Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Finding the Productive Sweet Spots in the Vapour and Transitional Vapour-Liquid Dominated Geothermal Fields of Java, Indonesia

Ian Bogie, Greg Ussher, Brian Lovelock and Ken Mackenzie

Jacobs Engineering, Talavera Office Park 15th Floor, Jl. TB. Simatupang Kav. 22-26, Jakarta 12430, Indonesia

IBogie@jacobs.com

Keywords: Indonesia, Java, sweet spot, vapour, transitional vapour-liquid

ABSTRACT

Some of the most highly productive (up to 40 MWe) vapour-dominated geothermal wells in the world have been drilled into the vapour and transitional vapour-liquid dominated fields in Java, Indonesia. Such wells are highly permeable, but are localised to only parts of the vapour reservoir that form exceptionally productive zones often referred to as 'sweet spots'. Counter-intuitively the sweet spots are not found in the deep steam upflows of the systems. While structural control is important in any one productive well the localisation of high permeability to a number of wells in a particular area cannot be satisfactorily explained on a purely structural basis. The sweet spots are located on the opposite side of deep steam upflows to where there are steam outflows; these are generally towards thermal features.

The sweet spots are interpreted to be zones of condensation by cooling at the top of the reservoir with the greatest cooling occurring where the steam flow is lowest. The condensate formed is acid and under-saturated with respect to silica and anhydrite and is thus capable of not only dissolving calcite, but silicates and anhydrite, as it trickles down into the reservoir until eventually it becomes saturated with these minerals and starts depositing them at greater depths within the reservoir. The sweet zones are thus likely to be shallow zones outside of deep steam upflows with poorly permeable zones below them.

The locations of surficial thermal features are known and can be subject to heat flow surveys to better characterize them. The location of deep steam upflows and outflows can be interpreted from MT geophysical surveys prior to drilling in combination with the heat flow data. Outflows without obvious surficial thermal features can be recognized on MT cross sections by the presence of slightly higher resistivity zones in the conductive cap. Thus, potential sweet zones can be drilled by excluding these areas and targeting the shallow part of the reservoir. It is likely that the more mature parts of geothermal systems on Java that have had major drilling campaigns have these zones, but in some of the systems high gas and magmatic acidity preclude them from being commercially exploitable. These targeting suggestions can thus be applied to make up wells in the low gas and non-acidic developed systems, as well as undrilled prospects that have thermal features with chemistries indicative of low gas and acidity.

1. INTRODUCTION

The island of Java, Indonesia (Figure 1) is host to andesitic arc vapour-dominated (Raharjo *et al*., 2012) and transitional liquid-vapour dominated geothermal systems (Bogie *et al*., 2008), with the latter also described as hybrid systems (Grant and Bixley, 2013). In the former all the known productive reservoir is vapour dominated; in the latter pre-exploitation vapour-dominated reservoirs with much less than hydrostatic pressures for depth sit above a liquid-dominated brine reservoir.

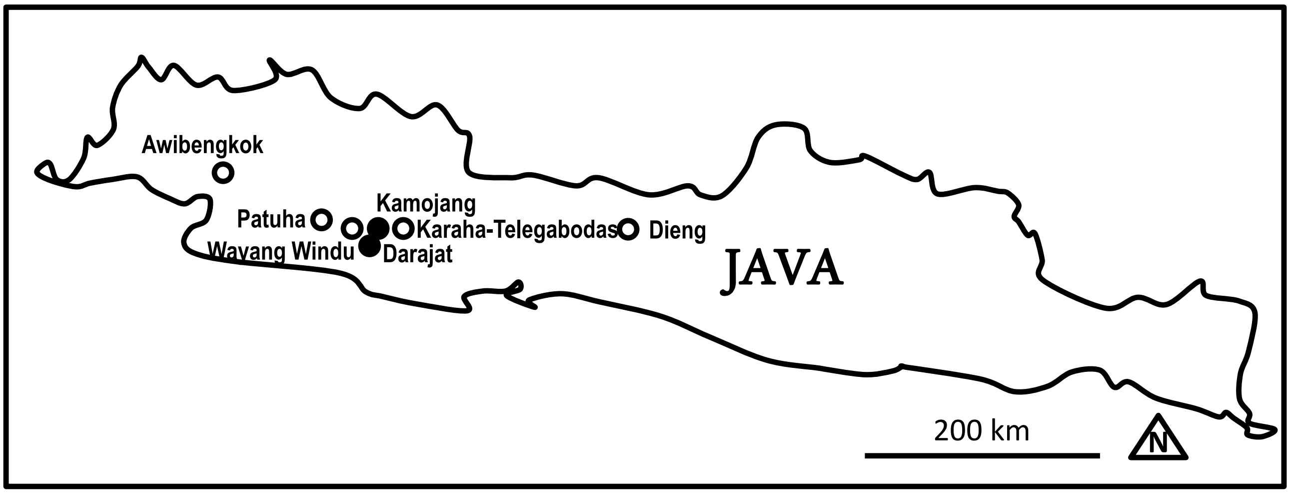

Figure 1: Geothermal systems of Java which have had major drilling campaigns. Wholly vapour dominated systems indicated by solid circles.

The brine can be very saline and at least at Dieng (Adityawan, *et al*., 2013), has caused problems with base metal sulphide scaling on production of the resource. Possible examples of both types of systems in volcanic arcs elsewhere are rare eg: possibly Casita, Nicaragua; Bogie *et al*., (2004); White *et al*., (2012).

Matsukawa in Japan has also been described as vapour-dominated, but may be better interpreted as an example of rapid drying out upon production (Hanano and Matsuo, 1990). The two currently non-volcanic arc hosted examples of vapour-dominated systems are The Geysers, California (Sanyal and Enedy, 2011) and Larderello, Italy (Cappetti, *et al*., 2000).

2. EXTENSIVELY DRILLED JAVAN GEOTHERMAL SYSTEMS

It is not widely appreciated that it is likely that all the geothermal systems on Java that have seen major drilling campaigns are either vapour dominated or transitional liquid-vapour dominated. Kamojang (Kamah *et al*., 2005) and Darajat (Whittome and Salveson, 1990) are the vapour dominated systems. Wayang Windu (Figure 2; Bogie *et al*., 2008) is the first identified example of a transitional liquid-vapour dominated system. Dieng (Figure 3: Layman *et al*., 2002) and Karaha-Telegabodas (Figure 4: Moore *et al*., 2002) appear to be less mature examples of such a system, but otherwise have similarities to Wayang Windu. These similarities include: deep brine reservoirs lying below multiple separate shallow vapour dominated reservoirs with separate deep steam upflows; a general north to northwest alignment of deep steam upflows; with the youngest vapour dominated reservoirs in the south where at Karaha-Telagabodas and Dieng acidic magmatic volatiles are encountered.

