[PS]The Enigma of Missing Jurassic and Cretaceous Rocks - Episodic Deposition and Unroofing of the UK and Adjacent Continental Shelves during the Mesozoic and Tertiary*

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Abstract

Jurassic and Cretaceous palaeogeographic reconstructions of the UK are constrained by extensive well and field exposures that provide both lithofacies and biostratigraphic control. However, this information is limited to ‘remnant’ sections preserved after regional erosional events presenting a biased perspective of originally more extensive pre-erosion depositional systems. Stratigraphic clues remain in the preserved section which can be used to develop a more comprehensive understanding of sequence architecture including: isolated outliers of sequences more fully developed in adjacent grabens; facies characteristics of once more laterally extensive depositional systems now limited to scattered erosional remnants; and sediment recycling of pre-tectonic sediments into intra-graben lows. While missing section cannot be studied directly, its effect can be detected by palaeo-thermal indicators such as apatite fission track analyses, sonic velocities and vitrinite reflectance, allowing a much more robust reconstruction than is possible from the preserved section alone. There are several key unroofing events in the Mid-Jurassic, Late Jurassic and Early Cretaceous alternating with periods of subsidence and deposition, culminating with severe uplift and exhumation in the Late Palaeocene, followed by an Oligo-Miocene event.

Early Jurassic rocks probably once covered much of the UK region, with shale and carbonates to the south and more clastic dominated facies in the north, prior to Aalenian uplift and unroofing of the mid-North Sea Dome. As this subsided during M-eL Jurassic, it was gradually onlapped by fringing deltaic-paralic and shallow marine depositional systems. With increasing rift-generated topography in later Jurassic time, much of this earlier sedimentary cover was stripped off inter-rift platforms and recycled into adjacent grabens. The main axis of rifting jumped westwards to the North Atlantic in the Early Cretaceous when the marginal areas of western Britain, Ireland and adjacent offshore were partially exhumed. As rifting waned, the region subsided and transgressed by shallow marine sands passing up into laterally extensive chalks with marls and shales in the north during the Late Cretaceous. Intra-Tertiary unroofing removed much of the Cretaceous and earlier remnant Jurassic from the western lands and caused a pronounced easterly tilt and progressive pattern of older subcrop to the west leaving the rather ambiguous stratigraphic record of today.

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Poster 1

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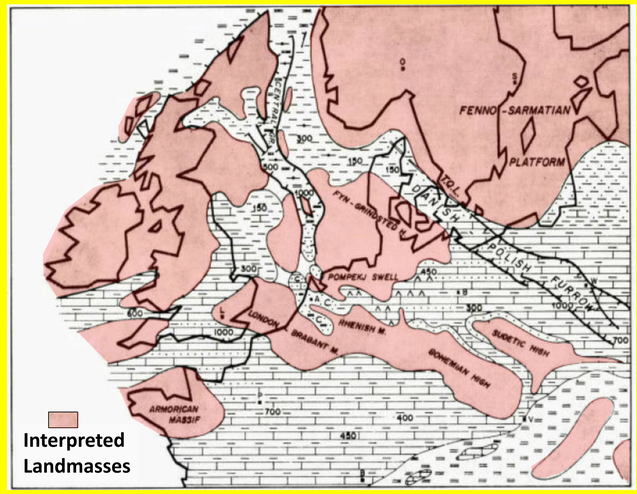
ABSTRACT

Jurassic and Cretaceous palaeogeographic reconstructions of the UK are constrained by extensive well and field exposures that provide both lithofacies and biostratigraphic control. However, this information is limited to 'remnant' sections preserved after regional erosional events presenting a biased perspective of originally more extensive pre-erosion depositional systems. Stratigraphic clues remain in the preserved section which can be used to develop a more comprehensive understanding of sequence architecture including: isolated outliers of sequences more fully developed in adjacent grabens; facies characteristics of once more laterally extensive depositional systems now limited to scattered erosional remnants; and sediment recycling of pre-tectonic sediments into intra-graben lows. While missing section cannot be studied directly, its effect can be detected by palaeo-thermal indicators such as apatite fission track analyses, sonic velocities and vitrinite reflectance, allowing a much more robust reconstruction than is possible from the preserved section alone. There are several key unroofing events in the Mid-Jurassic, Late Jurassic and Early Cretaceous alternating with periods of subsidence and deposition, culminating with severe uplift and exhumation in the Late Palaeocene, followed by an Oligo-Miocene event.

