

OR/19/049 Discontinuity log

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Introduction

Core GGC01 was made available for discontinuity logging in two stages: 0–140 m was examined on 20–22 March 2019, and 140–198.69 m (terminal depth) was examined on 10–11 April 2019. The core was laid out in Viewing Lab 5 of the National Geological Repository (NGR), at the BGS offices in Keyworth, Nottinghamshire. The core was intact (not sawn) at the time it was examined, and presented in 1-metre sticks sitting in plastic sleeves. The sleeves had been cut lengthwise, so that when the core was laid out horizontally the bottom half of each sleeve supported a core stick and the top half could be removed. Thus, only the top half of each core stick was generally visible. The core was not orientated, and lacked a core reference line. Lighting (artificial light provided by strip lights) was good.

Core quality in general was reasonably good, though parts of the core (notably those formed of mudstone and coal) are affected by multiple induced and natural breaks and are clearly deteriorating faster than other parts. Spacers and labels had been placed in/on the core to note the positions of short (<10 cm) sections of core that had already been removed for testing. There were several short sections of missing core; some of these appeared to be due to drilling problems, but the cause was not obvious in some cases.

The objective was to prepare a spreadsheet log of natural discontinuities (specifically fractures) in core GGC01, and make a preliminary record of their character. The log spreadsheet is included in the accompanying data release. The logging methodology is described in [Methodology](#), and a summary of the key observations of discontinuity character arising from this brief examination of the core is presented in section 0.

Methodology

The visible part (i.e. top half) of the core was examined visually, using a 10x hand lens where necessary. Core pieces were lifted out of their supporting plastic sleeves temporarily to allow the bottom half to be examined, where this was considered useful and it could be done easily; less than half the core was examined in this way. A solution of 10% HCl was used sparingly to test for reactive minerals (particularly calcite).

The log was created in a Microsoft Excel spreadsheet, with entries in most individual cells controlled by drop-down menus (controlled vocabularies). In most cases, an individual record (row) in the log corresponds to a single discontinuity in the core. However, in some cases, an individual record in the log is used to describe multiple discontinuities (a set, system or network) within a discrete interval

of core, usually because the high density of fractures in the interval made it impractical to record each one separately; this was the case in all beds of coal, for example. A summary of the headings and contents of all columns in the spreadsheet is provided in Table 6. The terms used throughout the log, and their definitions, are consistent with Gillespie et al. (2011)^[1].

Depth information recorded in the log was calculated by measuring the distance (obtained using a tape measure) from the top of a core stick to the logged feature and adding this to the 'drillers' depth' for the top of the stick. 'Drillers' depths' are uncorrected depths assigned by the borehole drillers, which are written on each core box in the National Geological Repository and indicate the top and bottom depth of the core stick.

The depth of logged features was recorded in several ways:

- the mid-point of the top and bottom depths of intersection was recorded for individual features that cut across the core (i.e. do not terminate within it);
- the top and bottom depths were recorded for individual features whose shallowest and deepest limits are contained within the core;
- the shallowest and deepest limits were recorded where details for multiple features (e.g. fracture systems and sets) were included in a single record.

The positions of several short sections of missing core are noted in the log. Unless stated otherwise in the log, it is considered unlikely that previously sampled and missing sections of core contain significant natural discontinuities.

Table 6 Summary of fields used in the Discontinuity Log spreadsheet.

Column heading	Explanation
No.	The record number, assigned sequentially from the top of the core.
Depth (m)	The depth, in metres, of the logged feature, based on 'Drillers' depths' (see text for explanation).
Discontinuity type	Indicates the type of discontinuity that has been logged. Terms in the controlled vocabulary are: <i>fracture (undifferentiated)</i> ; <i>joint</i> ; <i>slip surface</i> ; <i>fault</i> ; <i>deformation-band</i> ; <i>array</i> ; <i>network</i> ; <i>set</i> ; <i>system</i> .
Discontinuity origin	Indicates whether the feature is natural or induced, based on available evidence.
Dip (°)	The dip of the feature, with respect to horizontal (taken to be 90° to the core axis). In most cases, both a term denoting a bin (a given range) and a measured value are recorded. Terms used in the 'Bin' column are: <i>horizontal</i> = 0-5°, <i>gentle</i> = 5-30°, <i>moderate</i> = 30-60°, <i>steep</i> = 60-85°, and <i>vertical</i> = 85-90°. The 'Direction' column is for dip direction; this has not been measured, as the core was not orientated, and had no reference line, at the time the log was prepared.
Width (mm)	Indicates the average width of the logged feature, in mm. The option to record a bin (a given range) and a measured value is given, but in most cases only a bin has been recorded. Terms used in the 'Bin' column are: <1, 1-10, 10-100, and >100.
Filling history	Indicates whether the filling history (i.e. mineralization ± dissolution) and/or the displacement history of the logged feature is <i>simple</i> (formed through a single operation) or <i>compound</i> (formed through multiple operations), based on available evidence.

