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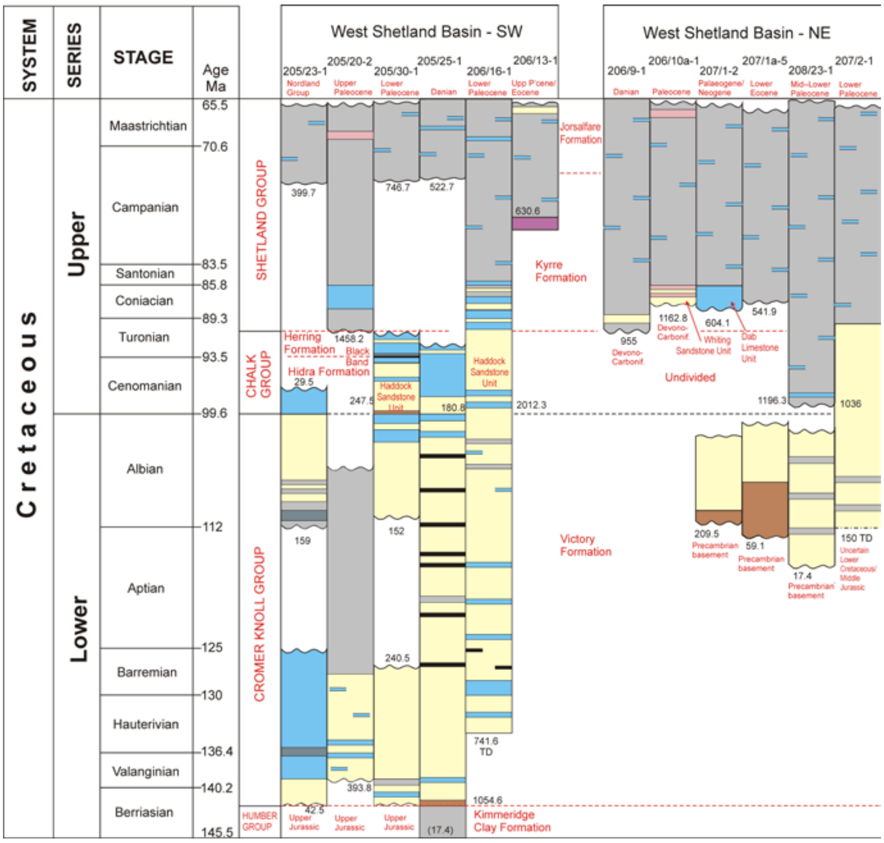
Cretaceous Tectonostratigraphy of the Faroe–Shetland Region

Marine Geoscience Programme

Commissioned Research Report CR/10/144



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Cretaceous Tectonostratigraphy of the Faroe–Shetland Region

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Cretaceous; Faroe-Shetland region; tectonostratigraphy.

Front cover

Stratigraphical-range chart for the West Shetland Basin (see Figure A1.2 for details).

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Foreword

This report is the result of a study by the British Geological Survey (BGS) into the Cretaceous tectonostratigraphic development of the Faroe–Shetland region. The report presents a detailed stratigraphical analysis of the released commercial well database, together with relevant BGS boreholes, and a series of stratigraphic-range charts have been produced. These charts form the basis for a set of timeslice reconstructions, based on the rock record, which have been utilised in order to gain an understanding of basin development in this region. In addition, key seismic sections linked to the stratigraphic-range charts provide a correlation tool for the identification of regionally synchronous unconformities. The timing of change recorded by both the rock record and the seismic data is investigated with regard to the tectonic setting of the Faroe–Shetland region in an attempt to better understand the driving mechanisms and controls on the development of the proto-NE Atlantic margin.

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Responsibilities of individual authors during the production of the report have been as follows:

M S Stoker	Summary, chapters 1–5, and Appendices 1 and 2
D B McInroy	Major contribution to chapter 2
H Johnson	General contribution to understanding the Cretaceous stratigraphy
J D Ritchie	General contribution to understanding the Cretaceous stratigraphy, and project management

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Summary

This report presents a set of observations from the rock record and seismic data that detail aspects of the Cretaceous succession in the Faroe–Shetland region, and which have provided the basis for a regional tectonostratigraphic framework. Timeslice reconstructions showing basin history and lithofacies, combined with seismic stratigraphic information that includes the record of contemporary tectonic events, provide chronological indicators of change in the Faroe–Shetland region. These changes are considered in relation to both local and regional tectonic events; the latter includes key events related to the developing North Atlantic spreading centre, in an attempt to better understand the driving mechanisms and controls on the development of the proto-NE Atlantic margin.

The first part of the report (Chapter 1) introduces the project and the context of the study. In particular, the common assumption that, along the NW European margin, Late Jurassic rifting extended into the Early Cretaceous as a single event; a premise that commonly overlooks one of the most fundamental events in the evolution of the NE Atlantic margin – the rotation of the principal extension vector from E–W to NW–SE. Another common misconception is that the Late Cretaceous interval represents a phase of thermal sag and general tectonic quiescence in the Faroe–Shetland region. Such assumptions have generally been the result of speculative application of the North Sea Cretaceous setting to the Atlantic margin; this study aims to rigorously test these assumptions by providing a clear set of regional observational data that provide a direct record of events for the Cretaceous succession in the Faroe–Shetland region. Due to the availability of data, our focus is on the eastern half of the Faroe–Shetland region.

This is followed in Chapter 2 by a summary of the regional geological framework, both of the proto-NE Atlantic margin and the Faroe–Shetland region. The latter incorporates published information combined with observations from this study, with a particular focus on the regional seismic-stratigraphic expression of the Cretaceous succession. By choosing a set of seismic profiles across the eastern part of the Faroe–Shetland region, a seismic-stratigraphic scheme has been established, which probably represents the first regional integration of seismic data. This scheme is calibrated with the well database and, thus, provides important chronological information for several regional unconformities.

Chapter 3 presents a summary of the Cretaceous tectonostratigraphy of the Faroe–Shetland region, based on a set of timeslice reconstructions that address: 1) basin history; 2) lithofacies; and, 3) lithostratigraphy. These timeslice maps are intended to provide a series of base layers for anyone wishing to undertake future palaeogeographic and/or palinspastic reconstructions. The timeslice reconstructions are underpinned by the set of stratigraphical-range charts and the regional correlation chart presented in Appendices 1 and 2, respectively. The stratigraphical-range charts detail the chronological range, lithology and lithostratigraphy of the Cretaceous record for each commercial well and BGS borehole, whereas the correlation chart summarises this record on the scale of the individual basin, sub-basin or high. The timeslice reconstructions reveal a highly variable history of differential uplift and subsidence throughout the Cretaceous period, which has important consequences for the tectonic development of this region. Key conclusions include: 1) confirmation that the Early Cretaceous rifting phase is distinct and separate from Late Jurassic rifting; 2) Cretaceous basin development was highly variable and occurred against a backdrop of polyphase extension, uplift and compression, as well as a rising eustatic sea level; and, 3) the Upper Cretaceous succession does not show a simple pattern of ‘post-rift’ subsidence – indeed it is difficult to define a classic post-rift phase to this framework.

In Chapter 4, we discuss the implications of our study with regard to the tectonic development of the proto-NE Atlantic margin, by correlation of key local tectonic phases with established regional tectonic events in Europe and the North Atlantic region. The pattern of co-eval extension and compression that is observed is consistent with regional strike-slip associated with transtension and transpression; thus, given the location of the Faroe–Shetland region relative to

the developing North Atlantic spreading centre (e.g. Figure 2.1), as well as the Alpine collisional zone, it is not surprising that this area developed as a zone of oblique strike-slip motion.

Chapter 5 presents a set of conclusions that summarise the key points of the study. There is no doubt that the highly variable pattern of sedimentation and protracted tectonic history were both influenced by the development of the proto-NE Atlantic margin.

1 Introduction

In general, the Cretaceous tectonic setting of the United Kingdom Continental Shelf (UKCS) has been poorly understood throughout much of its exploration history. In the North Sea, for example, extensional tectonic models for the Jurassic were commonly extrapolated into the Early Cretaceous, whereas Tertiary thermal subsidence/halokinetic models were applied downwards into Upper Cretaceous chalk sections (Oakman and Partington, 1998). Reconstructions of the Arctic–North Atlantic region have long considered that a rift system, including the North Sea and proto-NE Atlantic margin, connected the Arctic and Tethyan realms since the Late Permian, though marine connections are postulated only since the Jurassic (Ziegler, 1988; Knott et al., 1993; Torsvik et al., 2002). The presence of a Jurassic marine seaway along the proto-NE Atlantic margin has been confirmed by BGS and commercial drilling, though significantly, perhaps, most of the proven occurrences of Jurassic strata are confined to the basins and highs that occur peripheral to the eastern margin of the Faroe-Shetland and Rockall basins (Ritchie and Varming, 2011; Evans, In press).

There is no doubt that deposits of the Upper Jurassic Kimmeridge Clay Formation extend into the Berriasian (Lowest Cretaceous) in the Faroe–Shetland region; however, most wells in the area record an unconformity between this unit and the overlying Lower Cretaceous Cromer Knoll Group. Thus, the premise that Late Jurassic rifting extended into the Early Cretaceous as a single event may be fundamentally flawed, not least because the axis of rifting changed markedly from a N–S trend (E–W extension) in the Jurassic to a NE–SW trend (NW–SE extension) in the Early Cretaceous (Lundin and Doré, 1997; Doré et al., 1999; Torsvik et al., 2002; Lundin, 2002). This essentially represents the abandonment of the Tethyan-driven North Sea and Hebridean rift basins in favour of a tectonic stress regime linked to the northward propagation of seafloor spreading associated with the developing Central Atlantic Ocean.

Despite the ever-improving plate kinematic reconstructions of the Arctic–North Atlantic region, it is fair to say that considerable uncertainty and debate remain over the mechanics of basin formation along the developing plate margins. On the Norwegian margin, for example, a number of contrasting mechanisms have been invoked to explain postulated tectonic events, including extensional, strike-slip, compressional and salt tectonic models, in addition to non-tectonic scenarios (cf. Færseth and Lien, 2002 and references therein). Inspection of the released well database in the Faroe–Shetland region has proved a Cretaceous succession that is punctuated by numerous unconformities, most prevalent in the Lower to Mid-Cretaceous section, but also revealing a record of localised uplift of intrabasinal highs during Late Cretaceous time (Stoker and Ziska, 2011). In light of such uncertainty, the Faroe-Shetland consortium of oil companies commissioned this regional study of the Cretaceous development of the Faroe–Shetland region, with a view to providing a basis for the establishment of a better understanding of the Late Mesozoic evolution of this part of the proto-NE Atlantic margin.

1.1 SCOPE AND OBJECTIVES

The project was primarily based on a study of borehole and well data, supported by seismic data (where available), in order to better define the character and distribution of the Cretaceous succession in the Faroe–Shetland region. The area of study was focused on the eastern half of the Faroe–Shetland region as a consequence of the available data; essentially 58.5–63º N, 0–5º W (Figure 1.1). It should be noted that this designated area also incorporates the southern end of the Møre Basin; however, a detailed appraisal of this basin is beyond the scope and remit of this project. The structural elements (basins, sub-basins, faults and lineaments) underpinning the study area are as defined by Ritchie et al. (2011).

The major objective of the study was to establish the regional variability of Cretaceous uplift and subsidence in this area, in both time and space, with a view to setting the boundary conditions for anyone wishing to undertake palaeogeographic and/or palinspastic reconstructions. In order to achieve this, we have concentrated largely on the rock record as the basis for establishing the best possible Cretaceous tectonostratigraphic framework based on proven data points. Although this has built upon the lithostratigraphic framework of Ritchie et al. (1996), it should be noted that the well database available for this study has increased four-fold since the publication of their stratigraphic scheme. Seismic data, where available, have been utilised to aid the recognition and character of bounding surfaces, and internal geometry of the basin fill. As part of the general data gathering process, all stratigraphical information associated with this study will be incorporated into the ArcGIS database that is being created on behalf of the Faroe-Shetland Consortium.

1.2 DATA SOURCES

There are four main sources of information:

1. Published scientific literature.
2. BGS borehole database.
3. Released commercial well-logs.
4. Released seismic reflection data contributed by the Faroe-Shetland Consortium members.

1.3 METHODOLOGY

Well-log and core information taken from 122 released commercial wells and two BGS boreholes form the major component of this regional study (Figure 1.1 and Table 1.1). All available wells are from the UKCS. The stratigraphical-range of the Cretaceous sequence in each well-log/borehole has been captured on a series of seven charts (Appendix 1) that have been constructed for the various basins, sub-basins, and structural highs tested by the wells and boreholes within the study area (Table 1.1). In addition to the age range, the charts also include lithology, thickness, and lithostratigraphical information derived from the original well-logs, accompanying biostratigraphical reports (where available), and published papers. These charts are very slightly modified from those presented by Stoker and Ziska (2011) for the Faroe-Shetland Basin Regional Report. Each structural element has been further summarised in a single correlation chart (Appendix 2), which enables the regional context to be visualised on one diagram.

The dataset formed by the stratigraphical-range charts underpins the entire study as it enables a series of time-slice maps to be constructed for the Faroe–Shetland region. A total of fourteen maps has been produced; these comprise the twelve Cretaceous stages (Figure 1.2), as well as the Mid-Cretaceous (Albian/Cenomanian) and Cretaceous/Palaeogene boundaries. A distinction between Early Berriasian and Late Berriasian–Valanginian essentially represents the boundary between the Humber and Cromer Knoll groups. The value of these maps is that they provide an immediate visual appreciation of the spatial and temporal variation in structural development across the region, based on the actual rock record. Three different sets of maps have been established: 1) basin history (essentially recording when specific basins were actively receiving sediment); 2) lithofacies variation; and, 3) lithostratigraphy. These maps are intended to provide an impartial observational dataset, within the limits of the well database, for anyone wishing to undertake palaeogeographic and/or palinspastic reconstruction. In order to maintain the integrity of this dataset, we have refrained from such speculative reconstruction.

A series of seismic reflection lines, from the database available to us, has been incorporated to provide the basis for an appraisal of the Cretaceous seismic architecture of the main basins/sub-basins. This task was facilitated by the identification of three key mappable boundaries: 1) Base Cretaceous (commonly base of Cromer Knoll Group); 2) Near-base Upper Cretaceous; and, 3) Top Upper Cretaceous. The well database together with published information was utilised wherever possible to calibrate these boundaries, although it should be acknowledged that in large parts of the Faroe-Shetland Basin well control is poor. In this report, this appraisal of the basinal seismic architecture is included as part of the regional setting of the Cretaceous succession; however, key elements of the seismic stratigraphy are integrated into the tectonostratigraphic framework.

2 Regional Geological Framework

2.1 THE PROTO-NORTH-EAST ATLANTIC MARGIN

The Faroe–Shetland region forms part of the Atlantic margin of NW Europe, which encompasses Norway, Britain, Faroe Islands and Ireland. Prior to the development of this single passive margin, the geological history of the Faroe–Shetland region was inextricably linked to the evolution of the NE Atlantic rift system that dominated the proto-NE Atlantic margin. This zone of weakness was ultimately exploited during early Palaeogene continental breakup between NW Europe and Greenland. Palinspastic reconstructions of the proto-NE Atlantic margin (e.g. Ziegler, 1988; Knott et al., 1993; Doré et al., 1999; Roberts et al., 1999; Tate et al., 1999; Coward et al., 2003) have inferred a history of extension linked to the NE Atlantic rift system throughout Late Palaeozoic and Mesozoic times.

Within the Faroe-Shetland region, extensional tectonic activity is envisaged to have occurred mainly during Mid- to Late Devonian, Permo-Triassic, Jurassic and Cretaceous times (e.g. Dean et al., 1999; Coward et al., 2003; Ritchie et al., 2011). Extension was initially focused on the NE-trending Caledonian structural grain prevalent throughout basins of the NE Atlantic Margin. According to Doré et al. (1997 and 1999) and Spencer et al. (1999), the locus of rift activity migrated in a north-westerly direction through time, towards the present location of the NE Atlantic Ocean. For example, in the Faroe–Shetland area, Permo-Triassic half-graben development is mainly concentrated in 'marginal' basins such as the West Orkney and SW West Shetland basins that occur to the west of the Orkney and Shetland islands (e.g. Hitchen et al., 1995; Earle et al., 1989). In contrast, the contiguous Rockall, Faroe-Shetland and Møre basins mainly formed further to the west in response to Cretaceous extension (e.g. Duindam and van Hoorn, 1987; Dean et al., 1999; Musgrove and Mitchener, 1996).

Considerable uncertainty remains regarding the timing, duration and significance of many of the postulated rift events that influenced the development of the central and NW parts of the Faroe–Shetland region in particular. This is due to a combination of a lack of adequate deep well control and the poor seismic definition of the deep structure of the basin, with the latter caused by the high acoustic impedance contrasts associated with the widespread Palaeogene volcanic and intrusive rocks. A Late Jurassic–Valanginian onset of rifting was proposed by Roberts et al. (1999), whereas a distinct Early Cretaceous (late Berriasian–Barremian) instigation of rifting is favoured by other authors (Turner and Scrutton, 1993; Dean et al., 1999; Coward et al., 2003), which is consistent with regional evidence from the NE Atlantic margin between the Rockall Basin and Mid-Norway (Musgrove and Mitchener, 1996; Lundin and Doré, 1997; Doré et al., 1999). At this time, extension within the North Sea rift had effectively ceased and was replaced by a vigorous, NE-trending, Early Cretaceous NE Atlantic rift system that extended from the Vøring Basin to the Bay of Biscay (Rattey and Hayward, 1993; Roberts et al., 1999; Doré et al., 1999; Coward et al., 2003) (Figure 2.1).

According to Coward et al. (2003), there were two main Early Cretaceous phases of extensional fault activity within the NE Atlantic rift broadly correlating with the Valanginian to Hauterivian and Aptian to Albian intervals. However, in the Faroe–Shetland region there is significant variation in views regarding the timing and duration of rifting associated with the development of proven Lower Cretaceous marine clastic rocks, with Late Berriasian to Valanginian (Booth et al., 1993), Berriasian to Hauterivian (Dean et al., 1999), post-Berriasian (Lamers and Carmichael, 1999), Aptian to Albian (Stoker et al., 1993; Ritchie et al., 1996; Goodchild et al., 1999; Larsen et al., 2010) and Valanginian to Cenomanian (Dean et al., 1999; Grant et al., 1999) phases suggested.

The Late Cretaceous interval, in general, is commonly considered to be a thermal sag phase (cf. Roberts et al., 1999 and references therein); however, there is increasing evidence that the Faroe–Shetland region was far from tectonically quiescent. Thick, deep marine clastic successions are envisaged to have accumulated during periods of extension throughout the Turonian to Early Maastrichtian interval (Turner and Scrutton, 1993). More locally, there may have been diachroneity in the timing of extension, with some basins and sub-basins active during Cenomanian to Santonian time, whereas a more widespread phase of extension is envisaged during Campanian to Maastrichtian time (Booth et al., 1993; Dean et al., 1999; Goodchild et al., 1999; Grant et al., 1999; Lamers and Carmichael, 1999; Larsen et al., 2010). In addition, evidence of Late Cretaceous compressional tectonism is shown by compressional structures reported by Booth et al. (1993) in the East Solan and South Solan basins.

2.2 FAROE–SHETLAND REGION

2.2.1 Structural framework

The north-east-trending Faroe-Shetland Basin dominates the region, and comprises a complex amalgam of mainly Late Palaeozoic to Cenozoic sub-basins and intra-basinal highs up to 460 km long and 260 km wide that lie between the Faroe Islands and the Shetland/Orkney Islands in north-westerly and south-easterly directions, and the Munkagrunnur Ridge/Judd High and the Møre Basin in south-westerly and north-easterly directions, respectively (Ritchie et al., 2011) (Figure 1.1). As this study is focused on the eastern half of the Faroe–Shetland region, the main elements of the Faroe-Shetland Basin referred to herein are the Judd, Flett, Foula and Erlend sub-basins, and the Westray, Flett and Corona intra-basinal highs. The adjacent southern and south-east flanks of the Faroe-Shetland Basin are bounded by the Judd and Rona highs, which separate it from the West Shetland Basin, which comprises distinct NE and SW depocentres, and the East Solan, South Solan, West Solan and North Rona basins, which are collectively referred to as the 'south-east marginal basins'. The north-eastern margin of the Faroe-Shetland Basin is bounded by the Erlend and East Shetland highs. The nature of its transition into the Møre Basin is unclear, though Ritchie et al. (2011) suggest that this transition may be marked by the Brendan Lineament. This is one of a series of NW-trending lineaments, which also includes the Judd, Westray, Corona, Grimur Kamban, Clair, Victory, Erlend and Magnus lineaments, that trend orthogonal to the main (NE-trending) Caledonian structural grain.

These lineaments have been interpreted as transfer zones (Duindam and van Hoorn, 1987; Rumph et al., 1993), which, by definition, are defined as discrete zones of strike-slip and oblique-slip faulting that trend parallel to the extension direction, and typically facilitate a transfer of strain between extended domains arranged in an en-echelon pattern (Faulds and Varga, 1998). Figure 1 shows how these 'transfer zones' are commonly displayed as part of the tectonic framework of the Faroe–Shetland region (e.g. Rumph et al, 1993; Ritchie et al., 2011); it should be noted that this structural pattern depicts a more cross-cutting, basin-wide structural pattern than their definition implies (*sensu* Faulds and Varga, 1998; their Figure 5). Other workers (e.g. Doré et al., 1997) have proposed that these lineaments may have originated as shear zones in the basement, and in some instances have accommodated minor strike-slip movements. Regardless of their origin, numerous workers have generally accepted the tectonic architecture shown in Figure 1.1, and have proposed that the distribution of Paleocene sediments and volcanics in the Faroe–Shetland region has been influenced by these NW-trending structures (e.g. Mitchell et al., 1993; Grant et al., 1999; Lamers and Carmichael, 1999; Naylor et al., 1999; Jolley and Morton, 2007; Ellis et al., 2009). Nevertheless, the significance of some of these structures remains in doubt (Moy and Imber, 2009). Whereas the displacement between the Judd and Rona highs, and the Erlend and West Shetland highs may represent transfer zones offsetting the eastern margin of the Faroe-Shetland Basin, their basin-wide extension remains unclear.

According to Moy and Imber (2009), other proposed lineaments, such as the Victory and Clair lineaments, do not exist.

Despite the uncertainty surrounding the nature, origin and extent of the NW-trending lineaments, this structural grain remains an important element of the tectonic framework. Two recent examples in support of this are: 1) Ellis et al. (2009) recently demonstrated a link between several lineaments that transect the Faroe Islands, including the Westray Lineament, and the development of Paleocene lava sequences, interbedded coals and other sedimentary rocks; and, 2) Moy and Imber (2009) infer that the 'Judd fault system' probably is a transfer zone that developed in the Cretaceous. Thus, for the purpose of this study, we have included the lineaments within the structural framework. Following the lead of Moy and Imber (2009), we have used the non-generic term 'rift-oblique lineament'. Their depiction on Figure 1.1 is intended as a guide to understanding the distribution of the Cretaceous succession, the variation of which may or may not address the issue of whether or not such structures exist, and whether or not they were active during the Cretaceous.

2.2.2 Seismic architecture of the main basins/sub-basins

A summary of the seismic architecture of the main basins and sub-basins that comprise the eastern half of the Faroe–Shetland region is presented in Table 2.1. In general terms, and for the purpose of regional comparison, a broad two-fold subdivision of the basin infill – a lower package and an upper package – can be recognised separated by the 'Near-base Upper Cretaceous Unconformity'. The table has been compiled from the inspection of six seismic lines (chosen from the database available to the project) that transect the North Rona, West Solan, and West Shetland basins, together with the Foula, Flett, Judd and Erlend sub-basins of the Faroe-Shetland Basin (Figures 2.2–2.8). The seismic data has been calibrated by the well-logs (Appendices 1 and 2), and in-line and nearby wells relevant to the displayed sections are indicated. The seismic interpretation has been further guided and enhanced by the incorporation of published data where available. Such data was especially important for the East and South Solan basins (e.g. Booth et al., 1993), for which this project had no seismic coverage.

The stratigraphical-range of the lower and upper seismic packages as interpreted from all sources of information (see below) is indicated in Figure 2.9. Three key mappable surfaces – Base Cretaceous, Near-base Upper Cretaceous, and Top Upper Cretaceous – are also shown, and their significance (on the basis of seismic data) as regional stratigraphical breaks across most of the area is very apparent. The main points to note from this regional appraisal of the seismic architecture of the basins/sub-basins are as follows:

<u>The key boundaries</u>

- *The Base Cretaceous (BC) boundary*: The seismic data corroborates the bulk of the well data and confirms a widespread hiatus at the base of the Cromer Knoll Group (cf. section 2.2.3 and Figure 2.10). This unconformity truncates a range of older rocks, including Lowest Cretaceous (Humber Group), Upper Jurassic, Lower Jurassic, Permo-Triassic, Devono-Carboniferous, undifferentiated Palaeozoic and Precambrian strata (Appendices 1 and 2). The possible major exception to this is the Erlend sub-Basin. Although this sub-basin is considered to form part of the Faroe-Shetland Basin as a whole, Ritchie et al. (2011) suggest that the main rift event in this part of the area may have occurred during Jurassic times, with a SE-thickening wedge of syn-rift sediments developed against the flank of the East Shetland High (Figure 2.8). Nevertheless, wells in the study area reveal Lower Cretaceous rocks unconformable on Palaeozoic/Precambrian strata (Figure A1.7).
- *The Near-base Upper Cretaceous (NbUC) boundary*: This boundary is recognised on most of the illustrated seismic profiles as a high-amplitude reflection, which is commonly irregular and erosional in character (Figures 2.2–24 and 2.6–2.8). In the SE marginal basins, the NbUC separates the Cenomanian–Turonian Chalk Group (Figure 2.10) of the

lower package from the overlying Coniacian–Maastrichtian upper package deposits. This is well illustrated in the North Rona Basin, where the boundary is marked by the uppermost of a series of closely-spaced reflections that correspond to the limestones of the Chalk Group (Figure 2.2). In the East/South Solan basins, these limestones are folded and onlapped by Coniacian–Maastrichtian sediments of the upper package. In the Foula sub-Basin, the boundary is closely associated with highly reflective Cenomanian/Turonian limestone and sandstone of the Commodore, Svarte and Macbeth formations (Figure 2.10), which are unconformably overlain by Coniacian mudstone (Grant et al., 1999) (Figures 2.4 and 2.7). This reflector continues into the Flett sub-Basin, where a Cenomanian/Turonian break is recorded in well 205/21-2 (Figure A1.5). On this basis, a high-amplitude reflection within the Judd sub-Basin, which is unconformably overlain by the upper sediment package, is tentatively assigned a comparable age (Figure 2.6), though wells 204/14-1 and 204/29-1 might, collectively, indicate a Coniacian/Santonian break (Figure A1.4). By way of contrast, in the NE West Shetland Basin the NbUC is enhanced by the unconformable juxtaposition of Coniacian limestone (Dab Limestone Unit) on the underlying Lower Cretaceous sandstones (Goodchild et al., 1999). Although the well data, in general, record a variable hiatus in the early part of the Late Cretaceous record, our collective dataset suggests a probable Turonian/Coniacian age for the NbUC boundary.

- *The Top Upper Cretaceous (TUC) boundary*: Whereas the seismic data suggest that this boundary is a widespread unconformity (Figures 2.2–2.8), the well data are more ambiguous; this is especially the case in parts of the East Solan and North Rona basins (Figure A1.1), and the Judd (Figure A1.4) and Flett (Figure A1.5) sub-basins where a conformable contact with the overlying Paleocene section is indicated on well logs. There is no doubting the erosional character of the TUC shown on the profile across the North Rona Basin in Figure 2.2, and supported by the nearby well 202/12-1 (Figure A1.1); however, in order to retain a lack of bias in this study, we have noted both sets of observations (seismic and well log) as part of our reporting process.

The seismic packages

- *The lower package*: In the SE marginal basins and the SW West Shetland Basin the stratigraphical-range of this package extends from the late Berriasian to the Turonian, albeit as a punctuated succession which is difficult to resolve on seismic profile data. The East Solan Basin, in particular, preserves at least four basinwide breaks in the stratigraphy (Figures 2.9 and A1.1). In the SE marginal basins, the sequences that comprise the lower package are relatively thin (generally 10 to a few 100 metres), and they display a fairly uniform geometry (Table 2.1), whereas in the SW West Shetland Basin the lower package locally exceeds 1000 m thick (Figure A1.2). By way of contrast, lower package deposits in the NE West Shetland Basin (Goodchild et al., 1999), the NE Flett sub-Basin (Yell and Muckle basins of Larsen et al., 2010) and the Judd sub-Basin (Ritchie et al., 2011) (Figure 2.6) include wedge-shaped units that thicken into the footwall of adjacent fault blocks. In the Foula sub-Basin, the lower package locally exceeds 1000 m thick, but elsewhere, e.g. Judd and Flett sub-basins, it is generally only a few hundred metres thick (Figures A1.4 and A1.5). A key feature of the lower package is that whereas the SE marginal basins, and the SW West Shetland Basin, were sporadically active prior to the Aptian (Booth et al., 1993; Dean et al., 1999), all basins/sub-basins (except the Erlend sub-Basin) were active from Aptian/Albian time (Dean et al., 1999; Goodchild et al., 1999; Grant et al., 1999; Lamers and Carmichael, 1999; Larsen et al., 2010). It should be noted that the pre-Aptian record in the Judd and Flett sub-basins remains uncertain (Table 2.1). Moreover, it remains unclear whether or not the Early Cretaceous depositional history of the Erlend sub-Basin is more closely linked in to that of the adjacent Møre Basin (Brekke, 2000; Ritchie et al., 2011).

- *The upper package*: This is a generally thicker and more regionally extensive depositional package that locally exceeds 2000 m thick (Figures 2.4 and 2.7; Appendices 1 and 2). Although some authors generally attribute the Upper Cretaceous section to a passive tectonic setting (cf. Roberts et al., 1999 and references therein), indicators of Late Cretaceous faulting are recorded from most of the basins/sub-basins in the area (Figure 2.9), including: abrupt stratal termination against bounding faults (Table 2.1); localised footwall thickening of upper package deposits in the West Shetland Basin, and the Foula and Flett sub-basins (Dean et al., 1999; Larsen et al., 2010), as well as the North Rona Basin (Figure 2.2); and the identification of a late Campanian unconformity in the NE West Shetland Basin (Goodchild et al., 1999). An equivalent boundary may also occur locally in the north-east corner of the SW West Shetland Basin (Figure 2.5). In the Erlend sub-Basin, the upper package (in contrast to the lower package) preserves a comparable stratigraphy to the Faroe–Shetland region (Figure 2.9). Inspection of Figure 2.9 suggests that the basal age of the upper package deposits decreases landwards. It is possible that the upper package may have originally extended across the West Shetland High (Booth et al., 1993; Harker, 2002; Cope, 2006); thus, its present large-scale geometry has likely been modified by subsequent erosional processes.

2.2.3 Lithostratigraphy of the Cretaceous succession

The lithostratigraphical terminology used here is that of Ritchie et al. (1996) (Figure 2.10). This scheme was mainly constructed on the basis of wireline well-log responses, together with biostratigraphic data. As this framework has been formally defined in only 25% of the wells utilised in this report, its inclusion on the stratigraphical-range charts (Appendices 1 and 2) is intended to act as a guide only to interpretation and lithostratigraphical subdivision in the remaining wells.

The Cretaceous succession comprises three lithostratigraphical groups: the Lower Cretaceous Cromer Knoll Group and the Upper Cretaceous Chalk and Shetland groups (Figure 2.10). The Cromer Knoll Group largely rests unconformable on the Upper Jurassic–Lowest Cretaceous Humber Group; the contact with the overlying Chalk and Shetland groups is variable. An unconformity predominates within the NE West Shetland, North Rona and Solan basins, on the adjacent Rona and Solan Bank highs, on the Erlend High and in the southern Møre Basin, whereas a conformable transition occurs locally in the southern part of the West Shetland Basin and Rona High. A conformable boundary is more commonly developed in the Faroe-Shetland Basin, including the intra-basinal highs (excepting the northern Westray High). The Cretaceous/Palaeogene boundary is marked by a widespread unconformity along the eastern part of the study area, as well as on a number of the intra-basinal highs within the Faroe-Shetland Basin. Where a conformable boundary is recorded, deposition of the Shetland Group continued into the Paleocene where it is preserved as the Sullom or Tang formations.

The Cromer Knoll, Chalk and Shetland groups are further divided into fourteen formations and several informal limestone and sandstone units, though in some parts of the area the groups remain locally undivided. The relationship of these formations is illustrated schematically in Figure 2.10, and a summary of their lithology and environment of deposition is presented in Table 2.2. In the report area, the Chalk Group is restricted to the Cenomanian to Turonian interval. The spatial and temporal development of the lithostratigraphical units is described further in section 3.2.

Integrating the seismic-stratigraphic and lithostratigraphic schemes would suggest that the lower seismic package largely comprises the Cromer Knoll and Chalk groups, as well as the lower part of the Shetland Group (Svarte and Macbeth formations), whereas the upper package incorporates the Kyrre and Jorsalfare formations of the Shetland Group (Figure 2.10).

3 Cretaceous tectonostratigraphy of the Faroe–Shetland region

Tectonostratigraphy refers to the temporal and spatial relationships of lithostratigraphical units with emphasis on the tectonic effects on the stratigraphic record (Bates and Jackson, 1987). On this basis, we have produced a series of timeslice maps from which we are able to demonstrate the evolving history of Cretaceous basin development in the Faroe–Shetland region, in response to contemporary tectonic activity. The key set of maps - titled *Basin History* – are presented in Figures 3.1 to 3.14, and simply highlight, on the basis of the well-log data (Appendices 1 and 2), those areas actively receiving sediment at any particular time. Thus, they provide a context for establishing potential tectonic and other controls on sedimentation. Each map is accompanied by a set of summary notes highlighting the key areas of sedimentation and/or change in depocentre during each stage. A second set of maps – *Lithofacies* – shows the areal variation in the predominant lithological character of the basin fill through time (Figures 3.15–3.28). These lithofacies maps have been utilised in a third set of maps – *Lithostratigraphy* – that show the currently defined lithostratigraphical units and their geographical extent (Figures 3.29–3.42).

The key points arising from each set of maps are summarised below (sections 3.1–3.2), followed by a summary of basin development (section 3.3). Although the reconstructions on these maps remain true to the well database, additional information derived from the regional seismic-stratigraphic framework is included, where appropriate. For ease of description, the notes on lithofacies and lithostratigraphy have been combined in section 3.2.

3.1 BASIN HISTORY

Inspection of the basin history maps in combination with the regional seismic-stratigraphic framework has enabled a number of phases and transitions to be identified that may define key stages in the regional development of the Faroe–Shetland region; these are as follows:

- Berriasian (Humber Group/Cromer Knoll Group transition) (Figure 3.1): The well-log data imply a widespread unconformity between the Middle Jurassic–Lowest Cretaceous Humber Group and the Lower Cretaceous Cromer Knoll Group. This is strongly supported by the seismic data (Table 2.1). The few well-log exceptions to this suggest a conformable transition between the Kimmeridge Clay and Valhall formations in wells 204/30a-2 and 204/30a-3 in the East Solan Basin, well 202/8-1 in the North Rona Basin, and well 205/25-1 in the SW West Shetland Basin. However, even within the internal stratigraphic architecture of these basins, there is some ambiguity as to the conformable character of this boundary (Figures A1.1 and A1.2).

- Late Berriasian–Barremian (Figures 3.2–3.4): Initial basin activity was focused on the marginal basins in the southern part of the area, including the SW West Shetland Basin, North Rona Basin and East Solan Basin. Activity in the northern part of the area was instigated in Hauterivian–Barremian time, with the northern Flett Basin, the Erlend sub-Basin, and southern end of the Møre Basin recording deposition. The original well-log data suggest that the southern Flett and Judd sub-Basins, as well as part of the Westray High, may also have begun to accumulate sediment in this interval. However, the stratigraphic-range in wells 204/23-1 (Judd sub-Basin), 205/16-1 and 205/22-1A (Flett sub-Basin), and wells 204/19-1 and 204/15-2 (Westray High) is quite variable (Figures A1.4–A1.6) and may indicate either localised, sporadic accumulation or that the stratigraphic control requires improved resolution. A number of authors favour a Barremian–Aptian onset of deposition in the Faroe-Shetland Basin (e.g. Dean et al., 1999; Lamers and Carmichael, 1999; Larsen et al., 2010), which is consistent with a recent reappraisal of well data undertaken by Ichron (Oral communication, A Alderson, Ichron Limited, to M Stoker, BGS, November 2010). The Judd, Rona, Flett, Corona and Erlend highs remained largely emerged through this interval.

- Aptian–Albian (Figures 3.5–3.6): This interval marks the onset of a significant change in the basinal development of the region, as the Faroe-Shetland Basin becomes an integrated depocentre over most of the area. The instigation of the Foula sub-Basin (and possibly the southern Flett and Judd sub-basins – see above) and the submergence of the Corona High occurred in the Aptian, which was followed by widespread submergence of this sub-Basin and the adjacent Flett High during the Albian. The NE West Shetland Basin was also active at this time, whereas deposition persisted in the SW part of this basin, as well as in the south-eastern marginal basins and locally on the adjacent highs. The Solan Bank High became emergent in the Albian; at the same time the southern Møre Basin and adjacent Erlend sub-Basin became largely re-emerged.

- Albian/Cenomanian boundary (Figure 3.7): The emergence of the eastern flank of the Foula sub-Basin, NE West Shetland Basin and southern marginal basins marks a pronounced phase of uplift along the eastern flank of the Faroe-Shetland Basin, whereas the emergent northern Westray High reflects localised intra-basinal uplift.

- Cenomanian–Turonian (Figures 3.8–3.9): The Faroe-Shetland Basin was fully submerged during the Cenomanian–Turonian interval. This contrasts with the adjacent basins and highs for which a more variable pattern of activity is noted. The SW West Shetland Basin remained active, whereas in the SE marginal basins only the East Solan and North Rona basins preserve a Cenomanian–Turonian record. Localised inversion is reported from the East Solan Basin, where folded Cenomanian limestone is reportedly onlapped by Turonian–Santonian deposits (Booth et al., 1993), though well data largely suggest a hiatus in this interval. This, together with the seismic-stratigraphic framework, suggests that a combination of compressional deformation and erosion during the Turonian may have contributed to the formation of the NbUC boundary, at least within the marginal basins. Turonian and older Cretaceous rocks in the North Rona and West Shetland basins, as well as the Foula sub-Basin, also appear to be synclinally folded. Farther north, the Erlend High became fully submerged for the first time in the Turonian. Sedimentation along the Rona High was localised throughout this interval; only the Judd and Solan Bank highs remained fully emerged.

- Coniacian–Santonian (Figures 3.10–3.11): The Faroe-Shetland Basin and Erlend High remained submerged during the Coniacian–Santonian interval, though the northern Westray High began to re-emerge in the Santonian. In the West Shetland Basin, the focus of sedimentation switched to the NE part of the basin, whereas the SW basin largely re-emerged. Indeed, by Santonian time most of this southern region had re-emerged. The southern Møre Basin and Erlend sub-Basin were reactivated in the Coniacian; sedimentation along the Rona High continued to be localised in extent. The Judd and Solan Bank highs remained fully emerged.

- Campanian–Maastrichtian (Figures 3.12–3.13): This interval represents the most widespread phase of deposition in the study area, with all of the Faroe-Shetland sub-Basins, adjacent marginal basins, the southern Møre Basin and the Rona and Erlend highs fully submerged. However, the Westray High shows indications of increasing emergence, as does the Corona High and the eastern side of the Erlend High. It is interesting to note that an intra-Campanian unconformity has been reported from the NE West Shetland Basin (Goodchild et al., 1999), and is also observed at the NE end of the SW West Shetland Basin (Figure 2.5). The Corona High may be fully emerged in the Maastrichtian. Only the Judd High remains fully emerged throughout this interval (Figures 2.2 and 2.6).

- Cretaceous/Palaeogene boundary (Figure 3.14): This boundary is marked by a regional unconformity. The West Shetland Basin, Rona High, Erlend High, the eastern flank of the Foula sub-Basin, part of the Flett High, and the southern Møre Basin were all re-exposed. However, the area of exposure depicted in Figure 3.14 is regarded as a minimum, particularly in the southern marginal region where seismic data across the North Rona Basin indicates an erosional unconformity (Figure 2.2), which questions the validity of the conformable contact recorded in wells 202/2-1, 202/3-1A, and 202/3-2 (Figure A1.1). The character of the boundary in the East Solan and South Solan basins, as deduced from the wells, is also questioned; Booth et al. (1993) report an unconformity between the Cretaceous and overlying Paleocene. This is consistent with seismic data from the West Solan Basin (Figure 2.3). Seismic data also reveal a widespread unconformity between Upper Cretaceous and Paleocene deposits in the Judd, Flett and Foula sub-basins (Figures 2.4, 2.6 and 2.7), which may imply more widespread exposure than is currently shown in Figure 3.14, though the possibility of submarine erosion cannot be discounted.

3.2 LITHOFACIES AND LITHOSTRATIGRAPHY

Figures 3.15–3.28 depict the geographic variation in lithofacies during the Cretaceous, whereas Figures 3.29–3.42 show how this variation relates to the lithostratigraphic scheme of Ritchie et al. (1996). The intervals defined above are retained in this section.

- Berriasian (Humber Group/Cromer Knoll Group transition) (Figures 3.15 and 3.29): The area appears to have been largely exposed at this time. The status of localised claystone/mudstone deposition associated with the Kimmeridge Clay Formation in the southern marginal basins remains uncertain.

- Late Berriasian–Barremian (Figures 3.16–3.18 and 3.30–3.32): The SW West Shetland Basin was dominated by sandstone deposition during this interval, whereas a more mixed assemblage of sandstone, claystone/mudstone, limestone and argillaceous limestone accumulated locally in the adjacent marginal basins. The sandstone-dominated rocks in the West Shetland Basin are assigned to the Victory Formation, which also includes a section of Hauterivian–Barremian sandstone recovered in well 208/24-1A in the adjacent northern Flett sub-Basin (Figure A1.5). The mixed lithofacies assemblage preserved along the southern margin of the area belongs to the Valhall Formation. If the southern Flett Basin and the Judd Basin were active during this interval, the predominance of claystone/mudstone in the former can be assigned to the Valhall Formation, whereas a conglomeratic facies in well 204/23-1 (Figure A1.4) is termed the Neptune Formation. The latter formation also includes Hauterivian–Barremian sandstone and siltstone from the Westray High. As noted above (section 3.1), however, the stratigraphic resolution of the rocks in the southern Flett and Judd basins may need to be improved in order to better understand the Early Cretaceous depositional history of these sub-basins. Sporadic occurrences of sandstone and claystone/mudstone on the Judd and Erlend highs, respectively, and claystone/mudstone in the southern Møre Basin remain unassigned.

- Aptian–Albian (Figures 3.19–20 and 3.33–3.34): Victory Formation sandstones continued to accumulate in the West Shetland Basin, which had extended its activity to the north-east during this interval. In contrast, claystone/mudstone dominated the southern marginal basins, as well as the Judd and southern Flett basins as the Faroe-Shetland Basin became a more integrated structural feature in the Albian. In these areas, the Valhall and Neptune formations were superseded by the Carrack and Rødby formations. The instigation of the Foula sub-Basin in the Aptian was accompanied by an initial accumulation of predominantly sandstone, assigned to the Royal Sovereign Formation; this was subsequently overlain by the claystone/mudstone-rich Cruiser

Formation, which has also been assigned to comparable deposits on the Westray High. Localised sandstone and claystone/mudstone deposits on the Judd High, Corona High, Erlend High, and in the Møre Basin remain unassigned.

