Geothermal Resource Group
TAPPING THE EARTH'S ENERGY

Successful Planning and Drilling of Forked Injection Wells at Sorik Marapi Geothermal Project

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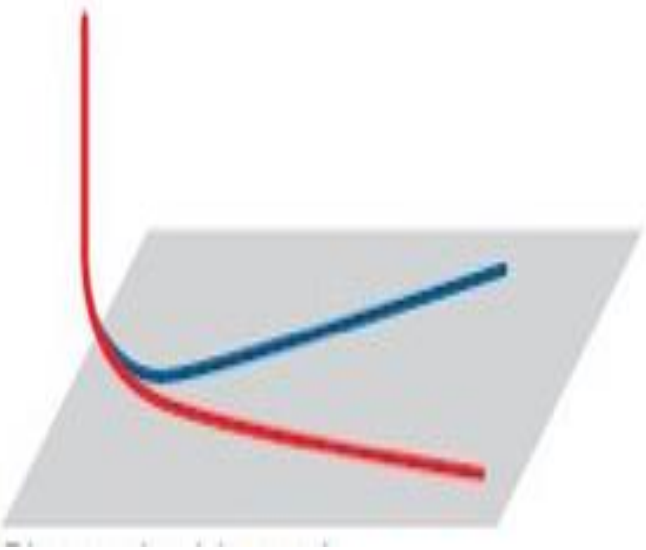
I. INTRODUCTION



What is a forked well (multi-lateral, multi-legged) ?

- Drilling multiple wellbores thru same reservoir using same wellhead

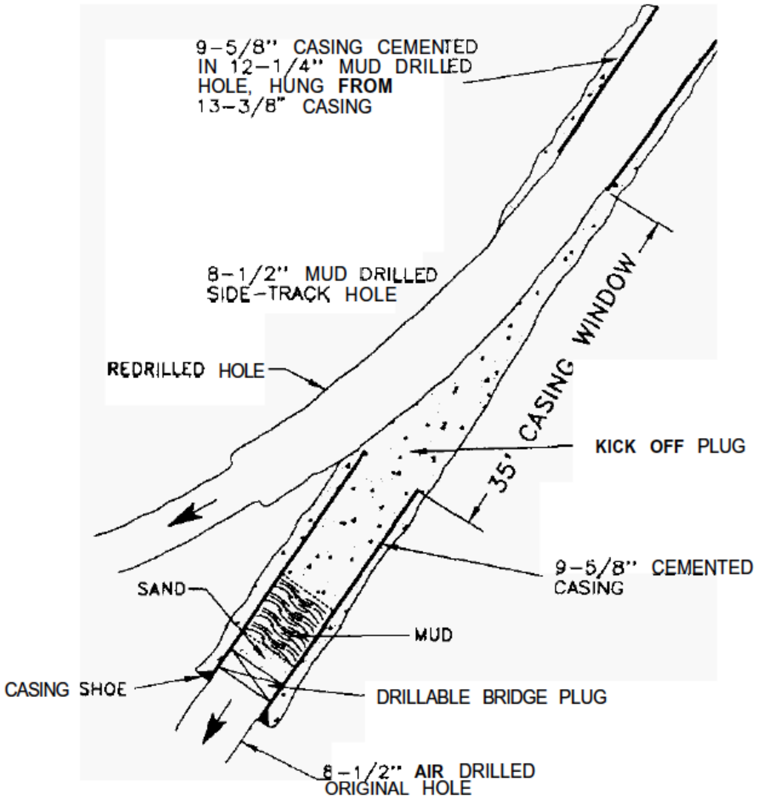
Why do we need it ?

- To improve injectivity while minimizing drilling cost (casing, wellhead, drilling time etc.)

How to sidetrack-it ?

