Testing of Anchors in North Wales Slate Mines 2014 & 15

Introduction

This work grew out of some work conducted by G Thomas and others in 2012 and 13 (see http://www.train4underground.co.uk/bolts-in-slate-testing-project/). A proposal was made to the BCA's Equipment and Techniques (E&T) Committee for funding to purchase a range of anchors of different types for testing in several types of slate (see item 9.1 in http://british-caving.org.uk/wiki3/lib/exe/fetch.php?media=equipment_techniques:141102_e_t_minutes_final.pdf). The aim was to check on the suitability of Petzl Collinox and Batinox resin based anchors and the 12mm Goujon expansion anchor coupled with the Coeur hanger which were widely used in North Wales. (It should be noted that Coeur hanger is only rated for a 25kN force.) The proposal was to locate a moderate number of anchors in 4 different types of slate.

Following discussion, it was agreed that the project should be focused on testing the Collinox and Goujon anchors together with E&T's currently preferred anchor, the Bolt Product (BP) GP8-100-16A4 resin based anchor. (The Batinox anchor was dropped on the grounds of being a larger version of the Collinox anchor. If the work showed a problem with Collinox anchors, then the committee agreed it would be prepared to fund work on Batinox anchors.)

Subsequently S Wilson agreed to make available the IC resin based anchor for inclusion in the project. In addition, following a report by the BMC (see https://www.thebmc.co.uk/warning-issued-over-slate-bolts) over a 10mm expansion anchor 'working loose', it was proposed to see if any deterioration might by prior loading one sub set before testing them.

Parameters

Thus the primary sets of variables were:

Petzl Collinox resin based anchor
12mm Goujon expansion anchor coupled with the Coeur hanger
Bolt Product GP8-100-16A4 resin based anchor
IC resin based anchor

Back Vein Cwmorthin slate mine, Blaenau Ffestiniog
Stripey Vein Cwmorthin slate mine Blaenau Ffestiniog
Cambrian slate mine, Llangollen
Braich Goch mine, Corris

Exercise by loading to 6kN six times
Not exercised

Two other variables were also investigated. The first relates to placing the anchor at right angles to the cleavage plane and also to pillar plane in the mine, see Annex 1. The second arose during placement when it was noted that cleaning the hole was difficult. The normal practice is to wash and brush the hole but it was felt that a muddy paste was being left at the bottom of the hole. So a fifth variable was included where by some holes were water washed and brushed cleaned whilst others were simply blown and brushed cleaned whilst keeping the hole dry. Dry blow and brush is the normally recommended technique by resin anchor suppliers.

The other variables were therefore

Cleavage plane
Pillar plane

Dry clean by blow and brush
Wet clean by wash and brush

Placement & Testing

Anchors were placed in December 2014 following normal procedures with two exceptions. The first is that for resin anchors it is normal to notch the rock so the 'ring' of the anchor can be slightly sunk into the rock face thus providing a direct line of resistance to the rock from rotational forces placed on the anchor. Based on previous experience with DMM Eco and BP anchors, it was considered that this should not materially impact on the resistance of the anchor to axial forces. (This assumption was subsequently challenged in the case of IC anchors.) The second exception was that IC anchors have only been characterised using Fischer FIS V 360 S resin. Both the BP and IC anchors were placed using KMR resin. The Collinox anchors were placed using the approved resin ampoules. The placement process did not run entirely smoothly and detailed problems were recorded, see later.

The anchors were then pulled in January 2015 using the BCA puller, see figure 1. The puller

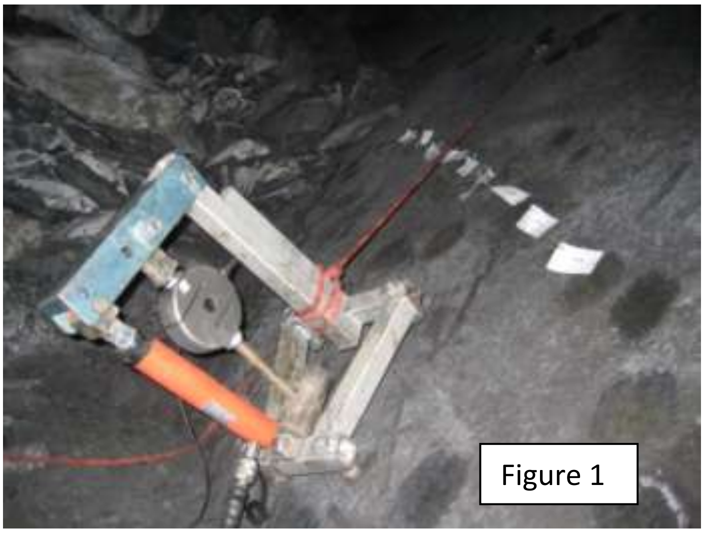
Figure 1

comprises of a 100kN load cell connected to the anchor via a bar which allows for rotation of the anchor. A force is applied via a lever using a hydraulic ram. The load cell is connected to a hand held meter capable of providing a direct read out as well as recording the peak force seen since being last reset. The load cell was calibrated in October 2013 and checked against another load cell in June 2015 which was less than one year old. The read out was found to be accurate within 1kN. The sub set of chosen anchors were exercised by using a Hydrajaws tester just prior to their extraction.

Each pull was videoed with a commentary on the meter read out. The peak value was recorded by one person reading out the peak value and another writing it down as well as the peak value being videoed. (The meter was then reset back to zero for the next pull.)

Results

The raw data is presented in Annex 2 in two tables[1]. (Footnotes indicate the sheet on the spread sheet file 1501 N Wales work v33.xlsx which analysed the data.) Video recordings of each extraction as well as still images were made and are available on request. Peak forces recorded by the meter were recorded to two decimal places, except for 5 cases where the detailed record does not exist and a value was taken from the sound track of the video recording.

A plot of all of the data is shown in Annex 3[2]. The first plot shows all the data together with the values set by the European Standard for mountaineering anchors (BS EN 959:2007) and the more recent revised UIAA standard (No 123, 2014) for the axial pull out test. Although both standards require the anchor to be exercised ten times to 8kN, this was not conducted in this work. The European Standard sets a threshold of 15kN. The UIAA standard has increased this to 20kN. E&T use criteria of:

> *The standard for acceptance of an anchor type on the basis of an axial load is based on the 15kN axial load value as cited in Section 4.3.1 of the Mountaineering Equipment – Rock Anchors – Safety requirements and test methods BS EN 959 : 2007, as computed as the 5% fractile value as specified in Section 4.2 (3) of the Euro Code Basis of Structural Design Standard BS EN 1990 : 2002 from the results of a batch test of a minimum of 5 anchors provided there is supplementary information showing the distribution of results follows a normal distribution, else the minimum size of the batch test should be 32.*

(see item 8 at http://british-caving.org.uk/wiki3/lib/exe/fetch.php?media=equipment_techniques:signed_minutes_e_t_050414.pdf).

As can be seen from the first plot in Annex 3, only one anchor, a Goujon failed below the 15kN threshold, being Pull No 47 at 11kN. Two other anchors failed below the 20kN threshold, another Goujon Pull No 11 and a Collinox, Pull No 43. (A third Goujon failed at 20.13kN, Pull No 66.) The mean value for this set of 76 anchors was 33kN[3]. The full set of

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[1] from sheet Orig Data
[2] from Sheet Plots 1
[3] from sheet all means etc

data did not fulfil a normal distribution as determined by the Shapiro-Wilk Test[4]. (This statistical test was chosen as being one of the better tests for this condition, as well as being available as an add on to the Excel spread sheet functions.) By excluding the lowest three values the data did exhibit a normal distribution with a mean of 34kN. Consideration of excluding results will be covered later.