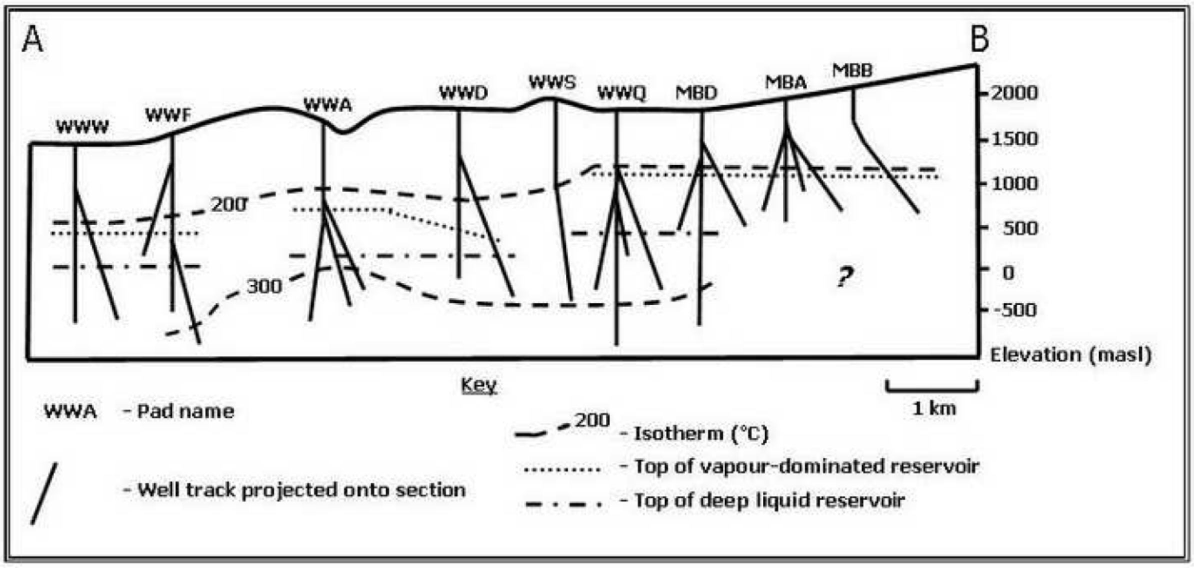

Figure 2 : South (A) – North (to WWQ) – Northwest (B) cross section of Wayang Windu. Note the three separate vapour dominated reservoirs. From: Bogie *et al*. (2008).

In the case of Dieng the vapour dominated reservoirs are too gassy to be productive (possibly because of the presence of carbonate sediments in the vicinity) and have been either cased off or the wells abandoned.

Patuha (Figure 5; Layman and Soerindo, 2003) differs by having a west-east orientation with the Cibuni (Fadillah *et al*. 2013) vapour dominated reservoir to the west, acid-magmatic thermal features in the centre closest to the volcanic eruptive centre and the main Patuha vapour-dominated reservoir to the east. Drilling problems prevented much acquisition of data from any deep reservoir and a deep downhole sample is condensate (Layman and Soemarinda, 2003) rather than brine, but this does not exclude deeper brine from being present. The surface morphology of the Patuha volcanic centre indicates that it is volcanically very young, similar to the immature southern parts of Karaha-Telaga Bodas and Dieng.

Grant and Bixley (2013) consider that there was a pre-exploitation steam cap at Awibengkok. This can be seen as an isothermal zone in early temperature measurements presented by them. This was probably cased off (Tom Powell pers. com.), so it is not clearly known if it was hydrostatically under pressured, but since the liquid reservoir is under pressured this is most likely the case. The formation of a post-exploitation vapour-dominated cap (Grant and Bixley, 2013) below cased depths supports this possibility as the rapid formation of this steam cap suggests that there is limited shallow recharge – a feature of transitional type systems. Multiple upflows have been identified in the liquid reservoir at Awibengkok (Figure 5: Stimac *et al*., 2010) that may originally have had separate associated vapour-dominated zones.

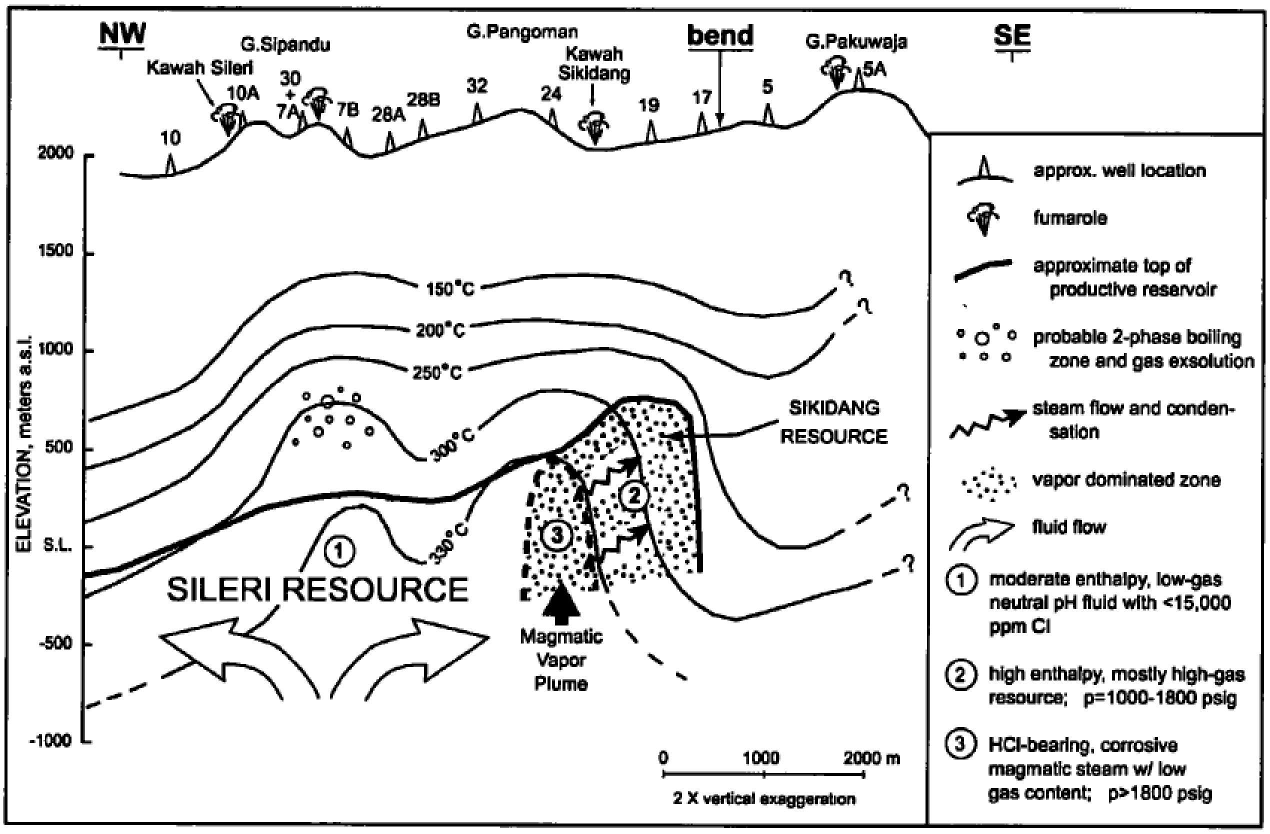

Figure 3: Cross-sectional model of Dieng resource running from northwest to southeast. Note the increase in temperature for elevation in the southeast suggestive of a third deep steam upflow. From: Layman et al., (2002). Note vertical exaggeration.