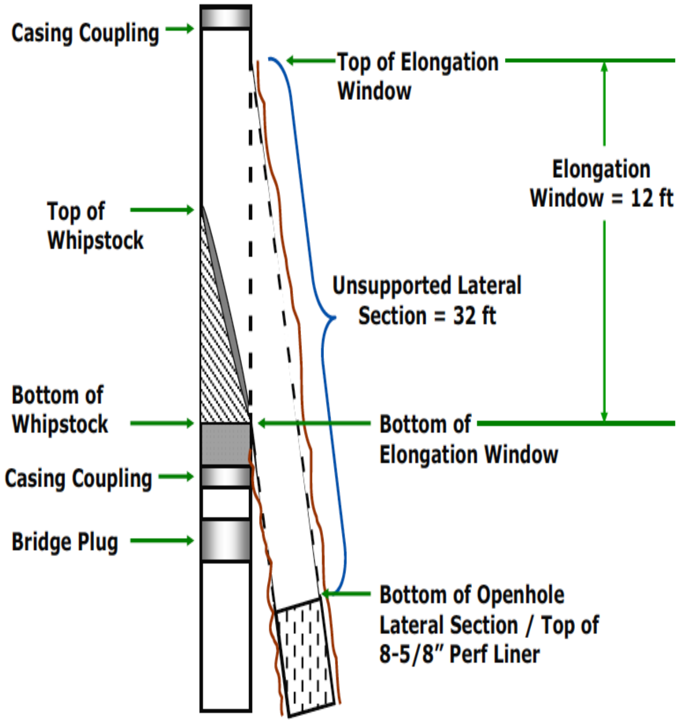
- Open Hole or Cased Hole (requires whipstock, cement retainer, cement plug(s)

Several wells drilled successfully in Geysers / California during 90s (Steffen, M.W, 1993)



- By placing a bridge plug inside the production casing and then a cement plug set on top of it
- ~ 40 ft casing window to be cut
- Cement and bridge plug to be drilled out to recover the original hole upon the drilling of 2nd leg
- Several stuck pipe incidents occurred while tripping in/out through cut window
- Costly fishing jobs and need for further side-tracking
- Formation damage (drill out cement & BP)

Stimac et al. (2010) described three forked wells drilled in Indonesia and Philippines



- By using a retrievable, cased-hole whipstock instead of a bridge plug
- Additional cost for CBL/CCL logging
- Requires cutting a casing window too
- Simplifies setting a perforated liner to the forked well
- Unsuccessful whipstock retrieval operation left a whipstock anchor and debris exclusion system in one of the wells
- Costly and time consuming
- Formation damage (drill out BP)

Given these challenges, the SMGP project team elected to use a technique that ;

- Does not require either a bridge plug or whipstock
- Uses a directional bottom-hole assembly (BHA) to ;
  - Form a ledge in open hole
  - Sidetrack can be made using time drilling
  - Minimize overall cost

Potential downsides and mitigations

- Damage to feedzones in the original hole (OH)
  - Cuttings from the sidetrack could settle into that leg rather than exiting to surface
  - Risk is minimized by using aerated water and sweeps
- Capacity of the second leg cannot be accurately determined
  - PTS tool cannot be stationed at the major feedzone in the 2^{nd} leg during injection testing
  - PTS tool is positioned above the fork when testing the 2^{nd} leg
  - Test data and WHP are both compared to injection test results in the OH to determine chance in injectivity
- Time drilling requires that ~100 m of open hole below the production casing shoe (PCS) is left un-lined
  - Only suitable for stable rock formation types

II. WELL DESIGN CONSIDERATIONS

i. Wellbore Stability below the PCS

Hole conditions need to be competent for ;

- Successful sidetrack operations
- The long-term stability of this zone

The stability of a well needs to maintained during the drilling (short-term) and over the lifetime of the well (long-term)

Injection wells are better suited to forking with time drilling because the boiling and flow direction of production is more likely to exasperate mechanical issues in the formation.