Early Jurassic rocks probably once covered much of the UK region, with shale and carbonates to the south and more clastic dominated facies in the north, prior to Aalenian uplift and unroofing of the mid-North Sea Dome. As this subsided during M-eL Jurassic, it was gradually onlapped by fringing deltaic-paralic and shallow marine depositional systems. With increasing rift-generated topography in later Jurassic time much of this earlier sedimentary cover was stripped off inter-rift platforms and recycled into adjacent grabens. The main axis of rifting jumped westwards to the North Atlantic in the Early Cretaceous when the marginal areas of western Britain, Ireland and adjacent offshore were partially exhumed. As rifting waned, the region subsided and transgressed by shallow marine sands passing up into laterally extensive chalks with marls and shales in the north during the Late Cretaceous. Intra-Tertiary unroofing removed much of the Cretaceous and earlier remnant Jurassic from the western lands and caused a pronounced easterly tilt and progressive pattern of older subcrop to the west leaving the rather ambiguous stratigraphic record of today.

Historical – Conventional Thinking

- Based on field exposures and well penetrations
- Limited to remnant preserved sections
- A biased perspective of wider original distributions
- Erosion, unroofing and recycling rarely incorporated and original facies extent not commonly mapped



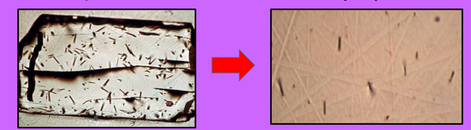
Upper Jurassic Palaeogeography (after Zeigler, 1975)

Missing Section Detection

- Biostratigraphy tied into seismic
- Structural events dated
- Burial and thermal histories, plus unroofing events documented
- Using **AFTA**, **Sonic Velocities** and **VR** integrated to indicate extent of missing section and more continuous extent of original Jurassic and Cretaceous cover

AFTA

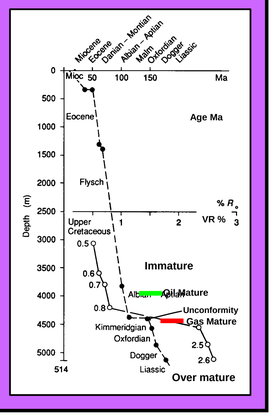
- **A**patite **F**ission **T**rack **A**nalysis - based on analysis of spontaneous uranium radiation-damage trails (fission tracks) in detrital or accessory apatite grains



- Tracks anneal with increasing temperature
- Provides thermal history of rocks up to ~110-120˚C (largely depending on Chlorine content)
- High palaeotemps. at shallow depths used to estimate cooling timing and amount of unroofing

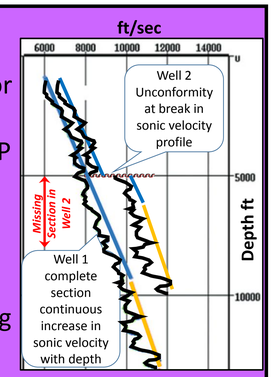
VR

- **V**itrinite **R**eflectance (%) of coal macerals from cuttings and core samples used to estimate thermal history
- Thermal history correlates with AFTA
- Increasing **VR** indicates higher temperatures with burial depth
- High **VR** values at shallow depths used to estimate original burial depth and amount of uplift/unroofing



Sonic Velocities

- Well log sonic velocities for shales get faster with increasing burial depth (HP zones excepted)
- Fast velocities at shallow depths used to estimate original burial depth and amount of uplift/unroofing