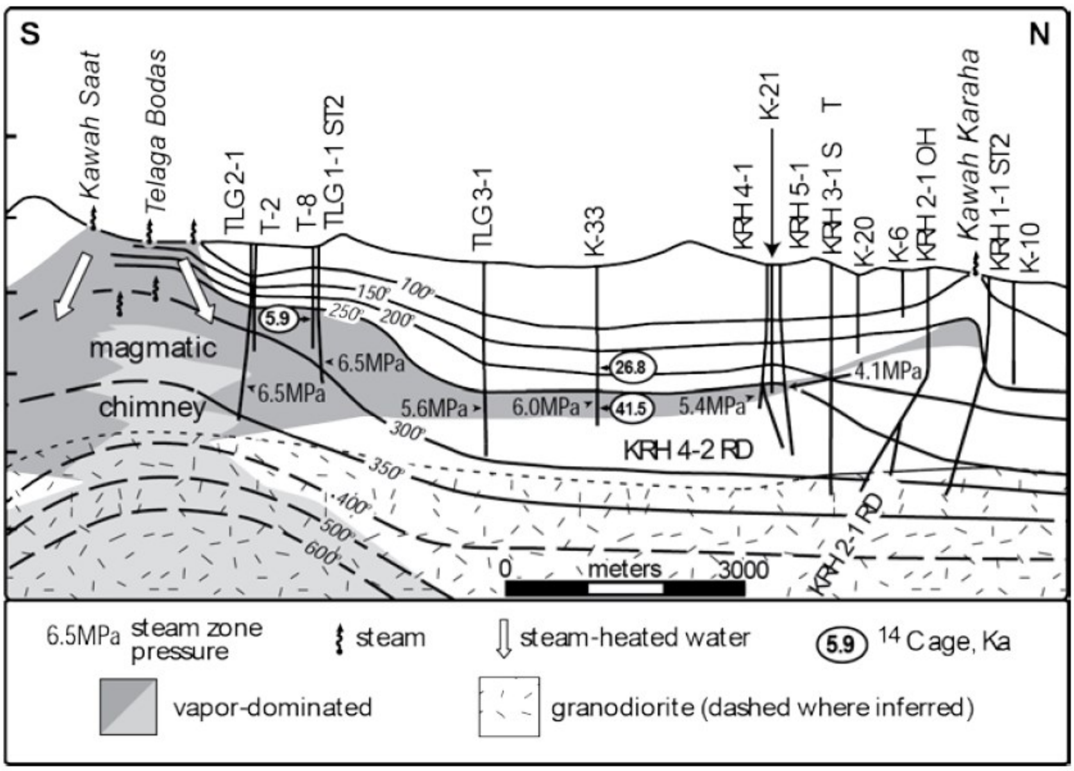

Figure 4: South-north cross section of Karaha-Telegabodas. From: Moore (2012). Note the variation in the "steam zone" pressure that requires at least two deep steam upflows to be present and the decrease in radiometric dates to the south.

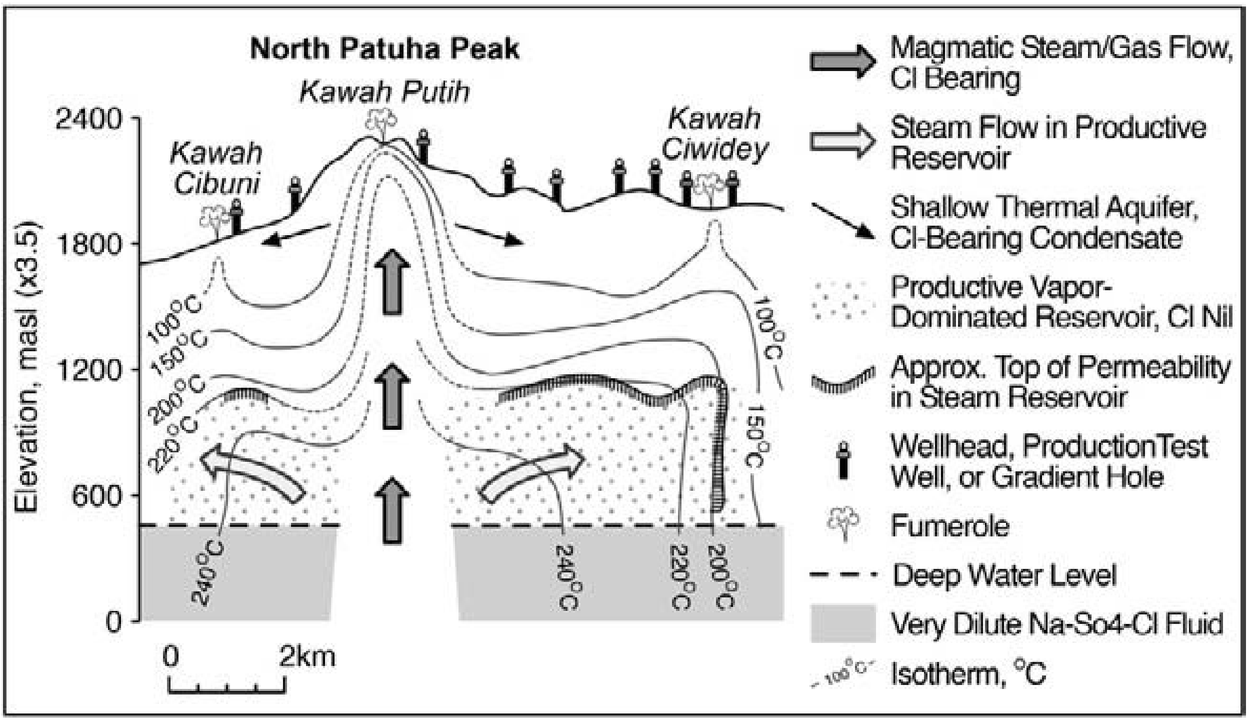

Figure 4: Cross-section illustrating conceptual model of the Patuha geothermal system. From: Grant and Bixley (2012) after Layman and Soerindo (2003). Note vertical exaggeration.

The two vapour-dominated systems (Darajat and Kamojang) have clear mineralogical evidence for initial liquid-dominated conditions (Utami, 2000; Herdianati, 2012). The presence of pyrophyllite at both Darajat and Kamojang, and at Wayang Windu (Abrenica, *et al*., 2010) indicates the earlier occurrence of hot acid waters of possible magmatic origin. Darajat, in contrast to the transitional systems, has only two deep steam upflows, with the youngest in the north and at a distance of 2 km from the deep steam upflow in the south, is much closer together than the deep steam upflows in the transitional systems that are 3 to 4 km apart. At Kamojang there are possibly two deep steam upflows that are also about two km apart, similar to Darajat. The deep steam upflows in the vapour dominated systems are thus more tightly clustered than in the transitional systems and thus have potential for a higher heat flow for volume over a longer time allowing a greater degree of boiling off. This may be why fully vapour-dominated systems have only formed at Darajat and Kamojang. Conversely, at Awibengkok the spacing of upflows is the widest (up to 4.5 km) of these fields and this appears to be the “wettest” of the fields. Therefore, the term hybrid may be more appropriate for the transitional systems as not all of them may have sufficient heat flow for volume and time to entirely boil off.