Well stability monitoring procedures that is conducted during drilling of the first 100 m below the PCS

- Check average hole diameter regularly via pumping rice or hi-vis pill (or dye) and record any enlargement in daily reports
  - Hole enlargements > 10% together with evidence of sloughing (i.e., larger cuttings and increased fill) could indicate that the formation is not sufficiently stable for open hole side-track
- Test for fill while drilling the 100 m interval that would be left open hole
  - Stop every 20 meters, pick-up into the production casing shoe, wait for 30 minutes, and then trip back in and record the depth of fill on bottom
- Compare the trend of calculated torque and drag (T&D) to the measured
  - Any measured T&D that is significantly above the calculated values indicate potentially problematic conditions
- Monitor losses to identify open fractures
  - Zones with open fractures may present a hole stability risk during long-term operation of the well in an unlined well

- Cutting monitoring and analysis
  - Samples collected at 2-meter intervals (note that the typical sample frequency is 3 meters)
  - An aggregate sample approach is preferred during stability monitoring
    - More likely to identify the presence of thin, problematic zones
  - Note their depth, size, and shape
  - Check carefully for the presence of cavings that would indicate stress-induced mechanical failure
  - Samples collected at 2-meter intervals (note that the typical sample frequency is 3 meters)
  - Frequent MeB tests to ensure that the index is less than 10 (offset data)
  - A micro resistivity borehole image (MBI) was acquired in the open hole of the first leg
    - Conducted a rush interpretation
      - To locate any borehole breakout or well oversizing
      - MBI revealed max. 2” over-gauge (no evidence of local fracture-driven mechanical failure)

ii. Kick-off Point Selection

The ideal KOP would have consistent and competent rock mechanical properties

- Lithology
- Drilling parameters
- MBI

The preferred KOP has a

- relatively softer rock, and
- consistent mechanical properties to ease the forming of a ledge

iii. Well Trajectory Concerns

Well trajectories are defined to;

- Reach geologic targets to provide the permeability required for injection
- Achieve sufficient interference standoff (~250 m for these injection wells)
- Minimize torque and drag (rig capabilities)

iv. Hole Cleaning Concerns

Protecting the main wellbore from permeability damage

- Cuttings from the 2nd leg may cause fill and/or restricted permeability due to settling
- If drilling with PLC ; keep good mud in hole and maintain mud properties
  - AA-02OH/ST had minor PLC at a 132 bbls/hr rate
- If drilling with major losses or TLC ; use aerated water with sweeps and foam to maintain circulation to surface
  - P-117OH/L2 had major losses at a 540 bbls/hr rate

III. CASE STUDIES

i. AA-02OH/ST

AA-02OH is drilled to TD at 2,450 m-MDRF (August, 2021)

13-3/8" PCS was set and cemented at 1,397 m-MDRF

A short injectivity test revealed that the well had not reached the targeted injection magnitude prior to liner run

A 10-3/4" perforated liner was set at 2,385 m-MDRF

- 65 m off bottom due to hole conditions
- Top of liner was set ~150 m below the PCS to provide enough room for time-drilling the 2nd leg

A full completion test was after the perforated liner was run to characterize the magnitude and distribution of permeability in the original hole prior to forking

AA-02ST was time drilled with a KOP selected at 1,440 m-MDRF

The ledge was formed by washing a 1.83-degree bent motor up and down at 1,420 – 1,440 m-MDRF

- Remarkably low pipe speed
- Minor PLC

AA-02ST (12-1/4”) was drilled to the proposed TD at 2,450 m-MDRF with minor PLC throughout

The final completion test of AA-02OH/ST revealed a ~25% increase in injectivity when compared with the AA-02OH alone

ii. P-117OH/L2

P-117OH drilled to TD at 2,450 m-MDRF (March, 2023)

