Geothermal vs Petroleum – A Perspective from Asia-Pacific

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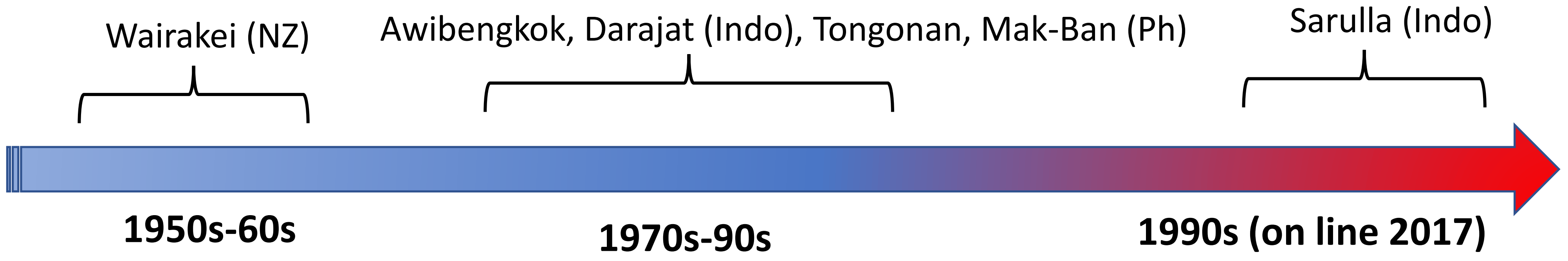
Contents

Geothermal Exploration Asia-Pacific

- The Wairakei geothermal field in New Zealand was the first geothermal field developed in the Asia-Pacific region, followed by Awibengkok and Darajat on the island of Java, Indonesia, and the Tongonan field on the island of Leyte and Mak-Ban on Luzon, Philippines.

Exploration timeline (major fields):



Geothermal Installed Capacity in Asia-Pacific

- In terms of installed geothermal electrical generating capacity, most sources list:
- Indonesia first in the region with approximately **2,200** Megawatts (MW),
- Philippines second with roughly **1,900** MW,
- New Zealand third in the region with about **1,000** MW installed capacity.

Figure 1: Occurrence of Geothermal Fields in Indonesia and Philippines

The geographical distribution of geothermal fields in Indonesia and the Philippines predicably follows the volcanic arc through Sumatra, Java, the Indonesian archipelago, and up through the Philippines Islands.

All the currently operating geothermal fields in Asia-Pacific are volcanic-hosted high temperature resources (220C-330C) .

