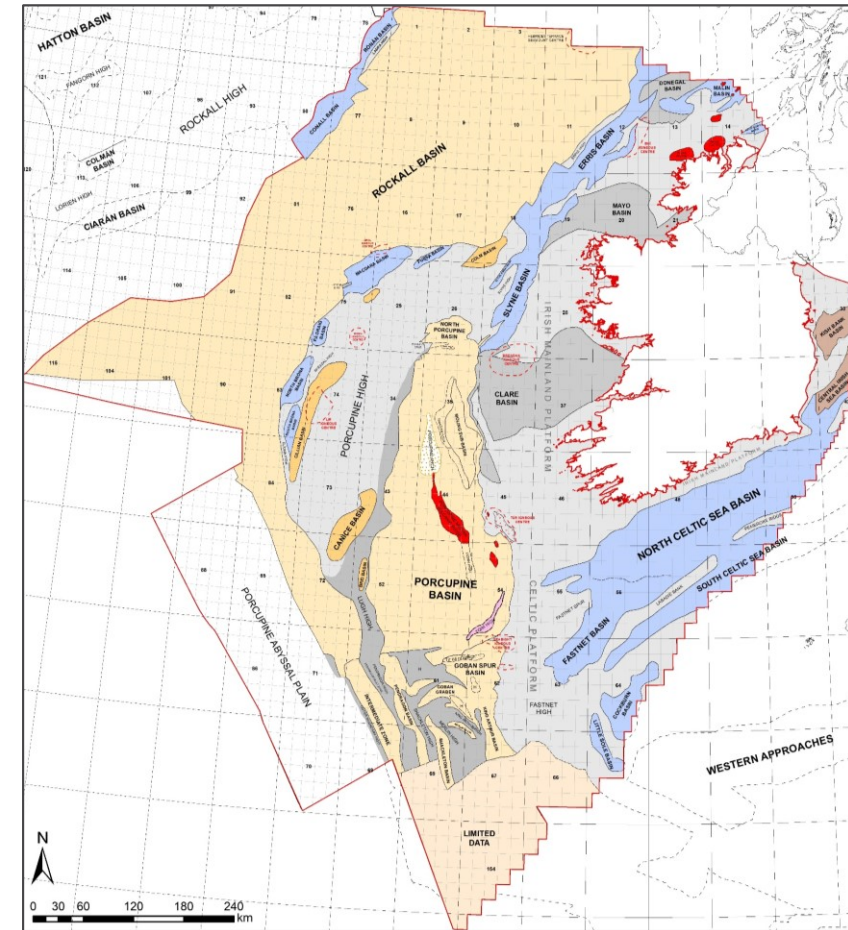


Offshore Ireland: a whole new story

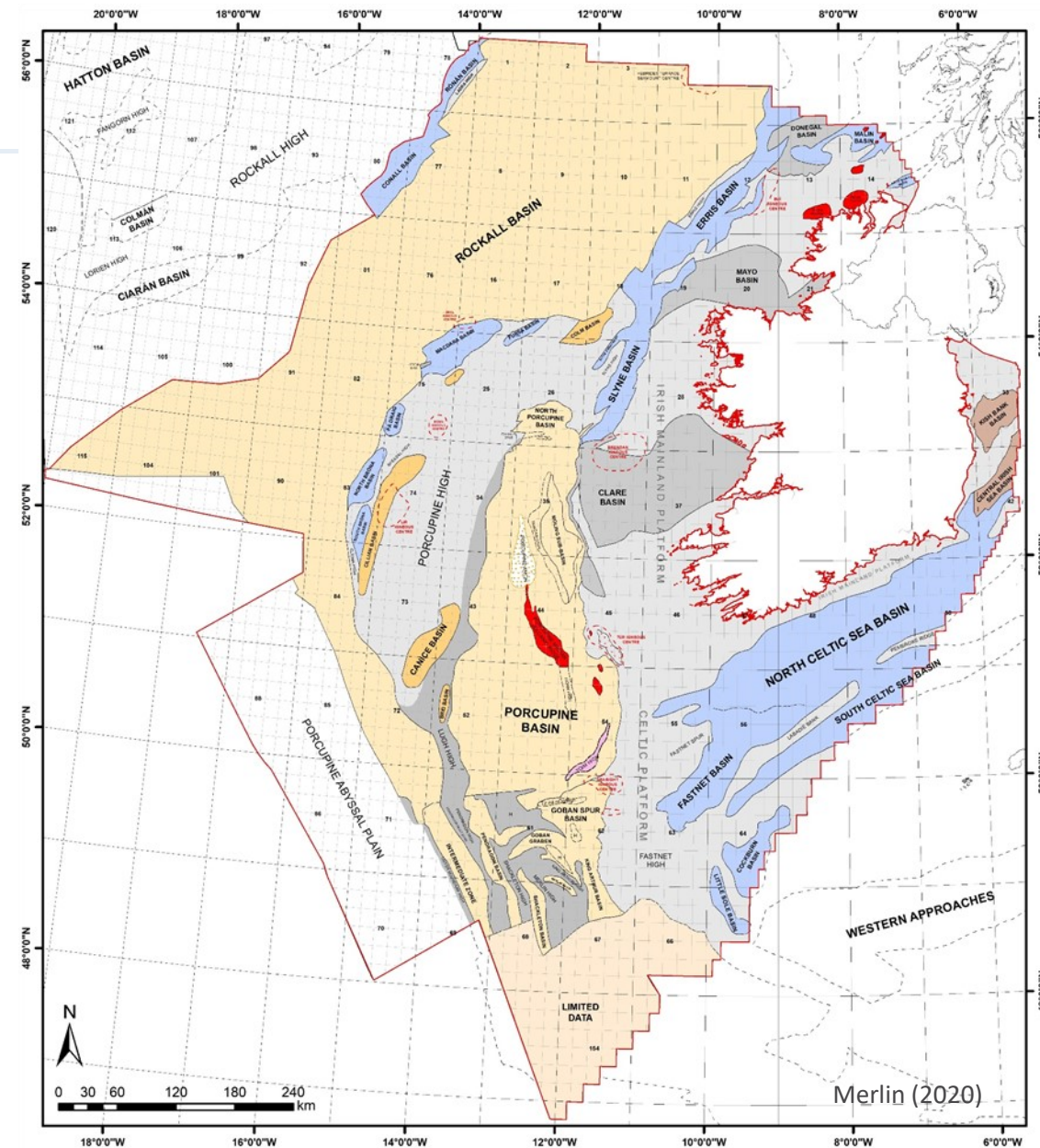
Ainsworth, N. R.², Gallagher, L. T.³, Hampton, M. ³, **Copestake, P.**¹

¹Merlin Energy Resources Ltd, ²Palaeodate Ltd, ³Network Stratigraphic Consulting Ltd



Background & Presentation Aims

- To rectify this, in 2016, a Merlin led consortium was commissioned by the Irish Government (PAD) and 18 operating companies to
 - Define a new stratigraphy for offshore Ireland
 - Lithostratigraphy, biostratigraphy, sequence stratigraphy
 - Palaeozoic to Quaternary
 - 309 lithostratigraphic units recognised
 - of which 63 are previously existing names from the UK area
 - radiometric dating of selected extrusive igneous units
- Project finished in 2020 and released publicly in 2021 as a special publication (Merlin Energy Resources Consortium, 2020). Free download at: <https://www.gov.ie/en/publication/d4923-the-standard-stratigraphic-nomenclature-of-ireland/>
- Aim today to present key results of the study
 - Focus on biostratigraphy & its applications



New lithostratigraphic framework for offshore Ireland



Merlin (2020)

Merlin Consortium Members

The Biostratigraphic Team

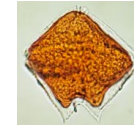


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Phil Copestake

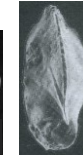
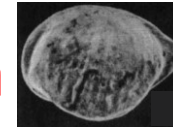


