OR/17/048 Discussion

From Earthwise
[Jump to navigation](#) [Jump to search](#)

Fellgett, M W, Kingdon, A, Williams, J D O, and Gent, C M A. 2017. State of stress across UK regions. *British Geological Survey Internal Report*, OR/17/048.

Figure 19 shows the distribution of data available to characterise the UK onshore stress field.

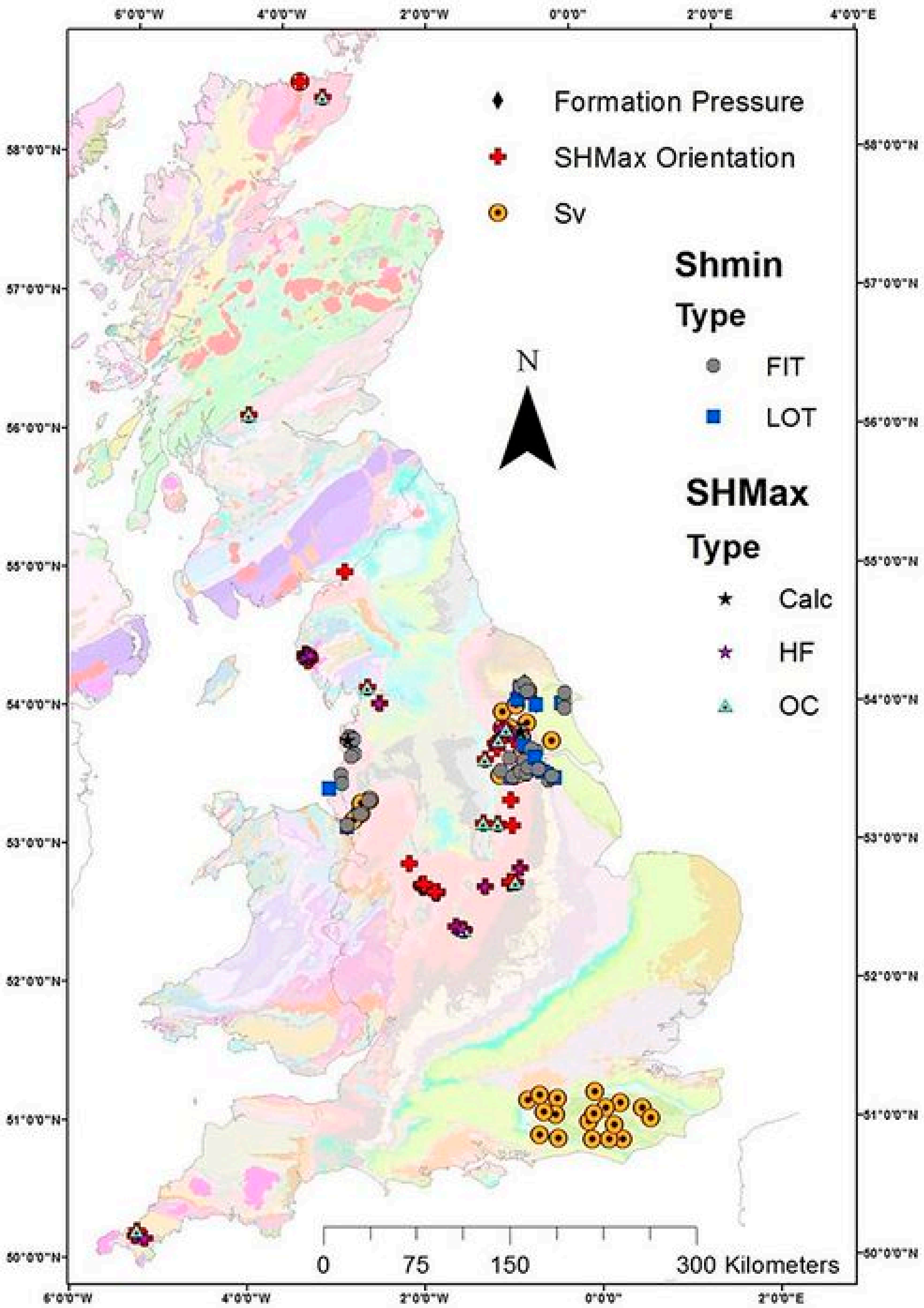

Figure 19 Map showing geographical location of borehole data available to characterise the UK stress field: FIT – Formation Integrity Test, LOT – Leak off test, H – Hydraulic Fracturing, OC – Overcoring and Calc – S_{HMax} calculation from borehole breakouts and DIFs. Contains British Geological Survey materials © NERC 2017.

Across the UK landmass there are similarities in the state of stress between the regions investigated (Figure 10, Figure 17, Figure 20). This is despite the contrasting tectonic settings and separations of 100's of kilometres. Whilst relationships between pore pressure, vertical stress and minimum horizontal stress data are all discussed, due to the scarcity of S_{HMax} data across the UK it is difficult to establish regional relationships. Despite variations in stress magnitude it does appear in almost all cases that $S_{HMax} > S_v$ indicating a strike-slip/reverse faulting environment.

