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

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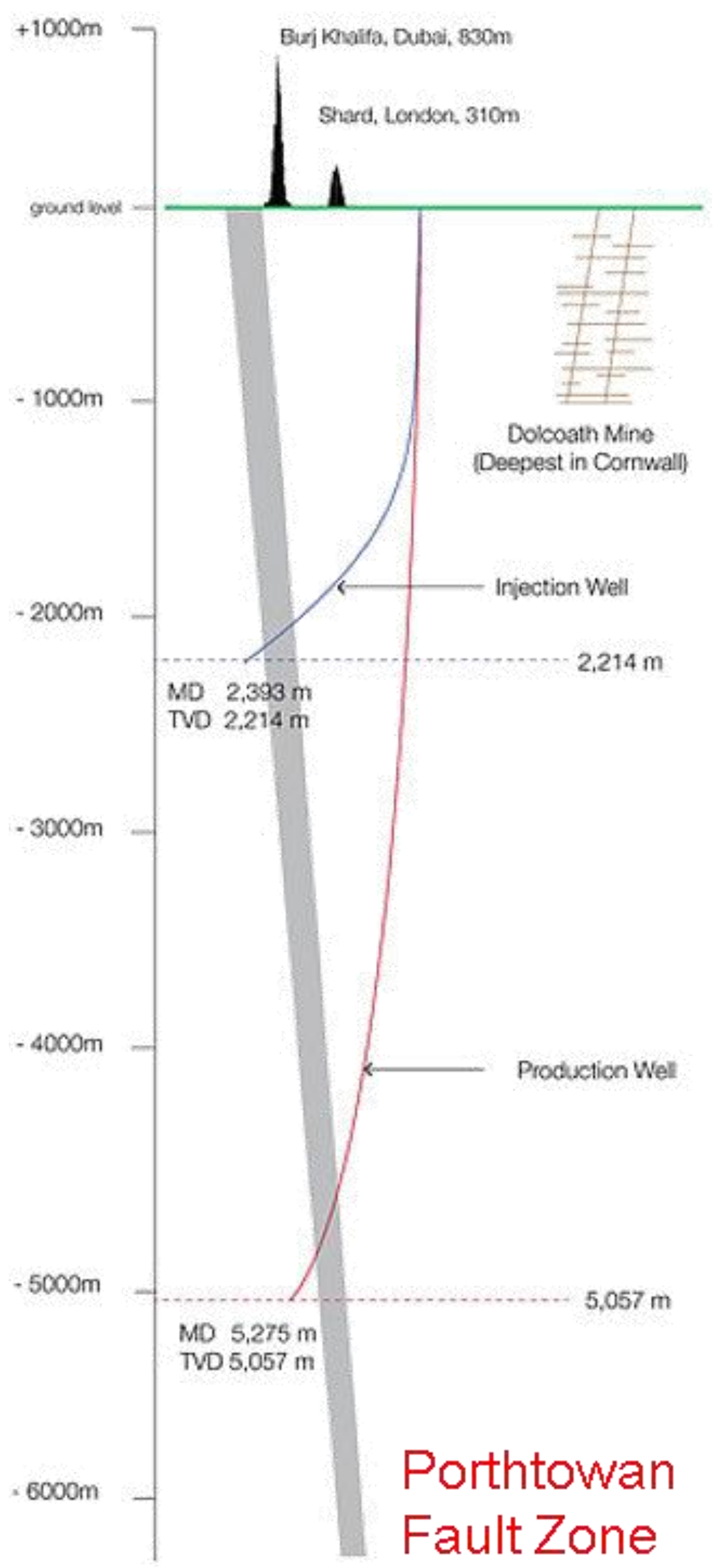
1 British Geological Survey

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:

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



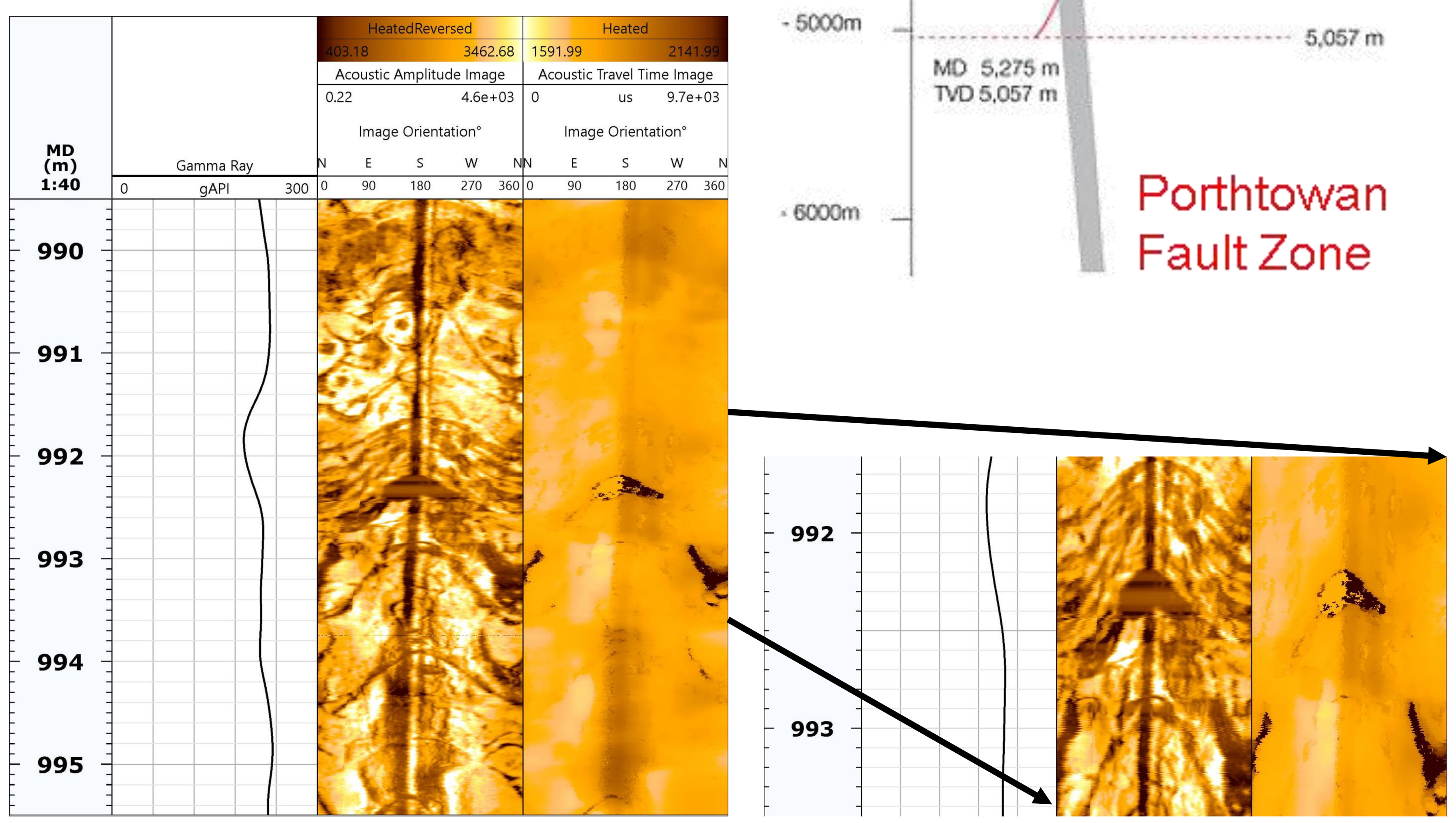
Fracture characterisation

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:

