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De-risking geothermal drilling: the mixed fleet approach. A cost effective, time saving drilling method

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ABSTRACT

The two main costs of geothermal development projects are drilling and power plant construction. Mixed fleet drilling offers a proven method to significantly reduce a project's drilling costs by making use of less expensive 'top-holing' rigs for the upper sections of wells, typically down to the production casing depth. A standard 2,000 hp 'big-rig' can then complete the well. Taking an example from a production drilling campaign in Kenya using Cluff Geothermal's 1,000 hp Epiroc Predator rig, it is shown that the mixed fleet approach can also be adopted in the exploration drilling phase, where expensive drilling related risks are prevalent owing to poorly understood subsurface conditions. In volcanic settings, the top section typically presents the most challenging drilling conditions. Using a small, inexpensive drilling rig for this section can save developers significant sums of equity capital, even when factoring in the cost of mobilising both a top-holing rig and a big-rig to a project, as challenging downhole conditions can result in delays to the drilling process and downtime. The deep geothermal drilling industry is motivated to provide developers with high cost big-rigs as this results in greater returns for their shareholders. The mixed fleet drilling approach is cost comparative to a 'budget' big-rig drilling operator across a campaign of three or more wells. There should be a step change within the global geothermal sector to deploy mixed fleet drilling as a standard means of de-risking drilling operations.

1 INTRODUCTION

Drilling presents the highest risk phase of a geothermal development, especially the exploration drilling phase in greenfield geothermal project areas. De-risking exploration drilling is of great importance to project developers, financiers, and government regulators alike. Historically, a mixed fleet drilling approach has been considered appropriate only for later stage drilling operations, namely production or injection well drilling. Benefits of the mixed fleet approach include a faster completion of the drilling campaign, minimising the cost of delays and reducing costs of the campaign. This paper demonstrates that in a typical three well exploration drilling campaign, it is always cheaper to deploy a mixed fleet drilling approach.

There are terms used throughout this paper which readers may be unfamiliar with. Firstly, the 'top section' of a well, which is defined by the authors as the section of the well typically comprising the surface casing, anchor casing and production casing (see *Figure 1*). The production casing setting depth is typically around 800 – 1,300 m below ground level.

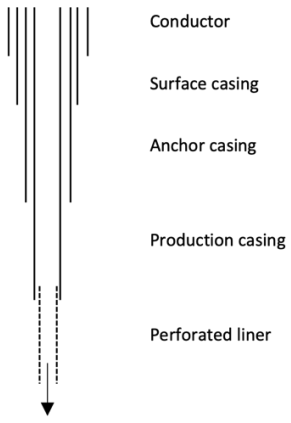


Figure 1. Typical geothermal well design

Secondly, the concept of mixed fleet drilling: in a typical geothermal drilling operation targeting a total depth of 2,500 m, a single rig is deployed to the project site. This rig would tend to have 2,000 hp and a hook load capacity of around 1,000,000 lbs. In this paper these rigs are defined as 'big-rigs' (see *Figure 2*). A mixed fleet drilling approach utilises a big-rig for the deeper section of the well (i.e. below 1,000 m depth), but a smaller rig for the well's top section (as defined above). This paper uses an Epiroc Predator 220 drilling rig as the example rig proposed for the top section. The Predator is a 1,000 hp rig with 220,000 lbs hook load capacity, and well suited to drilling the top 1,000 m of a geothermal well.



Figure 2. Images of Cluff Geothermal's Predator rig (left) and a typical 'big-rig' (right, Khaemba et al., 2015)

2 BENEFITS OF MIXED FLEET DRILLING

2.1 Time saving

2.1.1 Drilling rates

A common misconception is that rates of penetration for smaller rigs are lower than for big-rigs. Drilling data from Kenya has shown that the Predator can drill geothermal top sections just as fast, or faster than a big-rig. *Figure 3* presents time-depth plots from two fields in Kenya: Menengai and Olkaria. The Menengai wells were drilled in a relatively undeveloped geothermal field, where there are many uncertainties with the drilling operation. By contrast, the Olkaria wells were drilled by an international contractor in a well understood geothermal field, which has been operating for decades. The Predator top sections at Menengai are shown in yellow, the GDC Menengai big-rig wells are shown in grey, and the Olkaria big-rig production wells are shown in green. Similar rates of penetration are seen across all three options, with the smaller Predator rig able to compete with, and often better than the big-rigs.

