Chapter 4

Culm Basin

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To the south of the Mississippian platform carbonate successions of South Wales (Chapter 5) and Bristol, Mendips and Somerset (Chapter 6), Carboniferous rocks predominantly occur within the strongly deformed Culm synclinorial belt of South-west England. The Culm Basin has a broad graben architecture, with an inner graben (Central Devon Sub-basin) flanked by half-grabens (Bideford and Launceston sub-basins) (Fig. 4.1; Leveridge & Hartley 2006; Waters *et al*. 2009). The Bideford Sub-basin is bounded to the north by the Brushford Fault, the Central Devon Sub-basin by the Greencliff Fault and the Launceston Sub-basin by the Rusey Fault. To the north of the Brushford Fault is the Northern Margin of the Culm Basin. The Tavy Basin has limited development of Famennian to Tournaisian strata. The High separating the Tavy Basin and Launceston Sub-basin includes a Tournaisian to ?Visean succession (Yeolmbridge and Laneast Quartzite formations). Remnants of Carboniferous strata also occur in the South Devon Basin.

In many areas there is no clear lithological break between the Tournaisian and the underlying Upper Devonian rocks, both of which are dominated by shallow marine and deeper water mudstones. The succession, commonly referred to as the Transition Series or Group (Dearman & Butcher 1959; Freshney *et al*. 1972), are assigned to the Exmoor Group in north Devon, the Hyner Mudstone and Trusham Mudstone formations of the eastern part of the Central Devon Sub-basin and the Tamar Group in south Devon.

During the late Tournaisian, both the Culm and South Devon basins displayed a transition to deposition within a pelagic and hemipelagic marine environment (Culm Supergroup). From late Tournaisian to mid Namurian, the Culm Supergroup is predominantly argillaceous, represented in the Culm Basin by the Teign Valley Group and in the South Devon Basin by the Chudleigh Group (Fig. 4.2). During this time the first major regional deformation migrated northwards through the province following closure of the oceanised Gramscatho Basin of southern Cornwall in the Late Famennian/Early Visean (Leveridge *et al*. 1990). Consequent uplift sourced deposits along the southern margin of the Culm Basin.

Following continental collision the predominantly Devonian southerly basins closed, inverted and deformed progressively, with deformation reaching the Culm Basin in the mid Namurian. Strata already deposited along the southern side of the basin, particularly in the Launceston Sub-basin, were inverted and thrust southwards out of the basin. Northward migration of the deformation continued through the Culm Basin, as the major lithostratigraphical divisions of the Pennsylvanian were being deposited (Lloyd & Chinnery 2002). The related contemporaneous uplift along the terrane bounding Bristol Channel/ Bray Fault to the north and east appears to have sourced the bulk of middle Namurian to Westphalian deposits of the Holsworthy Group (see Leveridge & Hartley 2006). With basin closure and consequent shallowing, continuing compression resulted in regional deformation in the late Westphalian.

Tournaisian

The outcrop of Tournaisian strata is limited to the northern and southern margins of the main Culm synclinorial belt (Fig. 4.1). In the Northern Margin of the Culm Basin (Fig. 4.2, Col. 1) and the Bideford Sub-basin (Col. 2), the Exmoor Group is represented wholly by the Pilton Mudstone Formation. Trilobites and ammonoids show the formation to range from the late Famennian *Wocklumeria* Zone to the Tournaisian *Gattendorfia* Zone and possibly into the *Ammonellipsites* Zone *s.l.* (Zone II) [T+1] (Goldring 1955). The pale greenish grey Pilton Mudstone Formation passes up into the black anoxic laminated unfossiliferous shales of the Doddiscombe Formation.