Much of the legacy vertical stress data is from coal industry hydraulic fracturing reports. However these data are often based on an assumed vertical stress gradient of 22–26 $MPakm^{-1}$. There are only a small number of published studies on vertical stress which do support this but they are geographically constrained (Nirex, 1997[1]; Williams et al., 2016[2]). The vertical stress profiles from the density log inversion calculations illustrate that the vertical stress gradient ranges from 23–26 $MPakm^{-1}$ (Figure 20), supporting the assumptions made by the Coal Authority. There is a three $MPakm^{-1}$ difference in vertical stress gradients between North West England and Scotland when compared with Yorkshire and the Weald.

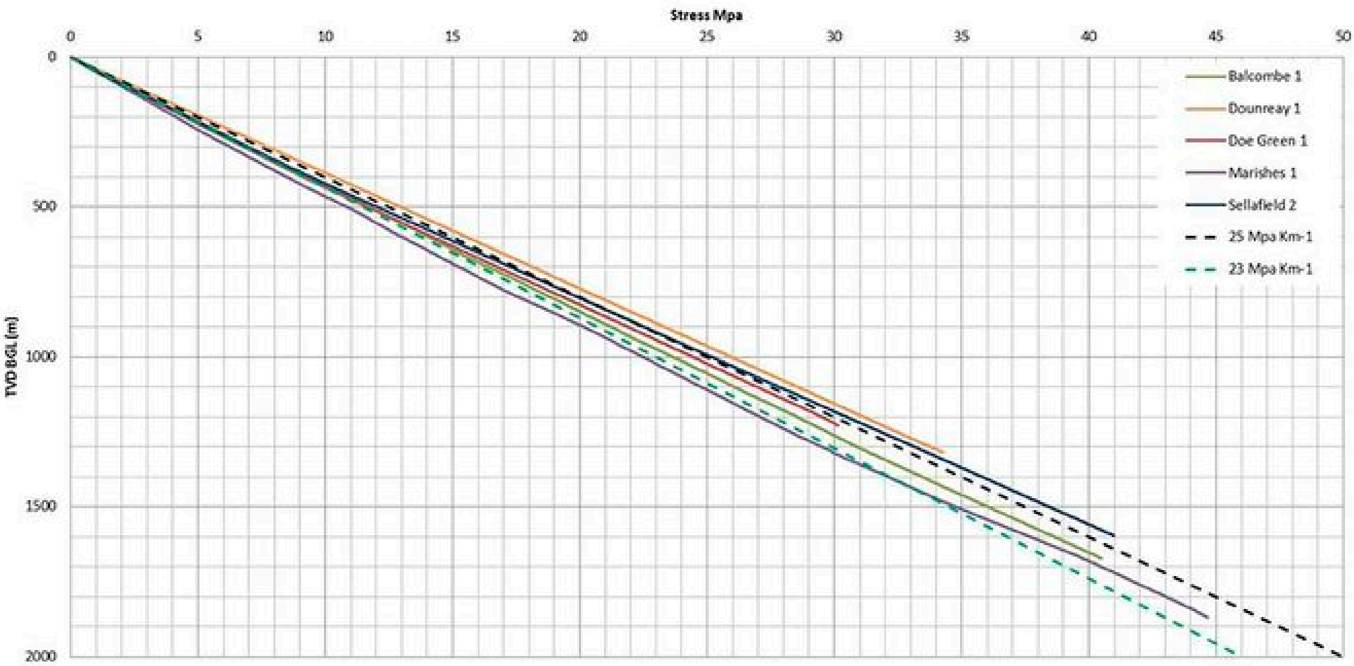

Figure 20 Vertical stress gradients for a variety of UK Regions. Dashed lines representing gradients of 23 and 25 $MPakm^{-1}$ are included for reference. Balcombe 1 is a well from the Weald, Marishes 1 is from North Yorkshire, Doe Green 1 is from Lancashire, Sellafield 2 was drilled in Cumbria and Dounreay 1 was drilled on the North Coast of Scotland.

The pore pressure data shows no indication of over or under-pressure conditions. As both over and under pressure can affect vertical stress this data is supported by the vertical stress profiles. For this study some 227 wells were inspected for RFT data, but pressure data were only available for 10 wells (Figure 21). The available data reveal that for a small number of sites pore pressure is consistent with a gradient of 10.19 $MPakm^{-1}$.