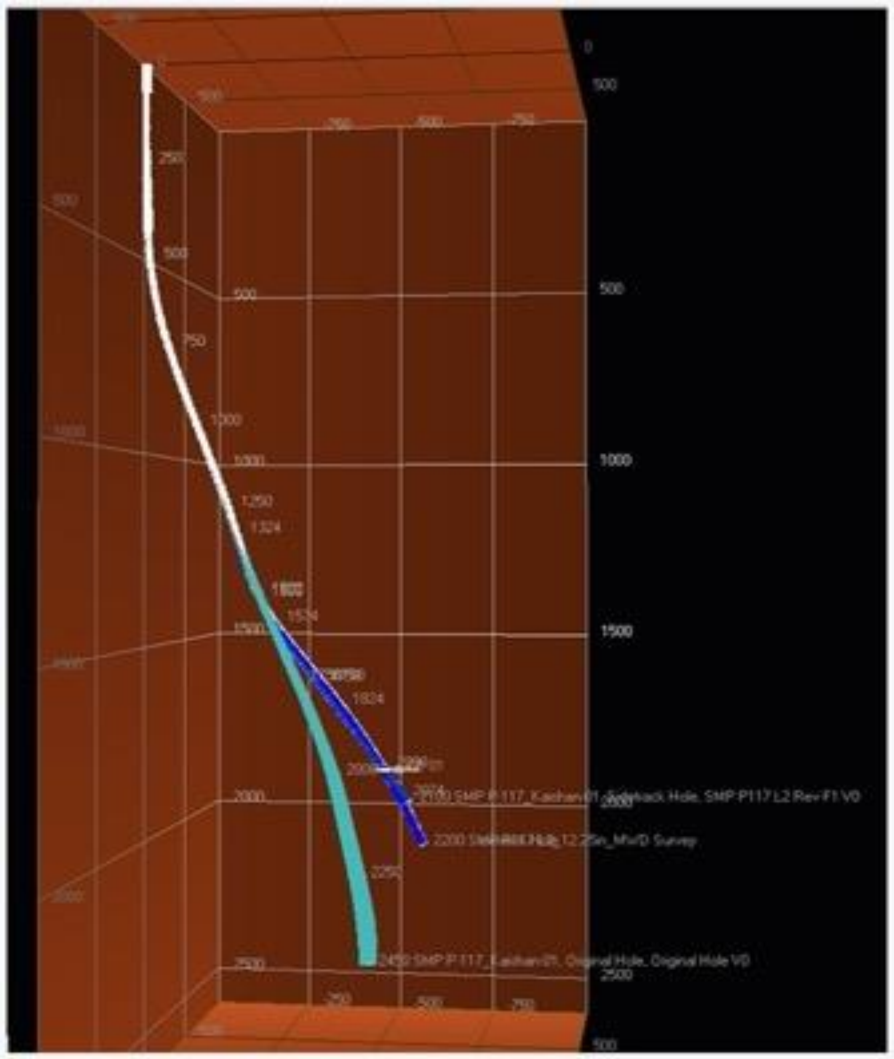
- 300 bbls/hr losses were encountered from 1,999 m-MDRF to TD