The mean and other data for all of the different types of anchors[5] are given in Table 1.

Anchor	No	Mean kN	SD kN	k	5% kN	Normality
BP	20	37	5.4	2.2	24	0
IC	16	33	4.2	2.2	24	-2
Goujon	20	32	8.0	2.2	15	-5
Collinox	20	30	4.4	2.2	21	-3

Table 1 Data for all Anchors

Only 16 IC anchors were supplied for the project. The data in Table 1 is presented in descending order of their mean rounded to a whole number, reflecting the accuracy of the load cell calibration.

The standard deviations (SD) are given to one decimal point. The parameter k is a based on assuming normal distribution of the data and is taken from Section 5.3, page 126 of the "Handbook of Statistical Tables" by D B Owen, 1962. The 5% fractile (5%) column is computed by subtracting the product of the unrounded values of SD and k from the mean and rounded to a whole number. The 5% fractile represents the value at which 5% of the population will lie below the value. Thus 95% of the population will have values which will lie above the value cited in the table.

The adoption of this approach was based on using a reasonable threshold taken from the construction industry. Suggestions of using a 3 standard deviation were rejected as being unduly pessimistic. 3 SD would be equivalent to 0.3% of the population lying below the value. Curiously it is understood that the European Standard does not require any statistical consideration of the results of tests; thus implying only one sample need be tested to demonstrate compliance!

The value given in the Normality column is the number of smallest results required to be excluded in order for the remaining data set to become normally distributed. Thus only the BP anchor was found to have a normal distribution across all of the data in Table 1. The IC anchor required to have excluded the lowest 2 results from the data set, the Goujon, 5 and the Collinox, 3, to achieve a normal distribution. It is worth noting that there is <u>no</u> justification for these exclusions.

Table 1 shows that all anchors meet both the European Standard and UIAA criterion. But only BP anchors meet E&T's criteria. It is likely that testing more anchors would cause their results to become normally distributed thus meeting E&T's criteria.

[4] from sheet all means etc
[5] from sheet all means etc

The mean and other data for all of the different types of slate are given in Table 2[6].

Slate Type	No	Mean kN	SD kN	k	5% kN
Back Vein	21	31	4.8	2.2	20
Stripey Vein	20	36	3.8	2.2	28
Cambrian	20	31	8.2	2.2	13
Corris	15	34	4.8	2.3	23

Table 2 Data for all Slates

No IC anchors were placed in Corris. All four sub sets were found to be normally distributed[7].

The behaviour of each type of anchor in the four types of slate is also plotted in Annex 3[8]. The means, SD and 5% of each sub set are shown in Table 3[9].

Anchor	Slate Type	No	Mean kN	SD kN	k	5% kN
BP	Back Vein	5	32	4.4	3.4	17
	Stripey Vein	5	40	5.5	3.4	21
	Cambrian	5	36	3.5	3.4	24
	Corris	5	36	5.3	3.4	18
IC	Back Vein	6	36	3.0	3.1	27
	Stripey Vein	5	36	1.5	3.4	31
	Cambrian	5	36	4.9	3.4	19
Goujon	Back Vein	5	29	8.6	3.4	0
	Stripey Vein	5	37	0.7	3.4	35
	Cambrian	5	26	10.4	3.4	-9
	Corris	5	36	2.1	3.4	29
Collinox	Back Vein	5	31	1.6	3.4	25
	Stripey Vein	5	33	1.8	3.4	27
	Cambrian	5	27	5.8	3.4	7
	Corris	5	31	5.3	3.4	13

Table 3 Data for all Anchors and Slate types

The sub sub sample size of 5 is too small to determine whether the sub sub sample has a normal distribution.

The two sub sets of anchors which were either exercised or not exercised gave very similar means of 31 and 32kN[10] respectively. Whilst the not exercised sub set was found to be normally distributed, the exercised sub set was not.

6 sheet Plots 2
7 Sheet Plots 2
8 sheet Plots 2
9 sheet Plots 2
10 All data 3

The two sub sets of anchors placed in cleavage or pillar plane gave slightly different values of 35 and 31kN[11] respectively. Whilst the cleavage plane sub set was found to not be normally distributed, the pillar plane sub set was.

The two sub sets of anchors placed using either dry or wet cleaning method gave slightly different values of 35 and 33kN[12] respectively. Both sub sets were found to be normally distributed.

During placement, several problems arose. As a consequence the anchors listed in Table 4[13] were excluded from further analysis.

Pull No	Anchor	Force	Slate Type	Plane	Reason
1	BP5	26	Back Vein	Pillar	not enough resin used
2	BP6	28.99	Back Vein	Pillar	not enough resin used
20	BP15	31.58	Back Vein	Cleavage	possibly compromised by extraction of previous anchor
21	IC26	33.06	Back Vein	Cleavage	possibly compromised by extraction of previous anchor
35	BP12	42.44	Stripey Vein	Cleavage	doubts over recorded value as puller jammed
42	IC16	34.83	Cambrian	Pillar	soft rock
43	C2	18.53	Cambrian	Pillar	soft rock. Install error, hole drilled too deep (90mm not 70mm)
44	G7	20.23	Cambrian	Pillar	soft rock
45	BP12	41.44	Cambrian	Pillar	soft rock
46	BP11	33.13	Cambrian	Pillar	soft rock
47	G6	11.46	Cambrian	Pillar	very soft rock
48	C1	22.91	Cambrian	Pillar	very soft rock. possibly compromised by extraction of previous anchor
49	IC17	25.39	Cambrian	Pillar	very soft rock. possibly compromised by extraction of previous anchor
61	C5	30.68	Cambrian	Cleavage	possibly compromised by extraction of previous anchor
65	BP11	31.91	Corris	Pillar	possibly compromised by extraction of previous anchor
71	BP13	36.05	Corris	Cleavage	install error, anchor proud of the rock approx 10mm

Table 4 Excluded Anchors

It was noted that on several occasions the extraction of an anchor probably impacted on the location of one or more anchors yet to be extracted, see Figure 2.

[11] Sheet all data 4
[12] Sheet all data 5
[13] sheet sel data

The softness of slate within the Pillar plane of the Cambrian type of slate was of sufficient concern to exclude all placed samples. It is considered that this softness of the rock can be taught to installers as a feature of the resistance of the slate to being drilled. This should not therefore present a problem for future installers.

Pull No 35 was excluded when the puller jammed during extraction thus possibly causing the peak force to be artificially raised. There were also four known installation errors.

However subsequently a query was raised as to whether resin would have been injected to the base of the hole for the IC anchors. The argument ran that the nozzle used for KMR resin has a large diameter relative to the size of hole required for IC anchors and thus may not have been able to reach to the base of the hole. It was reported that some IC anchors did 'bounce out' and required careful pressing in during placement. The hypothesis is that an air bubble was left at the base of the anchor. Given the IC anchor design locates the mechanical interference features of the anchor at its base, if part of the base was not in resin, then part of a key feature of the anchor would not be available. Hence the extraction forces would be reduced. A review of the videos gave insufficient information to make a judgement on the validity of a claim that the base of the anchor was not in the resin.