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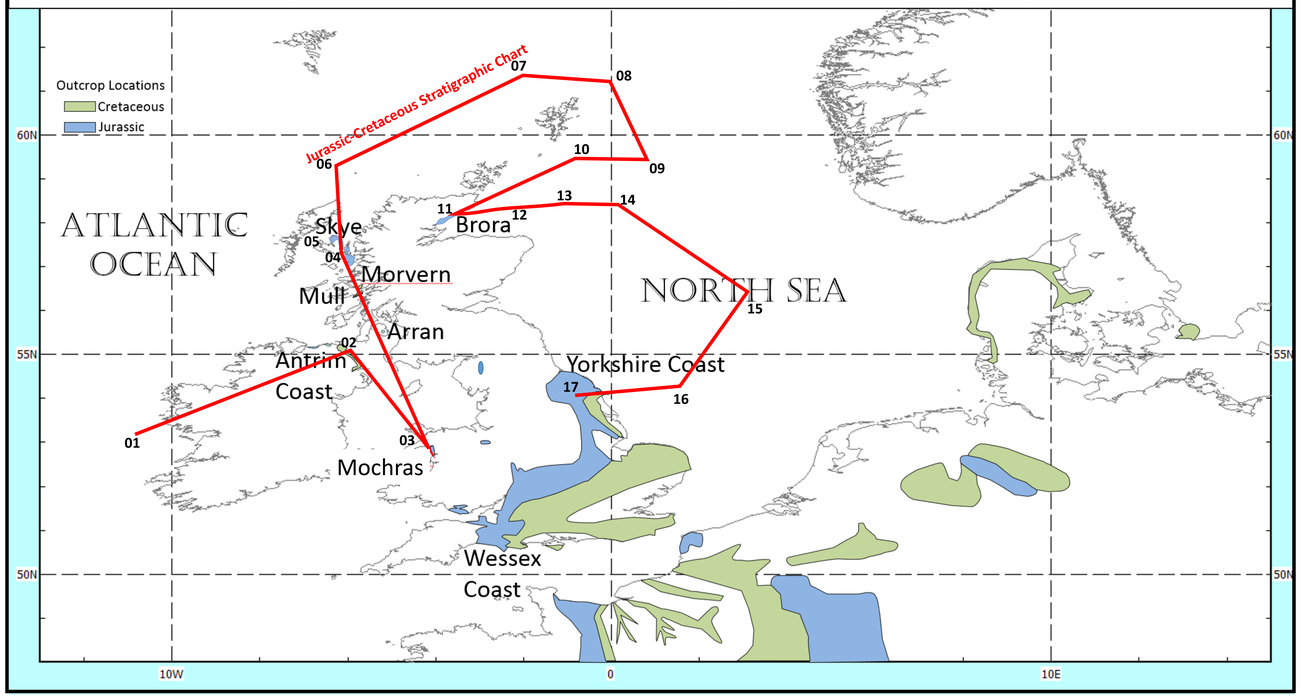
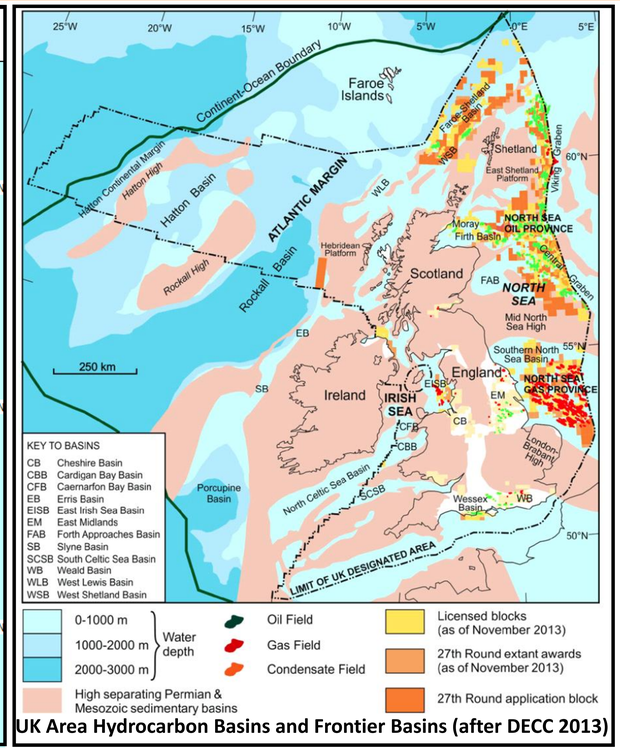
Key Jurassic and Cretaceous Outcrop Locations N W Europe





UK Area Hydrocarbon Basins and Frontier Basins (after DECC 2013)

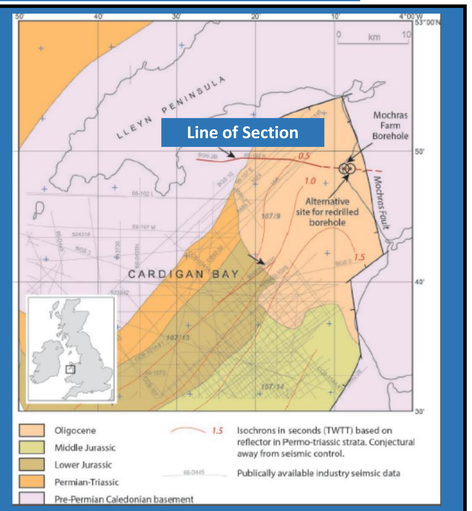
EARLY JURASSIC

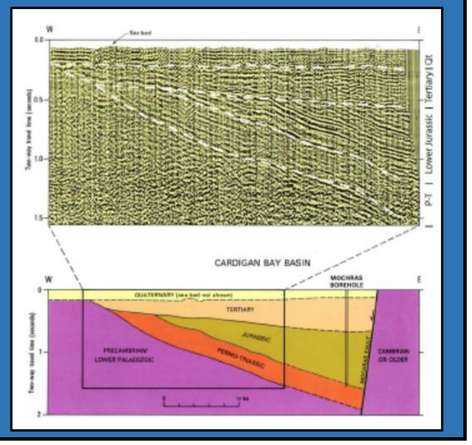
The Mochras Farm borehole, located on the west coast of Wales, was drilled (1967-1969) through Tertiary cover and unexpectedly encountered a very thick (1305m) section of Lias.