3. OVERALL HYDROLOGY OF JAVAN SYSTEMS

The restriction to and abundance of vapour and transitional vapour-liquid dominated fields on Java is likely to be due to perpendicular subduction (Raharjo *et al*., 2012) and the presence of sediments, including carbonates, at depth. The sediments in themselves are not very permeable; as reported at Awibengkok (Stimac *et al*., 2010). They are also in compression from the perpendicular subduction and have formed west-east fold-thrust belts that will have limited structural permeability but given the similarities in orientation, deep thrust faults could have some control over the west-east orientation in upflows or, in the case of Patuha, to other aligned systems to the east. This low permeability limits cold recharge at depth. It is also possible that there is very limited cold recharge overall and the deep recharge is mainly by hot magmatic volatiles that in the exploitable systems have been neutralised at depth by rock reaction. There can also be pre-hydrothermal meteoric pore waters originally present to dilute the magmatic waters so that their waters do not have entirely magmatic isotopic signatures or connate waters in the more saline reservoirs. Alternatively, the magmatic volatiles have been sourced from progressively greater depths with time and the volatiles degassed from the intrusive no longer include the species that upon condensation are highly acidic (e.g.: HCl, SO_2, Giggenbach, 1992) or have been neutralised above drillable depths.

Vapour dominated reservoirs are generally also very well sealed off from what in Javan systems can be very permeable shallow parts of the reservoir, so there isn't much, if any, shallow recharge either. What recharge there is ultimately reaches the maximum enthalpy for steam at about 235-245°C and 35-40 bar in the wholly vapour-dominated reservoir, and they are nearly isothermal and isobaric. Higher temperatures and pressures have been reported (eg: Karaha-Telegabodas; Moore, 2012) in the shallow vapour dominated reservoirs in the transitional systems reflecting either feeds of magmatic steam into the reservoirs, or ongoing boiling off of zones where the rock temperature originally exceeded that of the maximum enthalpy of steam. Lower temperatures and pressures have also been reported (eg: Patuha; Layman and Soerindo, 2003) and it is likely that in these instances there is cold water entering the reservoir and condensing steam. Production from such areas risks catastrophic pressure collapse and scaling. There can also be cooling by condensation on the margins of the reservoir that can produce colder liquid down flows in the reservoir that if produced can also result in scaling (eg: Darajat 13; Rejeki *et al*., 2010).

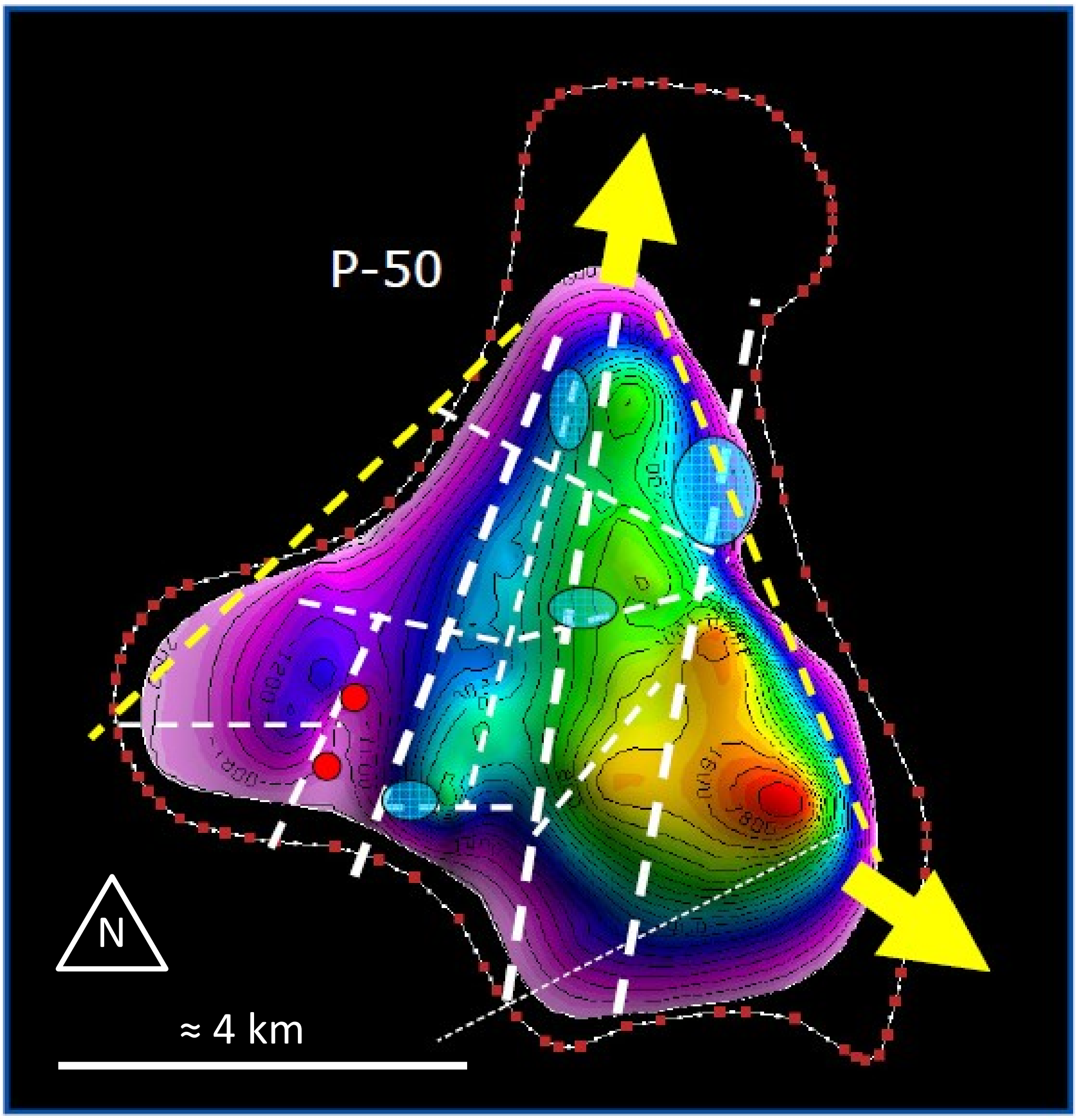

Figure 5 : Multi-coloured contouring of top of reservoir at Awibengkok. From: Stimac et al., (2010). All else being equal, potential and possibly some fossil deep upflows may be located at the various peaks in the contouring. The hottest (Kusumah *et al*., 2013)) and possibly youngest part of the overall system is in the west. Estimated scale and northing added; units of contours not given in the original paper.