The Tournaisian rocks of the Central Devon Sub-basin crop out only along the southern margin (Fig. 4.1). In the Boscastle area (Fig. 4.2, Col. 3) conodonts from a limestone near the top of the Barras Nose Formation indicate a IIß/γ Zone [O1], of late Tournaisian age (Freshney *et al*. 1972). South of Tintagel, however, conodonts from a limestone at the top of the Barras Nose Formation and which was injected while still unlithified between the pillows of the succeeding Tintagel Volcanic Formation, indicate a Visean (IIδ/IIIα) age [O2] (Freshney *et al*. 1972). In the south-east of the sub-basin, in the Teign Valley (Fig. 4.2, Col. 5), the bluish grey Hyner Mudstone Formation spans the Devonian to Carboniferous boundary. A calcareous siltstone near the top of the formation yielded ostracodes indicating the presence of the late Famennian *hemispherica-dichotoma* ostracode Zone and latest Famennian *Wocklumeria* Zone trilobites. Mudstones immediately above this yielded *latior* Zone ostracodes from the basal Carboniferous *Gattendorfia* Zone [#1] (Selwood *et al*. 1984). The Hyner Mudstone is succeeded by the olive green and pale grey micaceous mudstones of the Trusham Mudstone Formation, which also contain ostracodes ~~ostracods~~ of the *latior* Zone [#2] (Selwood *et al*. 1984). In the central part of the Launceston Sub-basin (Fig. 4.2, Col. 7) the sandstone turbidites of the St Mellion Formation include ammonoids, ostracodes, conodonts and palynomorphs indicating that deposition commenced at least during the early Tournaisian *Siphonodella sandbergi* Zone[+O^1] (Whiteley 1983).

The Yeolmbridge Formation of the Tavy Basin (Fig. 4.2, Col. 8) contains *Gattendorfia* Zone ammonoids[+2] (Selwood 1960), upper *costatus* Zone (*Wocklumeria* Zone) and *duplicata* Zone (*Gattendorfia* Zone) conodonts (Stewart 1981) [O1] and mid Tournaisian miospores of the VI Zone (Whiteley 2004), which demonstrate that the formation ranges from the late Famennian to the early Tournaisian. In the South Devon Basin (Fig. 4.2, Col. 8), ammonoids, ostracodes, conodonts, and trilobites indicate an age range for the Whiteway Mudstone Formation of mid Famennian to early Tournaisian (e.g. House & Butcher 1973; Tucker & van Straaten 1970; Selwood *et al*. 1984). The uppermost part of the Whiteway Slate Formation contains *Gattendorfia* Zone ostracodes and trilobites [#T3], while conodonts in the lowermost part of the overlying Winstow Slate Member (basal Winstow Chert Formation) are of the upper *Siphonodella crenulata* Biozone[O4] (and probably post *Gattendorfia*, pre-*Pericyclus* Zone *s.l.* (Zone II)) (Matthews 1969). Remnants of a Famennian-Visean succession derived from the flanks of the Landulph High (Leveridge *et al*. 2002), at the northern margin of the South Devon Basin, are preserved in thrust sheets near Landulph as the Saltash Formation. The sequence yields Givetian to Famennian conodonts from limestone turbidite and nodular beds and slumped blocks within the mudstone (see Leveridge *et al*. 2002). It passes up through grey laminated mudstone

of early Tournaisian (Tn 1a and possible Tn 2) age with a diverse miospore population (Owens *et al*. 1993; Dean 1992) to black mudstone, with interbedded dark grey chert, yielding palynomorphs of probable Tournaisian age (Dean 1992).

Visean

The Visean succession of the Culm Basin Northern Margin, in the vicinity of Barnstaple, is characterised lithologically by chert. In the Fremington area (Fig. 4.2, Col. 1) a succession of dark shales, chert and impure limestone beds, the Fremington Member (Codden Hill Chert Formation) is about 46 m thick . The occurrence of the ammonoid *Goniatites* aff. *falcatus* suggests the presence of zones P_{1a} [+T2] and P_{1b} [+T3], with the top of the formation marked by *Neoglyphioceras spirale*, indicating a P_{2a} age [+4] (Prentice 1959). Farther to the south in the vicinity of Tawstock, but still in the Northern Margin Basin, the Codden Hill Chert Formation is around 91m thick and consists dominantly of chert with some shale and no limestone. Prentice (1959) described a trilobite fauna from his Bed 'X', which he recognised as occurring in Zones II and IIIα in Germany, suggesting proximity to the junction of late Asbian B_2 and P_{1a} Zones [+T2]. 64 m higher within the formation Prentice (1959) described a trilobite fauna from his Bed 'Y' suggestive of the IIIβ zone, equivalent to early Brigantian P_{1b-c} Zone [+T3].