, Tony Loy



PALAEODATE LTD

Nigel Ainsworth



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Liam Gallagher



, Matt Hampton

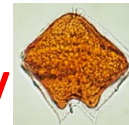


Haydon Bailey

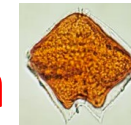


RILEY GEOSCIENCE LTD

Les Riley

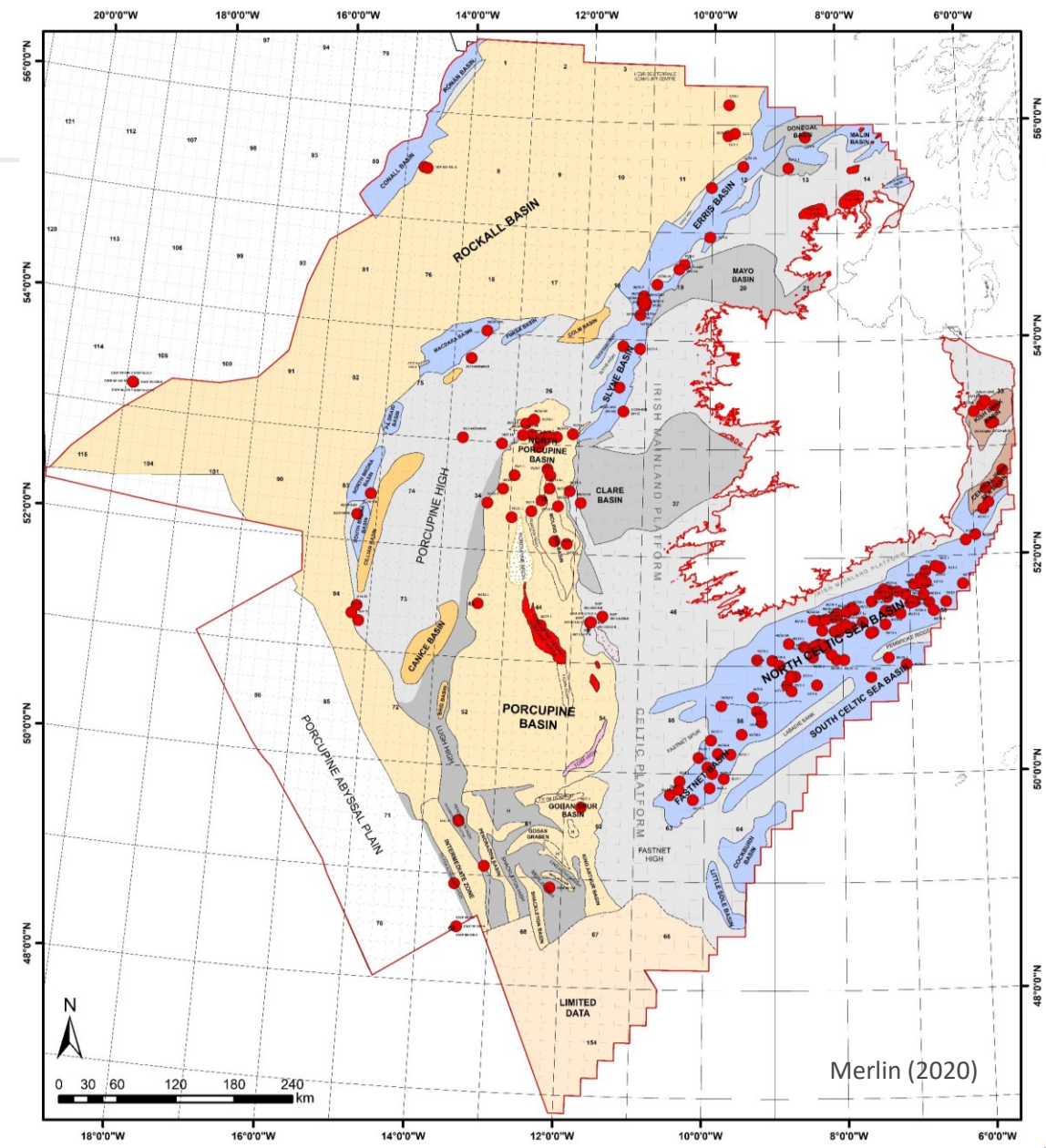


, Keith Gueinn



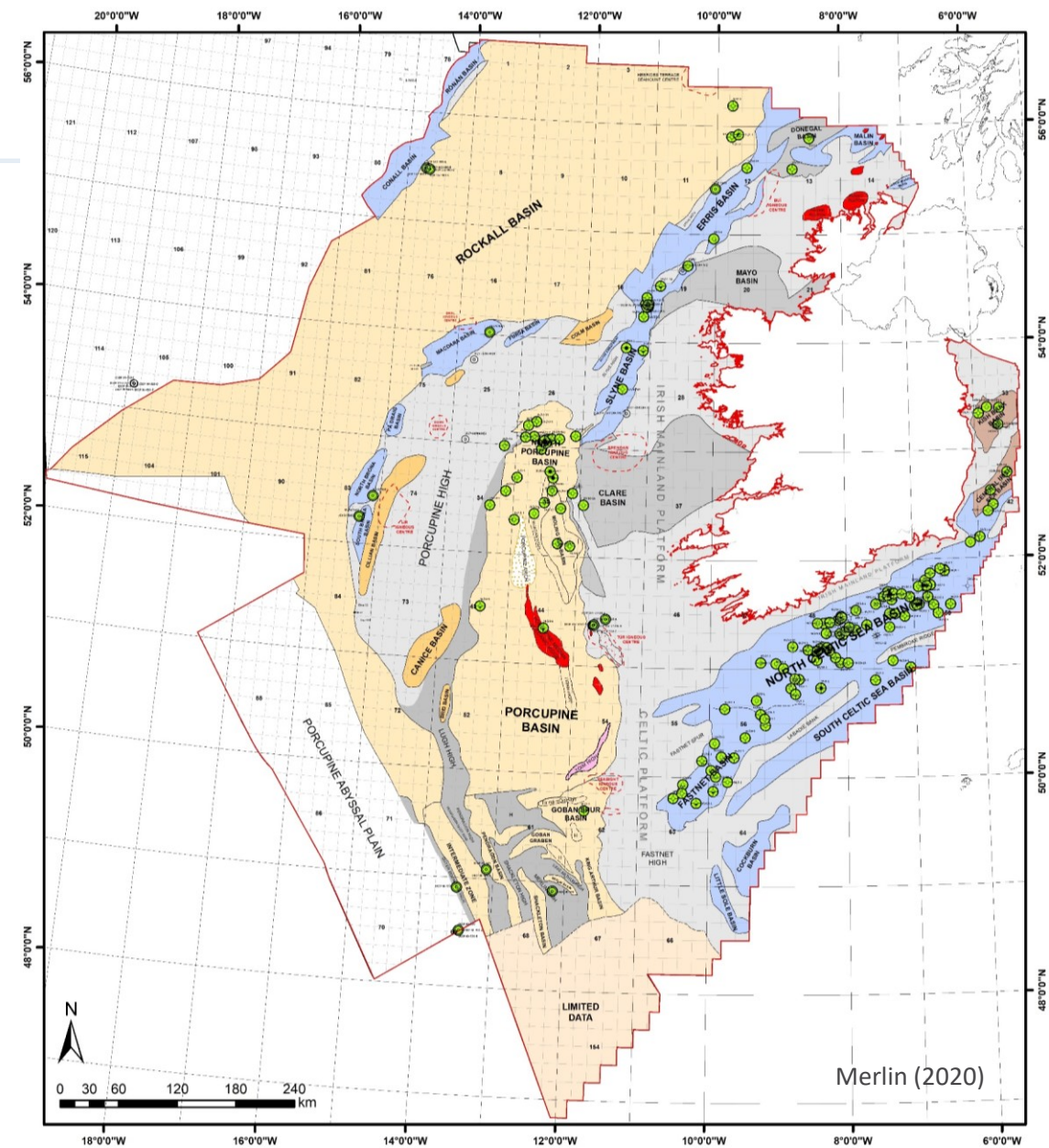
Well & borehole database

- 264 wells & boreholes
 - 219 oil and gas wells
 - 31 DSDP/ODP/IODP boreholes
 - 14 shallow/mining boreholes