It should be noted that the term "condensate" has been used in the Javan systems for two types of waters. A condensate *sensu strictu* is water that is directly condensed from steam with no mixing with colder water. Unfortunately this term is also used for ground waters that have mixed with steam and gas to condense the steam and dissolving the gas. The former is found within vapour dominated reservoirs while the latter occurs as perched aquifers above them and as lateral outflows from the perched aquifers and, as such, should be called steam heated groundwater. However, steam-heated groundwater can be chemically very similar to pure condensate if the original groundwater is little mineralized.

The condensation of steam on the side and top of the reservoir results in a slight drop in temperature and pressure going upwards and outwards from the steam upflow from depth. If all else is equal there should be a general homogeneous flow of steam upward and outward in the reservoir. There are also decreases in temperature and pressure in the direction of major surficial thermal features (eg: Patuha, Layman and Soerindo, 2003; Karaha-Telegabodas, Moore 2012) reflecting the presence of steam outflows.

This formation of condensate in the reservoir is a key factor in establishing the overall capacity of vapour dominated systems in two ways. Firstly, the condensate forms an important part of total water stored in the reservoir probably maintaining the partial liquid saturation of pore space that is dominated by the mobile steam phase. Without stored liquid the minimal recharge of this type of reservoir would mean dry out and consequent pressure decline would rapidly occur upon production. If however there is condensate present the drop in pressure with production will cause it to boil to produce more steam. Thus overall porosity and the proportion of condensate filling it are very important in determining the system's overall power generating capacity. As this porosity has to be linked to be productive, the key factor in the production is permeability. Secondly, condensate can leach the reservoir rocks to create new permeability (Grant and Bixley, 2013). Acidic CO_2-rich waters have been documented in a number of geothermal fields and are implicated in external casing corrosion (e.g.: Zarrouk, 2004). The key is to understand where this leaching is taking place in relationship to pre-drilling information in order to target cost effective wells that limit their production sections specifically to the lateral and vertical extents of the leached high permeability zones.

4.0 SPECIFIC EXAMPLES

A map showing the overall distribution of permeability has been published for Darajat (Figure 6: Rejeki *et al*., 2010). A map (Figure 7) showing areas of high transmissivity (permeability) has been published for Kamojang (Sasradipoera, 1995). A more complex map showing permeability zones at Kamojang has also been published (Sudarman *et al*., 2000; Kamah et al., 2005), but as these combine the interpretation of geophysical data with well measurements they are considered to be more speculative.

There are zones within the overall productive reservoirs of both fields where 20 MWe wells (if variations in completion size are taken into account) can be reliably drilled; with one well at Darajat reaching 40 MWe (Whittome, 1999) upon initial testing. A similar sized well has been drilled at Wayang Windu (Syah *et al*., 2010) indicating very high permeability, but information on the overall distribution of very high permeability at Wayang Windu is not in the public domain.

At Patuha (Layman and Soemarinda, 2003) the well average of 8 MWe exceeded the world wide average of 5 MWe with the best well giving 14 MWe (assuming similar power conversion factors as that at Darajat and Wayang Windu are applied), but completion sizes are not given, so permeability found to date has been high, but not very high.

At Karaha-Telaga bodas less information is available and for the wells capable of discharge it is mainly from the deep reservoir. So there isn't clear evidence for high permeability. At Awibengkok and Dieng initial production excluded the vapour cap so there is no information with regard to permeability in the vapour cap. Later, large diameter, shallow make-up wells at Awibengkok have been successful (Acuna *et al*., 2008), but it is not clear if the production is from the sweet spot in pre-production parts of the vapour zone or is more simply from the expanded later post-production vapour zone developed following production of the deeper reservoir.

A major feature to note in Figures 6 and 7 is the shape of the inner resource boundaries at Darajat and Kamojang. Simple models of a single central upflow of deep steam do not easily apply. The peanut shell shaped outline at Darajat requires two upflows as is suggested by the presence of two main intrusive bodies with near coincident high tops of reservoir (Rejeki, 2010) and this interpretation is confirmed by Herdianita (2012). The highest elevations of the top of the reservoir are interpreted to indicate the location of the deep steam upflows. At Kamojang temperature for elevation contouring (Zuhro, 2004) indicates that the highest temperatures and thus main deep steam upflow is in the south with a strong outflow to the northeast. A weaker and possibly older second deep steam upflow is interpreted in the northwest with a weak outflow to the northeast. In addition, a fossil deep steam upflow is postulated by Sudarman *et al*. (2000). Its existence appears necessary to explain the northward continuation of the 10 Ωm resistivity boundary that constitutes the inner reserve boundary.

At both Darajat and Kamojang the lateral extent of highly permeable zones are offset from the interpreted location of deep steam upflows. At Darajat there is a repeated pattern of northeast trending highly permeable zones lying to the northwest of the deep steam upflows with the largest permeable zone in the older part of the system. They are in the opposite part of the system to the main thermal features. At Kamojang the permeable zones are also offset from interpreted deep steam upflows, but in a less systematic pattern, with only one of the zones having a northeast orientation. There are also three permeable zones, but only two upflows. Possibly, the third permeable zone is associated with the proposed fossil upflow. If so the permeable zones are located away from direct flow paths towards the thermal features, similar to Darajat. This is consistent with there being a heterogeneous pattern of condensation at the top of the reservoir with more condensation in the more stagnant parts of the reservoir with steam flow into them driven just by the drop in pressure with condensation rather than being on a higher pressure gradient pathway towards the atmosphere to feed thermal features. A further factor is the change in chemistry moving away from the deep steam upflow to zones of condensation. In general, in vapour dominated reservoirs, gas contents and the CO_2/H_2S and CO_2/NH_3 ratios increase away from the centre of the field. This is due to condensation of steam at the top of the reservoir that preferentially takes up the more soluble H_2S and NH_3. The condensate then trickles down into the reservoir with the remaining steam moving outward. The condensation process at the top of the reservoir is successively repeated until the steam reaches the field's boundaries where more condensation could take place. Drainage of the condensate is essential to keeping this process going. This may result from some fault control - for example the NE trending faults at Darajat and Kamojang that are in the direction favoured by the regional stress regime (Bogie, 2000) and the caldera margin at Kamojang. However, it must be stressed that the highly permeable zone is in the vicinity of the faulting rather than the fault being the highly permeable zone itself as other similar faults elsewhere in the reservoir lack the highly permeable zones.