The mean force for all selected anchors was 34kN[14] (compared to 33kN for all anchors). But the selected anchors were not normally distributed.

The mean and other data for the different types of selected anchors[15] are given in Table 5.

Anchor	No	Mean kN	SD kN	k	5% kN	Normality
BP	12	38	4.7	2.4	27 (24)	0
IC	13	34	4.0	2.4	24 (24)	-1
Goujon	18	34	5.8	2.2	21 (15)	-3
Collinox	17	31	3.0	2.3	25 (21)	-1

Table 5 Selected Data for all Anchors

[14] sheet sel data 1 etc
[15] from sheet sel data 1 etc

The second value in brackets in the 5% column is the corresponding value for all data. Rejecting some data on justifiable grounds has resulted in an improvement to the 5% confidence values. However the reduced data sets for the IC, Goujon and Collinox anchors remain not normally distributed. The number of smallest values required to be excluded has reduced. The selected data shows that all four types of anchors do meet the European Standard and the UIAA criterion, but again, only the BP anchor meets the E&T criteria.

The statistical ANOVA test provides a technique for determining if there is a difference between two or more sub sets of data, assuming the sub sets are normally distributed. Given that three out of four sub sets of data in Table 5 are not normally distributed, it is inappropriate to apply the standard statistical tests to determine if there is a difference between the sub sets. However an analysis has been conducted using ANOVA to determine possible differences the data sub sets so as to give an indication of difference despite it being strictly inappropriate if the sub sets are not normally distributed.

ANOVA indicates that there is a difference between all 4 types of anchors[16]. And looking at combinations of just two of the sub sets of anchors, a difference was indicated between BP & IC, BP & Goujon and BP & Collinox. But ANOVA indicates that there is not a significant difference between IC & Goujon, IC & Collinox or Goujon & Collinox.

The mean and other data for all of the different types of slate are given in Table 6[17].

Slate Type	No	Mean kN	SD kN	k	5% kN
Back Vein	17	31	5.1	2.3	20 (20)
Stripey Vein	19	36	4.5	2.2	26 (28)
Cambrian	11	35	4.3	2.5	24 (13)
Corris	13	34	5.1	2.4	22 (23)

Table 6 Selected Data for all Slates

The entry in the 5% column in brackets is the corresponding value for all data. All four sub sets of slate type were found to be normally distributed. The ANOVA test confirms that all four sub sets locations are statistically different[18]. But an analysis of each of the combinations of two sub sets indicates that only statistically different sub sets were Back and Stripey vein[19].

The means, SD and 5% of the selected data for each type of anchor in the four types of slate are shown in Table 7[20] .

[16] sheet sel data 4 etc
[17] sheet sel data 2 etc
[18] sheet sel data 2 etc
[19] sheet sel data 2 etc
[20] Sheet sel data 2 etc (2)

Anchor	Slate Type	No	Mean kN	SD kN	k	5% kN
BP	Back Vein	2	36	1.8	13.9	11 (17)
	Stripey Vein	4	39	6.1	4.0	15 (21)
	Cambrian	3	40	1.9	5.3	30 (24)
	Corris	3	37	6.8	5.3	1 (18)
IC	Back Vein	5	32	3.3	3.4	21 (27)
	Stripey Vein	5	33	5.3	3.4	15 (31)
	Cambrian	3	36	1.7	5.3	27 (19)
Goujon	Back Vein	5	29	8.6	3.4	0
	Stripey Vein	5	37	0.7	3.4	35 (35)
	Cambrian	3	33	5.0	5.3	6 (-9)
	Corris	5	36	2.1	3.4	29 (29)
Collinox	Back Vein	5	31	1.6	3.4	25 (25)
	Stripey Vein	5	33	1.1	3.4	29 (27)
	Cambrian	2	31	1.2	13.1	15 (7)
	Corris	5	31	5.3	3.4	13 (13)

Table 7 Selected data for anchors in the four types of slate

The entry in the 5% column in brackets is the corresponding value for all data. As can be seen, the small size of the sub sub samples makes the data subject to substantial uncertainty as reflected by the size of most of the SDs. The size also makes it impossible to determine if the sub sub sets are normally distributed.

The two sub sets of selected anchors which were either exercised or not exercised gave the same mean of 32kN[21] (compared to 31 & 32kN for all data). As for all data, the selected anchors not exercised sub set was found to be normally distributed whilst the exercised sub set was not. ANOVA indicates that there is no difference between the selected exercised and not exercised anchors[22]. ANOVA also indicates there is no difference between the selected non exercised anchors and exercised anchors for each of the different types of slate. ANOVA did indicate that there was a difference between the selected non exercised anchors and exercised anchors for each of the different types of anchors. But whilst ANOVA indicated that BP anchor differed from the other three anchor types, the other three anchor types did not differ between themselves.

The two sub sets of selected anchors placed in cleavage or pillar plane gave slightly different values of 35 and 33kN[23] respectively (compared to 35 and 31kN for all data). As for all data, the selected anchors placed in the cleavage plane sub set were found to not be normally distributed whilst the pillar plane sub set was. ANOVA indicates that there is no difference between the selected exercised anchors placed in cleavage or pillar plane. However ANOVA indicates there is a difference between the sub sets of anchors placed cleavage and pillar planes of Back, Stripey, Cambrian and Corris slate[24]. When investigated on a pairs basis, ANOVA indicates that there are differences between Back cleavage and pillar as well as

[21] Sheet sel data 10
[22] Sheet sel data 5 etc
[23] Sheet sel data 3 etc (2)
[24] Sheet sel data 3 etc

Corris cleavage and pillar. ANOVA indicates that there was no discernible difference for Stripey cleavage and pillar. (Cambrian had no usable pillar results.)

The two sub sets of selected anchors placed using either dry or wet cleaning method gave similar value of 34kN[25] (compared to 35 and 33kN respectively for all data). Whilst the wet cleaning sub set was found to be normally distributed, the dry cleaning sub set was not. ANOVA indicates that there is no difference between the selected anchors placed used either dry or wet cleaning. However this includes the Goujon anchors which it seems reasonable to claim would not be grossly affected by wet or dry cleaning methods since the anchor works on the principle of expansion rather than resin glue in. An analysis of the selected resin based anchors excluding Goujon anchors gave similar values of 34kN for wet cleaning and 35kN for dry[26]. Both reduced sub sets were normally distributed. The ANOVA test shows there is no difference between the wet and dry cleaning techniques for the resin based BP, IC and Collinox anchors in all slates. A more detailed analysis by slate type indicates there is no difference between the wet and dry cleaning techniques for BP, IC and Collinox anchors in each slate type.

Discussion

The project over extended itself in terms of variables. The original advised size of 5 anchors per parameter was insufficient to cope with the natural variations, let alone the subsequently introduced variables. Whilst it is unwise to undertake statistical analysis when the data does not fit the underlying assumptions of the statistical technique, it was considered that doing so would provide a useful indication. In most cases that indication was of no difference between sub sets. Apart from a need in many cases to increase sample size of the sub set to achieve normal distribution, it seems unlikely that doing so would change the indication of no difference. It is likely that only a few extra results in some sub sets would transform the set of data to become normally distributed.