The Cambrian and older section outcrops just to the east, upthrown to the Mochras fault.

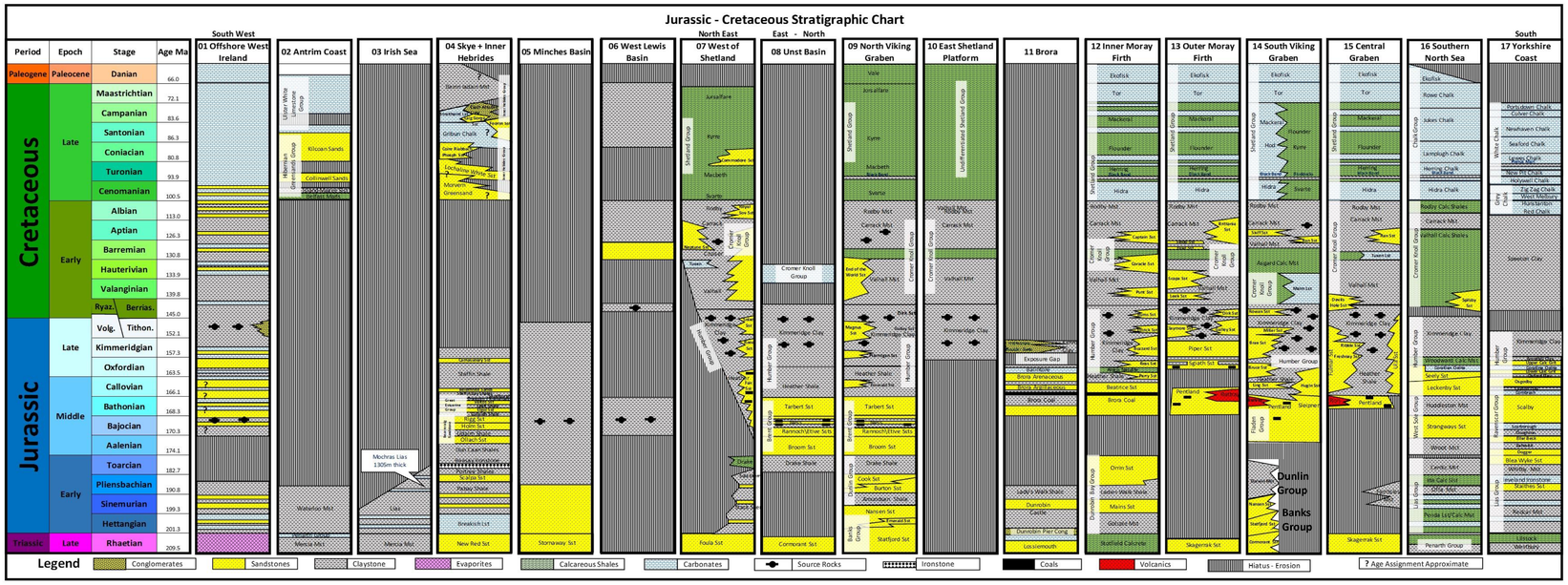
The conventional concept of Wales and much of northern and central England being an ancient high landmass during the Mesozoic has to be revisited.

AFTA data from adjacent onshore outcrops show Early Cretaceous cooling, interpreted as due to uplift and erosion involving removal of Triassic and Jurassic cover, with remnants only preserved in downthrown faulted areas.





Jurassic - Cretaceous Stratigraphic Chart

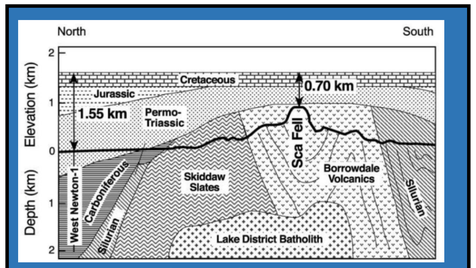


UNST BASIN

The lowermost Jurassic in the Unst Basin (Chart column 8) is a section of mudstones with interbedded thin silts and calcareous beds. This correlates with the Drake Formation in the Viking Graben (Chart column 9) and indicates the widespread occurence of the Lias around the UK.