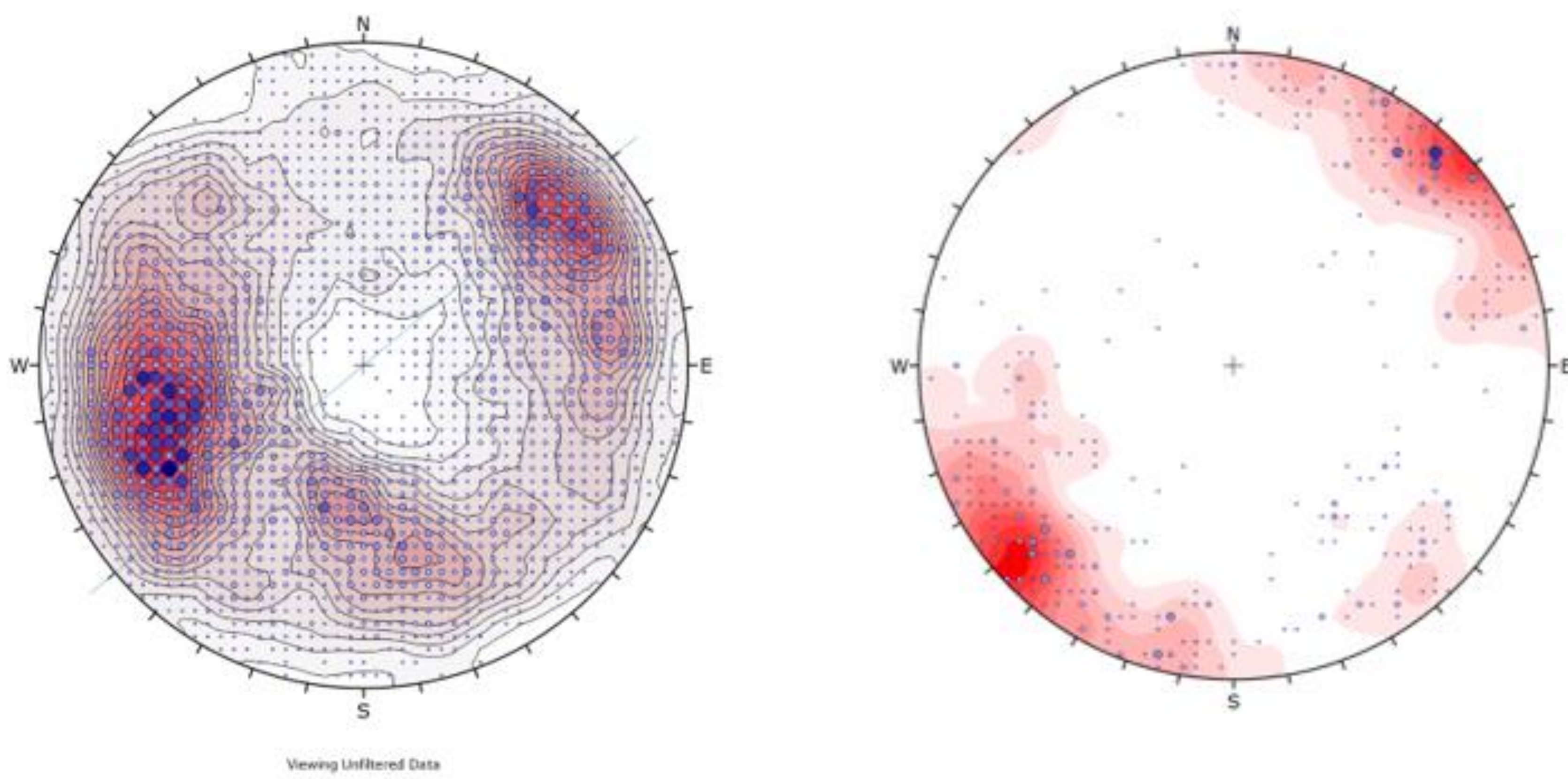
- Acoustic and resistivity borehole imaging
- Spectral Gamma Ray and Neutron – Density
- P and S wave transit time

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.

