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Using drilling and geological parameters to estimate rock strength in hydrothermally altered rock – A comparison of mechanical specific energy, R/N-W/D chart and Alteration Strength Index

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ABSTRACT

Many methods for estimating rock strength for drilling rate optimization were developed for the oil and gas industry, some of which are being used in geothermal fields. We have developed a methodology for using estimated rock strength for drillability assessment in the hydrothermally altered lithologies encountered in the geothermal industry. The Modified Alteration Strength Index (mASI) provides rock strength estimates using simple intact rock properties observable in drill cuttings, such as mineralogy and fractures. We show that rock strengths for hydrothermally altered rock estimated using mASI correlate better to drillability indicators than convetional methods from the oil and gas industry.

1. Introduction

Drilling optimisation is accomplished through real time downhole data capture and analysis that allows drilling operators to adapt to the geologic conditions in the well. To further control, optimize, monitor and enhance field production it is necessary to incorporate accurate, and timely data on rock properties. Modeling and optimisation of drilling processes are extremely important to increase productivity and decrease costs (Bharadwaj and Vinayaka, 2013). There have been many attempts at analytical (Maurer, 1962; Galle and Woods, 1963; Reed, 1972) and statistical (Bourgoyne and Young, 1974; Tansev, 1975; Fear, 1999) methods for drilling optimisation with alternative methods including drill-off tests and the use of simulators monitoring real time drilling parameters (Bourdon et al., 1989; Koederitz and Weis, 2005; Frenzel, 2006; Kelessidis and Dalamarinis, 2009). However, these methods are only effective over the interval through which the test was conducted (Koederitz and Weis, 2005).

A fundamental task of drilling engineers is selection, operation and evaluation of drill bits (Azar and Samuel, 2007) to optimize rate of penetration (ROP) because time spent drilling is usually a significant portion of total well cost (Fear, 1999). Each drill bit is designed to function best under particular conditions. At present, there is no exact scientific approach for drill bit selection; evaluation of bit records from nearby wells and mechanical rock properties are typically used to select the best bit for the given material (Azar and Robello Samuel, 2007). ROP responds to changes in drilling approach, for example, changing the weight on bit (WOB) can cause the ROP to increase or decrease, and depends strongly on rock properties that include mineralogy, strength, density, porosity and permeability (Onyia, 1988; Fear, 1999; Yarali and Kahraman, 2011).

Bingham (1964a) believed that the drilling industry was unlikely to accurately predict drilling rates without a means of relating it to rock property measurements. These rock property measurements would assist in improving drilling performance as it would give a basis for addressing the conditions which optimal drilling operates. As a result, many researchers have assessed the drillability of rock from physical rock properties using porosity, density, hardness, textures, and ultrasonic wave velocities, and compared it to the strength of the rock (Gstalder and Raynal, 1966; Howarth and Rowlands, 1987; Spaar et al., 1995; Thuro, 1997; Altindag, 2002; Tanaino, 2005; Hoseinie et al., 2008; Bilim, 2011; Kelessidis, 2011; Yaşar et al., 2011; Yarali and Kahraman, 2011). Some researchers, developed indices from these physical properties to predict rock drillability, which are widely used in drillability analysis (Protodyakonov, 1962; Deere and Miller, 1966; Gstalder and Raynal, 1966; Howarth and Rowlands, 1987; Wijk, 1989; Thuro, 1997; Kahraman et al., 2000; Hoseinie et al., 2008; Saeidi et al., 2013).

Drilling optimisation or studies related to drillability are heavily

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focused on the oil and gas and mining industries and not conventional geothermal fields. The geothermal industry needs an equation to assess ROP and drillability in geothermal reservoirs because existing empirical equations developed in non-hydrothermally altered rocks (Chang et al., 2006; Tamrakar et al., 2007; Rigopoulos et al., 2010; Singh et al., 2012; Karakul and Ulusay, 2013) are only useful as a first order approximation. Existing empirical equations do not consider the secondary mineralisation that exists in hydrothermally altered rocks. The first objective of this research is to compare how three methods estimate rock strength using drilling data over a drill hole interval with semi-constant energy input. The three methods are: specific energy (Teale, 1965), mainly its variation known as mechanical specific energy (MSE), and the work by Bingham (1964b) on the R/N-W/D chart, both developed for drilling in oil and gas fields, and a modified version of Alteration Strength Index – ASI (Wyering et al., 2015), which was developed for hydrothermally altered rocks. The second objective is to assess how well each method predicts drilling performance in hydrothermally altered rocks.

2. Geological setting of the Ngatamariki geothermal field

The Taupo Volcanic Zone (TVZ) is located in the central North Island, New Zealand, in a 300 km long (200 km on land) and 60 km wide belt (Fig. 1), defined by caldera structural boundaries and vent positions (Wilson et al., 1995). The Ngatamariki Geothermal Field is located in the central part of the TVZ approximately 20–25 km north-east of Lake Taupo. Ngatamariki is one of more than 23 high-temperature geothermal systems located in TVZ, of which more than 14 systems are designated for commercial geothermal development by the associated regional regulatory authority. Mercury Limited commissioned an 82 MW ORMAT binary plant power station at Ngatamariki that went into operation in mid-2013 (Boseley et al., 2010).