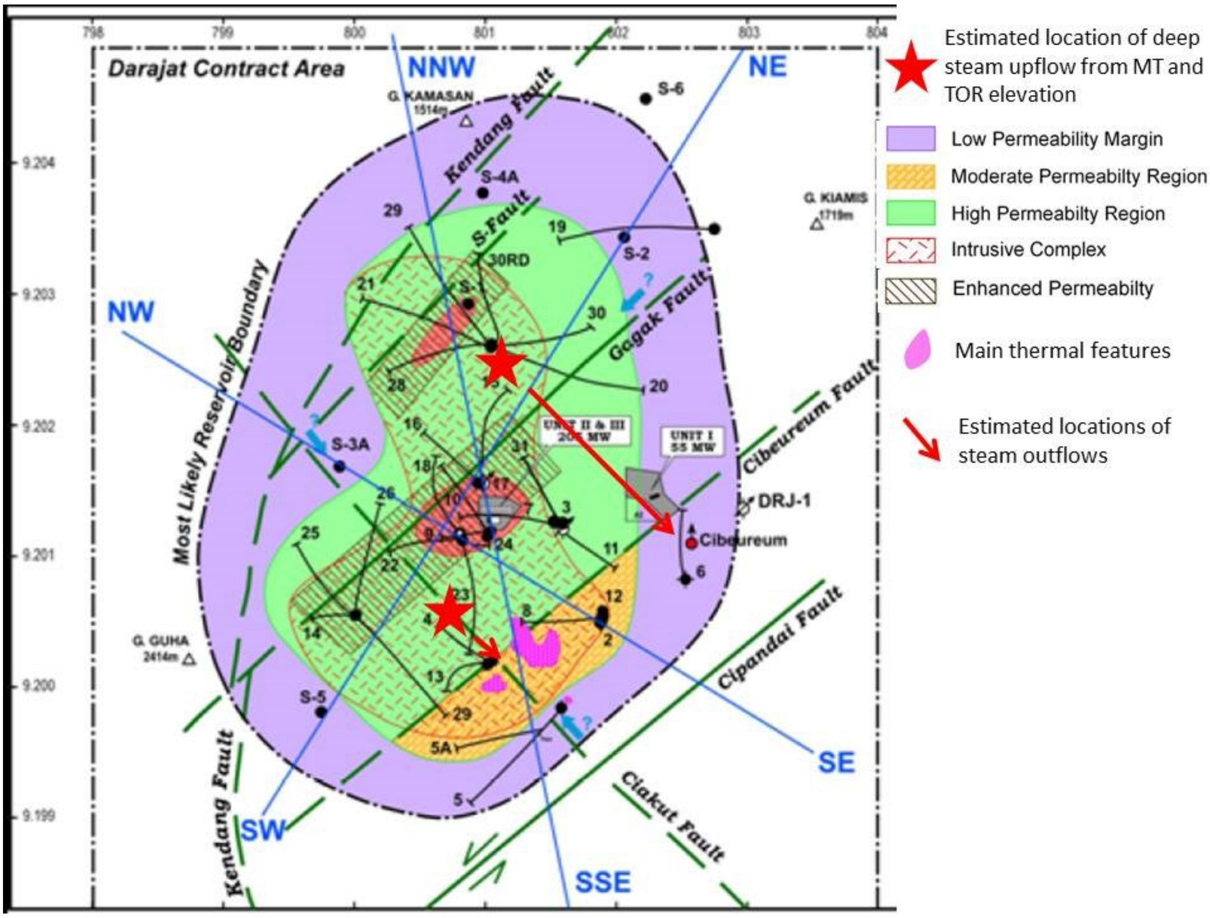

Figure 6: Lateral permeability distribution at Darajat from Rejeki *et al.* (2010). Interpreted deep steam upflow locations from magnetotelluric (MT) and top of reservoir (TOR) added from information in the same paper. Estimated steam outflow locations based on the shortest path between the steam upflow and thermal features.

As CO_2 is not only less soluble than H_2S and NH_3, it forms more acidic condensates, particularly if it is being concentrated by steam loss and less constrained by pH buffering by weaker acids as it moves outwards. Thus, any condensate formed near the deep steam upflow will be less acid than that closer to the system's margin and chemically leaching will be strongest away from the deep steam upflows in addition to the heterogeneous distribution of condensate formation due to steam flow variation. However, since condensation may be strongest on the edge of the field and the permeable zones do not go right to the edge of the field the key appears to just getting the right amount of condensation, not necessarily how acid the condensate is, as it is not just dissolved gases as the leachate. Hot, un-mineralized water is a good solvent in itself (there is leached quartz at depth at Karaha-Telegabodas (Moore, 2012), which needs something else besides acid to occur). In fact the argument could be made that if the condensate is too acid it will produce kaolinite alteration and as this involves an increase in mineral volume causes a decrease in permeability. This may be why the immediate sides of the reservoir aren't highly permeable despite being the site of condensation; particularly if there is any cold water coming in. To get condensation elsewhere requires that the temperature drops more than the pressure does and this mostly occurs at the top of the reservoir away from flows ie: stagnant zones.

While in plan view the relationship between the location of deep steam upflows and zones of high permeability is variable, in section the very high permeability occurs predominantly shallow at both Kamojang and Darajat (Huntono *et al*., 1996; Kamah, 2005; Rejeki *et al*., 2010). This is consistent not only with condensate leaching and a decrease in leaching with depth as the condensate is neutralised, but with deeper mineral deposition from the condensate, as it becomes more mineralized and less acid such that mineral deposition rather than leaching takes place.

The most obvious mineral to be leached is calcite in direct response to the acidity of the condensate. However, the initially formed condensate will be unsaturated with respect to anhydrite and thus be able to dissolve pre-existing anhydrite. Similarly, it will be unsaturated with respect to quartz and other silicates and be capable of dissolving them to provide silica in solution. How much silica can go into solution may not be necessarily simply controlled by the solubility of quartz if the solution retains its acidity so even though there might be a slight increase in silica solubility with depth in reservoir with the slight increase in temperature, silica may deposit in response to neutralization of the condensate with depth. Calcite should deposit in response to mainly neutralization, but since both it and anhydrite have inverse solubility some deposition will be produced by the slight increase in temperature with depth in the reservoir. This deposition can only take place after condensation and as condensation is considered to be limited above the deep steam upflows and what there is will not be strongly mineralized there is unlikely to be a reduction in permeability at depth in these areas to block off the steam flow from depth. Thus, the deep steam upflow should have moderate permeability and the offset zones of very high permeability should have poor permeability at depth. A schematic cross section is provided in Figure 8.