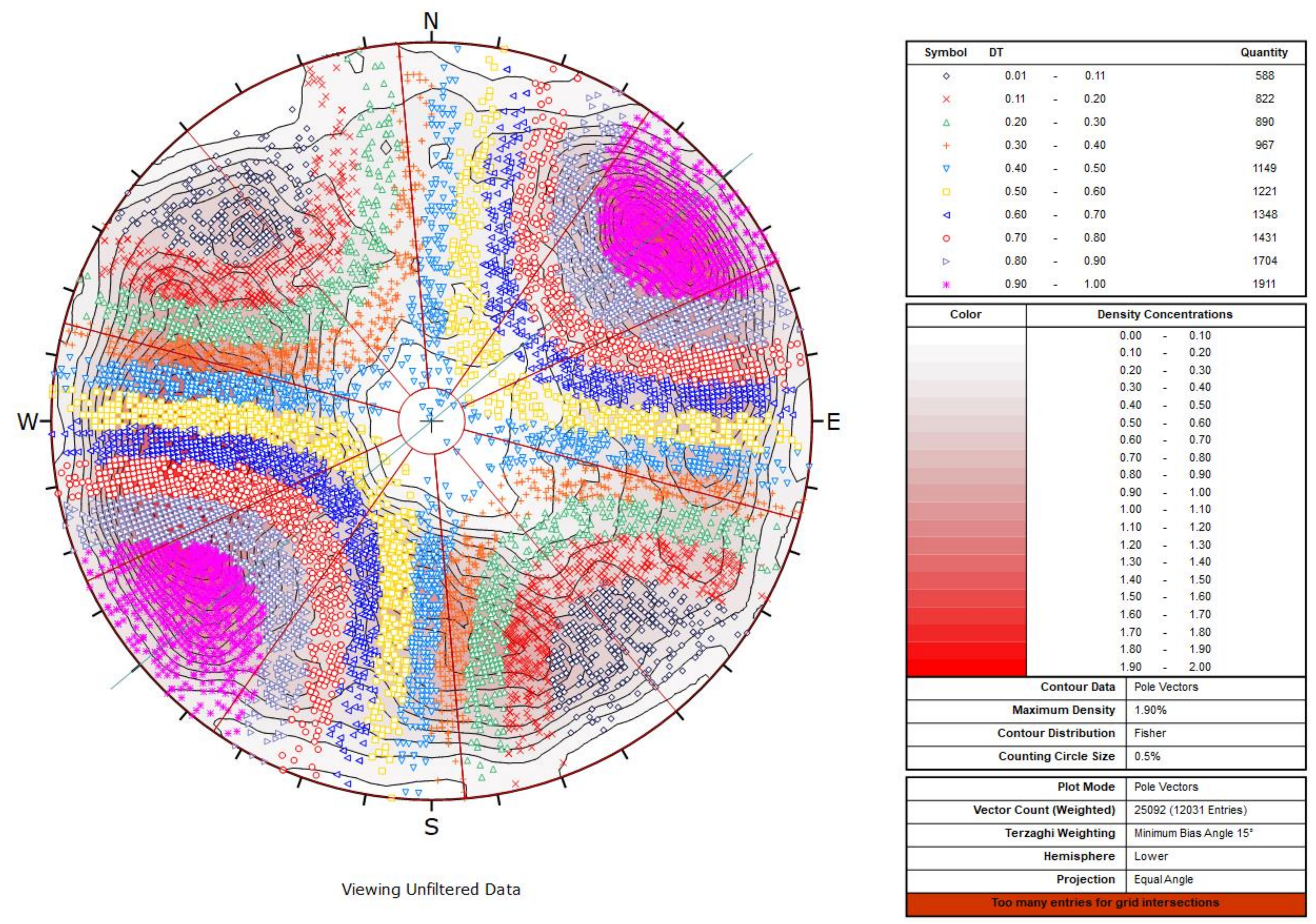


Fracture Network

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

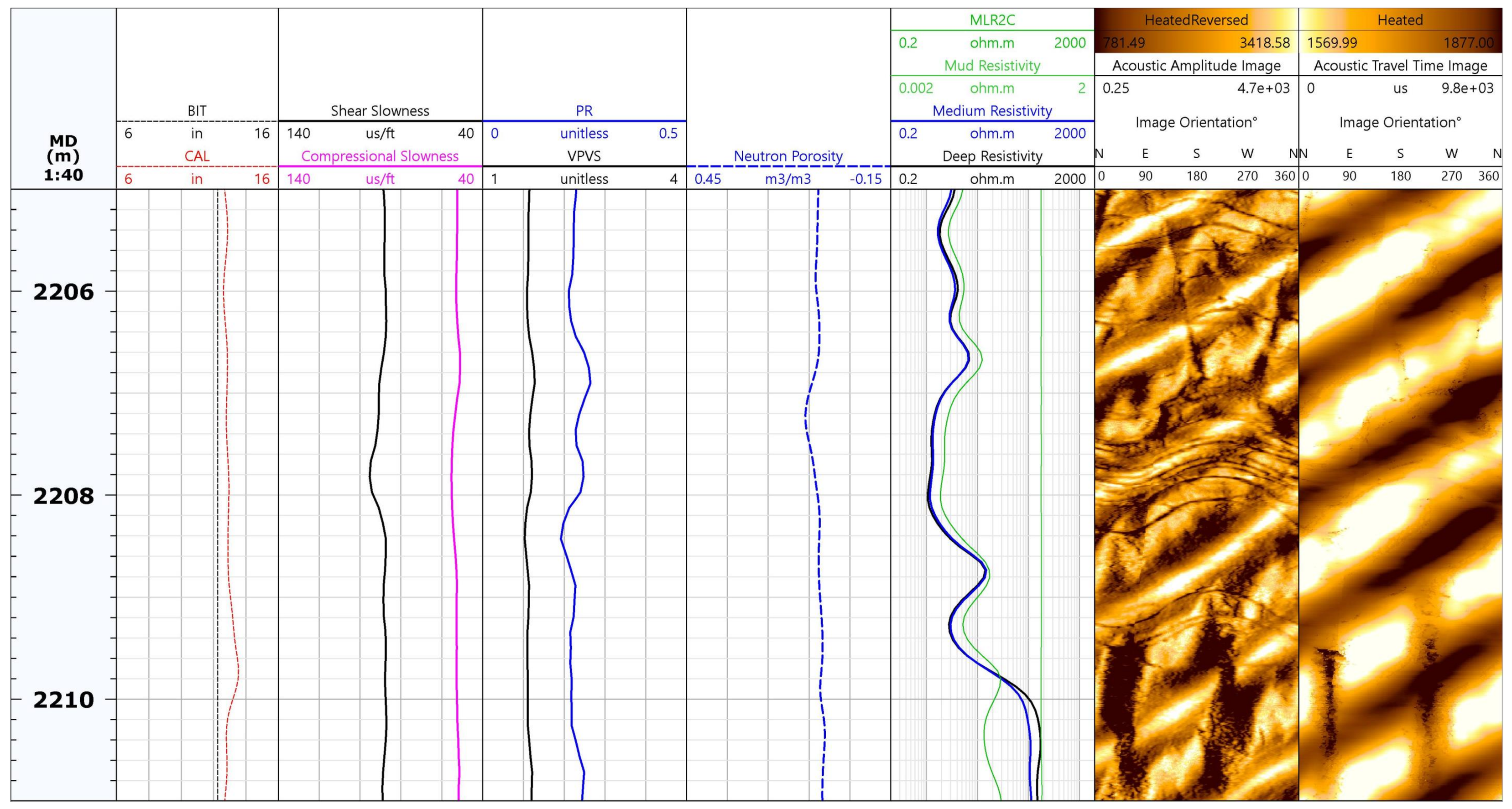


Fracture Set	1m	1w	2m	2w	3m	3w	4m	4w	5m	5w
Dip	81.9	78.6	81	76.6	87.8	84.5	85.38	81.98	83.27	81.94
Dip Direction	82.9	83.7	16.3	15.3	51.7	51.8	120.5	120.9	338.5	338.1