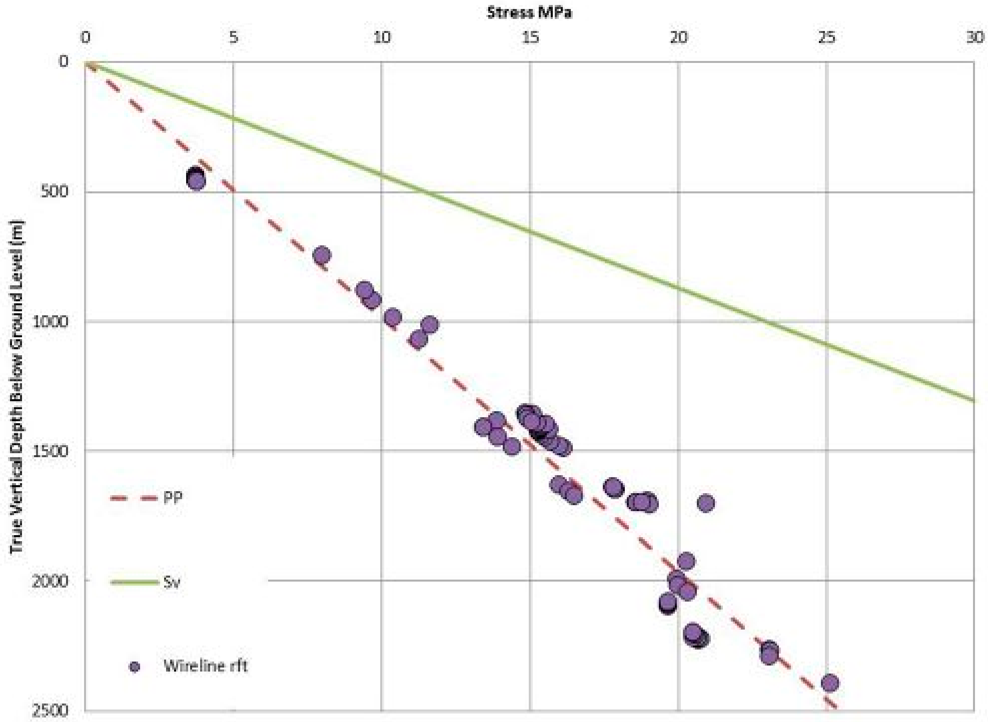

Figure 21 Diagram showing the available pressure data from Cheshire, Lancashire, East Yorkshire and North Nottinghamshire. PP corresponds to a gradient of 10.19 $MPakm^{-1}$. This data supports the assumption of hydrostatic pore pressure in these regions.

The majority of the pore pressure data are hydrostatic and plot slightly above the 10 $MPakm^{-1}$ line. Three measurements from Marishes 1 plot around 5 MPa above the hydrostatic line. After checking the log scans these measurements were collected in a Namurian Sandstone–Claystone formation. These tests were not marked as supercharged but there were a number of tool failures in this area and this may be an effect of low permeability strata. Due to the small number of occurrences it is not possible to state that there is evidence of overpressure but more data is needed to investigate this.

Despite the consistency of the pore pressure measurements there are variations in the vertical stress profiles across the UK (Figure 20). The greatest variations are between Scotland (Dounreay 1) and North Yorkshire (Marishes 1), but there also downhole variations in vertical stress which may be a result of the stratigraphy.

A compilation of FIT and LOT data from the wells included in this study are shown in Figure 22.

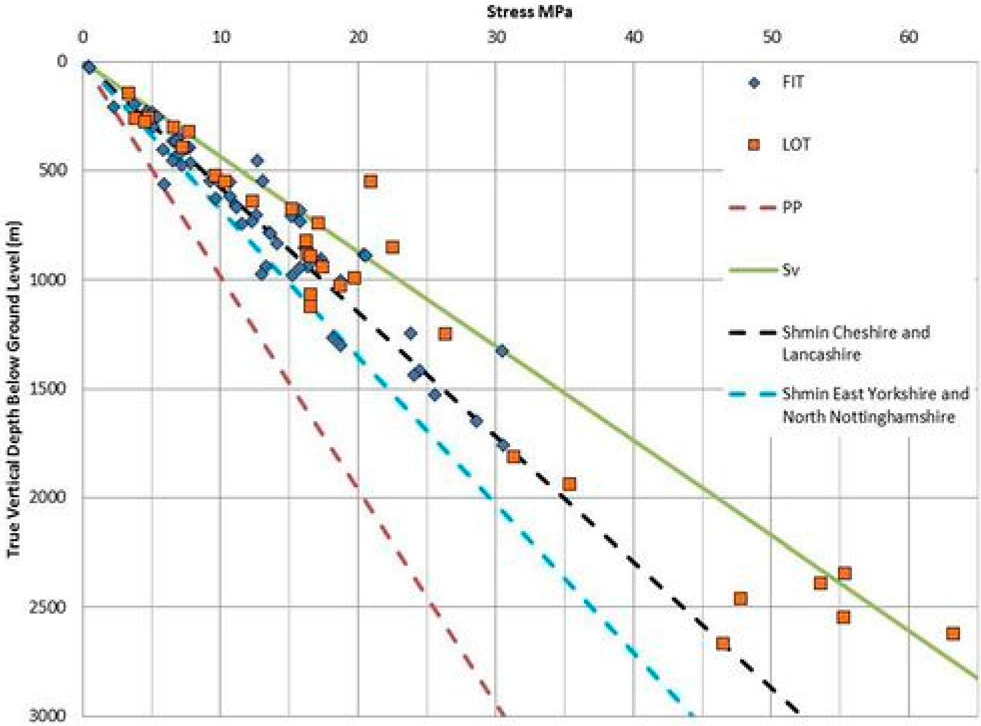

Figure 22 Compilation of FIT and LOT data and estimates of S_{hmin} from: Cheshire, Lancashire, East Yorkshire and North Nottinghamshire, S_v is 23 $MPakm^{-1}$ after Figure 20. Figure 21 demonstrated that the pressure data for the region corresponded to hydrostatic pressure; PP represents a gradient of 10.19 $MPakm^{-1}$. At depths of < 1000 m there are 12 FIT/LOT measurements which plot at or above the vertical stress line. This indicates that Shmin ≈ S_v but more work is needed to confirm this. Regional Shmin gradients plotted using the lower bound of the LOT's after Addis et al (1998).