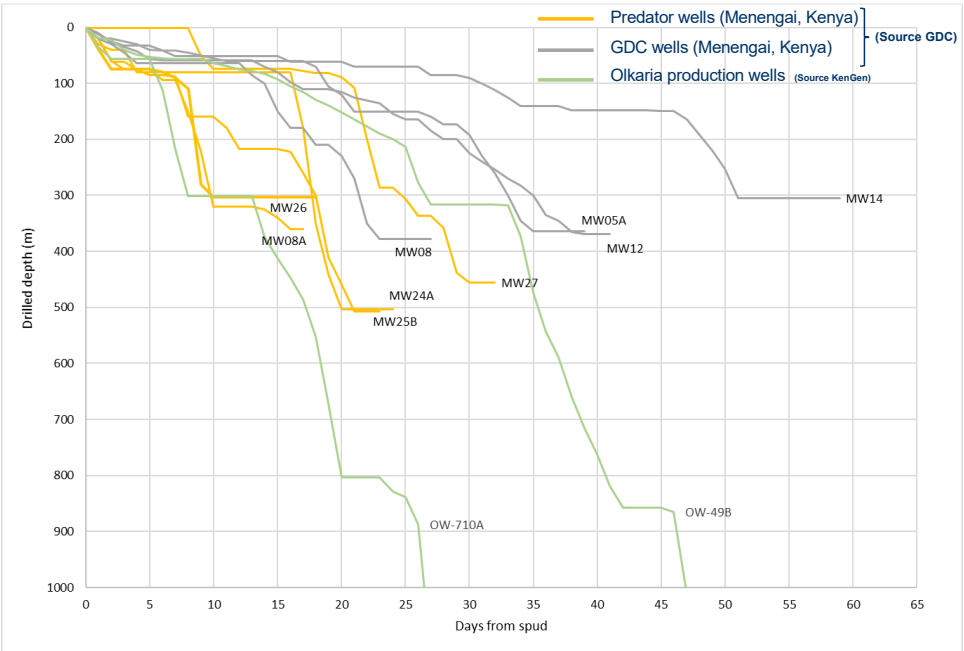


Figure 3. Time-depth rate of penetration comparison for geothermal drilling in Kenya. The top sections drilled by the Predator rig are no slower, or even faster, than wells drilled by big-rigs (Khaemba et al., 2016).

2.1.2 Mobilisation

The second advantage of a smaller drilling rig such as the Predator is its manoeuvrability. A typical big-rig will have upwards of 140 container loads whereas the Predator has only fifteen (including one self-driving rig carrier unit). This advantage makes the Predator significantly easier to mobilise to a site and between well pads than a big-rig, resulting in substantial time savings. It can take around two weeks for a big-rig to carry out a rig move between well pads, but the Predator can complete a full rig down, rig move and rig up within three days. Indeed, when the air drilling method is being used, (the Predator can drill with either air or mud, interchangeably) it is possible for the Predator to rig down, move, rig up and begin drilling on a new well pad all within one day, as there is no requirement to have moved the mud package to commence drilling.

2.1.3 Campaign lengths

The mixed fleet approach offers an excellent opportunity to save time. *Figure 4* demonstrates the time savings possible by deploying two rigs for a three well drilling campaign. The upper timeline presents a mixed fleet approach, where a Predator rig (in yellow) drills the top 1,000 m of a 2,500 m well (the big-rig is shown in blue). It is assumed that both rigs drill at the same rate, and that there are no major delays with the drilling process. The upper timeline demonstrates that over the duration of the campaign, by having two rigs on site drilling concurrently the developer will save around ten weeks, or more simply, they will complete three wells using a mixed fleet approach in the time it takes to drill two wells using a big-rig alone.