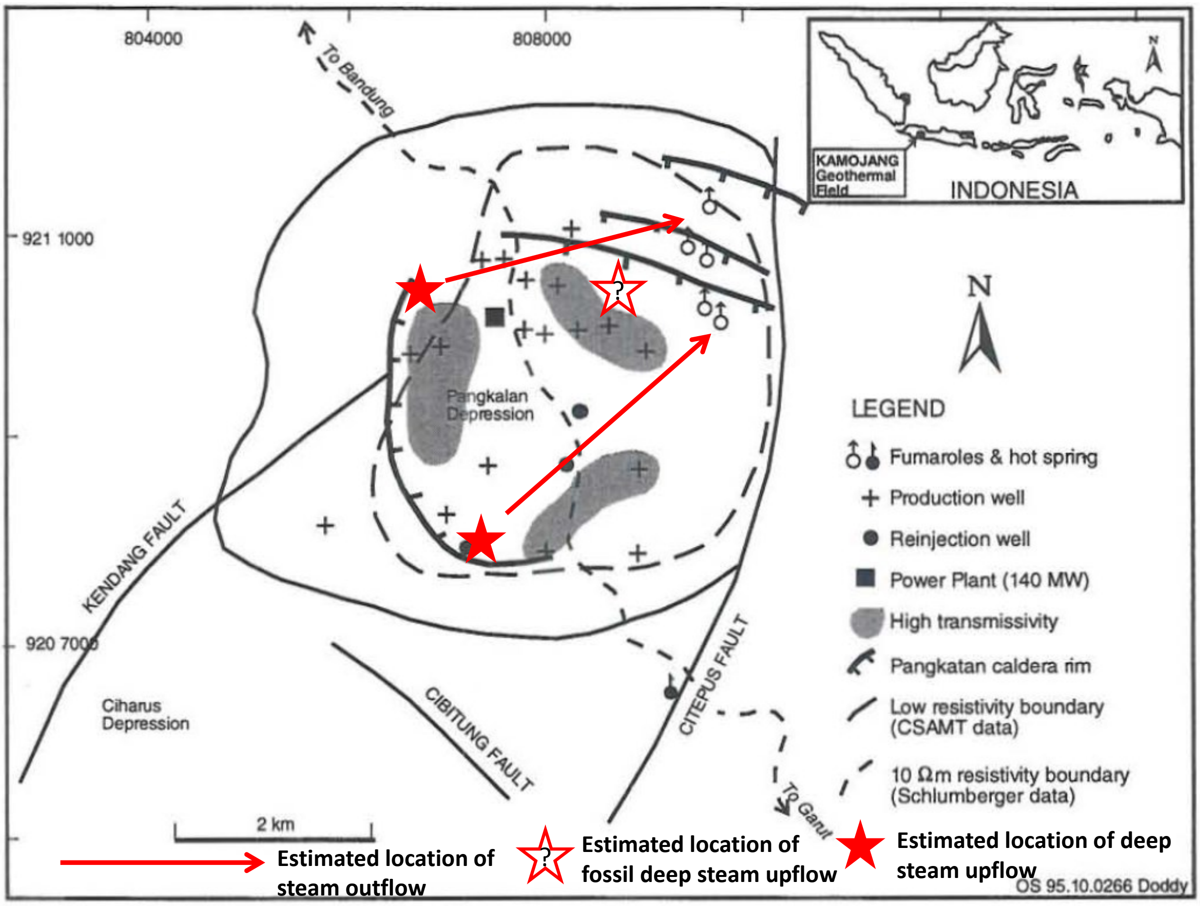

Figure 7: Estimated locations of deep steam upflows and steam outflows from temperature for elevation contouring (Zuhro, 2004) on base map (from Sasradipoera, 1995) that indicates zones of high transmissivity at Kamojang.

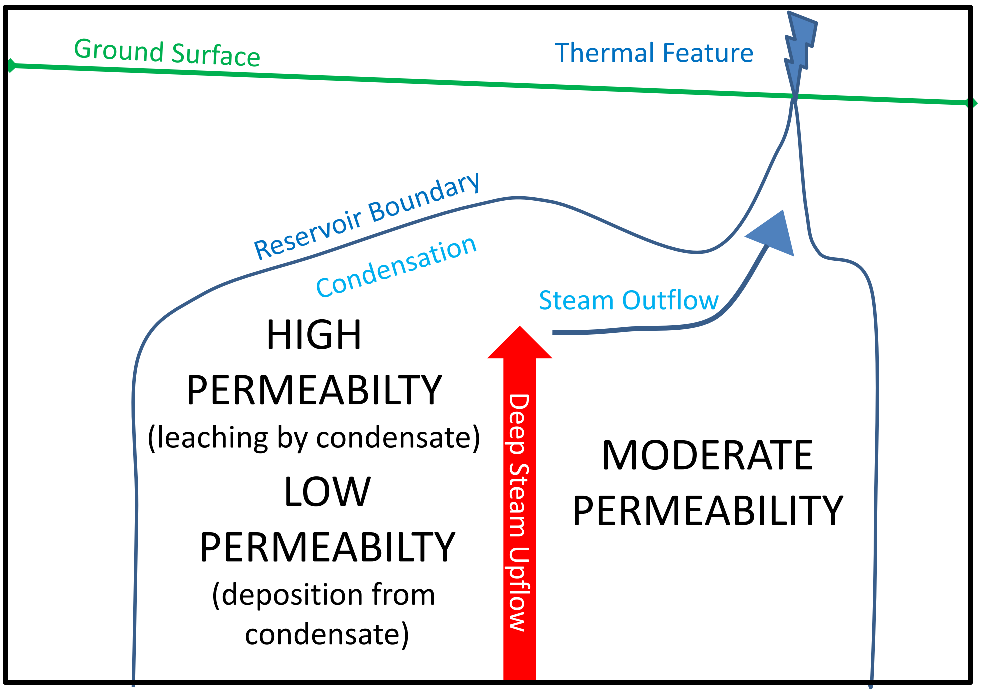

Figure 8: Schematic cross section (not to scale) of potential permeability distribution in the vapour dominated reservoirs of Java.

5.0 CONCLUSIONS

If the characteristics described above hold true for all the vapour-dominated and liquid-vapour dominated systems on Java, if not elsewhere, high permeability targets can be identified for drilling from pre-existing surficial data by a process of exclusion of zones in which condensation leaching is likely to be limited or deposition from condensate has occurred. This is not to say there may be a total absence of permeable features in the zones lacking condensation leaching, with either structural or stratigraphic permeability possibly present, but it will be far more difficult to consistently drill very good wells in these zones.

In order to drill highly productive wells into vapour dominated reservoirs the exclusion zones are:

1) The reservoir in the immediate vicinity of the deep steam upflow, as the overall high vertical flux of steam will limit condensation and any condensates created may not be particularly acid. This zone can be identified prior to drilling by contouring the base of the conductive clay cap from MT inversions which have robust terrain corrections.

2) The reservoir in the immediate vicinity of major thermal features as it is more dominated by a steam flux to the surface rather than condensation. Mapping and establishing the heat flows of the thermal areas to establish where the major features are can establish this.

3) The outflow zone between the deep steam upflow and the major thermal areas; this can be established using a combination of robust terrain corrected MT and surficial heat flow mapping. Outflows without obvious surficial thermal features can be recognized on MT cross sections by the presence of slightly higher resistivity zones in the conductive cap that correspond to perched steam heated groundwater aquifers that alter the smectite cap to kaolinite.

Where there are multiple vapour dominated zones and thermal features are located close to the boundary between them, it must be clearly established which thermal area is associated with which vapour dominated reservoir

The wells drilled into potential zones of very high permeability should be drilled as shallow as possible, due to the anticipated overall reduction in permeability postulated to occur below the shallower leached zone.

In Java there is a strong northeast orientation to some of the very highly permeable zones, which is in agreement with the regional stress regime; appropriate well azimuths should be adopted to take maximum advantage of this trend.

