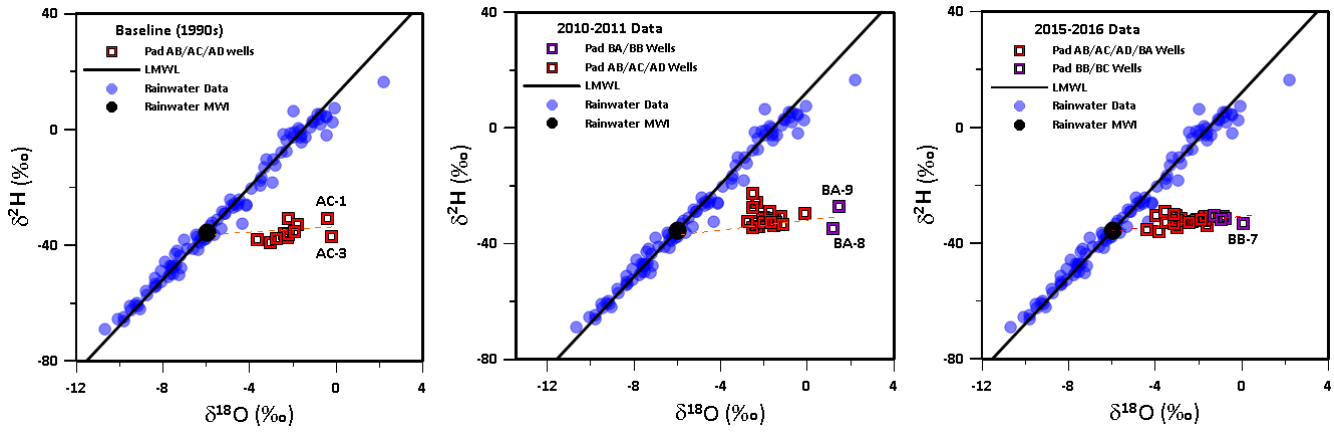

Figure 6: δ^2H vs $\delta^{18}O$ crossplots from 1990s, 2010-2011 and 2016-2017.

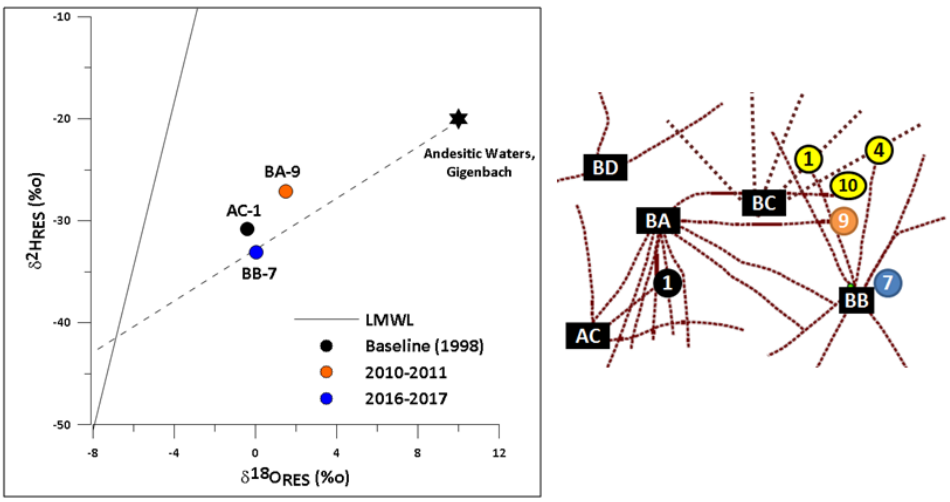

Figure 7: Comparison of %geothermal fluids of the isotopically-enriched wells thru time & locations of the wells of interest.

Contour plots of reservoir temperature, chloride and OXYGEN-18 of Mahanagdong through time are in agreement with the change in the location of the upflow of the Mahanagdong field. All three contour plots of the baseline data (Figure 8), indicate the location

of the upflow area within the vicinity of Pad AC, with the outflow towards Pad BD and AF. The 2010-2011 contour plots (Figure 9), the area with the hottest reservoir temperature, highest Cl_{RES} concentration and most enriched O^{18}_{RES} is now towards the vicinity of the Pad BB where well BA-9 is also directed. Thus, the availability of new data during the initial expansion hinted the area of a hotter upflow. The incursion of brine returns from pads BD and AF are characterized by the decline in Cl_{RES} and depletion of O^{18}_{RES} compared to that in the upflow area. Recent data from 2016-2017 (Figure 10) continues to indicate the upflow the area of pads BB and BC, where new wells are being drilled, while the central part of the field continuous to be encroached by brine returns from Pad BD and AF, resulting to decrease in Cl_{RES} and depletion of O^{18}_{RES}. The continuous encroachment of cooler fluids to the central area of the field is the consequence of mass extraction for production.