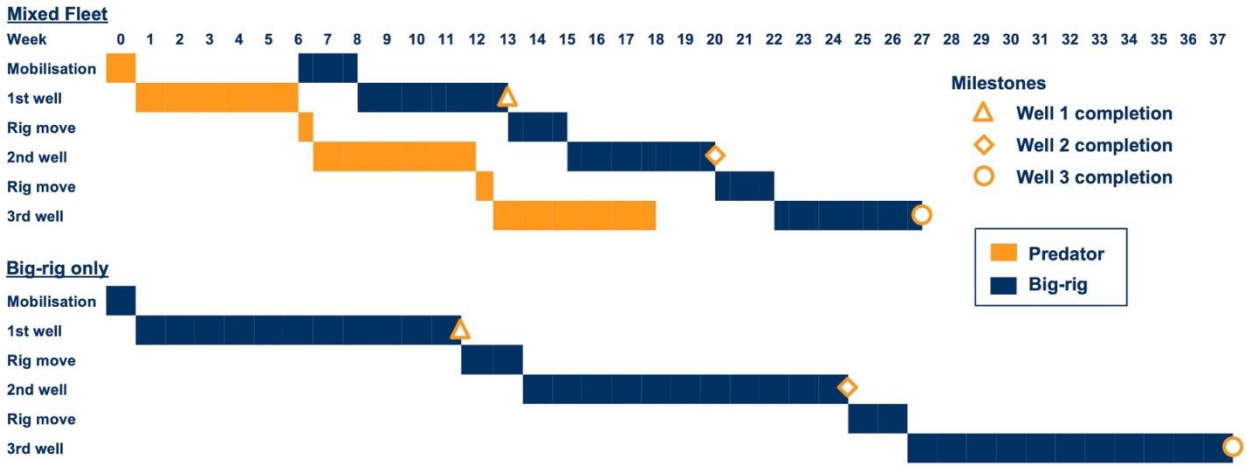


Figure 4. Time saving potential when deploying a mixed fleet approach for a three well exploration drilling campaign.

2.2 Cost savings

There have been examples in recent years of geothermal drilling rigs being offered by rig owners to developers at very low operating cost, ostensibly as loss leader contacts to encourage future work. In this paper these rig operators are termed 'budget operators', typically operating with rig package day rates below $22,000. On the other hand, a premium operator is considered one charging in the region of $40,000 per day for the full drilling package (including rig hire, crew and rig ancillaries). *Figure 5* presents a hypothetical cost breakdown for a three well exploration drilling campaign with all wells drilled to 2,500 m bgl. In this scenario, all three wells are successful, with no significant delays.

On the left of *Figure 5*, a cost breakdown for a mixed fleet drilling campaign is compared to a big-rig only approach using a budget big-rig operator. Four costs are presented for each rig: mobilisation, drilling, rig move and demobilisation. The cost of a successful three well mixed fleet drilling campaign is comparable to the cost of using a big-rig alone. It is worth noting that this eventuality assumes the drilling campaign goes according to the planned time-depth schedule. These schedules often slip and given the lower operating day rate of the Predator rig, if issues arise in the top section of the well, the developer will benefit from great cost savings compared to using a big-rig for the top section of the well. The right of *Figure 5* shows that the cost savings with the mixed fleet approach are significant when using a premium big-rig operator. A mixed fleet approach can offer a 20% saving over the three well campaign compared to using a premium big-rig alone.

While previously it has been thought that top-hole drilling using a mixed fleet should be limited to larger, production drilling campaigns, *Figure 5* highlights the significant cost benefits a mixed fleet approach can offer

to a developer in a three well campaign, with comparable costs to a budget big-rig operator, yet significant cost savings should any delays occur during drilling