13-3/8” PCS was set and cemented at 1,350 m-MDRF

A 10-3/4” perforated liner was set at 2,445 m-MDRF

- Top of liner was set ~150 m below the PCS

P-117L2 was deviated from parent hole using the same procedures



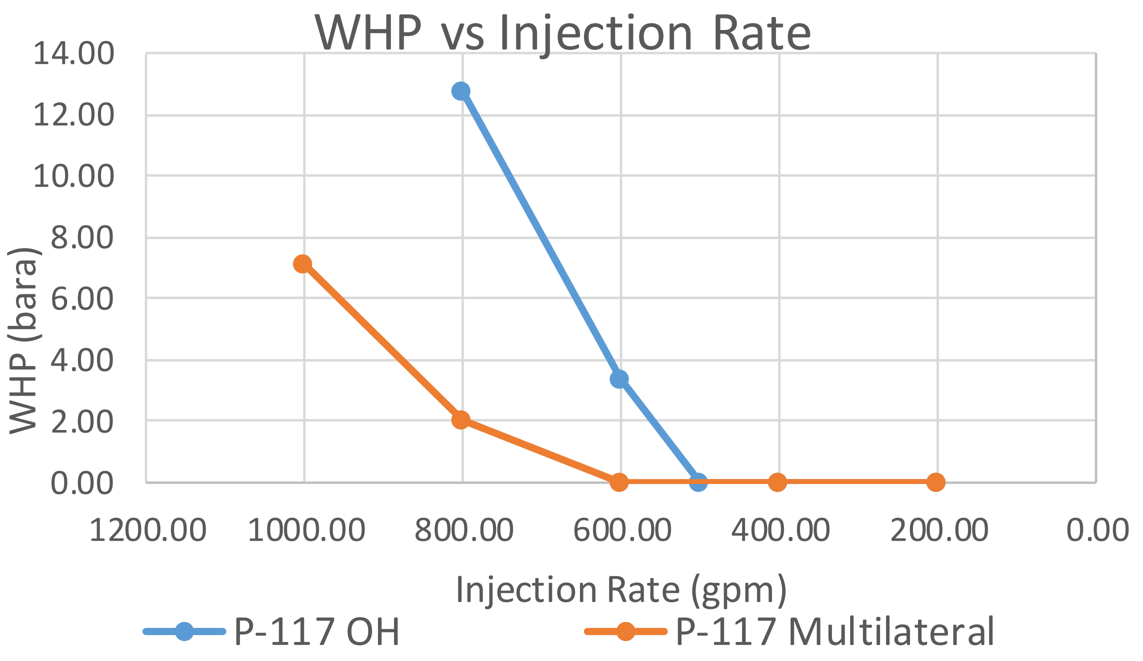
P-117L2 (12-1/4”) was drilled to the proposed TD at 2,200 m-MDRF with 600 bbls/hr losses from 1,400 m-MDRF to TD

Like AA-02OH/ST, two completion tests performed

- One on the original hole with the PTS tool positioned at the main feedzone
- One after forking with the tool above the fork
- Comparison of these tests indicated that the 2nd improved injectivity by around 45%.

Lower WHP in the combined P-117OH/L2 when compared to P-117OH at the same and higher injection rates supports the conclusion that permeability has improved

P-117 OH		P-117 Multilateral	
WHP	Inject Rate	WHP	Inject Rate
bara	gpm	bara	gpm
12.76	800.00	7.14	1000.00
3.38	600.00	2.03	800.00
0.00	500.00	0.00	600.00
0.00	400.00	0.00	400.00
0.00	200.00	0.00	200.00



IV. COST SAVINGS

Well Name	TD (m-MD)	KOP (m-MD)	Total Cost (MM$)	Cost Saving (m-MD)	Cost Reduction (%)
AA-02OH	2,450	N/A	3.70	-	-
AA-02ST	2,450	1,440	1.42	2.3	62
P117OH	2,450	N/A	3.60	-	-
P117L2	2,200	1,390	0.80	2.8	77

~75 % cost reduction due to reduction/elimination of ;

- Drilling both 26” and 17-1/2” HS
- Cost of 20” & 13-3/8” casings and accessories
- Wellhead equipment cost
- Cement and mud material
- Service costs (directional drilling, H2S, mud logging etc.

V. CONCLUSION

Time drilling is not a new technique for forked wells as it has been used in other Indonesian geothermal projects. However, this paper contains the first published case studies of time-drilled forked wells

Forked wells using time drilling can provide significant cost savings while improving the capacity per wellhead

A time-drilling approach also reduces risk by removing the need to recover a whipstock and minimizing stuck-in-hole issues generated by windows cut through casing

Well forking using any approach is a complex operation with inherent risk

The well design considerations described herein can be applied to reduce risk.

They also illustrate the importance of collaboration between drilling and geoscience during program design and management.

THANK YOU !

ANY QUESTIONS ?