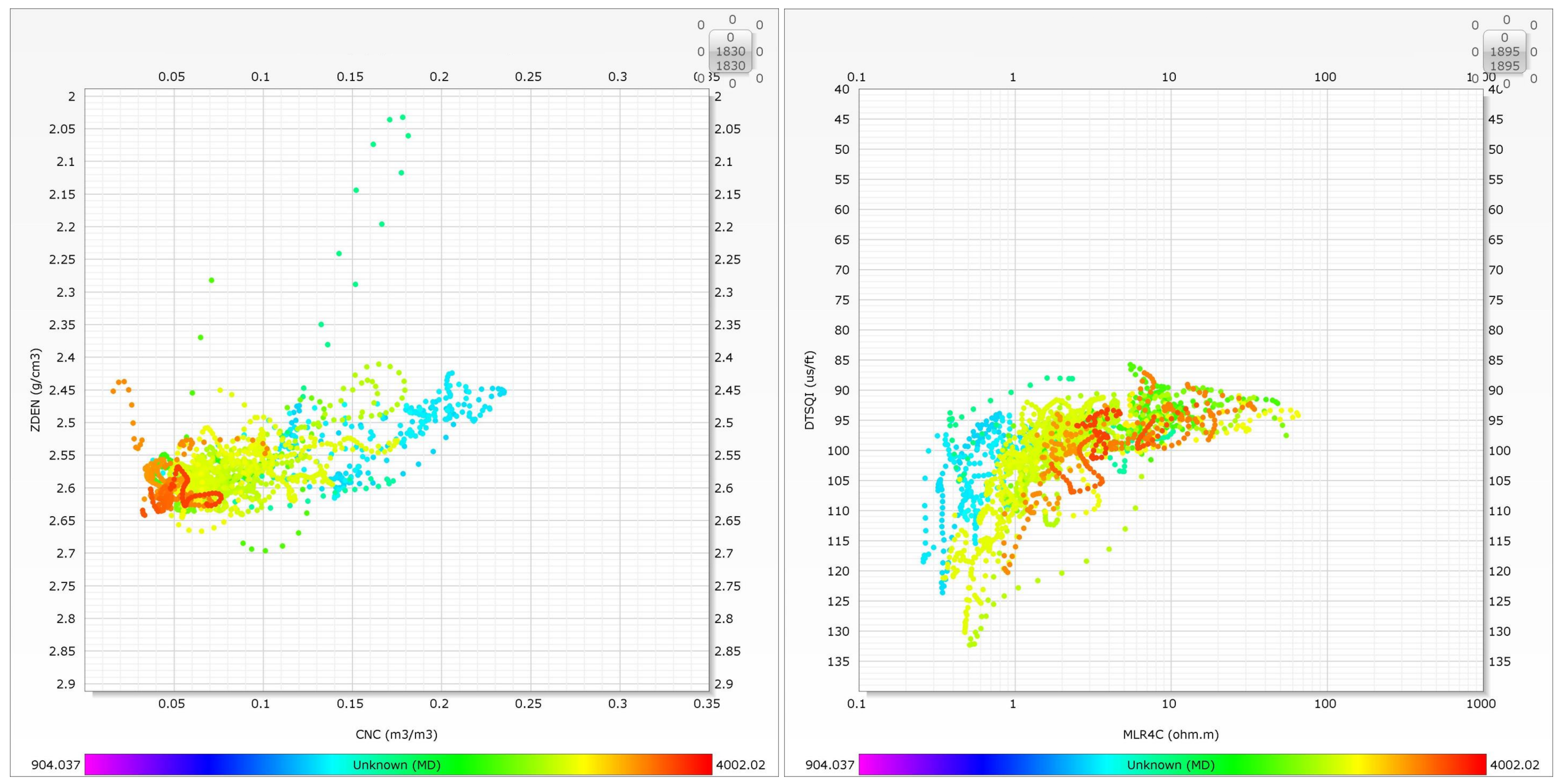
Identifying possible flow zones

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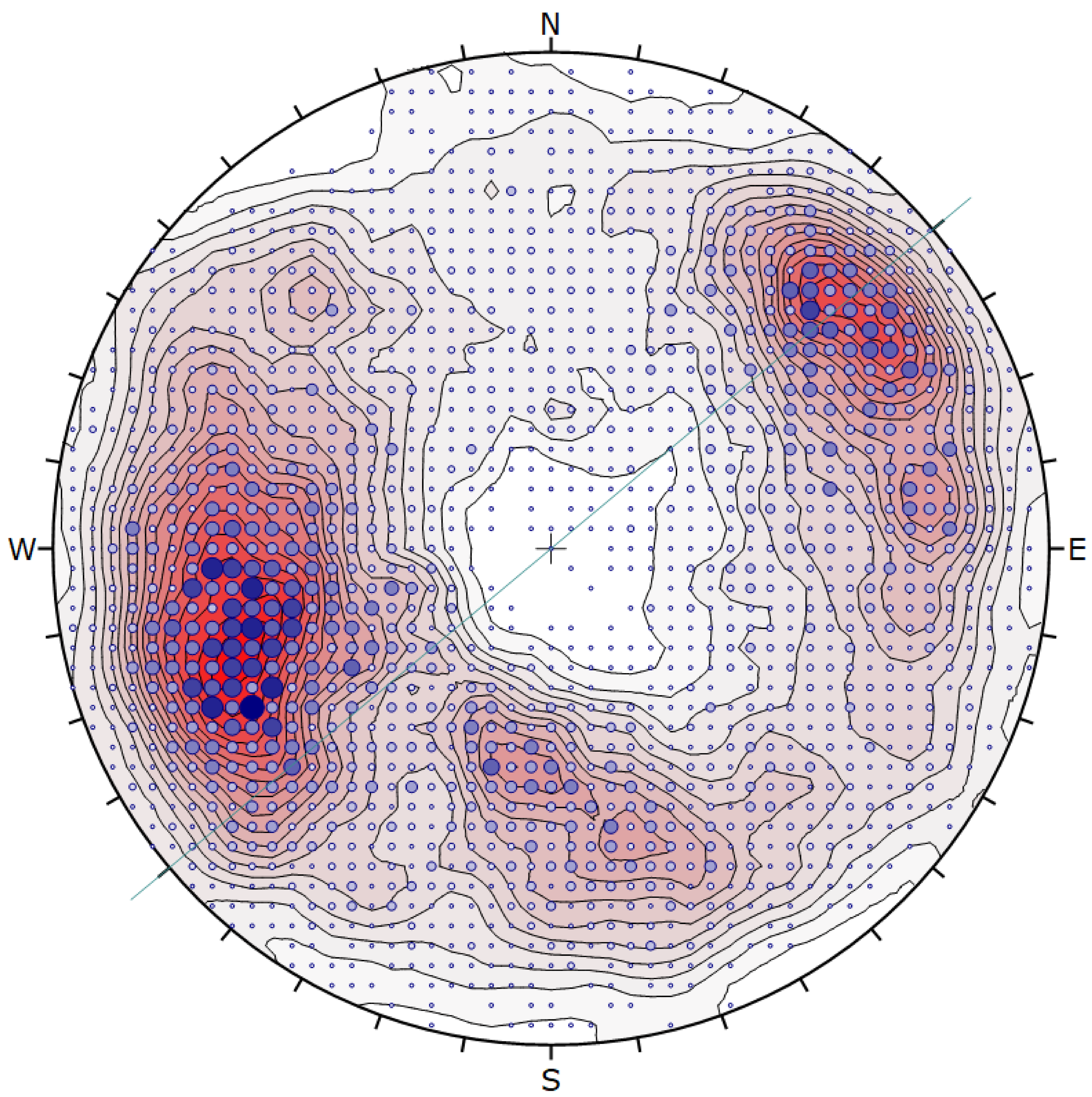
Fracture sets: a comparison of outputs from United Downs and Hot Dry Rock Project