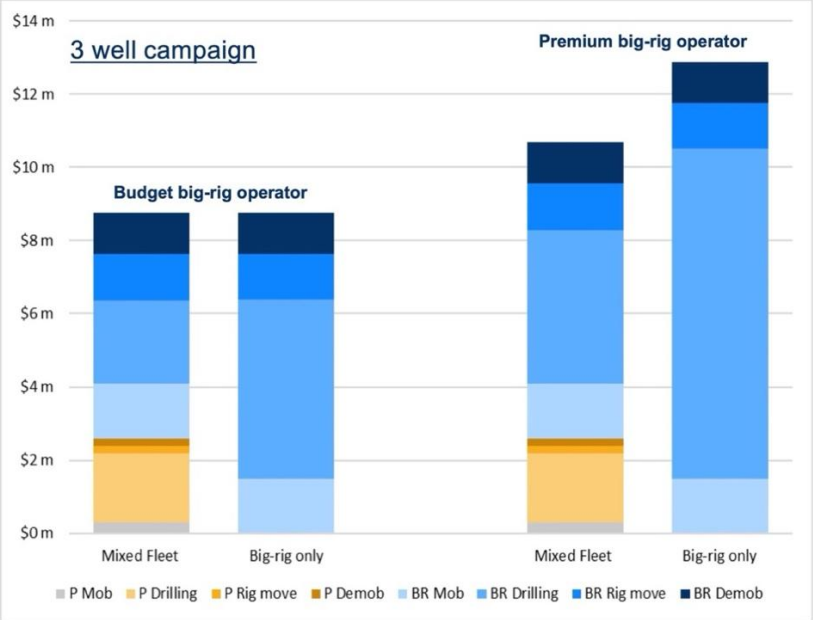


Figure 5. Cost saving potential when deploying a mixed fleet approach for a three well exploration drilling campaign.

2.3 De-risking early stage exploration

Geothermal drilling is notoriously challenging in the top section of wells. Geological conditions, particularly in high enthalpy volcanic environments, are hazardous, inconsistent, and demanding for drilling crews to tackle. Total losses of circulation are common, often only controlled by multiple cementing runs to pass through unconsolidated material or vast lava tubes. Further, drilling operations often must contend with other, non-geological risks. Supply of cement and water can be a serious issue for drilling contractors, especially when working in remote regions or with a developer who has opted to reduce costs by taking on the provision of such drilling services themselves.

The delays associated with these risks, most noticeable in the first few exploration wells, and predominantly the top section of these wells, can be de-risked significantly by deploying a mixed fleet approach. *Figure 6,* a schematic based on a real geothermal exploration well in East Africa, demonstrates the time impact of an unforeseen delay in the top section of a well. In this example, the use of a smaller top-holing rig such as the Predator would have substantially reduced cost escalation when drilling on a day rate.

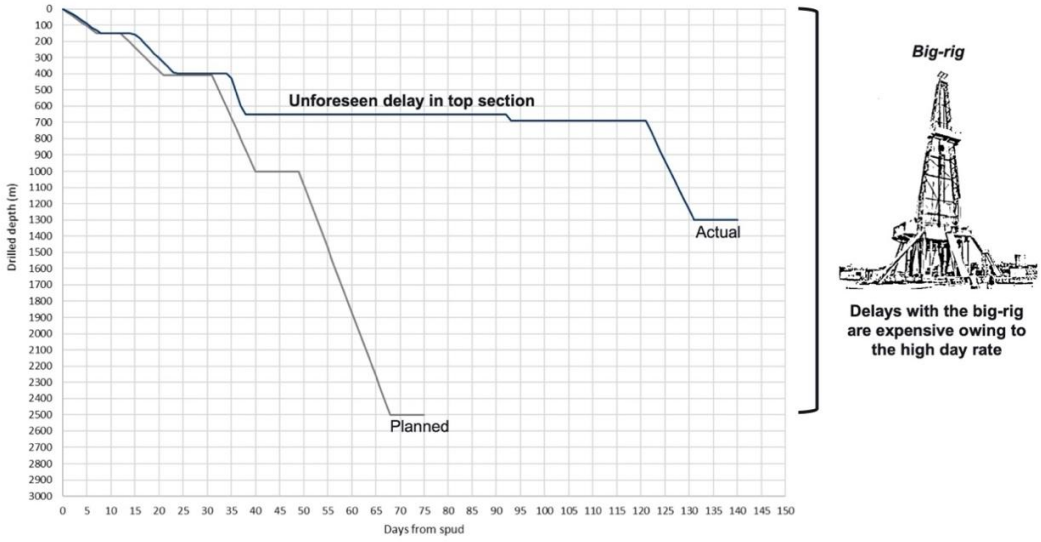


Figure 6. Mixed fleet drilling can vastly reduce expenditure if problems are encountered during drilling.

