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The Neutral High-Cl Thermal springs of Java, Indonesia

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ABSTRACT

A limited number of neutral high-Cl thermal springs are found on Java, Indonesia. Only one of them appears related to a known exploitable deep neutral-Cl geothermal reservoir and that is the Sarimaya springs at Awibengkok. Only two of the other groups of springs appear related to undrilled, possibly exploitable systems. One may be sourced from the Sunda caldera just north of Bandung. Springs at Ngebel may also be related to a high temperature system, but with a sedimentary reservoir that may limit exploitation. Springs at Cilayu and Ungaran appear to be neutralised outflows from magmatic vapour cored systems that may have limited associated exploitable resources.

Springs at Kromong, Sangkan Hurup and Lawu do not fit into the above categories. They are interpreted to be from systems in which the weight of the volcanic pile has deformed underlying sediments to create permeability to allow deep circulation of meteoric waters that become saline upon being heated under the regional temperature gradient of Java and thus are unlikely to be associated with high temperature resources. Understanding this and the resulting spring chemistry, provides an additional tool for assessing geothermal development potential.

1. INTRODUCTION

The developed geothermal systems of Java and those that have seen major drilling campaigns (Figure 1) rarely have associated neutral high-Cl springs (Figure 2). The Sarimaya springs (Stimac and Sugiaman, 2000), may be associated with the developed Awibengkok system. Six other groups of springs with neutral pH and high Cl (> 1200 ppm) are found on Java some distance (Figure 2) from the developed fields (Kamojang, Wayang Windu, Darajat and Dieng) or extensively drilled systems (Patuha and Karaha Telegabodas). This may reflect that the developed and drilled prospects are the vapour-dominated or vapour-liquid type systems, preferentially formed under the Javanese tectonic setting (Bogie et al., 2015 in press) that either don't have neutral high-Cl waters or have deep neutral high-Cl reservoirs that are poorly connected, if at all, to the surface. Other neutral-Cl springs are found at the Cisolok-Cisukrame system (Herdianita and Mandradewi, 2010), but with lower Cl concentrations (550 ppm) and it has been interpreted to be a warning system, on the basis of a change in surface precipitates with time.

An Indonesian country-wide inventory of geothermal resources (NZMFA, 1986) contains geochemical analyses of Javan neutral high-Cl springs (Table 1), albeit not entirely full analyses, with possible doubts over SiO_2 and Mg results from potentially variable sampling protocols, as the analyses were compiled from various sources. Despite these draw backs, this set of analyses has the virtue of being extensive, helped by the addition of more recent analyses. A more recent analysis from the Kromong system (Intertek, 2008) has been added as its consideration is helpful in interpreting the chemistry of some of the other springs as the Kromong springs have some stable isotope data available (Herdianita et al., 2010).

This paper reviews this geochemical data with the aim of establishing if any of these neutral high-Cl springs are associated with potentially commercially viable, liquid-dominated geothermal resources. If not, are they from other types of magmatic related systems? Or are they from some other type of system entirely?

2. METHODOLOGY AND RESULTS

The hot spring geochemical data have been plotted on the Log KMg v Log SiO_2 (Figure 3), Giggenbach's (1992) ternary diagrams of anion proportions (Cl-HCO_3-SO_4; Figure 4), rock interaction (Cl-B-Li; Figure 5) and cation geothermometry equilibria (Na-K-Mg; Figure 6).

Where the necessary SiO_2, K and Mg data is available they have been plotted in Figure 3. The low SiO_2 value for Ungaran is suggestive of poor sampling technique. Sangkan Hurup and Lawu plot close to being at equilibria with chalcedony suggesting that they come from reservoirs of relatively low temperature (110 to 140°C). The other springs are not at equilibria rendering any geothermometry moot, but none are obviously showing indications of being directly derived from a high temperature reservoir.