The indicated lack of differences is significant in that it implies that there is no difference between slate types of Cwmorthin Back and Stripey Veins or Cambrian or Corris slate. There is an exception to this in that the pillar Cambrian slate site was found to be of soft rock. Whether this is site specific and other pillar rock would be more resistant to drilling is not known.

The choice of the four types of North Wales slate was based on covering four common types of north welsh slate. No evidence is to hand to consider the relationship of these types of slate to all slates. Geological evidence can no doubt be produced which will show which other mines are made in one of these slates. So it would be inappropriate to limit the consideration of using these anchors to just the 3 mines used as test beds.

Collinox anchor has a shaft 70 mm long by 10mm OD compared to 100mm long by 14mm OD for a Batinox anchor. Given the anchors work by gluing into the rock, it would seem reasonable to assume that the Batinox anchor would be stronger than a Collinox anchor for

[25] Sheet sel data 6 etc
[26] Sheet sel data 6 etc (2)

a given adequately strong rock substrate. (The information by Petzl indicates the Batinox anchor is suitable for softer rock than the Collinox anchor.) The results for Collinox anchors support the claim that the larger Batinox anchors are also likely to be adequate.

The IC anchors were placed without recessing the head. This causes the shaft to be around 1cm higher than would normally be the case. A hypothesis has been put forward that with the nature of notches at the base of the shaft, the force placed on the anchor would be transmitted mostly near the base of the shaft into the rock. Thus a greater placement depth of an IC anchor in rock would resist more force than a placement at a shallower depth. This hypothesis is based on a rock failure rather than a rock / resin bond failure (or failures within the resin, resin metal bond or metal). None of the IC anchor extractions exhibited 'deep' rock failure affecting the lower part of the shaft. The anchors mostly pulled out some distance before spalling occurred. Of the 16 IC anchors tested, only one resulted in substantial (more than 10cm) spalling away from hole. However, it is possible that recessing the head would have lead to even higher axial extraction forces.

In addition, the IC anchors were not set with the approved resin. Work recently undertaken on the approved resin (Fischer FIS V 360 S) with BP anchors (see http://british-caving.org.uk/wiki3/lib/exe/fetch.php?media=equipment_techniques:bp_anc_fischer_resin_report_150418.pdf) indicates that similar if not better results would be achieved for the IC anchor in conjunction with Fischer resin. Regrettably, the data cannot be used to make a judgement on the suitability of IC anchors in slate, even thought the mean force exceeds the criterion. However the data is strongly supportive that a proper test set would result in a set of data meeting the E&T criteria.

There was a suggestion of a link between depth of placement and extraction force. Table 8 presents the mean force from Table 5 together with length of the shank of the anchor and diameter of the drilled hole.

Anchor	Mean kN	SD kN	Length mm	Diameter mm
BP	38	4.7	96	16
IC	34	4.0	70	10
Goujon	34	5.8	60	12
Collinox	31	3.0	82	12

Table 8 Anchor forces and dimensions

The data shows no clear relationship.

It is noted that the Goujon anchors which failed below 37kN did so by being extracted from the rock. Whilst those which failed above 37kN did so by the Couer hanger snapping. The Couer hanger is rated to 25kN. It is emphasised that the hanger was subject to distortion in all cases.

Conclusions

A few extra samples are likely to improve the nature of the results by producing normally distributed sets of results for the major variables.

The results show that BP anchors meet the E&T criteria for adoption in the four types of North Wales slate of Cwmorthin Back and Stripey slate, Cambrian slate and Braich Goch Corris slate.

The results also show that both Collinox and 12mm Goujon meet expansion anchor coupled with the Coeur hanger meet both the European Standard and the UIAA criteria in the four type of North Wales slate.

The results for Collinox anchors support a claim that Batinox anchors are likely to also meet the European Standard and the UIAA criteria in the four type of North Wales slate.

The results show that IC anchors with KMR resin meet the meet the European Standard and the UIAA criteria in the four type of North Wales slate. Although the results are strongly indicative that IC anchors using Fischer resin would meet E&T's criteria, a new test set using the approved resin is required to be conducted before E&T should consider adopting the IC anchor for the four type of North Wales slate.

Recommendations

That E&T designate the BP anchor for use in slate mines which are located in the four types of North Wales slate of Cwmorthin Back and Stripey slate, Cambrian slate and Braich Goch Corris slate.

Thanks

Photographs were by G Thomas. Thanks go to Corris Mine Explorers for use of Corris Mine and Go Below for use of Cwmorthin Mine plus the many persons who helped carry gear, place anchors and conduct the tests.

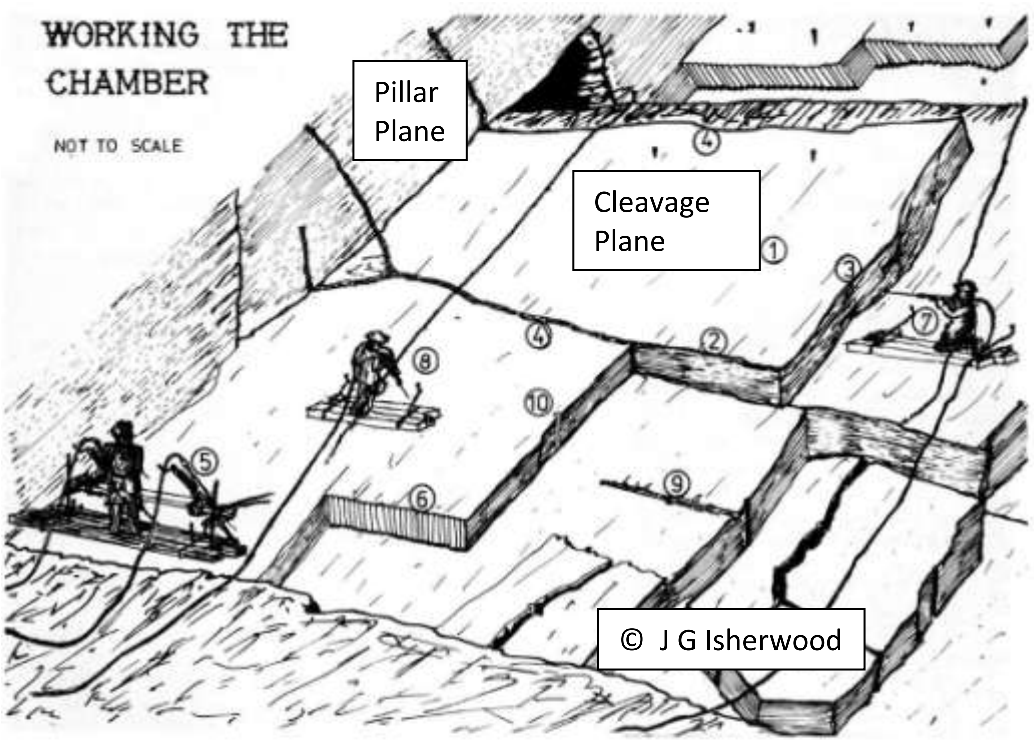
Bob Mehew
Gethin Thomas

October 2015

Annex 1 Cleavage planes in Slate

Slate is a metamorphosed rock made from mud and silt stones formed by mud and silt depositing out in water. Although the mud or silt stone may show bedding features based on the deposition, the process of metamorphosis involving both pressure and temperature can effectively remove this original bedding, replacing it by parallel cleavage planes which are at right angles to the orientation of the pressure. The metamorphosis can also cause segregation of minerals in changed forms aligning to the new cleavage planes. Metamorphosis usually occurs several times with different orientations of pressure, so different orientations of cleavage planes can build up in the slate. This leads to the ability to cleave a piece of slate in several ways.