The general trend on the data suggests that $S_{hmin} < S_v$, however a number of the tests above 1000 m plot at or above the 23 $MPakm^{-1}$ line (Figure 22). Two FIT test plot on the hydrostatic pressure line. These anomalies may be the result of tool failure such as bleeding off.

Estimates of S_{hmin} have been derived for each of the regions from the Leak-off test data after Addis et al (1998)[3]. There are no XLOT's to validate these measurements and there is a considerable spread in the LOT data (Figure 22). This data does appear to support the trend shown in Figure 20 with the Shmin estimate for Cheshire and Lancashire greater than East Yorkshire and North Nottinghamshire.

Out of the 91 FIT/LOT data points compiled in this study only 11 exceed the estimate S_v (23 $MPakm^{-1}$), this is data strongly supports a strike slip faulting environment. Twelve of the 14 measurements that plot above the 23 $MPakm^{-1}$ line, were collected at depths of <1000 m (Figure 23) which may indicate more variability in the stress field at these depths. Ten of the 14 measurements were collected in Permo–Triassic strata and in particular the Mercia Mudstone and the Zechstein Groups. These are highly heterogeneous formations with muds, sand, silts and variable thicknesses of evaporites. This heterogeneity may also be a factor in the increased variability of S_{hmin}.

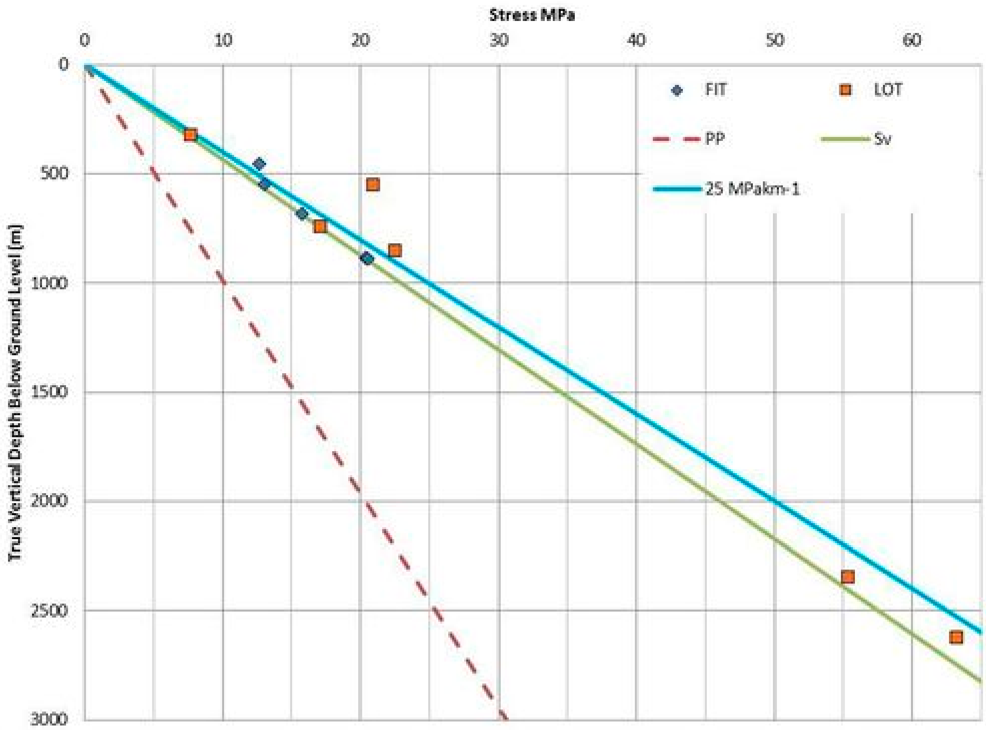

Figure 23 Compilation of all FIT, LOT and RFT data Which exceeds Sv shown by the green line which corresponds to a gradient of 23 $MPakm^{-1}$. Figure 21 demonstrated that the RFT data for the region corresponded to hydrostatic pressure and has not been plotted. PP represents a gradient of 10.19 $MPakm^{-1}$. Nine of the eleven measurements were collected at depths of <1000 m suggesting either changes in the stress field at this point of less heterogeneity in the strata.

With a single exception (Melbourne 1), all of the S_{HMax} magnitude data across the UK were compiled from legacy data (Pine et al., 1983[4]; Cooling et al 1988[5]; Bigby et al., 1992[6]; Nirex 1997[1]; Becker and Davenport, 2001[7]; Baker Hughes, 2011[8]). Figure 24 shows the spatial distribution of S_{HMax} magnitude estimates across the UK. There are currently 93 estimates from 30 sites including: boreholes, quarries, collieries and Mines. The stress magnitude data are mainly calculated from overcoring and hydraulic fracturing tests, but several measurements were calculated from borehole breakouts in the Preese Hall 1 well.