As would be expected for springs selected for high Cl concentrations the waters plot predominantly in the "mature" section of the Cl-HCO_3-SO_4 diagram (Figure 3). Only the Cilayu waters have significant amounts of SO_4, although HCO_3 is an important anion for Cilayu as well as Ngebel, Sigalurherang and Ungaran. This higher SO_4 proportion at Cilayu supports the possibility that it is a neutralised outflow from Papandayan or Patuha (Herdianita and Priadi, 2008), which are magmatic vapour-cored type systems (Reyes, et al., 1993). Patuha differs from the Alto Peak example (discussed by Reyes et al.) by having a lateral vapour-dominated reservoir (Layman and Soemarinda, 2002). In the case of Papandayan the thermal activity represents degassing between volcanic eruptions (last eruption 2002; Smithsonian 2014); no historic eruptions are recorded for Patuha, but it has a very youthful volcanic morphology. As the favoured structural direction for permeability on Java is to the northeast (Bogie et al., 2015, in press) and Papandayan is to the northeast of Cilayu, Papandayan is the favoured source. Cilayu has also been previously interpreted to be a southern outflow from Wayang Windu (NZMFA, 1986). However, reservoir pressure gradients for elevation at Wayang Windu (Bogie et al., 2008) indicate that there is little lateral flow at drilled depths that would be necessary to have an outflow.

Table 1: Analyses of neutral high-Cl springs of Java.

	Sarimaya	Cilayu	Sigalurherang	Sangkan Hurup	Kromong	Lawu	Ungaran	Ngebel
pH	6.43	7.21	9.1	7.46	6.45	6.85	7.08	6.88
Na	1392	1000	1300	1357	2740	4833	5300	1180
K	120	74.7	96	196.4	151	166.7	213.3	127
Li	7.2	2.8	4.39	3.25	NA	8.75	3.9	3.8
Ca	NA	73.5	5.7	271.6	332	826.4	60	185
Mg	NA	11.5	66.7	79.6	25.2	15.81	42	70
SiO2	115	160	66	100	NA	137	40	208
HCO3	651.2	507	734	153.9	1210	969.3	4500	853
SO4	12	345	17	9.27	156	425	9	5
Cl	2660	1260	1747	2840	4350	7720	5900	2112
B	82.3	57	82.3	13.22	17.8	9.53	261.8	16
Cl/B	10	7	6	66	75	247	7	40

NA - Not available. Kromong analysis from Intertek (2008); the remaining analyses are from NZMFA (1986).

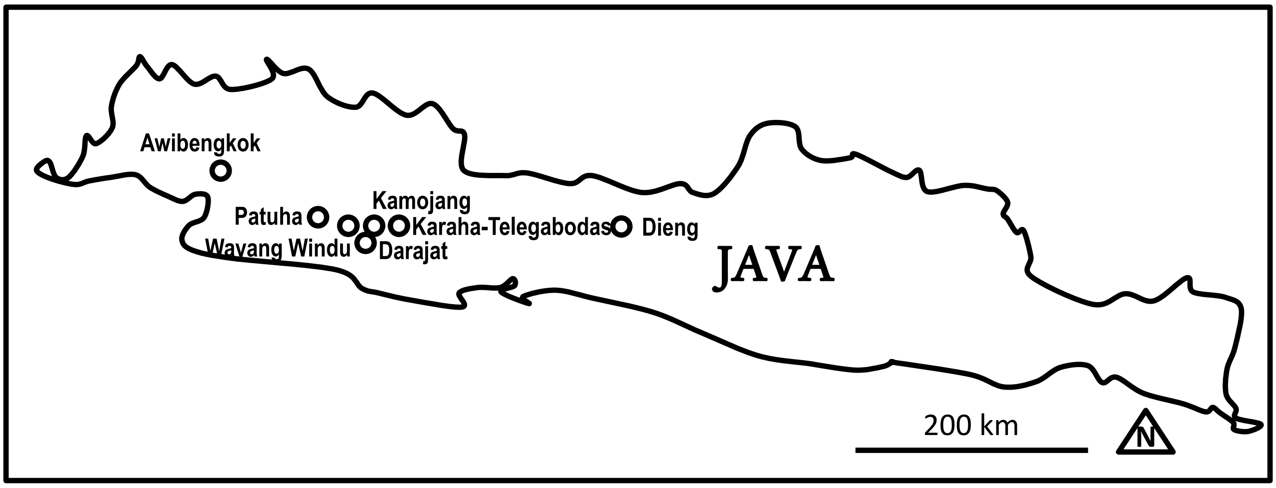

Figure 1: Developed and extensively drilled geothermal systems of Java, Indonesia.