These different lines of weakness enable the slate miners to mine in slate by using one plane, known as the cleavage plane to break out large pieces of slate whilst also breaking the slate along another plane, known as the pillar plane to terminate the piece of slate and thus leave pillars or walls of the excavated cavern. This is portrayed in the diagram below.



Annex 2 Raw Data

Pull order	Anchor Number	Confirmed Peak Load	Anchor type	Anchor location	Rock Plane	Exercise d	Dry	Failure mechanism	.mp4 file	re use hole
1	BP5	26	BP	Back Vein	Pillar	Yes	No	Resin/rock	PON 1 BP5	Y
2	BP6	28.99	BP	Back Vein	Pillar	No	No	Resin/rock	PON 2 BP6	Y
3	IC27	28.66	IC	Back Vein	Pillar	Yes	No	Resin/rock	PON 3 IC27	Y
4	IC30	29.37	IC	Back Vein	Pillar	No	No	Resin/rock	PON 4 IC30	Y
5	G4	37.48	Goujn	Back Vein	Pillar	No	No	Hanger snapped	PON 5 G4	N
6	C3	31.13	Collinox	Back Vein	Pillar	No	No	Resin/rock	PON 6 C3	Y
7	C1	30.58	Collinox	Back Vein	Pillar	Yes	No	Resin/rock	PON 7 C1	Y
8	G2	35.6	Goujn	Back Vein	Pillar	Yes	No	Rock cone failure	PON 8 G2	N
9	IC31	31.8	IC	Back Vein	Pillar	No	Yes	Resin/rock	PON 9 IC31	Y
10	BP11	34.5	BP	Back Vein	Cleavage	Yes	No	Resin/anchor	PON 10 BP11	N
11	G8	18	Goujn	Back Vein	Cleavage	Yes	No	Rock cone failure	PON 11 G8	N
12	G7	22	Goujn	Back Vein	Cleavage	No	No	Rock cone failure	PON 12 G7	N
13	C9	30.5	Collinox	Back Vein	Cleavage	Yes	No	Resin/rock	PON 13 C9	N
14	C10	32.61	Collinox	Back Vein	Cleavage	No	No	Resin/rock	PON 14 C10	N
15	IC29	35.19	IC	Back Vein	Cleavage	Yes	No	Resin/rock	PON 15 IC29	Y
16	BP14	37.02	BP	Back Vein	Cleavage	No	No	Anchor/resin	PON 16 BP14	Y
17	C12	28.23	Collinox	Back Vein	Cleavage	No	Yes	Resin/rock	PON 17 C12	Y
18	G13	32.15	Goujn	Back Vein	Cleavage	No	Yes	Rock cone failure	PON 18 G13	N
19	IC28	35.92	IC	Back Vein	Cleavage	No	Yes	Resin/rock	PON 19 IC28	Y
20	BP15	31.58	BP	Back Vein	Cleavage	No	Yes	Rock cone failure	PON 20 BP 15	N
21	IC26	33.06	IC	Back Vein	Cleavage	No	No	Rock cone failure	PON 21 IC26	N
22	BP6	36.64	BP	Stripey Vein	Pillar	Yes	No	Anchor/resin	PON 22 BP6	Y
23	G5	38.03	Goujn	Stripey Vein	Pillar	Yes	No	Hanger snapped	PON 23 G5	Y?
24	C1	32.16	Collinox	Stripey Vein	Pillar	No	No	Resin/rock	P1061453	Y
25	IC21	24	IC	Stripey Vein	Pillar	No	No	Resin/rock	PON 25 IC21	Y
26	C4	34.21	Collinox	Stripey Vein	Pillar	Yes	No	Resin/rock	PON 26 C4	Y

27	IC22	35.89	IC	Stripey Vein	Pillar	Yes	No	Resin/rock	PON 27 IC22	Y
28	G2	37.27	Goujn	Stripey Vein	Pillar	No	No	Hanger snapped	PON 28 G2	Y?
29	BP3	41.87	BP	Stripey Vein	Pillar	No	No	Anchor/resin	PON 29 BP3	Y
30	IC24	37.1	IC	Stripey Vein	Cleavage	No	No	Resin/rock	PON 30 IC24	Y
31	IC25	33.94	IC	Stripey Vein	Cleavage	No	No	Resin/rock	PON 31 IC25	Y
32	BP15	31.98	BP	Stripey Vein	Cleavage	No	No	Complex	PON 32 BP15	N
33	C7	34.12	Collinox	Stripey Vein	Cleavage	No	Yes	Resin/rock	PON 33 C7	Y
34	BP11	46.1	BP	Stripey Vein	Cleavage	No	No	Anchor/resin	P1061472	N
35	BP12	42.44	BP	Stripey Vein	Cleavage	No	Yes	Anchor/resin	P1061473	N
36	IC23	35.55	IC	Stripey Vein	Cleavage	No	Yes	Resin/rock	P1061474	Y
37	G10	38.12	Goujn	Stripey Vein	Cleavage	No	Yes	Hanger snapped	P1061475	Y?
38	G8	36.5	Goujn	Stripey Vein	Cleavage	No	No	Rock cone failure	P1061477 & 8	N
39	C9	31.86	Collinox	Stripey Vein	Cleavage	No	No	Resin/rock	P1061481	Y
40	C14	32.4	Collinox	Stripey Vein	Cleavage	No	No	Resin/rock	P1061483	Y
41	G13	37.56	Goujn	Stripey Vein	Cleavage	No	No	Hanger snapped	P1061484	Y?
42	IC16	34.83	IC	Cambrian	Pillar	No	No	Resin/rock	P1071511	Y
43	C2	18.53	Collinox	Cambrian	Pillar	No	No	Resin/rock	P1071512	Y
44	G7	20.23	Goujn	Cambrian	Pillar	No	No	Resin/rock	P1071513	?
45	BP12	41.44	BP	Cambrian	Pillar	Yes	No	Complex	P1071514	N
46	BP11	33.13	BP	Cambrian	Pillar	No	No	Rock cone failure	P1071515	N
47	G6	11.46	Goujn	Cambrian	Pillar	Yes	No	Rock cone failure	P1071516	N
48	C1	22.91	Collinox	Cambrian	Pillar	Yes	No	Rock cone failure	P1071517	N
49	IC17	25.39	IC	Cambrian	Pillar	Yes	No	Complex	P1071518	N
50	BP13	41.72	BP	Cambrian	Cleavage	No	No	Complex	P1071519	N
51	BP14	37.95	BP	Cambrian	Cleavage	Yes	No	Anchor/resin	P1071520	?
52	IC18	37.4	IC	Cambrian	Cleavage	No	No	Resin/rock	P1071521	?
53	G9	35.25	Goujn	Cambrian	Cleavage	Yes	No	Rock cone failure	P1071522	N
54	C21	31.72	Collinox	Cambrian	Cleavage	No	No	Resin/rock	P1075123	Y
55	G8	36.15	Goujn	Cambrian	Cleavage	No	No	Hanger snapped	P1075124	Y?
56	IC19	37.12	IC	Cambrian	Cleavage	Yes	No	Anchor/resin	P1075125	Y