- Albian/Cenomanian boundary (Figures 3.21 and 3.35): Sedimentation across this boundary was largely restricted to the SW West Shetland Basin, which accumulated the uppermost part of the Victory Formation, and the Faroe-Shetland Basin where the contemporary Cruiser and Rødby formations were deposited. However, in association with the uplift of the Rona High, a sandstone unit, termed the Commodore Formation, accumulated along the eastern margin of the Flett and Foula sub-basins. This formation appears to straddle the Albian/Cenomanian boundary, and is, in part, laterally equivalent to the Cruiser and Rødby formations. The claystone/mudstone on the Corona High remains unassigned.

- Cenomanian–Turonian (Figures 3.22–3.23 and 3.36–3.37): The deposition of the clastic Commodore Formation may have persisted into the Cenomanian/Turonian; however, a carbonate facies spanning these stages was deposited in the southern marginal basins. The latter represents the Chalk Group, which is preserved largely in the SW West Shetland, East Solan and North Rona basins, and comprises the Hidra and Herring formations. These units are composed largely of a mix of limestone and argillaceous limestone, and are separated by a high-pyritic mudstone (Black Band). In the SW West Shetland Basin, the limestone is interbedded with sandstone, which is termed the Haddock Sandstone Unit. The rest of the region was dominated by the deposition of claystone/mudstone with subordinate siltstone, sandstone and limestone, which in the Judd, Flett and Foula sub-Basins are assigned to the Svarte (Cenomanian) and Macbeth (Turonian) formations. In the Foula and Judd sub-basins, Turonian limestone appears to be closely associated (at least spatially) with the NbUC (Figure 2.9). Claystone, mudstone and sporadic limestone began to encroach onto the Rona and Erlend highs, particularly in the Turonian. The Judd and Solan Bank highs were fully exposed throughout this interval.

- Coniacian–Santonian (Figures 3.24–3.25 and 3.38–3.39): The general trend toward a finer-grained clastic lithofacies continued through this interval, and became wholly dominant in the Santonian stage as deposition continued to encroach onto the Rona High. The NE West Shetland Basin became a focus of fine-grained clastic sedimentation in the Coniacian, together with the Erlend sub-Basin and southern Møre Basin. In the Faroe-Shetland Basin, these sediments are assigned to the Kyrre Formation; farther north, and including the Corona High, these deposits remain essentially unassigned. Sporadic Coniacian sandstone and limestone in the NE West Shetland Basin are termed the Whiting Sandstone Unit and Dab Limestone Unit, respectively. In contrast, the southern marginal region, including the SW West Shetland Basin, may have been mainly exposed during Coniacian–Santonian time. The Judd and Solan Bank highs were fully exposed throughout this interval.

- Campanian–Maastrichtian (Figures 3.26–3.27 and 3.40–3.41): The claystone/mudstone lithofacies extends onto the Rona High and into the West Shetland and other marginal basins, as the eastern part of the region becomes fully submerged. These deposits are associated with the Kyrre and Jorsalfare formations, though the northern area remains essentially unassigned. However, parts of the area may have become increasingly emerged during this interval, and the Corona and Westray highs and the eastern part of the Erlend High may have been exposed in the Maastrichtian. Local basinal readjustments are also noted, such as in the NE West Shetland Basin where a late Campanian unconformity has been reported (Goodchild et al., 1999). The Judd High was fully exposed throughout this interval.

- Cretaceous/Palaeogene boundary (Figures 3.28 and 3.42): Regional exposure associated with this boundary probably confined the area of deposition to the Faroe-Shetland Basin and several of the southern marginal basins, though the extent of these depocentres has been queried (section 3.1): seismic data suggest that the area of deposition may be less than is depicted in Figure 3.28. Where sediment was deposited, the claystone/mudstone lithofacies of the Jorsalfare Formation prevailed.

3.3 SUMMARY OF BASIN DEVELOPMENT

The key phases in the Cretaceous development of the Faroe–Shetland region as identified from the tectonostratigraphic framework are depicted in Figure 3.43, which shows very clearly that subsidence and uplift throughout this period was variable. This sequence of events can be summarised as follows:

Berriasian (ca. 142 Ma)	Period of regional uplift and erosion.
Late Berriasian–Barremian (ca. 142–125 Ma)	Localised, scattered, commonly punctuated deposition in SE marginal basins; submergence of southern Møre Basin and Westray High instigated in Hauterivian; southern Flett and Judd basins possibly initiated in this interval, though this remains ambiguous.
Aptian–Albian (125–99.6 Ma)	Instigation of widespread rifting in the Faroe-Shetland Basin, with submergence of sub-basins and intrabasinal highs; marginal basins continue to be active, with deposition also in the NE West Shetland Basin; however, southern Møre Basin and Erlend sub-Basin uplifted.
Albian/Cenomanian boundary (99.6 Ma)	Uplift of marginal basins (excluding SW West Shetland Basin), eastern flank of Faroe-Shetland Basin, and northern Westray High.
Cenomanian–Turonian (99.6–89.3 Ma)	Faroe-Shetland Basin remains submerged; Erlend High becomes submerged in Turonian; SW West Shetland Basin remains active; SE marginal basins reactivated, though inversion in East Solan Basin initiated in Turonian; Turonian and older Cretaceous rocks in North Rona and West Shetland basins, as well as the Foula sub-Basin, also appear to be folded; Rona High locally accumulating sediment.
Coniacian–Santonian (89.3–83.5 Ma)	Southern Møre Basin becomes re-submerged in Coniacian; switch in activity of marginal basins from SW to NE, including adjacent Rona High; SW marginal region re-exposed; northern Westray High emerges in the Santonian.
Campanian–Maastrichtian (83.5–65.5 Ma)	Widespread submergence including the Rona High; concomitant uplift of Westray and Corona highs, and the eastern part of the Erlend High; intra-basinal unconformity in Foula sub-Basin.
Cretaceous/Palaeogene boundary (65.5 Ma)	Regional exposure of marginal basins and highs, and southern Møre Basin; seismic data suggest Faroe-Shetland Basin may also have been extensively eroded, though it is unclear whether this was subaerial or submarine. It is uncertain whether widespread exposure as a consequence of regional uplift, a lowered eustatic sea level, or a combination of both.

Although our data indicate that tectonic activity in the Faroe–Shetland region prevailed throughout the Cretaceous period, we recognise a regional intensification of tectonism since the Aptian–Albian and throughout the Late Cretaceous. This also coincides with a regional increase in sediment accumulation rates calculated for both the basins and the highs*, as indicated below (cf. Figures 3.43 and 3.44):

Stage	*Basins*	*Highs*
Late Berriasian–Barremian	7 m Ma^{-1}	2.5 m Ma^{-1}
Aptian–Albian	11 m Ma^{-1}	4 m Ma^{-1}
Cenomanian–Turonian	20 m Ma^{-1}	32 m Ma^{-1}
Coniacian–Santonian	35 m Ma^{-1}	31 m Ma^{-1}
Campanian–Maastrichtian	58 m Ma^{-1}	23 m Ma^{-1}

(*Generalised mean maximum rates (undecompacted) derived from well-logs in Appendix 1, and summarised in Figure 3.44)

The localised character of the tectonic activity and the relatively low sediment accumulation rate associated with the Late Berriasian–Barremian interval contrasts with that assigned to the Aptian–Albian interval, where an almost doubling of the accumulation rate accompanies the instigation of the Faroe-Shetland Basin. The sediment accumulation rate increased markedly in the Late Cretaceous, locally by an order of magnitude relative to the Early Cretaceous (Figure 3.44). A high eustatic sea level prevailed in the Faroe–Shetland region since the Albian, and throughout the Late Cretaceous (Figure 3.43), and the Campanian–Maastrichtian interval represents the most widespread submergence of the region, including (ultimately) the Rona High. However, regional evidence of compression together with the emergence of the Corona and Westray highs, and the eastern side of the Erlend High, during Turonian–Maastrichtian times may be indicative of an overall tectonic control on Late Cretaceous sedimentation. The evidence for widespread erosion at the Cretaceous/Palaeogene boundary adds further weight to this premise, though, as previously noted, there is also a fall in eustatic sea level at this time.

It is interesting to note that the cessation of the coarse clastic input into the Faroe-Shetland Basin and adjacent marginal basins occurred during the Turonian (Figure 3.43). As eustatic sea level was already high at that time, and continued to be high in the Coniacian–Maastrichtian interval, the cut-off in coarse clastic material may further invoke a tectonic control on sedimentation, especially as the subsequent mudstone-dominated deposition was associated with the highest average regional sediment accumulation rates (Figure 3.44). This cut-off in sand supply also seems to coincide with the onset of regional compression (Figure 3.43). The significance of these observations remains unclear at the present time.

The north-easterly trend of the main basins suggests that their development has been strongly influenced by similarly-trending faults, such as the Shetland Spine Fault, and the fault-bounded Rona, Flett and Corona highs. However, inspection of the basin history maps (Figures 3.1–3.14) reveals a number of other structural elements – basins and highs – whose orientation and uplift/subsidence history may have been controlled to some degree by the north-westerly-trending rift-oblique lineaments. In particular, the Erlend and Judd highs were exposed for long intervals during the Early and Late Cretaceous, respectively. Both of these highs remained emerged during the Aptian–Albian instigation (or full integration) of the Faroe-Shetland Basin, whereas the Judd High was exposed during maximum Campanian–Maastrichtian submergence. The Erlend sub-Basin and southern Møre Basin became re-emerged during the Aptian–Albian, whereas the uplift/subsidence history of the Westray High is highly variable, and commonly contrary to the adjacent Flett and Judd sub-basins. Although it is well established that the Rona High was generally exposed prior to the Campanian (Dean et al., 1999), the rock record reveals a variable history of deposition along its length (Figures 3.43, A1.3 and A2.1). As the Rona High is segmented by a number of rift-oblique lineaments, the possibility cannot be excluded that these structures may have exerted some control on deposition.

4 Implications for the tectonic development of the proto-NE Atlantic margin

This section discusses the implications of our study with regard to the tectonic development of the proto-NE Atlantic margin. The Cretaceous development of the SE Faroe–Shetland region (Figure 3.43) is further summarised and simplified in Figure 4.1, which essentially identifies the key local tectonic phases and their correlation to established regional tectonic events in Europe and the North Atlantic region. In order to contribute to the boundary conditions that need to be addressed by anyone wishing to develop ideas on the tectonic development of the proto-NE Atlantic margin, we have focused our discussion on three specific issues: 1) Late Jurassic–Early Cretaceous transition; 2) Cretaceous tectonics; and, 3) Cretaceous/Palaeogene boundary.

4.1 LATE JURASSIC–EARLY CRETACEOUS TRANSITION

There is general agreement that the Arctic–North Sea rift had ceased by earliest Cretaceous times, and was superseded by a new, active Early Cretaceous rift that extended from the Vøring margin to the Bay of Biscay (Doré et al., 1999; Roberts et al., 1999). However, there remains considerable uncertainty regarding the geometry of this rift, particularly in the Vøring–Møre–Faroe–Shetland region, in part due to the problem of imaging the top of the Upper Jurassic (Roberts et al., 1999). This has led to several major contradictions in the literature concerning Late Jurassic–Early Cretaceous palaeogeography and tectonics, including: 1) palaeogeographic reconstructions that show a rift system hosting conflicting shelf (Roberts et al., 1999) and deep marine (Knott et al., 1993; Coward et al., 2003) settings for this interval, with the latter presented as a continuation from the Late Jurassic; and, 2) whether or not Late Jurassic–Early Cretaceous rifting was a single event or two separate events. On the latter point, Doré et al. (1999) suggest that there were separate Late Jurassic and Early Cretaceous rift phases, albeit almost coincident in time, but not in space. They further indicate that this confusion has tended to mask one of the most fundamental events in the evolution of the North Atlantic margin, i.e. the rotation of the regional extension vector from E–W to NW–SE.

There is regional evidence to indicate the existence of a marine seaway within the Faroe–Shetland region during Mid- to Late Jurassic times (cf. Ritchie et al., 2011 and references therein); however, our study suggests that this seaway was not continuous into the Early Cretaceous. From the well data, we record a regional hiatus in the earliest Cretaceous (intra-Berriasian), which leads us to support the likelihood of a break between ‘Late Jurassic’ and ‘Early Cretaceous’ rifting events. It is interesting to note that most of the proven occurrences of Jurassic strata (and including Humber Group (Kimmeridge Clay Formation) rocks of early Berriasian age) within the Faroe–Shetland region are mainly confined to the marginal basins and highs along the southeastern and southwestern flanks of the Faroe-Shetland Basin (Ritchie et al., 2011) (Figure 3.1 and Appendix 1). Consequently, the tectonic and palaeogeographic setting of the Faroe–Shetland region in Late Jurassic–Early Cretaceous times remains to be established with any certainty, and published reconstructions of an Atlantic rift in this interval, based on a repeating rift model (e.g. Ziegler, 1988; Knott et al., 1993; Roberts et al., 1999; Coward et al., 2003) should be treated with caution. On the premise that there was some kind of Late Jurassic seaway, we have indicated a phase of earliest Cretaceous regional uplift to account for this hiatus (Figures 3.43 and 4.1). By way of contrast, if one adopts the migrating model of rifting proposed by Doré et al. (1999: their Figure 6) then parts of the Atlantic margin, including the Faroe–Shetland region, may have been largely devoid of any Late Jurassic extension. Thus, much of the study area may have been subaerial for a much longer time, and prolonged exposure rather than uplift may account for the break. This remains to be tested by further data acquisition.

4.2 CRETACEOUS TECTONICS

It is becoming increasingly apparent that the Cretaceous development of the Faroe–Shetland region was controlled by a protracted history of both extensional and compressional tectonism. Various authors have previously described multiple phases of rifting and subsidence (Dean et al., 1999; Goodchild et al., 1999; Grant et al., 1999; Lamers and Carmichael, 1999; Larsen et al., 2010) interspersed with compressional deformation (Booth et al., 1993) (Table 2.1), though a consensus on the timing of these events has remained ambiguous (see section 2.1) largely due to the generally restricted areas of study of individual groups (cf. Figure 2.9). Nevertheless, Dean et al. (1999) recognised that the locus of fault activity, and hence depocentres, varied with time, from which they concluded that 'uplift and subsidence within the Cretaceous period was thus highly variable and a single, discrete rift model (that implies a predictable subsidence history throughout the basin) is inappropriate'.

On the basis of our regional study, we concur with this general tectonic model. Furthermore, we propose seven tectonic phases (cf. (1)–(7) in Figure 4.1) that describe an overall process of progressive basin enlargement interspersed with compressional deformation. In the following summary of the various phases, we have built upon ideas put forward (particularly) by Booth et al. (1993), Dean et al. (1999), and Larsen et al. (2010).

1. *Early Cretaceous extension in SE marginal basins* – Scattered, unconnected faulting during the late Berriasian–Barremian interval; basinal subsidence, albeit limited, mainly focused on the SE marginal area.
2. *Late Early Cretaceous extension in Faroe–Shetland Basin* – Unambiguous instigation of this basin during the Aptian–Albian, together with expansion of West Shetland Basin suggests that faults may have begun to link up, thereby creating greater subsidence. Contemporary uplift of SW Møre Basin?
3. *Mid-Cretaceous differential uplift and subsidence* – A large part of the SE marginal area bounding the Faroe-Shetland Basin was uplifted at the Albian/Cenomanian boundary; this was complemented by a significant coarse clastic input shed into the Faroe-Shetland Basin (particularly the Foula sub-Basin). Were both the Judd High and the re-emerged northern Westray High controlled by transfer/rift-oblique lineaments?
4. *Early Late Cretaceous compression* – A major phase of compression affected the entire SE Faroe–Shetland region during the Turonian; flower structures in the East Solan and South Solan basins; synclines in the North Rona Basin and Foula sub-Basin (Figures 2.2, 2.4 and 2.7). This phase of deformation is marked regionally by the NbUC boundary; commonly an angular unconformity.
5. *Mid-Late Cretaceous extension in Faroe-Shetland and Møre basins* – A major increase in the regional sediment accumulation rate in the Faroe-Shetland Basin in the Coniacian–Santonian interval (Figure 3.44) suggests both a dramatic increase in the subsidence of this basin, as well as a rejuvenated source region, which may have included the re-emerged SE marginal area. The fault(s) bounding the SE margin of the Faroe-Shetland Basin may have formed a linked system at this time. To the NE, the Møre Basin was re-submerged synchronous with this phase of extension.
6. *Late Cretaceous compression* – This is exemplified by synclinal development in the West Shetland Basin where intra-Campanian folding (and/or uplift of Rona High) has resulted in the formation of an angular unconformity (Figure 2.5). The regional extent of this phase remains unclear.
7. *Late Cretaceous extension in all basins* – The Campanian–Maastrichtian phase of extension is manifest by the combination of the highest regional sediment accumulation rate and the most widespread deposition in all basins (Figures 3.12, 3.13

and 3.44). This may imply that a completely linked master fault system existed at this time, including the Shetland Spine Fault. The re-emergence of the Corona and Westray highs may indicate may indicate coeval footwall uplift of these intrabasinal blocks. It should be noted that eustatic sea level, which had been steadily rising throughout the Late Cretaceous interval, reached a highstand maximum in the latest early Campanian (Oakman and Partington, 1998) (Figure 3.43); whilst this may have contributed to the widespread drowning of the area, including the Rona High, it does not explain the basinal geometry of the Upper Cretaceous sediments (Table 2.1; see section 2.2.2), intrabasinal uplift, nor the sediment accumulation rates (Figure 3.43). Similarly, the absence of coarse clastic input during much of the Coniacian–Maastrichtian interval has been used to indicate tectonic quiescence during the Late Cretaceous; again, this contradicts the observation of increasing sediment input.

Figure 4.1 places the local tectonic phases that we recognise across the Faroe–Shetland region against established regional tectonic events, which essentially document the cessation of spreading in the Tethys region, the northward propagation of Atlantic seafloor spreading, and the replacement of the Arctic–North Sea rift by a new Arctic–NE Atlantic rift (Ziegler, 1988; Doré et al., 1999; Roberts et al., 1999; Eide, 2002; Coward et al., 2003; Tsikalis et al., 2005). In general terms, we suggest that the tectonic development of the Faroe–Shetland region can be broadly correlated to the evolving North Atlantic Ocean and proto-NE Atlantic margin, in the following manner:

- The localised, punctuated, basin development in the SE marginal area during late Berriasian–Barremian time may reflect a relatively unfocused response to the gradual rotation of the regional extension vector, as the main NE Atlantic rift (Rockall Basin to Vøring Basin) was initiated, albeit intermittently.
- The Aptian–Albian instigation of the Faroe-Shetland Basin, and the uplift of the southern Møre Basin, appears to coincide with the opening of the southern North Atlantic (between the Iberian margin and the Grand Banks).
- The Mid-/early Late Cretaceous uplift, subsidence and compression that we observe may have been a response to the propagation of the North Atlantic rift axis into the Labrador Sea during Turonian time. The subsequent phase of increased subsidence that we record from the Faroe-Shetland and Møre basins appears to be coincident with rifting in the Labrador Sea. This was also an interval of active extension offshore Norway.
- The Campanian–Maastrichtian phase of uplift, subsidence and compression coincides with the onset of seafloor spreading in the Labrador Sea and the concomitant anti-clockwise rotation of Greenland.

The pattern of co-eval extension and compression is consistent with regional oblique-slip associated with transtension and transpression (Roberts et al., 1999). Given the location of the Faroe–Shetland region relative to the developing North Atlantic spreading centre (e.g. Figure 2.1), as well as the Alpine collisional zone, it is not surprising that this area developed as a zone of oblique-slip motion, though the detail of this tectonic zone remains to be worked out.

4.3 CRETACEOUS/PALAEOGENE BOUNDARY

This study – incorporating both well and seismic data – indicates that the Cretaceous/Palaeogene boundary in the Faroe–Shetland region is marked by the regional TUC unconformity. The well data indicate that the oldest rocks overlying the TUC are Early Paleocene in age (Figure A2.1). The regional extent of the TUC as depicted in Figure 3.14 is regarded as a minimum in terms of possible subaerial exposure, due to the conflict between some of the well data (indicating conformable transition) and the seismic data in the southwestern part of the Faroe-Shetland

Basin. Thus, it is not possible to determine whether or not the unconformity surface as observed on seismic from the Faroe-Shetland Basin was generated by subaerial or submarine processes.

There are two main factors to consider in determining the origin of the TUC unconformity: 1) eustatic sea-level change; and, 2: tectonics. In terms of sea level change, Gradstein et al. (2004: modified from Hallam, 1992) indicate a major eustatic fall in sea level at the Cretaceous/Paleocene boundary, in excess of 100 m (Figure 4.1). This would clearly have an impact on the degree of exposure across the region. From a tectonic perspective, it is fairly well established that regional uplift incorporating the region between Scotland and Norway began in the latest Cretaceous (Coward et al., 2003). Whether or not tectonic movements were local or regional also remains unclear. In general terms, Late Cretaceous–Early Paleocene uplift in Scotland is commonly considered to be due to the development of the North Atlantic hot spot; however, evidence from the Faroe–Shetland region suggests that some of this uplift may be driven by oblique-slip tectonics. Several authors (e.g. Turner and Scrutton, 1993; Booth et al., 1993; Grant et al., 1999) have reported evidence for latest Cretaceous–earliest Paleocene inversion and local and regional uplift in the Faroe–Shetland region; in particular, Booth et al. (1993) describe a number of localised, but very intense, inversion structures from the East Solan and West Solan basins, which are onlapped by Lower Paleocene rocks. Inversion structures have also been described offshore Mid-Norway, including the Turonian Vigrid Syncline and its inversion in Maastrichtian–Paleocene time (Blystad et al., 1995). Our data are incomplete as to whether or not the origin of the TUC unconformity is related to sea-level change, tectonic movement, or a combination of both; though the latter seems most likely.

5 Conclusions

A regional tectonostratigraphic framework for the Cretaceous succession in the Faroe–Shetland region shows that it is characterised by a highly variable pattern of sedimentation, which is indicative of the major rifting that took place during this period. On the basis of this framework our key conclusions are as follows:

- The Early Cretaceous rifting phase is distinct and separate from Late Jurassic rifting. A regional hiatus separates the Late Jurassic–earliest Cretaceous Humber Group from the Early Cretaceous Cromer Knoll Group.
- Cretaceous basin development was highly variable and occurred against a backdrop of polyphase extension, uplift and compression, as well as a rising eustatic sea level. The following regional pattern of basin development is proposed:
    1. An initial late Berriasian–Barremian phase of scattered, isolated, basin development in the SE marginal area. This was followed by:
    2. An increase in the sediment accumulation rate from the Aptian–Albian as the Faroe-Shetland Basin was fully instigated.
    3. A phase of Mid-/early Late Cretaceous differential uplift and subsidence culminated (in the Turonian?) with a regional compressional event, which created a widespread unconformity. This was followed by:
    4. Greatly increased sediment accumulation rates and enhanced subsidence in most basins from the Coniacian onwards, locally interrupted by a phase of compression in the Campanian. The highest accumulation rates occurred in the Campanian–Maastrichtian interval, concomitant with co-eval uplift of intrabasinal highs.
- The Upper Cretaceous succession does not show a simple pattern of 'post-rift' subsidence; indeed it is difficult to define a classic post-rift element to this framework.
- The pattern of co-eval extension and compression observed from the Faroe–Shetland region throughout the Cretaceous period is consistent with regional oblique-slip associated with transtension and transpression. Correlation between local and regional tectonic events suggests an intimate linkage to the evolution of the proto-NE Atlantic margin, with key changes in extension and subsidence rates, sediment accumulation rates and phases of compression correlating with far-field events related to the developing North Atlantic spreading centre, including the NE Atlantic rift (Rockall–Vøring basins) and line of incipient breakup.
- The Faroe–Shetland region was extensively subaerially exposed at the Cretaceous/Palaeogene boundary. This may have been a combination of eustatic sea-level fall and local and/or regional tectonic uplift. Although uplift at this time is commonly considered to be due to the development of the North Atlantic hot spot, evidence from the Faroe–Shetland region suggests that some of the uplift may linked to oblique-slip tectonics.

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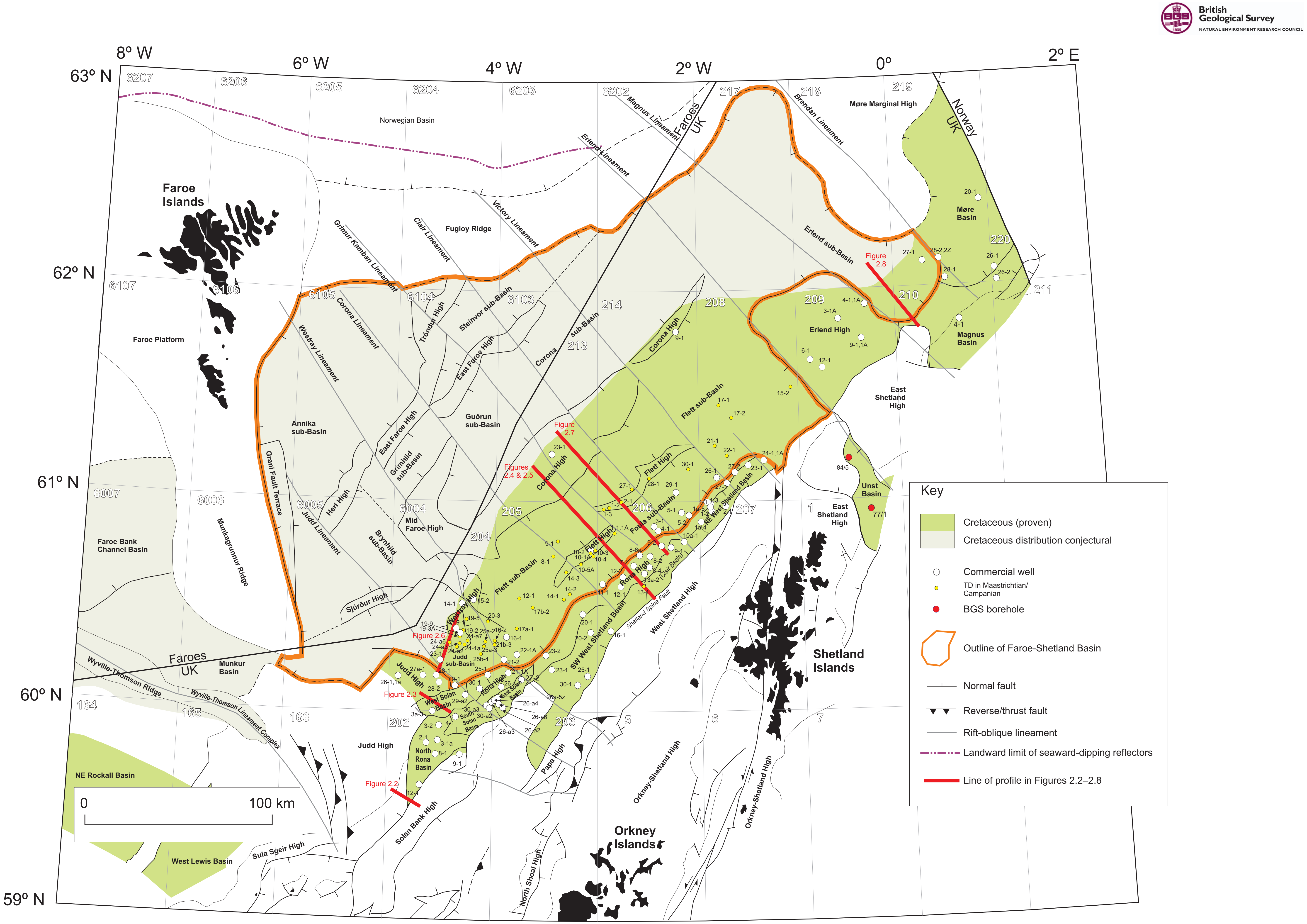


Figure 1.1 Location of study area, distribution of Cretaceous rocks, and position of commercial wells and BGS boreholes used in this project. Structural framework from Ritchie et al. (2011).

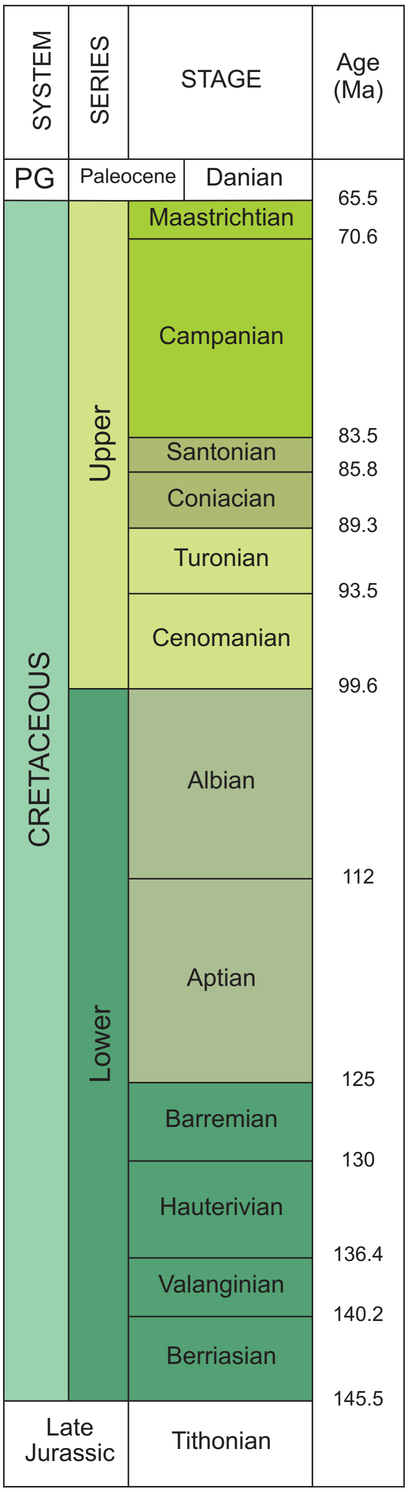


Figure 1.2 Cretaceous chronostratigraphical subdivision used in this study. Timescale from Gradstein et al. (2004). Abbreviation: PG, Palaeogene.

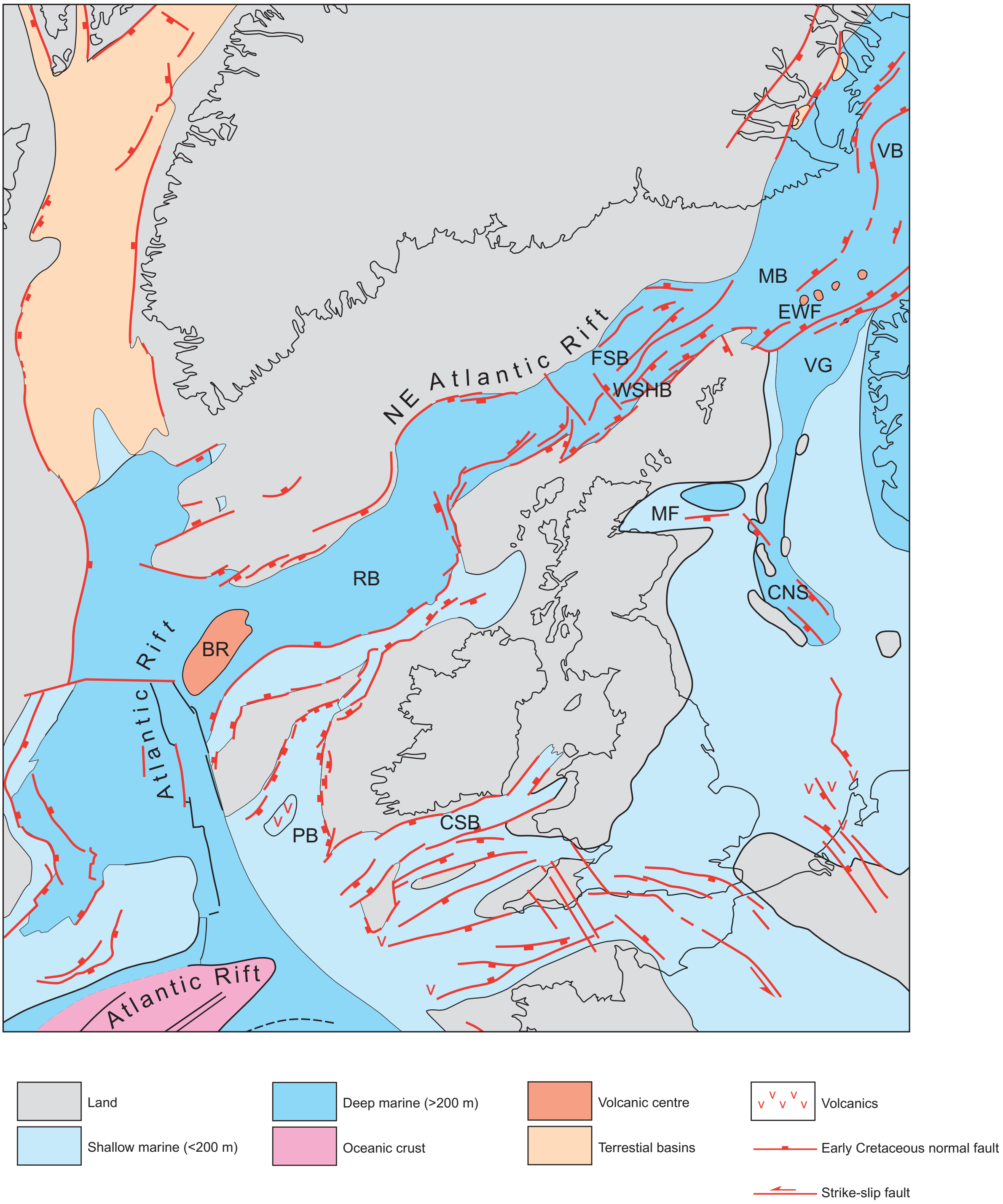


Figure 2.1 Palaeogeographical and palaeofacies plate reconstruction of the Faroe–Shetland region and surrounding area for Early Cretaceous times (modified from Coward et al., 2003 and Ritchie et al., 2011). Abbreviations: BR, Barra Volcanic Ridge Complex; CNS, Central North Sea; CSB, Celtic Sea Basin; EWF, End Of The World Fault; FSB, Faroe-Shetland Basin; MB, Møre Basin; MF, Moray Firth; PB, Porcupine Basin; RB, Rockall Basin; VB, Vøring Basin; VG, Viking Graben; WSHB, West Shetland Basin.

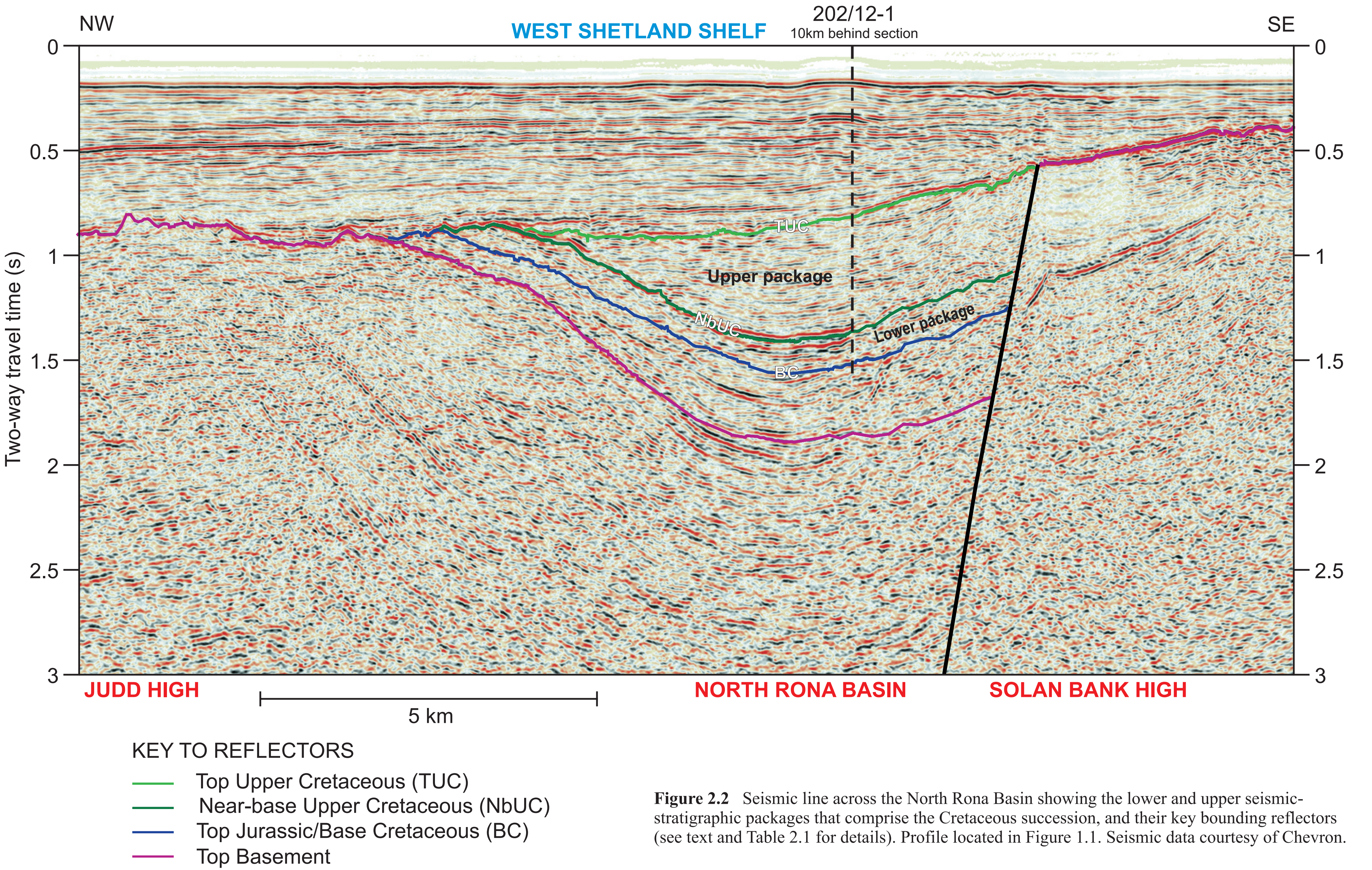


Figure 2.2 Seismic line across the North Rona Basin showing the lower and upper seismic-stratigraphic packages that comprise the Cretaceous succession, and their key bounding reflectors (see text and Table 2.1 for details). Profile located in Figure 1.1. Seismic data courtesy of Chevron.

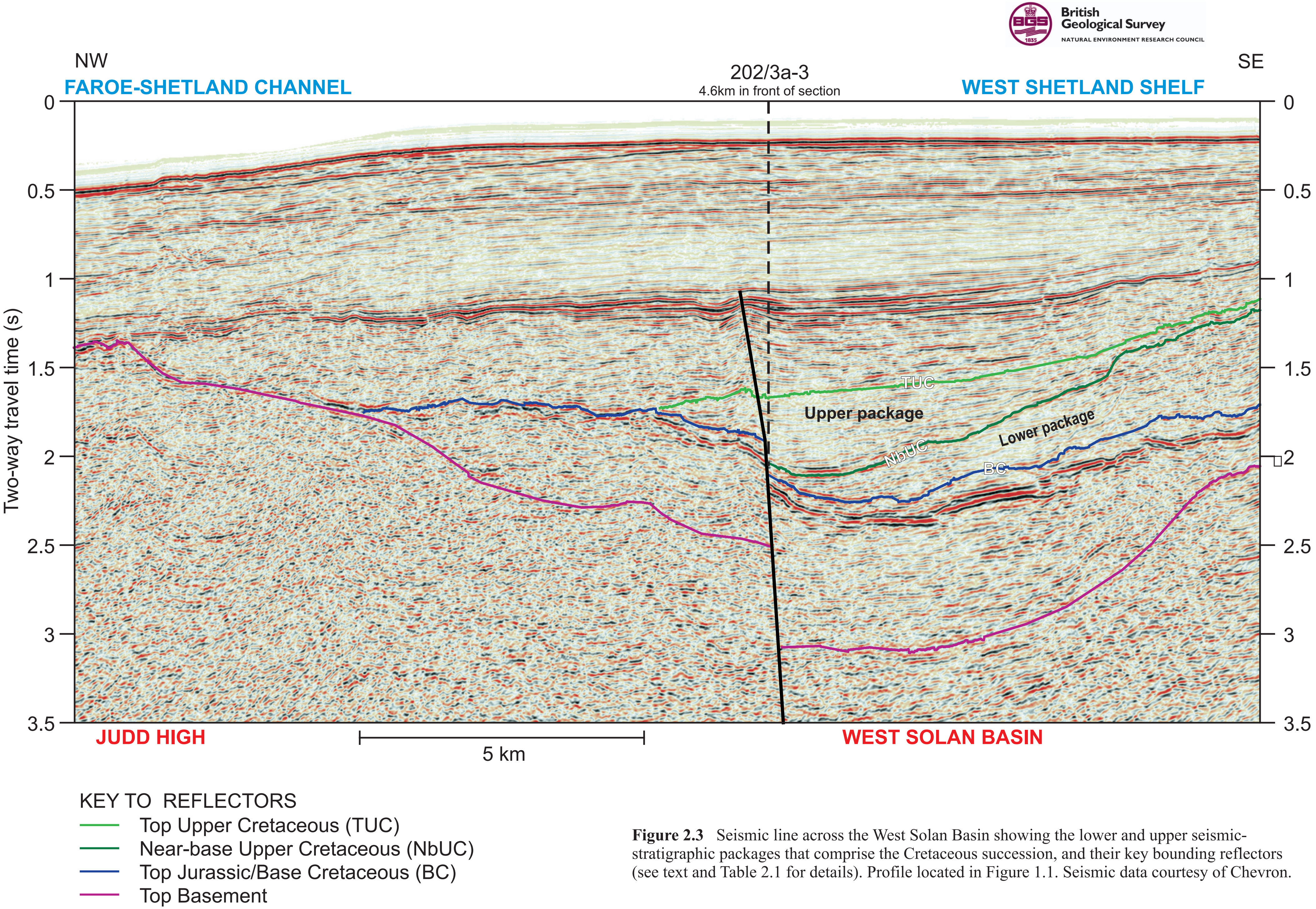
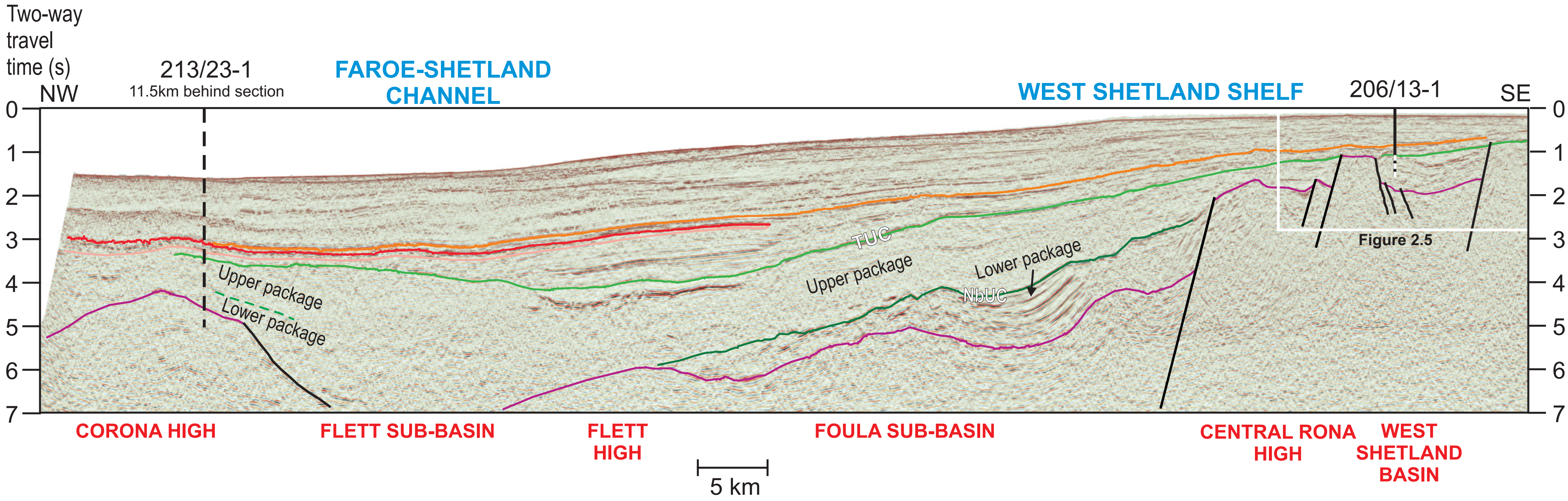


Figure 2.3 Seismic line across the West Solan Basin showing the lower and upper seismic-stratigraphic packages that comprise the Cretaceous succession, and their key bounding reflectors (see text and Table 2.1 for details). Profile located in Figure 1.1. Seismic data courtesy of Chevron.