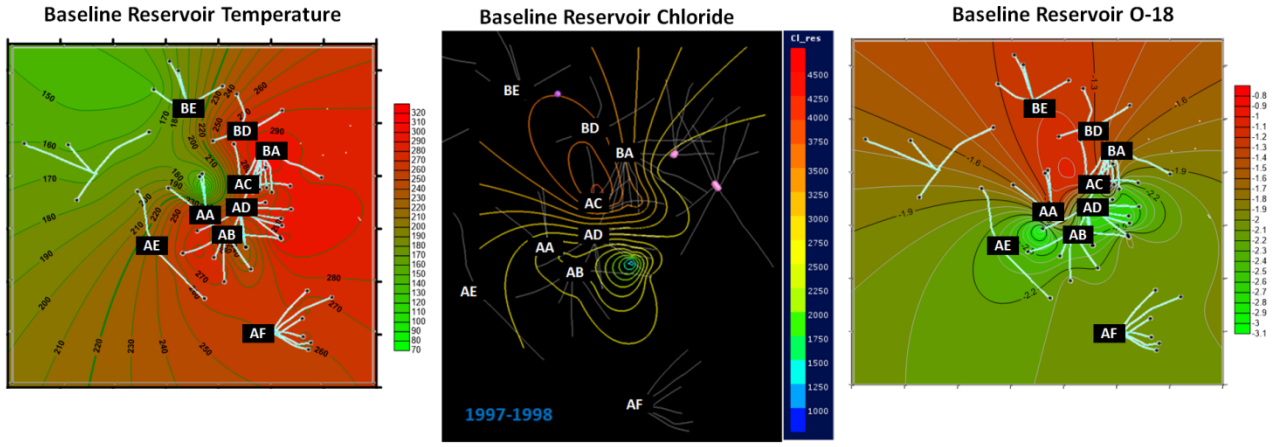

Figure 8: Reservoir temperature, reservoir chloride and reservoir OXYGEN-18 contour baseline (1990s) data indicate the outflow in the vicinity of Pad-AC.

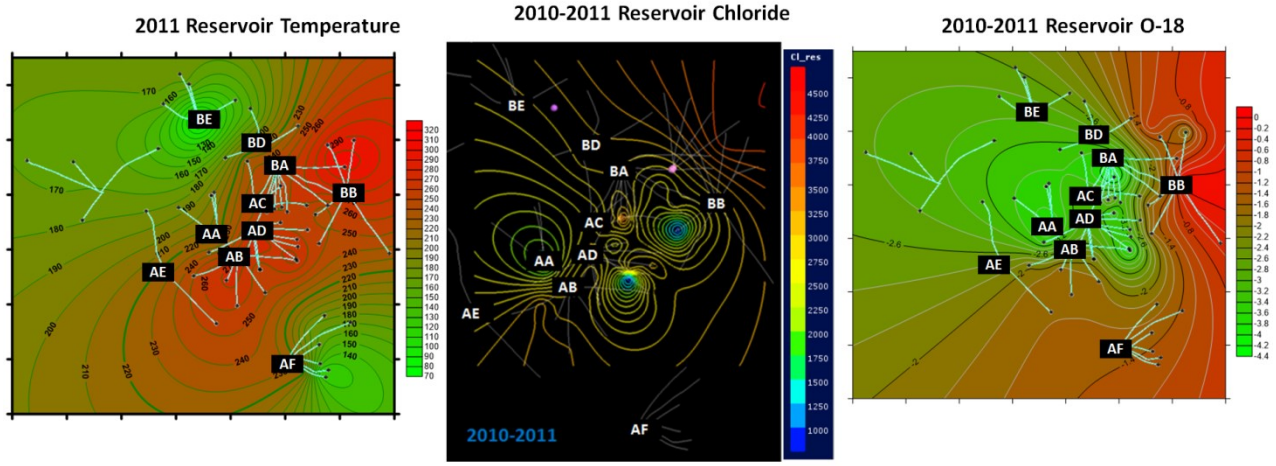

Figure 9: Reservoir temperature, reservoir chloride and reservoir OXYGEN-18 contour 2010-2011 data indicate the outflow in the vicinity of Pad-BB.