INTERPRETATION

- Isolated preserved remnants of the Early Jurassic suggest that a large part of the UK and adjacent continental shelves were originally blanketed by Liassic calcareous mudstones, passing north into mixed sand-shale systems.
- Regional palaeogeographic reconstructions are constrained by the widespread mid-Aalenian erosional unroofing and younger events.



AFTA constrained restored cross section across the Lake District, NW England. An Intra-Cretaceous unroofing event which partially removed Jurassic and Permo-Triassic cover was followed by burial prior to final Cenozoic unroofing.

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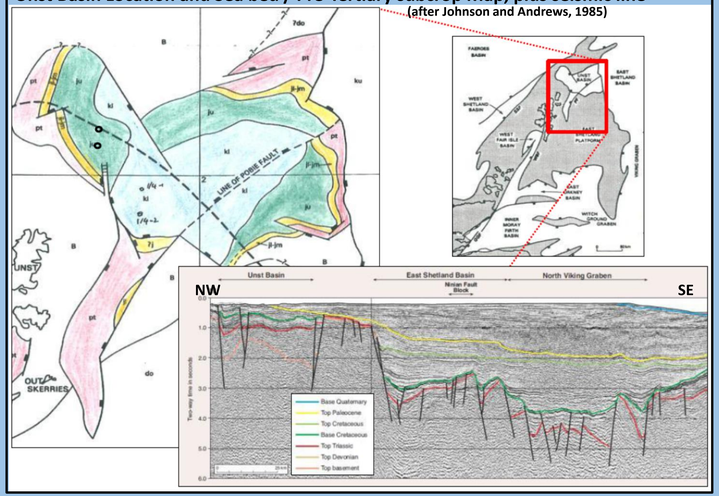
MIDDLE JURASSIC

Note the remarkable similarity of Middle Jurassic deltaic facies from Skye, Unst Basin, North Viking Graben and the Yorkshire Coast (Chart columns 4, 8, 9 and 17)

Unst Basin Location and Sea bed / Pre-Tertiary subcrop Map, plus seismic line
(after Johnson and Andrews, 1985)

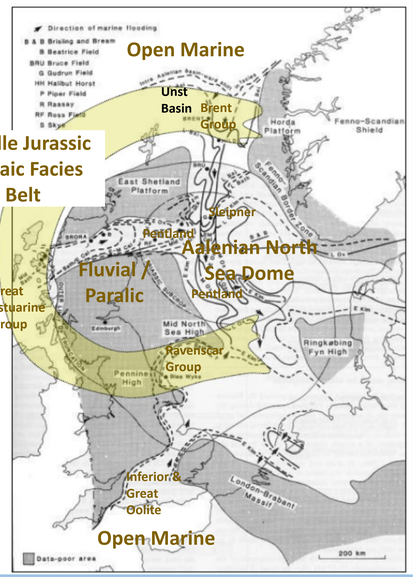


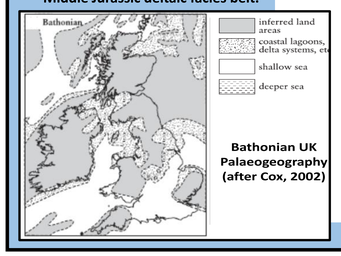
The Unst Basin lies in a shallow perched position. The facies similarity and subcrop geometry suggest that the Jurassic and Early Cretaceous cover extended across Scotland prior to intra Tertiary upift and unroofing.

Middle Jurassic Palaeogeographic Reconstruction modified after Underhill and Partington, 1993

INTERPRETATION

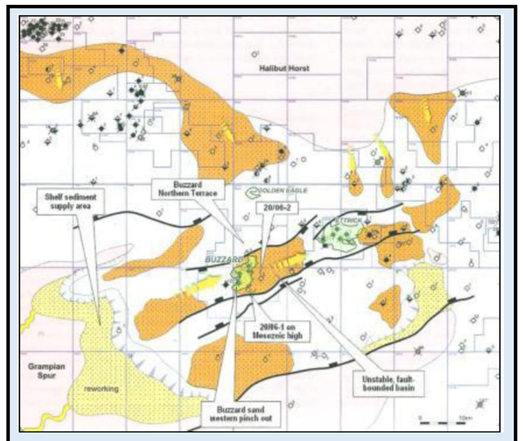
- Previous reconstructions constrained by outcrop and well control, but lack incorporation of impact of later erosional events (Late Jurassic, Early Cretaceous and Intra Tertiary).
- Here we propose to link the preserved outcrop remnants to the subsurface occurrences to extrapolate more extensive depositional systems across the UK area.
- Evidence includes the reworking of older Jurassic into the Late Jurassic (Helmsdale, Claymore, Magnus)
- Plus stratigraphic continuity of the Middle Jurassic deltaic facies belt.