2.4 Well abandonment

Unexpected sub-surface issues may arise which result in well abandonment being the most rational financial decision to take. However, developers and project decision makers are often wary to abandon a well given the large sums of money that have been spent on it to date, the time and financial cost of an additional rig move, and the potential for shareholder grievance or negative press coverage associated with drilling failure. The mixed fleet drilling approach, especially with the Predator rig package, makes well abandonment a more viable option owing to the Predator's manoeuvrability and low-cost rig moves.

As is demonstrated in *Figure 7* below, top-holing with the Predator enables well abandonment at a fraction of the cost of a big-rig. Using the same example from *Figure 6* above, with hindsight it may have been most cost effective to abandon the well at 650 m depth, with the well ultimately failing to reach target depth after 140 days. Alas, the developer was using a big-rig and may have felt compelled to continue the drilling operation to avoid a costly rig move, and because of the expense already incurred on the well to 650 m. Had the developer been using the Predator rig for this section, the cost of the abandoned well (on day 50) plus the rig move would be around $825,000 cheaper than if abandoned using a budget big-rig operator, and $1,750,000 cheaper than if using a premium big-rig operator.

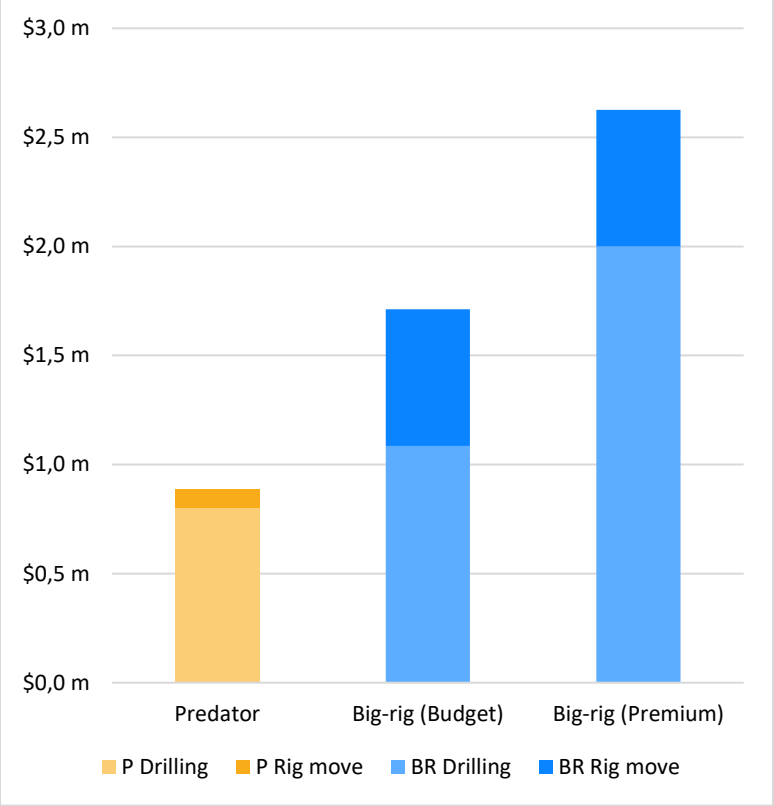


Figure 7. Cost of well abandonment at 650 m.

The benefits of well abandonment are especially relevant in volcanic environments, typical for high-enthalpy geothermal systems, where drilling into inconsistent, unconsolidated volcanic terrain or a lava tube can cause extensive and expensive delays. Drilling even tens of metres away may encounter vastly different (and possibly favourable) subsurface conditions.