KEY TO REFLECTORS

- Top Balder Formation (Eocene)
- Top Paleocene Basalt
- Base Paleocene Basalt
- Top Upper Cretaceous (TUC)
- Near-base Upper Cretaceous (NbUC)
- Top Basement (but includes Triassic and/or Devono-Carboniferous on Corona High)

Figure 2.4 Seismic line across the SW West Shetland Basin, and the Foula and Flett sub-basins. Subdivision of the Cretaceous succession and identification of the key Cretaceous boundaries is variable in these basins/sub-basins; the Base Cretaceous boundary is especially difficult to ascertain on this profile except on the Corona High where it overlies Triassic and/or Devono-Carboniferous rocks (see text and Table 2.1 for details). Inset box shows location of enlarged section in Figure 2.5. Profile located in Figure 1.1. Seismic data courtesy of BP.

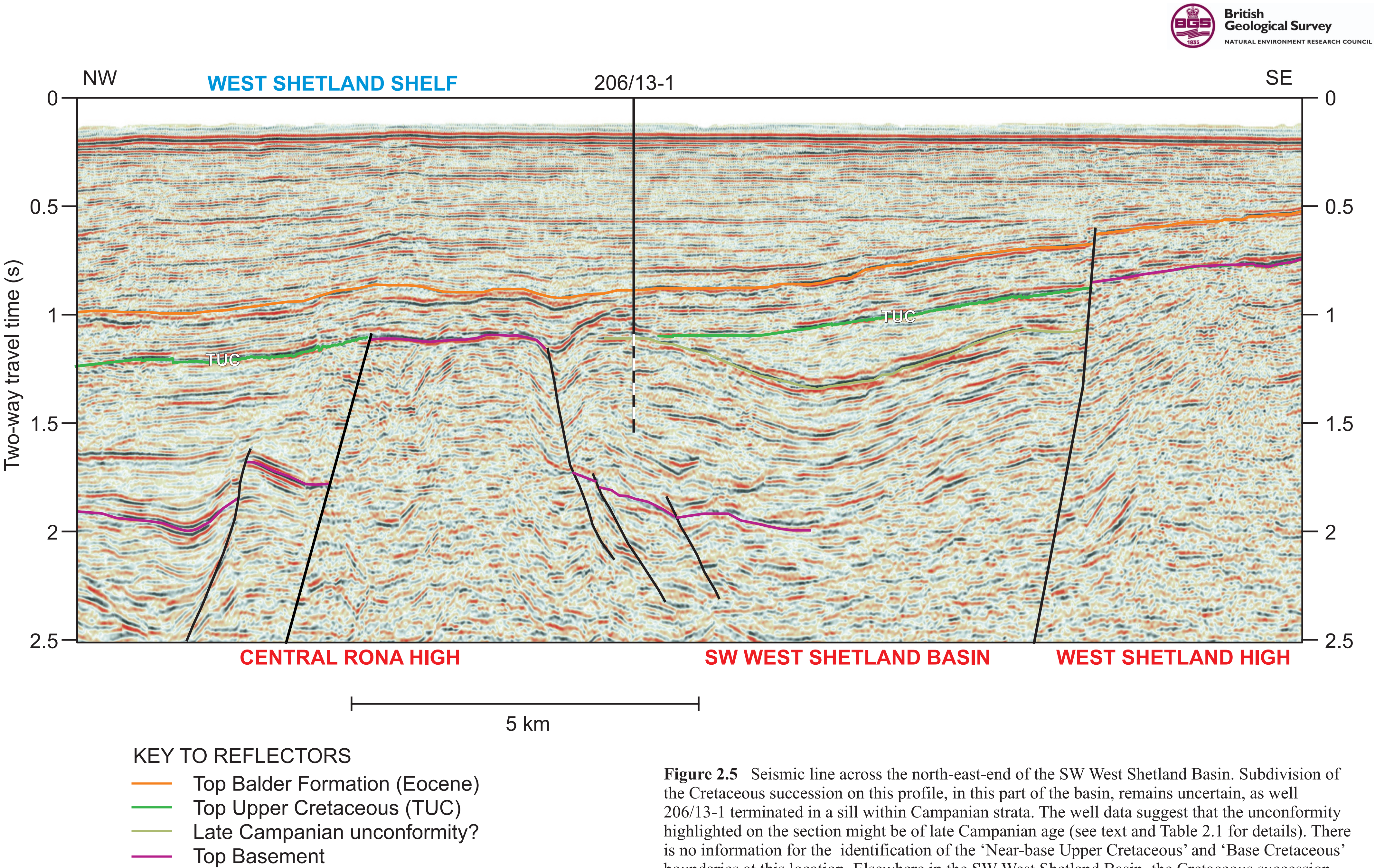
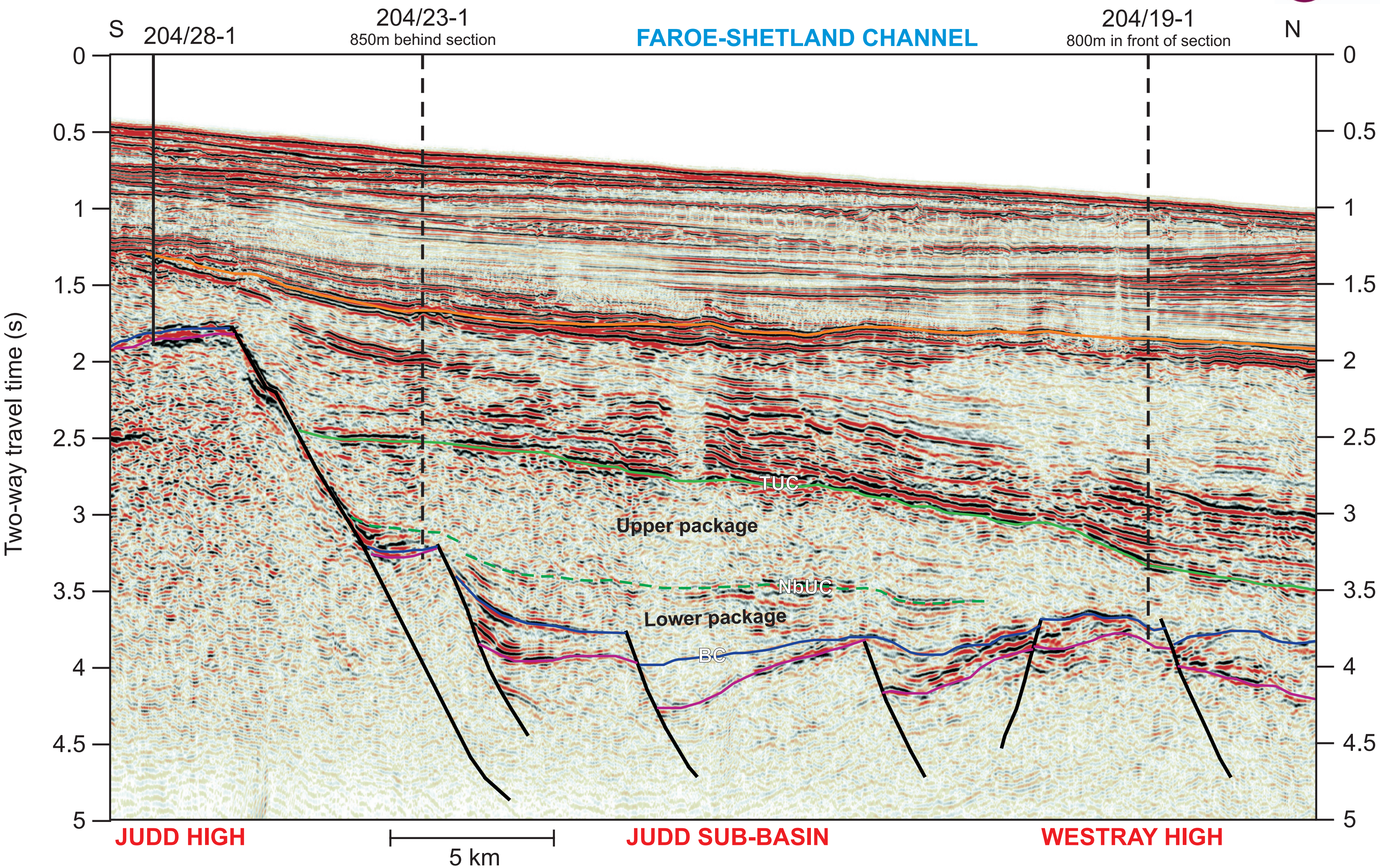


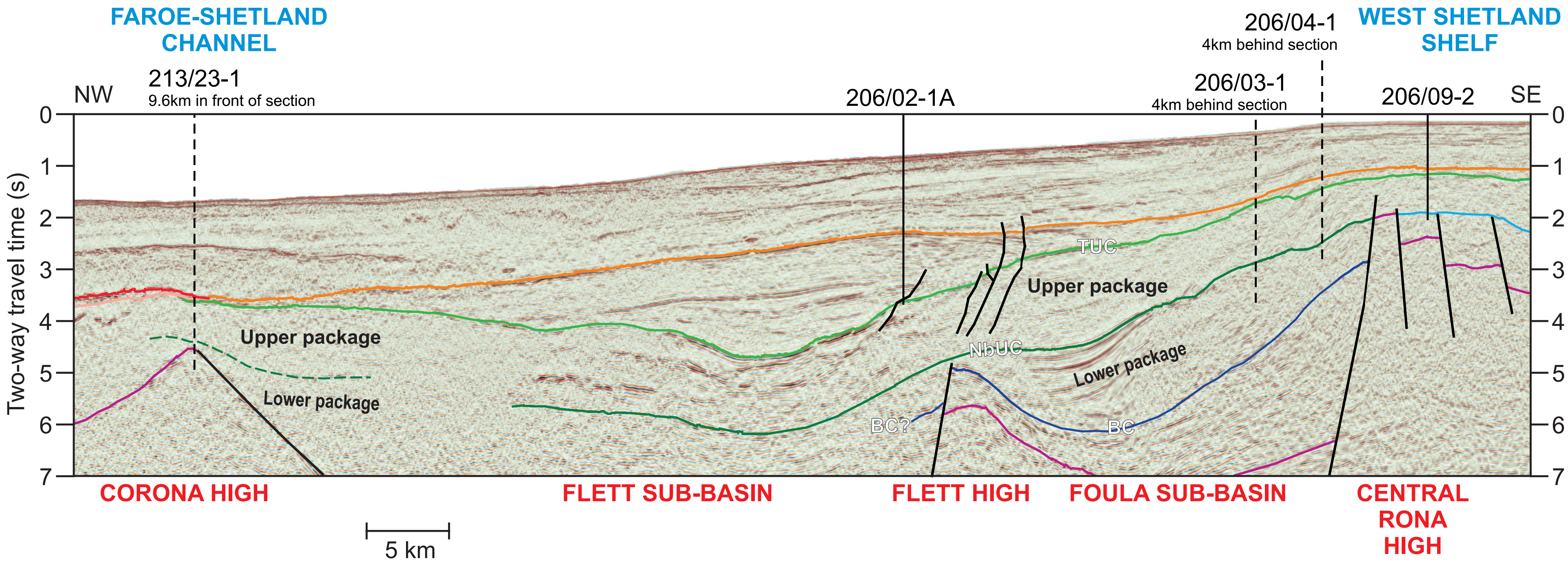
Figure 2.5 Seismic line across the north-east-end of the SW West Shetland Basin. Subdivision of the Cretaceous succession on this profile, in this part of the basin, remains uncertain, as well 206/13-1 terminated in a sill within Campanian strata. The well data suggest that the unconformity highlighted on the section might be of late Campanian age (see text and Table 2.1 for details). There is no information for the identification of the 'Near-base Upper Cretaceous' and 'Base Cretaceous' boundaries at this location. Elsewhere in the SW West Shetland Basin, the Cretaceous succession unconformably overlies Upper Jurassic rocks (Figure A1.2). Profile located in Figure 1.1. Seismic data courtesy of BP.



KEY TO REFLECTORS

- Top Balder Formation (Eocene)
- Top Upper Cretaceous (TUC)
- Near-base Upper Cretaceous (NbUC)
- Top Jurassic (Top Triassic on Westray High)/Base Cretaceous (BC)
- Top Basement (including Devono-Carboniferous on Westray High)

Figure 2.6 Seismic line across the Judd sub-Basin, showing the lower and upper seismic-stratigraphic packages that comprise the Cretaceous succession, and their key bounding reflectors (see text and Table 2.1 for details). Profile located in Figure 1.1. Seismic data courtesy of BP.



KEY TO REFLECTORS

- Top Balder Formation
- Top Paleocene Basalt
- Base Paleocene Basalt
- Top Upper Cretaceous (TUC)
- Near-base Upper Cretaceous (NbUC)
- Top Jurassic (simplified from Lamers & Carmichael, 1995)/Base Cretaceous (BC)
- Top Devono-Carboniferous
- Top Basement (but includes Triassic and/or Devono-Carboniferous on Corona High); (simplified from Lamers & Carmichael, 1995)

Figure 2.7 Seismic line across the Foula and Flett sub-basins. showing the lower and upper seismic-stratigraphic packages that comprise the Cretaceous succession, and their key bounding reflectors. Subdivision of the Cretaceous succession is problematic in the Flett sub-Basin; the Base Cretaceous boundary is especially difficult to ascertain except on the Corona High where it overlies Triassic and/or Devono-Carboniferous rocks (see text and Table 2.1 for all details). Jurassic and Permo-Triassic rocks are interpreted to underlie the Cretaceous succession in the Foula sub-Basin (Lamers and Carmichael, 1999). Profile located in Figure 1.1. Seismic data courtesy of BP.

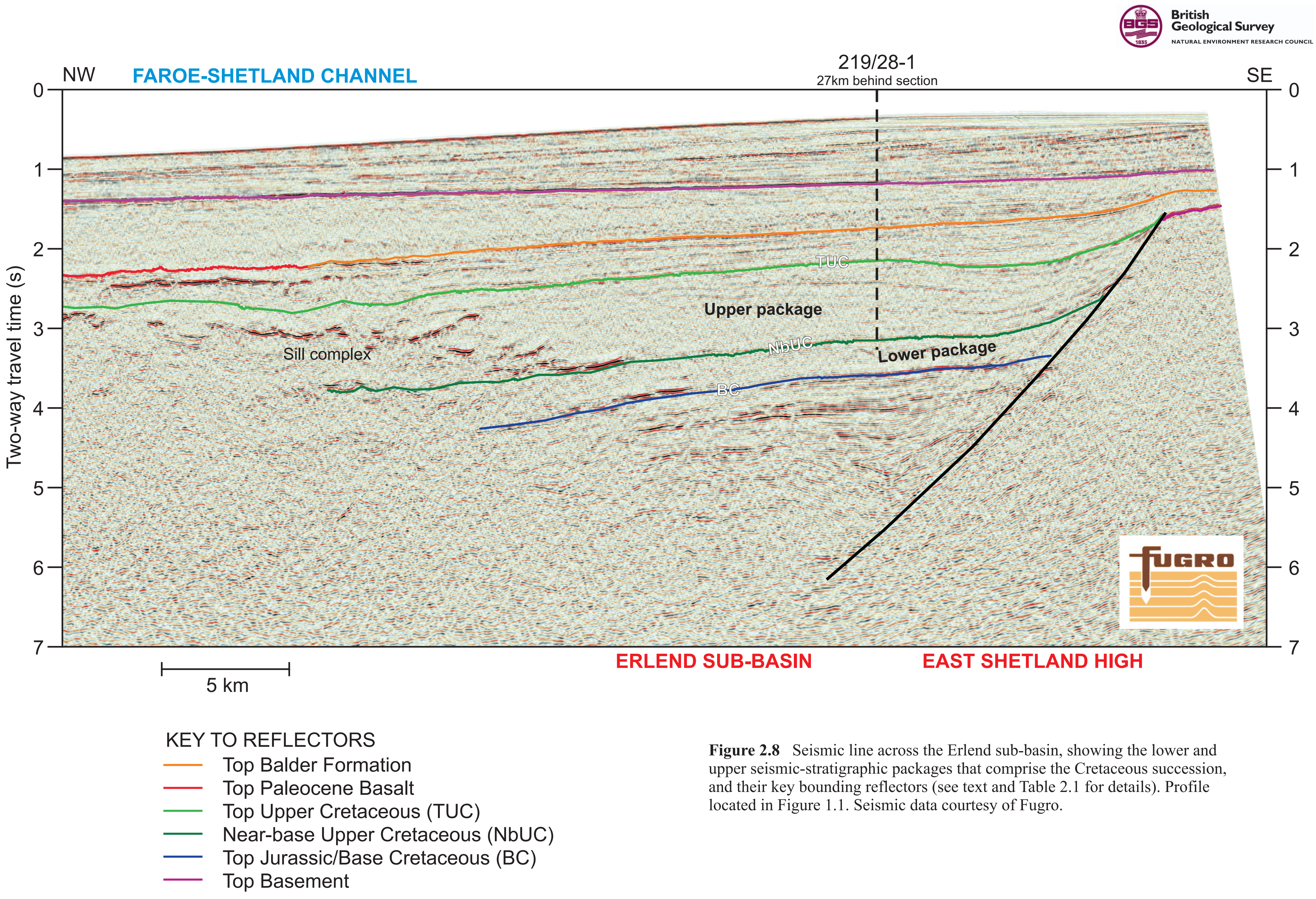


Figure 2.8 Seismic line across the Erlend sub-basin, showing the lower and upper seismic-stratigraphic packages that comprise the Cretaceous succession, and their key bounding reflectors (see text and Table 2.1 for details). Profile located in Figure 1.1. Seismic data courtesy of Fugro.

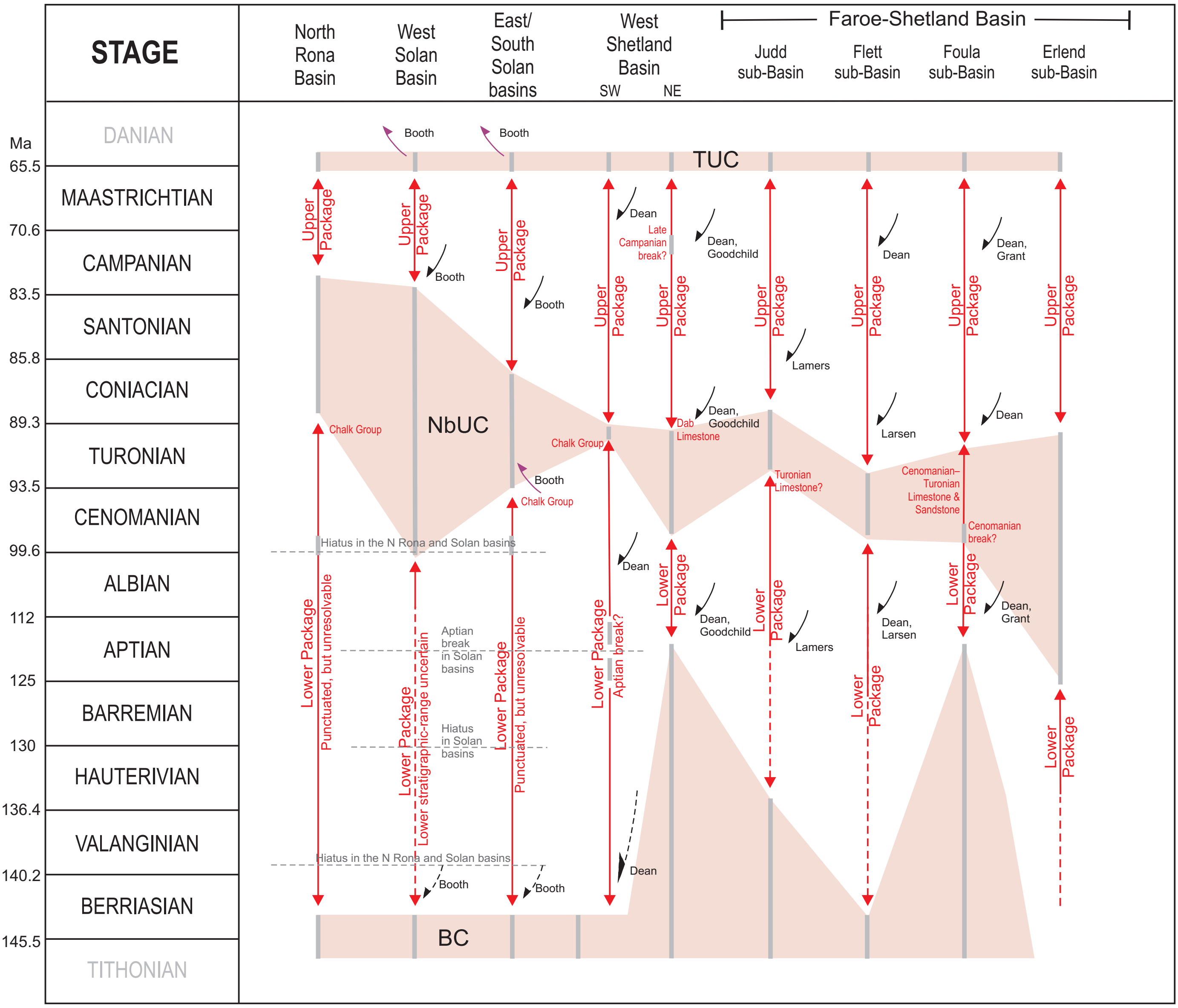


Figure 2.9 Summary of seismic stratigraphy calibrated by well-log and lithostratigraphic data, highlighting the age range of the lower and upper packages and their bounding surfaces (pink shading) within the main basins/sub-basins. Published timings of extensional (black downward arrows) and compressional/inversion (purple upward arrows) taken from: Booth et al., 1993; Dean et al., 1999; Goodchild et al., 1999; Grant et al., 1999; Lamers and Carmichael, 1999; Larsen et al, 2010). Abbreviations: BC, Base Cretaceous boundary; NbUC, Near-base Cretaceous boundary; TUC, Top Upper Cretaceous boundary. (See text for details).

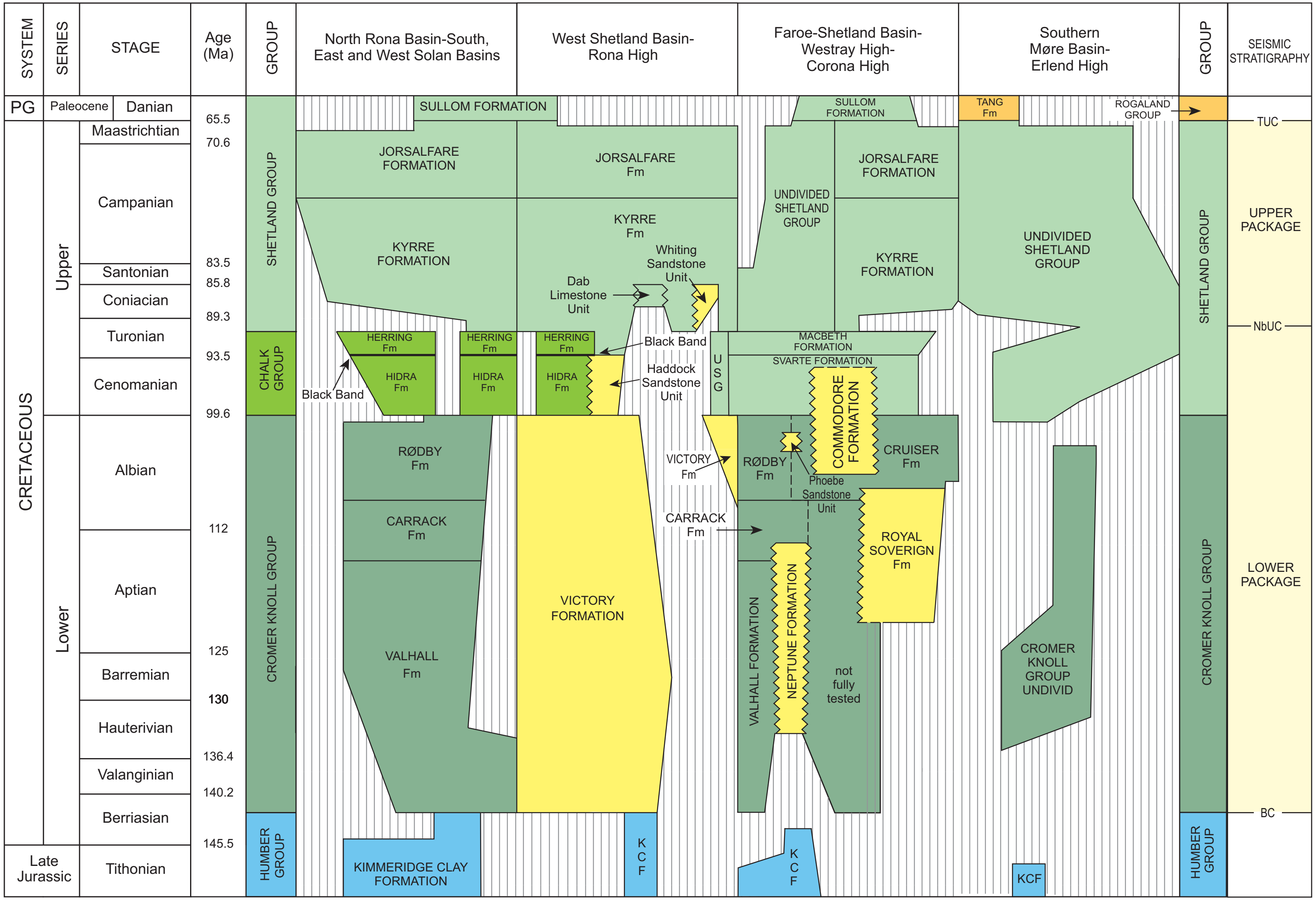
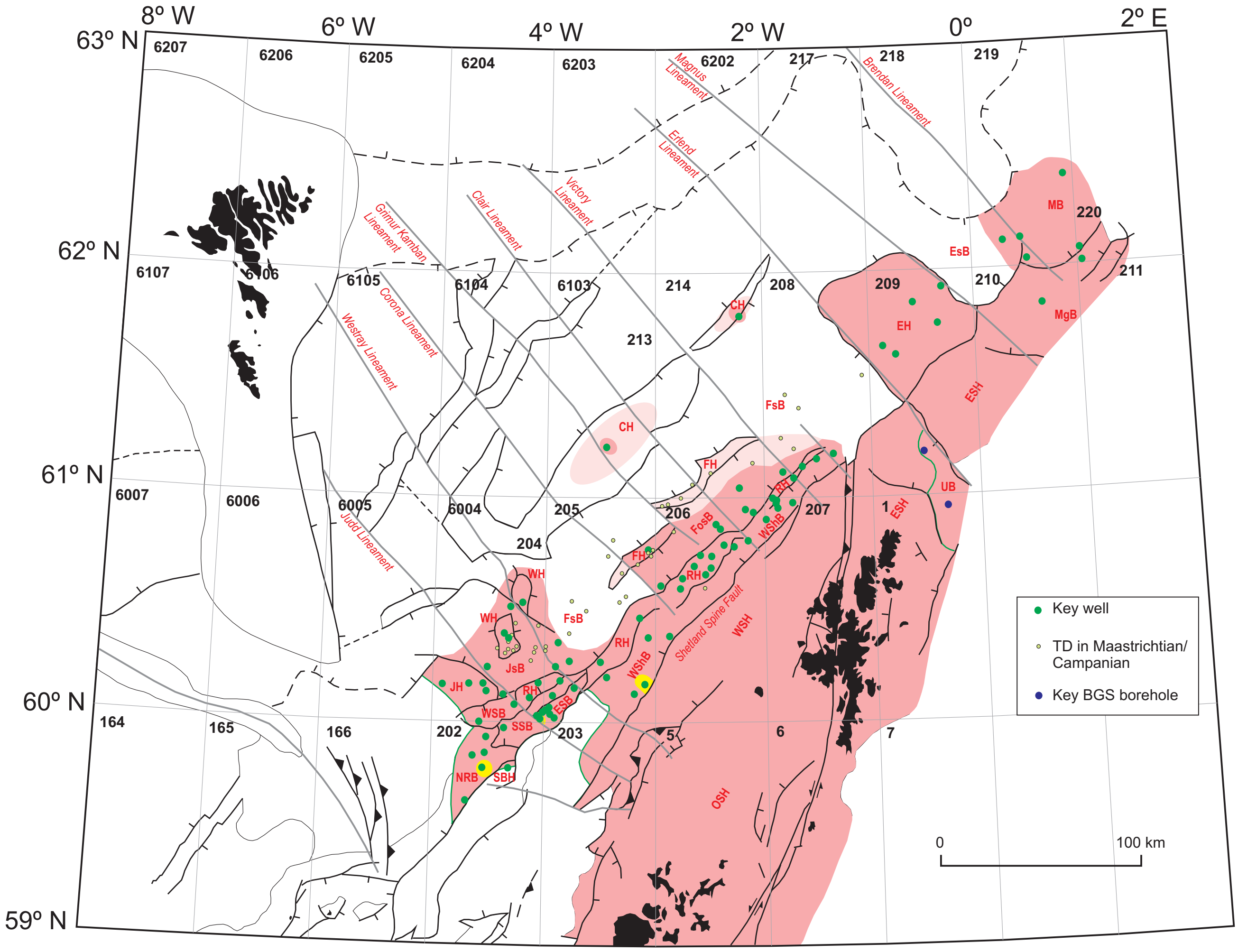


Figure 2.10 Cretaceous lithostratigraphy for the Faroe–Shetland region (modified from Ritchie et al., 1996 and Stoker and Ziska, 2011), and its inferred correlation to the regional seismic stratigraphy. Abbreviations: USG, Undivided Shetland Group; KCF, Kimmeridge Clay Formation; BC, Base Cretaceous boundary; NbUC, Near-base Upper Cretaceous boundary; TUC, Top Upper Cretaceous boundary; PG, Palaeogene. Timescale after Gradstein et al. (2004).



Berriasian (ca. 142 Ma)

(Humber Group/Cromer Knoll Group transition)

SUMMARY NOTES:

- Widespread hiatus – regional exposed landscape?
- Restricted deposition in North Rona, East Solan and SW West Shetland basins?
- This general scenario contrasts with the North Sea where, according to Underhill (1998) and Oakman & Partington (1998), continuity in deposition across the Humber Group/Cromer Knoll Group boundary was more widespread.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

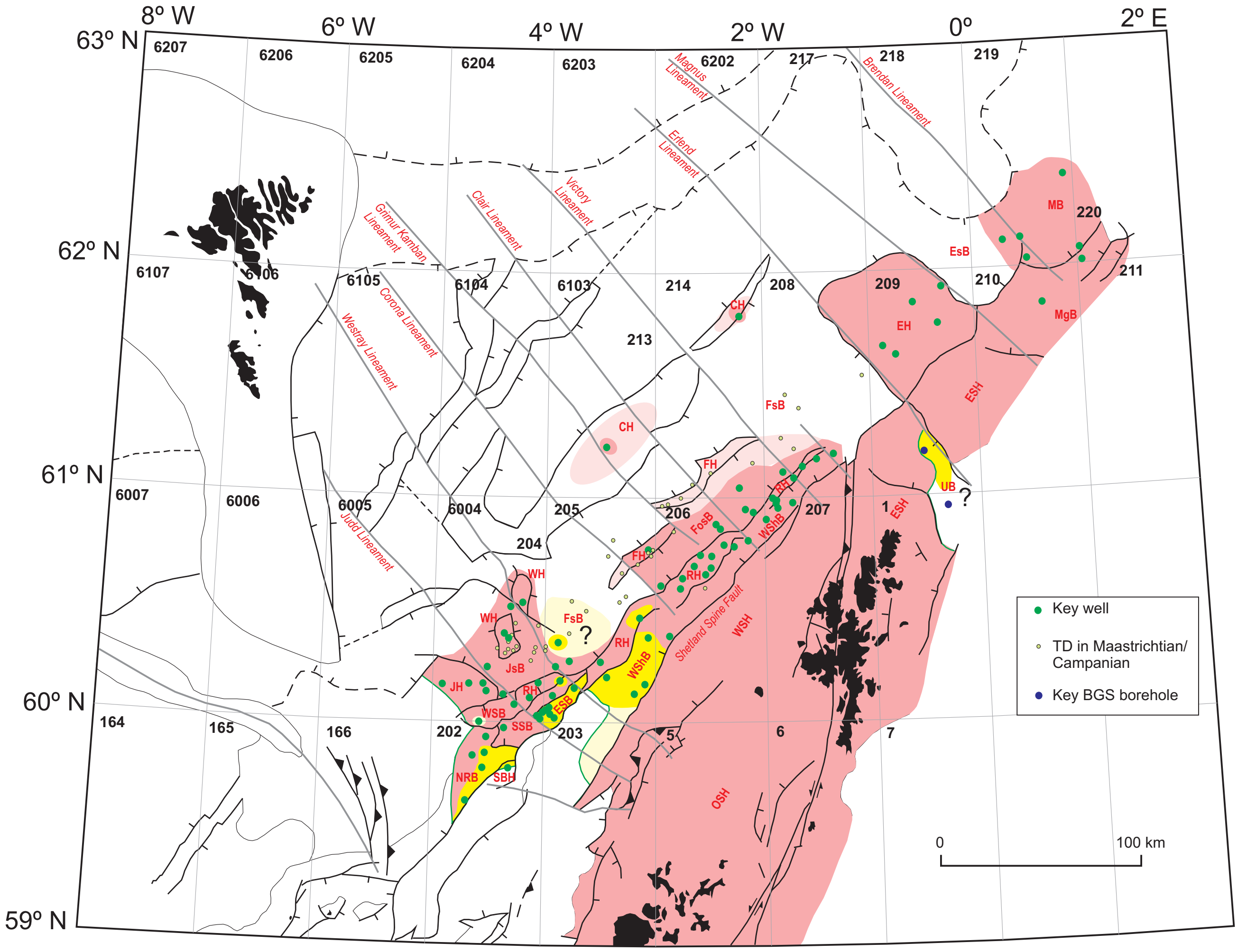
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.1 Basin history: Berriasian (ca. 142 Ma) (Humber Group/Cromer Knoll Group transition). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Late Berriasian–Valanginian (ca.142–136.4 Ma)

SUMMARY NOTES:

- Active basins in south-west part of area, with deposition occurring in:
  - SE marginal basins, especially the North Rona and East Solan basins, and the SW part of the West Shetland Basin.
  - Northern part of the Solan Bank High.
  - Southern Flett sub-Basin.
    Note: Reappraisal of well data by Ichron Limited suggests later (Barremian/Aptian) onset of deposition in this basin (Oral communication, A Alderson, Ichron Limited, to M Stoker, BGS, November 2010).
- Judd, Rona, Westray, Flett, Corona and Erlend highs remain largely exposed. Localised deposition on south-west–central Rona High.
- Active deposition in the Unst Basin.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

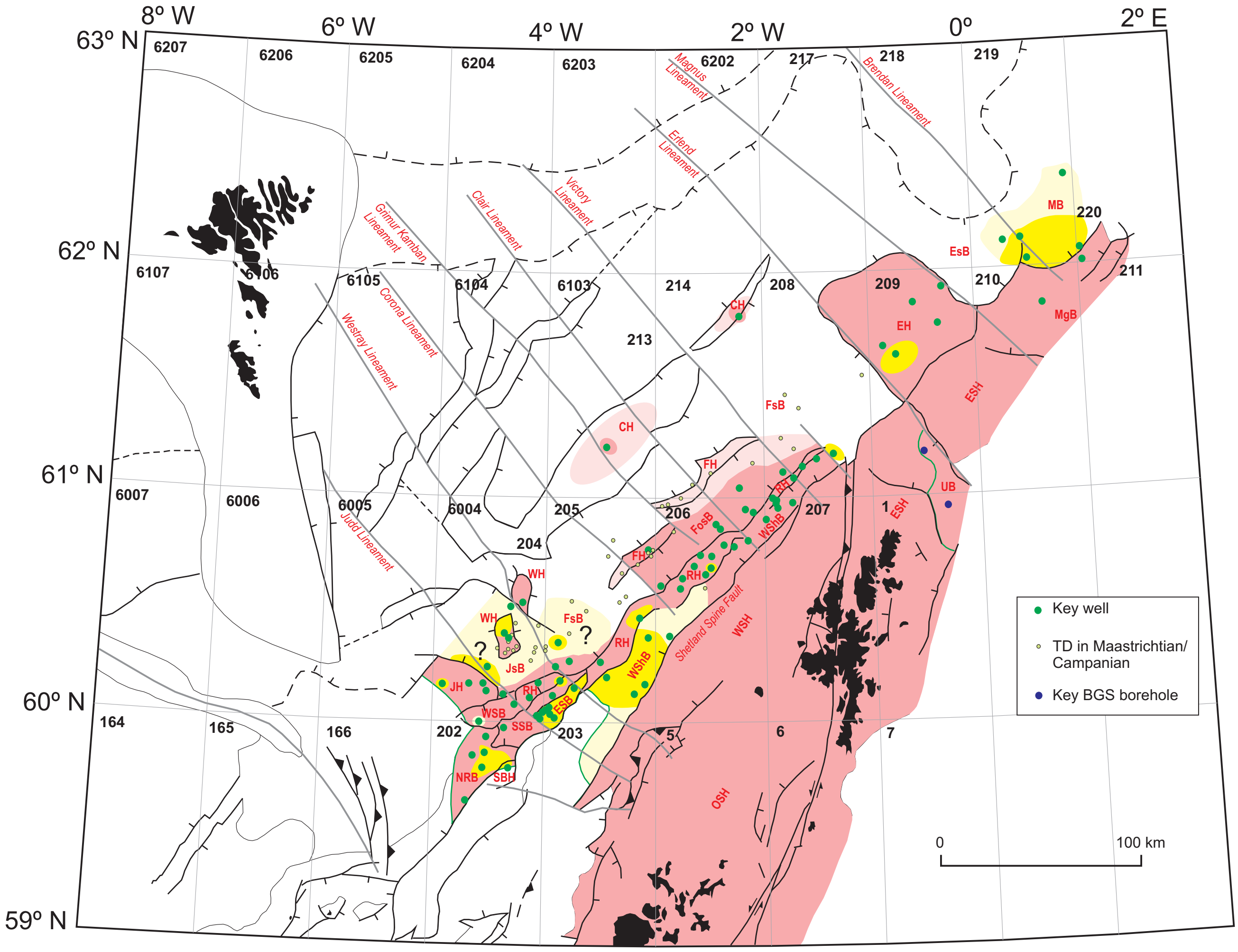
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.2 Basin history: Late Berriasian–Valanginian (ca. 142–136.4 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Hauterivian (136.4–130 Ma)

SUMMARY NOTES:

- Localised deposition persists in the south-western part of the area, but now may also include the Judd sub-Basin.
  Note: Reappraisal of well data by Ichron Limited suggests later (Barremian/Aptian) onset of deposition in the SW Faroe-Shetland Basin (Oral communication, A Alderson, Ichron Limited, to M Stoker, BGS, November 2010).
- The north-eastern part of the Flett sub-Basin may have become active, together with the Erlend sub-Basin and Møre Basin.
- The Judd, Rona, Westray, Flett, Corona and Erlend highs remain largely exposed, though partial submergence of the Judd, south Westray, south-west–central Rona, and southern Erlend highs is noted.
- Unst Basin re-emerged.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

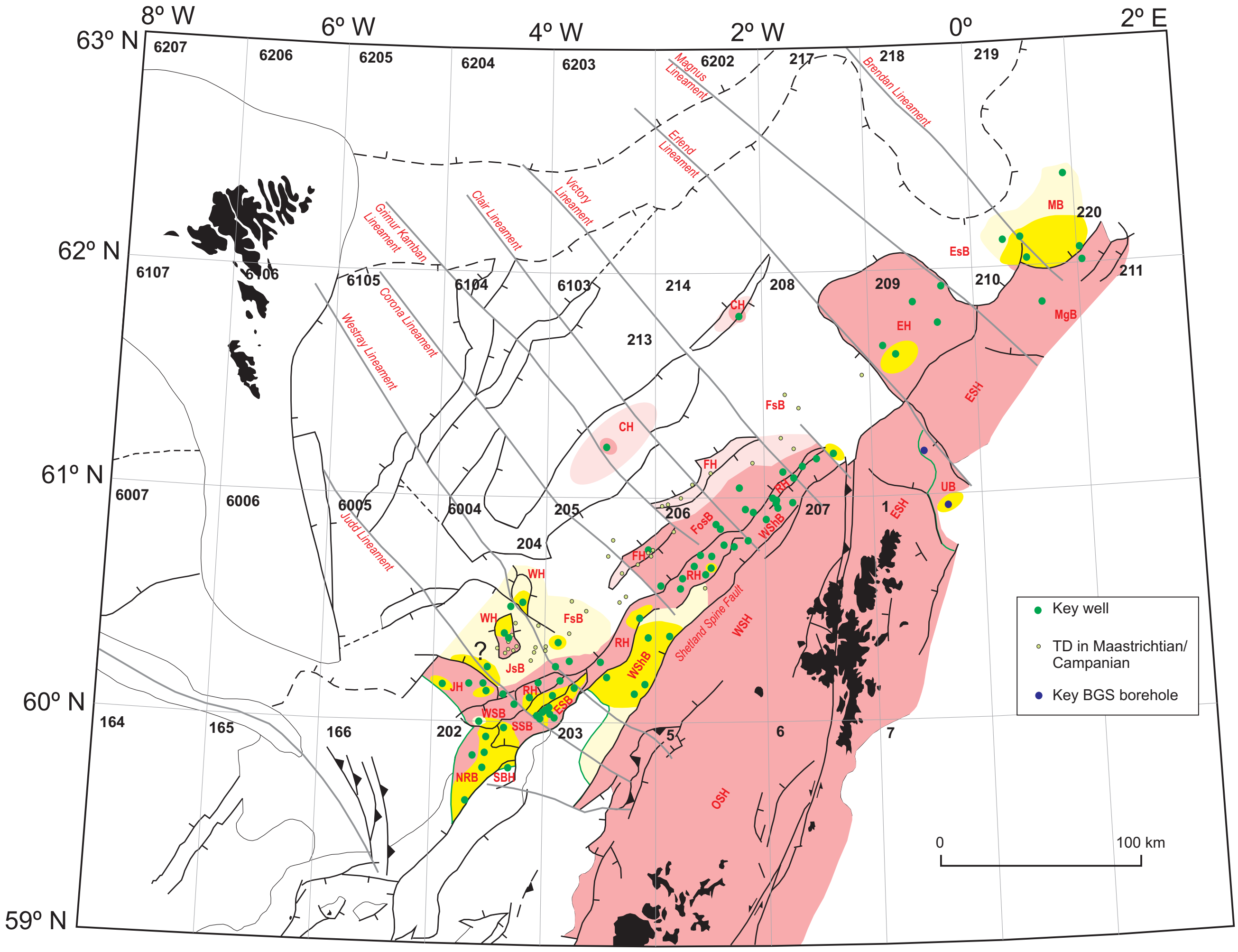
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.3 Basin history: Hauterivian (136.4–130 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Barremian (130–125 Ma)