Bathonian UK Palaeogeography (after Cox, 2002)

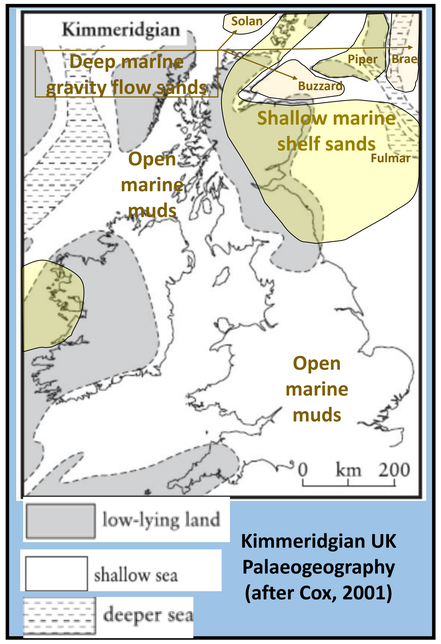
LATE JURASSIC



Buzzard Field - Late Jurassic deep marine gravity flow sands sourced from the Grampian Spur to the SW. Buzzard sands contain recycled sediments from Permo-Trias redbeds and older Jurassic paralic sediments. Recycling of older Jurassic into the coeval deep marine Helmsdale Boulder Beds also identified indicating the proximity of coastal Jurassic sediments to the west *(after Dore and Robbins, 2005)*

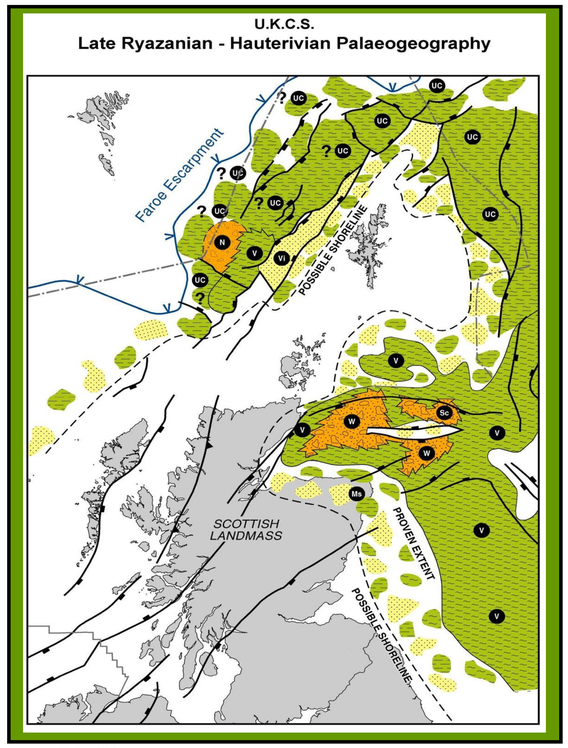
Note:

- Authors' views in Brown text.
- Fully revised maps are work in progress

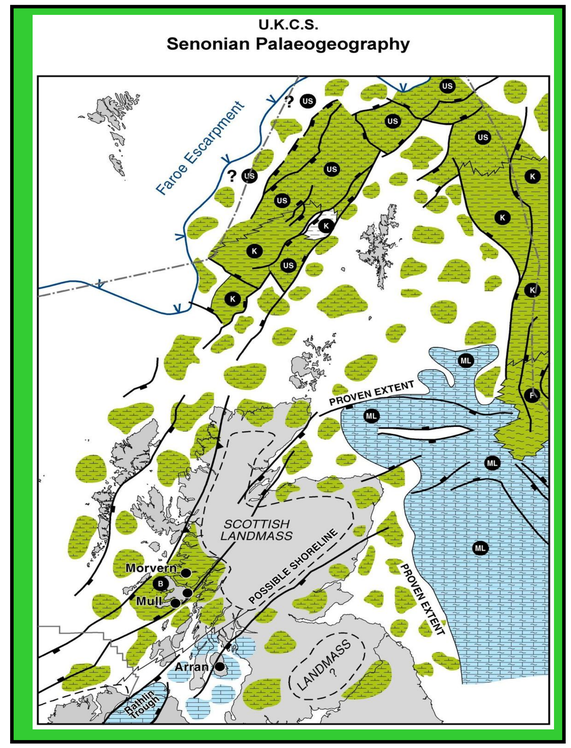


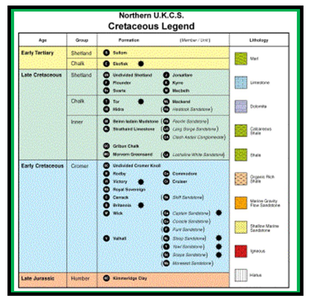
Kimmeridgian UK Palaeogeography (after Cox, 2001)