57	C3	30.02	Collinox	Cambrian	Cleavage	Yes	No	Resin/rock	PON 57 C3	Y
58	IC20	34.34	IC	Cambrian	Cleavage	No	Yes	Anchor/resin	P1075127	Y
59	BP20	39.8	BP	Cambrian	Cleavage	No	Yes	Resin/rock	PON 59 BP20	N
60	G10	27	Goujn	Cambrian	Cleavage	No	Yes	Rock cone failure	PON60 G10	N
61	C5	30.68	Collinox	Cambrian	Cleavage	No	Yes	Rock cone failure	P1071535	N
62	BP12	29.59	BP	Corris	Pillar	Yes	No	Anchor/resin	P1131561	N
63	C2	32.02	Collinox	Corris	Pillar	Yes	No	Resin/rock	P1131562	Y
64	G7	35.33	Goujn	Corris	Pillar	Yes	No	Rock cone failure	P1131563	N
65	BP11	31.91	BP	Corris	Pillar	No	No	Anchor/resin	P1131564	Y
66	C1	21.89	Collinox	Corris	Pillar	No	No	Resin/rock	P113165	N
67	G6	36	Goujn	Corris	Pillar	No	No	Hanger snapped	PON 67 G6	Y?
68	BP14	38.43	BP	Corris	Pillar	Yes	No	Anchor/resin	P113167	N
69	C4	34.65	Collinox	Corris	Pillar	Yes	No	Resin/rock	P113168	Y
70	G9	38.81	Goujn	Corris	Pillar	Yes	No	Hanger snapped	P1131569	Y?
71	BP13	36.05	BP	Corris	Cleavage	No	No	Anchor/resin	P1131570	N
72	C3	32.68	Collinox	Corris	Cleavage	No	No	Resin/rock	P1131571	N
73	G8	37.99	Goujn	Corris	Cleavage	No	No	Hanger snapped	P1131572	Y?
74	BP15	43.07	BP	Corris	Cleavage	No	Yes	Anchor/resin	P1131573	Y
75	C5	34.44	Collinox	Corris	Cleavage	No	Yes	Resin/rock	P1131574	Y
76	G10	33.56	Goujn	Corris	Cleavage	No	Yes	Hanger snapped	P1131575	Y?

Pull order	Anchor Number	Confirmed Peak Load	peak load justified by	possibly discount	reason	Placement notes	Failure narrative
1	BP5	26	nmp, from rs	##	placement data	not enough resin used	Resin extracted as a plug, with the upper section looking dirty
2	BP6	28.99	nmp, from rs	##	placement data	not enough resin used	Resin extracting as a plug
3	IC27	28.66	nmp, from rs				Slight spalling. Maintained high load throughout extraction. Resin extracted with the anchor appeared to be acting as a wedge as the lower section of the anchor became visible
4	IC30	29.37	nmp, from rs				Slight spalling. Maintained high load throughout extraction, with resin extracted with the anchor
5	G4	37.48	nmp, from rs				Some indication of rock damage
6	C3	31.13	nmp, from rs				Resin cracked around peak load, then extracted relatively steadily
7	C1	30.58	nmp, from rs				Resin cracked around peak load, then extracted relatively steadily
8	G2	35.6	nmp, from rs				Spalling along the cleavage plane
9	IC31	31.8	nmp, from rs				Slight spalling. Maintained high load throughout extraction
10	BP11	34.5	nmp, from rs				Spalling 10-15cm around head. Twisted out leavening resin
11	G8	18	? This taken from voice record on movie, nmp, rs same				Significant rock failure (approx. 30cm around anchor). Anchor was placed a little over 20cm away from a clear crack
12	G7	22	? This taken from voice record on movie, nmp, rs same				Significant rock failure 30-40cm long
13	C9	30.5	nmp, from rs				Small amount of surface spalling, pulled out relatively steadily with resin around the anchor between the broad threads

14	C10	32.61	nmp, from rs				Small amount of surface spalling, pulled out relatively steadily with resin between the broad threads of the anchor. Anchor slightly bent
15	IC29	35.19	nmp, from rs				Very clean hole. Maintained high load throughout extraction
16	BP14	37.02	mp				Unscrewed leaving resin plug (cork screw)
17	C12	28.23	mp				Slight surface spalling, steady extraction
18	G13	32.15	mp				Large rock failure at peak load, at least 50cm long, approx. 2-3cm deep
19	IC28	35.92	mp				Very small amount of spalling, maintained high load throughout extraction
20	BP15	31.58	mp	##	post data	possibly compromised by previous anchor	Large spalling, likely relating to the crack generated by G13
21	IC26	33.06	mp	##	post data	possibly compromised by previous anchor	Large spalling, likely relating to the crack generated by G13
22	BP6	36.64	mp				Slight spalling, twisted out leaving resin. Maintained high load on extraction
23	G5	38.03	mp				Clean break of the hanger with some deformation of anchor
24	C1	32.16	mp wrong video				Clean extraction with resin still attached
25	IC21	24	rs gives 32.16, movie shows 31.16 but voice says maximum value at 24, assume failed to clear meter				Suspect error with reset of gauge. Probably more like 24kN peak load