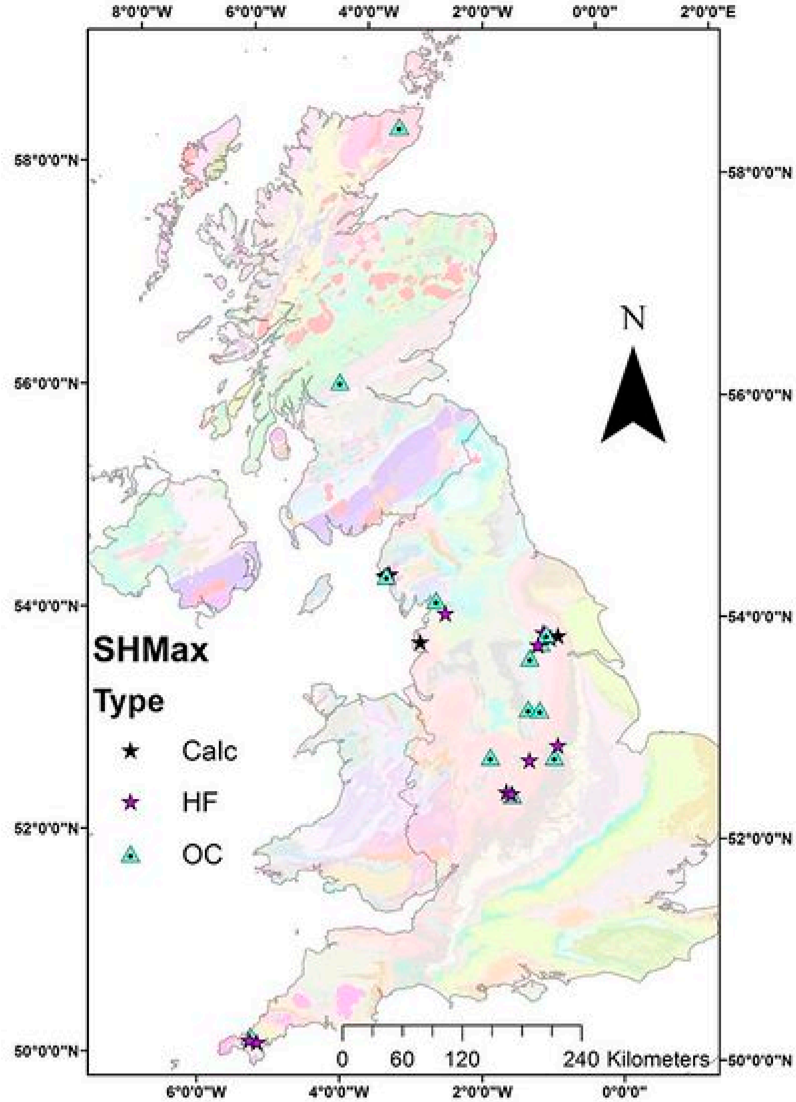

Figure 24 Location of all of the measurements of S_{HMax} magnitude across the UK. These magnitudes have been estimated using: Overcoring (OC), Hydraulic Fracturing (HF) and calculations from observations of borehole breakouts and DIFs (Calc). Contains British Geological Survey materials © NERC 2017.

Figure 25 compares the magnitudes of S_{HMax} from legacy data against the estimates of UK vertical stress (Figure 20).

