Characterising Fracture Networks in Granites an example from the United Downs Geothermal Project

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Decarbonising Energy

With the UK targeting NetZero by 2050 there has been renewed efforts to decarbonise heat and energy production. One such project is the United Downs Deep Geothermal Power Project which aims to build the UK's first Geothermal Power Plant at the United Downs Industrial Site in Cornwall.

The Geothermal potential of granites in Cornwall has long been known with exploration taking place during the 1980's and 1990's as part of Hot Dry Rock Project (HDR). At United Downs two deep wells have been drilled into the Porthtowan Fault zone, a regional scale NW-NNW strike strike-slip fault:

ground level

- 2000m

- 3000m

4000m

MD 2,393 r

TVD 2,214 m

- A production well with a depth of 5725 m (md)
- An injection well with a depth of 2392 m (md)

Fracture characterisation

Successful development of the site at United Downs requires a good understanding of the fault and fracture networks within the Porthtowan Fault zone. Porosity and permeability are highly variable around fault zones and can be difficult to determine.

The first stage in planning an operation is to identify features which may be optimally orientated for flow. There was no core collected at the site, however there was an extensive suite of wireline logs collected for the Production well over a depth of 4 km. This included:

- Acoustic and resistivity borehole imaging
- Spectral Gamma Ray and Neutron Density
- P and S wave transit time

The acoustic borehole imaging is particularly valuable for fracture characterisation as they can distinguish between fractures which are associated with damage to the borehole wall and those which are not.



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Analysis of the borehole imaging from the production well identified 11953 features of which 8600 were associated with some damage to the borehole wall. Initial analysis showed a much greater variability in fracture data than had been seen at the HDR project.



In total the fracture data can be subdivided into five fracture sets



Viewing Unfiltered Data

Fracture Set	1m	1w	2m	2w	3m	3w	4m	4w	5m	5w
Dip	81.9	78.6	81	76.6	87.8	84.5	85.38	81.98	83.27	81.94
Dip Direction	82.9	83.7	16.3	15.3	51.7	51.8	120.5	120.9	338.5	338.1

Burj Khalifa, Dubai, 830m

Shard, London, 310m

Dolcoath Mine (Deepest in Cornwall) Injection Well 2,214 m Production Wel





Identifying possible flow zones

Slip and Dilation Tendency analysis show that in the current stress regime fracture sets 1 and 2 are optimally orientated for reactivation and Fracture set 3 is optimally orientated for dilation.

To investigate flow characteristics the borehole was split into zones where fracture set 3 was particularly well developed. Within these zones possible flowing features can be identified from the wireline logs including neutron porosity, resistivity and S wave velocity.



Analysis of 31 features within the zones showed that there is no clear trend in the properties of these features. However analysis of areas above and below these features showed changes in the average wireline log response. This has allowed the independent identification of potential flowing features. Which is in good agreement with the fracture analysis.



Within complex faulting environments in the absence of core it can be difficult to identify key features and zones which may contribute towards permeability.

By analysing fracture data and comparing against wireline it is possible to identify potential zones even with a significant degree of structural complexity.

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Fracture sets: a comparison of outputs from United Downs and Hot Dry Rock Project



Viewing Unfiltered Data

United Downs 1

Symbol Scatter • 1 - 4 Pole Vectors • 5 - 6 Pole Vectors • 9 - 12 Pole Vectors • 13 - 16 Pole Vectors • 17 - 20 Pole Vectors • 21 - 24 Pole Vectors • 21 - 24 Pole Vectors • 25 - 28 Pole Vectors • 29 - 32 Pole Vectors • 0.00 - 0.10 0.10 - 0.20 0.30 0.20 - 0.30 0.40 0.40 - 0.50 0.60 0.60 - 0.70 0.60 0.60 - 0.70 0.60 0.60 - 1.00 1.10 1.10 - 1.120 1.20 1.20 - 1.30 1.40 1.40 - 1.50 1.50 1.50 - 1.60 1.60 1.50 - 1.60 1.60 1.50 - 1.60 1.80 1.90 × 2.00 2.00 Contour Data Pole Vectors							
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Hot Dry Rock Project







Symbol	Scatte	r				
0	1 Pole \	/ectors				
•	2 Pole Vectors					
•	3 Pole Vectors					
•	4 Pole \	/ectors				
	5 Pole \	/ectors				
Color		Dens	ity Co	once	ntrations	
		0	00		1.30	
		1	30	-	2.60	
		2	60	-	3.90	
		3	90	_	5.20	
		5	20	_	6.50	
		о а	50	_	7.80	
		7	80	_	9.10	
		q	10	_	10.40	
		10	40	_	11 70	
		11	.70	-	13.00	
		Contour Data	Pole	Ved	tors	
	Ma	ximum Density	12.5	3%		
	Cont	our Distribution	Fish	er		
	Counting Circle Size			6		
		-				
Plot Mode			Pole Vectors			
Vector Count (Weighted)			621 (349 Entries)			
Terzaghi Weighting			Minimum Bias Angle 15°			
Hemisphere			Lower			
		Projection	Equ	alAn	gle	