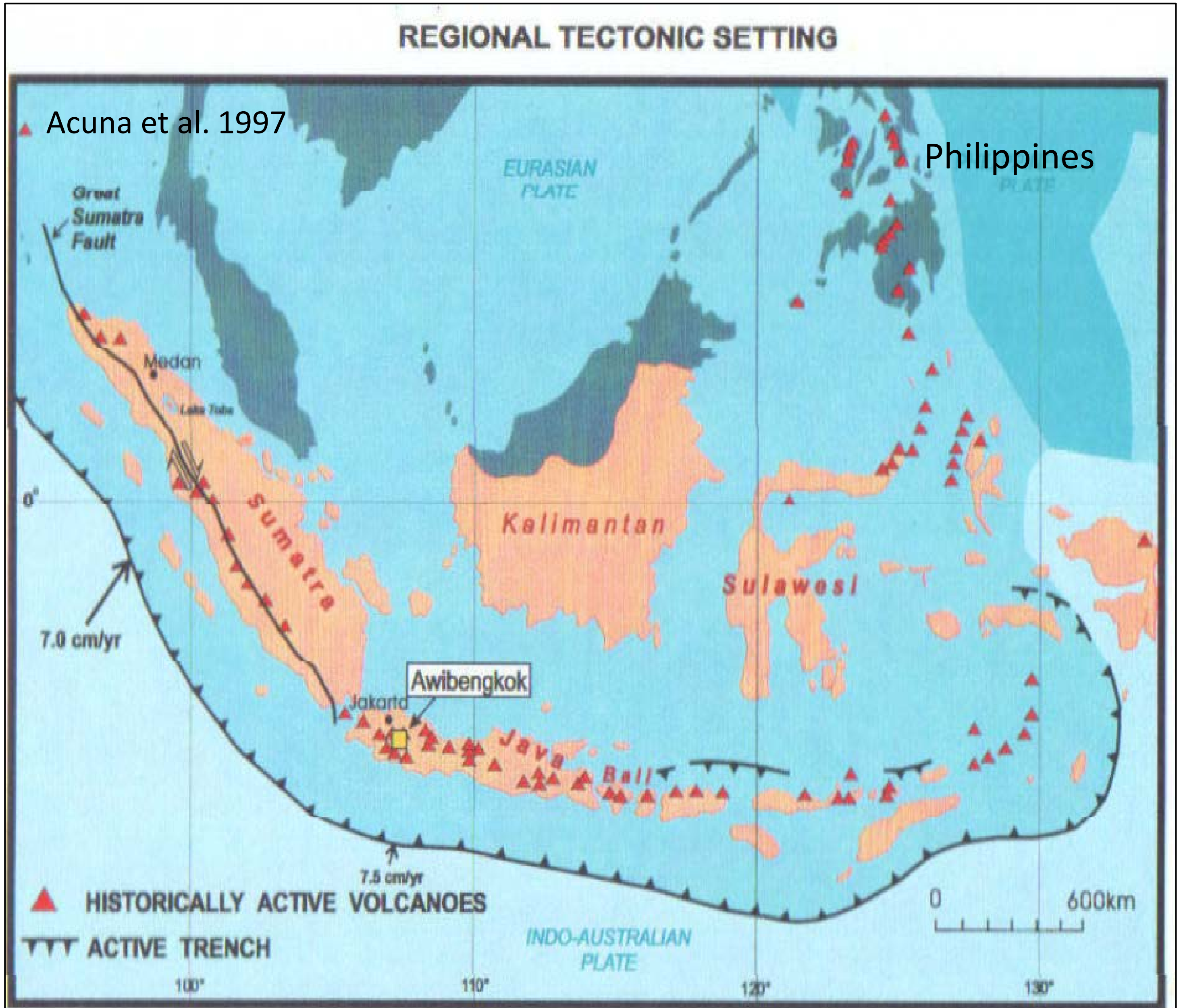
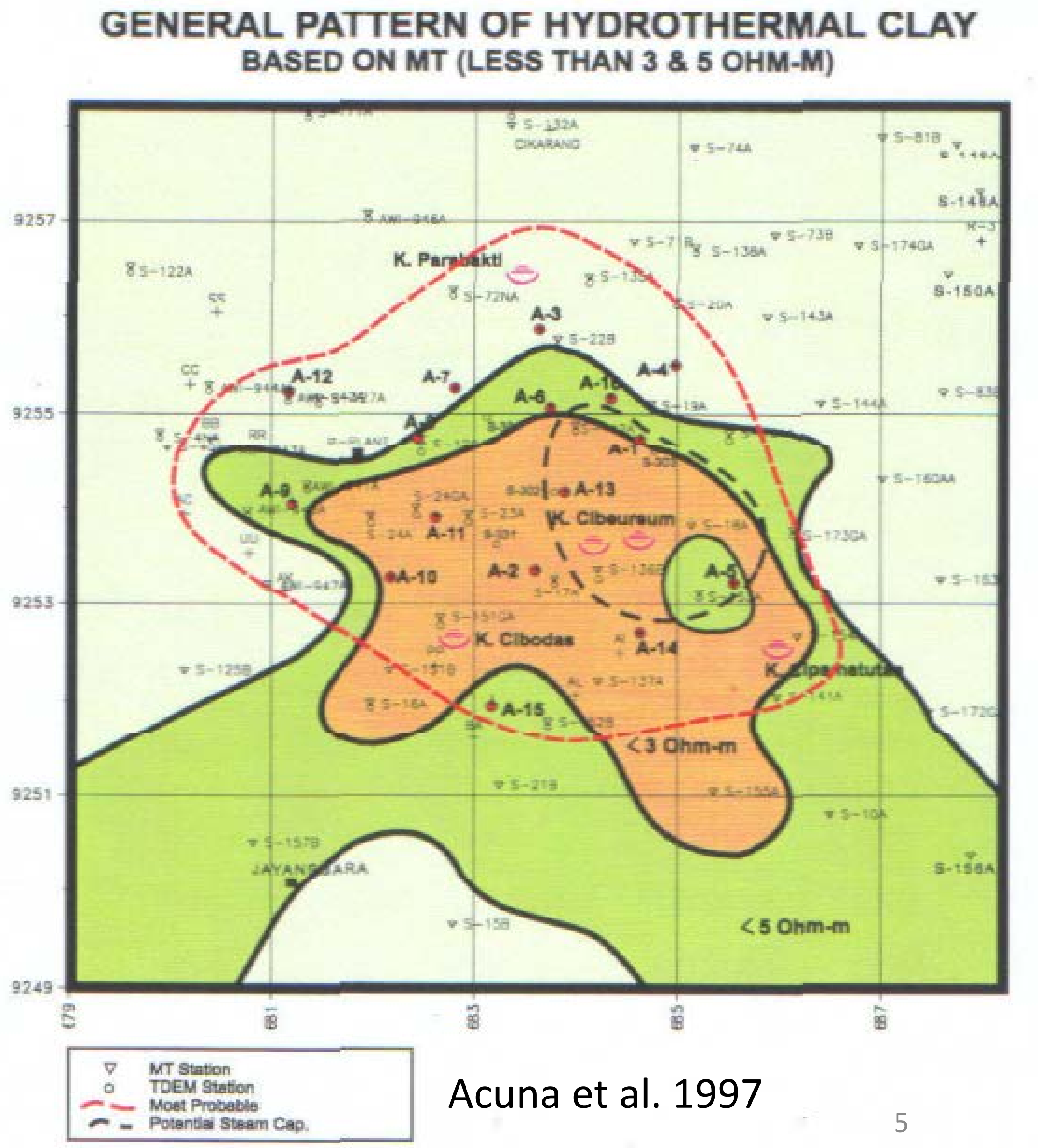