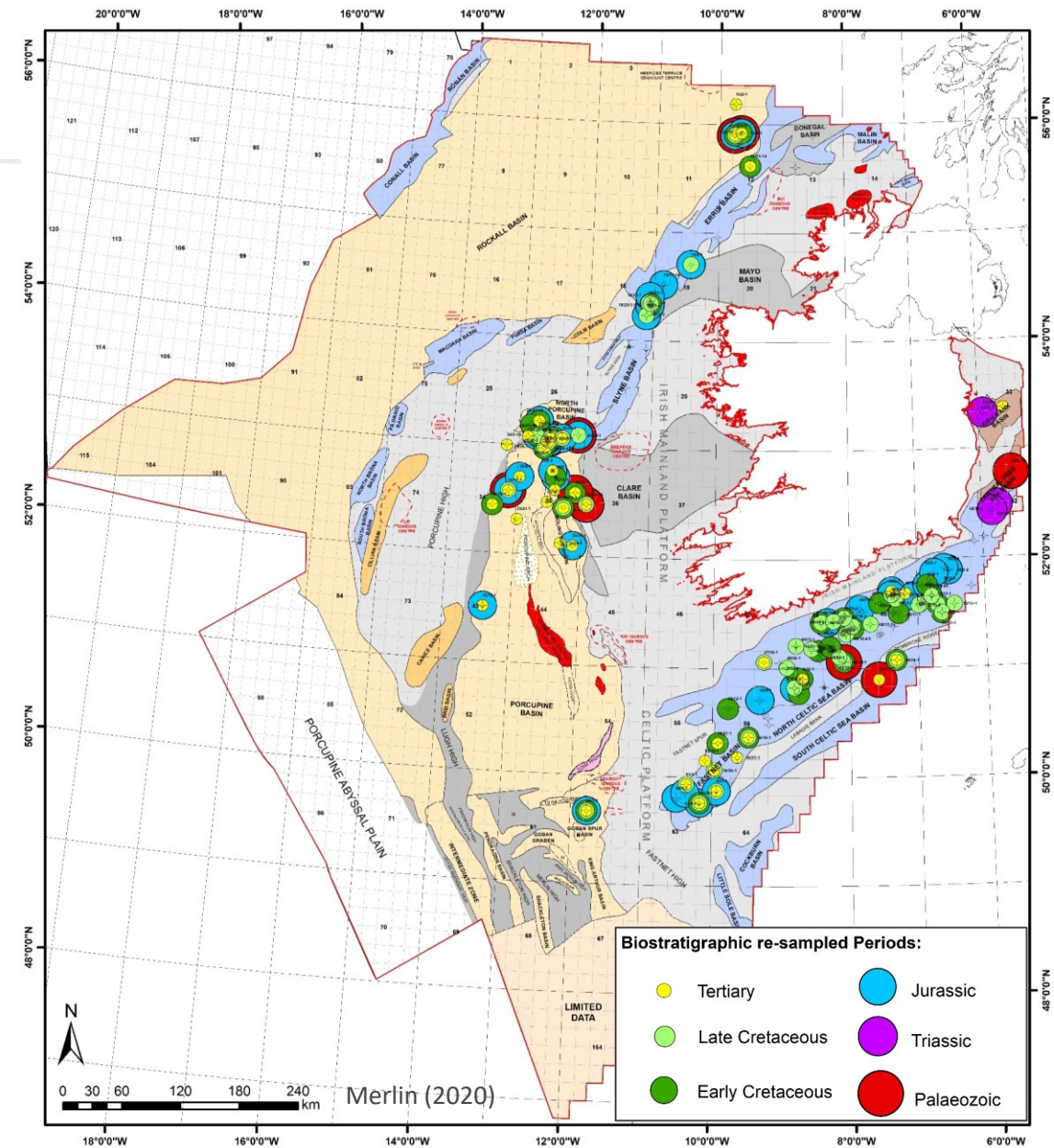
Wells & boreholes with legacy biostratigraphic data

- 198 wells & boreholes with biostratigraphic data
- 531 legacy biostratigraphic data/reports
 - Released wells, boreholes, PhD theses, published papers, published DSDP/ODP/IODP reports



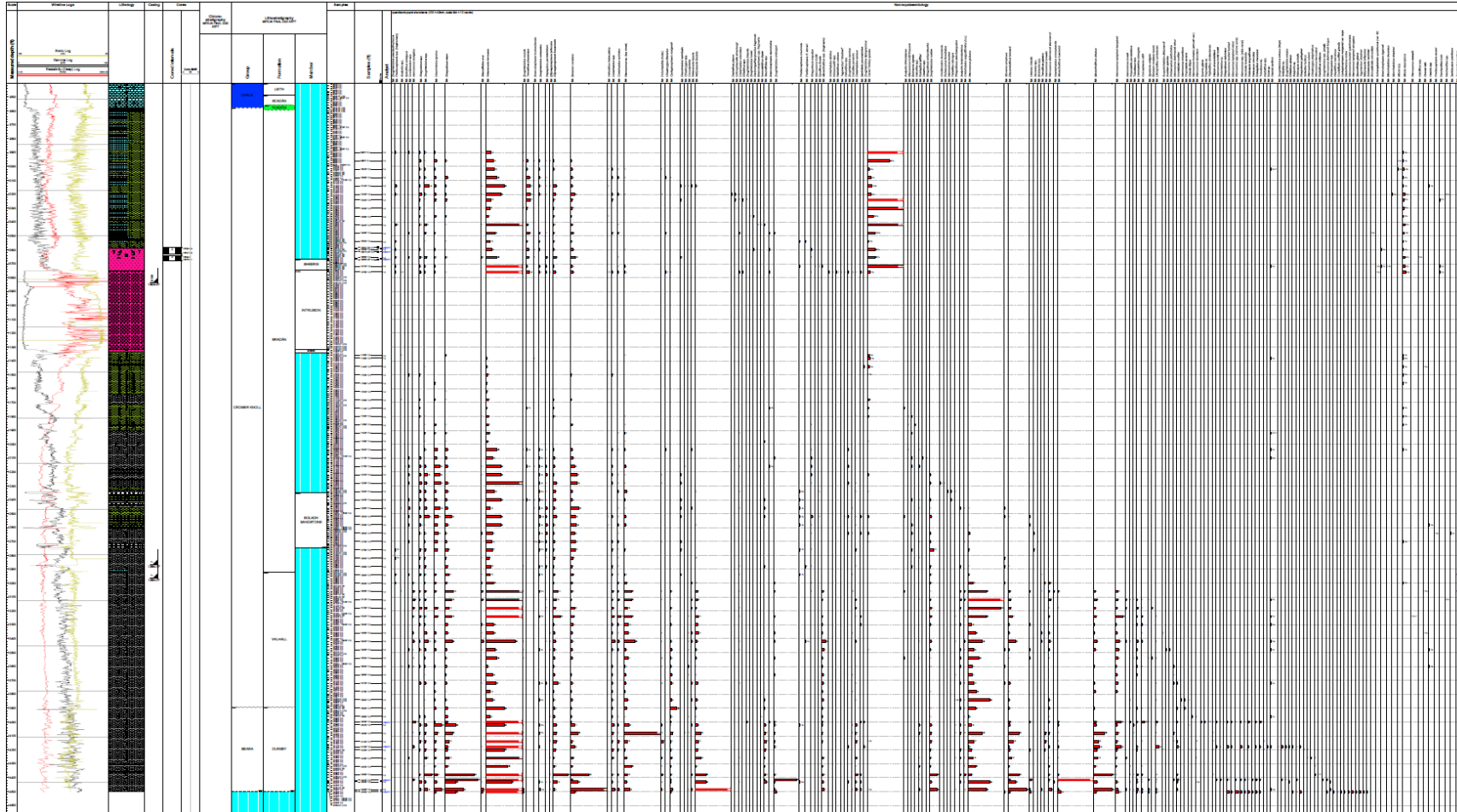
New biostratigraphic analysis

- Supplemented by new biostratigraphic analysis on >3000 samples from 106 wells
 - Targeted at particular intervals where more data was required
- All legacy & new biostratigraphic data compiled, interpreted & displayed in