When an abandoned well is modelled within a typical three well exploration drilling campaign (*Figure 8)*, which includes three successful wells and one abandoned well at 650 m depth (day 26), the mixed fleet approach is considerably cheaper as any top section challenges are borne by the Predator rig, and any rig move delays are reduced as the Predator can move rapidly following a decision to abandon and prepare another top section for the big-rig

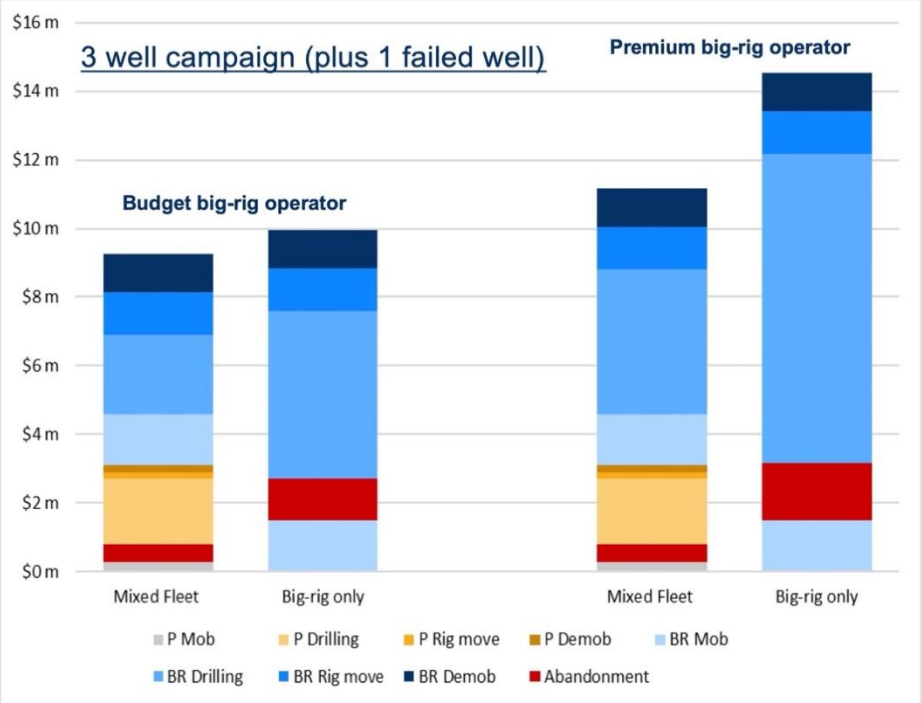


Figure 8. Cost saving potential when deploying a mixed fleet approach for a three well exploration drilling campaign, which comprises three successful wells, and one failed well (abandoned at 650 m).

3 DISADVANTAGES OF MIXED FLEET DRILLING

3.1 Increased water requirement

The primary disadvantage to the mixed fleet drilling approach is the increased water requirement when operating two rigs simultaneously. Geothermal drilling is often undertaken in areas with scarce water resources, with sensitive arrangements between developers and host governments or local communities to access the water resources required. Care should be taken to ensure an appropriate water management plan is in place, and wherever possible recycled. In especially dry regions, or if the subsurface is suitable, the Predator rig can use the air hammer technique which reduces the mixed fleet water requirement significantly. Alternatively, mixed fleet drilling can be undertaken in a phased approach, with the top-holing completed prior to mobilising the big-rig to the site. However, this impacts well site decision making and impacts the time benefits over the course of the campaign.

3.2 Well site decision making

The example provided in *Figure 4* implies that developers would not know the full results of Well 1 before the top-holing rig had progressed onto drilling Wells 2 and 3. Developers may not be comfortable with this approach, however, if they had conducted an appropriate slim well drilling campaign prior to embarking on full-size exploration wells, they would have greater confidence in the suitability of the target area and key information about the reservoir. A preliminary drilling campaign could be carried out at minimal additional cost by using the Predator rig for slim wells to the target depth, combining mobilisation costs with the full-size exploration campaign and substantially improving knowledge of the reservoir.