Figure 2: Conductive Clay Cap as Exploration Method

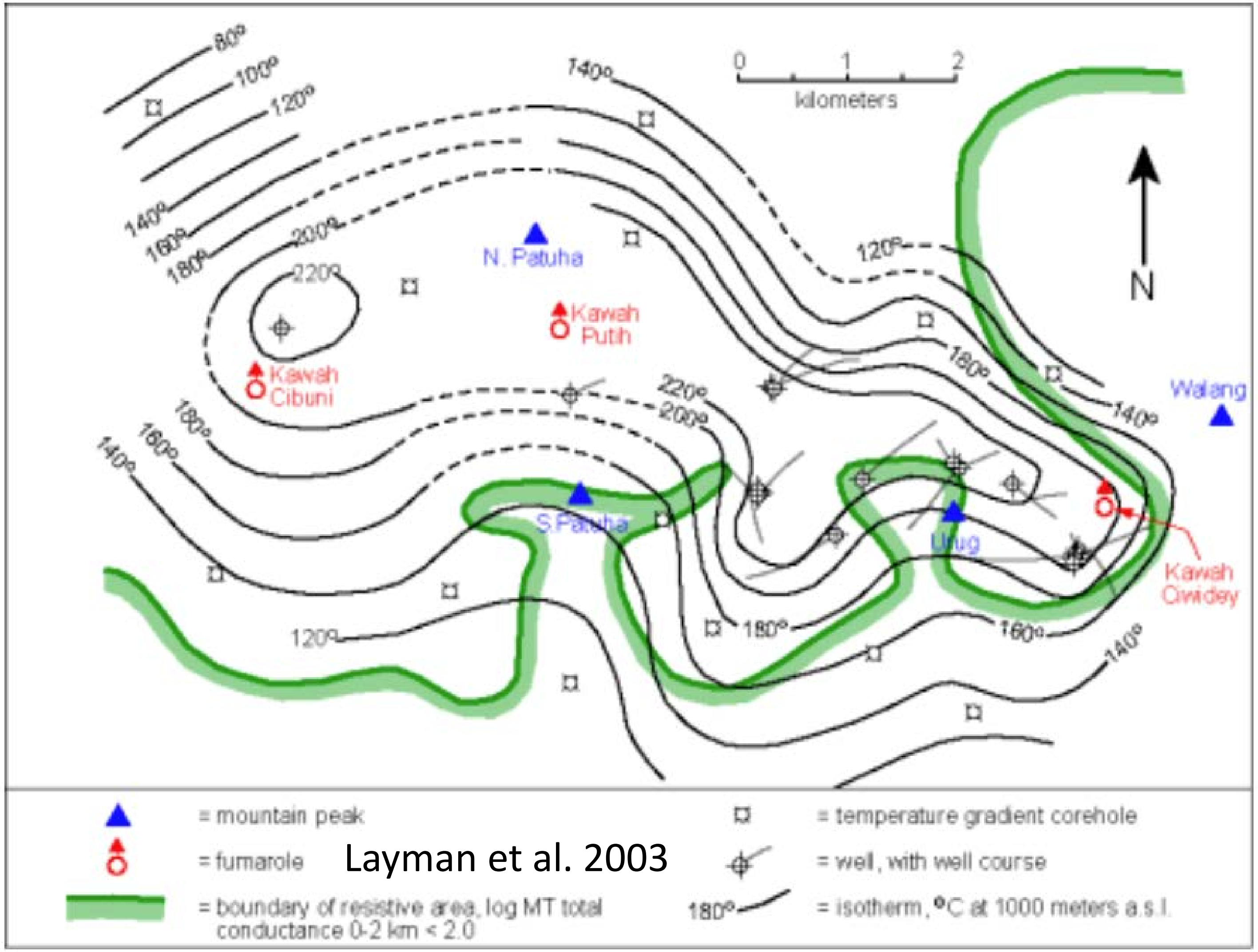
- Conductive clay caps are commonly observed overlying geothermal reservoirs.
- Magnetotelluric (MT) surveys can detect this clay cap and used as an exploration tool.
- **Figure 2** shows the conductive clay cap (orange colour) superimposed on the field limits of Awibengkok, later proven by drilling (red dashed line).