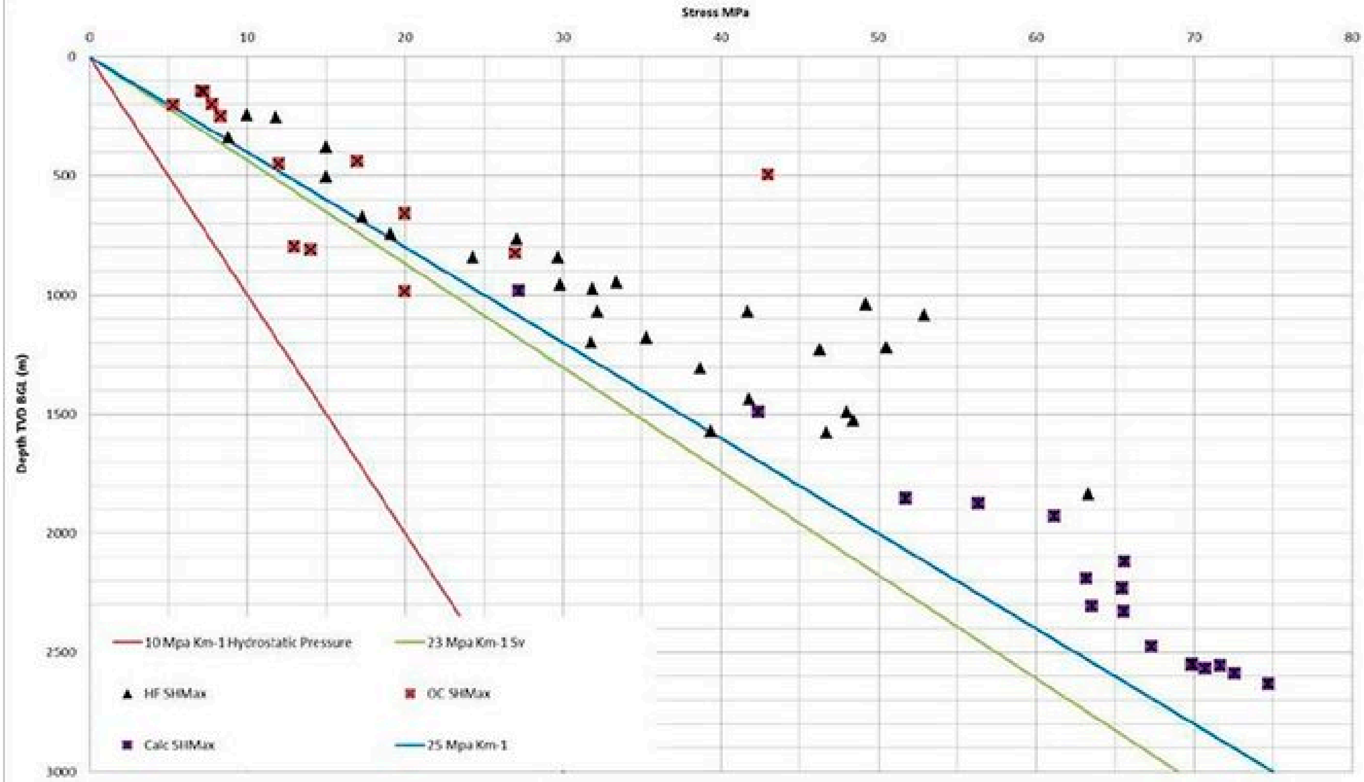

Figure 25 Compilation of all SHMax magnitudes from: Overcoring (OC), Hydraulic Fracturing (HF) and calculations from observations of borehole breakouts and DIFs (Calc). With the exception of three overcoring measurements S_{HMax} magnitude is greater than the S_v of 23 $MPakm^{-1}$ suggesting that $S_{HMax} \geq S_v$ however this is based on data from a small number of locations.

Figure 25 shows that with three exceptions, all of the S_{HMax} estimates plot above 23 $MPakm^{-1}$ and on, or above the upper bound of S_v 25 $MPakm^{-1}$ (Figure 20). Based on the available data S_{HMax} is $\geq S_v$ indicating a predominately strike slip/reverse environment, supporting the conclusions of Baptie (2010)[9]. There is evidence of reverse faulting regimes in the data largely from hydraulic fracturing measurements (Figure 26).