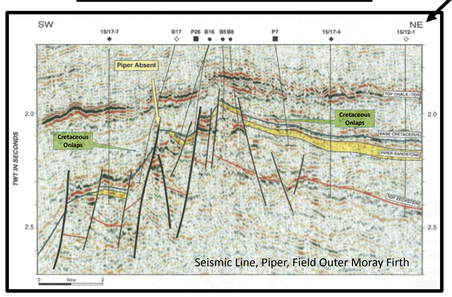
CRETACEOUS



(after Harker. 2003)







Cretaceous Summary

- Deposition of onlapping Early Cretaceous units during Late Cimmerian Tectonism – Rifting of Atlantic borders and North Sea with associated burial of rifted margins by younger Cretaceous deposits..
- Early Cretaceous infill of rifted topography dominated by calcareous muds plus prominent deep marine clastic reservoirs in the Moray Firth. Coastal sediments recycled into deep marine or later eroded. Erratics of these present to north of Aberdeen.
- Late Cretaceous general subsidence dominated by chalks in south and calcareous muds in the north. Some shallow marine sands preserved on the west coast of Scotland and the Antrim area of Ireland.
- Probable near total submergence of Scotland occurred during the Senonian (Millenium Atlas).

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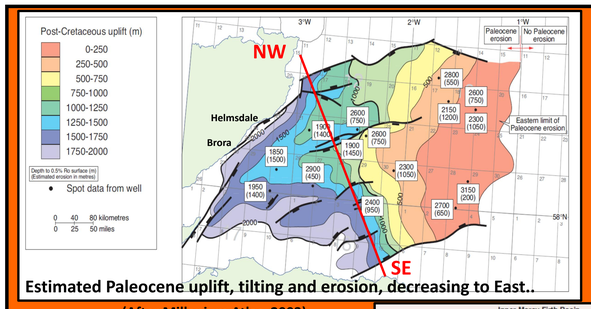
TERTIARY

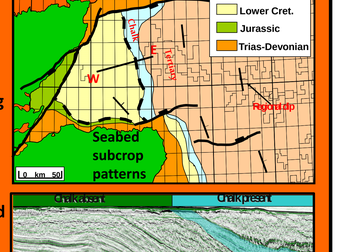


Estimated Paleocene uplift, tilting and erosion, decreasing to East..

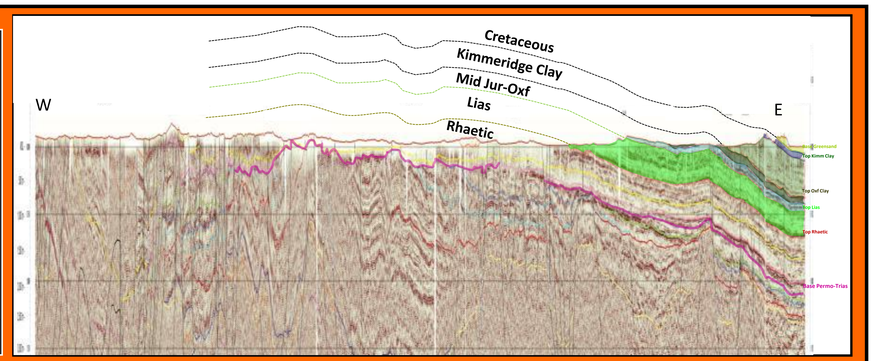
(After Millenium Atlas, 2003)

Inner Moray Firth

Eastward tilting of Northern Scotland supported by Vitrinite Reflectance and Sonic Log data



NW-SE seismic line showing limit of Jurassic constrained by erosion over upthrown blocks. Thick Jurassic must have extended over the Scottish landmass prior to Paleocene erosion (note outcrops Brora-Helmsdale).



Seismic line across Central UK to show possible Jurassic – Cretaceous cover removed by Tertiary uplift and erosion.