Acuna et al. 1997

Figure 3: Use of Core Holes in Geothermal Exploration

- MT can help identify a resource, but unlike seismically defined oil & gas structures, the contours of geothermal reservoirs are unknown until drilling.
- 4" core holes can be used to delineate the shape of the thermal area more cheaply than big holes.
- **Figure 3** shows the shape of the field from temperature isotherms mapped from a core hole program in Patuha, Indonesia.



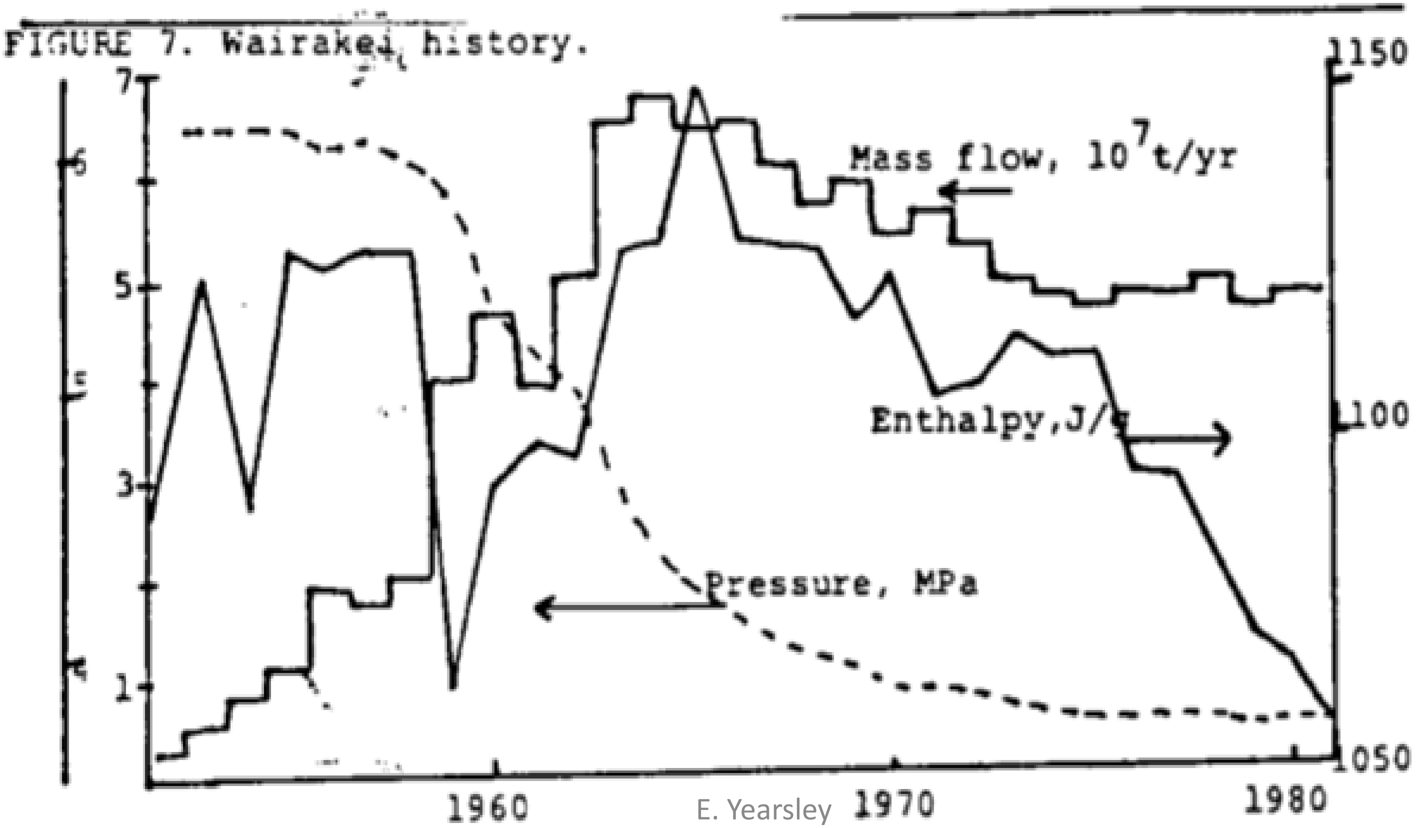
Layman et al. 2003

History of Geothermal Reservoir Engineering

- The term **Reservoir Engineering** arose within the field of the study of oil & gas reservoirs and was adapted to geothermal (i.e. Henry **Ramey** at Stanford).
- The First Workshop on **Geothermal Reservoir Engineering** held at Stanford in 1975.