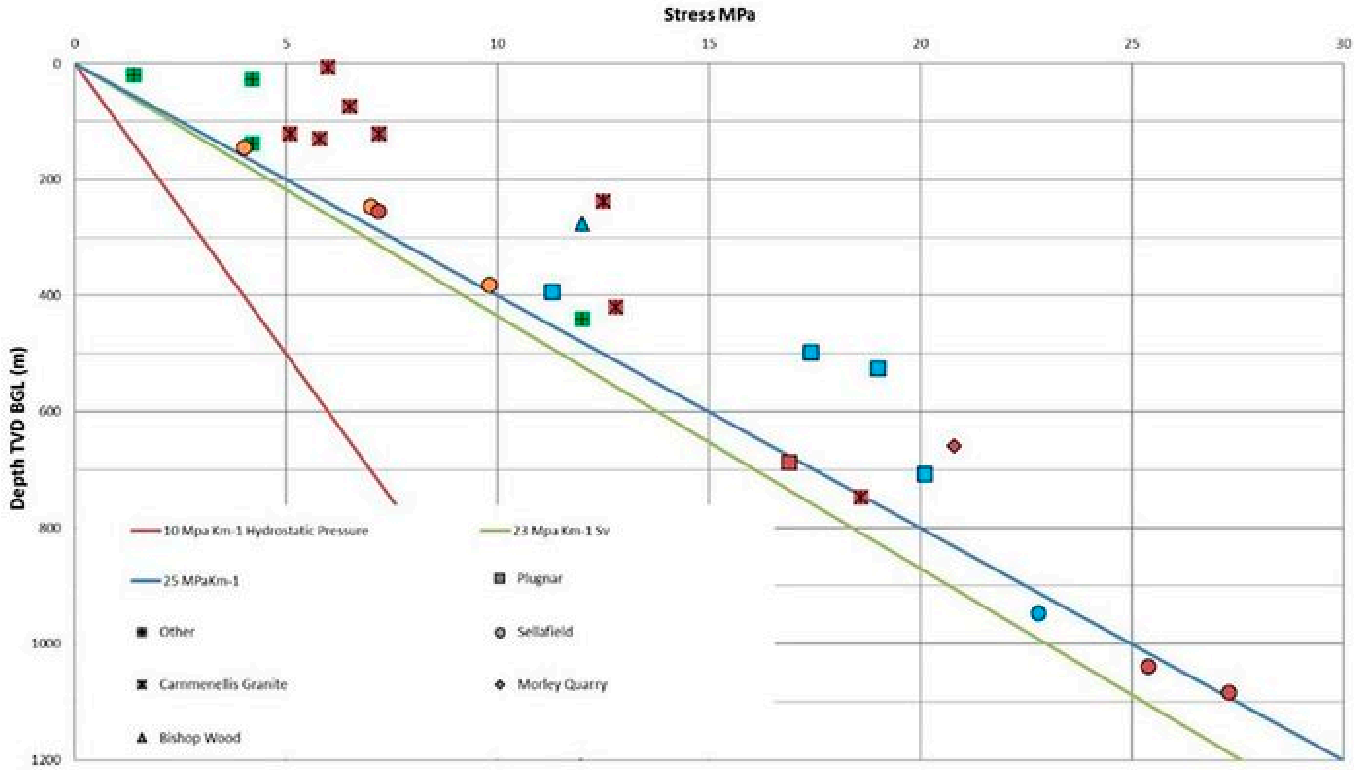

Figure 26 S_{hmin} values which exceed the vertical stress gradient of 23 MPakm^{-1} indicating possible reverse Faulting regimes. S_{hmin} values derived from hydraulic fracturing and overcoring methods. Values have been shaded broadly by lithology and age. Green: Unknown source and age, Red: Igneous source, Orange: Triassic Sediments, Blue: Carboniferous sediment.

The majority of the data indicating a possible thrust faulting environment was collected either as part of the Hot Dry Rock (HDR) research project in the Cornish Granite (Parker, 1999[10]), or shallow quarry measurements e.g. Gatur and Spittal in Scotland (Becker and Davenport, 2001[7]). As such they are outside the main focus of this report. This dataset is limited both spatially and stratigraphically but does indicate possible reverse/strike slip faulting regimes from Sellafield in Cumbria, Plungar in Nottinghamshire and Bishop Wood in North Yorkshire.

As discussed in Maximum horizontal stress there are significant issues with S_{HMax} magnitudes from both hydraulic fracturing and overcoring techniques. At Rosemanowes there is an uncertainty of 15 MPakm^{-1} in the values of S_{HMax} (Pine et al., 1983[4]).

Much of the published literature on the UK stress field relates to the orientation of S_{HMax} and focuses mainly on the North Sea (Klein and Barr, 1986[11]; Williams et al., 2015[12]). Kingdon et al (2016)[13] reviewed previous studies of stress field orientation onshore and characterised the stress field orientation using a borehole imaging dataset. The results of the study indicated a consistent S_{HMax} orientation of 150.9° (with a circular standard deviation of 13.1°). This orientation was attributed to ridge-push stresses associated with the Mid Atlantic Ridge system (Klein and Barr, 1986[11]).

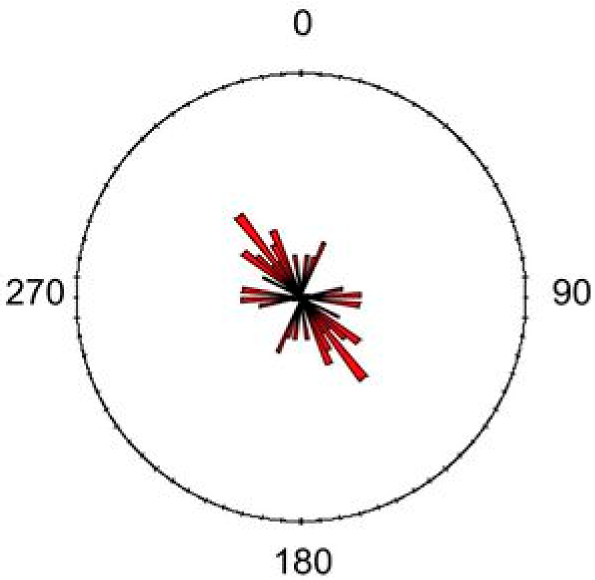

Figure 27 S_{HMax} orientations from Hydraulic Fracturing and Overcoring binned at 5° intervals.

The dominant S_{HMax} orientation for these observations is 141° (with a circular standard deviation of 32°) (Figure 27). The large standard deviation of these measurements (shown on Figure 27) results from nine observations: four indicating a NNE–SSW direction of S_{HMax} and five an E–W trend of S_{HMax}. Observations indicating an E–W direction of S_{HMax} were recorded in two boreholes in the Midlands: Morley Quarry 1 and a single observation in Back Lane Plungar. The single observation at Plungar was from Carboniferous volcanic strata and is >60° different to the other three observations from this well. The observations from Morley Quarry were recorded in Precambrian foliated lavas or tuffs. This would appear to indicate that pre-Variscan igneous strata is preserving relic stress orientations. By comparison, the orientations from the Permian Carnmenellis granites are predominantly NW–SE.

As these strata are not prospective for hydrocarbons there is very little additional data available to investigate if stress orientations are being preserved by igneous strata. The E–W orientations are different to the vast majority of those documented in Kingdon et al (2016) though this may be due to the geographic and stratigraphic constraints on the available data. The majority of the remaining observations support the NE–SW trend of S_{HMax} as recorded in Kingdon et al (2016)[13].