4 EXAMPLES OF MIXED FLEET DRILLING

4.1 Science Central Borehole, Newcastle upon Tyne, United Kingdom

An example from the United Kingdom of a successful proof of concept for mixed fleet drilling is the 1,821 m deep Science Central geothermal exploration borehole drilled in Newcastle City Centre in 2011. This project, led by the late Professor Paul Younger at Newcastle University, considered innovative methods to reach the drilling target given the challenging geological conditions in the top section and the significant budgetary constraints of the project (Younger et al., 2016). A 200 hp Beretta T151S drilling rig completed the top section to 245 m, followed by a 600 hp Drillmec HH102 rig for the remaining section to 1,821 m below ground level (see *Figure 9*). The smaller Beretta rig was chosen for the top section owing to the challenging drilling conditions faced by the historically mined coal measures beneath the drill site. There was also a considerable risk of suffering circulation losses owing to unconsolidated mined material or large voids. The contractor operating the Beretta rig was local to the

area and highly experienced in drilling through the coal measures. Consequently, deploying the Beretta rig significantly reduced the financial risk associated with any sub-surface delays from challenging drilling conditions. The Science Central borehole was completed with a total cost of GBP 1.35 million, partly owing to the cost savings from deploying a mixed fleet drilling approach.



Figure 9. Mixed fleet drilling at the Science Central geothermal site, Newcastle, United Kingdom (Younger et al., 2016).

4.2 Menengai geothermal production drilling, Kenya

Cluff Geothermal's Epiroc Predator 220 drilling rig was contracted in 2013 to carry out top-hole drilling for the Geothermal Development Company (GDC) at the Menengai geothermal development near Nakuru, Kenya, approximately 100 km north-west of Nairobi. Menengai is a remote location with restricted access roads; the drill sites are located inside a large volcanic caldera, with particularly complex subsurface conditions for drilling. The Predator is designed to be flexible, its minimal size and the rig's independent mobility was well suited and effective when operating in the challenging geological and logistical environment at Menengai.

The 20 well contract was a proof-of-concept endeavour by GDC, the first of its kind in Africa and likely a first for the global geothermal sector at that scale. The Predator was commissioned to drill the top section of Menengai's production wells, initially to a depth of 1,000 m, and later reduced to 500 m owing to alterations in the well design. The remaining section of the wells were drilled using GDC's own big-rigs (see *Figure 3*).

The Menengai drilling project successfully proved the mixed fleet drilling approach for drilling geothermal wells in an operational setting. It proved that the mixed fleet drilling approach was both quicker and cheaper than using a big-rig alone (Khaemba, 2016), and the results form the basis for deploying a mixed fleet approach to an earlier stage exploration drilling campaign.

5 CONCLUSION

An underused yet proven methodology, the mixed fleet drilling approach offers developers a prudent method for significantly de-risking their drilling campaigns. Where previously it has been thought that a mixed fleet approach is only appropriate for large drilling campaigns, the drilling data from the top-hole contract for GDC at Menengai evidences that using a smaller, more flexible rig to drill top-hole sections offers greater value for money for the operator even in an exploration drilling campaign of just three wells.

Mixed fleet drilling on a campaign of just three wells is cost competitive with a budget big-rig operator over the course of a successful drilling campaign, predominately owing to the small additional mobilisation cost of a top-

holing rig. Most delays during geothermal drilling, both logistical and geological, tend to occur in the early stages of campaigns and wells. When the top section is being completed in a mixed fleet drilling programme, the smaller, cheaper rig bears these delays with a great cost saving to the developer.

The two main capex items of any geothermal development are drilling costs and power plant construction. Geothermal developers often need to be innovative to make otherwise marginal projects financially attractive to investors. A widespread uptake of the mixed fleet drilling approach throughout all stages of geothermal field development presents a clear means of de-risking drilling, saving both time and money for the project developer.

Further, if slim wells are planned prior to a full-size exploration drilling campaign, the use of a drilling rig such as the Epiroc Predator offers more advantages still, as this rig can be used to complete slim wells to target depth, as well as completing the top section of full-size exploration/production wells, allowing mobilisation costs to be shared across the campaigns.

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