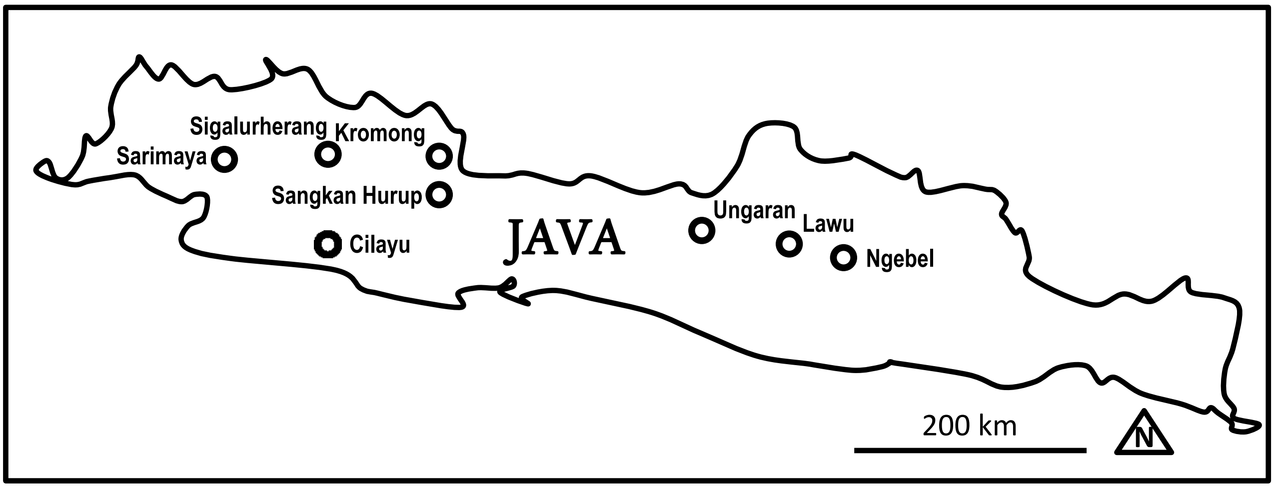

Figure 2: Neutral-High Cl springs of Java, Indonesia.

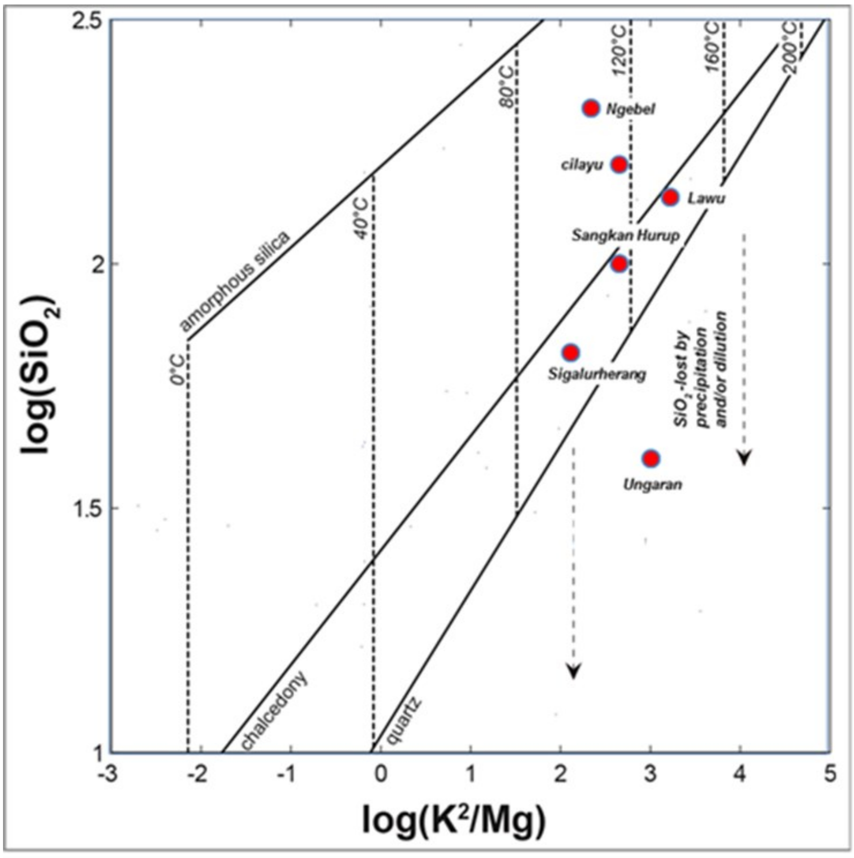

Figure 3: Log KMg v Log SiO_2.