Su et al., (2001)[14] have shown that coal cleats form in the orientation of S_{HMax} when σ1 > σ2. In an attempt to assess palaeo stress orientation, Rippon et al (2006)[15] following on from: Ellison (1997)[16]; Jones, (2004)[17] mapped the coal cleats across the UK. This method has been utilised in other locations ahead of potential coal bed methane developments where there is an absence of borehole data (Paul and Chatterjee, 2011[18]). The palaeo stress orientations identified by Rippon et al (2006)[15] and Ellison (1997)[16] are predominately NW–SE and are thought to result from compression due to the Variscan orogeny. There were significant deviations in cleat orientations in both South Wales and the Midland Valley, which are thought to be the result of fault block rotations (Rippon et al., 2006[15]). Given the similarities between the stress field orientation in the Variscan and the present day, it is difficult to say if the coals are preserving a palaeo-stress orientation. Where significant differences the palaeo-stress orientation existed (e.g. the Midland Valley and the south Wales coalfield) there is insufficient borehole data to characterise the S_{HMax} orientation.

References

1. ↑ 1.0 1.1 Nirex. 1997. Sellafield Geological and Hydrogeological Investigations: Assessment of In-situ Stress Field at Sellafield. Nirex Report S/97/003.
2. ↑ Williams, J D O, Fellgett, M W, and Quinn, M F. 2016. Carbon dioxide storage in the Captain Sandstone aquifer: determination of in situ stresses and fault-stability analysis. Petroleum Geoscience, 22, 211–222. DOI: 10.1144/petgeo2016-036
3. ↑ Addis, M, Yassir, N, Willoughby, D, and Enever, J. 1998. Comparison off leak-off test and extended leakoff test data for stress estimation. SPE/ISRM Eurock'98, Trondheim, Norway.
4. ↑ 4.0 4.1 Pine, R J, Ledingham, P, and Merrifield, C M. 1983. In situ Stress Measurement in the Carnmenellis Granite .2. Hydrofracture Tests at Rosemanowes Quarry to Depths of 2000-M. International Journal of Rock Mechanics and Mining Sciences 20(2): 63–72.
5. ↑ Cooling, C M, Hudson, J A, and Tunbridge, L W. 1988. In situ Rock Stresses and Their Measurement in the Uk .2. Site Experiments and Stress-Field Interpretation. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts 25(6): 371–382.
6. ↑ Bigby, D N, Cassie, J W, and Ledger, A R. 1992. Absolute stress and stress change measurements in British Coal Measures. In: Hudson, J.A. (Ed.), Rock Characterisation: Proceedings of the International Symposium on Rock Stress. United Kingdom, Chester, pp.390–395.
7. ↑ 7.0 7.1 Becker, A, and Davenport, C A. 2001. Contemporary in situ stress determination at three sites in Scotland and northern England, J. Struct. Geol., 23, 407–419.
8. ↑ Baker Hughes, 2011. Wellbore Failure Analysis and Geomechanical Modelling in the Bowland Shales, Blackpool, UK, GMI. Peliminary Technical Report. Cuadrilla Resources. Last Accessed 04-Feb-2017.
9. ↑ Baptie, B. 2010. Seismogenesis and state of stress in the UK. *Tectonophysics*, 482 (1–4). 150–159. 10.1016/j.tecto.2009.10.006
10. ↑ Parker, R. 1999. The Rosemanowes HDR project 1983–1991. *Geothermics*, 28, 603–615.
11. ↑ 11.0 11.1 Klein, R J, and Barr, M V. 1986. Regional state of stress in Western Europe. In: Stephansson, O. (Editor.) Proceedings of the International Symposium on Rock Stress and Rock Stress Measurements, Stockholm, 1–3 September 1986. Centek, Lulea, 33–44.
12. ↑ Williams, J D O, Fellgett, M W, Kingdon, A, and Williamson, P J. 2015. In-situ stress

orientations in the UK Southern North Sea: Regional trends, deviations and detachment of the post-Zechstein stress field. Marine and Petroleum Geology. 67. 769–784. DOI: 10.1016/j.marpetgeo.2015.06.008

13. ↑ [13.0] [13.1] Kingdon, A, Fellgett, M W, and Williams, J D O. 2016. Use of borehole imaging to improve understanding of the in-situ stress orientation of Central and Northern England and its implications for unconventional hydrocarbon resources. Marine and Petroleum Geology, 73, 1–20. DOI: 10.1016/j.marpetgeo.2016.02.012
14. ↑ Su, X B, Feng, Y L, Chen, J F, and Pan, J N. 2001. The characteristics and origins of cleat in coal from Western North China. International Journal of Coal Geology, 47, 51–62.
15. ↑ [15.0] [15.1] [15.2] Rippon, J H, Ellison, R A, and Gayer, R A. 2006. A review of joints (cleats) in British Carboniferous coals: indicators of palaeostress orientation. Proceedings of the Yorkshire Geological Society, 56, 15–30.
16. ↑ [16.0] [16.1] Ellison, R A. 1997. Observations of coal cleat in British coalfields. British Geological Survey Technical Report WA/97/58 (Keyworth: British Geological Survey.)
17. ↑ Jones, N S, Holloway, S, Creedy, D P, Garner, K, Smith, N J P, Browne, M A E, and Durucan, S. 2004. UK Coal Resource for New Exploitation Technologies. Final Report. British Geological Survey Commissioned Report CR/04/015N.
18. ↑ Paul, S, and Chatterjee, R. 2011. Mapping of cleats and fractures as an indicator of in-situ stress orientation, Jharia coalfield, India. International Journal of Coal Geology, 88, 113–122.

Category:

- OR/17/048 State of stress across UK regions