To the south of the Brushford Fault, within the Bideford Sub-basin (Fig. 4.2, Col. 2), proximal limestone turbidites of the Westleigh Limestone Formation occur to the south of the distal carbonate turbidites of the Bampton Limestone Formation in the east of the basin, between South Molton and Bampton. The Kersdown Chert Member, present in the lower part of the Bampton Limestone Formation includes ammonoids of the *Fascipericyclus-Ammonellipsites* Zone [+O1] (Prentice & Thomas 1965). The latter location also includes conodonts which indicate a Zone II age (late Tournaisian to early Visean) (Matthews & Thomas 1974). *Neoglyphioceras spirale* is found near the top of the Bampton Limestone, Westleigh Limestone and Codden Hill Chert formations (Prentice 1959; Whiteley 2004), indicating a lateral correlation of the formations across the Bideford Sub-basin and Culm Basin Northern Margin (see above). This and other ammonoids present (Prentice & Thomas 1965; Mathews & Thomas 1974) indicate a P_{1b} to P_{2a} (early to mid Brigantian) age for the upper part of the Bampton Limestone Formation and late Asbian (B_2) and Brigantian (P_{1d} to P_{2a}) age for the upper part of the Westleigh Limestone Formation [+O4], the latter supported by the presence of indigenous conodonts (Matthews & Thomas 1974) which suggest an equivalent age of *bilineatus* up to *nodosus* conodont zone ages (Zone II to IIIγ).

Outcrop of Visean strata in the Central Devon Sub-basin is limited to its southern margin and it is fragmented by tectonics. The Teign Chert Formation (in this area previously termed the Firebeacon Chert) present in the Wilsey Down Borehole (Fig. 4.2, Col. 3) includes *Posidonia becheri* and *Neoglyphioceras spirale* (McKeown *et al*. 1973), indicating a Brigantian age [+*3]. Farther east and towards Launceston (Fig. 4.2, Col. 4) the formation contains ammonoids and bivalves showing a range of between P_1 and P_{2a} [+*1] (McKeown *et al*. 1973). In the Teign Valley (Fig. 4.2, Col. 5), near the base of the *Posidonia* beds, present within the upper part of the Teign Chert Formation, a B_2 Zone is indicated by the occurrence of *Entogonites grimmeri* and *Bollandoceras micronotum* as well as conodont material [+O3] (Butcher & Hodson 1960; Selwood *et al*. 1984; Riley 1991). Other ammonoids such as *Girtyoceras* sp., *Hibernioceras* cf. *carraunense* and *Sudeticeras* aff. *ordinatum* suggest the zones

present in the *Posidonia* beds ranges from B_2 to P_{2a} [+4]. Only the topmost *Posidonia* beds of the Teign Chert Formation yielded *Posidonia becheri* and *Neoglyphioceras spirale*.

In the western part of the Launceston Sub-basin, conodonts indicative of the *Gnathodus texanus* Zone (e.g. *G. texanus*, *G. pseudosemiglaber*, and *Polygnathus* cf. *bischoffi*) and the *G. bilineatus* Zone (Whiteley 1983) in the Boscastle Formation (Fig. 4.2, Col. 6) indicate a Chadian to Asbian age for the formation. The interdigitating Buckator Formation contains conodonts ranging from the Famennian *Scaphignathus velifer* Zone (Selwood *et al*. 1985) to the late Visean *Gnathodus bilineatus* Zone. Ammonoids of P_1-P_2 age (McKeown *et al*. 1973) from the Teign Chert (formerly Fire Beacon Chert) Formation indicate a late mid and late Visean age [+1]. In the central part of the Launceston Sub-basin (Fig. 4.2, Col. 7) the Teign Chert (formerly Newton Chert) Formation contains a varied fauna which includes bivalves (e.g. *Posidonia becheri*), ammonoids (e.g. *Neoglyphioceras spirale*), Cyrtosymbolinid and Griffithidinid trilobites, and conodonts of the *Scaliognathus anchoralis*, *Gnathodus texanus* and *Gnathodus bilineatus* zones [+O~T2] indicating an early to late Visean age for the formation (Leveridge *et al*. 2002). The sandstone turbidites of the St Mellion Formation, first deposited within the sub-basin during the Tournaisian, extend throughout the Visean.

In the South Devon Basin (Fig. 4.2, Col. 8) *Posidonia* beds towards the top of the Winstow Chert Formation are rich in corals, brachiopods, posidoniids, ammonoids, with some trilobites, and indicate an age range extending from B_2 (House & Butcher 1973) to P_{2a} (Selwood *et al*. 1984) [*+T6].