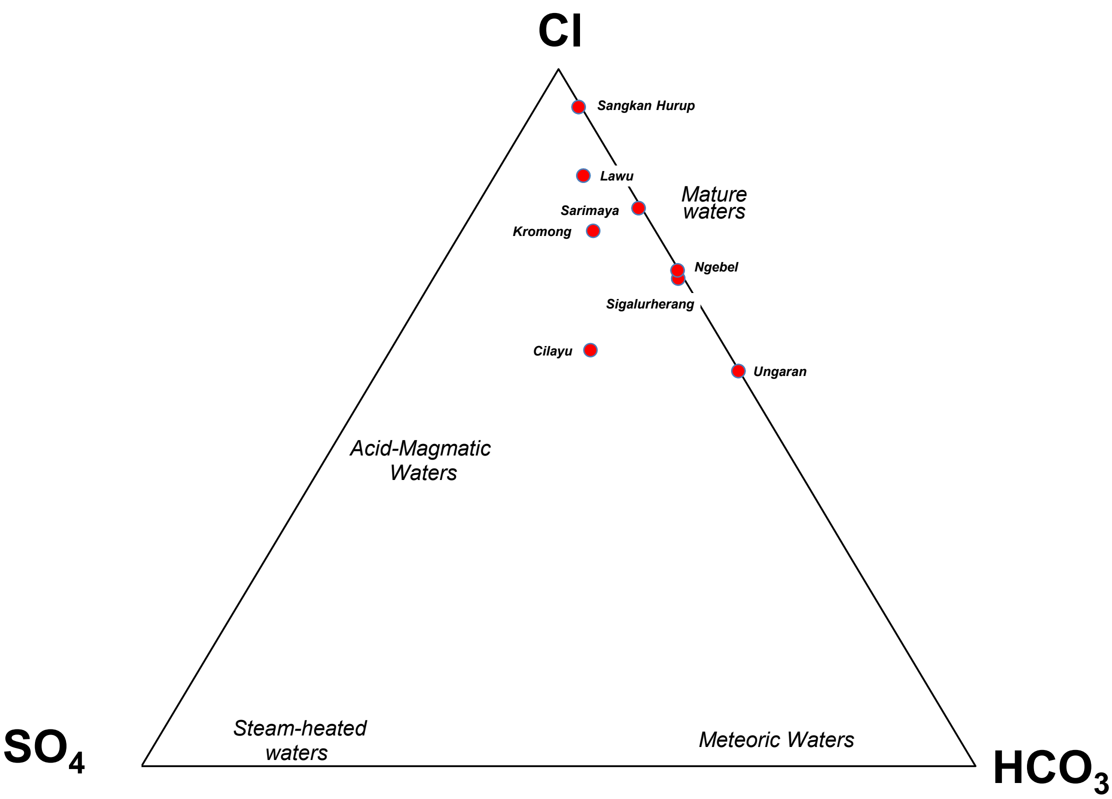

Figure 4: Cl-HCO_3-SO_4 plot.

The Cl-B-Li diagram (Figure 4) has the analyses resolving themselves into two groups. As Li is generally comparatively low, this grouping is mainly indicative of the variation in Cl/B ratio (Table 1). Cilayu, Sigalurherang, Sarimaya and Ungaran have low Cl/B ratios of around 7, which is typical of closely magmatically related geothermal systems (Giggenbach, 1997). It is only clay-rich, deep water, pelagic marine sediments that are rich in boron (Harder, 1970) and thus have potential to decrease Cl/B ratios by rock water reaction. This is because not only are pelagic sediments mainly made of clays that can absorb B from seawater; they have very low rates of deposition, which provides the time for the absorption to occur. The Cenozoic sediments of Java that underlie the Recent volcanics are shallow-water shelf and basinal sediments and while claystones are common they were mainly deposited very rapidly as turbidites (Muljana et al., 2012); too rapidly to become B-rich by B absorption from seawater. The Cenozoic sediments of Java thus have limited ability to influence B concentrations in geothermal waters by rock leaching.