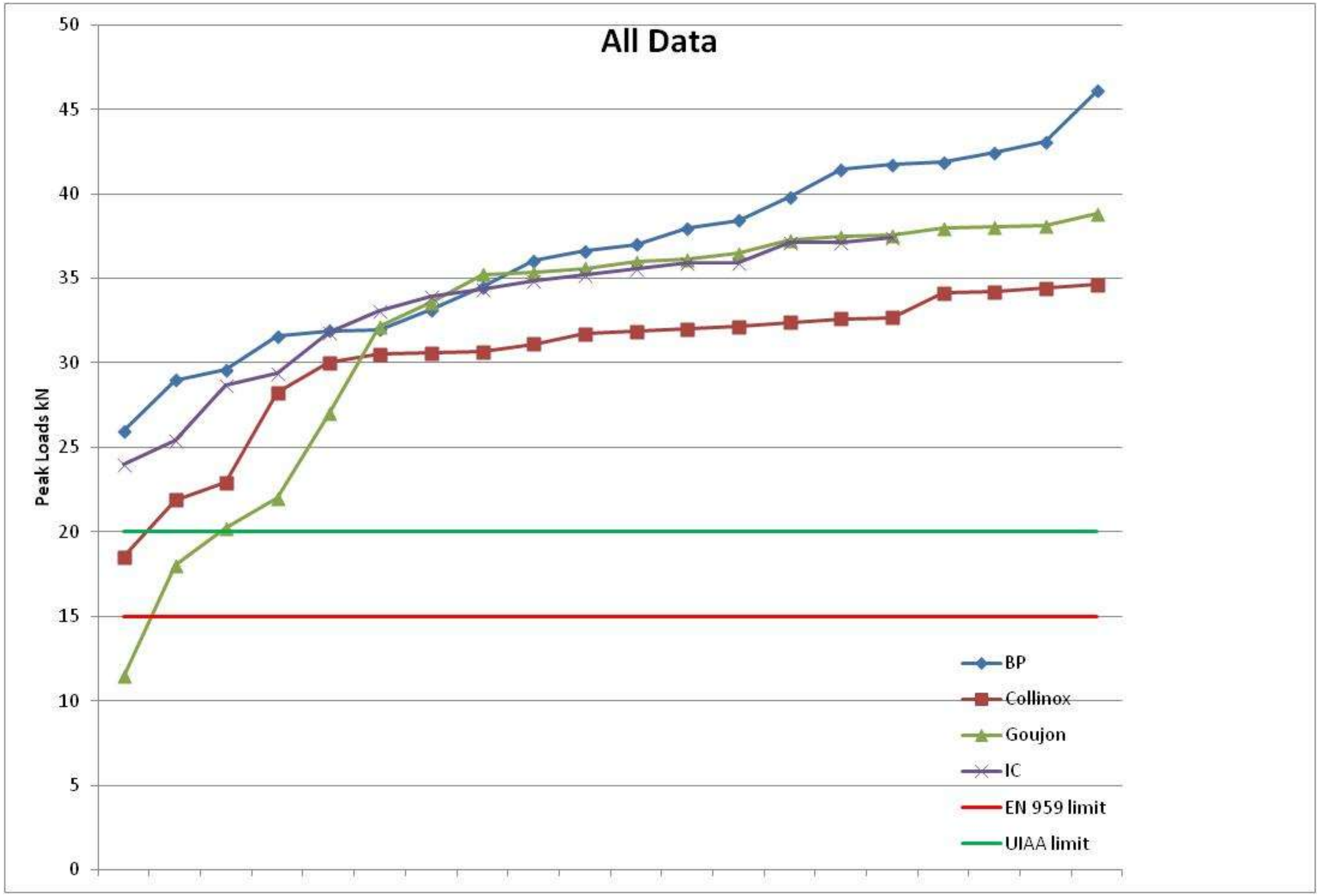
26	C4	34.21	mp				Clean extraction with resin still attached
27	IC22	35.89	mp note label in video wrong				Clean extraction maintaining high loads throughout
28	G2	37.27	mp				Hanger snapped, anchor slightly bent
29	BP3	41.87	mp				Twisted out leaving some resin in place. Fast extraction, quicker pumping!
30	IC24	37.1	mp				Very clean extraction maintaining high loads throughout
31	IC25	33.94	mp				Very clean extraction maintaining high loads throughout
32	BP15	31.98	mp				Initial anchor/resin failure but significant spalling at the end of the extraction (20cm)
33	C7	34.12	mp				Very slight spalling, extraction with resin plug
34	BP11	46.1	mp shows 46.10,voice said 46.01 in error				Twisted out with slight spalling. Maintained high load
35	BP12	42.44	mp note puller jammed which may have affected peak value	? ##	post data		Rig jammed during extraction. Spalling as anchor twisted out (approx. 10cm)
36	IC23	35.55	mp				Very clean extraction maintaining high loads throughout
37	G10	38.12	mp				Hanger snapped, anchor slightly bent
38	G8	36.5	mp				Significant "dinner plate" failure approx. 2-3cm deep and 30cm long
39	C9	31.86	mp				Slight surface spalling, clean extraction with some resin attached
40	C14	32.4	mp				Very slight surface spalling, clean extraction with resin attached

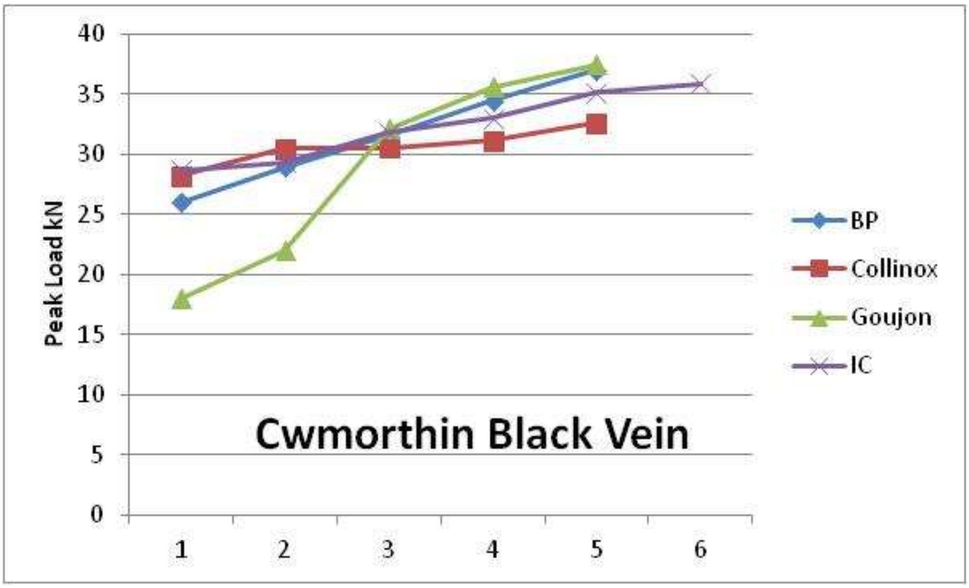
41	G13	37.56	mp showed 37.56, rs 37.58				Hanger snapped, anchor slightly bent
42	IC16	34.83	mp	##	placement data	soft rock	Clean extraction
43	C2	18.53	voice cites peak value, nmp, rs same	##	placement data	soft rock. Install error, hole drilled to deep (90mm not 70mm)	Clean extraction with resin clearly attached
44	G7	20.23	mp	##	placement data	soft rock	Relatively clean extraction
45	BP12	41.44	voice cites peak value, nmp, rs same	##	placement data	soft rock	Twisting out initially (resin/anchor bond failure), followed by rock failure along the cleavage plane
46	BP11	33.13	voice cites peak value, nmp, rs same	##	placement data	soft rock	Slight twisting at early stages followed by significant (40cm) rock failure along cleavage plane
47	G6	11.46	voice cites peak value, nmp, rs same	##	placement data	very soft rock	Some spalling, then relatively clean extraction
48	C1	22.91	voice cites peak value, nmp, rs same	##	placement + post data	very soft rock. Possibly compromised by G6	Rock failure along the cleavage plane
49	IC17	25.39	mp	##	placement + post data	very soft rock. Possibly compromised by G6	Small amount of rock spalled, and cracking followed by usual clean resin/rock failure and extraction
50	BP13	41.72	mp				Spalling around mid way through extraction, with cone failure. Mixed resin/anchor bond failure
51	BP14	37.95	mp				Small amount of surface spalling
52	IC18	37.4	mp				Very clean extraction maintaining high load throughout

53	G9	35.25	mp				Cone failure approx 15cm, as well as a larger (approx 30cm long) surface flake
54	C21	31.72	mp note label in video wrong				Clean extraction with resin plug evident
55	G8	36.15	mp				Anchor bent and hanger snapped in one place
56	IC19	37.12	mp				Very clean extraction maintaining high load throughout
57	C3	30.02	voice cites 30.04 but mp shows 30.02				Clean extraction with resin plug evident
58	IC20	34.34	mp just about voice says 30.04				Very clean extraction maintaining high load throughout, again!!
59	BP20	39.8	mp no voice to say BP 20 though anchor no 290 matches. note label in video wrong				Clean extraction with resin plug evident
60	G10	27	lost reading on meter voice cites 27				Significant spalling approx 40cm
61	C5	30.68	mp	##	post data	possibly compromised by G10	Significant spalling, piece approx 2cm deep and 30cm long. Possibly related to the previous anchor G10
62	BP12	29.59	mp				Some surface spalling, anchor "unscrewed" leaving the resin in place
63	C2	32.02	mp				Clean extraction with resin visible between the broad thread of the anchor
64	G7	35.33	mp				Catastrophic spalling around 50cm long, 20cm wide and 3cm+ deep