Namurian

Rocks of Namurian age form an extensive outcrop in the Central Devon Sub-basin and lesser outcrops in the subsidiary half-grabens to the north and south. The early Namurian succession is mudstone-dominated and represents continuation of deposition of the pelagic/hemi-pelagic Teign Valley Group. During the mid to late Namurian there is a markedly diachronous influx of northerly-sourced distal turbiditic sandstones into the Culm Basin (Holsworthy Group).

In the Northern Margin of the Culm Basin (Fig. 4.2, Col. 1), the Dowhills Mudstone Formation (former Limekiln Beds) of the Fremington area, contain the ammonoids *Reticuloceras reticulatum* and *Bilinguites gracilis* along with the bivalve *Dunbarella* rhythmica, indicative of R_{1c} [+5] and R_{2a} [+6] zones (Moore 1929; Butcher & Hodson 1960). Here the formation rests directly upon the Visean Codden Hill Chert Formation. To the south-east, along the east-west trending Tawstock Anticline, Prentice (1959) showed similar Dowhills Mudstone (Limekiln Beds) resting on Codden Hill Chert. However, just to the north of this anticline, at Venn Quarry, a sequence of turbiditic sandstones (Venn Sandstone), interpreted to be part of the Crackington Formation, yielded ammonoids of H_{1b} age [+4]. The Venn Sandstone may represent a feeder system supplying the Crackington Formation further south.

In the Bideford Sub-basin (Fig. 4.2, Col. 2), the dominantly mudstone-rich Dowhills Mudstone Formation of the Bampton area yield Brigantian (P_{2a}) [+5] and early Namurian (E_2) [+6] ammonoids in the basal beds (Edmonds 1974). In this sub-basin, the youngest fauna from the formation is of R_{1b} Zone [+7] (Prentice & Thomas 1960;

Edmonds 1974) whilst the earliest fauna from the overlying Crackington Formation between Bideford and Brushford areas is R_{2c} age [+8] (Butcher & Hodson 1960). In the western end of this sub-basin, the Crackington Formation is overlain by the Westward Ho! Member (Bideford Formation), which comprises sandstones deposited at or near wave base on an offshore slope (Xu Li, 1990). Xu Li (1990) quoted Eagar as suggesting that the species of *Carbonicola* and *Naiadites* present in the basal part of the overlying paralic Bideford Formation indicates a late Namurian age, below the *Gastrioceras cumbriense* marine band.

Namurian strata, mainly represented by the Crackington Formation, have a wide outcrop area within the Central Devon Sub-basin. Ammonoids have been found showing the presence of almost all the zones with the exception of those of Pendleian to early Arnsbergian between E_{1a} and E_{2b} ages (Fig. 4.2, Cols. 3, 4 & 5). In the Boscastle–Crackington Haven area (Fig. 4.2, Cols. 3) the Crackington Formation includes ammonoids of the H_{1a}, H_{1b}, $R_{1a}2$, $R_{1b}2$, R_{1c}, R_{2b}, $R_{2c}1$ and $R_{2c}2$ [+4] zones (Freshney *et al*. 1972). Further to the east (Fig. 4.2, Cols. 4) ammonoids of the E_{2c}, H_{1a}, H_{1b}, H_{2b}, R_{1a}, R_{1b}, R_{1c}, $R_{2a}1$ and R_{2b} zones are recorded [+2] (McKeown *et al*. 1973). The boundary between the Ashton Mudstone Member (Dowhills Mudstone Formation) and the Crackington Formation is poorly constrained, though McKeown *et al*. (1973) suggested that the shale-dominated succession ranges up to strata of Alportian age. In the southeastern area of the Central Devon Sub-basin, the mudstone-dominated Ashton Mudstone Member (Dowhills Mudstone Formation) in the Teign Valley (Fig. 4.2, Col. 5) includes ammonoids indicating an E_{2b} age in the upper part [+5], and E_{2c} ages in the lower part of the overlying Crackington Formation [+6] (Selwood *et al*. 1984). In the Exeter area, the base of the Crackington Formation is diachronous, ranging from H_{1a} to R_{1c} age and youngest strata of R_{2b} age [+7] (Edwards & Scrivener 1999).