Biostratigraphic databases created; *StrataBugs*

- Integrated with all new biostratigraphic data, e.g. Lower Cretaceous nannofossils from 35/8-1 well

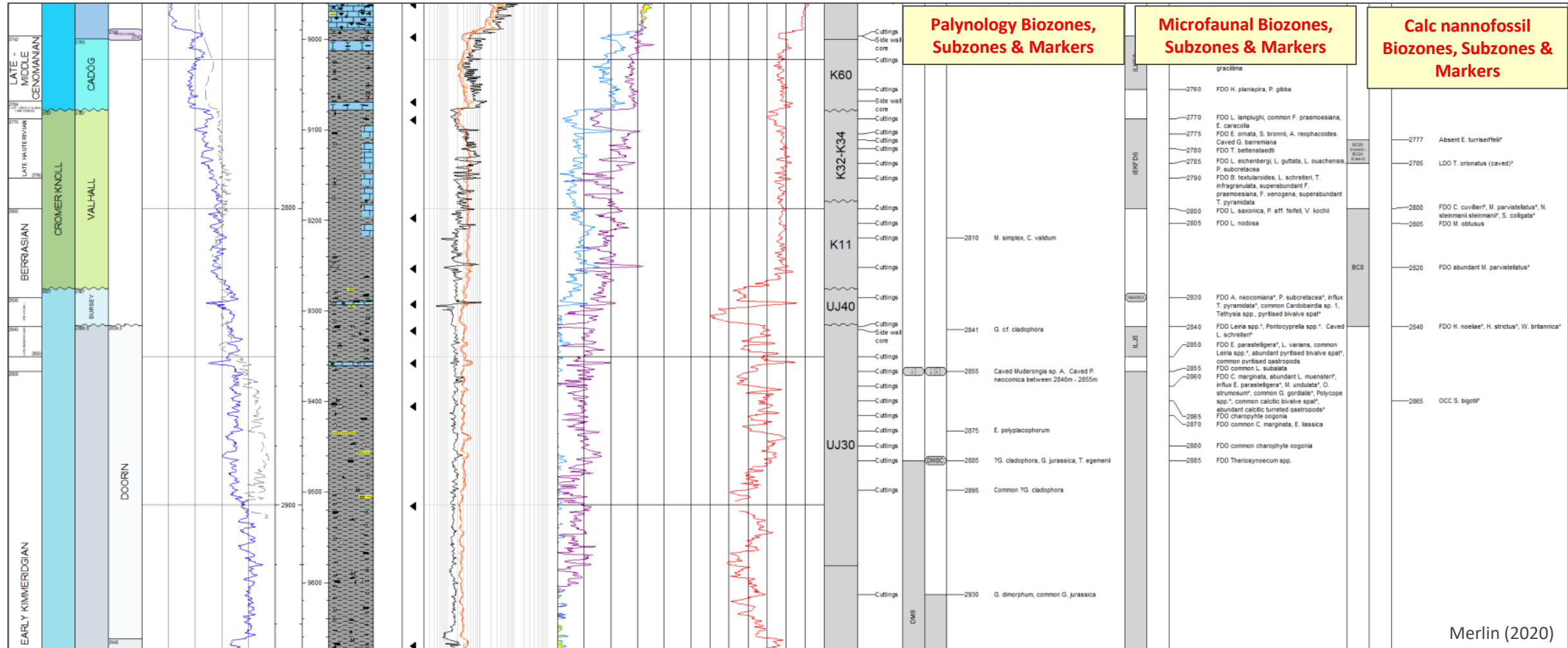


Biostratigraphic databases created; IC

198 stratigraphic summary logs are available via download



- Key biostratigraphic markers and biozones/subzones added to IC database



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How has the biostratigraphy been used in the offshore Ireland area?

- Characterisation of the lithostratigraphic units

SYBIL FORMATION

The Sybil Formation is defined here for a dominantly marine mudrock unit of Late Jurassic, intra Early Kimmeridgian to intra Late Oxfordian, age, which lies in the lower half of the Muckross Group, within the Slyne Basin. These sediments may all extend into the Conall, Rónán and Rockall basins. This formation is the lower formation of the Muckross Group. It is overlain by the Dawros Formation, which in turn overlies the Beara Group, Minard Formation.

The formation is equivalent to the Lower Kimmeridge Clay Formation unit of Terman (2006) in the "Slyne-Erris basin".

The formation is comparable in age and facies to the Heather Formation of the UK offshore area (North Sea and West Shetland) however, the formation in offshore UK area cannot be proven to be contiguous with the formations as developed in the offshore Ireland area and for this reason a new name has been applied to the Ireland lithostratigraphic unit.

Name. After Sybil Head, Dingle Peninsula, County Kerry.

Type section. 19/11-1A: 1294-2127.5m below KB. See Figure D.7. 20.

Reference section. 19/8-1: 960-1187.5m below KB. See Figure D.7. 20.

Lithology. This unit comprises a dominantly claystone/silty claystone succession, in association with thin limestone and dolomite stringers. Rare sandstone beds/laminae are also present in the 19/11-1A well.

The claystones and silty claystones are generally medium dark grey, olive black to greyish black, micromicaceous, locally silty or sandy, grains clear, very fine to fine grained, subrounded, non to slightly calcareous, subblocky to subfissile, and gradate into siltstones. The thin limestones and dolomites are pale yellowish grey, greyish orange to dark yellowish orange, mudstone microcrystalline, and well indurated. The thin interbedded sandstones are transparent, pale brown, olive grey, locally light greenish grey, dark yellowish orange, very fine to fine grained, well sorted, subangular to subrounded, locally micaceous, feldspathic, and calcareous. Black, subblocky, vitreous lustre, coal fragments have been reported below 1990m in the 19/11-1A well.

Wireline log character. The wireline log motifs are finely to locally highly serrated. In the latter case these reflect the presence of limestone and sandstone interbeds. A number of wireline log cycles can be recognised within the formation. These may prove to be correlatable between wells.

Upper boundary. The upper boundary is marked by a downsection lithological change from the organic-rich non-calcareous claystones of the Dawros Formation to the claystones of the Sybil Formation. The boundary is expressed by an increase in sonic velocity on wireline log criteria. This may coincide with a slight decrease in gamma ray values.

Lower boundary. The lower boundary is marked by a downward lithological change from dark grey to olive black mudrocks, to either medium dark grey to light brownish grey silty claystones/claystones or the more thickly bedded sandstones of the Minard Formation. This change is expressed on wireline log criteria either as an increase in gamma ray values and a corresponding increase in sonic velocity (claystones) or usually by a marked decrease in gamma ray values (sandstones). No sonic velocity curve was run over this boundary in the 18/20-7 well.