SUMMARY

- *Many Jurassic and Cretaceous palaeogeographic reconstructions of the UK and its continental shelf appear closely constrained by very extensive well and outcrop lithofacies and biostratigraphic control.*
- *However, this information is largely limited to 'remnant' sections, preserved after regional erosional unroofing events, and so offers a rather biased perspective of originally more extensive pre-erosion depositional systems.*
- *Any palaeogeographic interpretation attempting to account for such missing rocks must inevitably be speculative. Nevertheless stratigraphic clues remain in the preserved section which can be used to develop a more comprehensive understanding of Jurassic sequence architecture. Such clues include: isolated outliers of sequences more fully developed in adjacent grabens; facies characteristics indicative of once more laterally extensive depositional systems now confined to grabens; or scattered erosional remnants and sediment recycling of pre-tectonic sedimentary cover into deep water intra-graben systems. These lines of stratigraphic evidence are supported by a regionally extensive apatite fission track data base, which indicate the episodes of original deeper burial then uplift and erosion.*
- *Together they highlight a number of key unroofing events in the Mid-Jurassic, Late Jurassic and Early Cretaceous, culminating with severe uplift and exhumation during the Tertiary. These erosional events alternated with periods of subsidence and deposition.*
- *The interpretations presented in this poster are based on sound geological principles and provide a holistic approach to the late Mesozoic geological evolution of this area of North West Europe.*
- *Early Jurassic rocks probably once covered much of the UK region, with shale and carbonates to the south and more clastic dominated facies in the north, which was partially eroded by Aalenian uplift and unroofing of the mid-North Sea Dome.*
- *As this subsided in Middle to early Late Jurassic, the region was gradually onlapped by fringing deltaic-paralic and shallow marine depositional systems.*
- *But with increasing rift-generated topography in later Jurassic, much of this earlier cover was stripped off inter-rift platforms and recycled into adjacent grabens.*
- *The main axis of rifting relocated westwards to the North Atlantic margin during the Early Cretaceous and the associated uplift of western Britain, Ireland and adjacent offshore was responsible for further exhumation.*
- *As this waned in the later Cretaceous, the region subsided to be transgressed by shallow marine sands passing up into laterally extensive chalks with marls and shales to the north.*
- *A final phase of intra-Tertiary unroofing removed much of the Cretaceous and earlier remnant Jurassic from western lands to leave the rather ambiguous scattered stratigraphic records of today.*

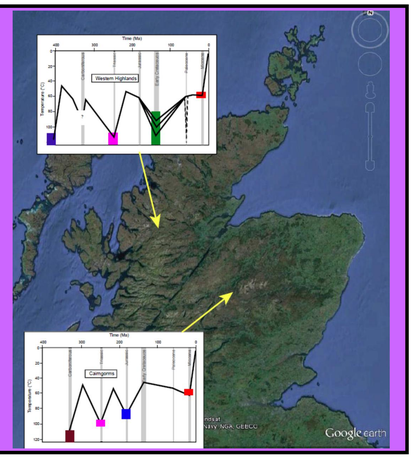
AFTA COOLING EVENTS INTERPRETATION

Scotland – Western Highlands

- Cooling below 110C episode in Late Palaeozoic due to uplift and erosion coincident with the Caledonian Orogeny.
- Reheating due to sediment burial through to Triassic led to another cooling episode (common throughout Scandinavia, Eastern Canada and parts of NW Europe), due to uplift and erosion (removal of much of the Palaeozoic cover, recycling of Carboniferous and Devonian) , possibly due to the early break up of Pangea.
- Further sediment burial from Triassic through Jurassic to Early Cretaceous (80 to 110C in different samples.
- Then cooling which began in the Early Cretaceous
- Re-burial though the Late Cretaceous to reach palaeotemperatures around 60°C, and subsequent Neogene uplift and erosion and recycling of former Mesozoic cover sediments, particularly into the Paleocene and Eocene (e.g. Forties sands in the North Sea and Vaila Sands in the West of Shetlands) .

Scotland – Eastern Cairngorms

- No early Palaeozoic cooling observed (overprinted by later events).
- Late Carboniferous cooling episode associated with uplift and erosion coincident with the Hercynian orogeny (removal of some of the Palaeozoic cover, recycling of Carboniferous and Devonian).
- Reheating due to sediment burial through to Triassic cooling episode (common throughout Scandinavia, Eastern Canada and parts of NW Europe), due to uplift and erosion (removal of much of the Palaeozoic cover, recycling of Carboniferous and Devonian).
- Reheating due to sediment burial in Late Triassic followed by Jurassic cooling associated with uplift and erosion, possibly resulting in burial of western highland region
- Slow burial of area through to Neogene with localised Paleocene cooling due to Neogene exhumation, then uplift and erosion through to recent with associated cooling (recycling of eastern area Paleogene cover into North Sea).



The Enigma of the Missing Rocks

Where have all the missing rocks gone, deep time passing
Onshore outcrops, there are none, that much we know
Not a trace, the rocks have gone
Eroded, recycled everyone
Uplifted and unroofed in turn
Enigma solving - our concern

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