Filling type	Indicates the type of filling in the logged feature. Terms in the controlled vocabulary are: <i>vein, crust, dendrite, layer, patch, spot, sediment, breccia, fault-rock</i> and <i>none</i> .
Filling components	Indicates the components comprising the filling in a logged feature. The controlled vocabulary includes a range of mineral names, terms for different classes of fault-rock, and the term <i>void</i> .
P±S	Indicates whether polishing and/or striations (slickenlines) produced by deformation are developed on slip surfaces and other places where the core has parted.
PPF	Indicates (using Y = yes, N = no, and ? = not known) whether the logged feature is considered to be a Potentially Flowing Feature (PPF; following the nomenclature used in Milodowski et al., 1995 ^[2]), i.e. a discontinuity that is unsealed, and therefore may be permeable and transmissive.
Comment	Additional, discretionary information, in free text

Summary of observations

The following summary of observations is based on a brief examination of core. The distribution of key features in the core is illustrated in Figure 10.

- The boundary between Quaternary materials and bedrock was placed at 30.7 m, so the total length of examined core below rockhead was approximately 168 metres.
- Natural discontinuities are distributed unevenly due to an obvious lithological control. Every bed of coal contains numerous thin veins that have exploited the coal cleat system (a dense, subregular network of subvertical and subhorizontal natural fractures). By contrast, natural discontinuities in all other lithologies are sparse; only 97 records of discontinuities, most describing a single feature, were made in 160 metres of core formed of lithologies other than coal.
- In coal beds, veins up to 3 mm thick consist of calcite, an unidentified white mineral (possibly a carbonate mineral that does not react to 10% HCl), and a subordinate proportion of Fe-sulphide, which is fresh or tarnished (Figure 11a).
- Of the 97 ‘features’ recorded outwith the coal beds, 38 are mineralised joints, 18 are non-mineralised joints, 28 are slip surfaces, 10 are faults, and 3 are other types of feature.
 - Mineralised joints are typically <1 mm thick; the thickest simple vein is c. 6 mm thick. Calcite is by far the most common filling. Only rare traces of sulphide mineral were recorded outwith the coal beds. An orange mineral – possibly a carbonate mineral or anhydrite – occurs locally (Figure 11b); nodules formed of, or including, the same orange mineral are scattered locally in the host rock. Most veins appear to have a simple filling history; only three were described as ‘compound’ in character (i.e. formed through more than one stage of mineralisation). Mineralised joints are scattered more or less evenly in the core, though concentrated locally. A set of subhorizontal calcite veins occurs between 31.93 and 32.58 m.
 - Non-mineralised joints (core partings with non-mineralised surfaces, which are likely to be natural rather than induced because they are discordant to bedding and/or have slightly weathered-looking surfaces) are relatively common down to 60 m, sparse between 60 and 163 m, and apparently absent below 163 m. This distribution probably reflects a general reduction with depth in the degree to which calcite and other soluble

minerals have been dissolved by modern meteoric groundwater. Iron and manganese oxide and oxyhydroxide minerals, which typically are residual products of carbonate dissolution in oxidising water, seem to be largely absent.