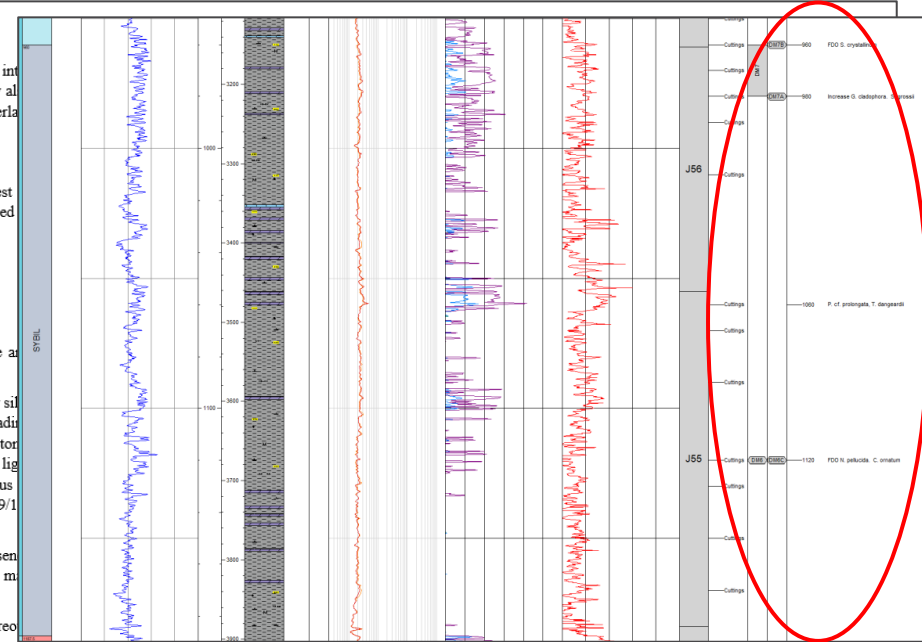
Subdivision. No subdivision is recognised.

Thickness. The formation varies in thickness from 121.5m (18/20-7) to 833.5m (19/11-1A).

Biostratigraphic characterization. Dated by dinocysts. Although rich and diverse foraminiferal faunas, in association with subsidiary radiolaria and very rare ostracod taxa are present in this sedimentary succession, no attempt has been made to erect a microfaunal zonation scheme over these sediments within the Slyne Basin at this present time. Occurring with Palynological Subzones DM7B to DM6B.

Age. Late Jurassic, intra Early Kimmeridgian-intra Late Oxfordian.

Depositional environment. Marine, inner to outer shelf, to possibly upper bathyal. Within the Sybil Formation of the 19/11-1A well two distinct transgressive cycles are recognised. The lowermost interval yields microfaunas suggesting an overall



Regional correlation. The Sybil Formation is laterally equivalent to the Bolus Formation, Rinroe Member, from the Porcupine Basin, west of Ireland. In the Fastnet and Celtic Sea basins the Sybil Formation is age equivalent to the Galley Formation, while in southern England it is laterally equivalent to the Clavellata, Sandsfoot, the upper part of the Amphihill Clay and lower part of the Kimmeridge Clay formations (Wright, 2001a, b). The formation is comparable in age and facies to the Heather Formation of the UK offshore area (North Sea and West of Shetland). Onshore north west Scotland this formation is a lateral equivalent to the upper part of the Staffin Shale Formation.

Comparison with Eastern Canada. The Sybil Formation is age equivalent to the mid part of the Rankin Formation (claystones and carbonates, below the Egret Member) in the Jeanne d'Arc, Flemish Pass and Orphan basins, offshore east coast of Canada.

Merlin (2020)

Sybil	<ul style="list-style-type: none"> ← <i>Trochammina</i> spp. ○ ← Increase <i>Lenticulina</i> spp. ← <i>L. ectypa</i> 	DM7	B	← <i>S. crystallinum</i>	<ul style="list-style-type: none"> ← <i>G. jurassica</i> "bald", <i>G. cladophora</i> (increase), <i>G. jurassica</i> ○ ← <i>N. pellucida</i> ← <i>G. cladophora</i> ○, <i>E. cinctum/gochtii</i> ○ ← <i>G. jurassica longicomis</i>
		DM6	A	← <i>E. cinctum/gochtii</i> , <i>S. galeritum</i> , <i>S. crystallinum</i> ○, <i>S. dictyotum</i> ○, <i>G. jurassica</i> ■	

How has the biostratigraphy been used in the offshore Ireland area?

- Fossil assemblages used to indicate depositional environments

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Depositional environment. Marine, inner to outer shelf, to possibly upper bathyal. Within the Sybil Formation of the 19/11-1A well two distinct transgressive cycles are recognised. The lowermost interval yields microfaunas suggesting an overall

deepening trend, initially a number of shallow water foraminiferal taxa (including *Palaeomitolina* spp., *Quinqueloculina egmontensis*) are present, which are replaced upsection by an increase in microfaunas and dinocysts suggesting a well oxygenated, middle to outer shelf environment, while midway through the member, rich and moderately diverse radiolarian assemblages are recorded indicating deeper waters (outer shelf to possibly upper bathyal). These are replaced upsection by a return to a middle to outer shelf environment, denoted by an increase in numbers of foraminifera and ostracods, with the upper part of the formation reflecting a deeper outer shelf to ?upper bathyal environment as suggested by the re-appearance of radiolaria. The whole formation is placed into the J55 stratigraphic sequence and the evidence of deepening and shallowing trends within the formation suggest there may be potential to subdivide this sequence in the future.

In the 19/8-1 well the Sybil Formation is considered to have been deposited in a well oxygenated, inner shelf, marine environment, denoted by the large numbers of foraminifera (mainly agglutinating taxa) and miospores, in association with rare ostracods and dinocysts.

Distribution. The formation is proven to be present in three wells (19/8-1, 19/11-1A and 18/20-7) in the Slyne Basin. The formation is considered to be possibly present in the Conall and Rónán basins, on the basis of seismic evidence (interpretation of the presence of the Base Cretaceous seismic horizon in these basins). The formation may also be present in the Rockall Basin, to the south west of the 12/2 area, where the Dawros Formation, that normally overlies the formation, is proven. The south westerly limit is tentatively taken as far south in this basin approximately in line with its interpreted southerly limit in the Slyne Basin.

The presence of Sybil Formation in the Upper Jurassic of the 18/20-7 well (Corrib Field area), truncated below the Base Cretaceous Unconformity, implies that in the undrilled Slyne Basin centre it is not unreasonable to expect that the formation, as seen in 19/8-1 and 19/11-1A to the north, is also present in the Slyne Basin to the south of the latter wells.

Source rocks. The Sybil Formation shows increased TOC contents in three wells in the Slyne Basin, but with a mainly Type III kerogen composition the source rock potential is limited, and the interval is mainly gas prone (Appendix E). Only few samples show elevated hydrocarbon yields (S2) and a more Type II/III kerogen composition, indicating increased hydrocarbon generative potential.

In well 19/8-1 in the Slyne Basin the Sybil Formation corresponds to source rock intervals Late J3 and Late J1 that were identified in project IS16/01 (BeicipFranlab, 2017). Interval Late J3 in 19/8-1 was considered as a Type II oil-prone source rock in project IS16/01, which is possibly an error.