United Downs 1



Viewing Unfiltered Data

Symbol	Scatter
	1 - 4 Pole Vectors
	5 - 8 Pole Vectors
	9 - 12 Pole Vectors
	13 - 16 Pole Vectors
	17 - 20 Pole Vectors
	21 - 24 Pole Vectors
	25 - 28 Pole Vectors
	29 - 32 Pole Vectors

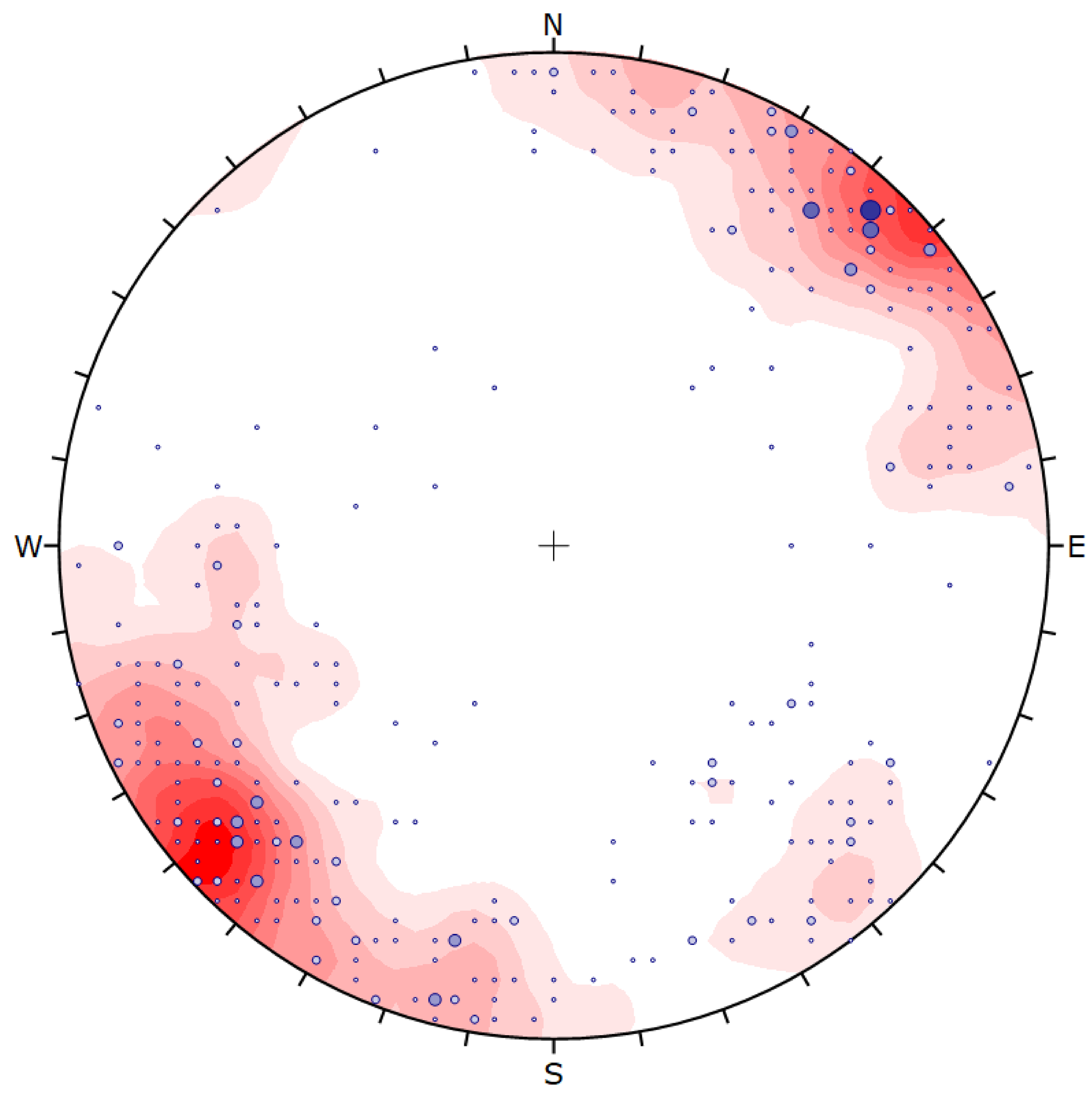
Color	Density Concentrations
	0.00 - 0.10
	0.10 - 0.20
	0.20 - 0.30
	0.30 - 0.40
	0.40 - 0.50
	0.50 - 0.60
	0.60 - 0.70
	0.70 - 0.80
	0.80 - 0.90
	0.90 - 1.00
	1.00 - 1.10
	1.10 - 1.20
	1.20 - 1.30
	1.30 - 1.40
	1.40 - 1.50
	1.50 - 1.60
	1.60 - 1.70
	1.70 - 1.80
	1.80 - 1.90
	1.90 - 2.00

Contour Data	Pole Vectors
Maximum Density	1.90%
Contour Distribution	Fisher
Counting Circle Size	0.5%

Plot Mode	Pole Vectors
Vector Count (Weighted)	25092 (12031 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Angle

Too many entries for grid intersections

Hot Dry Rock Project



Symbol	Scatter
	1 Pole Vectors
	2 Pole Vectors
	3 Pole Vectors
	4 Pole Vectors
	5 Pole Vectors

Color	Density Concentrations
	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

Contour Data	Pole Vectors
Maximum Density	12.53%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count (Weighted)	621 (349 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Angle