It is significant that the Sarimaya waters plot in the lower area of Figure 4 as it has the closest relationship to a known magmatically related system – Awibengkok. The Cl/B ratio is slightly higher for Sarimaya than the others in this group, but this may reflect absorption of B by clays along an outflow hosted in volcanic rocks (Bogie and Lovelock, 1984). This raises the possibility that the other members of this group are related to other magmatically related deep reservoirs. The Ungaran springs (Setyawan et al, 2009), are right on the arc although there are no historic eruptions recorded for the Ungaran volcano (Smithsonian, 2014). There is other chemical and isotopic data (Nukman, 2009) indicating that a magmatic vapour-cored system is present at Ungaran and the earlier analysis used here is from a neutralised outflow at Kailulo.

Sigalurherang is north of the active volcanic arc. The nearest volcanic structure is the 10 km wide Sunda caldera about 20 km directly to the south, which could be the source of an outflow to Sigalurherang given that outflows of this length have been documented elsewhere in andesitic volcanic arcs, (eg: Bacon Manito, Philippines; Ramos and Santos, 2012). The Sunda caldera is the lower part of the volcanic edifice which the active volcano of Tangkuban Perahu sits upon (Kartadinata et al., 2002). It is also likely that at least the more northern parts of this outflow are in low-B marine sediments similar to the Kailulo springs at Ungaran. However, higher Li contents are more suggestive of it coming from a deep neutral-Cl igneous reservoir rather than being associated with the magmatic vapour-cored system at Tangkuban Perahu that like Papandayan is a degassing volcano between eruptions (last eruption 2013; Smithsonian 2014).

Next to consider are the springs with B contents lower than that are typically found for arc type magmatically related geothermal systems. These are Kromong, Sangkan Hurup, Lawu and possibly Ngebel. Kromong and Sangkan Hurup are spatially related in that they are north and southeast, respectively, of the Ciremai volcano. There is fumarolic activity at high elevation on Ciremai and it has been proposed (Herdianita et al, 2010) that all these features (the crater fumaroles, Kromong and Sangkan Hurup) are all sourced from one large geothermal system. Unfortunately, there is no geochemistry from the fumaroles, but given the very youthful morphology of the volcano with the fumaroles in uneroded volcanic eruption craters (see: Google Earth) it is likely to be a magmatic vapor-cored system of a degassing volcano between eruptions (last eruption in 1951; Smithsonian 2014). The Kromong springs are more closely spatially related to a Cenozoic intrusive complex (Druji, 1995) that forms an entirely separate edifice to Ciremai and as the high-Cl springs are on the northern side and are related to a northwest striking thrust fault, it is hydrologically difficult to source them from Ciremai. These springs thus belong to the category of those that are spatially related to an igneous edifice, but are not necessarily magmatically related. This also applies to the Sangkan Hurup springs. Herdianita et al. (2010) reports stable isotope data for the waters at Kromong and Sangkan Hurup. Both spring waters plot on the meteoric water line indicating that they are not from a high temperature geothermal reservoir, or contain connate water, as in both cases there should be a significant oxygen shift.

Lawu is an active volcano (last erupted 1885; Smithsonian 2014). It has a major solfatara to the south of the partially eroded volcanic eruption craters but there is no available geochemical data from this feature. The spring analyses presented here does not match the chemistry of those springs elsewhere that are associated with either deep neutral Cl reservoirs or magmatic vapour-cored systems, most particularly B is low. It appears the Lawu springs belong to the separate geochemical group that includes Kromong and Sangkan Hurup.