SUMMARY NOTES:

- Localised deposition persists in the south-western part of the area, becoming increasingly widespread in the SE marginal basins, and the SW Faroe-Shetland Basin.
  Note: Reappraisal of well data by Ichron Limited suggests that onset of deposition in south-western Flett sub-Basin, and on the intra-basinal Westray High, occurred in this interval, but deposition in Judd sub-Basin remains ambiguous. (Oral communication, A Alderson, Ichron Limited, to M Stoker, BGS, November 2010).
- The north-eastern part of the Flett sub-Basin, the Erlend sub-Basin, and the Møre Basin remain active in the northern part of the area.
- The Judd, Rona, Flett, Corona and Erlend highs remain largely exposed, though increasing submergence of the Judd High is noted; deposition remains patchy on the south-west–central Rona and southern Erlend highs.
- Localised deposition renewed in Unst Basin.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

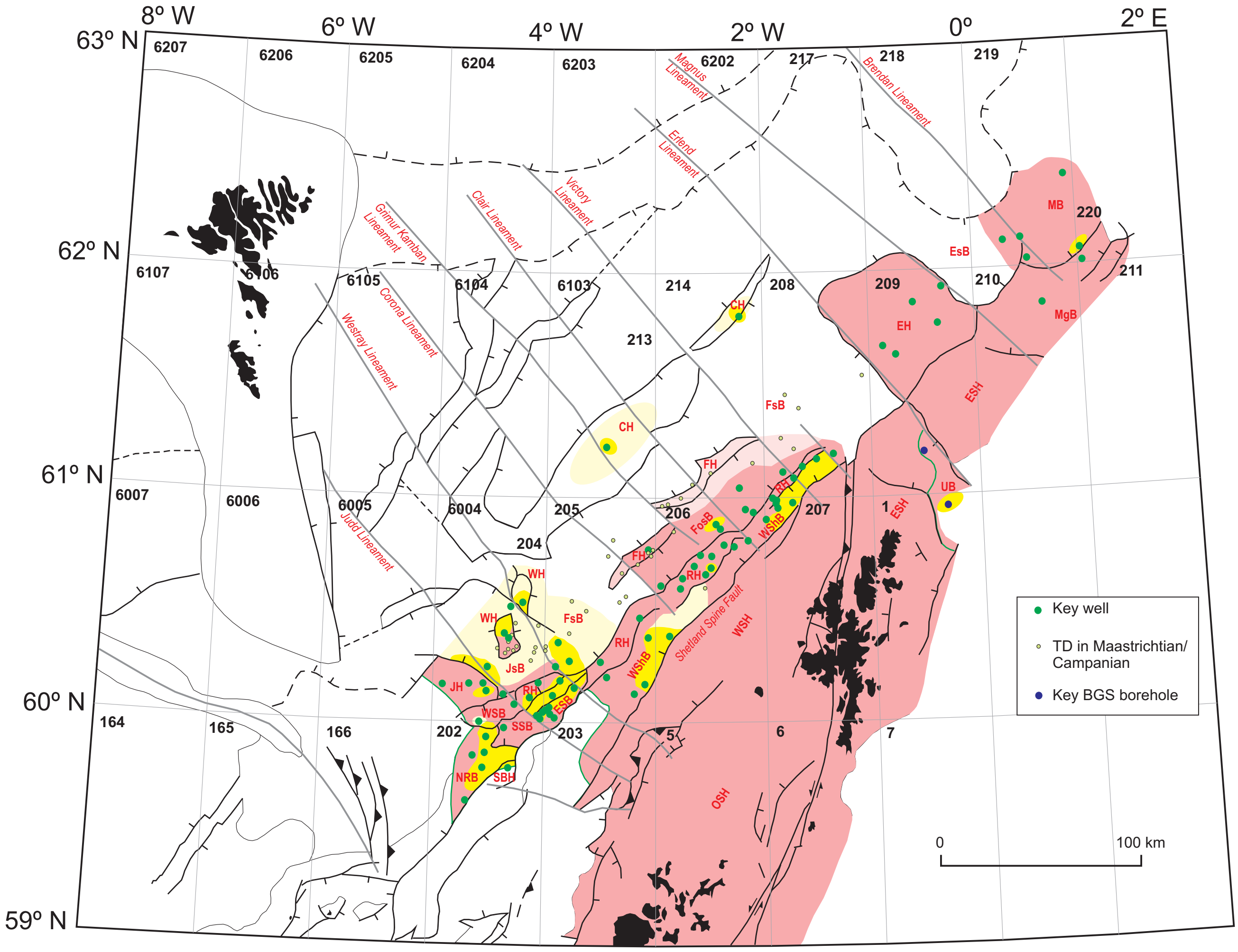
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
UB	Unst Basin
WSH	West Shetland High
MgB	Magnus Basin
ESH	East Shetland High
OSH	Orkney-Shetland High

Figure 3.4 Basin history: Barremian (130–125 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Aptian (125–112 Ma)

SUMMARY NOTES:

- Several major changes noted, including:
    - The submergence of the Corona High.
    - The NE West Shetland Basin becomes active.
    - The adjacent north-east part of the Flett sub-Basin is re-exposed.
    - Initiation of activity in the Foula sub-Basin
      Note: Reappraisal of well data by Ichron Limited suggests onset of deposition in Judd sub-Basin in this interval. (Oral communication, A Alderson, Ichron Limited, to M Stoker, BGS, November 2010).
    - The Erlend sub-Basin and Møre Basin are largely re-exposed.
- SE marginal basins active, but the area of deposition reduced in SW West Shetland Basin.
- The Judd, Rona, Flett, Corona and Erlend highs remain largely exposed.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

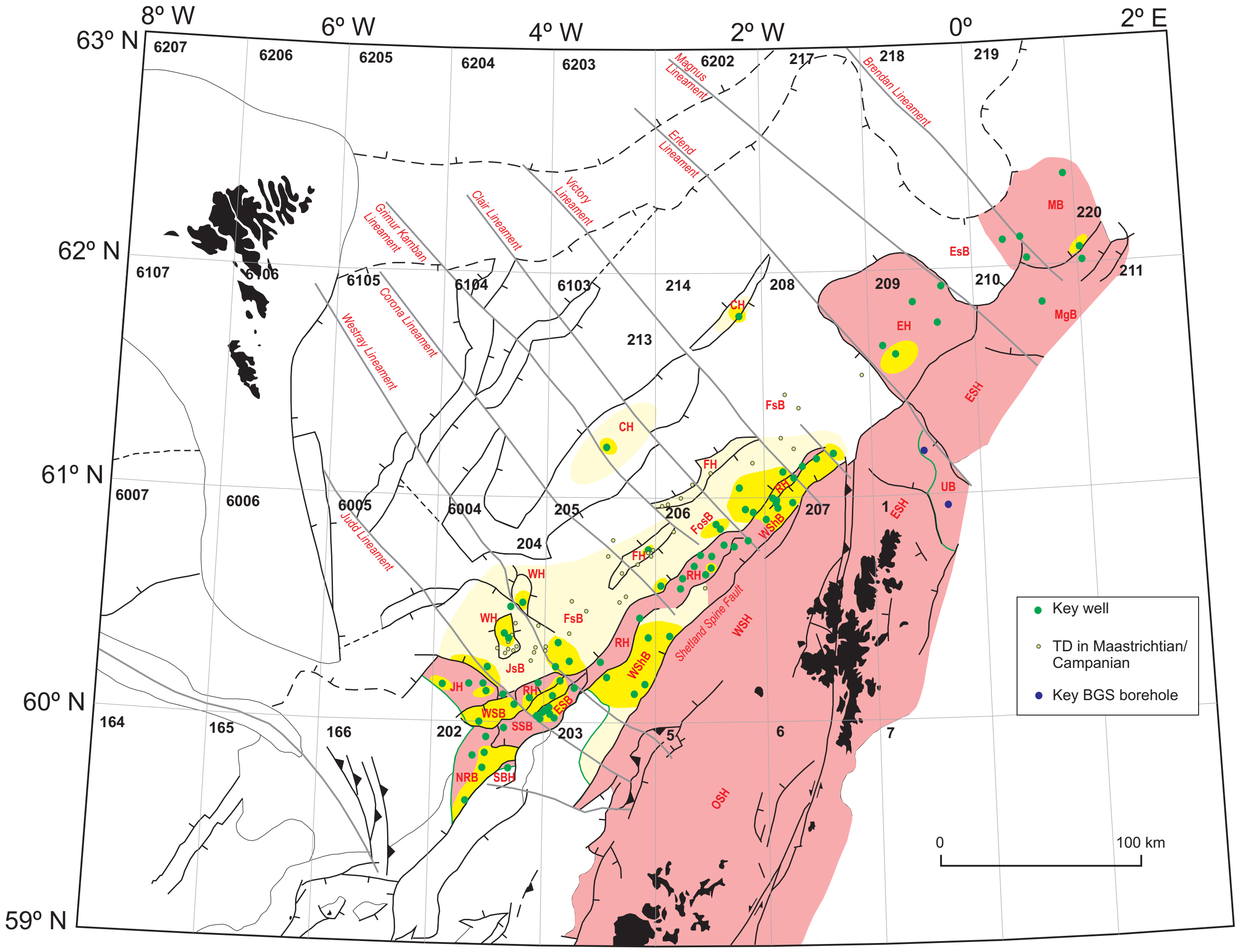
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
UB	Unst Basin
WSH	West Shetland High
MgB	Magnus Basin
ESH	East Shetland High
OSH	Orkney-Shetland High

Figure 3.5 Basin history: Aptian (125–112 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Albian (112–99.6 Ma)

SUMMARY NOTES:

- The Faroe-Shetland Basin becomes a single entity as indicated by:
    - Active deposition throughout the Foula sub-Basin, together with the Judd and Flett sub-Basins.
    - Total submergence of the Westray and Flett highs, together with the Corona High.
- The Erlend sub-Basin and Møre Basin remain largely exposed; the Unst Basin is re-exposed.
- Both the north-east and south-west parts of the West Shetland Basin are active, and the SE marginal basins remain active, though the Solan Bank High has become exposed.
- The Judd, Rona, Flett, Corona and Erlend highs remain largely exposed. Localised deposition on Judd, Rona and Erlend highs.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
    - intra-stage erosion?
    - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

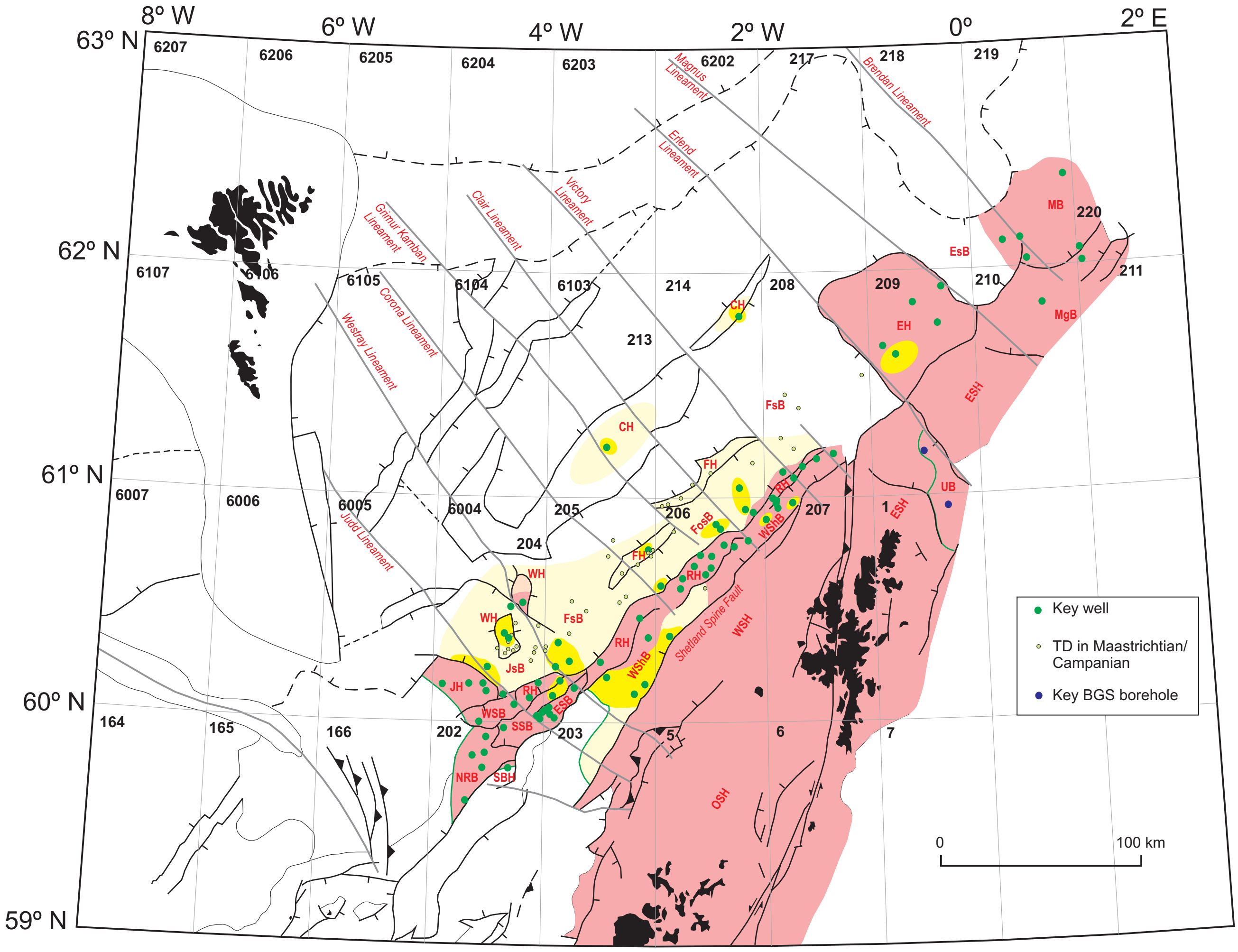
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.6 Basin history: Albian (112–99.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Albian/Cenomanian boundary (99.6 Ma)

SUMMARY NOTES:

- Uplift/rejuvenation of:
  - SE marginal basins.
  - NE West Shetland Basin (localised deposition).
  - Eastern margin of Foula sub-Basin.
  - Judd and Rona highs.
  - Northern part of Westray High.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

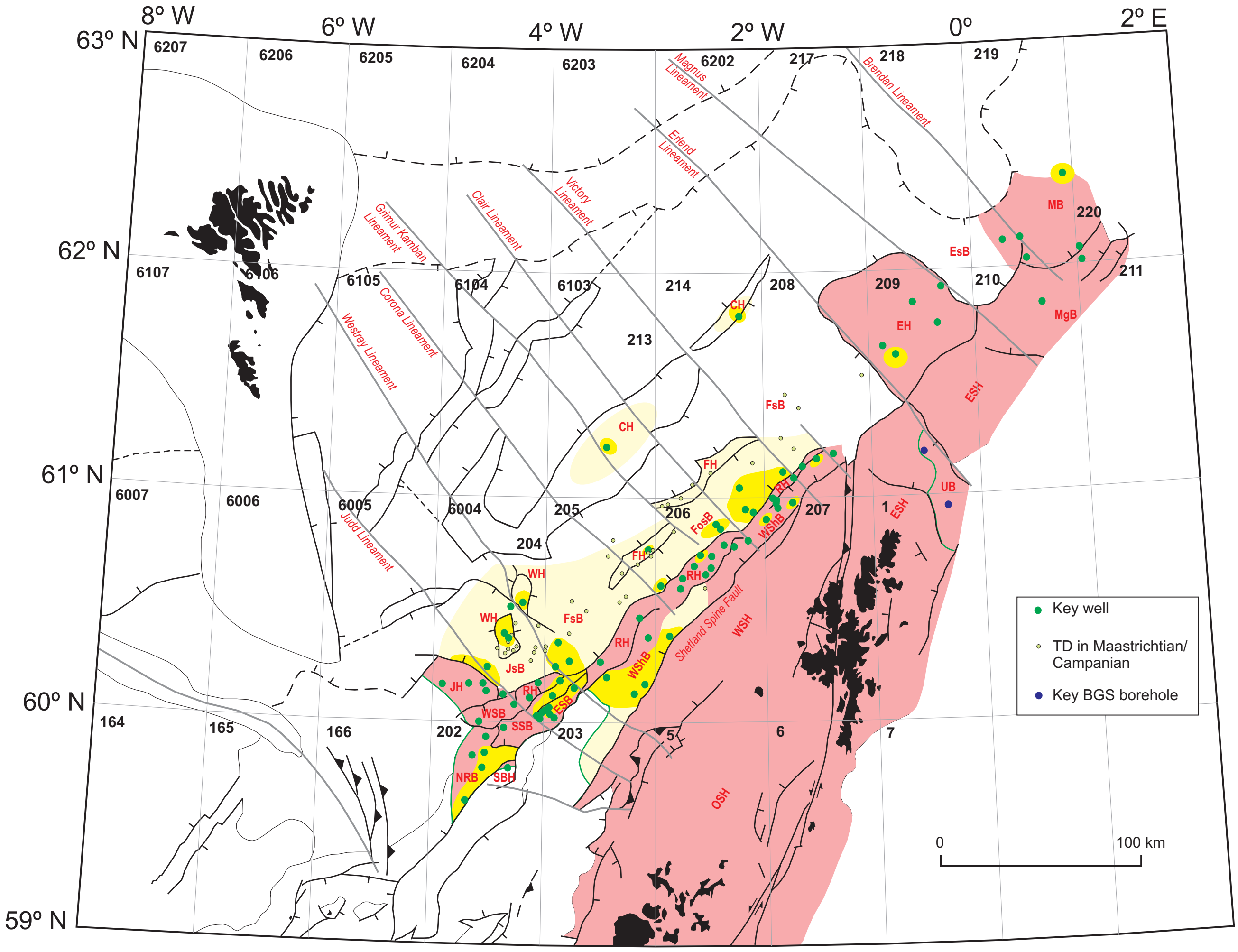
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.7 Basin history: Albian/Cenomanian boundary (99.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Cenomanian (99.6–93.5 Ma)

SUMMARY NOTES:

- The Westray High and Foula sub-Basin are fully re-submerged, resulting in an expansive Faroe-Shetland Basin.
- Localised reactivation of the SE marginal basins (the North Rona and East Solan basins), whilst SW West Shetland Basin continues to accumulate sediment.
- The Judd, Rona and Erlend highs remain largely exposed, though localised deposition noted on the Rona and southern Erlend highs.
- The Erlend sub-Basin and SW Møre Basin may also have remained largely exposed.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.8 Basin history: Cenomanian (99.6–93.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

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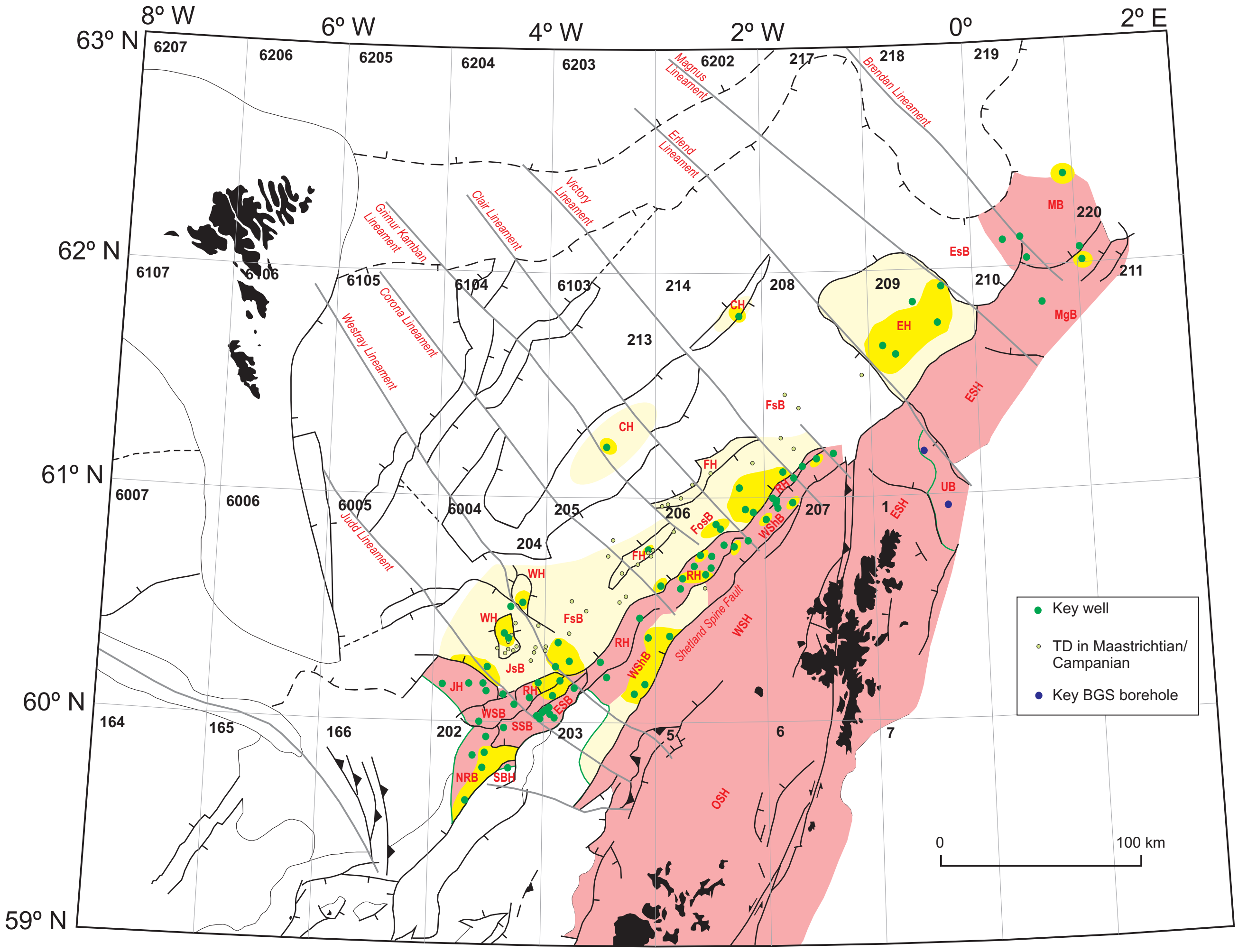


Turonian (93.5–89.3 Ma)

SUMMARY NOTES:

- Faroe-Shetland Basin remains fully submerged.
- Localised activity in the marginal basins is focused mainly in the North Rona and SW West Shetland basins; patchy deposition in NE West Shetland Basin.
- A major change is the submergence of the Erlend High.
- The Judd and Rona highs remain largely exposed, though localised deposition noted on the Rona High.
- The Erlend sub-Basin and Møre Basin remain largely exposed; patchy deposition in the latter.
- Compressional structures described from the East Solan Basin by Booth et al. (1993) probably instigated in the Turonian.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

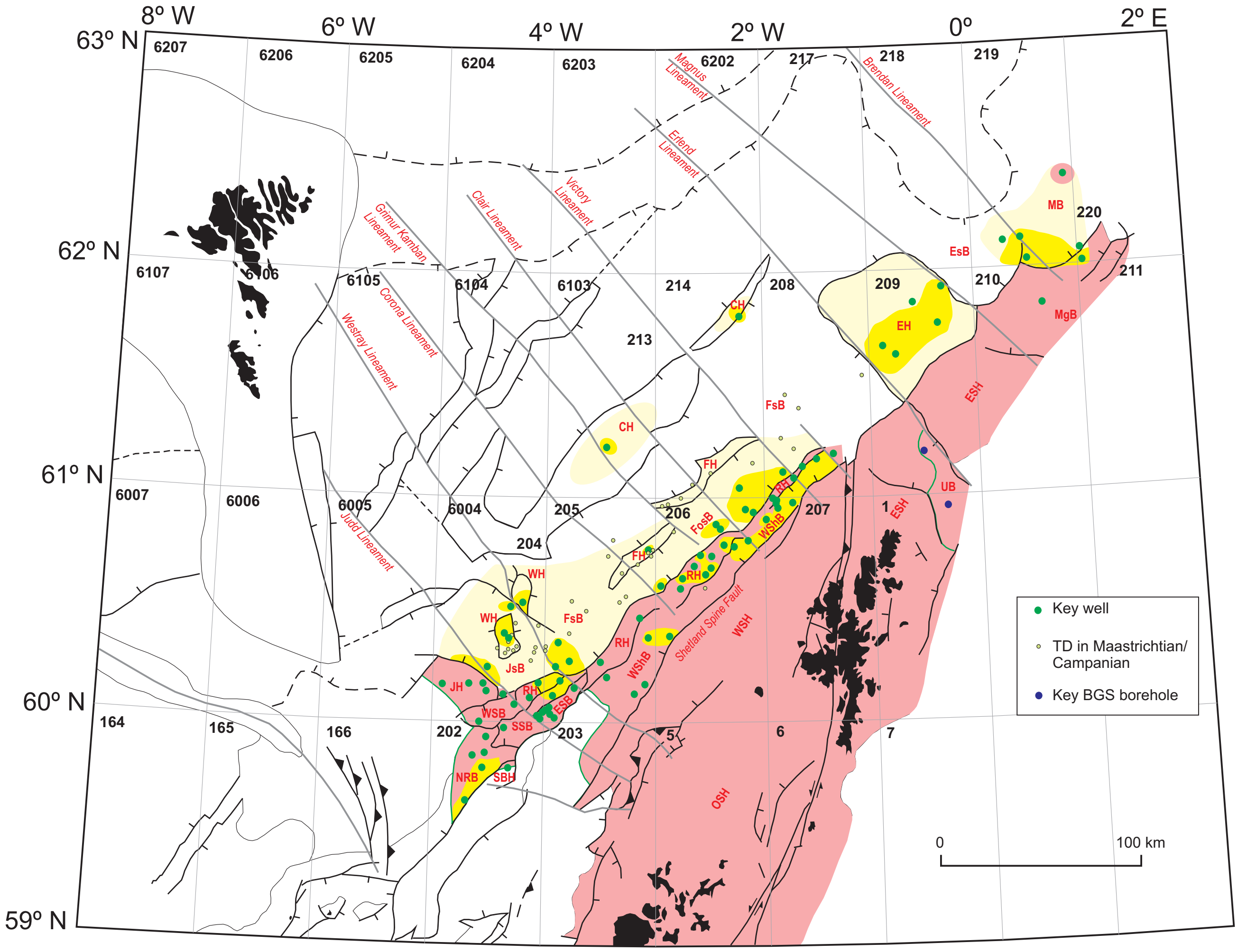
Key to structural elements

MARGINAL BASINS AND HIGHS		FAROE-SHETLAND BASIN	
NRB	North Rona Basin	JsB	Judd sub-Basin
WSB	West Solan Basin	FsB	Flett sub-Basin
SSB	South Solan Basin	FosB	Foula sub-Basin
ESB	East Solan Basin	EsB	Erlend sub-Basin
WShB	West Shetland Basin	WH	Westray High
JH	Judd High	FH	Flett High
SBH	Solan Bank High	CH	Corona High
RH	Rona High	EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.9 Basin history: Turonian (93.5–89.3 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Coniacian (89.3–85.8 Ma)

SUMMARY NOTES:

- Faroe-Shetland Basin remains fully submerged,with the Erlend sub-Basin and Møre Basin (mostly) re-submerged.
- Major change in the activity of the marginal basins, with a switch in focus to the NE West Shetland Basin, though patchy deposition persists in the North Rona and SW West Shetland basins.
- The Erlend High remains submerged.
- The Judd High remains exposed, whereas increased deposition is noted on the central and south-west Rona High.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

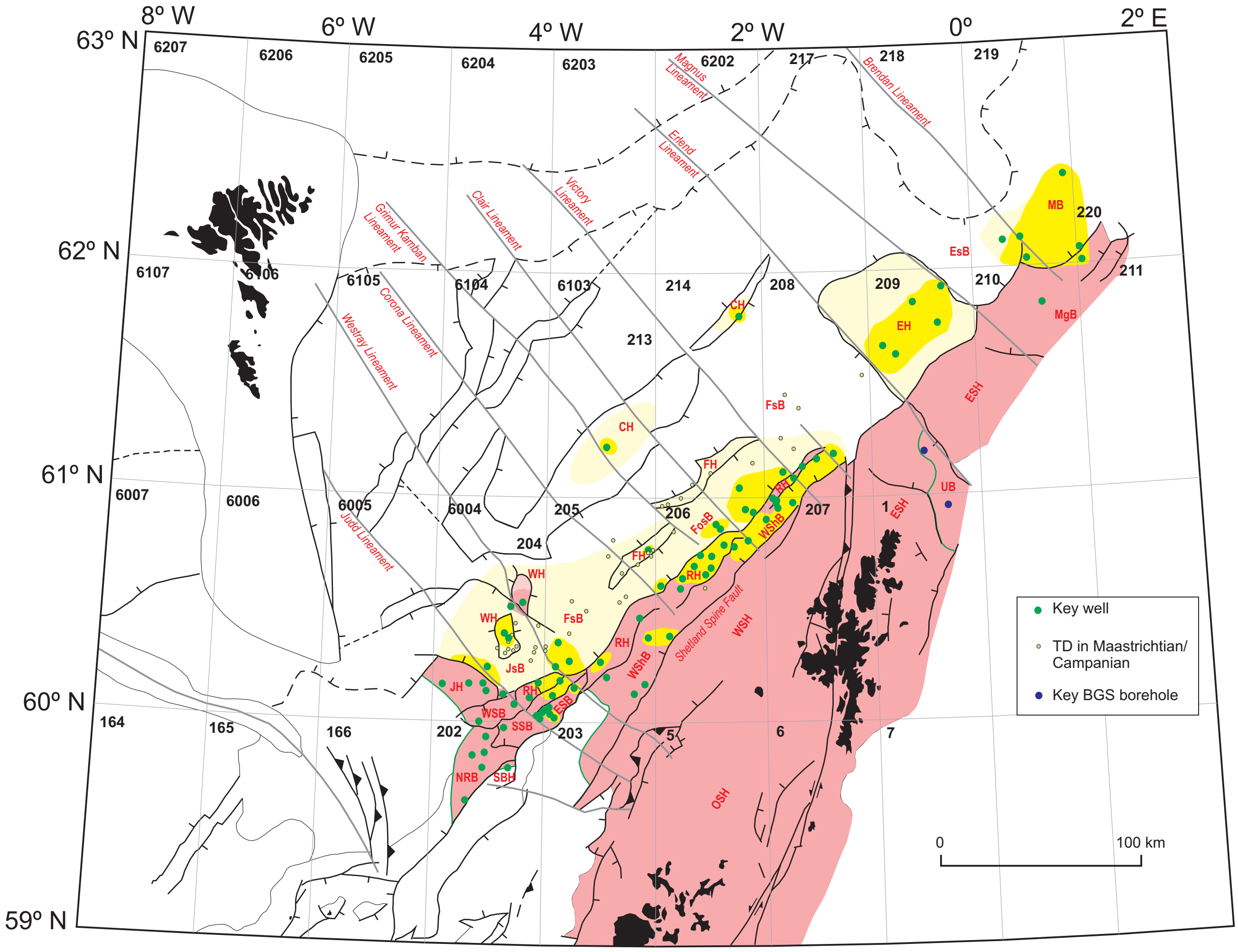
Key to structural elements

MARGINAL BASINS AND HIGHS		FAROE-SHETLAND BASIN	
NRB	North Rona Basin	JsB	Judd sub-Basin
WSB	West Solan Basin	FsB	Flett sub-Basin
SSB	South Solan Basin	FosB	Foula sub-Basin
ESB	East Solan Basin	EsB	Erlend sub-Basin
WShB	West Shetland Basin	WH	Westray High
JH	Judd High	FH	Flett High
SBH	Solan Bank High	CH	Corona High
RH	Rona High	EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.10 Basin history: Coniacian (89.3–85.8 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Santonian (85.8–83.5 Ma)

SUMMARY NOTES:

- Faroe-Shetland Basin remains largely submerged, though northern part of Westray High has re-emerged.
- Møre Basin fully submerged.
- Activity in the marginal basins remains focused in the NE West Shetland Basin; patchy deposition persists in the SW West Shetland basin, but the North Rona Basin is wholly emergent.
- The Erlend High remains submerged.
- The Judd High remains exposed, though deposition persists on the central and south-west Rona High.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
UB	Unst Basin
WSH	West Shetland High
MgB	Magnus Basin
ESH	East Shetland High
OSH	Orkney-Shetland High

Figure 3.11 Basin history: Santonian (85.8–83.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

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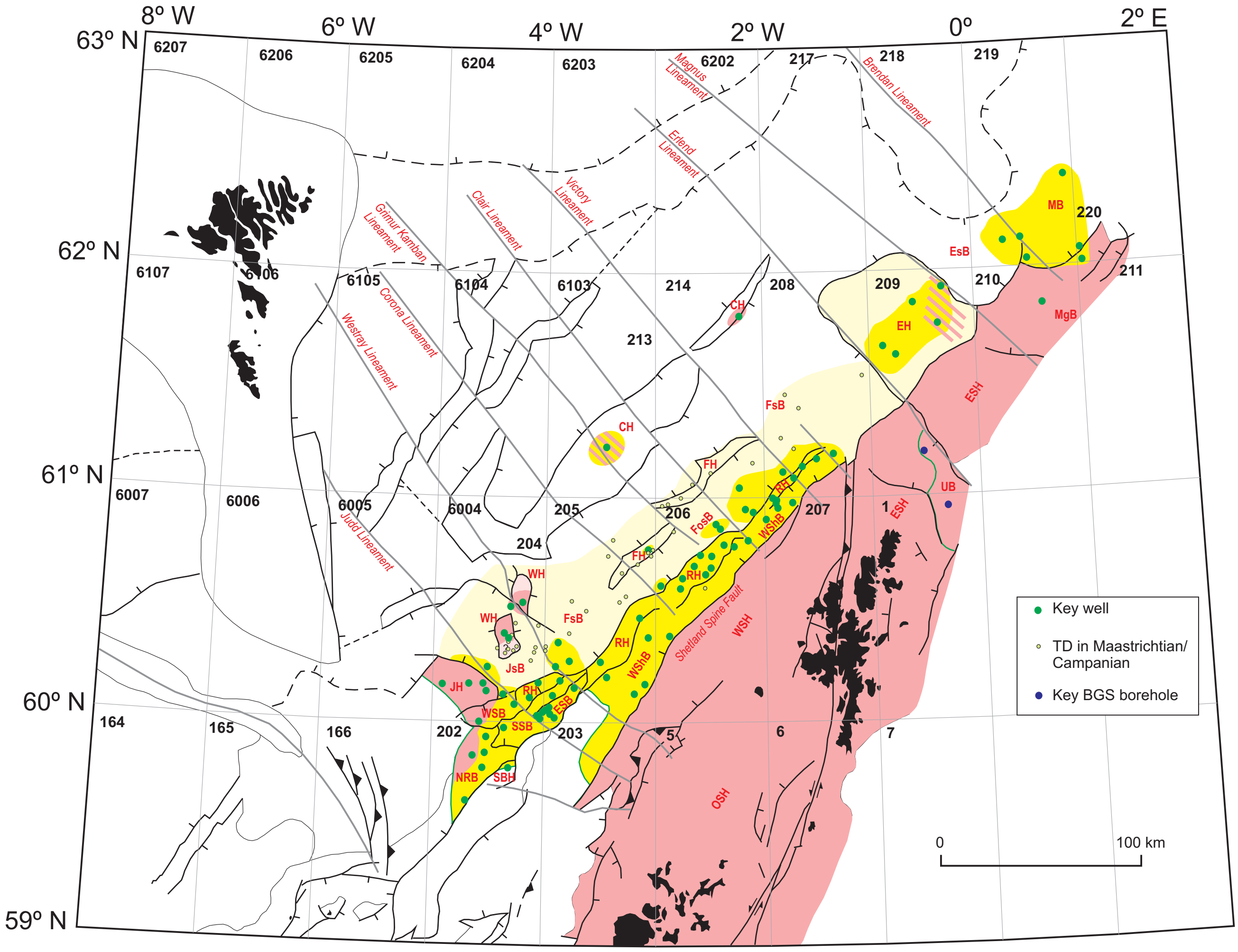


Campanian (83.5–70.6 Ma)

SUMMARY NOTES:

- Major regional changes, including:
  - Active deposition in all marginal basins, the Faroe-Shetland Basin and the Møre Basin.
  - Total submergence of the Rona High.
  - In contrast, the Westray High has re-emerged, and the Corona High may be partially-to-fully emerged.
  - There are also indications that the Erlend High is beginning to re-emerge.
- Intra-Campanian unconformity reported from the West Shetland Basin by Goodchild et al. (1999).

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

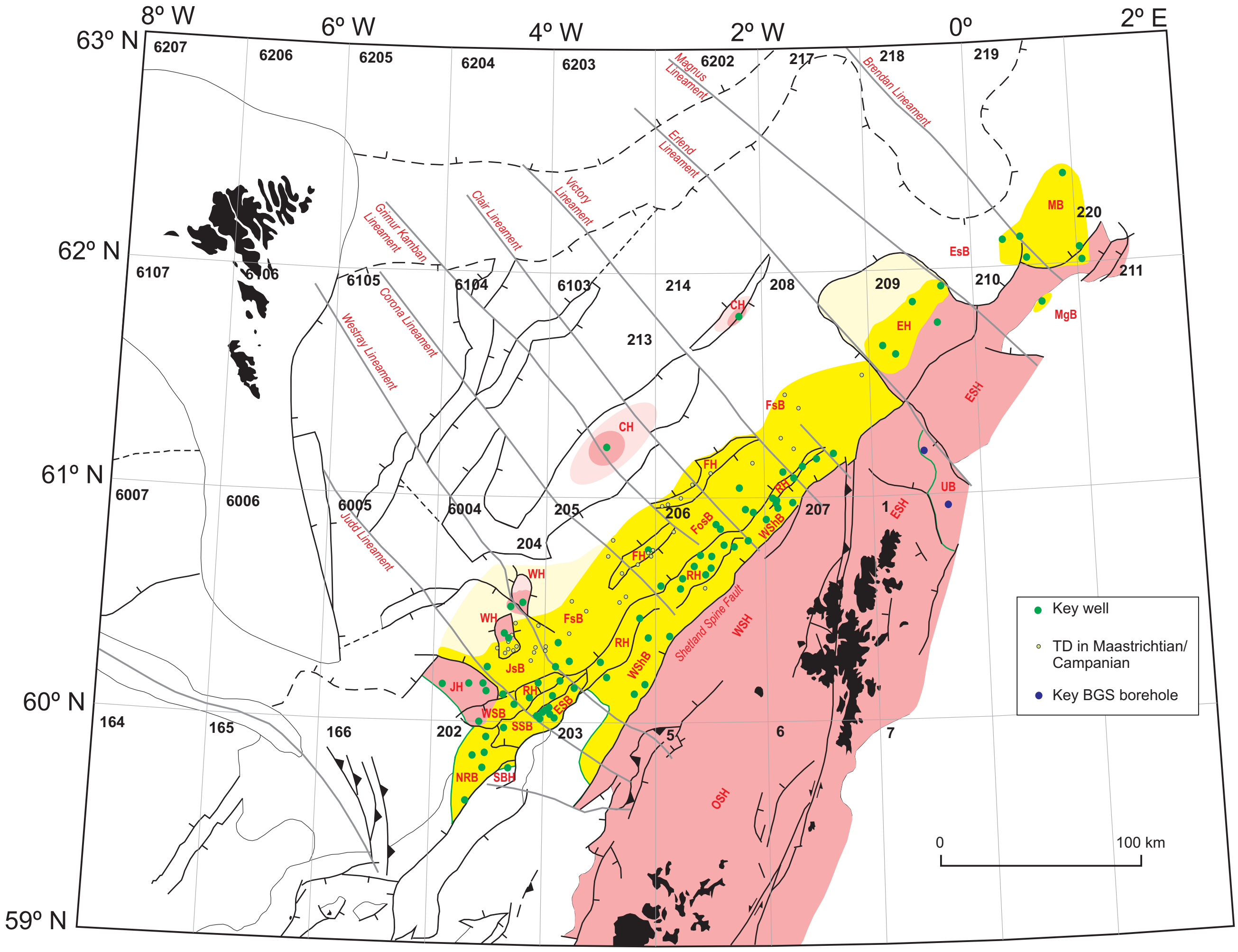
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.12 Basin history: Campanian (83.5–70.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Maastrichtian (70.6–65.5 Ma)

SUMMARY NOTES:

- Faroe-Shetland Basin, Møre Basin, marginal basins and Rona High remain submerged, BUT:
  - Corona High is fully exposed.
  - Westray High is largely exposed.
  - Erlend High is partially eexposed.
- There are also indications that the Erlend High is beginning to re-emerge.
- Magnus Basin is active.