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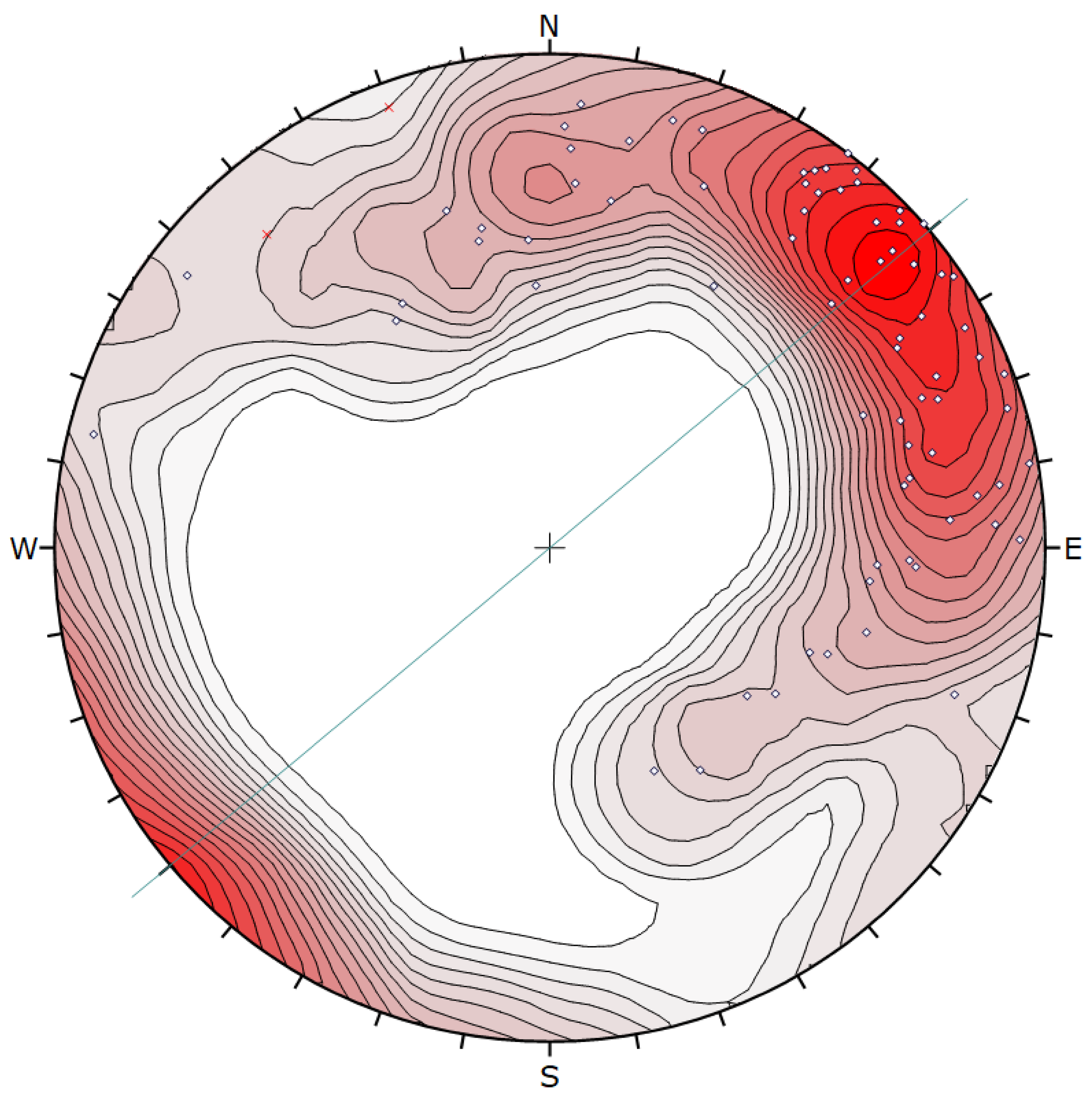
Orientation of Horizontal stresses

Larger variation in breakout orientation with depth and plunge of borehole

Main cluster for SHmax is towards 140 degrees

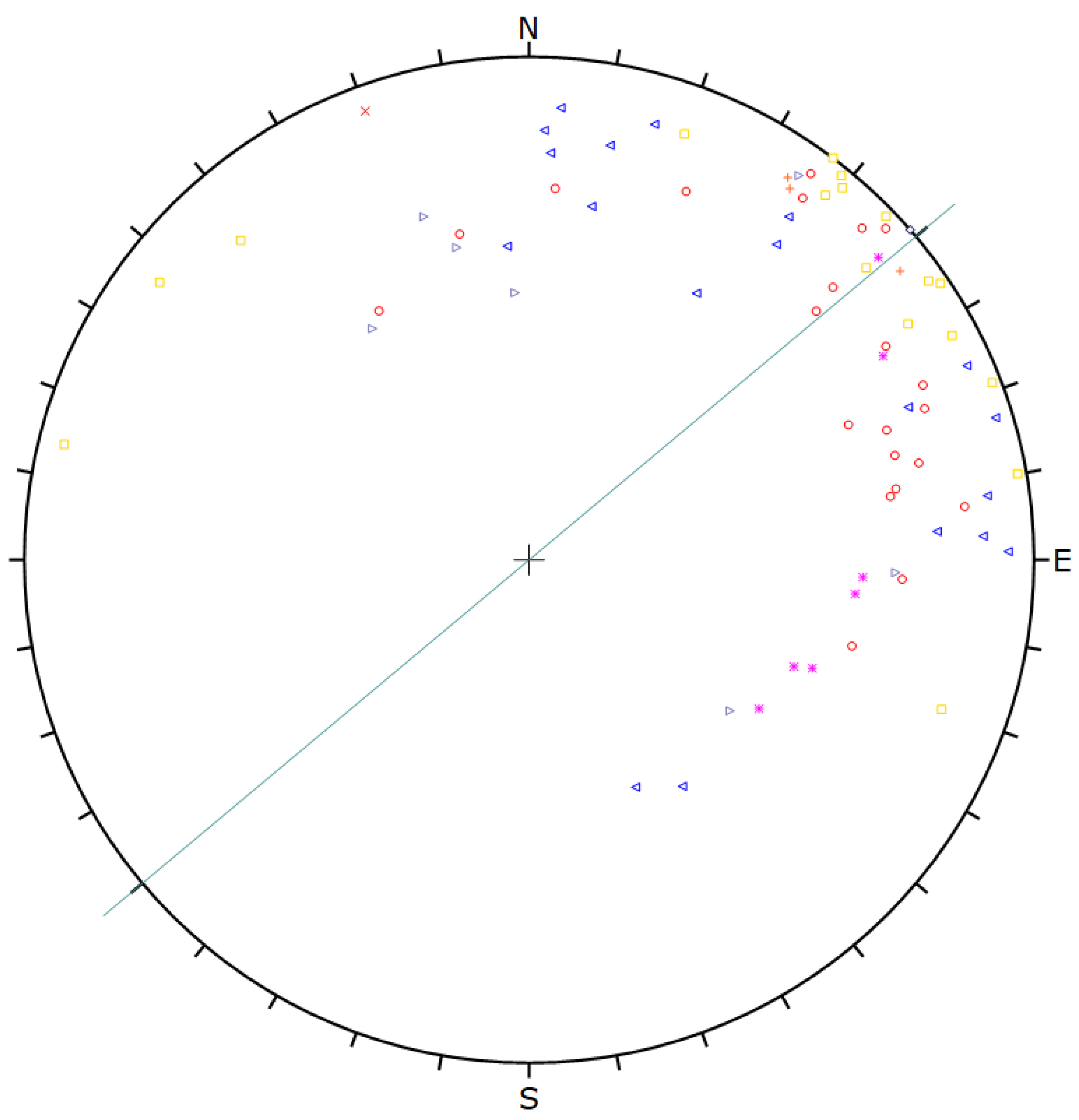


Viewing Filtered Data: Stress Field (TYPE == Breakout || TYPE == Inducedfracture)