In the western part of the Launceston Sub-basin (Fig. 4.2, Col. 6), extension of the Boscastle Formation into the Namurian is indicated by the presence of ammonoids *Nuculoceras nuculum* (E_{2c}) and *Isohomoceras subglobosum* (H_{1a}) (Freshney *et al*. 1972) [+4]. In the central part of the Launceston sub-basin (Fig. 4.2, Col. 7) the St Mellion Formation extends into the early Namurian [+3] with *Nuculoceras nuculum* and *Zephyroceras darwenense* assigned to E_{2c} by N Riley (*in* Leveridge *et al*. 2002). The age range of the overlying proximal turbidite sandstone succession of the Bealsmill Formation is not known but *Homoceras* Zone fossils [+4] are recorded (Butcher 1959).

In the South Devon Basin (Fig. 4.2, Col. 8) the Namurian succession is dominated by the southerly-sourced proximal turbidites of the Ugbrooke Sandstone Formation. Immature ammonoids from near the base of the formation are tentatively dated as Namurian E or H Zone [+3] (House & Butcher 1973).

Westphalian

The Westphalian rocks of the Culm Basin encompass the topmost distal turbidites of the Crackington Formation, all of the overlying more proximal Bude Formation and the upper part of the Bideford Formation. Since the Westphalian strata are less marine overall compared with the underlying Namurian succesion, faunas are restricted in the case of ammonoids to comparatively thin black shales representing marine incursions. Non-marine bivalves have proved of some use in the paralic Bideford Formation.

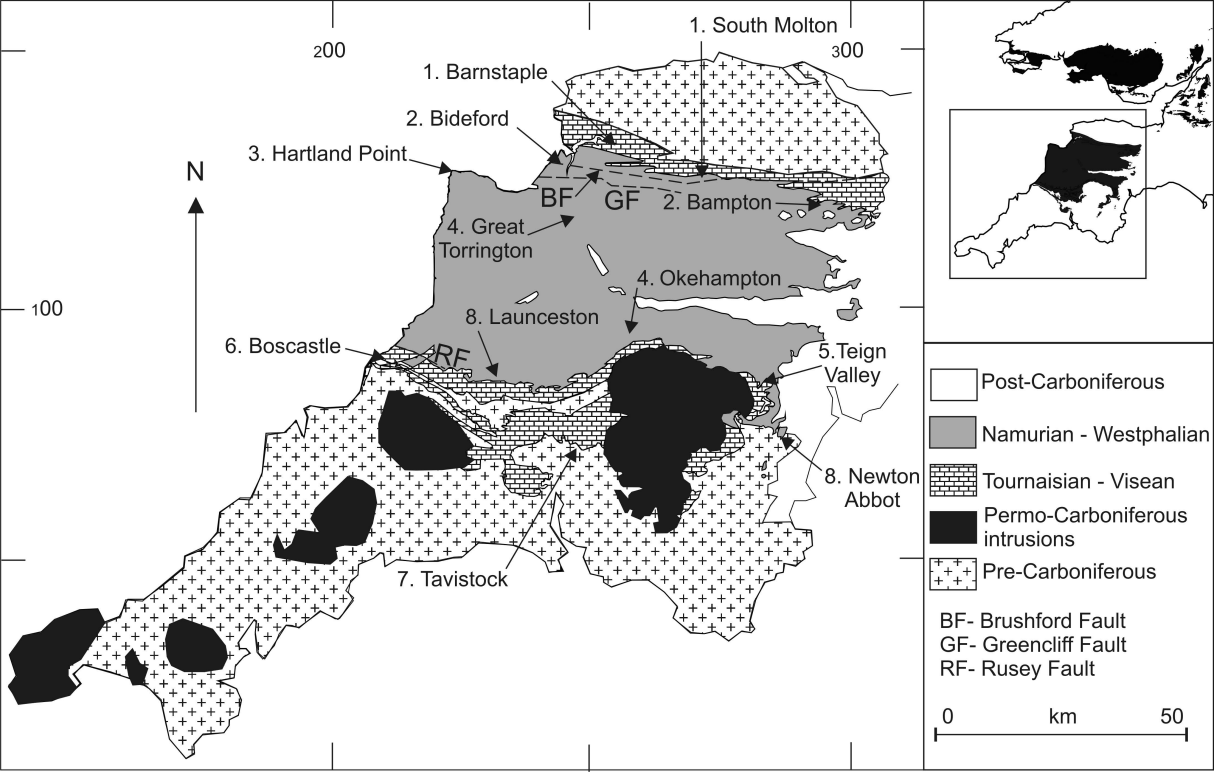
In the Northern Margin of the Culm Basin (Fig. 4.2, Col. 1) the only material dateable as Westphalian occurs at Instow, where Prentice (1959) described distal turbiditic sandstones and shales, with the Listeri and Amaliae marine bands $^{+7}$ occurring in the upper part of the Crackington Formation.