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

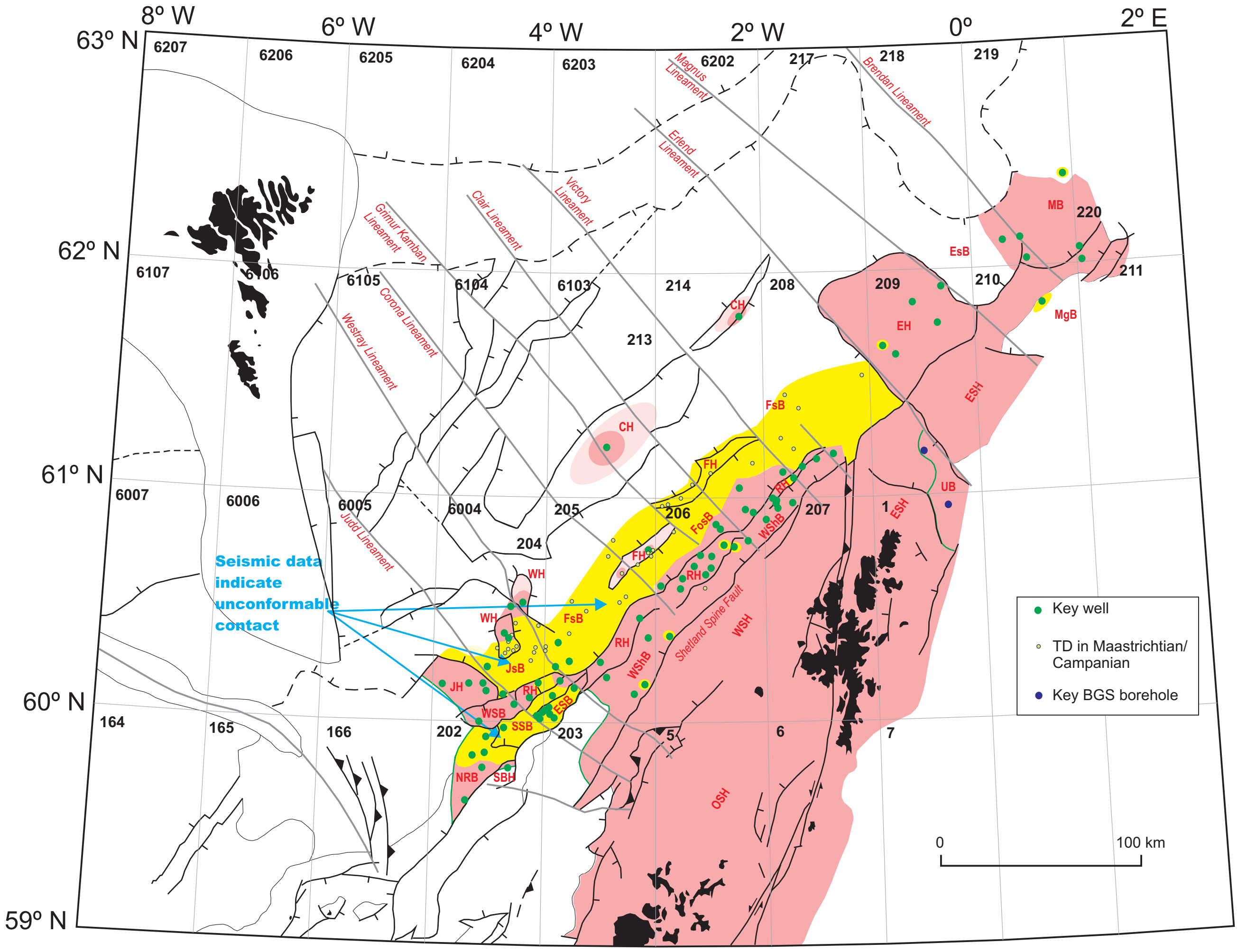
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.13 Basin history: Maastrichtian (70.6–65.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Cretaceous/Palaeogene boundary (65.5 Ma)

SUMMARY NOTES:

- Major change marked by re-exposure of:
  - Rona High.
  - West Shetland Basin, and parts of SE marginal basins.
    Note: Seismic data indicate a widespread unconformity, which may suggest that most of the SE marginal area was exposed.
  - Erlend High (now largely exposed).
  - Southern Flett High.
  - Eastern flank of Foula sub-Basin.
  - Erlend sub-Basin and Møre Basin.
- Corona and Judd highs remain exposed
- **Note:** Seismic data indicate a widespread unconformity in the Foula, Flett and Judd sub-basins. Subaerial or submarine erosion?

Key to colours

- Active deposition
- Possible deposition
- Possibly becoming exposed
- Absent - possibly exposed?
  - intra-stage erosion?
  - later erosion?
- Absent: inferred

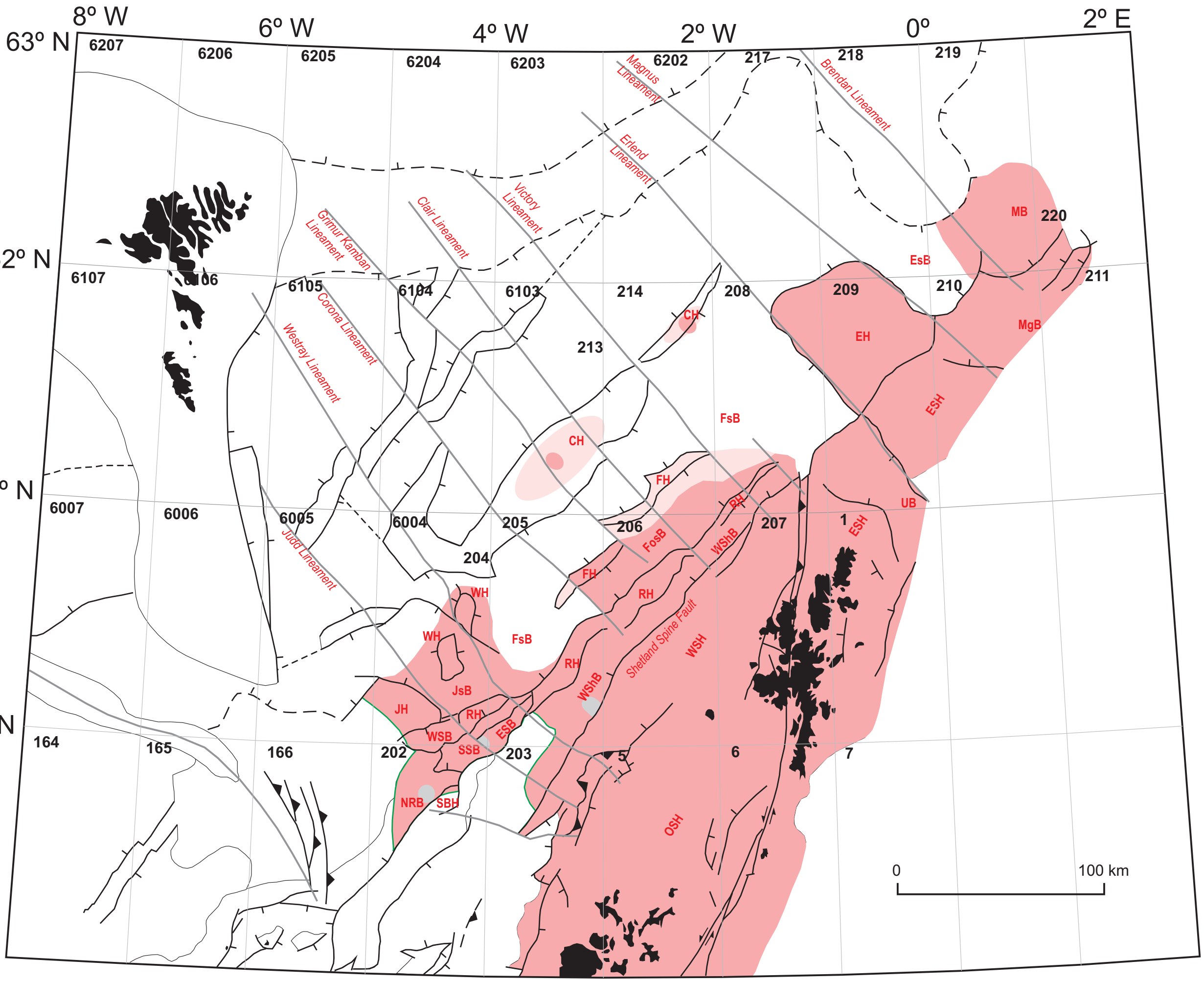
Key to structural elements

MARGINAL BASINS AND HIGHS		FAROE-SHETLAND BASIN	
NRB	North Rona Basin	JsB	Judd sub-Basin
WSB	West Solan Basin	FsB	Flett sub-Basin
SSB	South Solan Basin	FosB	Foula sub-Basin
ESB	East Solan Basin	EsB	Erlend sub-Basin
WShB	West Shetland Basin	WH	Westray High
JH	Judd High	FH	Flett High
SBH	Solan Bank High	CH	Corona High
RH	Rona High	EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin	MgB	Magnus Basin
UB	Unst Basin	ESH	East Shetland High
WSH	West Shetland High	OSH	Orkney-Shetland High

Figure 3.14 Basin history: Cretaceous/Palaeogene boundary (65.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Berriasian (ca. 142 Ma)

(Humber Group-Cromer Knoll Group transition)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

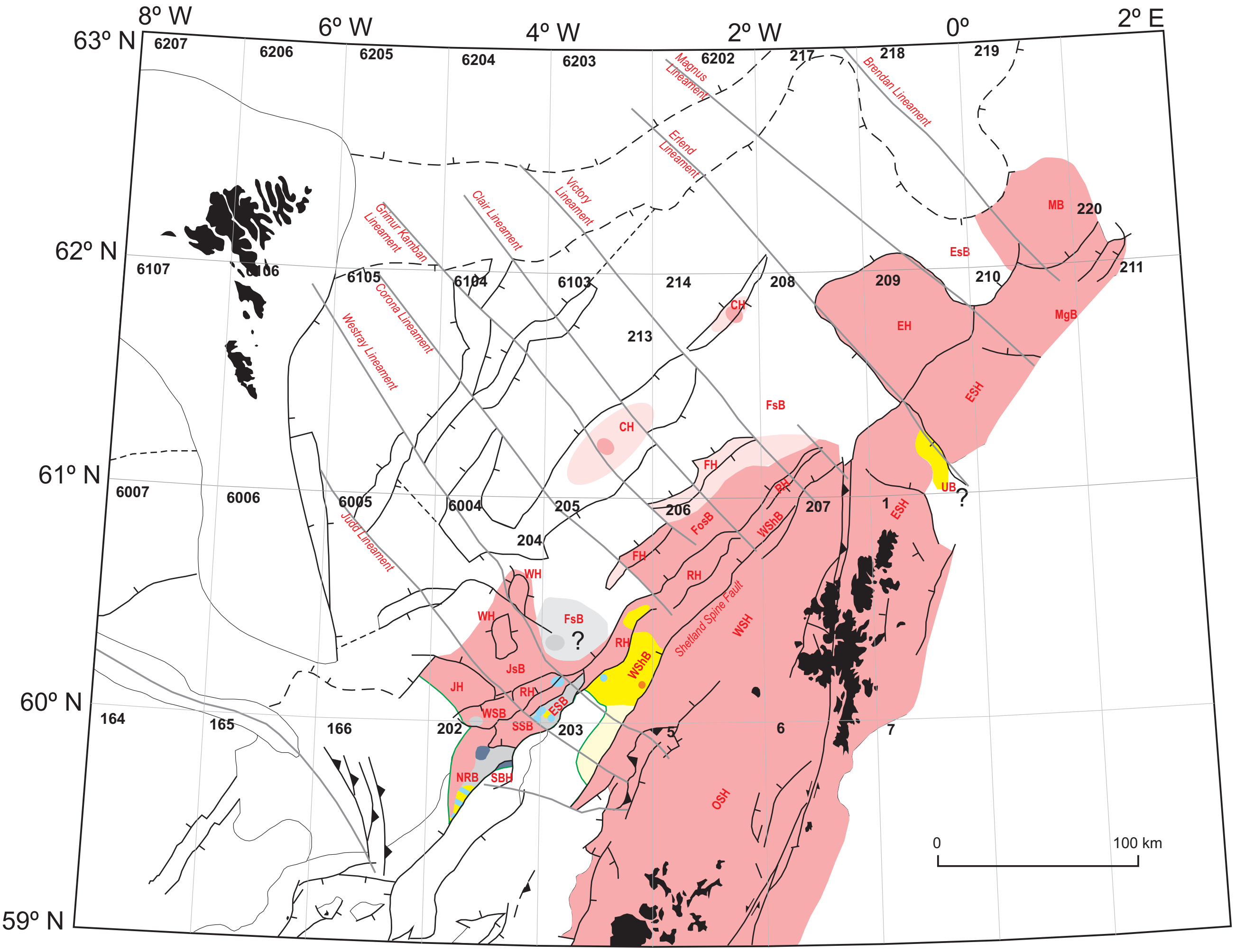
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.15 Lithofacies: Berriasian (ca. 142 Ma) (Humber Group/Cromer Knoll Group transition). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Late Berriasian–Valanginian (ca.142–136.4 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

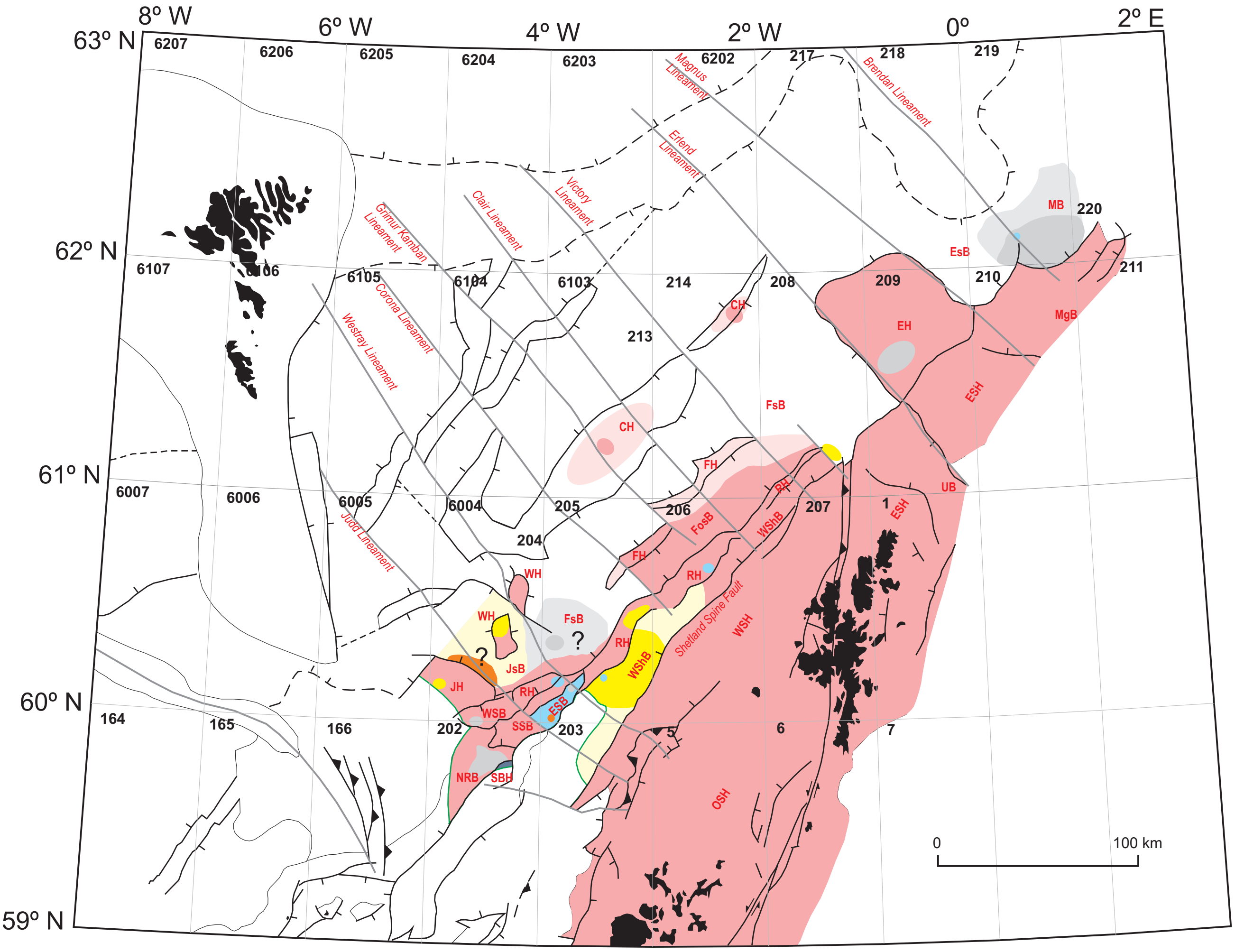
OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

NOTE ON FLETT SUB-BASIN

Uncertainty surrounds the timing of instigation of, and hence sedimentation within, the southern Flett sub-Basin: see text section 3.1 and Figures 3.2–3.3 for further details.

Figure 3.16 Lithofacies: Late Berriasian–Valanginian (ca. 142–136.4 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Hauterivian (136.4–130 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

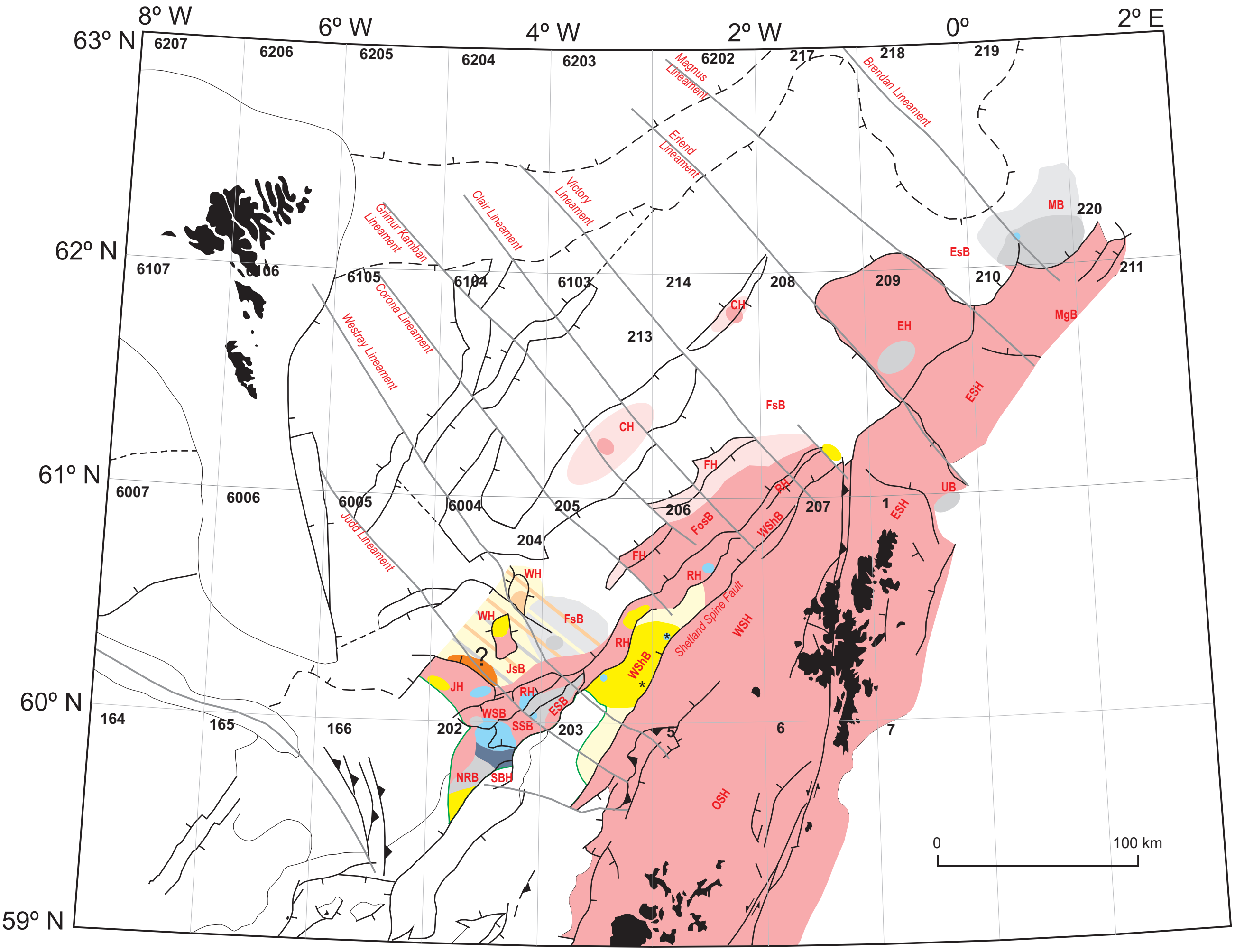
OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

NOTE ON FLETT & JUDD SUB-BASINS

Uncertainty surrounds the timing of instigation of, and hence sedimentation within, the southern Flett and Judd sub-basins: see text section 3.1 and Figures 3.2–3.3 for further details.

Figure 3.17 Lithofacies: Hauterivian (136.4–130 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Barremian (130–125 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

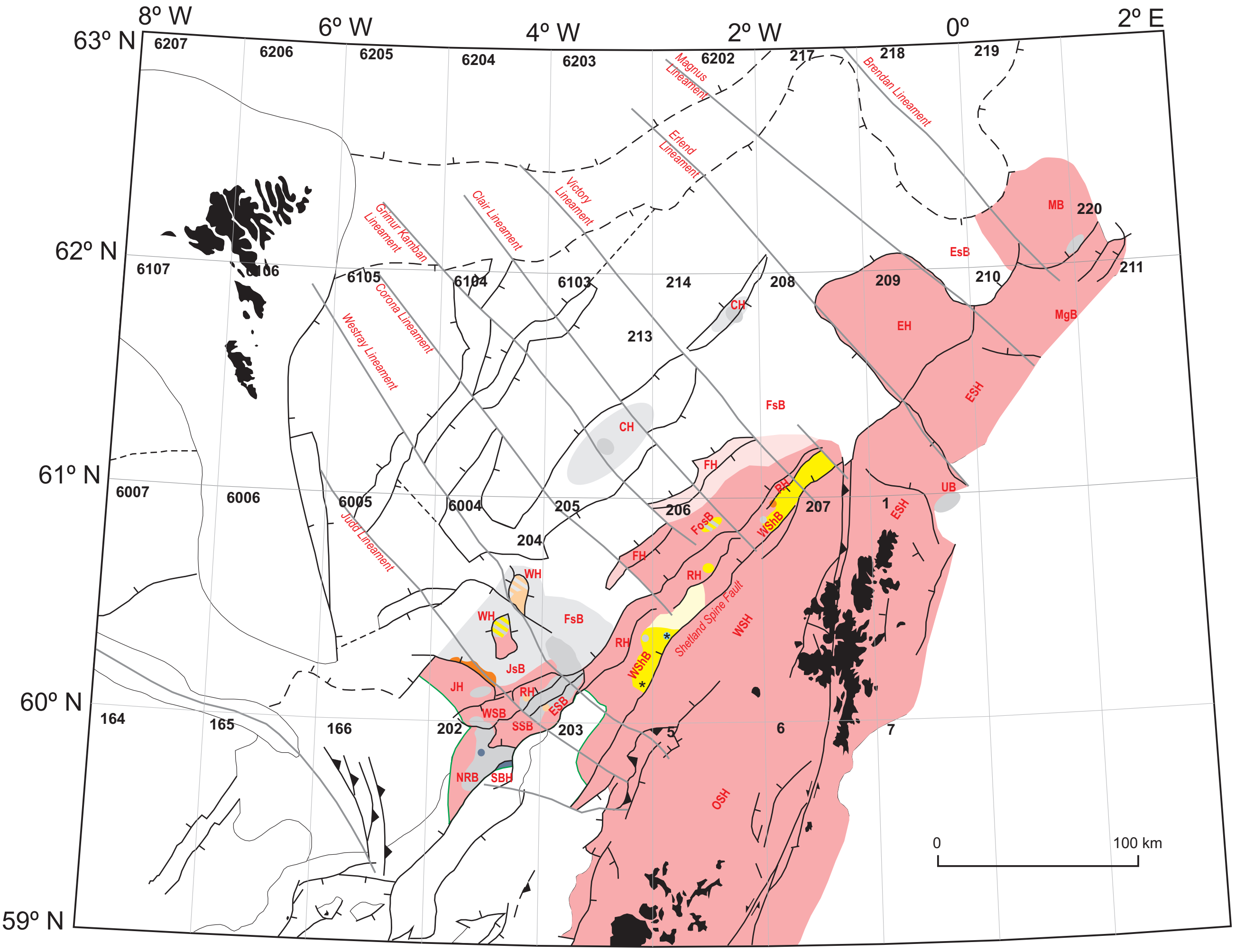
OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

NOTE ON JUDD SUB-BASIN

Uncertainty surrounds the timing of instigation of, and hence sedimentation within, the Judd sub-basin: see text section 3.1 and Figures 3.3–3.4 for further details.

Figure 3.18 Lithofacies: Barremian (130–125 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Aptian (125–112 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.19 Lithofacies: Aptian (125–112 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

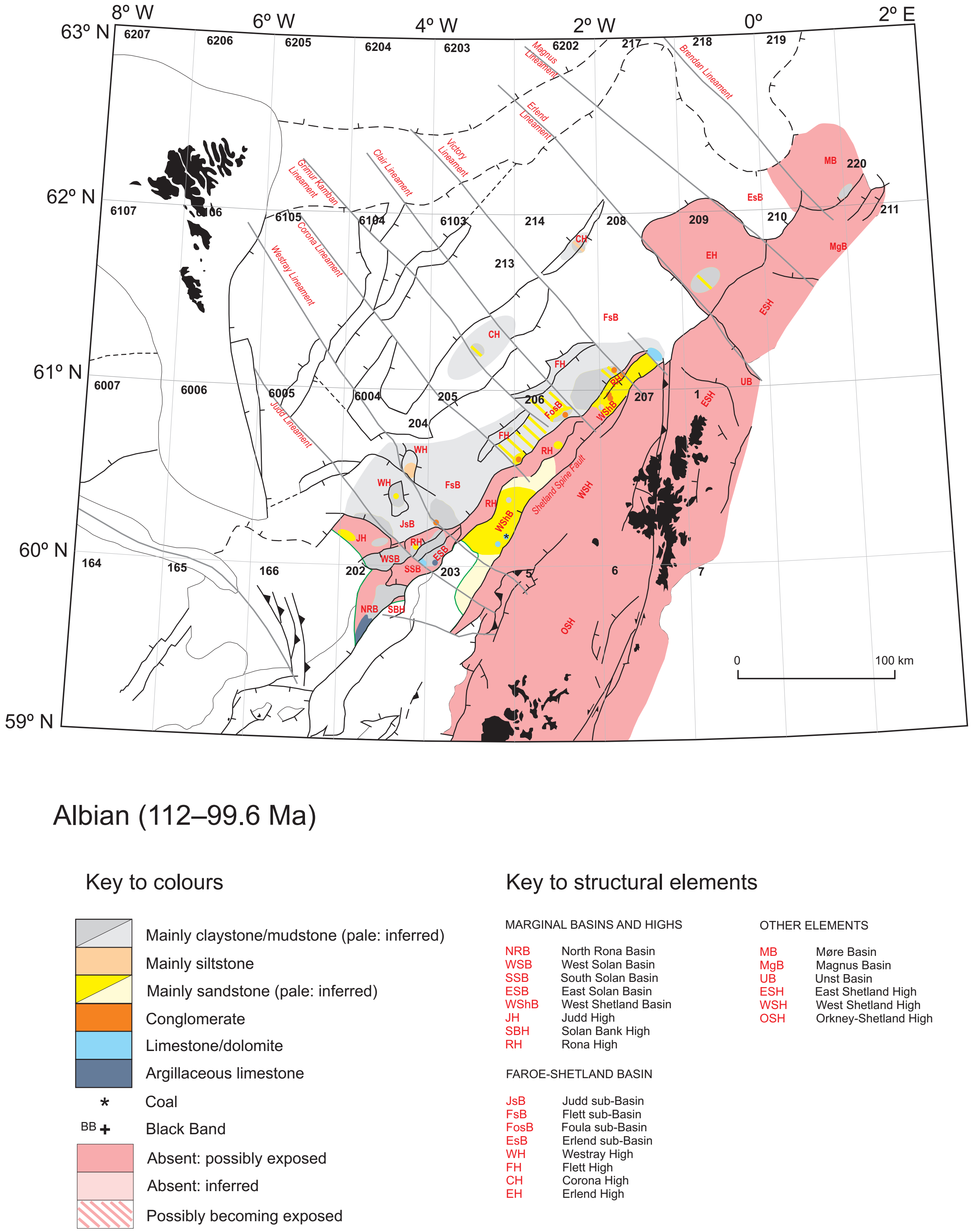
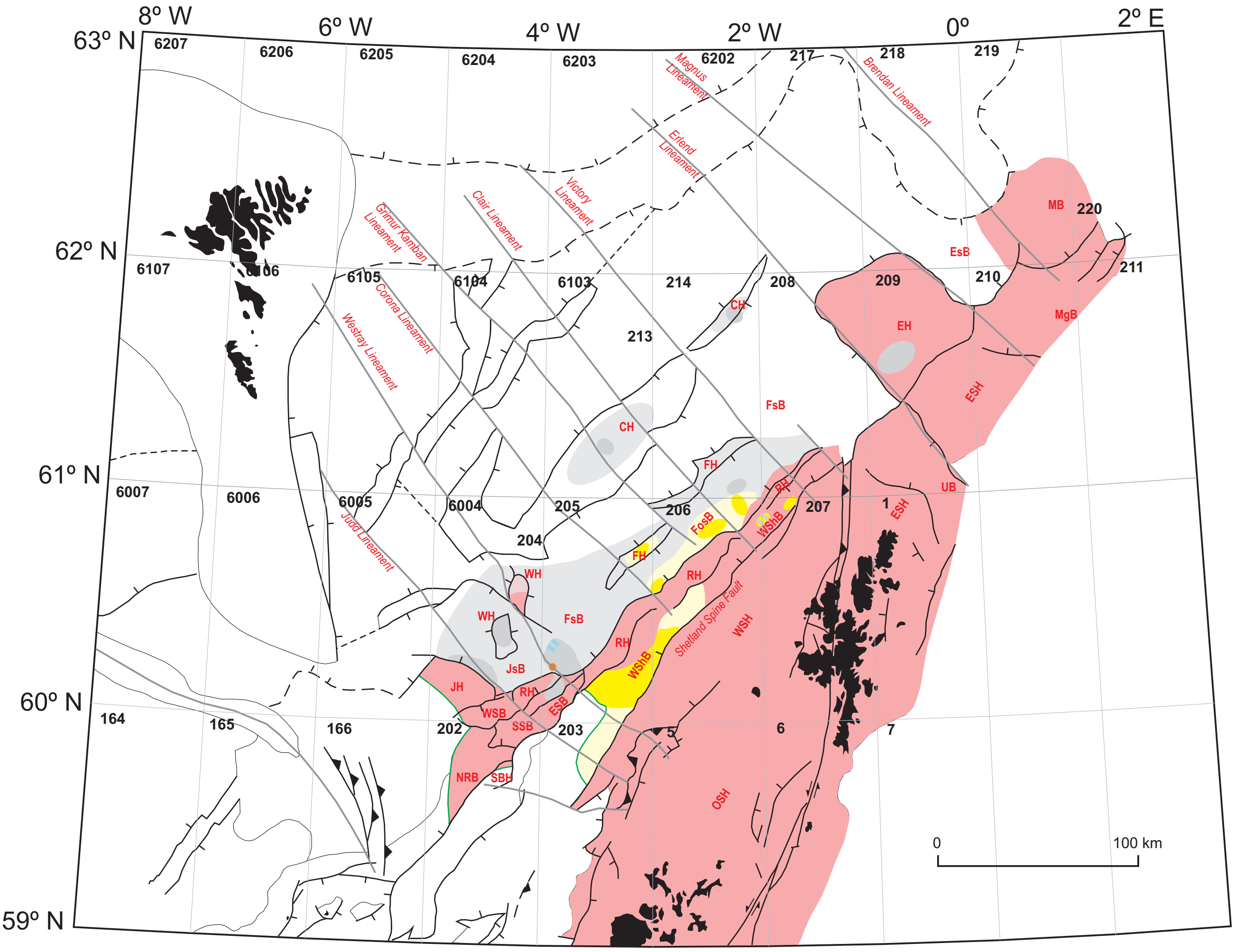


Figure 3.20 Lithofacies: Albian (112–99.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Albian/Cenomanian boundary (99.6 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

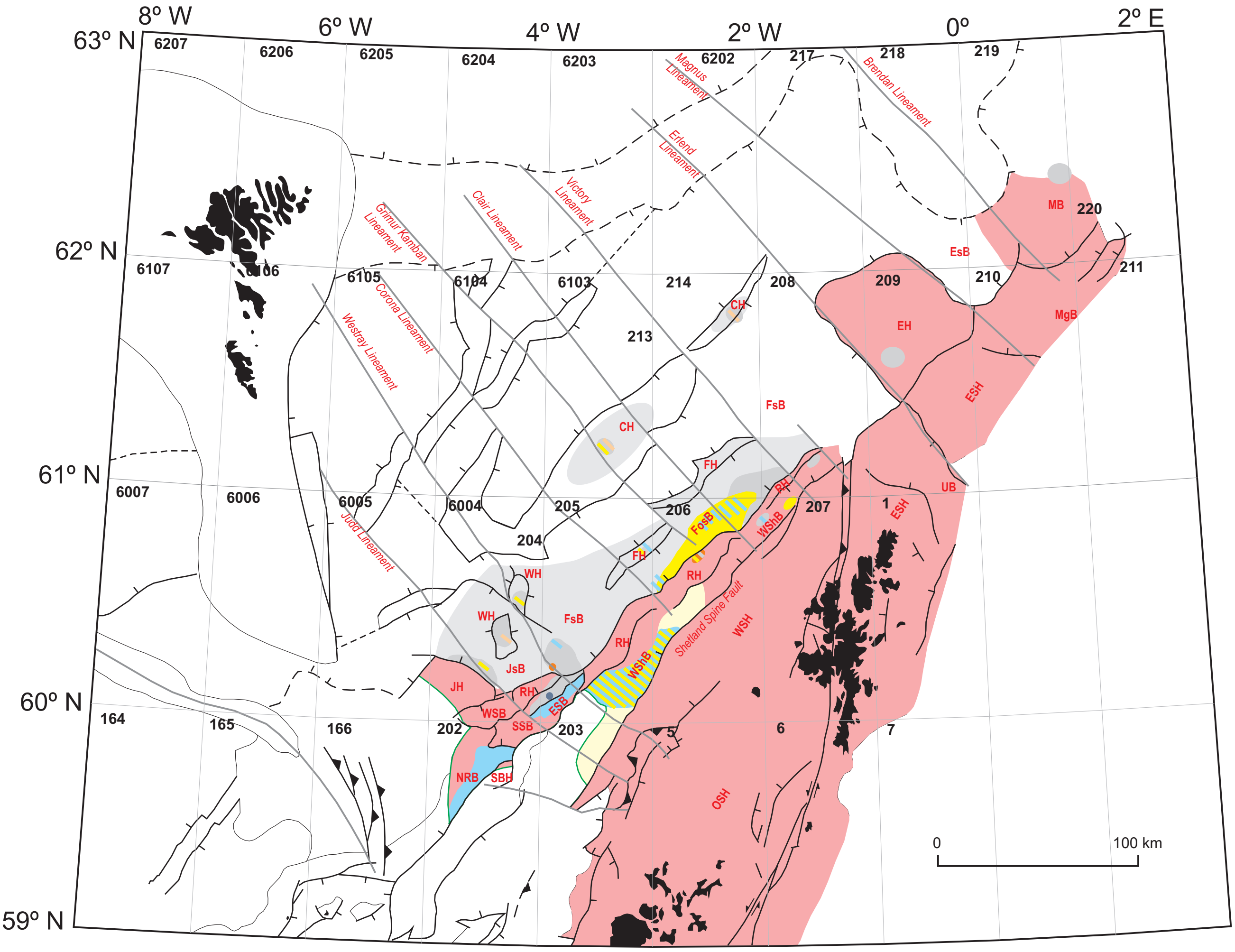
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.21 Lithofacies: Albian/Cenomanian boundary (99.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Cenomanian (99.6–93.5 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

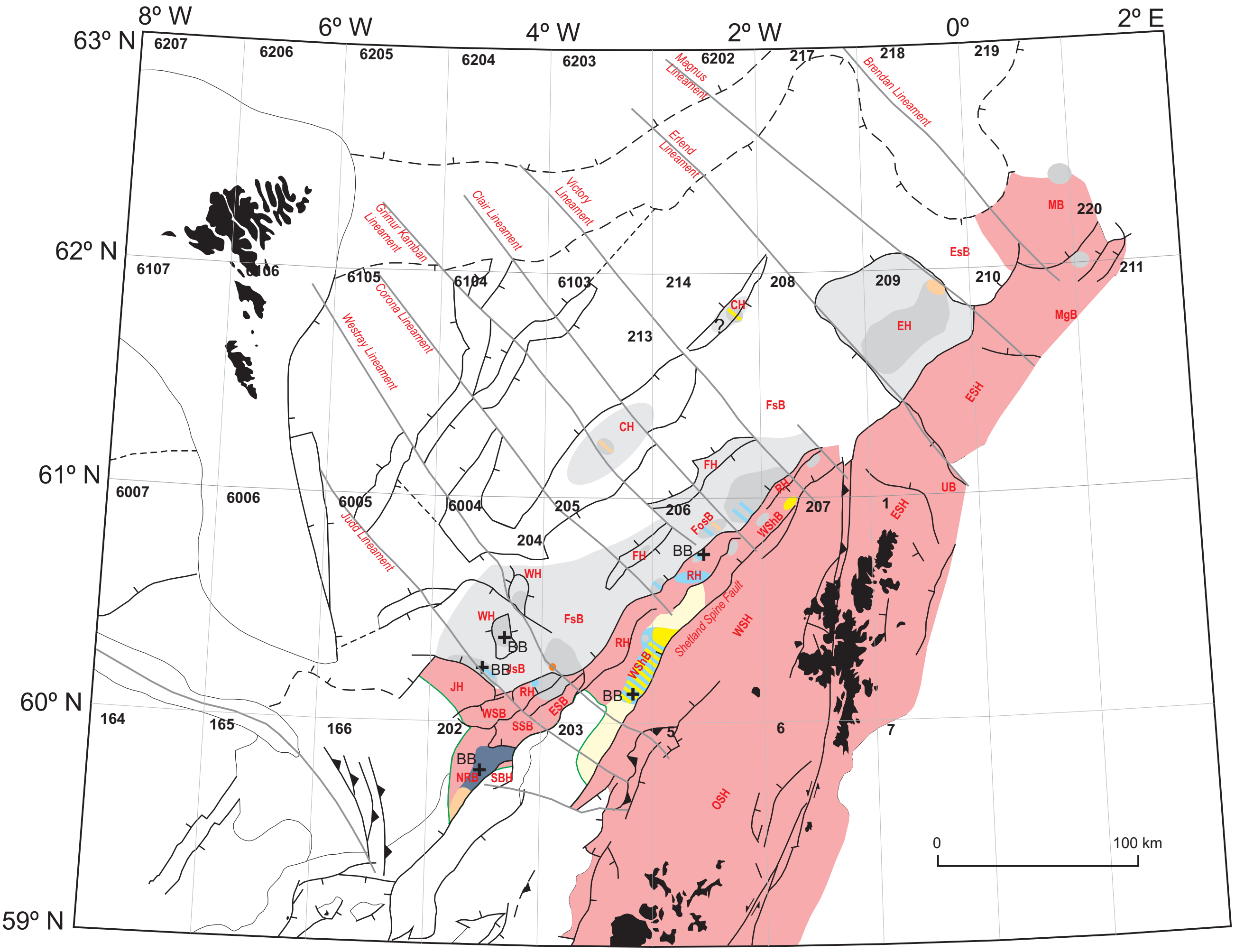
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.22 Lithofacies: Cenomanian (99.6–93.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Turonian (93.5–89.3 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

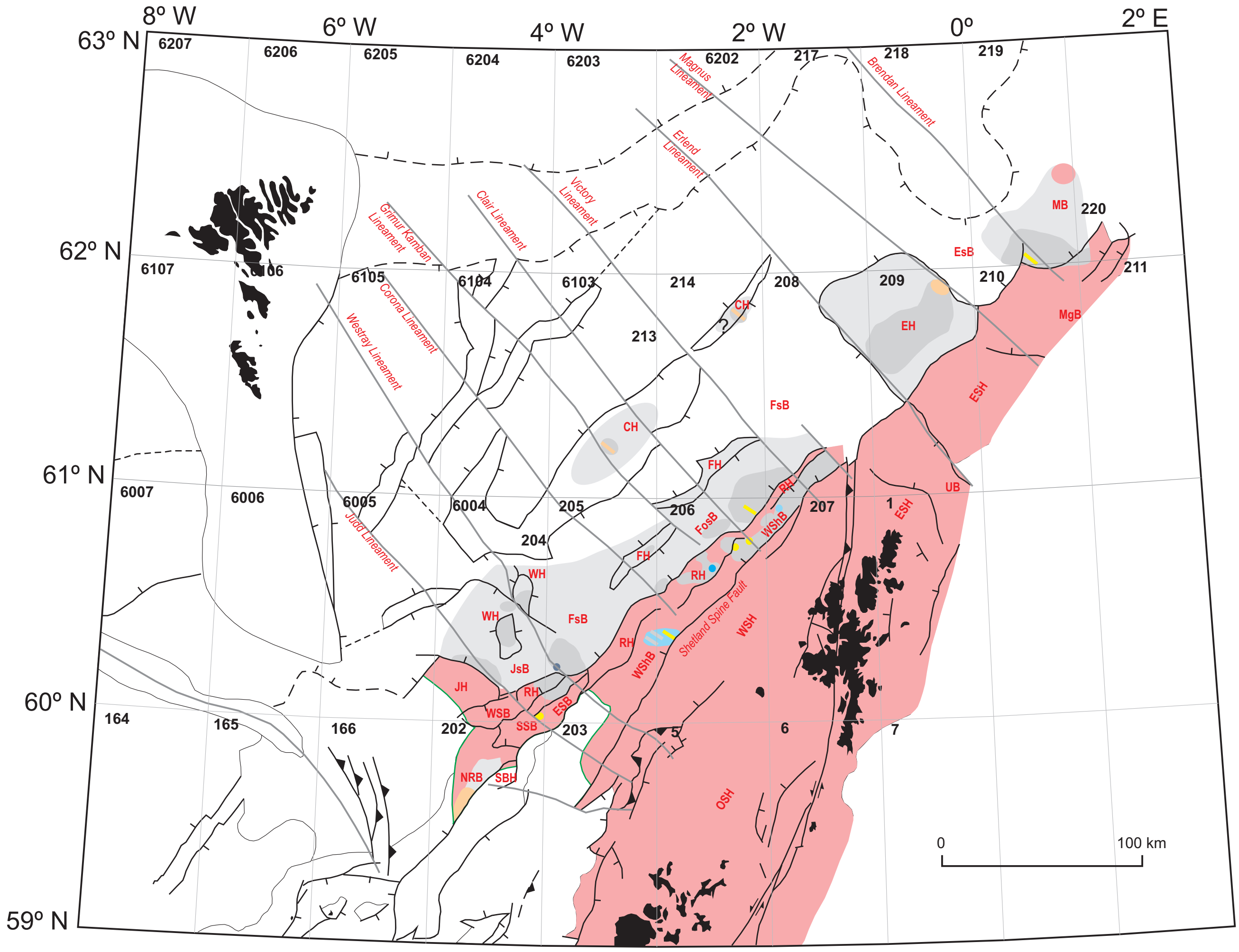
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.23 Lithofacies: Turonian (93.5–89.3 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Coniacian (89.3–85.8 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