Symbol	TYPE	Quantity
◇	Breakout	75
×	Induced fracture	2

Color	Density Concentrations
	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
Vector Count (Weighted)	113 (77 Entries)
Terzaghi Weighting	Minimum Bias Angle 15°
Hemisphere	Lower
Projection	Equal Angle
Too many entries for grid intersections	



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

Symbol	Distance	Quantity
◇	2210.07 - 2498.92	1
×	2498.92 - 2787.77	1
△	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
○	4232.02 - 4520.87	22
▷	4520.87 - 4809.72	7
✳	4809.72 - 5098.57	7

Plot Mode	Pole Vectors
Vector Count (Weighted)	113 (77 Entries)
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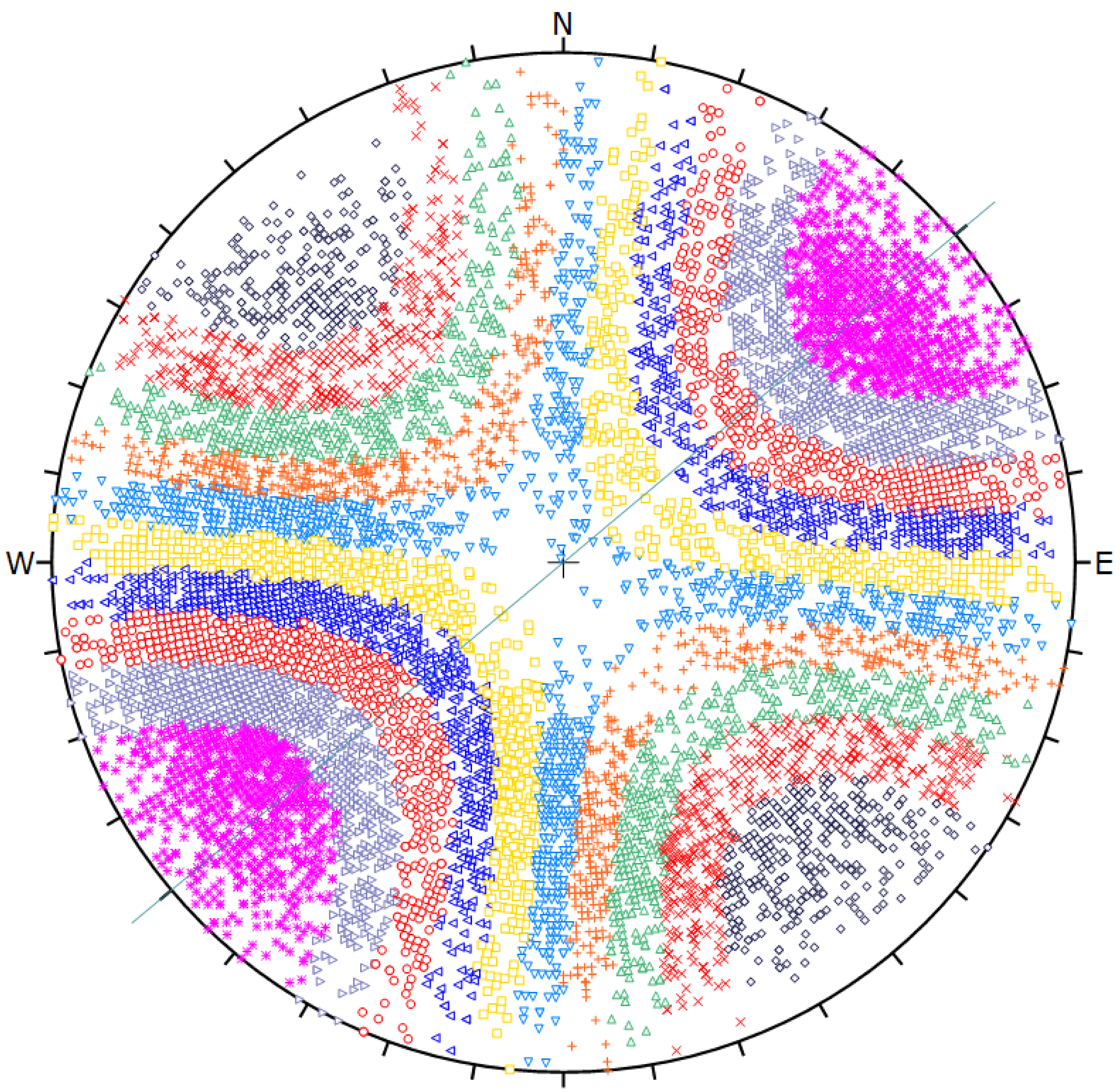
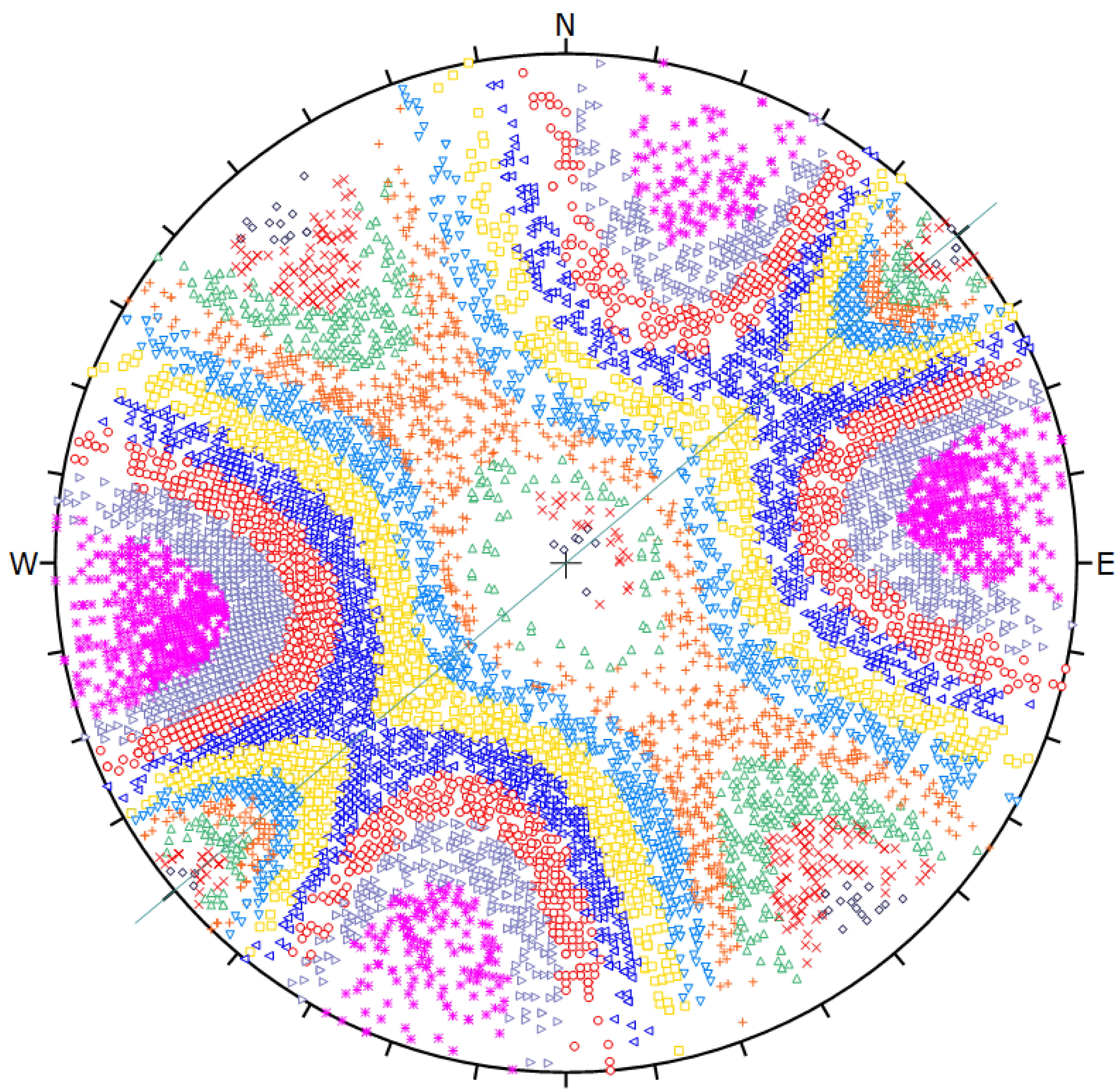
Too many entries for grid intersections	