The thickest formation in the Ngatamariki Geothermal Field is the Tahorakuri Formation (Fig. 2). The Tahorakuri Formation is a thick sequence of silicic primary volcanic and secondary volcaniclastic rocks overlain by interlayered sediment and tuffs. It is difficult to distinguish primary rock textures due to the intense hydrothermal alteration. However, the upper part of this formation's silicic sequence is characterised by crystal-rich welded ignimbrites, while the interlayered sequence of sediments and tuffs consist of crystal-poor tuff and poorly sorted, medium to coarse grained sandstone and carbonaceous mudstone. Rhyolitic lavas appear within the sedimentary sequence of the Tahorakuri Formation, which represents effusive volcanism during the Tahorakuri period of sedimentation. The Tahorakuri Formation overlays igneous intrusives and basement sedimentary rock, and is overlain by extrusive volcanics and surficial deposits (Rae et al., 2009; Chambefort and Bignall, 2011; Lewis et al., 2012; Wallis et al., 2012; Lewis et al., 2013a; 2013b; Chambefort et al., 2014).

3. Drilling data used in this study

The 800 m long 17 inch (432 mm) diameter section of well NM8 located in the Tahorakuri Formation from 1207 to 2002 m Total Vertical Depth (TVD) was used for our study because the drilling parameters in this section of the well were held near constant, with only small fluctuations. Two drill bits were used through this section of well (switched at 1479 m TVD). The first bit was pulled due to the total hours on bit and the second bit was pulled due to total depth achieved. The first bit was used previously, and was recorded to be in the same condition after use as when it had been tripped into the well. The

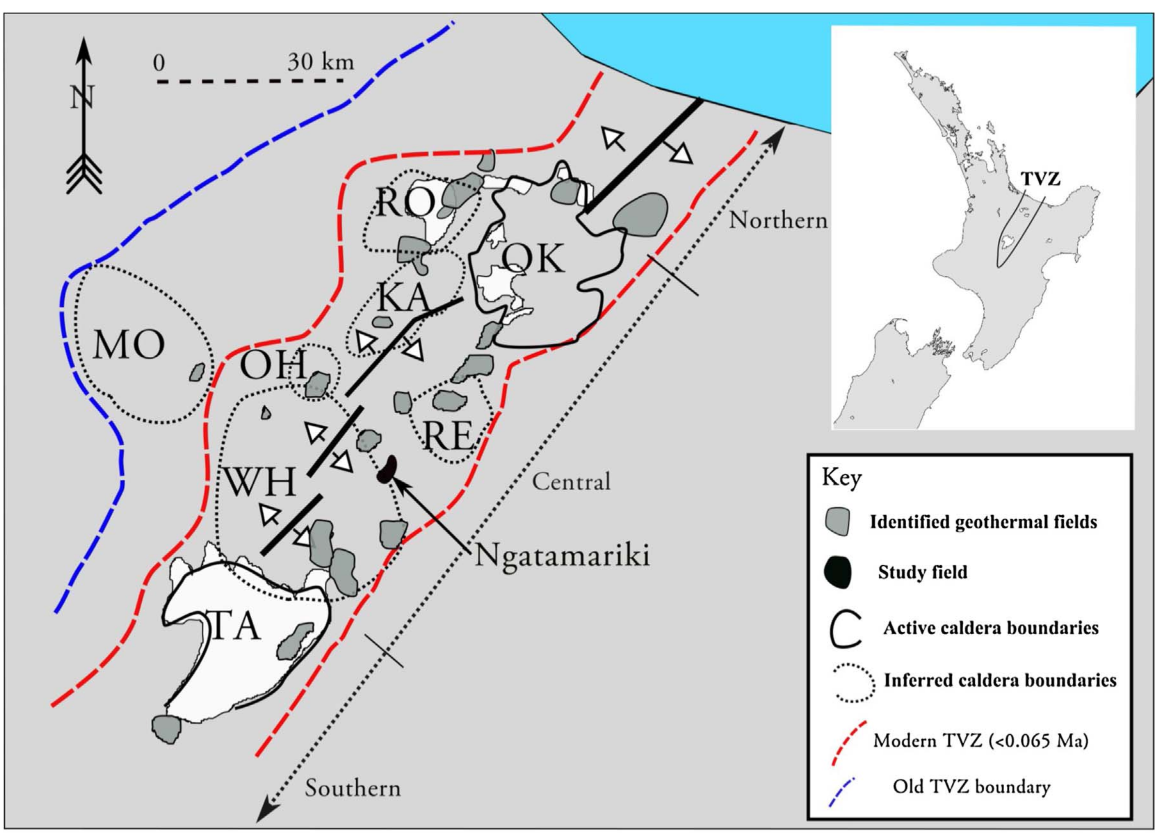

Fig. 1. Map of the geologic setting of geothermal activity in the Taupo Volcanic Zone (TVZ), showing the positions of geothermal systems, the active and inferred caldera boundaries and the Taupo Rift (white lines with arrows pointing in rift direction). The names represent the geothermal fields that are addressed in this study. Abbreviations are named calderas: KA = Kapenga, MO = Mangakino, OH = Ohakuri, OK = Okataina, RE = Reporoa, RO = Rotorua, TA = Taupo, WH = Whakamaru. The map is split up into the main volcanic activity in the TVZ and outlined by the boundary of the young TVZ (< 0.34 Ma) (Adapted from Wilson et al., 1995; Bibby et al., 1995; Rowland and Sibson, 2004; Kissling and Weir, 2005; Rowland and Simmons, 2012).