- Geothermal Reservoir Engineering was also being developed in New Zealand (i.e. Russel **James** in 1962 devised an ingenious method for measuring the total mass rate and enthalpy of flowing two-phase wells).
- Subir **Sanyal**, based in California, for 35 years was often the final word on issues of geothermal reserves and the sustainability of geothermal reservoirs.
- Geothermal Reservoir Engineering has developed **independently** from its petrolem cousin over the last 30 years.

Figure 4: Early Production History of Wairakei, NZ

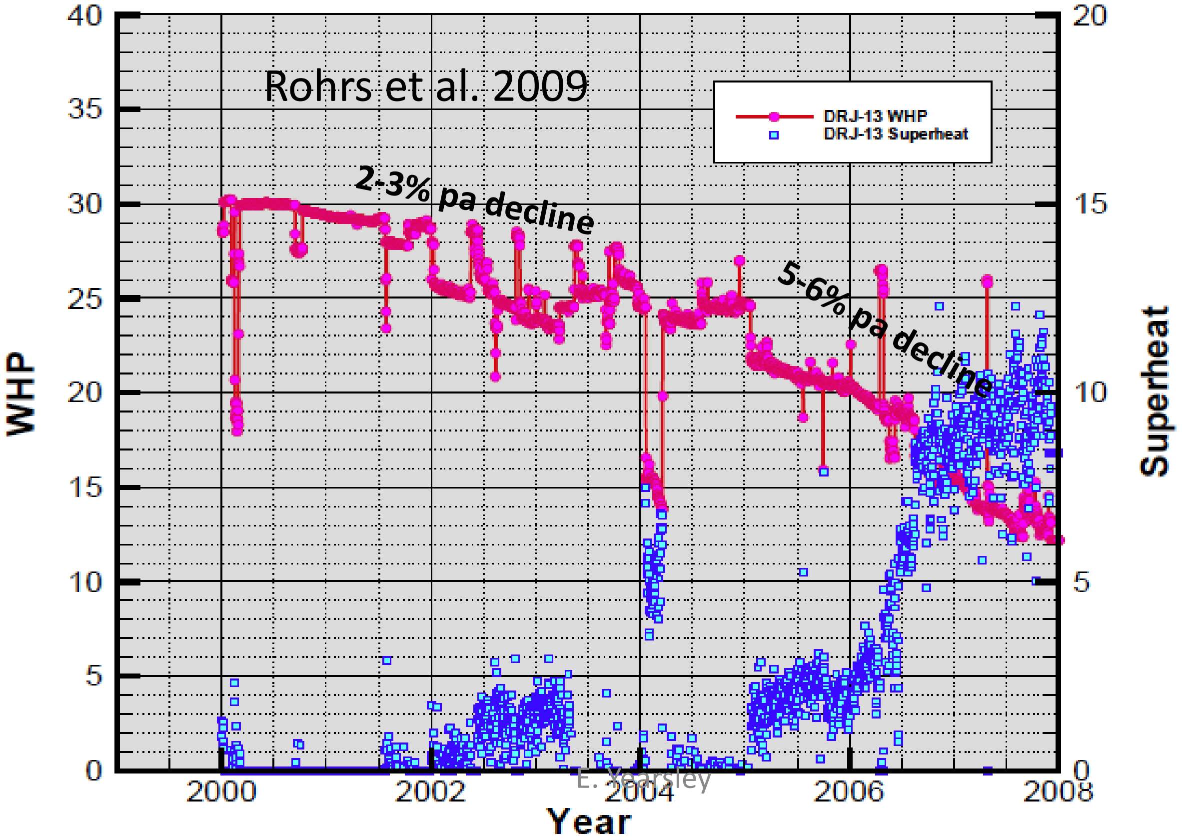
- Typically geothermal reservoirs reach long-term steady state at the expense of pressure decline and reservoir cooling.
- Drilling make-up wells, and re-injection of the separated water, are required to keep up steam mass rates.