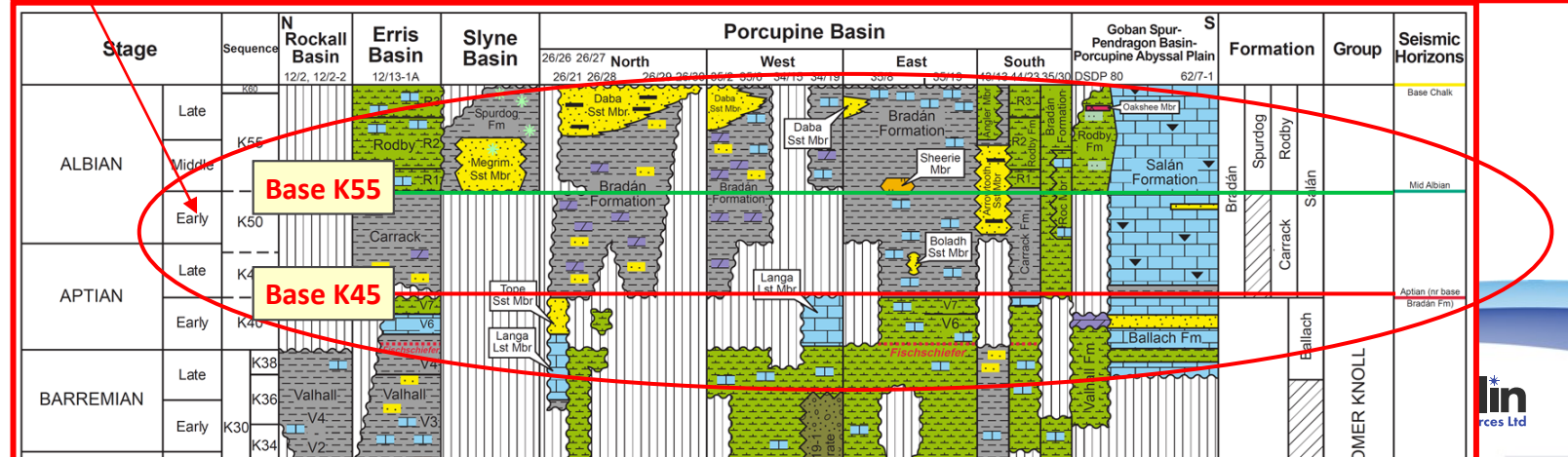
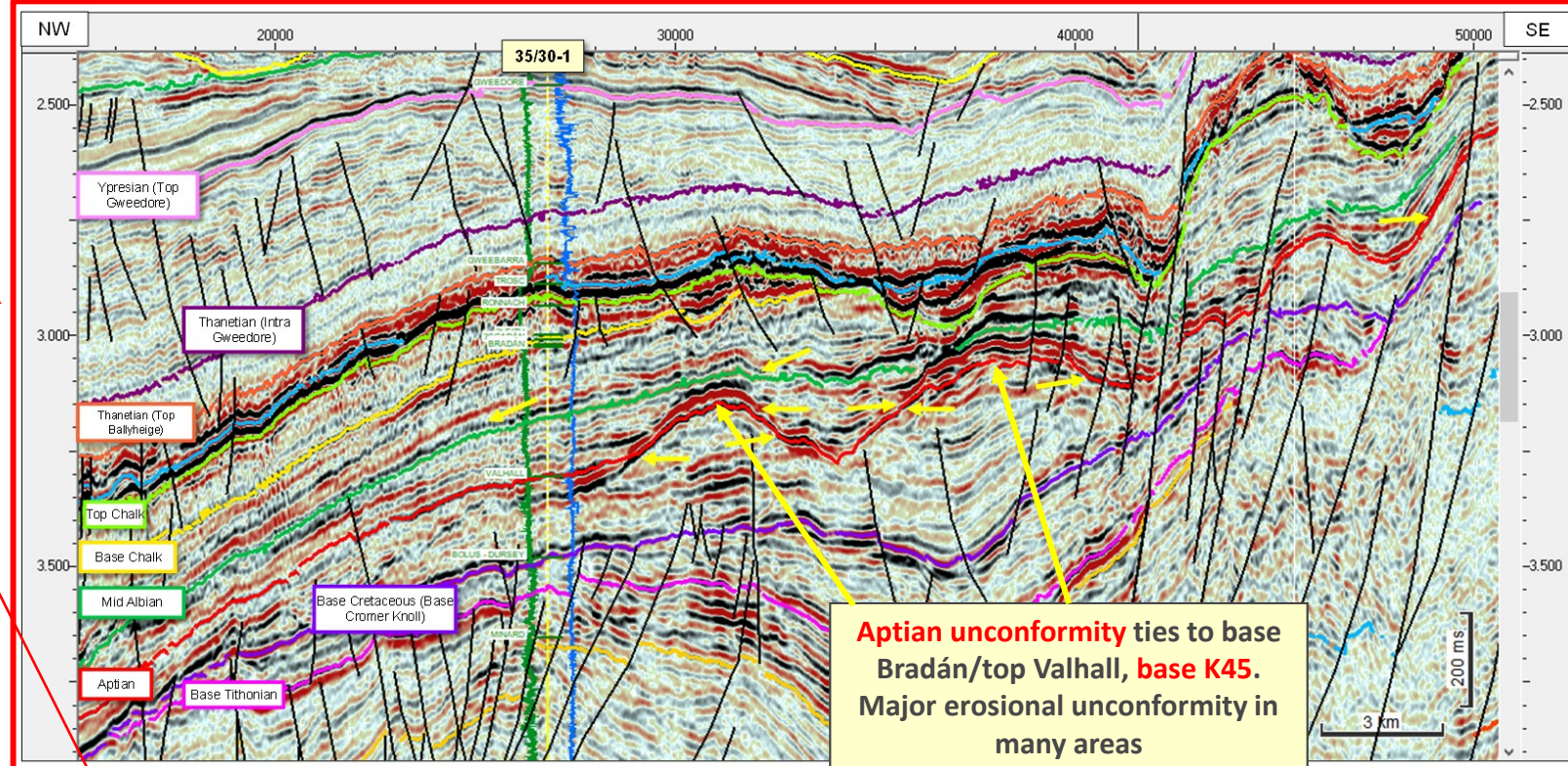
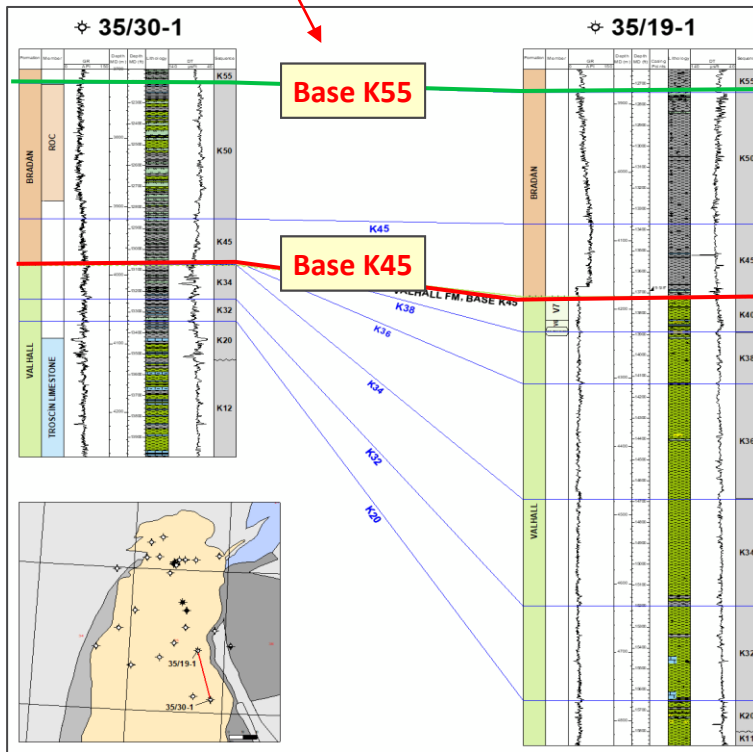
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Merlin (2020)

How has the biostratigraphy been used in the offshore Ireland area?

- Age dating & calibration of seismic horizons
- Age dating & calibration of unconformities/flooding surfaces/sequences



How has the biostratigraphy been used in the offshore Ireland area?

- Age dating of source rock units

Summary

Source rock potential

21 formations with a varying degree of source potential

Formation	Age/Stage	Rockall	Donegal	Slyne	Porcupine	Irish Mainland Platform	Goban Spur	Fastnet	North Celtic Sea	South Celtic Sea
Gweedore	Ypresian-Thanetian				●●					
Bradán	Albian-Aptian				●●					
Valhall	Aptian-Berriasian	●●?			●●	Lower Cretaceous: Excellent potential				
Wealden Group	Aptian-Valanginian				●●				●●	
Pike	Valanginian-Berriasian				●●				●●●●	
Perch	Berriasian				●●				●●●●	
Pollan	Berriasian				●●					
Dawros	Tithonian-Kimmeridgian	●●		●●	●●					
Dursey	Tithonian				●●●●					
Bolus	Kimmeridgian-Oxfordian				●●					
Minard	Oxfordian				●●					
Knockadoon	Tithonian				●●				●●	
Baginbun	Kimmeridgian				●●				●●	
Dun Caan Shale	Aalenian-Toarcian			●●	●●				●	
Tacumshin	Aalenian-Toarcian			●●	●●				●	
Whitby Mudstone	Toarcian			●●●●	●●●●		●	●	●●●●	
Pabay Shale	Pliensbachian			●●●●	●●●●		●	●	●●	
Glenbeg	Sinemurian						●	●	●●	
Currane	Sinemurian						●	●	●●	●●
Leane	Hettangian						●	●	●●	
Blackthorn Group	Asturian-Langsetian		●	●●	●●	●●?			●●	