It is likely that the more mature geothermal systems on Java that have had major drilling campaigns have these zones, but in some of the systems high gas and magmatic acidity preclude them from being commercially productive. These targeting suggestions can thus be applied to make up wells in developed systems with low gas and acidity, as well as undrilled prospects that have thermal features with chemistries indicative of low gas and non-acidic conditions.

It also requires noting that not only will the sweet spots give high productivity wells; they should also provide high long term productivity, because their surrounding reservoirs have both higher porosity and higher liquid water fraction. This needs to be taken into account in modeling these reservoirs and strategies for producing them.

REFERENCES

Acuna J.A., Stimac, J., Sirad-Azwar, L. and Pasikki, R.G.: Reservoir Management at Awibengkok Geothermal field, West Java, Indonesia. Geothermics 37, (2008), 332-346.

Adityawan, S. K., Saptadji, N.M., and Ashat, A.: Development of a Mathematical Model to Predict Sulfide Scaling in Geothermal Wells, Proceedings, 35th New Zealand Geothermal Workshop, Rotorua, New Zealand (2013).

Abrenica, A.B., Harijoko, A., and Kusumah, Y.I. and Bogie, I.: Characteristics of Hydrothermal Alteration in Part of the Northern Vapor-Dominated Reservoir of the Wayang Windu Geothermal Field, West Java. Proceedings World Geothermal Congress 2010, (2010).

Bogie, I.: The Use of Plate Motion Vectors to Predict the Orientation of Highly Permeable Structures in Active Geothermal Fields Related to Subduction. Proceedings, 22th New Zealand Geothermal Workshop, Rotorua, New Zealand (2000).

Bogie, I., Ussher, G.N., and Lawless, J.V.: The Casita Geothermal Field, Nicaragua. Proceedings, 26th New Zealand Geothermal Workshop, Rotorua, New Zealand (2004).

Bogie, I., Kusumah, Y.I., and Wisnandary, M.C.: Overview of the Wayang Windu Geothermal field, West Java, Indonesia, Geothermics, 37, (2008), 347-365.

Cappetti, G., Passaleva, G. and Sabatelli, F.: Italy country update report 1995-1999. Proceedings World Geothermal Congress, Kyushu-Tohoku, Japan, May (2000).

Fadillah, A., Nugraha, T., and Gumilar, J.: West Java, Geothermal Update. Proceedings, Thirty-Eighth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 11-13, (2013).

Giggenbach, W.F.: Magma degassing and mineral deposition in hydrothermal systems along convergent plate boundaries. Economic Geology, v. 87 (1992), 1927-1944.

Grant, M.A. and Bixley, P.F.: Geothermal Reservoir Engineering. 2nd Addition, Academic Press (2013).

Hanano, M., and Matsuo, G. Initial state of the Matsukawa Geothermal Reservoir: Reconstruction of a Reservoir Pressure Profile and its Implications Geothermics (1990) 541–560.

Herdianita, N.R.: The Evolution of the Darajat Geothermal System, West Java – Indonesia. A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Applied Geology, School of Environment, Faculty of Science, The University of Auckland, New Zealand, (2012).

Hochstein, M.P. and Sudarman, S.: History of geothermal exploration in Indonesia from 1970 to 2000. Geothermics 37.

Huntoro, T., Wathan, R.R., Hendrowibowo, K., Sumantri, H. and Lloyd, P.M.: Kamojang Field Case Study – Using Formation Images to Resolve Reservoir Delineation and Development Issues in West Java, Indonesia. Proceedings 18th NZ Geothermal Workshop (1996).

Kamah, M.Y., Dwikorianto, T., Zuhro, A.A., Sunaryo, D., and Hasibuan, A.: The Productive Feed Zones Identified Based on Spinner Data and Application in the Reservoir Potential Review of Kamojang Geothermal Area, Indonesia. Proceedings World Geothermal Congress (2005).

Kusumah, Y.I., Syaffitri, Y., Nelson, C. and Chemeng, P.: Evaluation of the Hottest Identified area in the Salak Geothermal Field. Proceedings, 13th Indonesia International Geothermal Convention & Exhibition 2013, (2013).

Layman, E.B., Irzawadi, A. and Samsudi, W.: The Dieng Geothermal Resource, Central Java, Indonesia. Geothermal Resources Council Transactions 26 (2002), 573-579.

Layman, E.B. and Soemarinda, S. The Patuha Vapour Dominated Resource. Proceedings Twenty Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 28-30, (2002)

Moore, J.N.: The Evolution of a partially vapor-dominated Geothermal System at Karaha-Telagbodas, Indonesia: Insights from mineral distributions and Fluid Inclusion Measurements. Proceedings New Zealand Geothermal Workshop 2012 (2012).

Raharjo, I.B., Allis, R.G., and Chapman D.S. Why Are the Only Volcano-Hosted Vapor-Dominated Geothermal Systems in West Java, Indonesia? GRC Transactions, Vol. 36 (2012).

Rejeki, S. Rohrs, D., Nordquist, G., and Fitriyanto, A.: Geologic Conceptual Model Update of the Darajat Geothermal Field, Indonesia. Proceedings World Geothermal Congress 2010, (2010).

Sanyal, S.K., and Enedy, S.L.: Fifty Years of Power Generation at the Geysers Geothermal Field, California – The Lessons Learned. Proceedings, Thirty-Sixth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 31 - February 2, (2011).

Stimac, J., Baroek, M., Suminar, A., and Sagala, B.: Integration of Surface and Well Data to Determine Structural Controls on Permeability at Salak (Awibengkok), Indonesia. Proceedings World Geothermal Congress (2010).

Sasradipoera, S.: Assessment of the South East Sector of the Kamojang Geothermal Field, Indonesia. The United Nations University, Orkustofnun, Grensásvegur 9, Number 12, (1995).

Sudarman, S., Guntur, B. Setiadji, D. and Sumantri, Y.: Mapping Reservoir Permeability with Geoelectrical, FMS and Spinner Data, Kamojang Field, Indonesia. Proceedings WGC 2005. (2000).

Syah, Z., Kajo, J., Antro, Z., M. Raharjo, R.M.: Project Development of the Wayang Windu Unit 2 Geothermal Power Plant Proceedings World Geothermal Congress 2010, (2010).

Utami, P.: Characteristics of the Kamojang Geothermal Reservoir (West Java) as Revealed by Its Hydrothermal Alteration. Proceddings WGC 2000, (2000).

Whittome, A.J., and Salveson, J.O.: Exploration and Evaluation of the Darajat Geothermal Field West Java, Indonesia. Geothermal Resources Council Transactions, (1990).

Whittome , A.J.: World's largest steam geothermal well completed in Indonesia. IGA Newsletter 35 (1999), pp6.

Zuhro, A.A.: Numerical Modelling of the Kamojang Geothermal System. The United Nations University, Orkustofnun, Grensásvegur 9, Number 20, (2004).

Zarrouk S.J. (2004) External Casing Corrosion in New Zealand. Proceedings, 26th New Zealand Geothermal Workshop, Rotorua, New Zealand (2004).