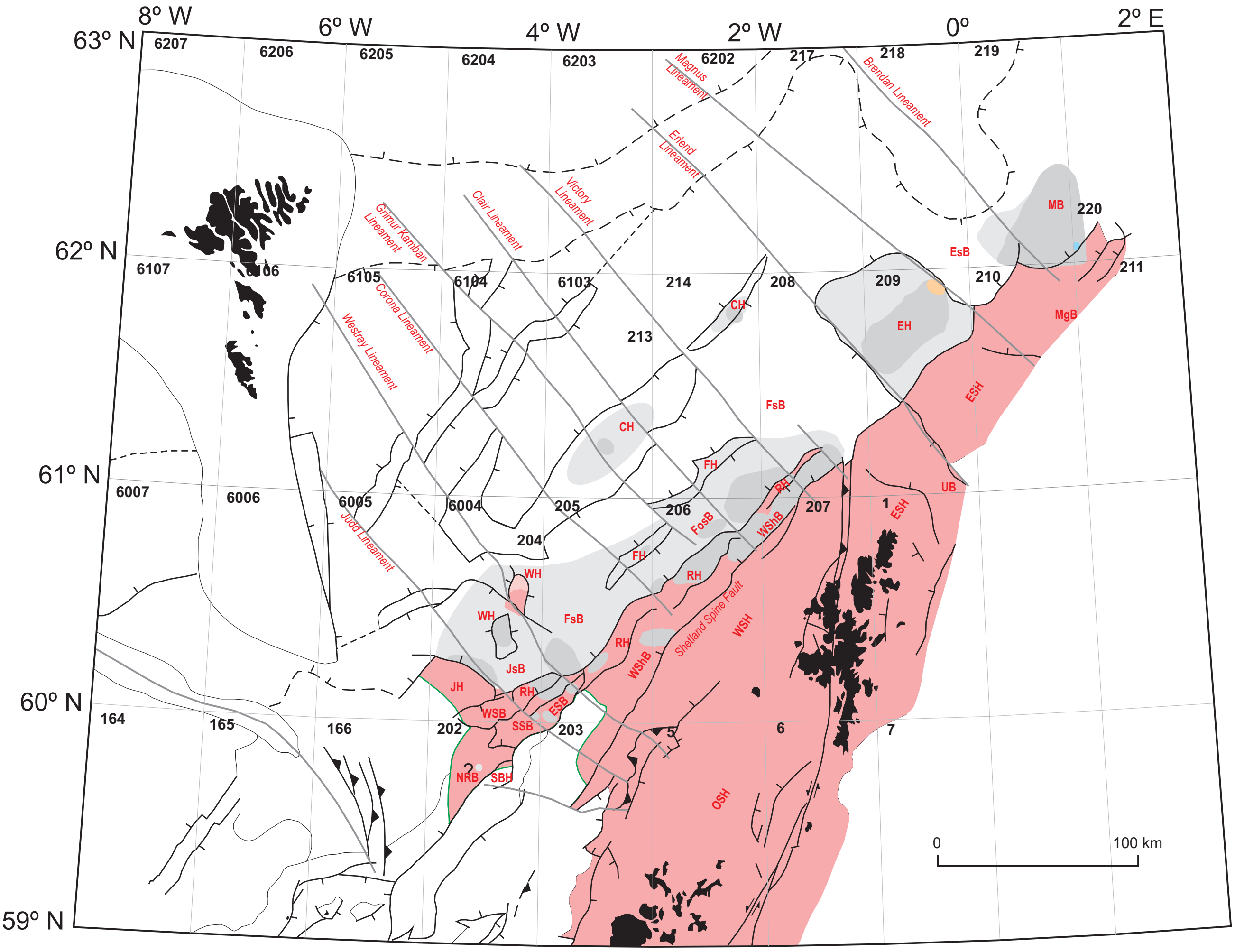
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.24 Lithofacies: Coniacian (89.3–85.8 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Santonian (85.8–83.5 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

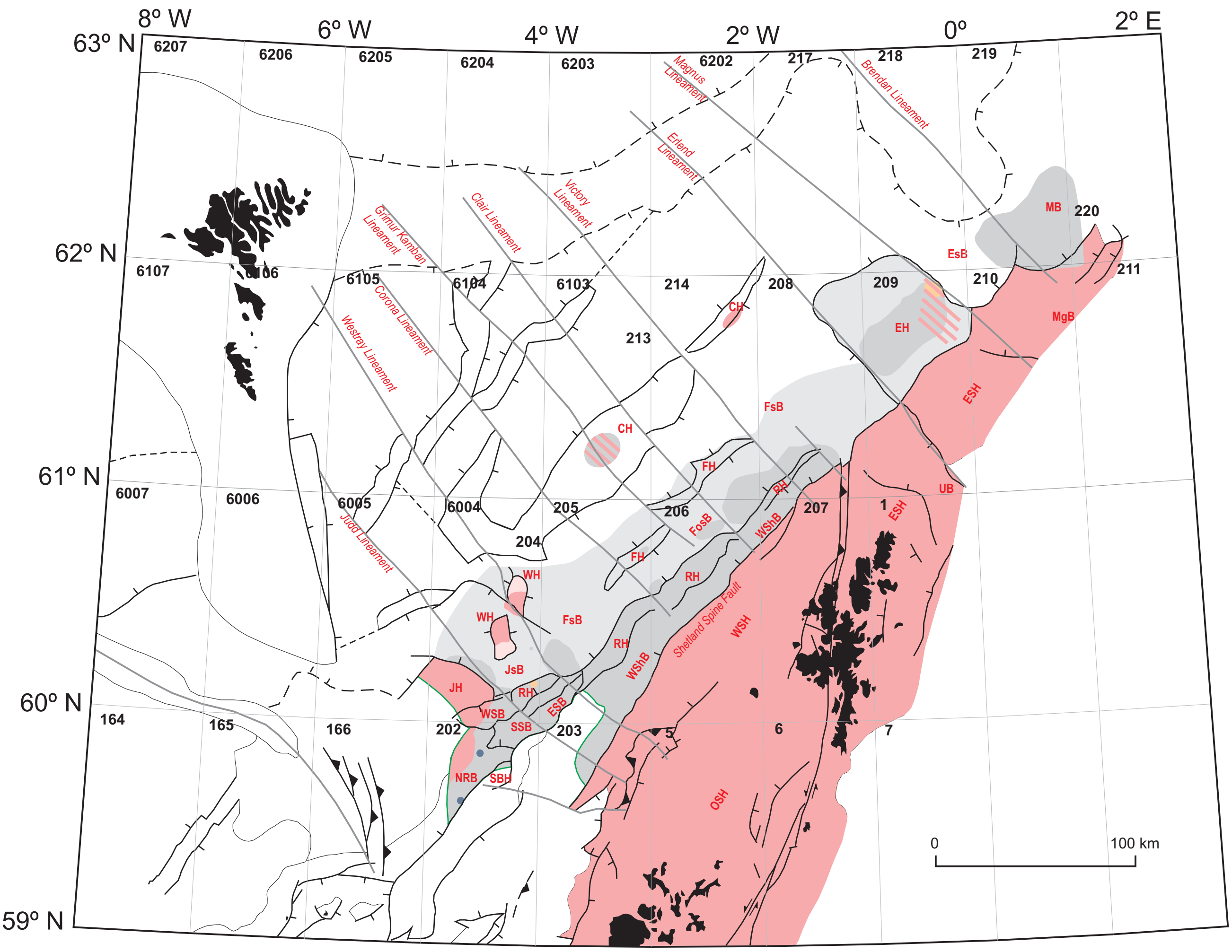
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.25 Lithofacies: Santonian (85.8–83.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Campanian (83.5–70.6 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

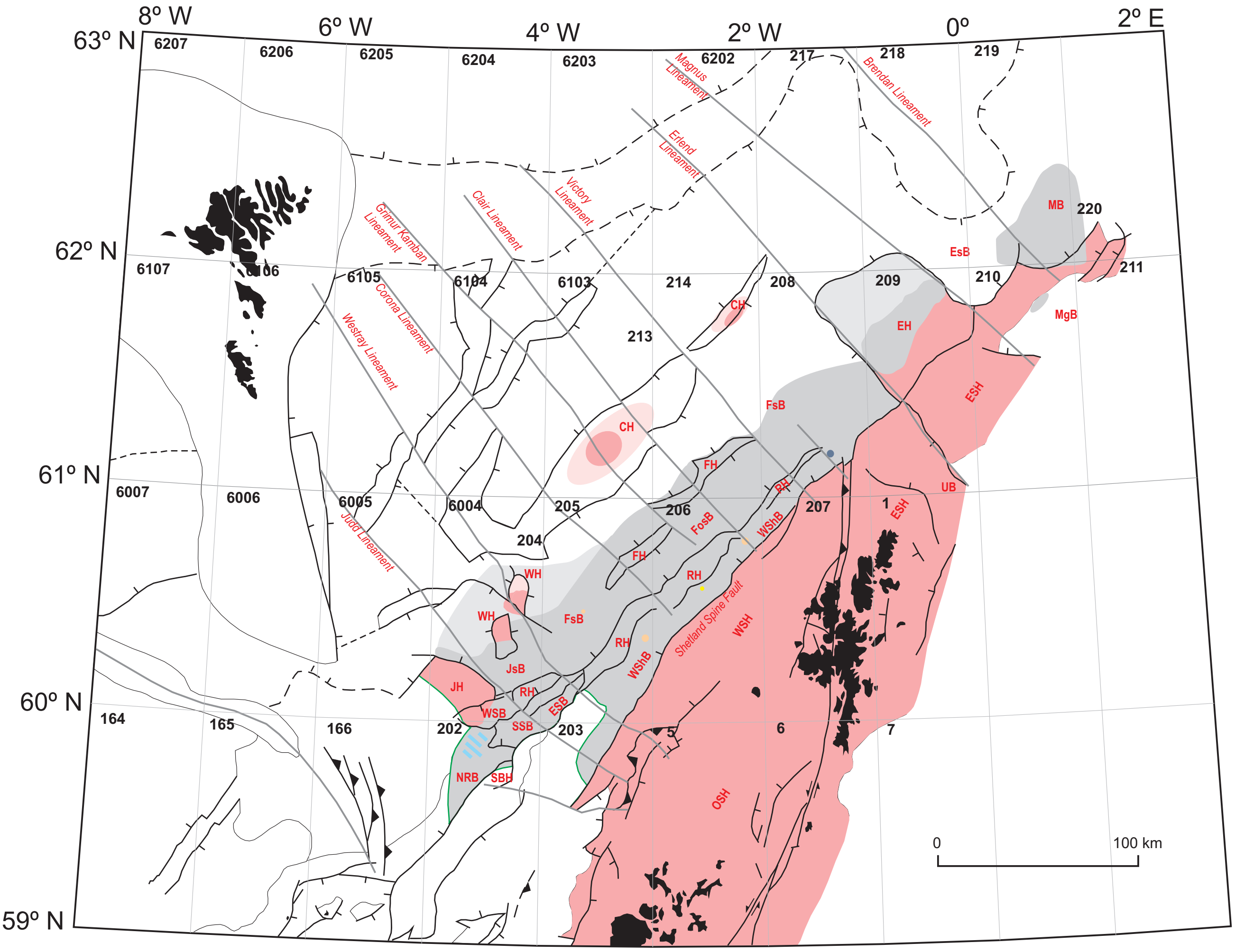
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.26 Lithofacies: Campanian (83.5–70.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Maastrichtian (70.6–65.5 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

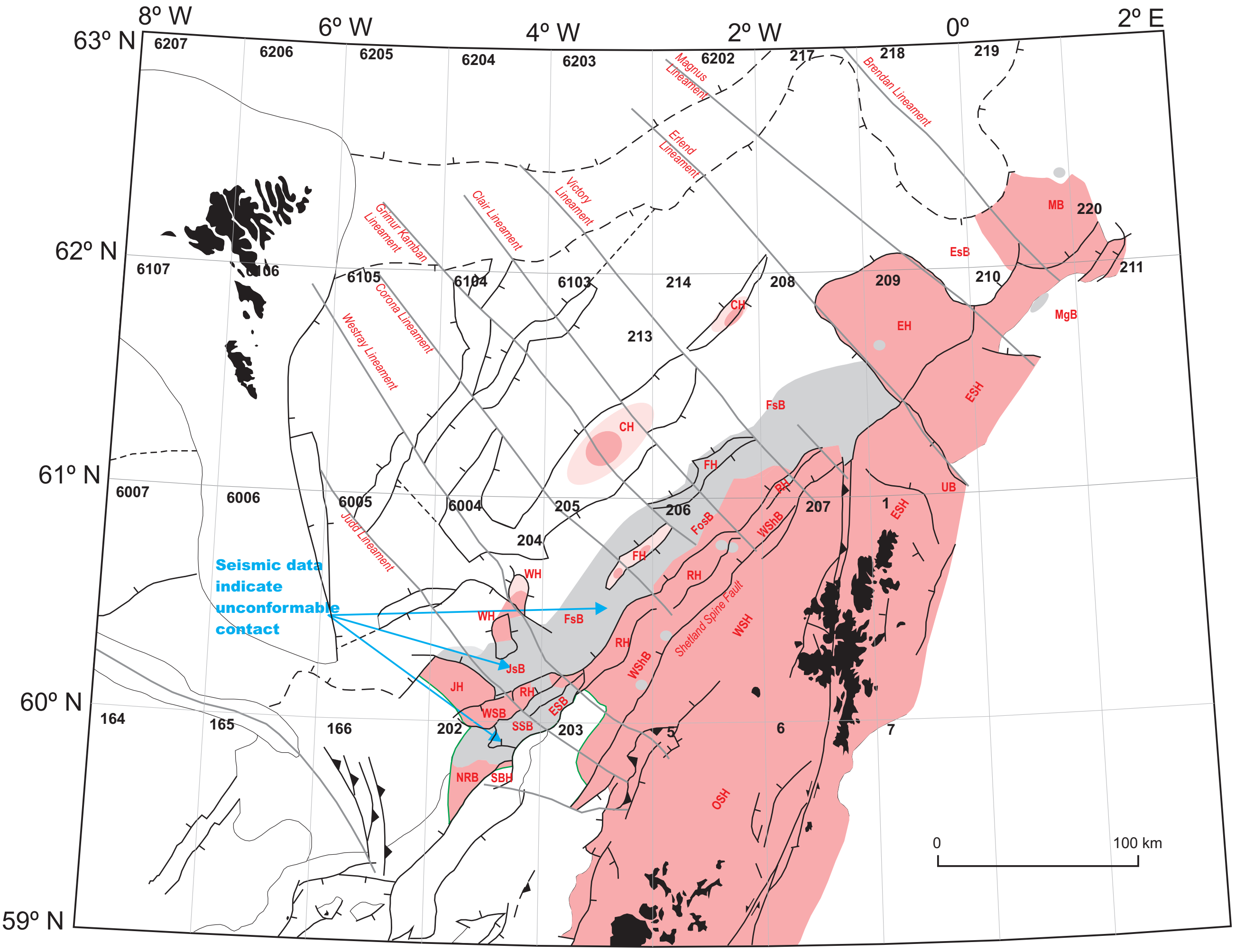
FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

Figure 3.27 Lithofacies: Maastrichtian (70.6–65.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Cretaceous/Palaeogene boundary (65.5 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly exposed
- Absent: inferred
- Possibly becoming exposed

Key to structural elements

MARGINAL BASINS AND HIGHS

NRB	North Rona Basin
WSB	West Solan Basin
SSB	South Solan Basin
ESB	East Solan Basin
WShB	West Shetland Basin
JH	Judd High
SBH	Solan Bank High
RH	Rona High

FAROE-SHETLAND BASIN

JsB	Judd sub-Basin
FsB	Flett sub-Basin
FosB	Foula sub-Basin
EsB	Erlend sub-Basin
WH	Westray High
FH	Flett High
CH	Corona High
EH	Erlend High

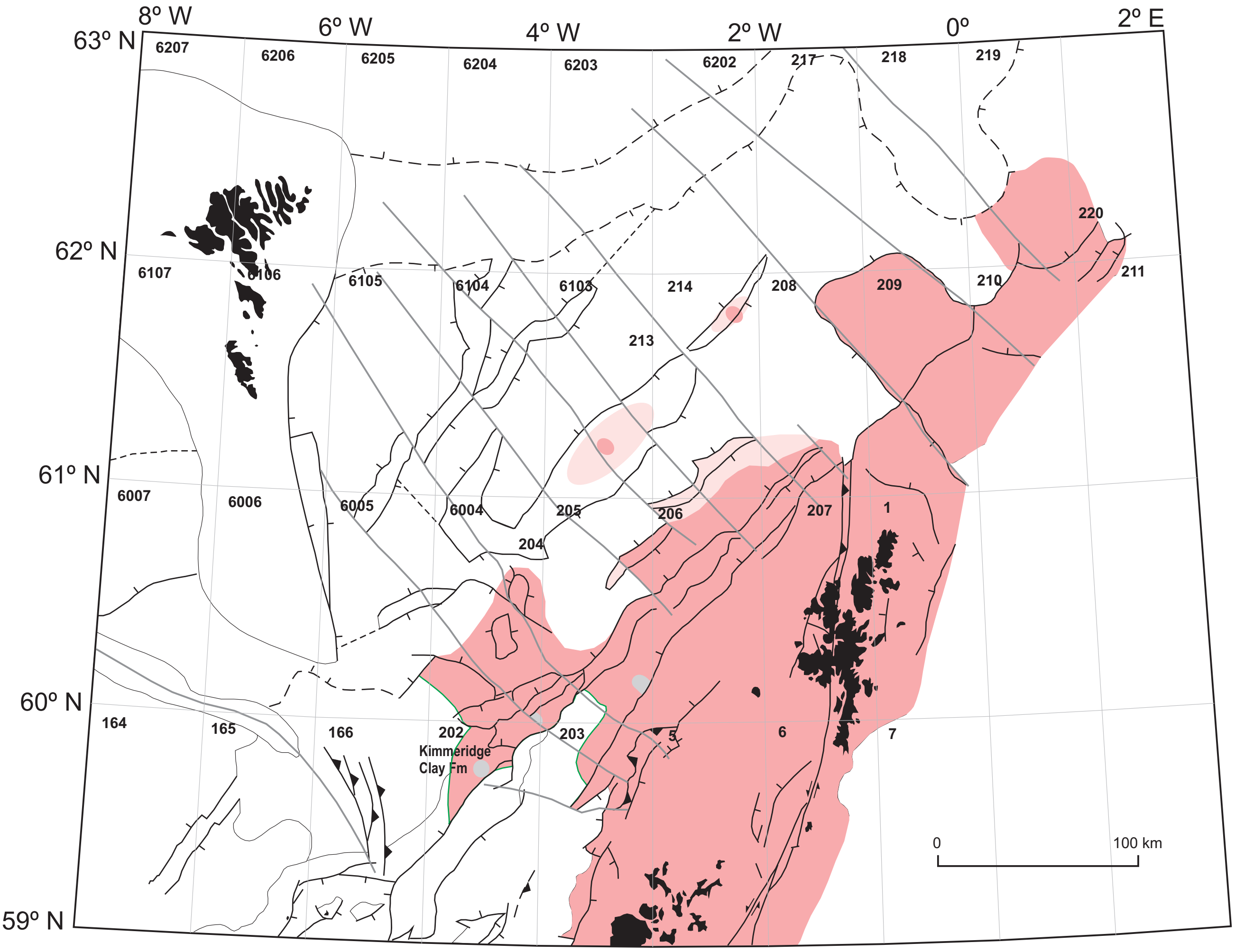
OTHER ELEMENTS

MB	Møre Basin
MgB	Magnus Basin
UB	Unst Basin
ESH	East Shetland High
WSH	West Shetland High
OSH	Orkney-Shetland High

NOTE ON EXTENT OF UNCONFORMITY

Seismic data indicate a widespread unconformity in the SE marginal basins as well as the Faroe-Shetland Basin. Whereas the SE marginal region may have been more widely exposed than is shown at this time, it is unclear whether erosion in the Foula, Flett and Judd sub-basins was subaerial or submarine.

Figure 3.28 Lithofacies: Cretaceous/Palaeogene boundary (65.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



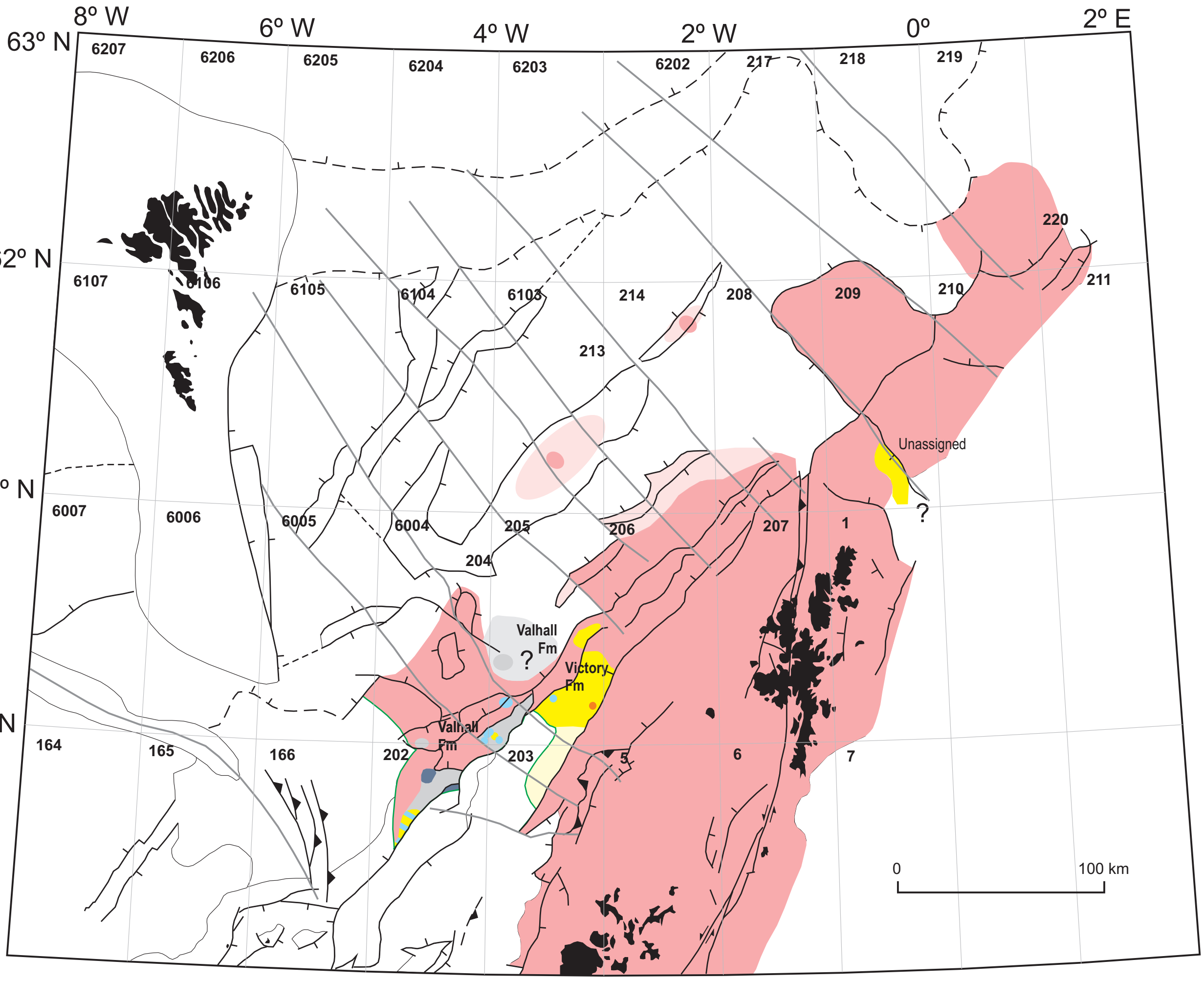
Berriasian (ca. 142 Ma)
(Humber Group-Cromer Knoll Group transition)

Key to colours

Mainly claystone/mudstone (pale: inferred)
Mainly siltstone
Mainly sandstone (pale: inferred)
Conglomerate
Limestone/dolomite
Argillaceous limestone

* Coal
BB + Black Band
Absent: possibly eposed
Absent: inferred
Possibly becoming exposed

Figure 3.29 Lithostratigraphy: Berriasian (ca. 142 Ma) (Humber Group/Cromer Knoll Group transition). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Late Berriasian–Valanginian (ca.142–136.4 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone

- * Coal
- BB ✚ Black Band
- Absent: possibly eposed
- Absent: inferred
- Possibly becoming exposed

NOTE ON FLETT SUB-BASIN

Uncertainty surrounds the timing of instigation of, and hence sedimentation within, the southern Flett sub-Basin: see text section 3.1 and Figures 3.2–3.3 for further details.

Figure 3.30 Lithostratigraphy: Late Berriasian–Valanginian (ca. 142–136.4 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

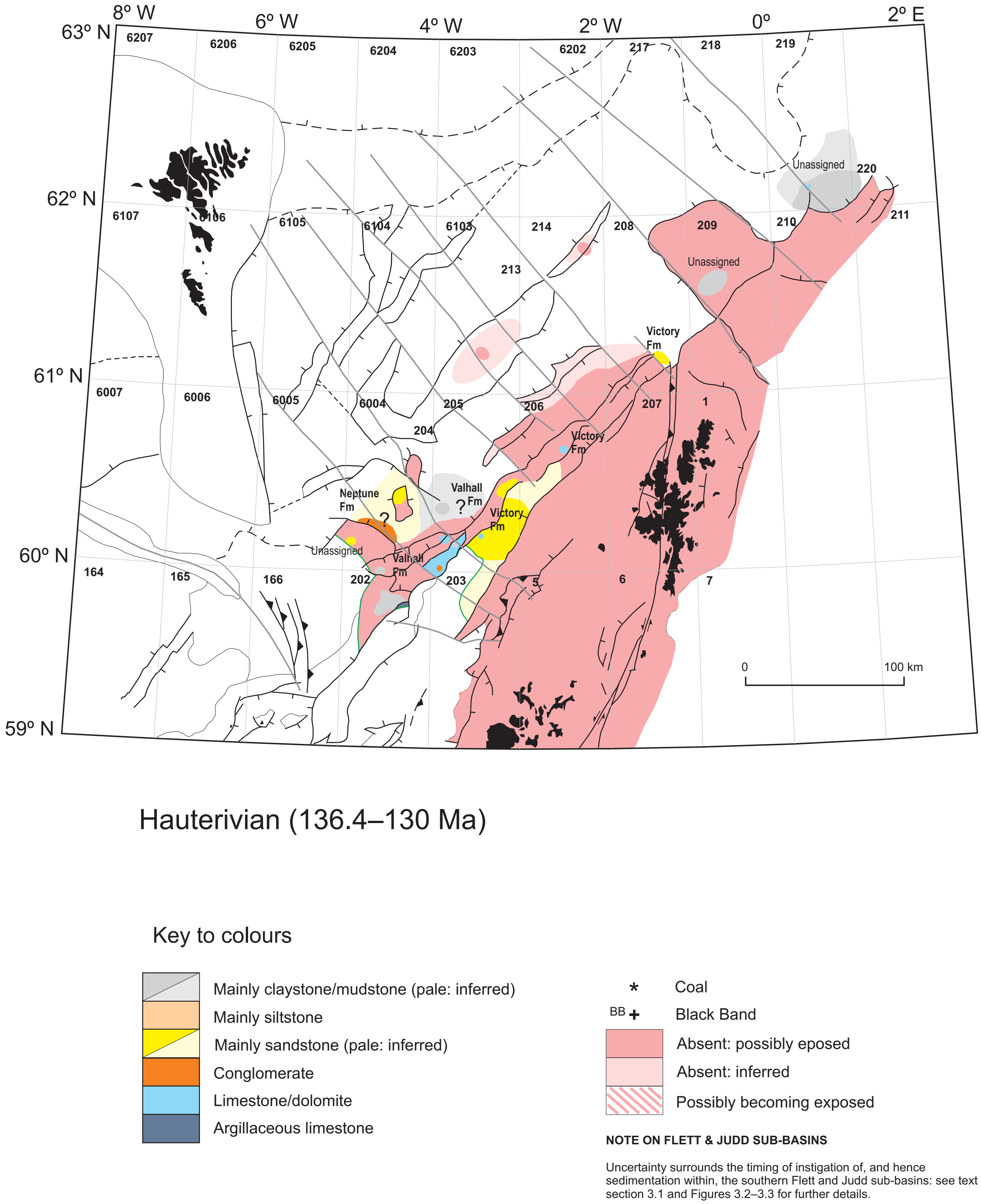
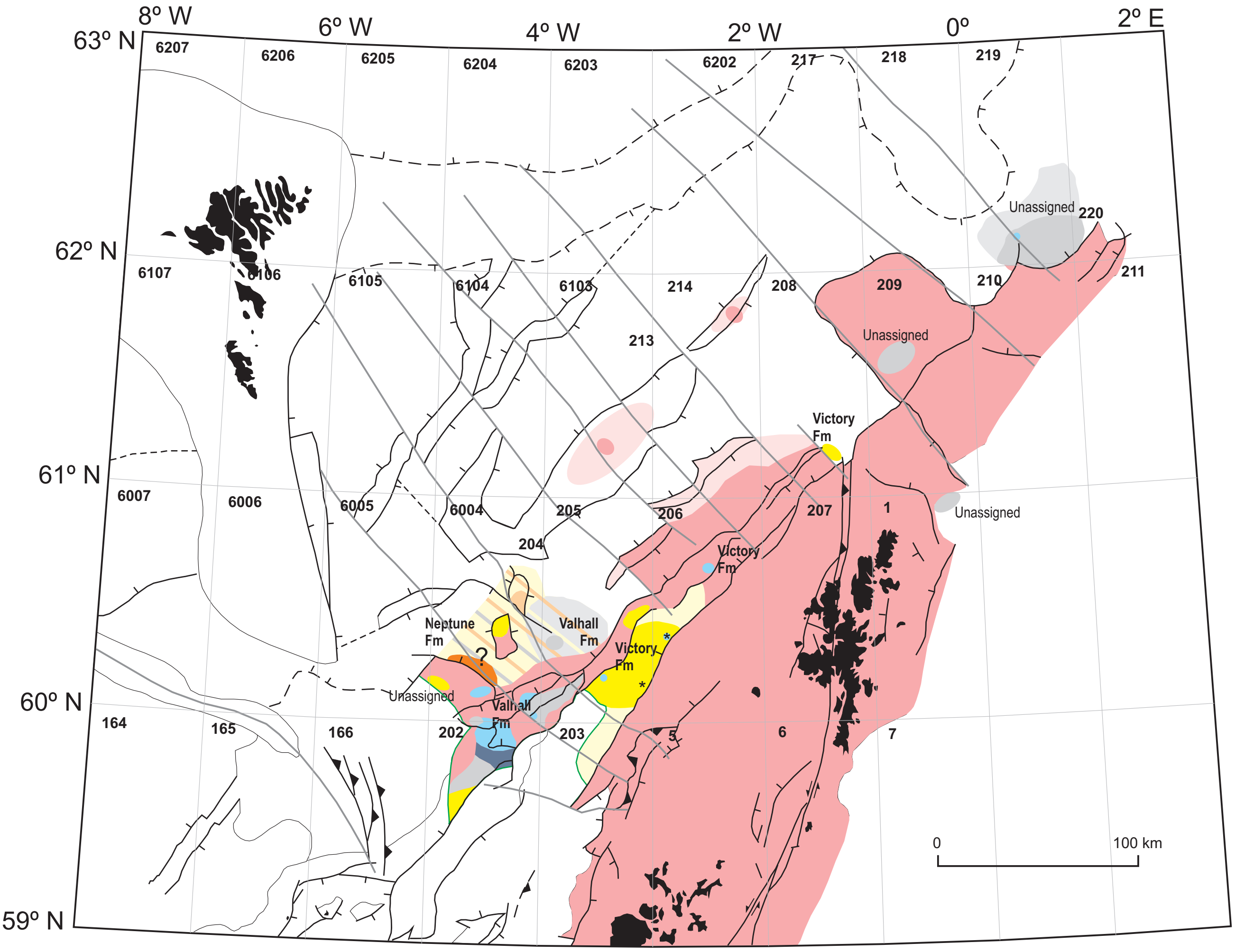


Figure 3.31 Lithostratigraphy: Hauterivian (136.4–130 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Barremian (ca.130–125 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone

- * Coal
- BB + Black Band
- Absent: possibly eposed
- Absent: inferred
- Possibly becoming exposed

NOTE ON JUDD SUB-BASIN

Uncertainty surrounds the timing of instigation of, and hence sedimentation within, the Judd sub-basin: see text section 3.1 and Figures 3.3–3.4 for further details.

Figure 3.32 Lithostratigraphy: Barremian (130–125 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

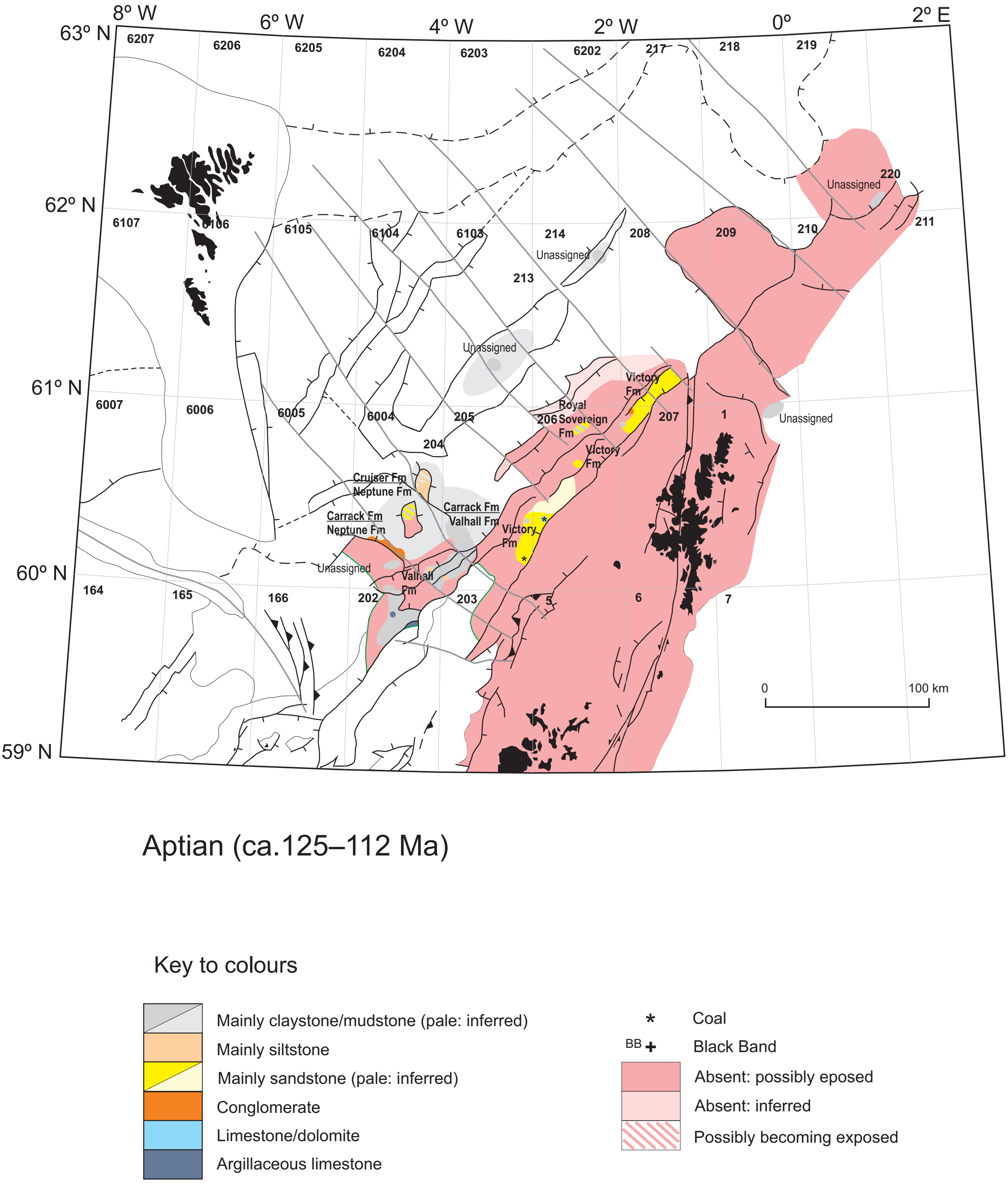
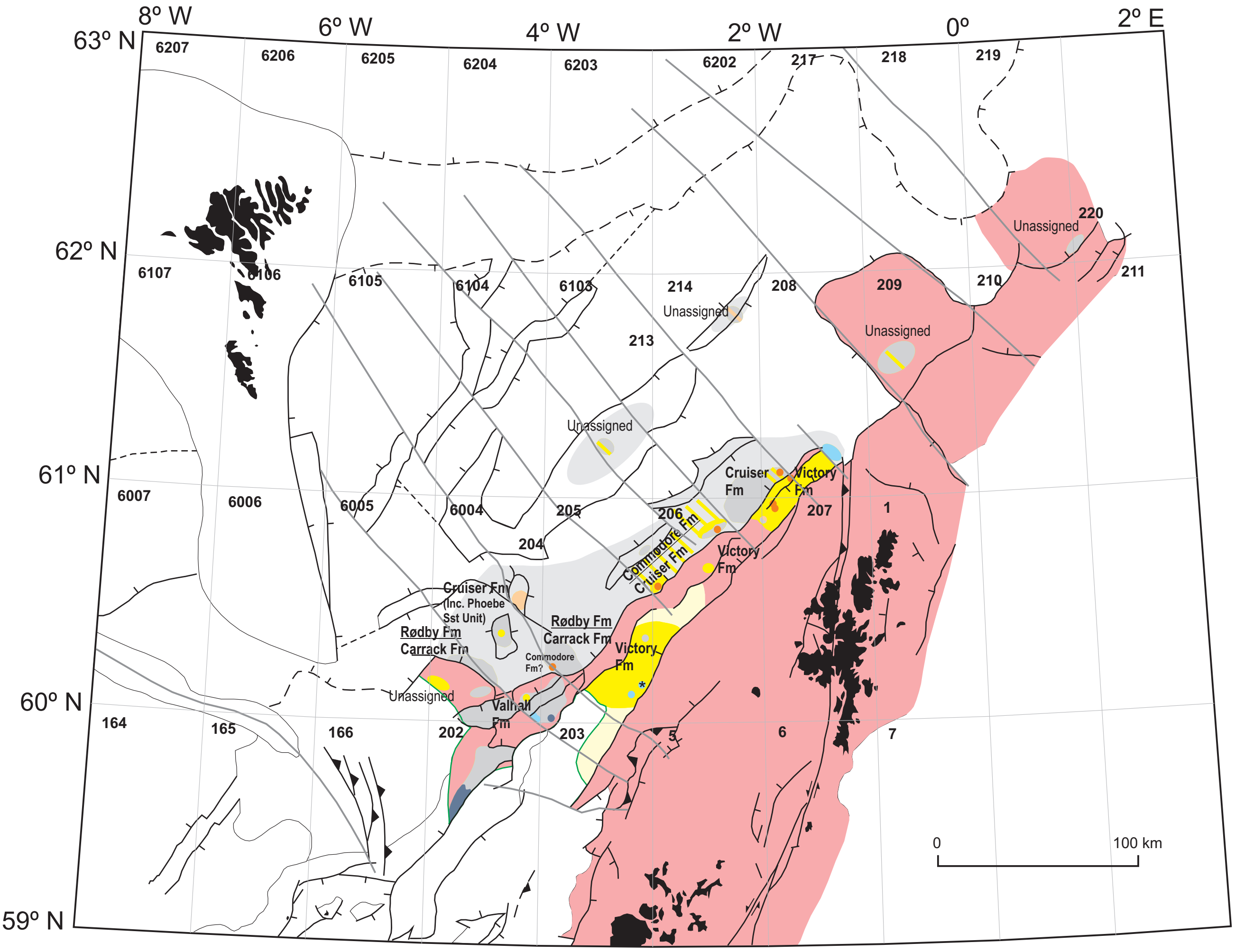


Figure 3.33 Lithostratigraphy: Aptian (125–112 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Albian (ca.112–99.6 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly eposed
- Absent: inferred
- Possibly becoming exposed

Figure 3.34 Lithostratigraphy: Albian (112–99.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

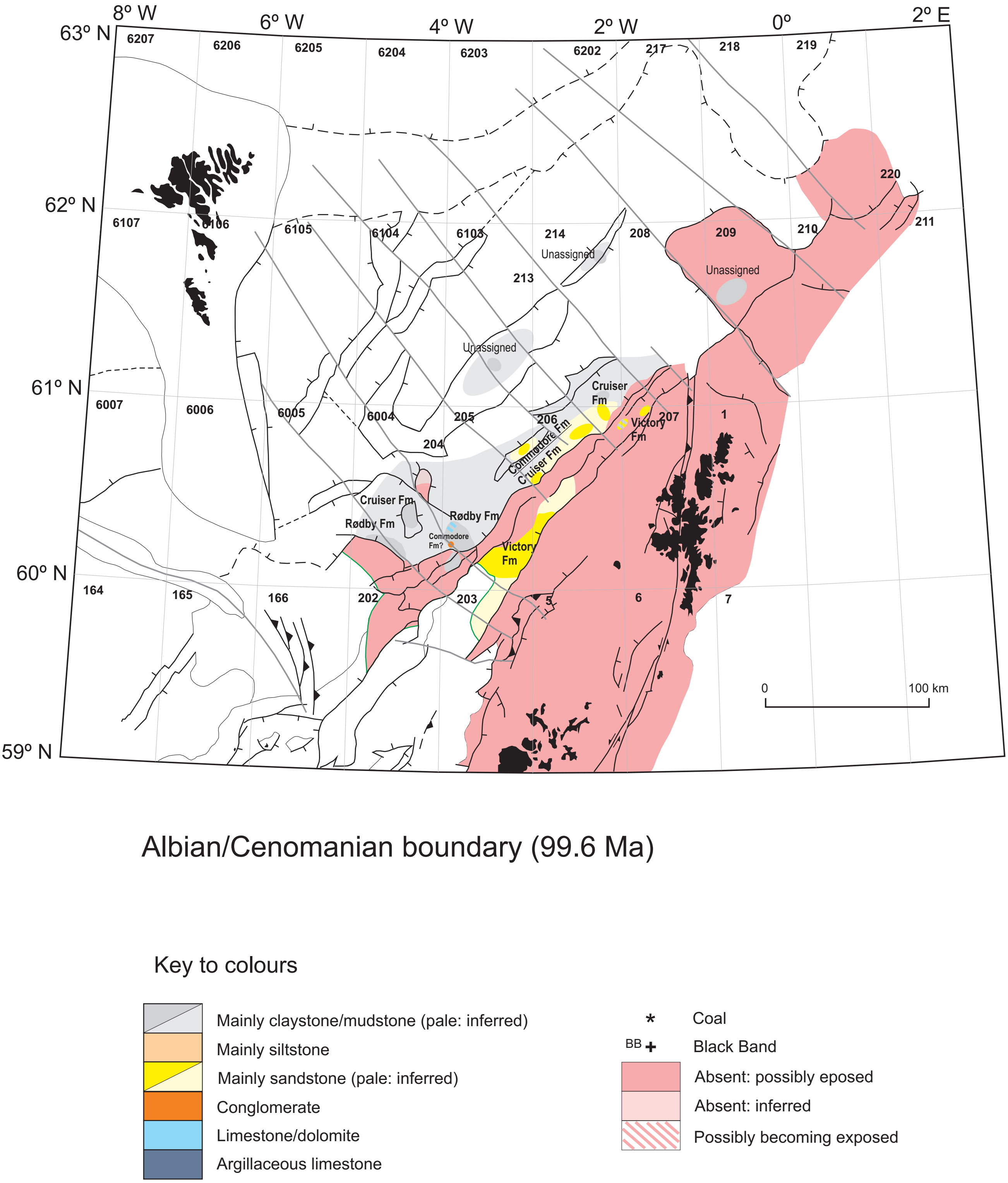


Figure 3.35 Lithostratigraphy: Albian/Cenomanian boundary (99.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