Upper Jurassic:
Good hydrocarbon potential

Lower Cretaceous:
Excellent potential

Upper Jurassic:
Good hydrocarbon potential

Lower Jurassic:
Excellent oil potential

Lower Jurassic:
Mixed oil and gas to gas potential

Carboniferous:
Gas potential

● Limited source potential ●● Good source potential ●●● Excellent source potential
 ■ Oil potential ■ Mixed oil & gas potential ■ gas potential

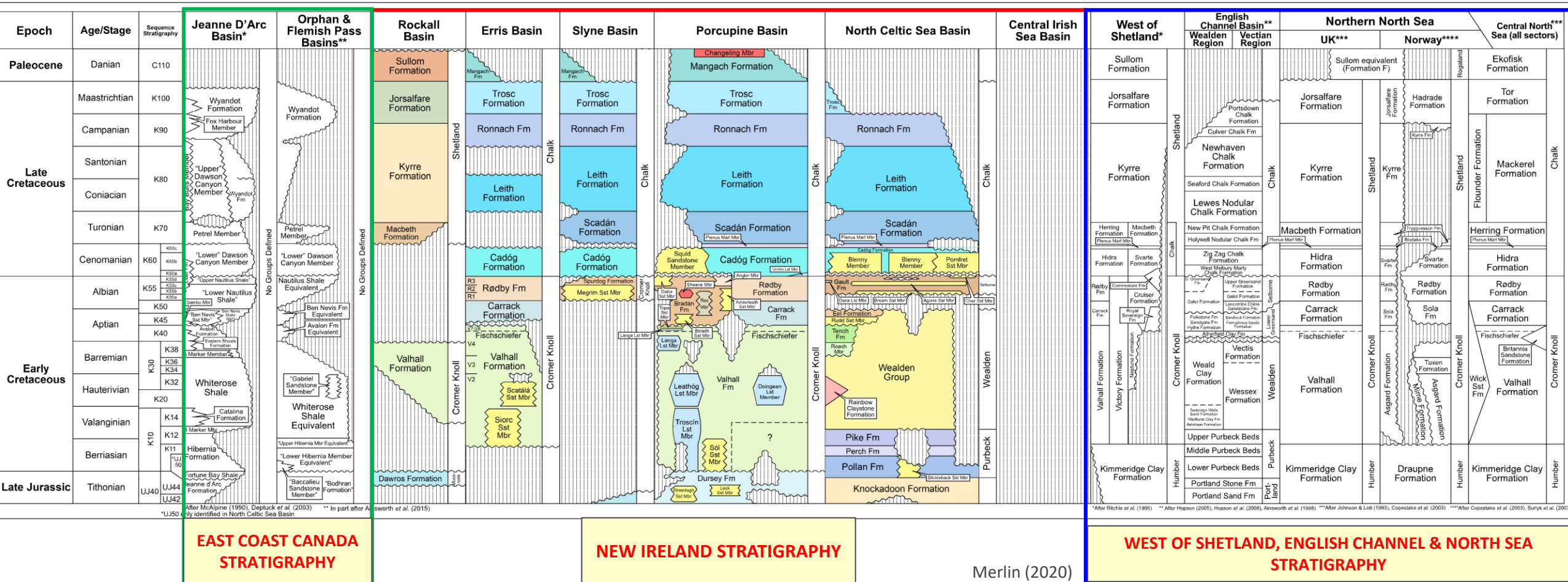


Gehlen et al. (2019)



Biostratigraphy used as basis for regional correlation

- Ireland stratigraphy compared to offshore Eastern Canada, UKCS and North Sea, e.g. Cretaceous



EAST COAST CANADA STRATIGRAPHY

NEW IRELAND STRATIGRAPHY

WEST OF SHETLAND, ENGLISH CHANNEL & NORTH SEA STRATIGRAPHY

Jurassic biozonation scheme (Fastnet – North Celtic Sea Basins)

Group	Formation	Epoch	Age/Stage	OSTRACOD BIOZONATION		FORAMINIFERA BIOZONATION		PALYNOLOGY BIOZONATION		NANNOPLANKTON BIOZONATION		SEQUENCE						
				Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones*	Zonal Bioevents				
Purbeck	Knockadoon	LATE JURASSIC	TITHONIAN	Late	IOEK1	← <i>D. cf. ellipsoides</i> Ainsworth, <i>M. cf. purbeckensis</i> Ainsworth								UJ50 (pars)				
				Early	IOJ23										UJ40			
				Baginbun	Late	IOJ22	← <i>F. boloniensis</i> o, <i>M. cf. cicatricosa</i> Collin											
					Early	IOJ21	← Persistent <i>Theriosynoecum</i> sp. A Ainsworth, <i>Theriosynoecum</i> sp. B Ainsworth, <i>T. fluxans fluxans</i> , <i>L. striata</i> o, <i>T. wyomingensis</i> , <i>T. hemisymphon</i>											
				Galley	Late	IOJ20												
					Early	IOJ19												
				Dunbratin	Late		← Ostracod faunas											
					Middle													
				Eagle	Sparrowhawk	MIDDLE JURASSIC	BATHONIAN	Late	IOJ18	← <i>K. levis</i> , <i>F. blakeana</i> , <i>F. juglandica</i>								
								Middle	IOJ17	← <i>S. polonica</i> , <i>N. besinensis</i>								
Early	IOJ14	← <i>P. cf. aureola</i> Dèpêche, <i>Praechulteridea</i> sp. B Ainsworth																
Late	IOJ13	← Poor recovery. Dominated by <i>Cardobairdia</i> spp., <i>Pontocyprilla</i> spp.																
Merlin	Early	IOJ12																
	Late																	
Peregrine	Late	IOJ11c	← <i>P. arguta</i>															
	Early	IOJ11b																
Lias	Whitby Mudstone	EARLY JURASSIC	TOARCIAN					Late	IOJ11a	← Decrease in ostracod fauna								
								Early	IOJ10	← <i>O. convexa</i> , <i>H. inflata</i>								
				Late	IOJ9	← <i>O. convexa</i> , <i>H. inflata</i> , <i>O. contractula</i> , <i>W. semiovarionensis</i>												
				Early	IOJ8	← <i>G. ubiqvata</i>												
				Late	IOJ7	← <i>G. obovata</i>												
				Early	IOJ5	← <i>O. celticensis</i> , <i>O. danica</i>												
				Pabay Shale	Late	IOJ4c												
					Early	IOJ4b												
				Glenbeg	Late	IOJ4a												
					Early	IOJ3b												
Currane	Late	IOJ3a																
	Early	IOJ2																
Leane Gill Blue Lias	Late	IOJ2	← <i>D. hettangiana</i> , <i>L. hortoniae</i>															
	Early	IOJ1																

Non-marine ostracods occur in Oxfordian-Kimmeridgian above red bed successions and major stratigraphic break. Equivalent faunas also in Slyne Basin & Portugal

Marine microfaunas continue through Aalenian – Bathonian. Notable occurrence of planktonic foraminifera in Bathonian. Also recorded from East Coast Canada.

Metacopine ostracods become extinct in earliest Toarcian.

Standard marine foram & ostracod associations in Sinemurian - Toarcian

Freshwater ostracods in the Hettangian (Leane Fm). Also recorded in the Hettangian-Early Sinemurian of France, Portugal, Porcupine & Slyne Basins.