HDR was SHmax 150 degrees

Slip Tendency and Dilation Tendency for United Downs 1



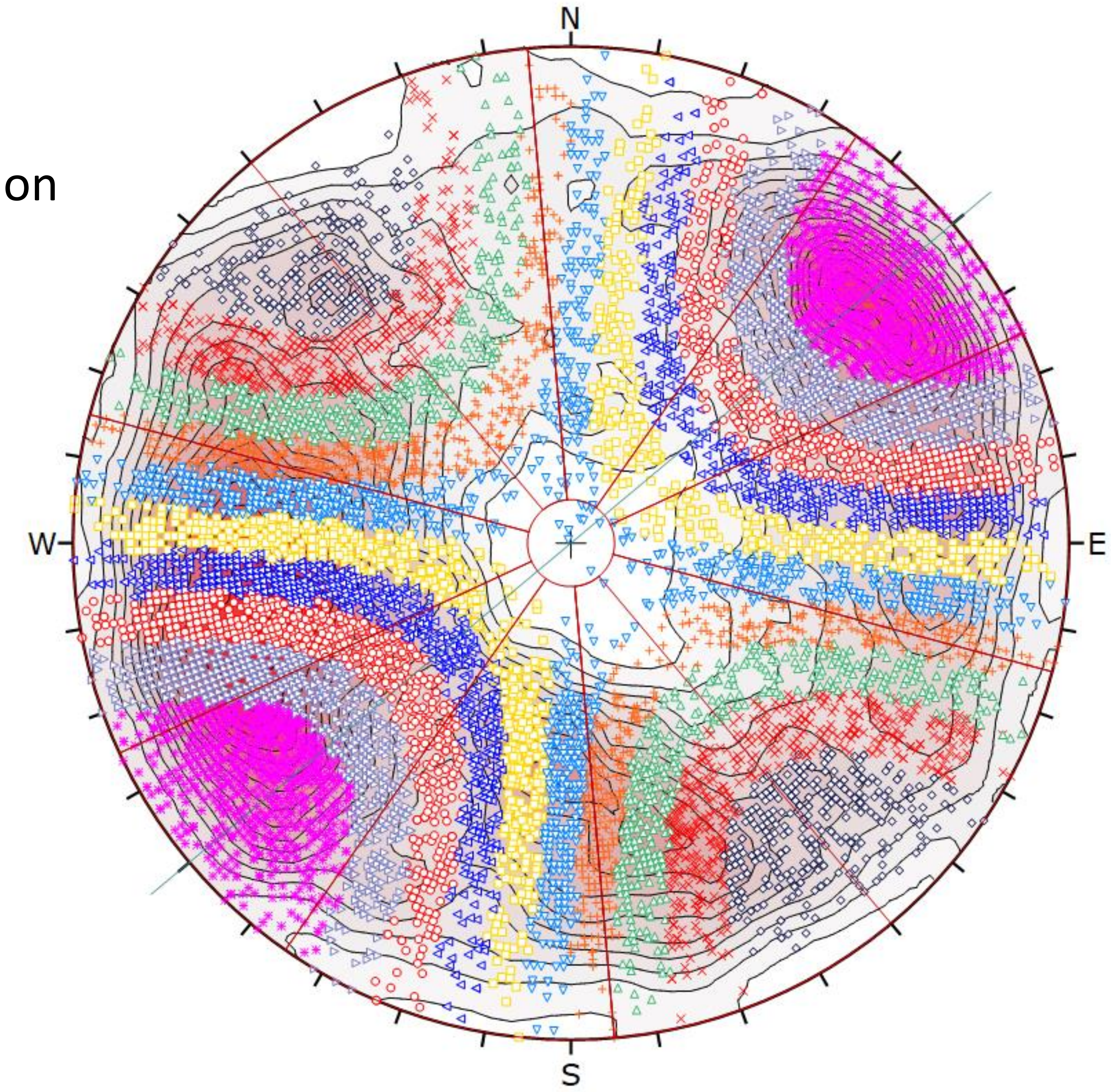
Viewing Unfiltered Data



Viewing Unfiltered Data

Fracture Sets

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



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Symbol	DT			Quantity
◇	0.01	-	0.11	588
×	0.11	-	0.20	822
△	0.20	-	0.30	890
+	0.30	-	0.40	967
▽	0.40	-	0.50	1149
□	0.50	-	0.60	1221
◁	0.60	-	0.70	1348
○	0.70	-	0.80	1431
▷	0.80	-	0.90	1704
*	0.90	-	1.00	1911

Color	Density Concentrations
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	0.20 - 0.30
	0.30 - 0.40
	0.40 - 0.50
	0.50 - 0.60
	0.60 - 0.70
	0.70 - 0.80
	0.80 - 0.90
	0.90 - 1.00
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