40 year old vintage geothermal production plot (Grant, 1988)

Figure 5: Geothermal Well Decline

- Geothermal reservoir decline is a complex combination of pressure decline, boiling and cooling.
- In single phase steam fields, the reservoir starts out in a saturated condition, but as reservoir pressure falls the steam becomes superheated, resulting in accelerated decline rates.



Reserves Estimation

- There is some overlap in geothermal vs petroleum reserves estimation methods.
- Volumetrics is used in geothermal but has significant uncertainties in reservoir boundaries and heat recovery factor.

Comparison of Reserves Estimation Methods

Method	Geothermal	Oil & Gas
Volumetrics	Acceptable but unreliable	Acceptable
Power density*	Becoming more common	Not used very often (SARF)
Decline analysis	Mainly for steam fields (complicated by phase behavior)	Common for gas (P/z)
Operating history	Acceptable for mature fields	Rarely used
Reservoir simulation	Reliable if production history – complex phase changes	Reliable if production history – shrinkage/expansion

* Analogy based electrical generating capacity per unit area

Well Testing and Production

- Geothermal wells produce either two-phase steam/water or "dry steam".
- A good geothermal well can produce over **500 tonnes per hour** total mass rate (steam and water), equivalent to about 20 MW.
- Wells are initially flow tested to atmosphere – then tied into separators that feed steam to the plant.

Energy Equivalence and Reserves

- A common question to arise when comparing petroleum and geothermal reserves is **energy equivalence**.
- One way to answer this is to convert geothermal energy to oil equivalent in terms of electrical generating capacity, which Sanyal and Sarmiento (2005) have previously done.

Conversion of Geothermal Energy to Oil Equivalent

Source	kWh[1]	MWh[2]	Bbls oil	Bbls per MWh	Thermal efficiency
Sanyal and Sarmiento (2005)	1,000,000	1,000	1,500	1.5	42%
Heat content of oil (Energy Information Agency)	1,600	1.6	1.0	0.6	100%
Conversion of oil to energy (U.S. Dept. of Energy)	1,000	1.0	1.6	1.6	39%

[1] kWh = kilowatt-hour

[2] MWh = 1,000 kWh

Awibengkok and Darajat Remaining Energy Reserves[1]

Field	Installed capacity (MW)	Contract years remaining[2]	Est. remaining reserves (GWh)[3]	Equiv. MMBO [4] (at 1.5 Bbls/MWh)
Awibengkok	377	22	67,000	100
Darajat	260	22	47,000	71
Total	637	22	114,000	171

[1] Yearsley, E., *Indicative Value of Geothermal Reserves Based on a Method from the Petroleum Industry,* Geothermal Resources Council Transactions (2019). These fields were about half way through their life at the time of this estimate – so the EUR for both fields is $\sim 340\ MMBO\ (oil\ equivalent)$

[2] From the transaction year of 2017

[3] GWh = 1,000 MWh

[4] MMBO = million barrels oil

Conclusions

1. Geothermal exploration methods are unique from oil & gas.
2. In Asia-Pacific all currently operating geothermal fields are volcanic-hosted high temperature resources.
3. Though Geothermal reservoir engineering had its roots in petroleum engineering, they have developed independently over the last 30 years.
4. There are some similarities between geothermal and petroleum for testing and production (i.e. both have flow tests, later tied into processing facilities), but the methodology is completely different.
5. Energy equivalence can be compared, but only for electrical generating capacity – a reasonable conversion is 1.5 Bbls oil per MWh.
6. It may be useful to covert geothermal reserves to Bbls oil for an understanding of materiality and value – a large geothermal field (i.e. 300 MW) is equivalent to about 170 MMBO (or 1 Tcf of gas).