65	BP11	31.91	mp	##	post data	possibly compromised by rock failure of G7	Slight surface spalling, with anchor twisting out leaving the resin in place
66	C1	21.89	mp				Small amount of surface spalling, anchor extracted clean with resin visible between the broad threads
67	G6	36	lost reading on meter voice cites 36				Anchor bent, hanger snapped in one place
68	BP14	38.43	mp				Some surface spalling, with anchor twisting out leaving the rein in place
69	C4	34.65	mp				Some surface spalling, then anchor extracted clean with resin visible between broad threads
70	G9	38.81	mp				Anchor bent and hanger snapped in one place
71	BP13	36.05	mp note label in video wrong	##	placement data	anchor proud of the rock approx 10mm, install error	Some surface spalling (approx 10cm) then anchor twisted out leaving resin
72	C3	32.68	mp				Some surface spalling, then anchor extracted clean with resin visible between broad threads
73	G8	37.99	mp note label in video wrong				Anchor bent and hanger snapped in one place
74	BP15	43.07	mp				Very small surface spalling then anchor twisted out leaving resin
75	C5	34.44	mp				Some surface spalling, then anchor extracted clean with resin visible between broad threads
76	G10	33.56	mp				Anchor bent and hanger snapped in one place
mp = meter peak reading is captured in video image, note also vocal record captured by video							
nmp = no image in video							
rs = record sheet made at time of extraction							

Annex 3 Plots of all of the data

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Peak Load kN
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Cwmorthin Black Vein
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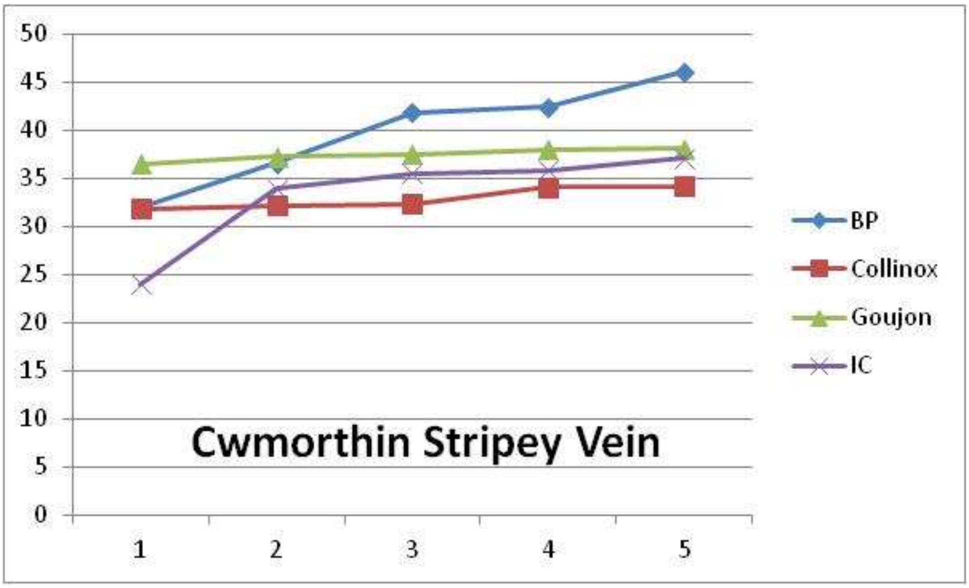
Collinox
Goujon
IC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Cwmorthin Stripey Vein
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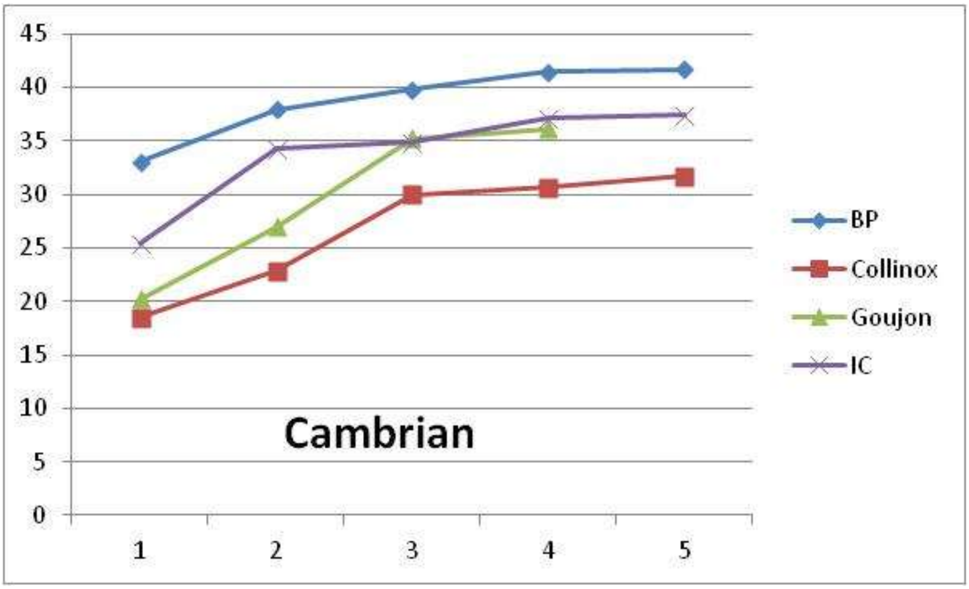
Collinox
Goujon
IC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Cambrian
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Collinox
Goujon
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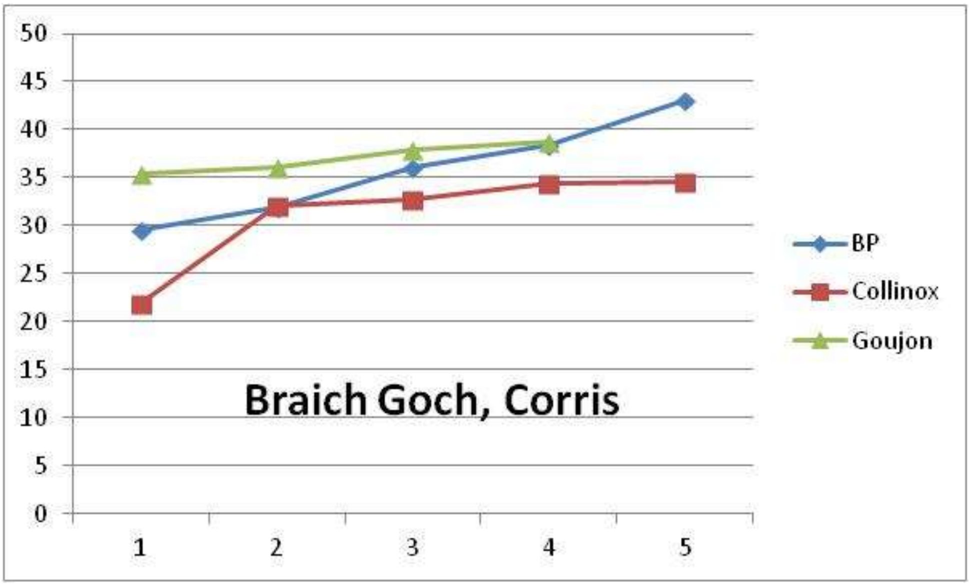
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Braich Goch, Corris
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Collinox
Goujon