- All but one of the features classified as a fault are of similar character: bands of rock up to 70 cm thick within which cm-scale offsets are discernible and protobreccia (fault-rock formed by very weak cataclasis) may be developed (Figure 11c). All such features, which are a product of very weak cataclasis, are healed, though the offset surfaces in some cases have been exploited by calcite veins. Nine of the ten features described as faults occur between 140 and 180 m, suggesting some or all of them are related. The features probably formed at an early stage in the rock history (during burial?). The apparent dip of such features can be difficult to discern, but there appears to be no consistent or dominant dip amount (steep, moderate and gentle dips were all recorded). One feature, at 178.62 m, consists of a c.3 cm-thick, subhorizontal band of protomylonite developed at the interface between layers of mudstone (above) and sandstone (below). Within this band, flattish 'augen' and variably fragmented layers of sandstone (forming clasts) are enclosed in a dark 'matrix' of deformed mudstone and organic matter, and the mylonitic fabric undulates but is broadly subhorizontal. The feature is a product of brittle-ductile deformation, but probably due to relatively weak strain in materials of strongly contrasting character.
- Slip surfaces are partings in the core on which there is evidence for displacement, in the form of tectonic polish and/or striation, but without visible fault-rock. They generally are developed in mudstone beds, which appear to have accommodated much of the (relatively insignificant) strain that has affected the heterolithic sequence. Many partings in the core have formed where the borehole has intersected fossil plant matter lying on a bedding plane, and these surfaces commonly display a striated character that is due to the structure of the plant rather than accommodation of strain. Two clusters of slip surfaces were recorded, one between 32 and 70 m and the other between 140 and 180 m. Both intervals correlate broadly with the position of faults in the core, suggesting a genetic relationship. However, slip surfaces are only observed on core partings, and as such are likely to form a strongly biased dataset in the log.
- Following the nomenclature used in Milodowski et al. (1995)^[2], any discontinuity that is unsealed, and therefore may be permeable and transmissive, has been labelled a Potentially Flowing Feature (PFF) in the log and on Figure 10. Ten PFFs and twenty possible PFFs were identified. The PFFs are mainly mineralised joints that are either largely mineralised but locally gapped (Figure 11d), or largely non-mineralised but with crusts of euhedral, fine- or very-fine-grained calcite crystals. In the latter case, the calcite crusts form discontinuous patches or scattered spots (giving joint surfaces a weakly spotted character). The possible PFFs are mainly non-mineralised joints. Many PFFs and possible PFFs are 'Type D' structures in the sense of Milodowski et al. (1995)^[2]; that is, they have formed by brittle fracturing adjacent to, and commonly between, one or more sub-parallel slip surfaces (Figure 11e, f). Typically, the brittle fracturing has occurred in sandstone and the slip surfaces have formed in mudstone. The PFFs are distributed broadly evenly throughout the core, while the possible PFFs are mainly between 40 and 60 m, where most of the non-mineralised joints were recorded.
- Very few cross-cutting relationships were observed, from which a fracture paragenesis can be interpreted. However:
 - hairline veins of calcite locally exploit, and therefore post-date, thin deformation bands

in some of the features logged as faults;

- a vein comprising early orange carbonate(?) and later calcite has exploited an earlier hairline vein of calcite;
- euhedral calcite crystals have grown on the surfaces of some unsealed joints.

- This evidence supports the following tentative fracture paragenesis:

1. Early weak faulting, possibly associated with development of slip surfaces.
 2. Formation of calcite veins, at least some of which may be contemporaneous with the faults and slip surfaces.
 3. Formation of rare veins of carbonate/anhydrite (?) and later calcite.
 4. Localised dissolution of soluble minerals in fractures (and probably in the rock matrix), most extensively in the near-surface zone, creating PFFs; this is likely to be geologically recent.
 5. Formation of new, euhedral calcite crystals in some PFFs; dissolution of soluble minerals and precipitation of new calcite may be ongoing in different parts of the rock mass.
- Rock matrix permeability was not tested systematically, but much of the sandstone may be permeable. Given the small number of PFFs, and their generally very small apertures, it seems likely that matrix permeability is more important than fracture permeability in controlling transmissivity in the rock mass. The sandstone seems mainly to be calcite-free, but is calcite-bearing locally around some calcite veins.