In the Bideford Sub-basin (Fig. 4.2, Col. 2) the Crackington Formation of the Bampton area extends into the Langsettian, with both *Gastrioceras subcrenatum* and *G. listeri* being present $^{+9}$ (Thomas 1963). The Westphalian in the west of this basin between, Westward Ho! and Umberleigh, is represented by the upper part of the Bideford Formation above and including Cycle 4 of De Raaf *et al.* (1965). Most of the formation is of deltaic origin but one marine incursion is marked by a black mudstone at the base of Cycle 6 which yielded *Gastrioceras amaliae* probably from the same level as the Vanderbeckei Marine Band. Higher up, at the base of Cycle 9, the presence of the non marine bivalves *Carbonicola extenuata, C. crispa, C.* cf. *extima* and *C. proxima* indicate the top of the Lenisulcata Chronozone $^{\sim 10}$ (Langsettian). The Bideford Formation appears to pass eastward beyond the River Taw into strata indistinguishable from those of the Bude Formation.

Westphalian strata occupy a large outcrop area in the Central Devon Sub-basin, mainly represented by the Bude Formation. The Subcrenatum Marine Band is found in the Crackington Formation at many localities ranging from North Cornwall to the Hartland area (Fig. 4.2, Col. 3) $^{+5}$ (Thomas 1963). The Listeri Marine Band is even better represented and commonly contains *G. listeri, G.* cf. *coronatum, G. circumnodosum, Anthracoceratites* cf. *reniformis* as well as the bivalve *Dunbarella papyracea.* In the Hartland area of the north Devon coast (Fig. 4.2, Col. 3), the top of the Crackington Formation includes the *A*maliae Marine Band $^{+6}$ from the Hartland Quay Shale (Freshney *et al*. 1979). The Sandy Mouth Shale, another higher marine band above the *A*maliae Marine Band, is characterised by the occurrence of the ammonoid *Anthracoceratoides cornubiensis* as well as the bivalves *Dunbarella* sp. and *Canyella* sp. (Freshney *et al*. 1979). The base of the Bude Formation is diachronous with respect to the Amaliae Marine Band. The characteristic facies, including the massive sandstones and slump beds, can start below or above the marine band. The highest Westphalian strata in the Culm Basin are from the base of the Bolsovian at the horizon of the Aegiranum Marine Band, identified by the occurrence of *Gastrioceras depressum* and '*Anthracoceras' hindi* $^{+7}$ in the Warren Gutter Shale (Freshney *et al*. 1979).

Fig. 4.1. Geological map showing the distribution of Carboniferous strata from the Culm Basin, adapted from IGS (1979).

Fig. 4.2. Correlation of Carboniferous successions in the Culm Basin of South-west England. The nomenclature is that of Waters *et al*. (2007; 2009), with details from the following publications: Col. 1 from Prentice (1959) and Waters *et al*. (2009); Col. 2 from Burt *et al*. (in prep.) and Waters *et al*. (2009); Col. 3 from Freshney *et al*. (1972); Col. 4 from McKeown *et al*. 1973; Col. 5 from Selwood *et al*. (1984); Col. 6 from McKeown *et al*. 1973; Col. 7 from Leveridge *et al*. (2002); Col. 8 from Selwood *et al*. (1984).


1. South Molton
200
300
1. Barnstaple
2. Bideford
3. Hartland Point
N
BF
GF
2. Bampton
4. Great Torrington
4. Okehampton
100
8. Launceston
6. Boscastle
RF
5.Teign Valley
8. Newton Abbot
7. Tavistock
Post-Carboniferous
Namurian - Westphalian
Tournaisian - Visean
Permo-Carboniferous intrusions
Pre-Carboniferous
BF- Brushford Fault
GF- Greencliff Fault
RF- Rusey Fault
0
km
50