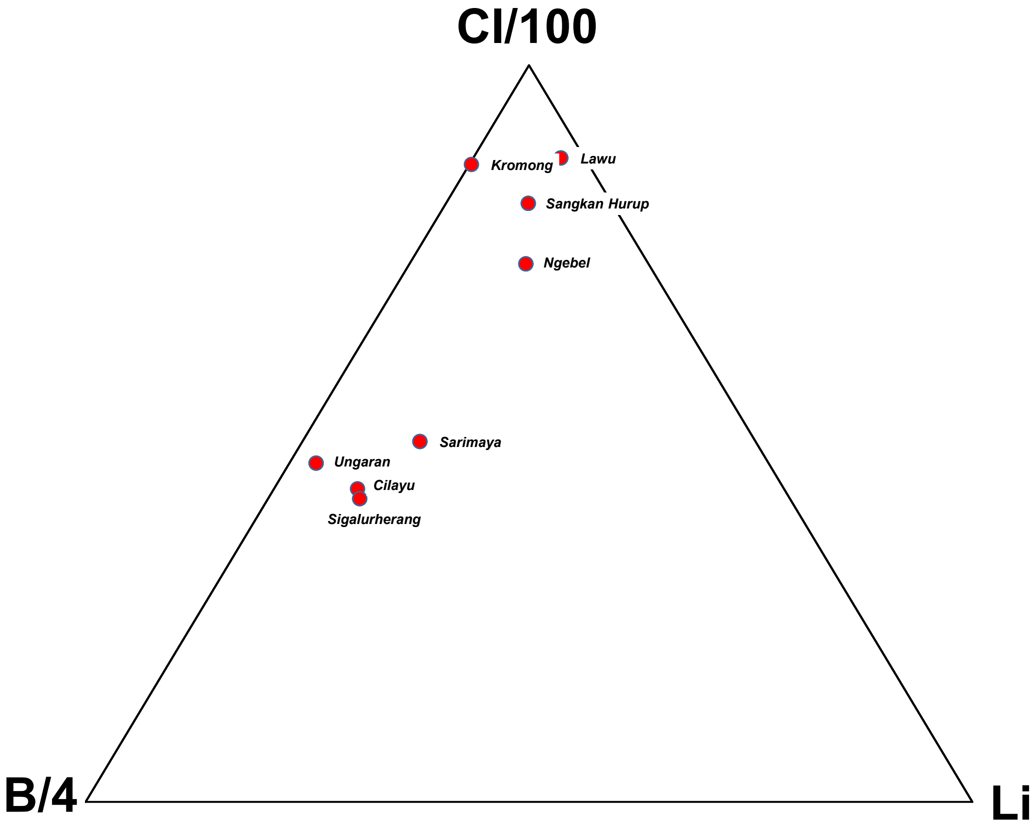

Figure 5: Cl-Li-B diagram. Note lack of Li data for Kromong.

The fact that the majority of all these springs are plotting in the non-equilibrium section of the Na-K-Mg diagram (Figure 5) possibly reflects that this diagram addresses equilibrium with hydrothermal minerals and not marine sediments. It is thus unjustified to use cation geothermometry and in particularly to extrapolate trends to the NaK equilibria line. Unfortunately there is no Mg analysis in this set of data for the Sarimaya springs to compare.