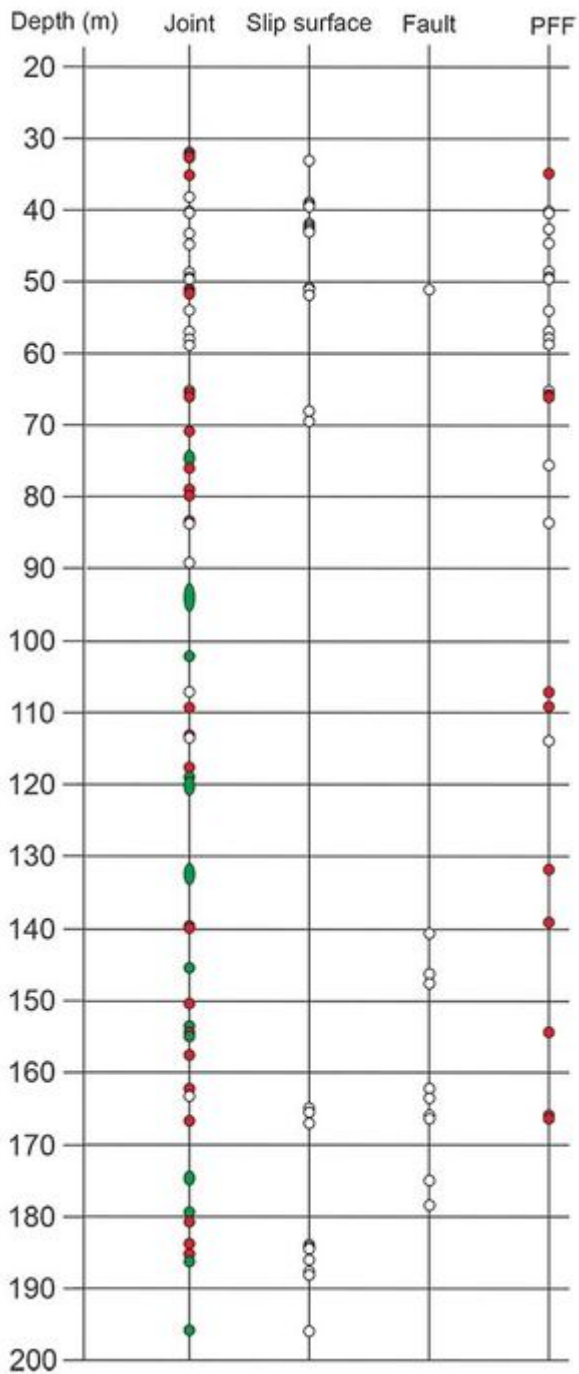


Figure 10 Distribution of logged discontinuities in GGC01 core. PFF = Potentially Flowing Feature. Circle colour denotes feature type: colourless = a single, non-mineralised feature; red = a single, mineralised feature; green = a system of mineralised joints in a coal bed.



Figure 11 Character of discontinuities in core GGC01.

a. A typical coal bed, showing disaggregated core with thin veins of white calcite and Fe-sulphide developed on numerous joint surfaces within the coal cleat system. Log feature no. 78, 132.45–132.63 m. **b.** A vein of early orange carbonate (or anhydrite?) and late white calcite, which has exploited an earlier hairline calcite vein. Log feature no. 61, 83.06 m. **c.** A small, healed fault bounded by dark grey deformation bands and containing weakly cataclastic fault-rock (protobreccia), developed in thinly interlayered sandstone and mudstone. Log feature no. 41, 51.20 m. **d.** A thin, subvertical vein with partial calcite filling, which is naturally gapped in places with possible calcite euhedra developed locally on surfaces, and therefore is classified as a potentially flowing feature (PFF). Log feature no. 16, c. 35.0 m. **e.** A steep joint with moderately rough, weathered-looking surfaces on which dip-parallel slickenlines are developed locally with possible later calcite on top. The joint terminates abruptly against subhorizontal bedding planes, indicating it is a 'Type D' PFF in the sense of Milodowski et al. (1995)^[2]. Log feature no. 50, 65.57–65.64 m. **f.** A subvertical joint with rough surfaces on which patches of small calcite crystals are scattered. The feature terminates abruptly at both ends against subhorizontal bedding planes, indicating it is a 'Type D' PFF in the sense of Milodowski et al. (1995)^[2]. Log feature no. 51, 66.00–66.22 m.

References

1. ↑ GILLESPIE, M R, BARNES, R P, and MILODOWSKI, A E. 2011. British Geological Survey scheme for classifying discontinuities and fillings. *British Geological Survey Research Report, RR/10/05*. ISBN 978 85272 674 7
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