Orientation of Horizontal stresses

Larger variation in breakout orientation with depth and plunge of borehole Main cluster for SHmax is towards 140 degrees



Viewing Filtered Data: Stress Field (TYPE == Breakout || TYPE == Inducedfracture)

Symbol	ТҮРЕ	Quantity
¢	Breakout	75
×	Induced fracture	2
Color	Density Concentration	IS
	0.00 - 1.30	
	1.30 - 2.60	
	2.60 - 3.90	
	3.90 - 5.20	
	5.20 - 6.50	
	6.50 - 7.80	
	7.80 - 9.10	
	9.10 - 10.40	
	10.40 - 11.70	
	11.70 - 13.00	
	13.00 - 14.30	
	14.30 - 15.60	
	15.60 - 16.90	
	16.90 - 18.20	
	18.20 - 19.50	
	19.50 - 20.80	
	20.80 - 22.10	
	22.10 - 23.40	
	23.40 - 24.70	
	24.70 - 26.00	
	Contour Data Pole Vectors	
	Maximum Density 25.78%	
	Contour Distribution Fisher	
	Counting Circle Size 5.0%	
	Plot Mode Pole Vectors	
Ve	ector Count (Weighted) 113 (77 Entries)	
	Terzaghi Weighting Minimum Bias Ang	le 15°
	Hemisphere Lower	
	Projection Equal Angle	
	Too many entries for grid intersections	





Viewing Filtered Data: Stress Field (TYPE == Breakout || TYPE == Inducedfracture)

HDR was SHmax 150 degrees







Symbol	Distance			Quantity		
<u>ہ</u>	2210.07	-	2498.92	1		
×	2498.92	-	2787.77	1		
Δ	2787.77	-	3076.62	0		
+	3076.62	-	3365.47	3		
▽	3365.47	-	3654.32	0		
	3654.32	-	3943.17	17		
⊲	3943.17	-	4232.02	19		
0	4232.02	-	4520.87	22		
⊳	4520.87	-	4809.72	7		
ж	4809.72	-	5098.57	7		
		P	lot Mode	Pole Vectors		
	Vector Coun	t (W	/eighted)	113 (77 Entries)		
	Terzag	hi V	Minimum Bias Angle 15°			
	I	Hen	Lower			
		Р	Equal Angle			
	Too many entries for grid intersections					



Slip Tendency and Dilation Tendency for United Downs 1



Viewing Unfiltered Data





Viewing Unfiltered Data





Fracture Sets

5 fracture sets in total FS3 optimal for dilation FS1 and FS2 optimal for reactivation





3w	4m	4w	5m	5w
84.5	85.38	81.98	83.27	81.94
51.8	120.5	120.9	338.5	338.1

DT	
0.	01
0.	11
0.	20
0.	30
0.	40
0.	50
0.	60
0.	70
0.	80
0.	90
	U.

	Ma
8	
	Conto
0	
	Coun
	10010510
<u>.</u>	
3	N
3	Vector Co
8	Vector Co
	Vector Co Terz





				Quantity		
- 0.11				588		
- 0.20				822		
- 0.30				890		
- 0.40				967		
0.50				11.40		
- 0.50				1149		
- 0.60				1221		
- 0.70				1348		
- 0.80				1431		
- 0.90				1704		
- 1.00				1911		
Der	nsity C	once	entration	s		
	0.00	-	0.10	-		
	0.10	-	0.20			
	0.20	-	0.30			
	0.30	-	0.40			
	0.40	-	0.50			
	0.50	1	0.60			
	0.60	×.	0.70			
	0.70	1	0.80			
	0.80	-	0.90			
	0.90	-	1.00			
	1.00	-	1.10			
	1.10	-	1.20			
	1.20	-	1.30			
	1.30	-	1.40			
	1.40	85	1.50			
	1.50	83	1.60			
	1.00	10	1.70			
	1.70	1	1.00			
	1.00	1	2.00			
Contour Data	Pol	e Vec	tors			
ximum Density	1.9	0%				
our Distribution	Fis	her				
ting Circle Size	0.5	%				
Plot Mode	Pol	e Vec	tors			
ount (Weighted)	250)92 (1	2031 Ent	ries)		
aghi Weighting	Min	imum	Bias Ang	le 15°		
Hemisphere	Lov	Lower				
Projection	Equ	Equal Angle				
any entries for	orid in	ters	ections			

5