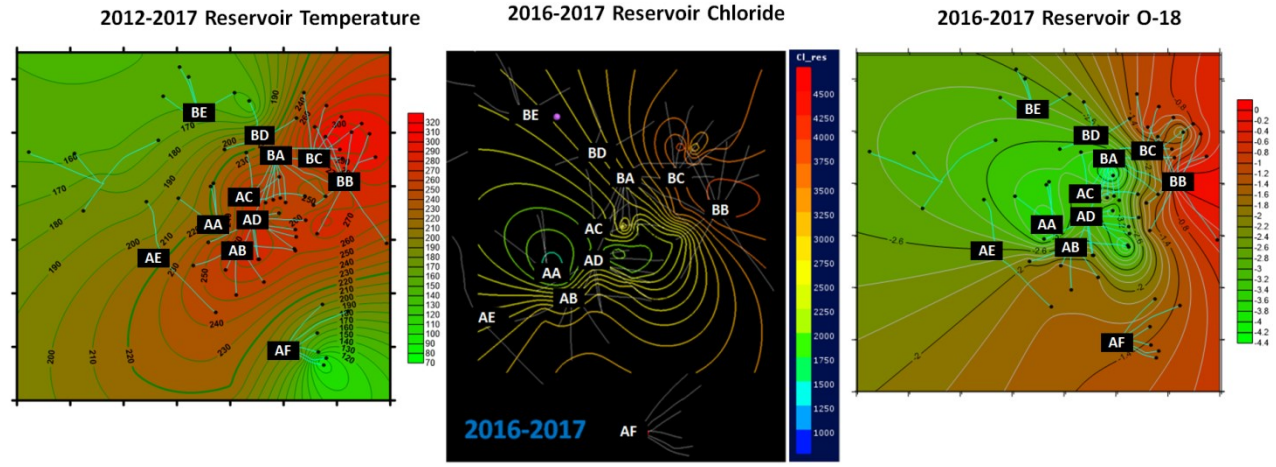

Figure 10: Reservoir temperature, reservoir chloride and reservoir OXYGEN-18 contour 2016-2017 data continue to indicate the outflow in the vicinity of Pad-BB.

In an attempt to further analyze the fluids affecting MG-A wells, crossplots of Cl_{RES} and $O^{18}{}_{RES}$ were made for all wells and compared with the prevailing cooler fluids affecting the sector (Figure 11). Wells in pad AB and AC show closer affinity for baseline AC-1 data thus it is used as a representative for the parent fluid. For wells AB-1 and AB-4 – they are presently shifting towards brine returns from pad AF. Wells AB-2, AC-3 and AB-5, which have been previously affected by brine returns, are now presently affected by a mixture of brine returns and Paril fluids. Paril fluids were characterized as encroaching groundwater using the Paril fault as a conduit. Wells AC-1 and AB-3 are continuously being affected by Paril fluids. Wells in pad AD show closer affinity to BB-7 fluids, thus it is used to represent the parent fluid. Wells AD-2, AD-3 and AD-8 which were initially just affected by Paril fluids are now also affected by fluids from AA-2. Well AA-2 in an infield reinjection well for powerplant condensates. This may be due to the increased loading in AA-2 since 2013 at ~200kg/s which has eventually declined to 120kg/s. Wells AD-4 and AD-9 continue to be affected by a mixture of AA-2 returns and Paril fluids. Well AD-10 is affected by Paril fluids only.

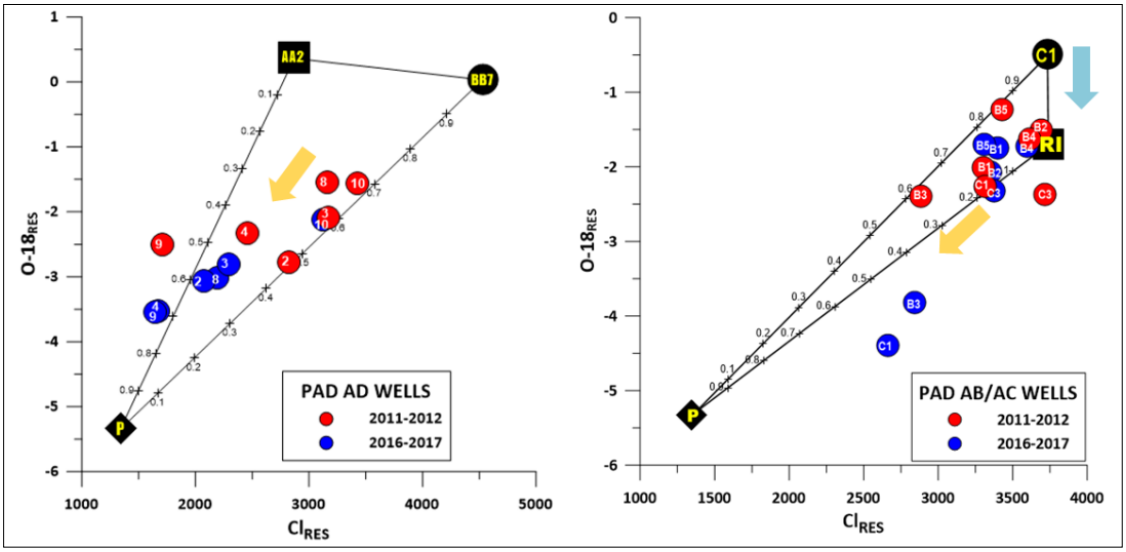

Figure 11: Reservoir chloride and O^{18} crossplot of MG-A wells. Parent fluid for Pad AB/AC wells is baseline AC-1, while parent fluid for AD wells is BB-7 at present. P stands for Paril fluids. RI is hot reinjection from AF and AA2 is for the reinjection fluids (thermal pond + PP condensate) in AA-2.