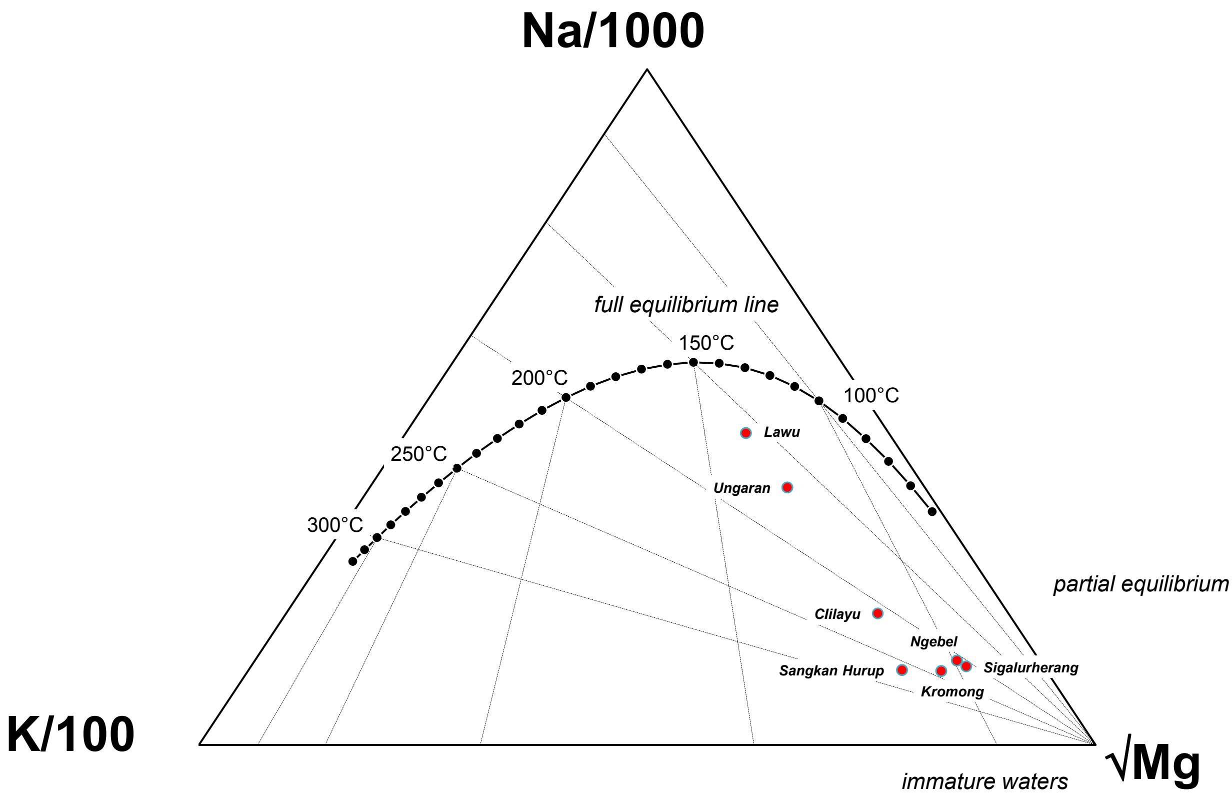

Figure 6: Na-Mg-K diagram.

The Ngebel springs have mixed indications in that they have chemistries similar to the systems with sedimentary affinities, but they have the highest silica content and thus the highest possibly reliable geothermometry temperature of 170°C. There are however no reported higher elevation thermal features. The springs have a volcanic association in that the lake just north of them is likely to be a maar. An outflow from Willis to the west has been suggested (NZFMA, 1986), but without higher elevation thermal features this is difficult to justify. It is suggested that while the reservoir associated with the springs is hosted by sediments, it has a higher than average thermal gradient due to the possible presence of small shallow intrusives; one of which initiated a phreato-magmatic eruption to form the maar. If a sedimentary reservoir is present it may be difficult to exploit due to possible low inherent permeability in the sediments and the possibility of high gas and carbonate scaling issues.

The sedimentary related group (Kromong, Sangkan Hurup and Lawu) have elevated Ca and Mg and limited amounts of SO_4, Li, F and B. Although some of these springs issue from volcanic rocks, these are the distal aprons of the volcanoes which sit on Cenozoic shelf sediments that include dolomites; some of the springs are found coming out of these sediments. The water's chemistry is entirely consistent with interaction with shelf sediments as these are low in Li and B, and the Ca and F levels in the spring waters are suppressed by the formation of anhydrite and fluorite due to the high Ca concentrations; with the Mg possibly derived from dolomite.

These sediments make up thrust-fold belts that run along Java that have formed in response to the compressional regional tectonics produced by perpendicular subduction. Such sediments under such a tectonic regime should not be inherently permeable, but some of these springs have high flow rates suggesting otherwise. However, the presence of large volcanic piles can deform the sediments to create radial fracture systems. The volcanos are also full of groundwater that can penetrate the sediments at depth along the radial fractures, is then heated by the high regional geothermal gradient of Java and emerges at the base of the volcano where the radial deformation has not extended due to the decrease in load. The salinity of the springs has developed largely from the interaction of meteoric water with sediments. Therefore, while such springs have an association with some of the andesitic stratovolcanos on Java it is not one that is indicative of an exploitable geothermal resource.

3. SUMMARY AND CONCLUSIONS

An old set of geochemical data has been used to compare the geochemistry of neutral high-Cl springs on Java. One of the springs is spatially related to the exploited Awibengkok geothermal system. Two other possible systems with possible deep neutral-Cl reservoirs are identified; at Sigalurherang north of Bandung, possibly related to the Sunda caldera to the south and at Ngebel where the system may be related to a maar with a reservoir that may be made up predominately of sediments that may hinder development.

Springs at Cilayu and Ungaran appear to be neutralised outflows from vapour-cored magmatic systems. Lateral extensions of vapour-cored systems elsewhere on Java have been successfully drilled, but only those with lateral groups of fumaroles are likely to have potential resources.

The other springs at Kromong, Sangkan Hurup and Lawu appear to have a spatial relationship to igneous edifies, but this is likely to be due to deep circulation and heating under Java's high geothermal gradients, where permeability has been created in otherwise impermeable sediments in response to deformation by the weight of the volcanic pile. The chemistry of the springs has developed largely from interaction of meteoric water with sediments under the high geothermal gradient of Java.

The processes discussed above are important for understanding the chemistry of high-Cl springs in Java and provide an additional tool for assessing geothermal development potential.

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