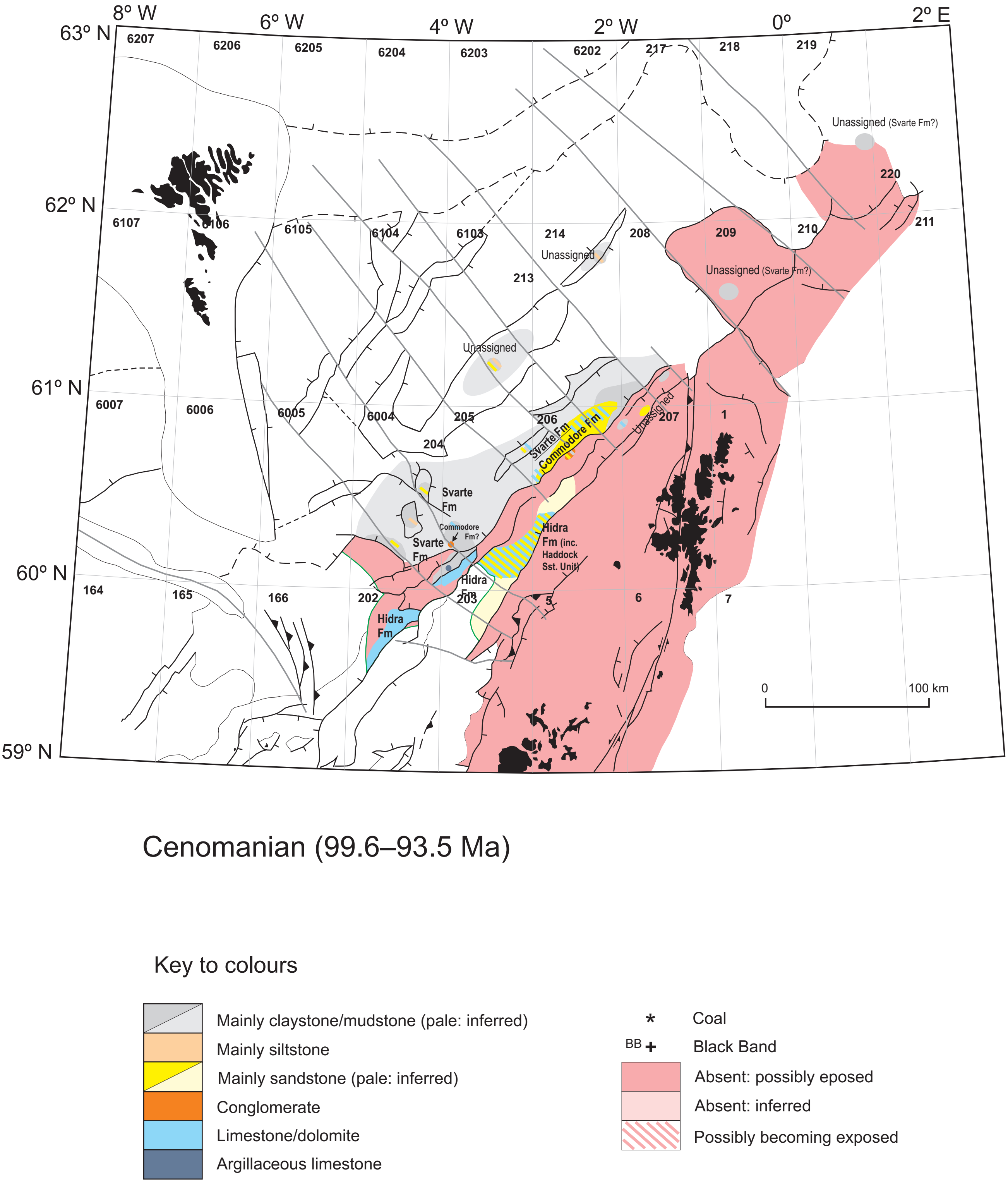


Figure 3.36 Lithostratigraphy: Cenomanian (99.6–93.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

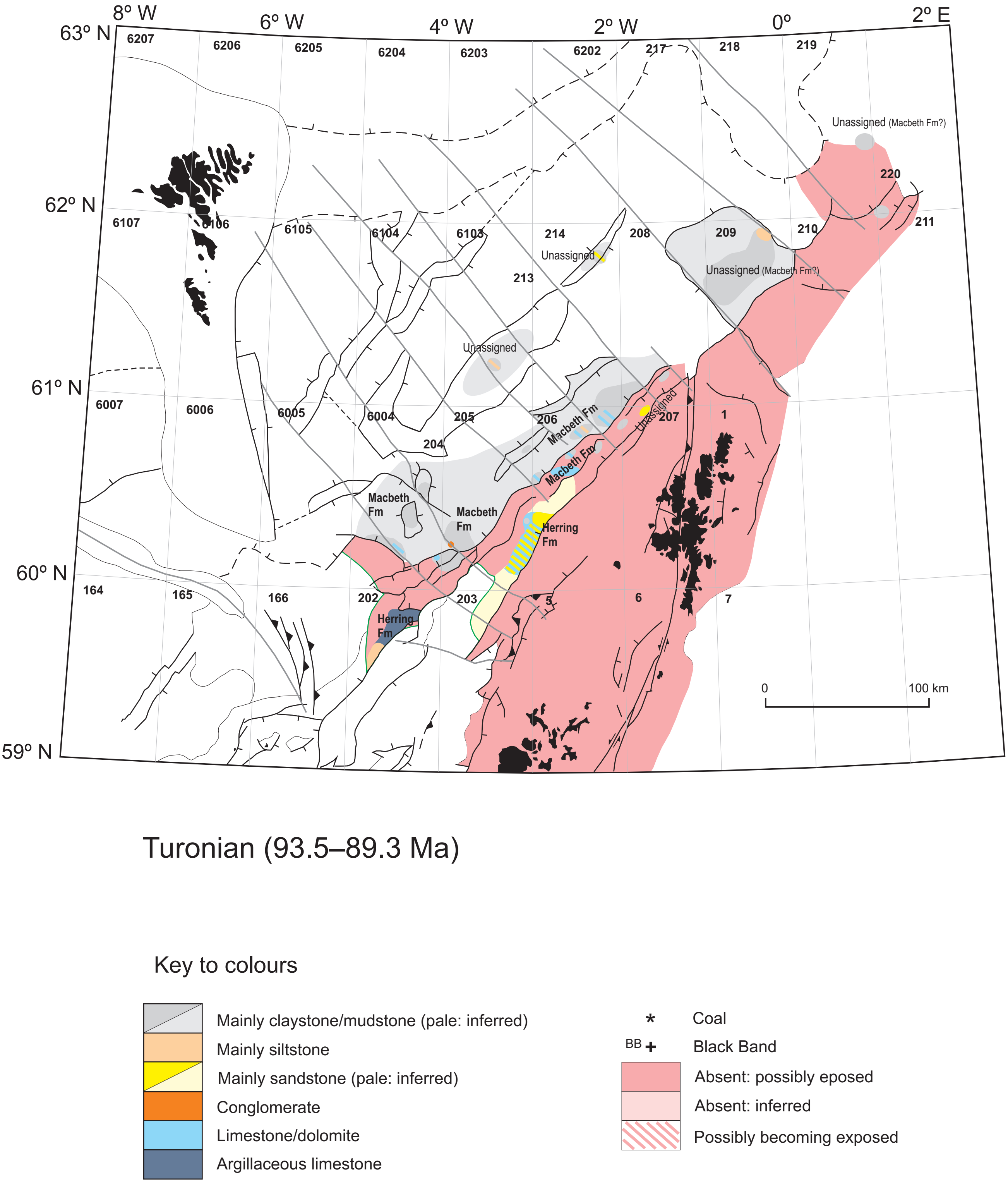


Figure 3.37 Lithostratigraphy: Turonian (93.5–89.3 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

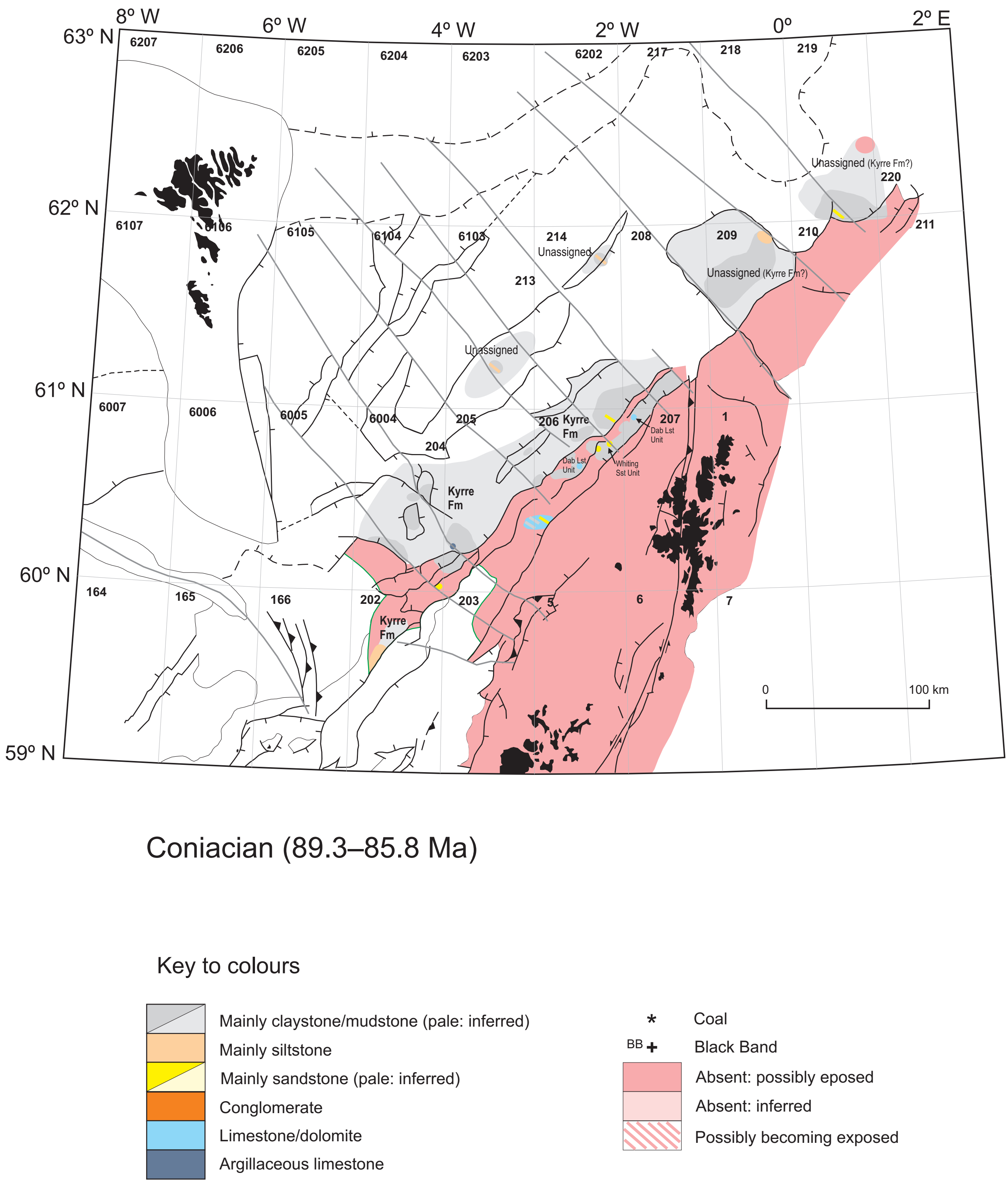


Figure 3.38 Lithostratigraphy: Coniacian (89.3–85.8 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

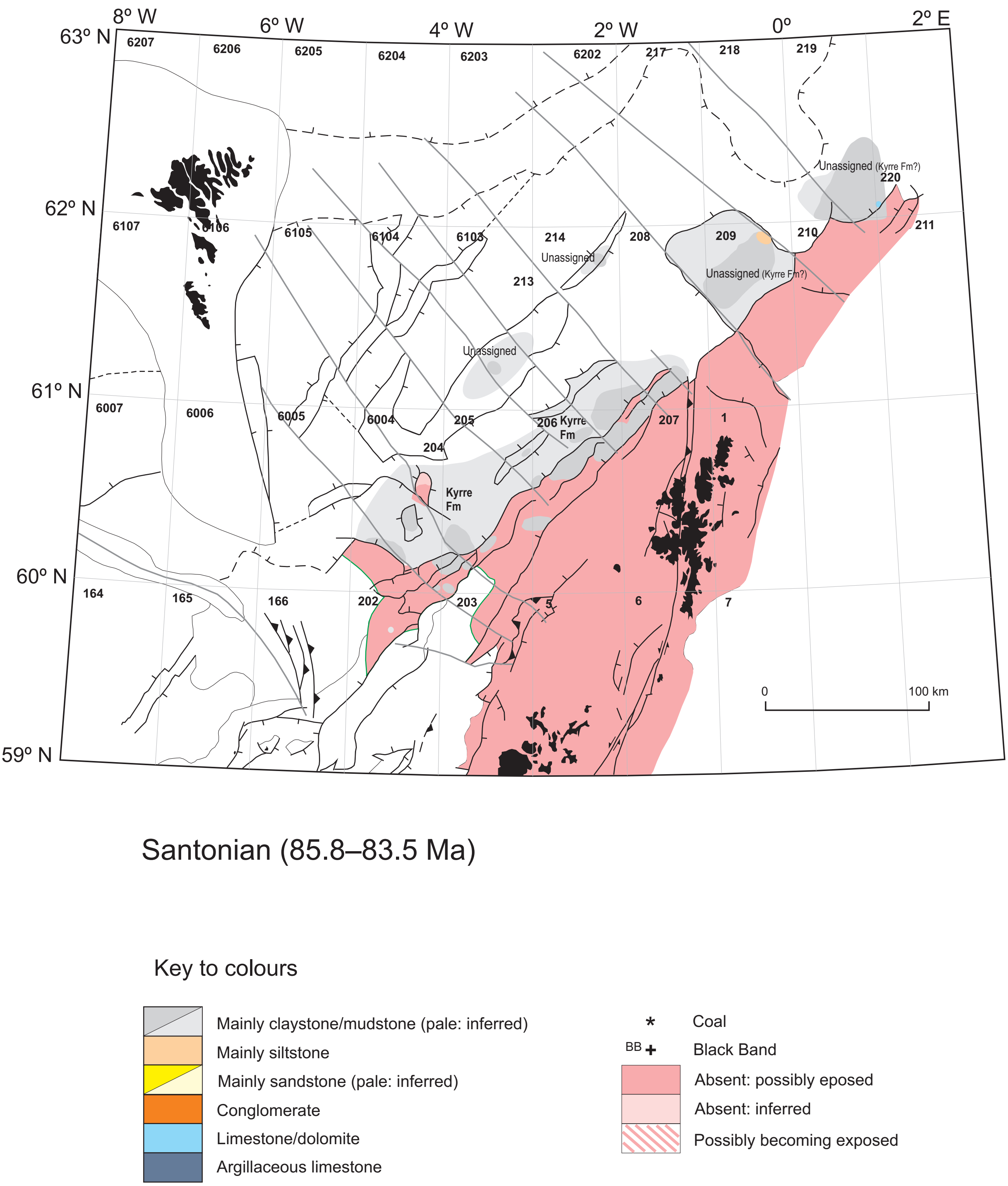


Figure 3.39 Lithostratigraphy: Santonian (85.8–83.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

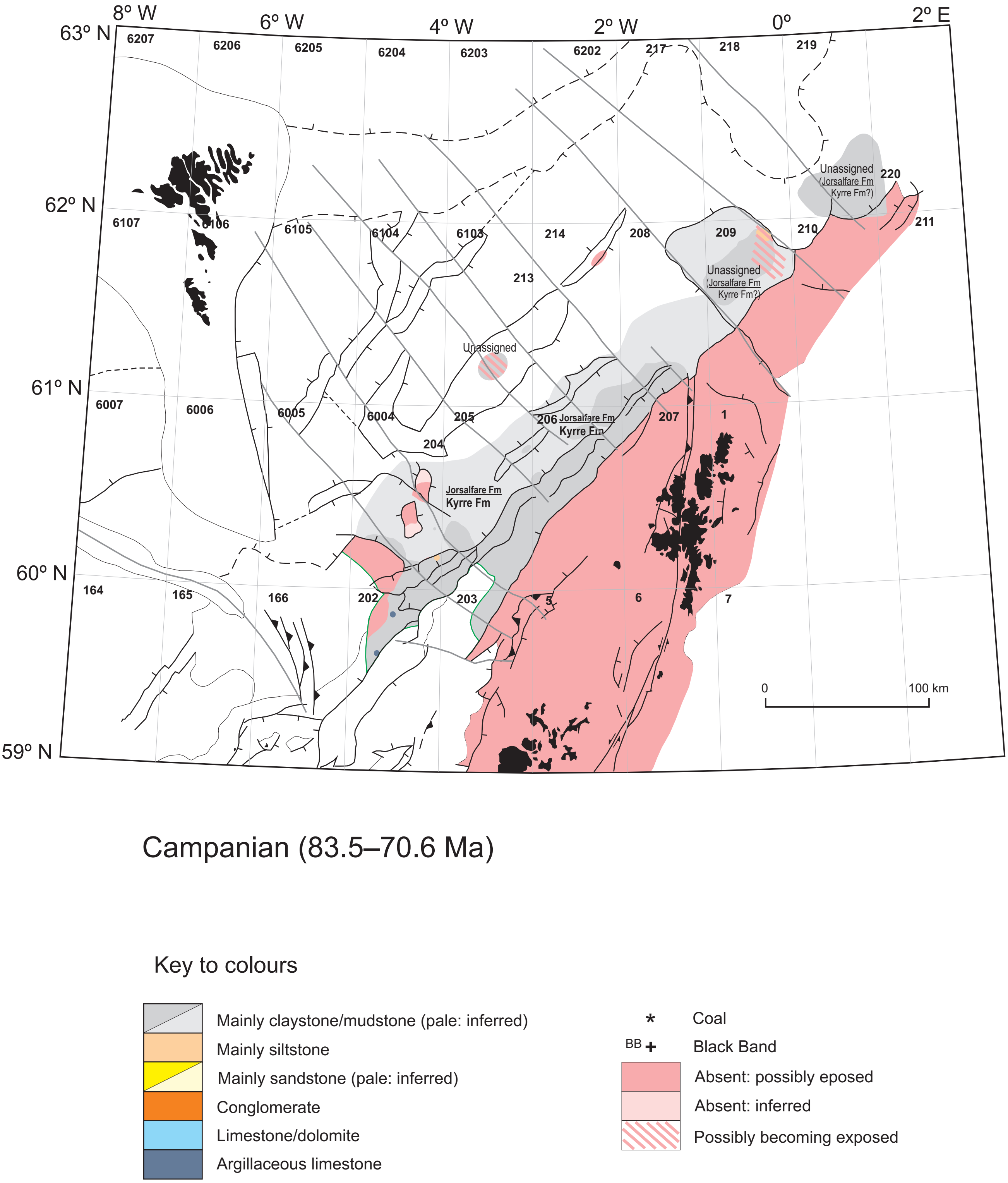


Figure 3.40 Lithostratigraphy: Campanian (83.5–70.6 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

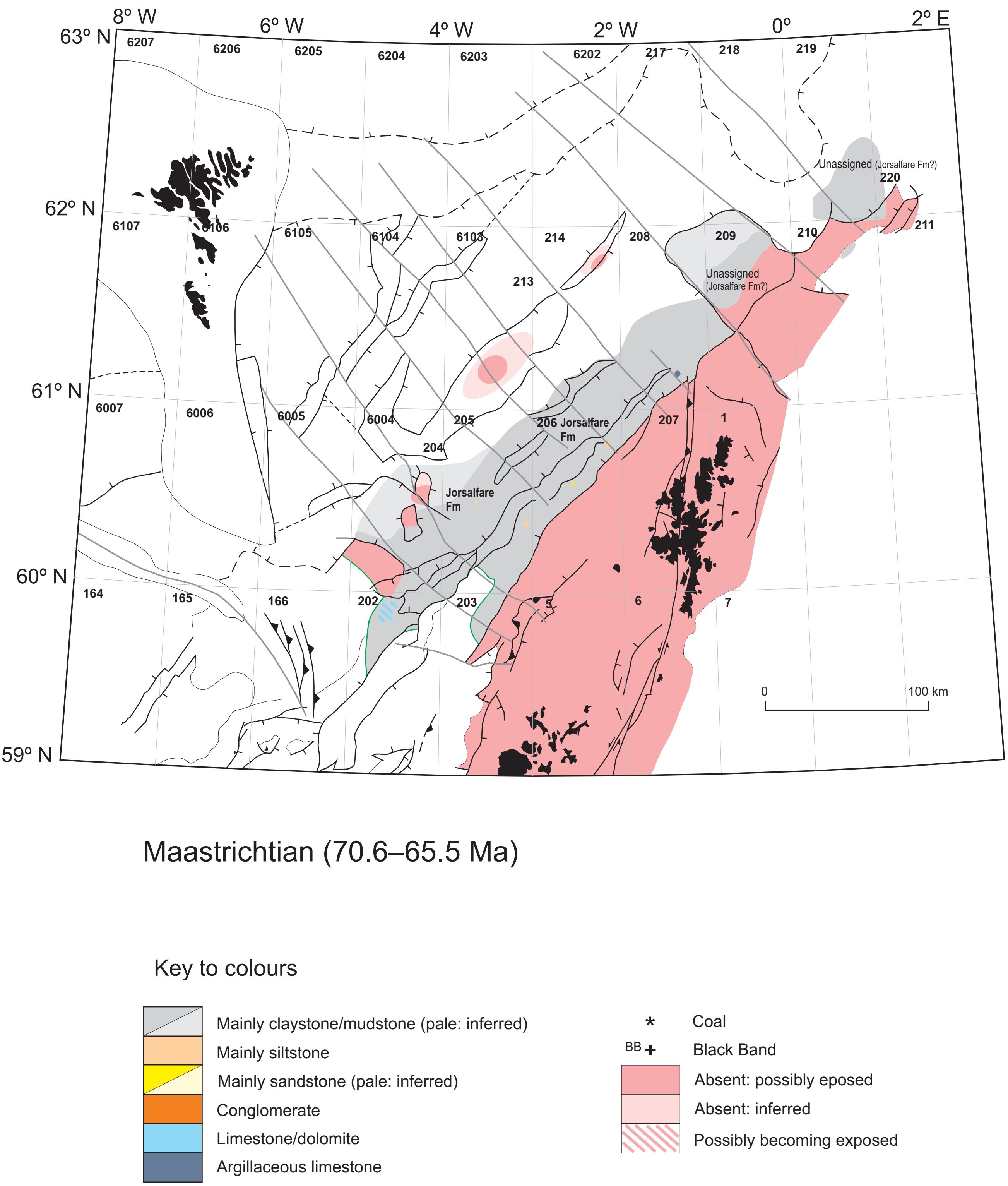
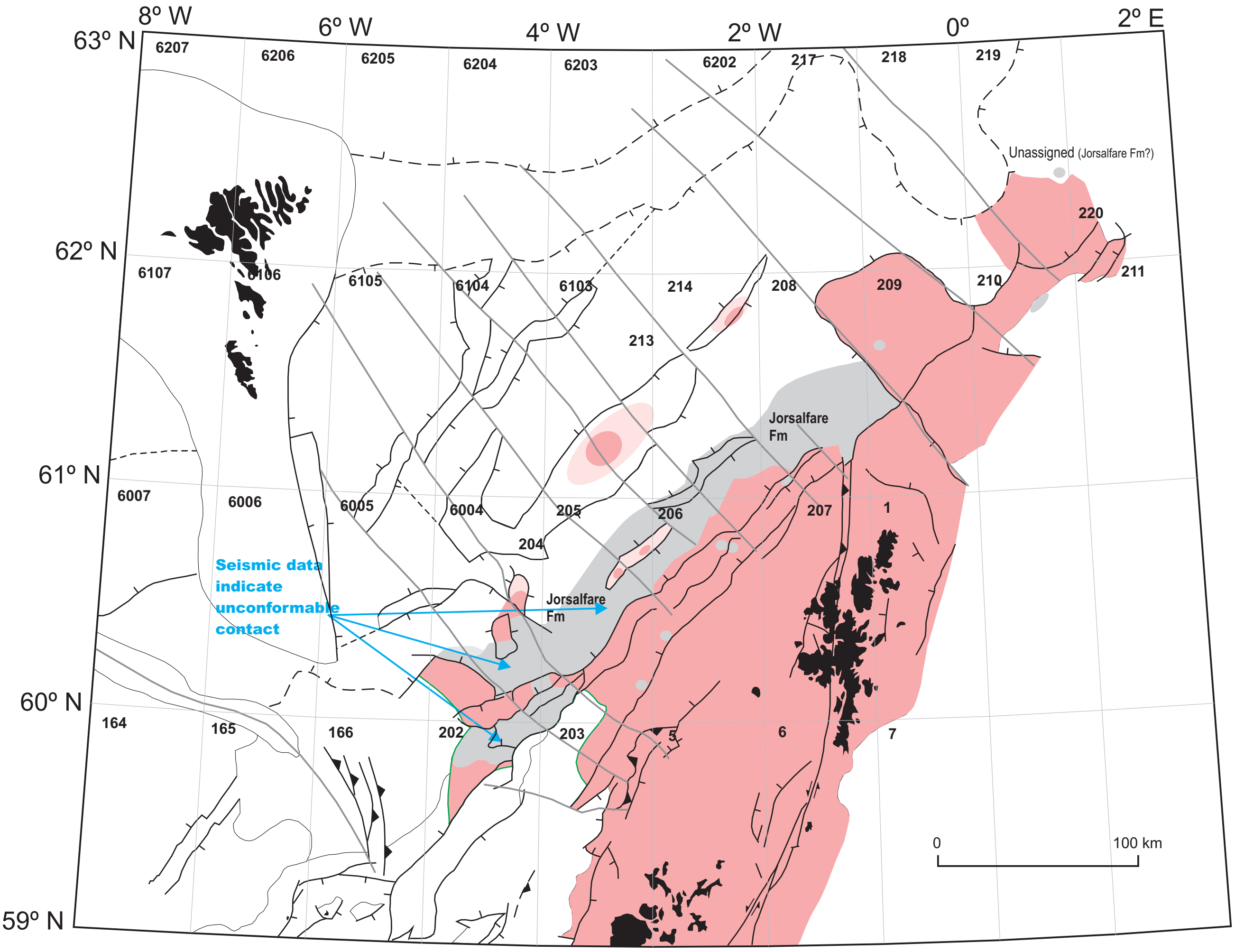


Figure 3.41 Lithostratigraphy: Maastrichtian (70.6–65.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.



Cretaceous/Palaeogene boundary (65.5 Ma)

Key to colours

- Mainly claystone/mudstone (pale: inferred)
- Mainly siltstone
- Mainly sandstone (pale: inferred)
- Conglomerate
- Limestone/dolomite
- Argillaceous limestone
- * Coal
- BB + Black Band
- Absent: possibly eposed
- Absent: inferred
- Possibly becoming exposed

NOTE ON EXTENT OF UNCONFORMITY

Seismic data indicate a widespread unconformity in the SE marginal basins as well as the Faroe-Shetland Basin. Whereas the SE marginal region may have been more widely exposed than is shown at this time, it is unclear whether erosion in the Foula, Flett and Judd sub-basins was subaerial or submarine.

Figure 3.42 Lithostratigraphy: Cretaceous/Palaeogene boundary (65.5 Ma). Structural framework from Ritchie et al. (2011); see Figure 1.1 for further details.

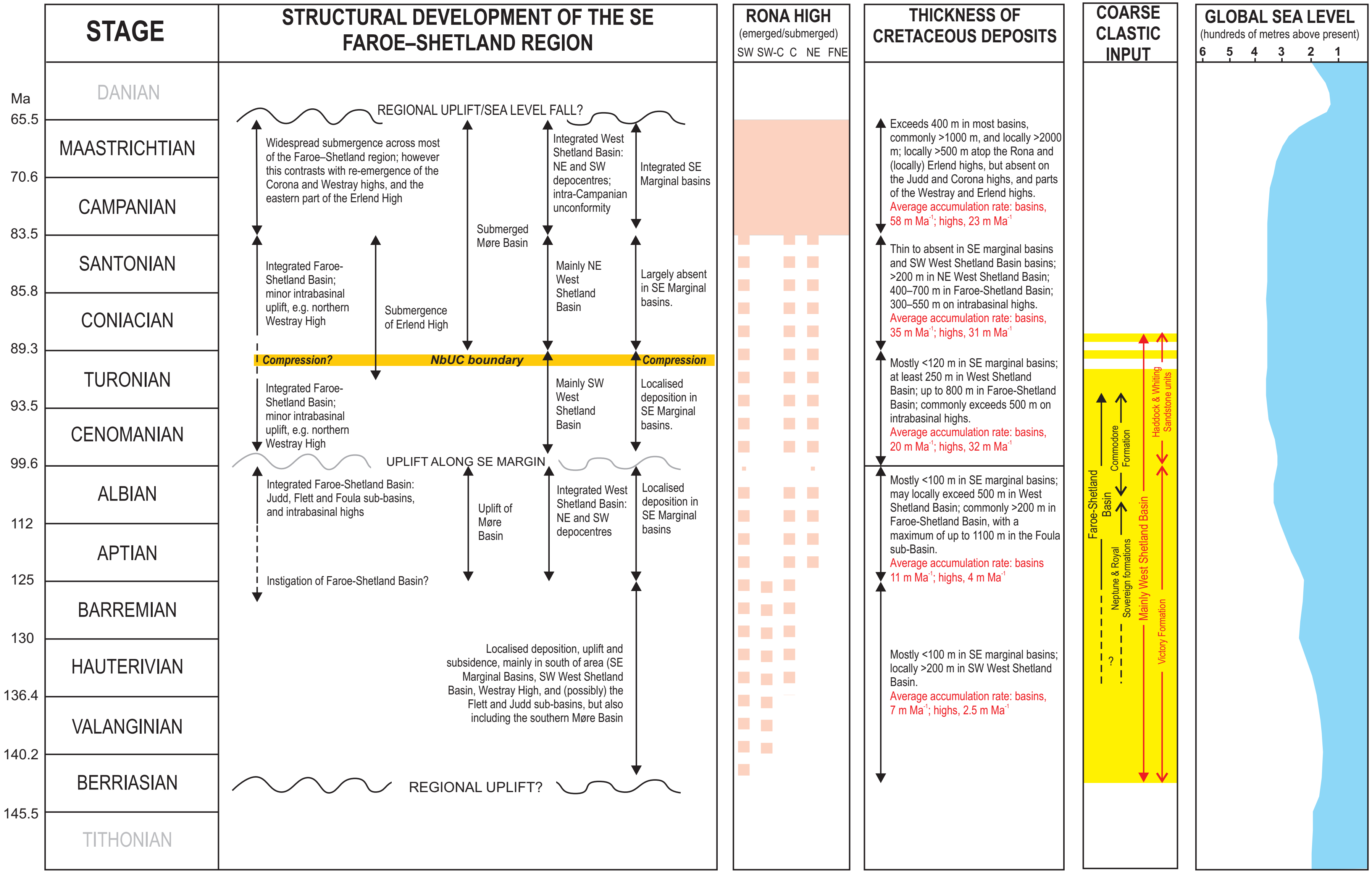


Figure 3.43 Summary of the Cretaceous development of the SE Faroe–Shetland region, showing: key phases in development of the main structural elements; exposure history of the Rona High (dashed pink lines indicate patchy, localised deposition; full shading indicates total submergence); variation in thickness and average regional sediment accumulation rate of the Cretaceous succession; temporal record of coarse clastic input, including the relevant lithostratigraphic units; global sea level curve (redrawn from Gradstein et al. (2004). Rona High abbreviations relate to descriptive notation of component segments used in this study as determined by the transection of rift-oblique lineaments: SW, south-west; SW-C, south-west–central; C, central; NE, north-east; FNE, far north-east. Other abbreviation: NbUC, Near-base Upper Cretaceous boundary. See text for details.

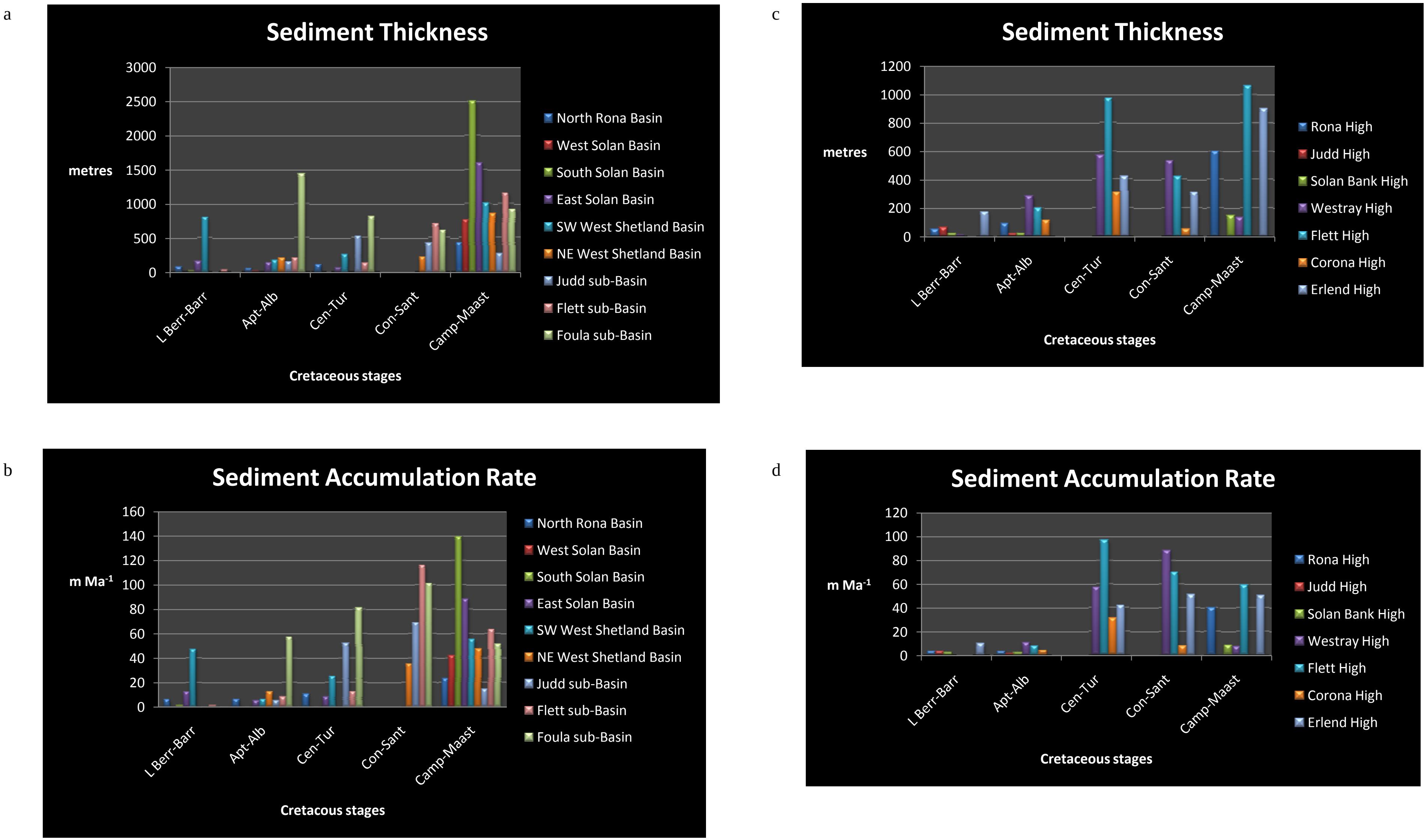


Figure 3.44 Series of histograms showing sediment thicknesses and sediment accumulation rates for the various basins (a & b) and highs (c & d). Information is derived from well-log data in Appendix 1. (See text for details).

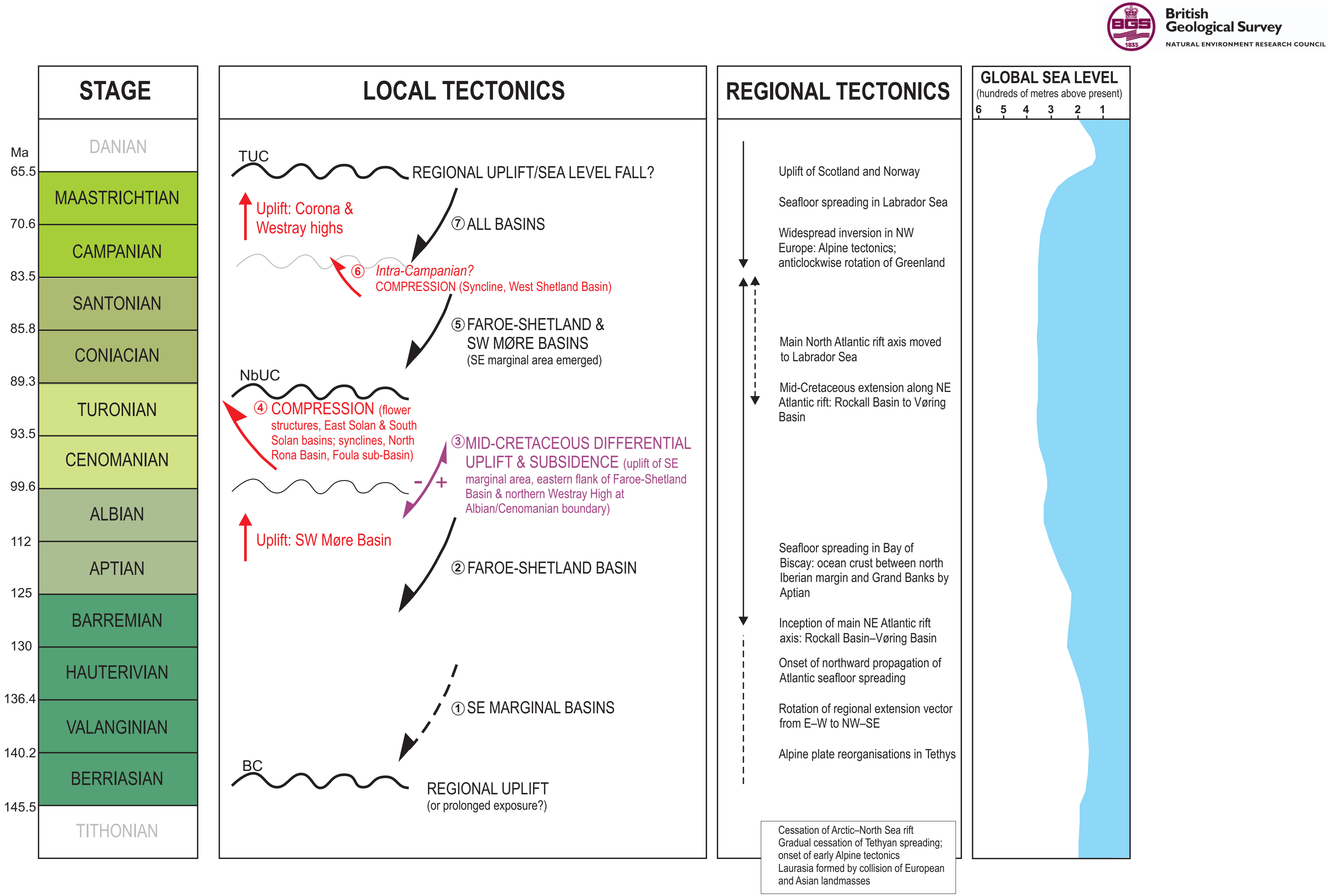


Figure 4.1 Correlation between local (Faroe–Shetland region) and regional (North Atlantic–western Europe) tectonic events; latter based on various sources, including: Ziegler, (1988), Doré et al. (1999), Roberts et al. (1999), Eide, (2002), Coward et al. (2003), and Tsikalis et al. (2005). Local tectonic symbols and abbreviations: black inclined downward arrow, extension and subsidence (dashed arrow indicates restricted connectivity); red vertical arrow, uplift; red inclined upward arrow, compression (including inversion; flower structures); purple bi-directional arrow, differential uplift and subsidence; BC, Base Cretaceous boundary; NbUC, Near-base Upper Cretaceous boundary; TUC, Top Upper Cretaceous boundary; wavy line, key unconformity. Circled numbers refer to discrete tectonic phases: see text for details. Global sea level curve redrawn from Gradstein et al. (2004)

Structure	Well
North Rona Basin	202/2-1
	202/3-1A
	202/3-2
	202/8-1
	202/12-1
West Solan Basin	202/3a-3
	204/29a-2
South Solan Basin	202/4-1
East Solan Basin	204/30a-3
	204/30a-2
	205/26a-2
	205/26a-3
	205/26a-4
	205/26a-5z
	205/26a-6
	205/27-2
West Shetland Basin (SW)	205/20-2
	205/23-1
	205/25-1
	205/30-1
	206/13-1
	206/16-1
West Shetland Basin (NE)	206/9-1
	206/10a-1
	207/1-2
	207/1a-5
	207/2-1
	208/23-1
Judd High	204/26-1,1A
	204/27-a1
	204/28-1
	204/28-2
Solan Bank High	202/9-1
Rona High (SW)	204/25-1
	204/30-1
	205/21-1a
	205/26-1
Rona High (SW-Central)	205/20-1
	205/23-2
Rona High (Central)	206/7-1
	206/8-2
	206/8-4
	206/8-6A
	206/9-2
	206/12-1
	206/12-2
	206/13a-2
Rona High (NE)	207/1-1
	207/1-3
	207/1a-4
	208/27-1
Rona High (Far NE)	208/27-2
Judd sub-Basin	204/14-1
	204/19-5
	204/23-1
	204/24a-6
	204/25a-2
	204/25a-3
	204/25-b4
	204/29-1
Foula sub-Basin (SW)	205/10-4
	205/10-5A
	206/1-1A
	206/3-1
	206/4-1
	206/11-1
	206/5-1
	206/5-2
	208/26-1
	214/29-1
	214/30-1
Flett sub-Basin	204/20-3
	205/8-1
	205/9-1
	205/12-1
	205/14-1
	205/14-2
	205/16/2
	205/16-1
	205/17a-1
	205/17b-2
	205/21-2
	205/21b-3
	205/22-1A
	208/15-2
	208/17-1
	208/17-2
	208/21-1
	208/22-1
	208/24-1A
	214/27-1
Westray High (south)	204/19-1
	204/19-2
	204/19-3A
	204/19-9
	204/24-1A
	204/24a-2
	204/24a-3
	204/24a-7
Westray High (north)	204/15-2
Flett High	205/10-1A
	205/10-2
	205/10-3
	205/14-3
	206/1-2
	206/1-3
	206/2-1A
	214/28-1
Corona High	213/23-1
	214/9-1
Erlend High	209/3-1
	209/4-1A
	209/6-1
	209/9-1A
	209/12-1
Erlend sub-Basin	219/27-1
	219/28-1
Møre Basin	219/20-1
	219/28-2
	220/26-1
	220/26-2
Unst Basin	BGS 77/1
	BGS 84/5
Magnus Basin	210/4-1