For MG-B wells, all wells show affinity for BB-7 as the representative for the parent fluid. Like the wells in the central portion of the field, Pad BA wells are also affected by Paril inflow and AA-2 returns. Wells BA-1 and BA-8 are affected by Paril fluids only; while wells BA-4, BA-5, BA-6 and BA-7 are affected by both Paril fluids and returns from AA-2. For pad BB and BC wells, only wells BB-8 and BC-1 show affinity towards fluids with brine returns. For the rest of the wells, the present data remains inconclusive with regards to incursion of cold injection returns from pad BD. There is a need to continue collecting more isotope data samples from the new wells to have a better grasp of the processes that will have a big impact on Pad BB and BC wells.

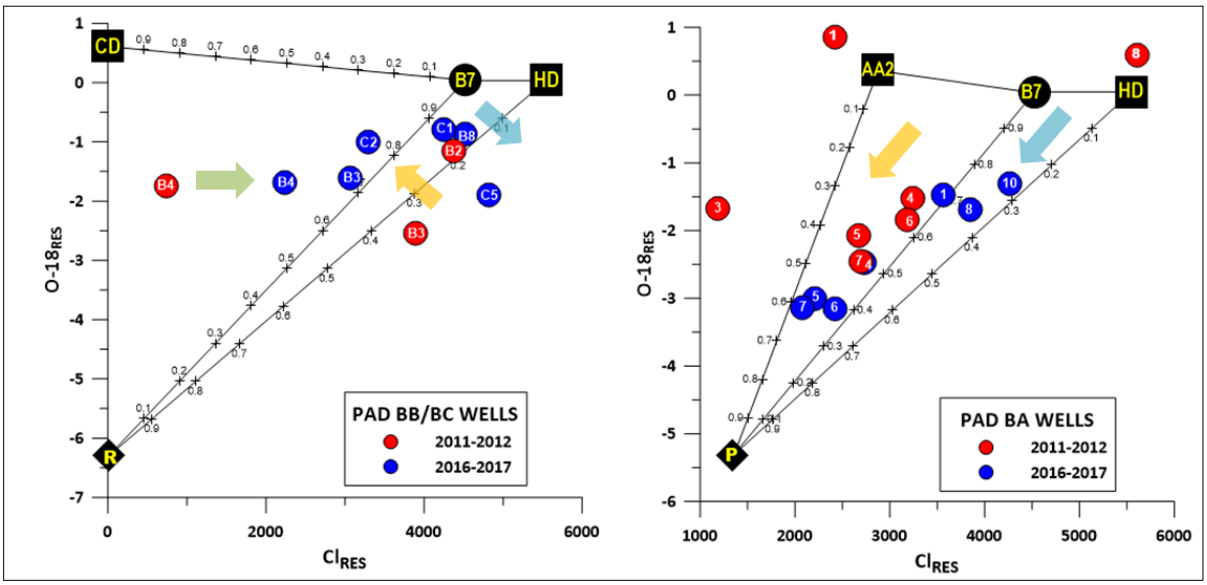

Figure 12: Reservoir chloride and O^{18} crossplot of MG-B wells. Parent fluid BB-7 at present. P stands for Paril fluids. HD is hot reinjection from pad BD, while CD is cold reinjection in pad BD. AA2 is for the reinjection fluids (thermal pond + pp condensate) in AA-2. R is for meteoric recharge from surface waters (Hanipulong river).

5. SUMMARY

The use of stable isotope – deuterium and oxygen-18 – data together with other physical and geochemical parameters remains an essential tool for monitoring and managing a geothermal resource especially in expansion areas. The correlation of reservoir temperature, chloride and oxygen-18 contours plots in Mahanagdong have shown that the previously interpreted upflow area in pad AC from baseline data has now been reinterpreted to be located in pad BB due to the new data gathered from the new wells drilled in the expansion areas. Aside from that, the three contours have also shown the different reservoir processes affecting Mahanagdong. Mixing models using isotopes paired with another conservative geochemical species such as reservoir chloride can help in the analysis on the cooler fluids that are affecting the wells in the production sector.

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