Table 1.1 Commercial wells and BGS boreholes used in this study

Basin	Geometry and seismic architecture	Base Cretaceous (BC) boundary	Seismic character of Lower/Middle Cretaceous fill	Near-base Upper Cretaceous (NbUC) boundary	Seismic character of Upper Cretaceous fill	Top Upper Cretaceous (TUC) boundary	Published timing of fault activity (extensional unless otherwise indicated)
North Rona Basin[1] (Figure 2.2)	NNE-trending half-graben bounded by Solan Bank High on its eastern margin. Two main seismic packages: uniformly-thick, synclinal lower unit, and upper wedge-shaped unit.	Sub-parallel but with low-angle discontinuity with underlying Jurassic. Well-logs support a mainly erosional hiatus with Upper Jurassic strata.	Relatively uniform thickness of Valanginian–Turonian? strata. Strong reflectivity (Chalk Group?) immediately below NbUC boundary; otherwise discontinuous reflections. Well logs indicate punctuated sequence.	Unconformity: high amplitude, slightly irregular, synclinal reflection, onlapped by Upper Cretaceous (Campanian–Maastrichtian?) strata.	Wedge-shaped deposit, with sub-horizontal and generally continuous reflections that infill syncline, and abut the Solan Bank High.	Unconformity: high-amplitude, irregular reflection; truncates Upper Cretaceous strata; onlapped by Cenozoic deposits.	
West Solan Basin[1,2,3] (Figure 2.3)	NNE-trending basin situated at the SW end of the Rona High. Two main seismic packages, which thin and/or are locally cut out to the NW, on Judd High[2].	Unconformity: irregular and erosive into underlying Upper Jurassic strata.	Generally discontinuous reflections that onlap to NW onto the BLC. Well-logs indicate Lower Cretaceous (Albian and older?) strata, though seismic data queries stratigraphic range in 202/3a-3.	Unconformity: moderate amplitude, irregular reflection that marks truncated and eroded Albian strata, and is onlapped by Campanian–Maastrichtian rocks.	Onlapping infill; continuous reflections have slight dip to the NW; fairly faint reflectivity.	Unconformity: onlap of Cenozoic onto truncated and eroded Upper Cretaceous strata. TUC locally offset by Late Cretaceous–Paleocene normal faults[3]; also locally intense early Paleocene inversion of Cretaceous succession[3].	• Late Berriasian[3] • Late Cretaceous[3] • Early Paleocene transpression[3]
East/South Solan Basin[1,3,4]	NNE-trending half-grabens; bounded in SE by Solan Bank High. Two main seismic packages: commonly lower synclinal package, and upper slightly wedge-shaped unit.	Localised truncation of Jurassic strata supports well-log data that mainly indicate an unconformity with rocks of the Humber Group.	Synclinally-disposed deposits of Valanginian–Cenomanian age; relatively uniform thickness (local pinch-out onto Rona High?); faulted and folded in East Solan Basin[3]. Well logs indicate punctuated sequence	Unconformity: high-amplitude reflection (top of Cenomanian limestone), folded and faulted strata onlapped by Coniacian–Maastrichtian rocks[3].	Semi-continuous reflections that onlap folded Lower Cretaceous strata, as well as abutting the Solan Bank High.	Unconformity – locally marked by folded, inverted surface – that is onlapped by Paleocene deposits. Localised inversion may have begun in Late Cretaceous, though mainly early Paleocene age[3].	• Late Berriasian[3] • Mid-Cretaceous–inversion[3] • Late Cretaceous[3] • Early Paleocene transpression[3]
West Shetland Basin[1,4,5,6,7] (Figures 2.4 and 2.5)	NNE-trending half graben bounded by Shetland Spine Fault. Two main seismic packages, both wedge-shaped and thinning to NW. Lower package rotated to SE prior to deposition of upper unit. Discrete NE and SW depocentres. Section cut by Late Cretaceous faults[5,6].	Unconformity[5,6]: moderate amplitude reflection marking contact with Upper Jurassic (SW depocentre) or Precambrian basement (NE depocentre).	Semi-continuous reflections abut Shetland Spine Fault; pinch-out onto Rona High. Well-logs indicate punctuated upper Berriasian–Turonian age range in SW, with an Aptian unconformity (at least locally). Aptian is lower age range in NE basin.	Unconformity: high-amplitude reflection in NE; irregular; Lower Cretaceous section truncated; onlapped by Upper Cretaceous deposits[6]. NbUC marks top of Victory Fm in NE, though variation in reflection strength due to overlying Dab Limestone Unit[6]. Truncates Chalk Group in SW[5].	Continuous, weak reflections imaged in NE depocentre, plus late Campanian unconformity[6]; latter not seen in well-logs. Overlying section downlaps this surface; also abuts Shetland Spine Fault. Lower section thins onto, and is locally absent from Rona High; upper section thinner over the high, thicker in basin.	Unconformity: high-amplitude reflection that truncates the Upper Cretaceous section. Overlying Cenozoic deposits onlap this surface.	Shetland Spine Fault: • Berriasian–Hauterivian (SW)[5] • Albian–Cenomanian[5,6] • Coniacian (NE)[5,6] • Late Campanian–Maastrichtian[5,6]
Judd sub-Basin[1,2,4] (Figure 2.6)	Generally NE-trending basin limited by the bounding faults of the Judd, Rona and Westray highs on the southern margin of the Faroe-Shetland Basin. Two main seismic packages: 1) a lower faulted package that thickens into footwalls, and thins over hangingwall crests; 2) a thicker, wedge-shaped upper package that downlaps onto the lower package.	Well-logs indicate an unconformity with rocks of the Humber Group. Seismic data also show Lower Cretaceous strata locally resting on Triassic strata on adjacent southern Westray High.	The internal reflections are variably weak to strong, but discontinuous. Well-log data indicate a possible Hauterivian–Turonian age, though the lower stratigraphic-range remains ambiguous.	Unconformity: top of lower package is marked by a moderate-to-high-amplitude reflection, albeit discontinuous, downlapped by the overlying package. This reflector may represent Turonian limestone (Macbeth Fm), though well-log data do not indicate a break across this boundary.	The upper package is generally transparent with weak reflectivity, which abuts Judd fault, and downlaps onto the NbUC. This character changes abruptly in the NW part of the basin where high-amplitude reflections associated with sills are prevalent.	Unconformity: moderate to high-amplitude reflection that appears to truncate Upper Cretaceous section; onlapped by Paleocene deposits. It should be noted that the available well-log data do not indicate an unconformity.	• Hauterivian? Or Aptian–Albian?[4] • Coniacian–Campanian?[4]
Flett sub-Basin[1,4,5,8] (Figures 2.4 and 2.7)	NE-trending basin bounded centrally by Corona and Flett highs. Poor seismic resolution in central area; much clearer in NE ('Yell Basin'[8]) where lower package of wedges overlain by thicker, more uniform upper package, though with local thickening into footwalls.	BC ambiguous in central area[4]; wells in SE indicate unconformity on Upper Jurassic and Precambrian rocks; seismic unconformity reported in NE[8].	Variably reflective lower package. Well-logs indicate a Valanginian–Cenomanian age range, though lower age remains ambiguous[5]. Aptian/Albian break reported[8].	Unconformity: weak reflection in central basin that is onlapped by Upper Cretaceous strata; strong reflection in NE[8] that may correlate with Cenomanian/Turonian unconformity.	Transparent to faintly reflective upper package, which locally abuts the Rona High[5]; continuity commonly disrupted by sporadic high-amplitude sills.	Unconformity: high-amplitude reflection that marks an erosional boundary that is onlapped and downlapped by Paleocene and younger rocks.	• Valanginian? Or Aptian–Albian?[5,8] • Campanian–Maastrichtian[5]
Foula sub-Basin[1,4,5,7] (Figures 2.4 & 2.7)	NE-trending half graben bounded by Rona High on SE margin and Flett High to NW. Two main seismic packages: synformally-disposed lower package and basinward-thickening upper package (may in part reflect later erosion).	Unconformity: locally moderate-amplitude reflection marking contact with Upper Jurassic strata and Precambrian basement.	Lower package comprises alternating strong, sub-parallel reflections and weaker, structureless intervals. Former associated with sandstone units (Commodore Fm?) as well as Turonian limestone[7].	NbUC marked by Turonian limestone and sandstone that forms a regional marker[7], though well-logs also indicate Cenomanian unconformity. NbUC onlapped by Upper Cretaceous deposits.	Upper Package is generally more transparent, with weaker, albeit continuous reflections, which abut Rona High[5]. Well-log data indicate that post-Turonian deposits are mudstone-prone.	Unconformity: moderate to high-amplitude reflection that marks faulted and erosional boundary that is onlapped by Cenozoic deposits.	• Aptian/Albian–Cenomanian[5,7] • Coniacian[5] • Campanian–Maastrichtian[5,7]
Erlend sub-Basin[1] (Figure 2.8)	Pre-Cenozoic structure is poorly defined: bounded in SE by Erlend and East Shetland highs; separated from Møre Basin by Brendan Lineament. Two main seismic packages: 1) a lower package that may be conformable with underlying Jurassic, forming a wedge-shaped unit; 2) an upper, more uniform sheet-like unit.	Appears to be generally conformable with underlying Jurassic (very subtle if unconformable), though unconformable at well-site locations in study area.	Highly transparent, very faint, but continuous, reflectivity.	Unconformity: slight angular discordance onlapped by Upper Cretaceous strata.	Generally transparent, though continuous low-amplitude reflections observed, which abut East Shetland High. Discontinuous high-amplitude reflections represent sills.	Unconformity: truncated Upper Cretaceous rocks onlapped by Cenozoic deposits.	• Late Mid-Jurassic–Early Cretaceous (comparable to Møre Basin)?[1,9]

Table 2.1 Seismic-stratigraphic characteristics of main basins/sub-basins, based on seismic and well-log data from this study as well as published information as follows: [1]Ritchie et al., (2011); [2]Moy and Imber, (2009); [3]Booth et al., (1993); [4]Lamers and Carmichael, (1999); [5]Dean et al., (1999); [6]Goodchild et al., (1999); [7]Grant et al., (1999); [8]Larsen et al., (2010); [9]Brekke, (2002).

System	Lithostratigraphy		Lithology	Depositional environment
UPPER CRETACEOUS	Shetland Group	Jorsalfare Formation	Mudstone with sporadic interbedded argillaceous limestone and rare sandstone	Aerobic siliciclastic marine shelf to upper bathyal slope
		Kyrre Formation	Mudstone with sporadic limestone, dolomite, sandstone and siltstone. In West Shetland Basin, mudstone grades to basal sandstone and limestone-rich facies, named the Whiting Sandstone and Dab Limestone units	Outer sublittoral to bathyal, though Dab Limestone deposited on a marine inner shelf
		Macbeth Formation	Mudstone with interbedded limestone, minor dolomite and sporadic sandstone and siltstone	Aerobic siliciclastic marine shelf
		Svarte Formation	Mudstone with interbedded limestone, argillaceous limestone and sporadic siltstone	Aerobic siliciclastic marine shelf to bathyal slope
	Chalk Group	Herring Formation	Cryptocrystalline limestone with interbedded argillaceous limestone and mudstone, and high gamma pyritic mudstone (Black Band) at base	Mostly aerobic carbonate shelf, though Black Band represents minor pulse of anaerobic conditions
		Hidra Formation	Fine-grained limestone and argillaceous limestone with interbedded mudstone, which, in West Shetland Basin, pass laterally to the sandstone-rich Haddock Sandstone Unit	Aerobic carbonate shelf fringed by shallow-marine sands derived from West Shetland Platform
LOWER CRETACEOUS	Cromer Knoll Group	Commodore Formation	Fine- to medium-grained sandstone with interbedded thin mudstone and limestone	Deep-water mass-flow sandstones on eastern margin of Faroe-Shetland Basin sourced from Rona High. Correlative Phoebe Sandstone Unit sourced from North Rona or Westray highs
		Rødby Formation	Mudstone interbedded with thin limestone, siltstone and sandstone	Aerobic marine shelf, though base of formation deposited in an anaerobic environment (based on agglutinated foraminifera)
		Carrack Formation	Non-calcareous, carbonaceous and pyritic mudstone and siltstone	Basinal marine with anaerobic bottom waters and sporadic incursions of oxygenated surface waters (indicated by planktonic foraminifera)
		Cruiser Formation	Non-calcareous, carbonaceous and pyritic mudstone with sporadic thin siltstone, fine-grained sandstone and limestone	Basinal marine with fluctuating anaerobic–aerobic bottom waters
		Royal Sovereign Formation	Conglomerate and fine- to coarse-grained sandstone with interbedded mudstone	Deep-water mass-flow deposits on eastern margin of Faroe-Shetland Basin sourced from Rona High
		Neptune Formation	Fine- to medium-grained sandstone with interbedded thin mudstone	Deep-water mass-flow sandstones in SW Faroe-Shetland basin possibly sourced from the Westray or Judd highs
		Valhall Formation	Mudstone grading into thin argillaceous limestone	Aerobic marine basin
		Victory Formation	Fine- to medium-grained sandstone, locally conglomeratic at base, with sporadic mudstone and thin coal	Shallow marine to paralic setting in the West Shetland Basin. Coal beds indicate episodic exposure of the delta plain

Table 2.2 Summary of lithology and depositional environment of the Cretaceous lithostratigraphic formations. Information derived from Ritchie et al. (1996) and Harker (2002).

Appendix 1 Stratigraphical-range charts

This appendix presents a series of seven stratigraphical-range charts (Figures A1.1–A1.7) that places the commercial well data and BGS boreholes utilised in this study (Table 1.1) into a temporal context, thereby providing a means of correlation between structural elements. The main source of stratigraphical data was provided by released well-logs, supplemented with published information from Ritchie et al. (1996), Dean et al. (1999), Goodchild et al. (1999) and Grant et al. (1999). The lithostratigraphical framework of Ritchie et al. (1996) is superimposed on the charts. Additional information includes: 1) general lithological and thickness information; 2) the age of the sub- and post-Cretaceous rocks; 3) notes on the character of the Cretaceous/Cenozoic boundary where there is apparent conflict between the well-log and seismic reflection data; and, 4) notes indicating seismic evidence for a regional intra-Late Cretaceous unconformity (the Near-base Upper Cretaceous boundary: see section 2.2.2) in the Faroe-Shetland Basin, but which is not apparent from the well-log data.

These charts are provided as an aid to the interpretation of the SE Faroe–Shetland region. They should be used in conjunction with the seismic data, and modifications to the stratigraphical ranges may be required as and when improved biostratigraphical information becomes available for individual wells.

The seven stratigraphical-range charts are as follows:

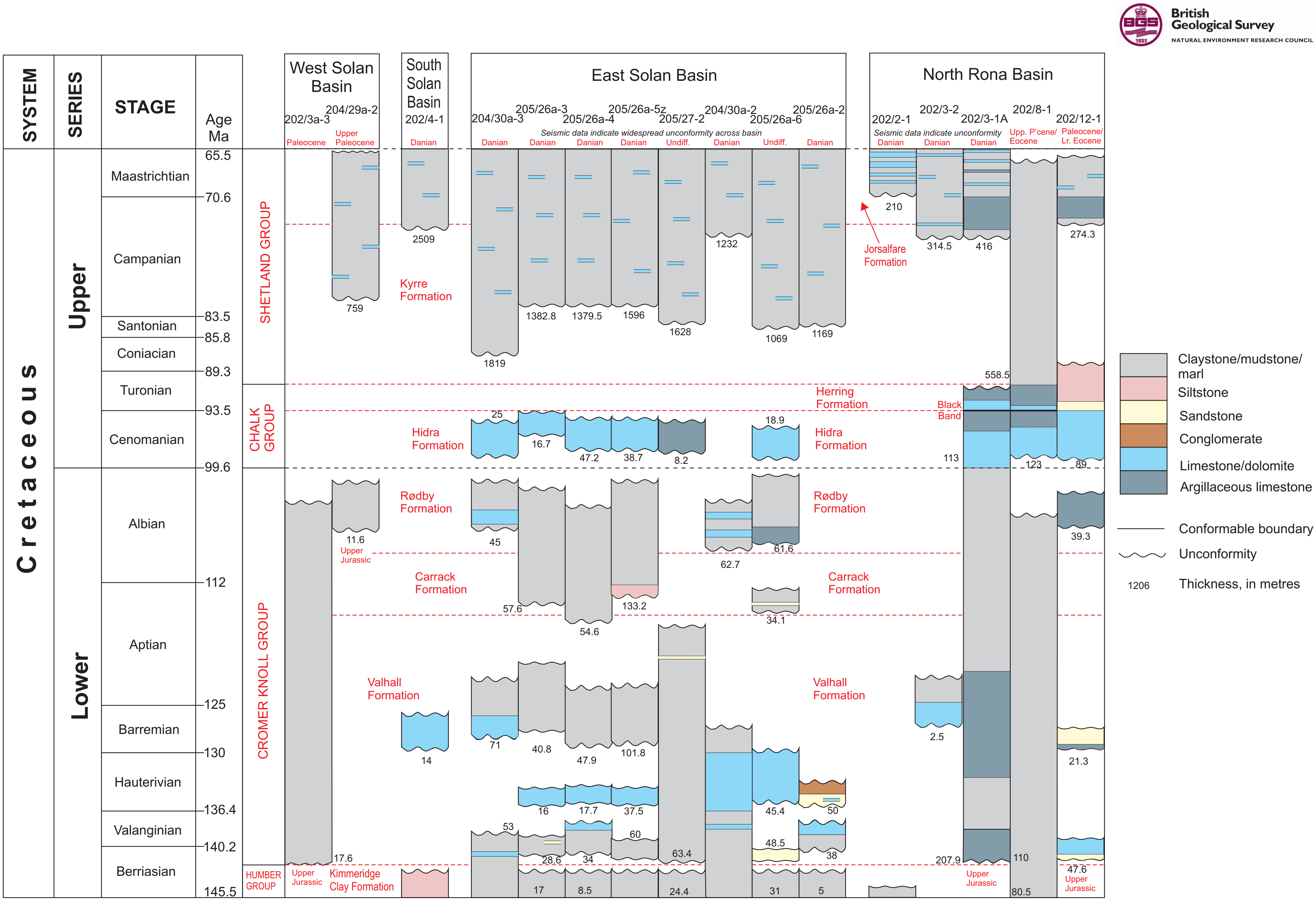


Figure A1.1 Stratigraphical-range chart showing generalised lithology, thickness and lithostratigraphical framework of Cretaceous rocks in the West Solan, South Solan, East Solan and North Rona basins. Locations of wells are shown in Figure 1.1. Chart also shows age of sub- and post-Cretaceous rocks. Timescale after Gradstein et al. (2004).

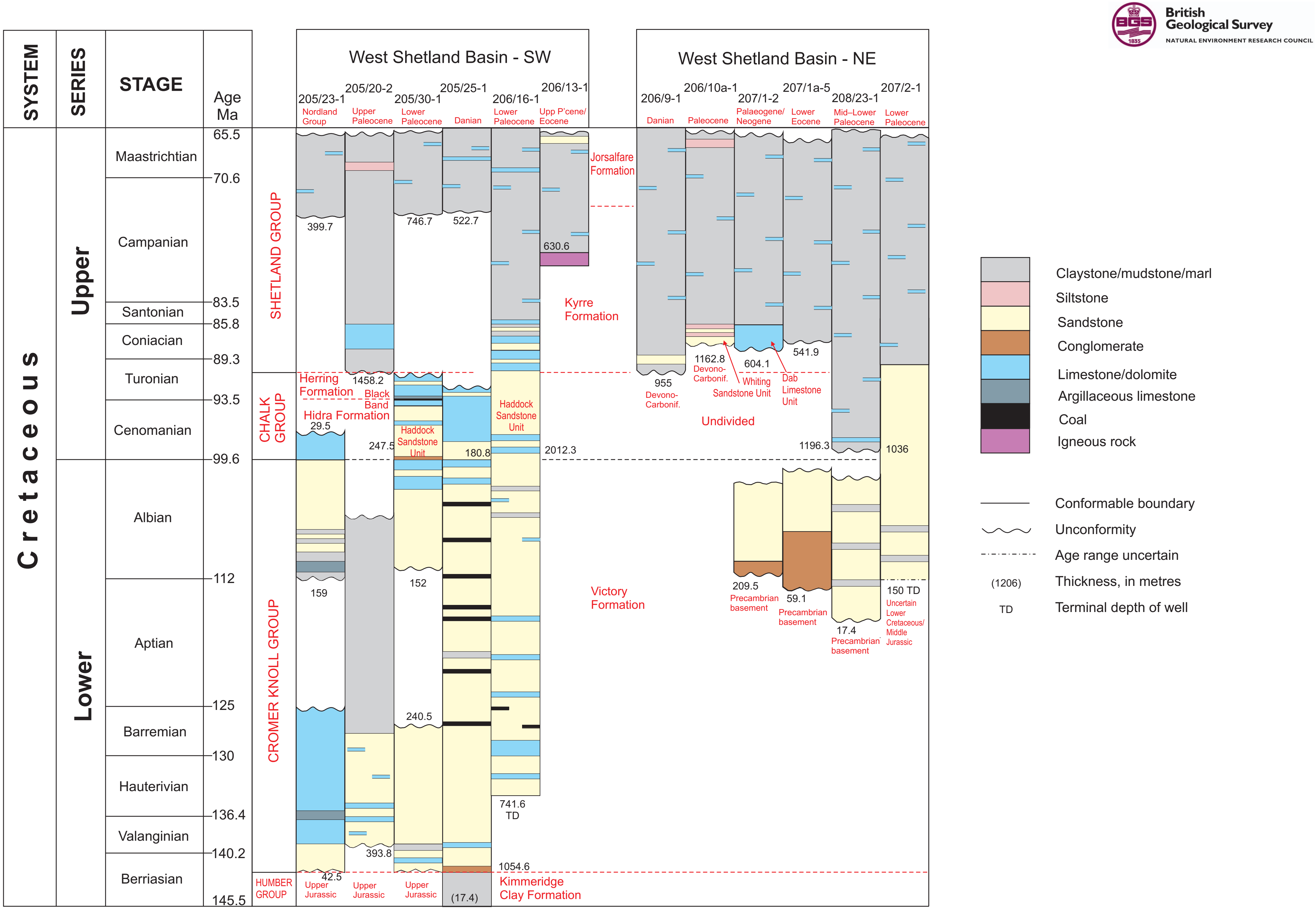


Figure A1.2 Stratigraphical-range chart showing generalised lithology, thickness and lithostratigraphical framework of Cretaceous rocks in the West Shetland Basin. Locations of wells are shown in Figure 1.1. Chart also shows age of sub- and post-Cretaceous rocks. Timescale after Gradstein et al. (2004).

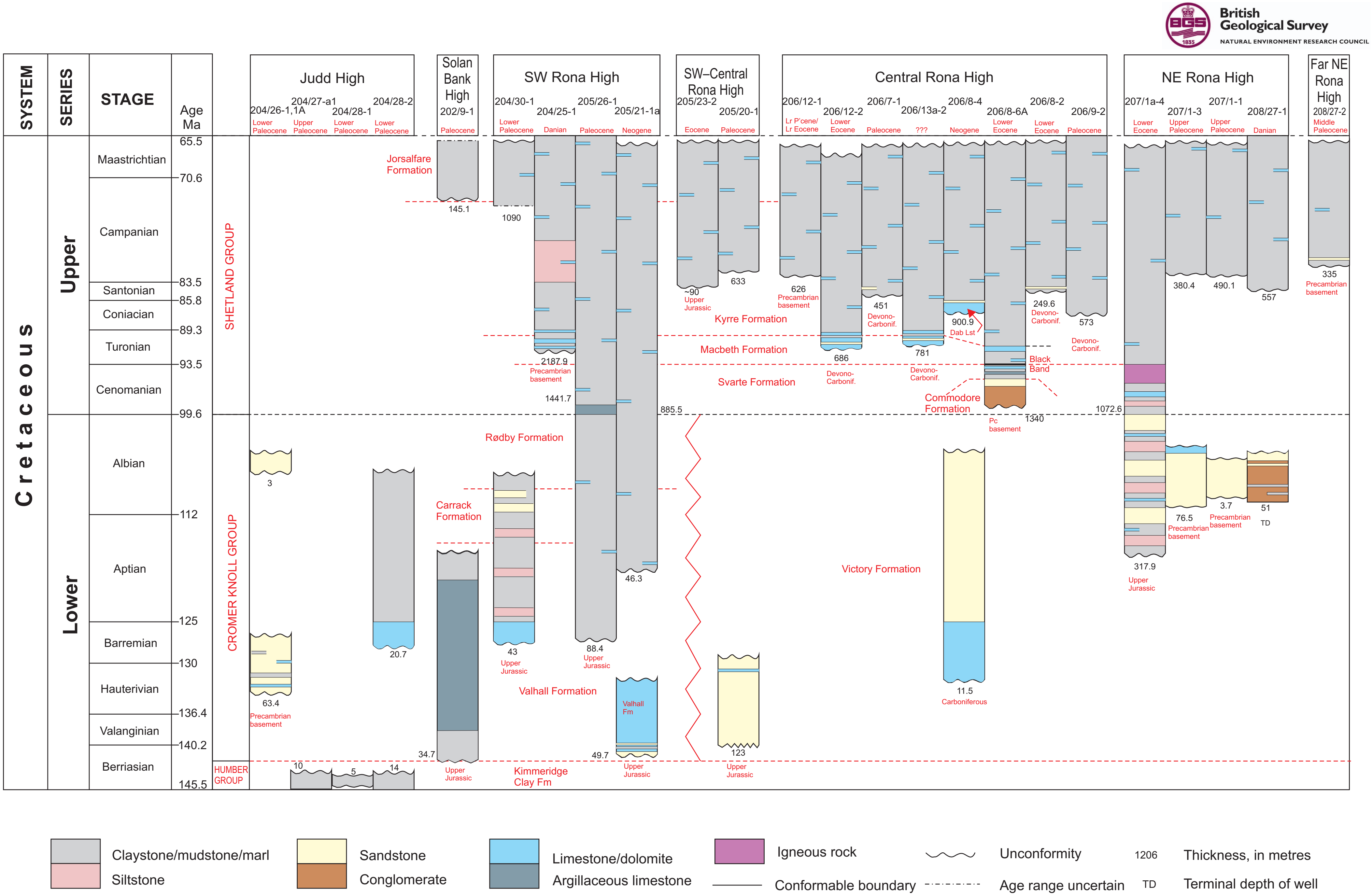


Figure A1.3 Stratigraphical-range chart showing generalised lithology, thickness and lithostratigraphical framework of Cretaceous rocks on the Judd, Solan Bank and Rona highs. Locations of wells are shown in Figure 1.1. Chart also shows age of sub- and post-Cretaceous rocks. Timescale after Gradstein et al. (2004).

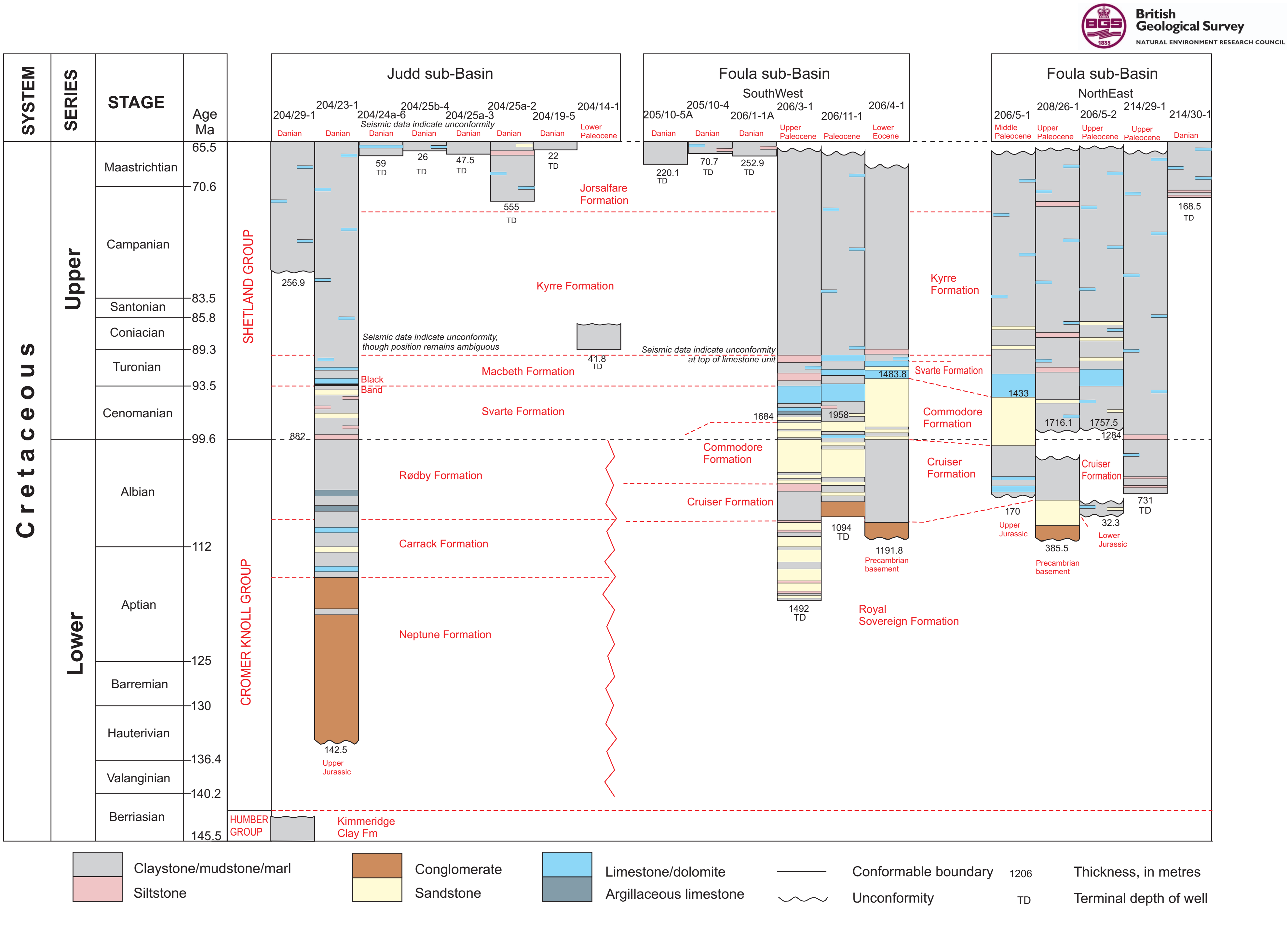


Figure A1.4 Stratigraphical-range chart showing generalised lithology, thickness and lithostratigraphical framework of Cretaceous rocks in the Judd and Foula sub-basins. Locations of wells are shown in Figure 1.1. Chart also shows age of sub- and post-Cretaceous rocks. Timescale after Gradstein et al. (2004).

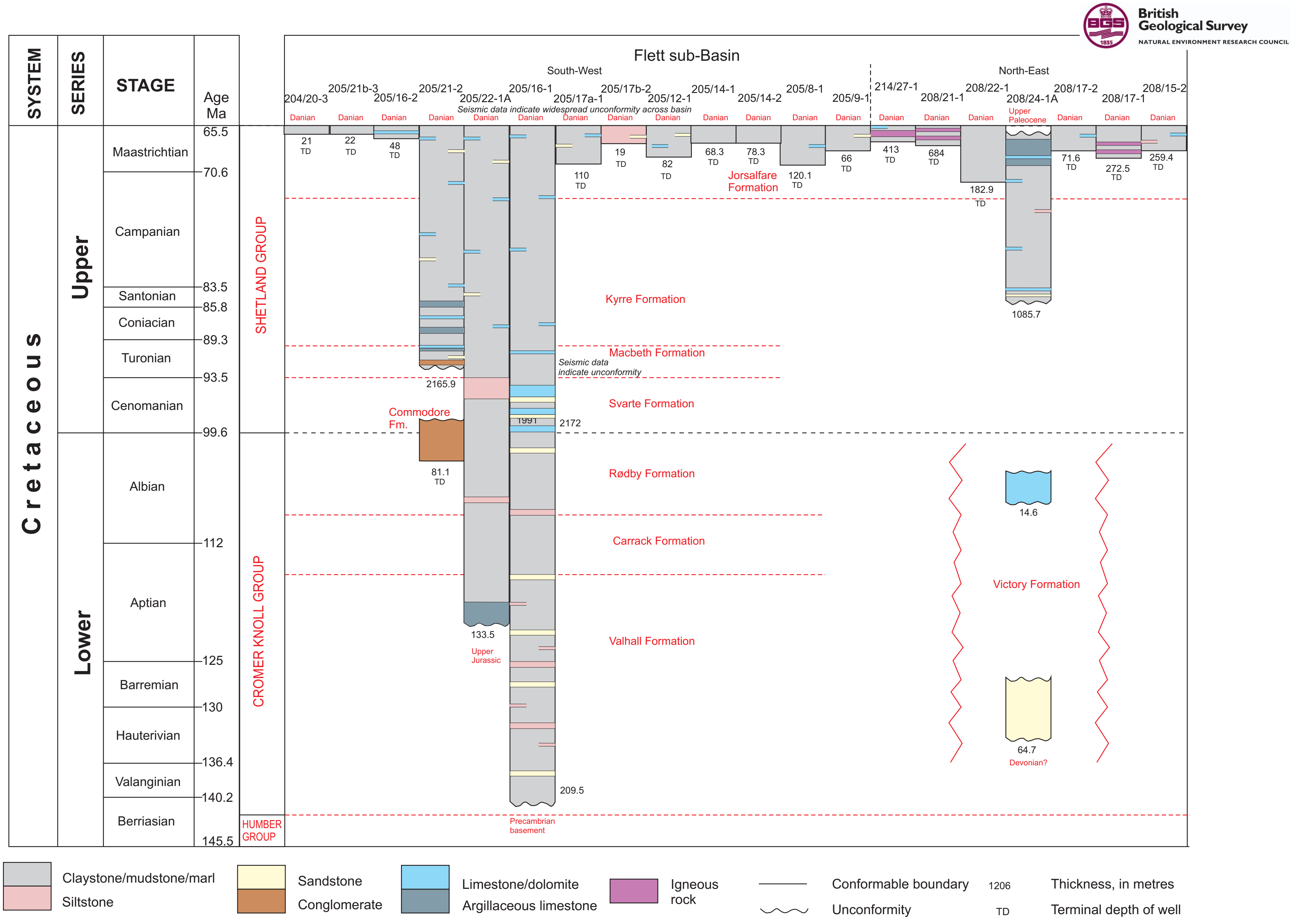


Figure A1.5 Stratigraphical-range chart showing generalised lithology, thickness and lithostratigraphical framework of Cretaceous rocks in the Flett sub-Basin. Locations of wells are shown in Figure 1.1. Chart also shows age of sub- and post-Cretaceous rocks. Timescale after Gradstein et al. (2004).

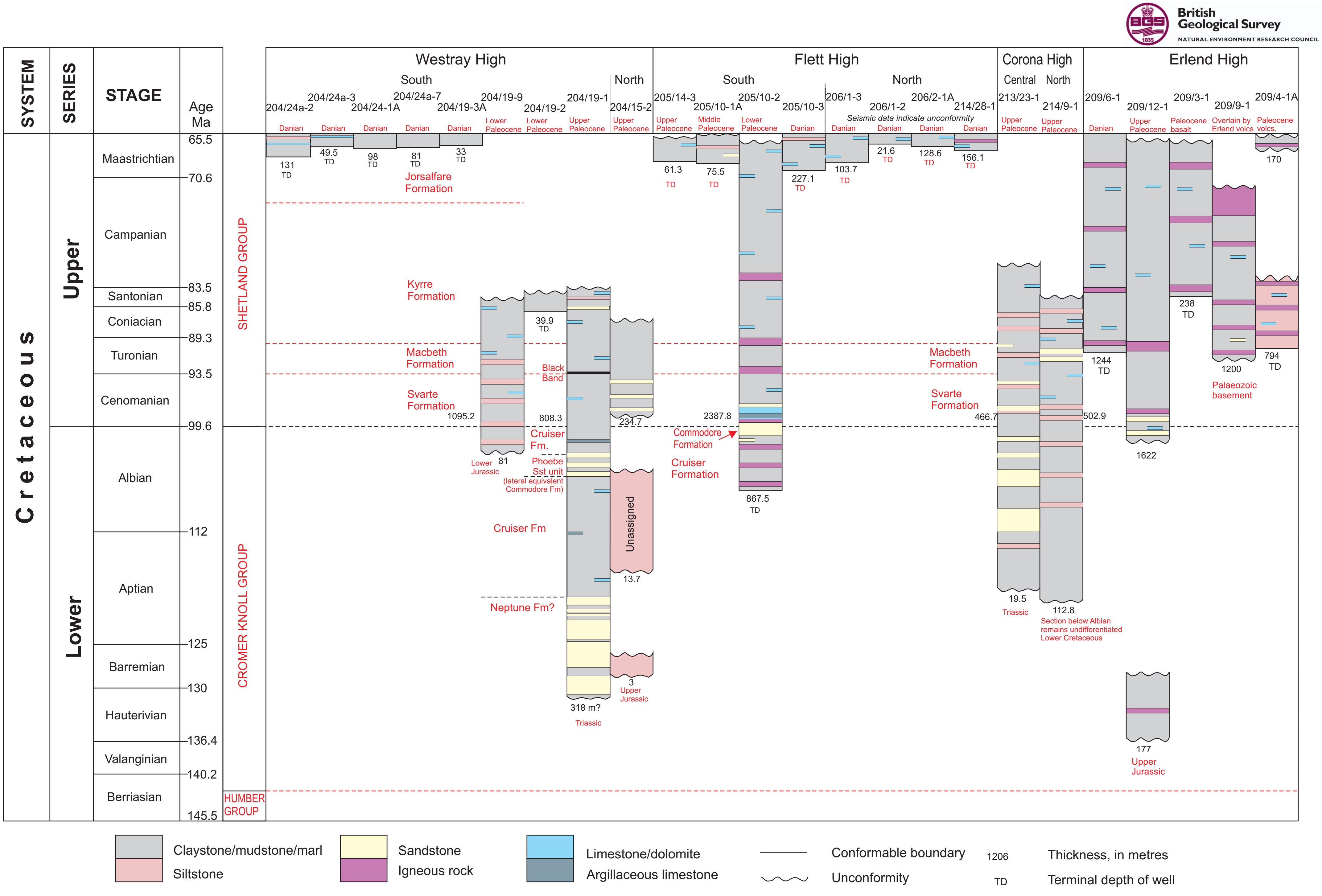


Figure A1.6 Stratigraphical-range chart showing generalised lithology, thickness and lithostratigraphical framework of Cretaceous rocks on the Westray, Flett, Corona and Erlend highs. Locations of wells are shown in Figure 1.1. Chart also shows age of sub- and post-Cretaceous rocks. Timescale after Gradstein et al. (2004).

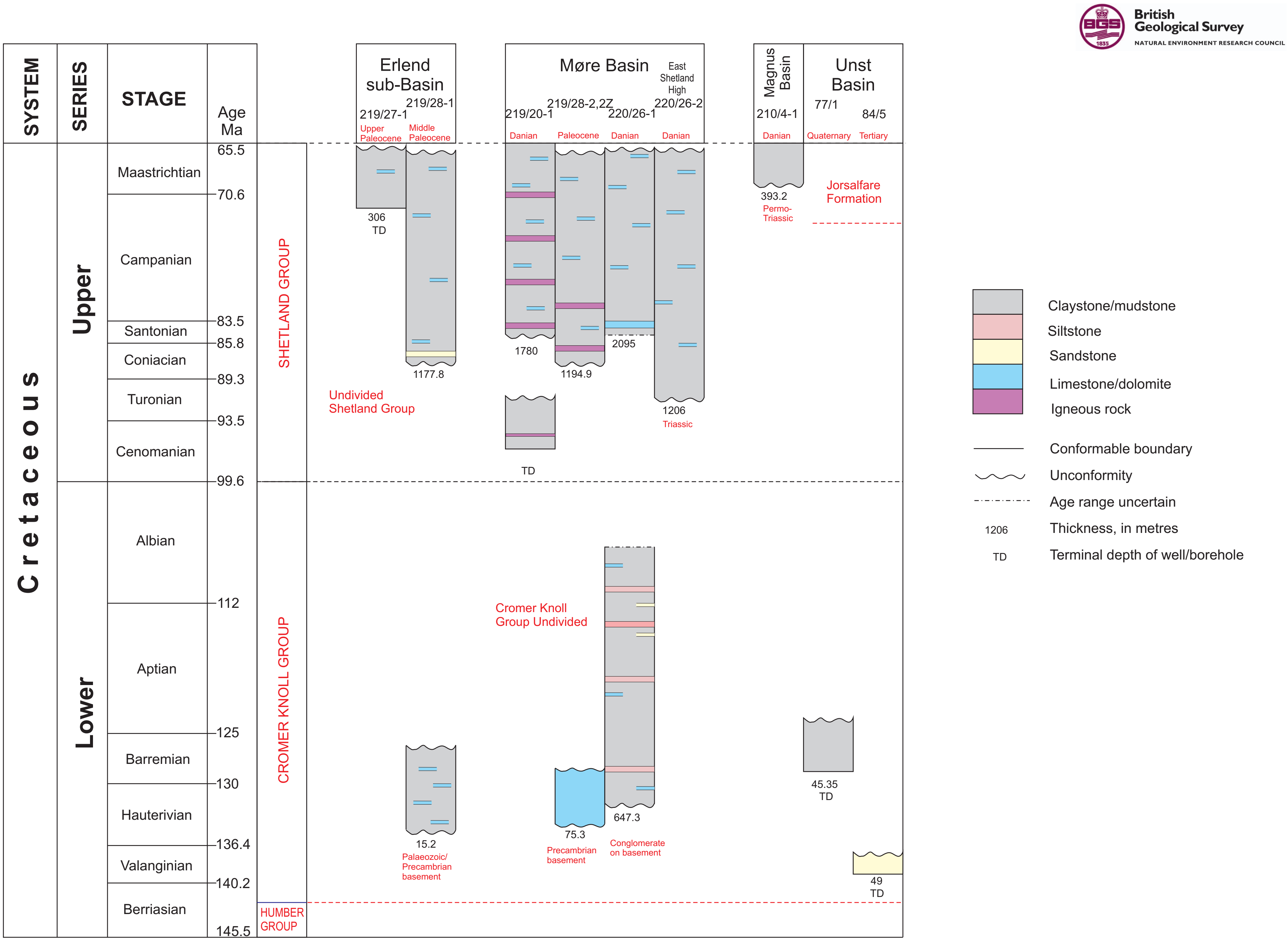


Figure A1.7 Stratigraphical-range chart showing generalised lithology, thickness and lithostratigraphical framework of Cretaceous rocks in the Erlend sub-Basin, and the Møre, Magnus and Unst basins. Locations of wells are shown in Figure 1.1. Chart also shows age of sub- and post-Cretaceous rocks. Timescale after Gradstein et al. (2004).

Appendix 2 Regional correlation chart

This appendix presents a regional correlation (Figure A2.1) between all of the main structural elements within the study, summarised from the stratigraphical-range charts in Appendix 1. In common with Figures A1.1–A1.7, the lithostratigraphical framework of Ritchie et al. (1996) is superimposed on this chart, which also includes: 1) general lithological and thickness information; 2) the age of the sub- and post-Cretaceous rocks; 3) notes on the character of the Cretaceous/Cenozoic boundary where there is apparent conflict between the well-log and seismic reflection data; and, 4) notes indicating seismic evidence for a regional intra-Late Cretaceous unconformity (the Near-base Upper Cretaceous boundary: see section 2.2.2) in the Faroe-Shetland Basin, but which is not apparent from the well-log data.

This chart is provided as an aid to the interpretation of the SE Faroe–Shetland region. It should be used in conjunction with the seismic data, and modifications to it may be required as and when improved biostratigraphical information becomes available for individual wells in the various basins/sub-basins and highs.

Figure A2.1 Regional correlation chart showing generalised lithology, thickness, and lithostratigraphical framework of the Cretaceous rocks preserved in the main basins, sub-basins and highs in the SE Faroe–Shetland region. The chart also shows the age of the sub- and post-Cretaceous rocks. Timescale after Gradstein et al. (2004).