Published nannofossil scheme of Bown & Cooper (1998) applied

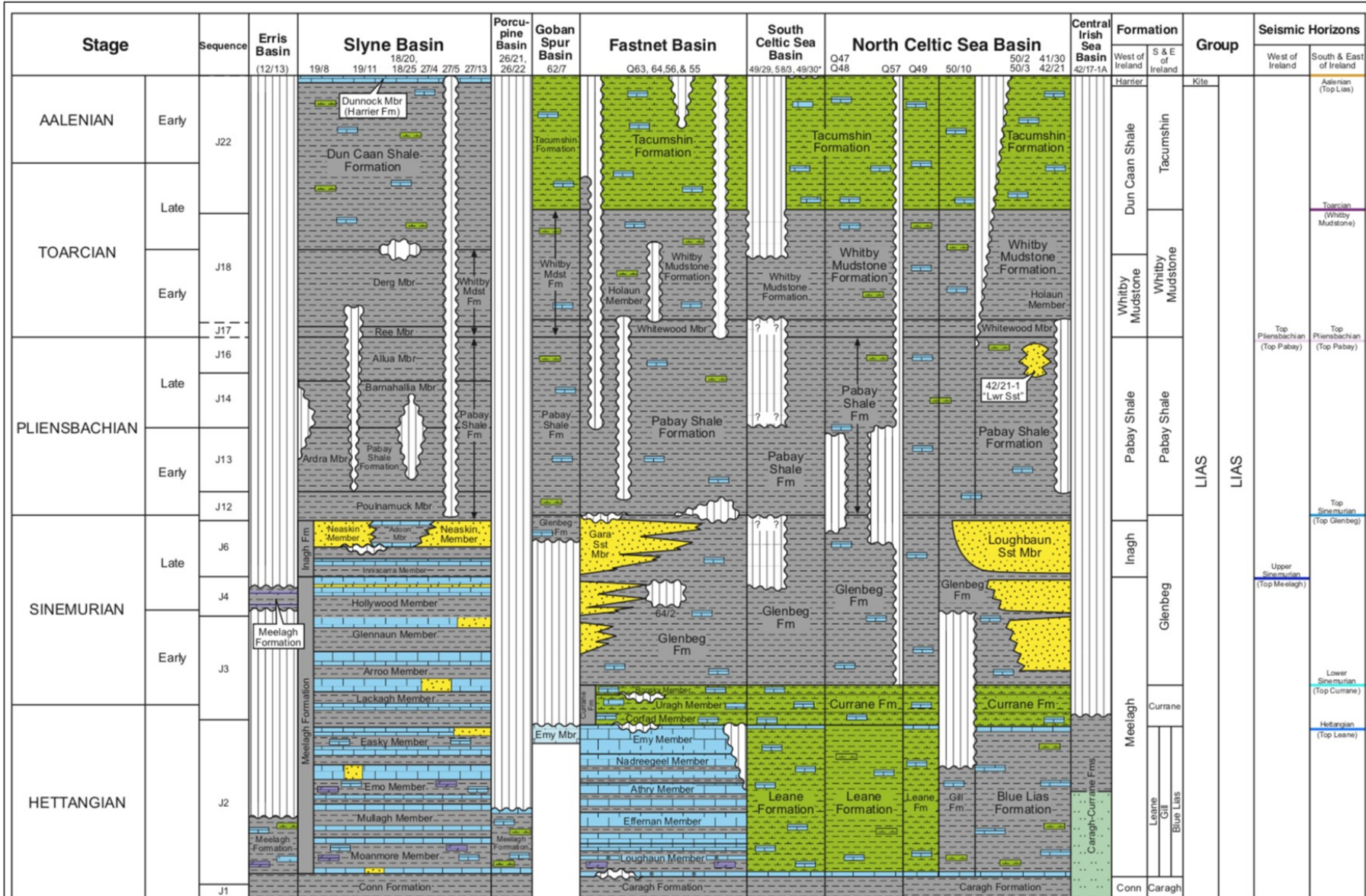
Legend
1 *M. reticulata*, persistent *P. prolongata*

* Bown & Cooper in Bown (1998)

Merlin (2020)



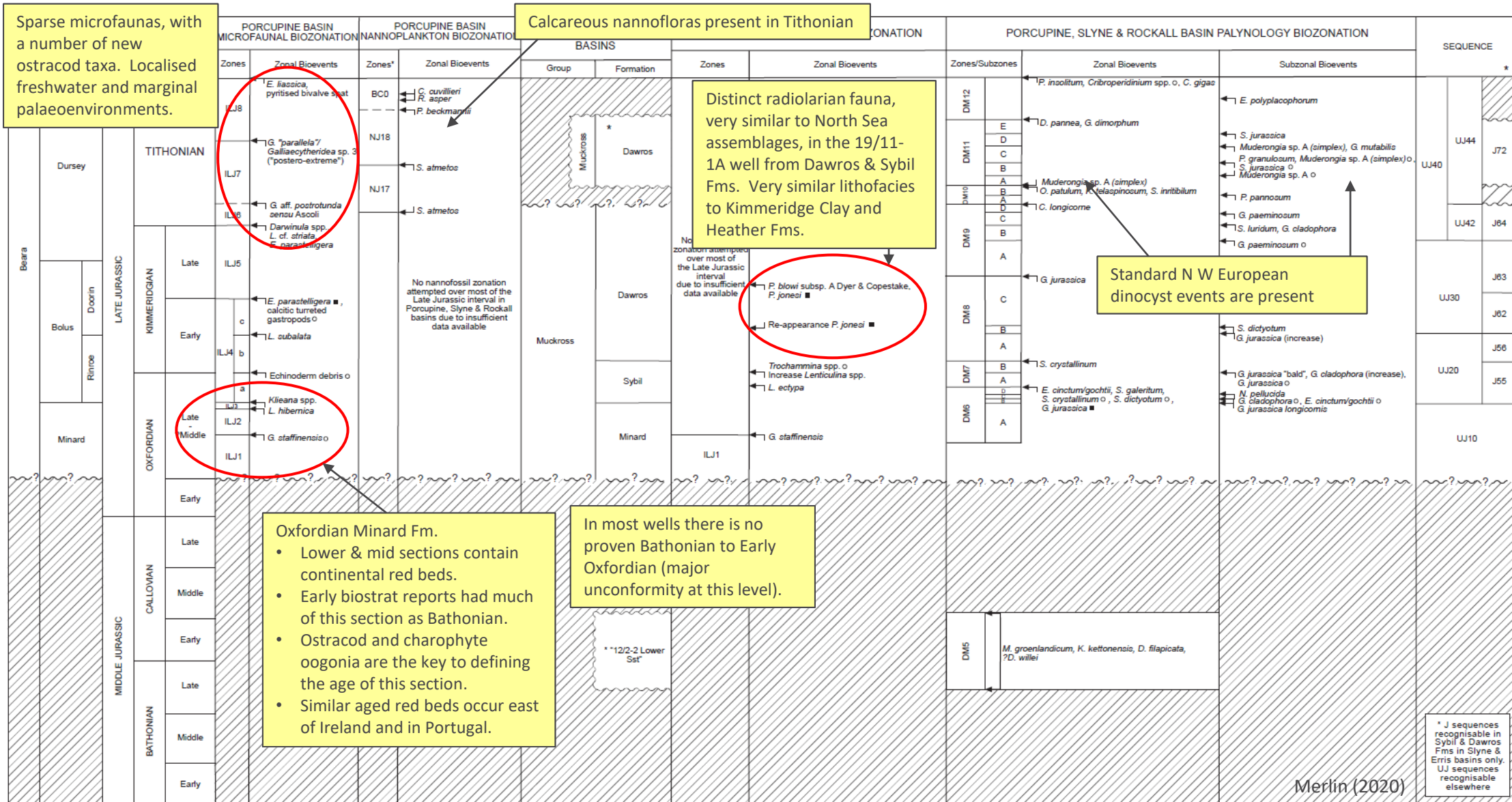
Stratigraphic scheme for Hettangian – Aalenian of offshore Ireland



Rockall Basin; Jurassic absent/unproven; wells 5/22-1, 12/2-1, 12/2-2

* 49/30-1 TD in Tacumshin Fm, section below this interpreted on seismic evidence.

Late Jurassic biozonation scheme west of Ireland (Porcupine, Slyne & Rockall Basins)



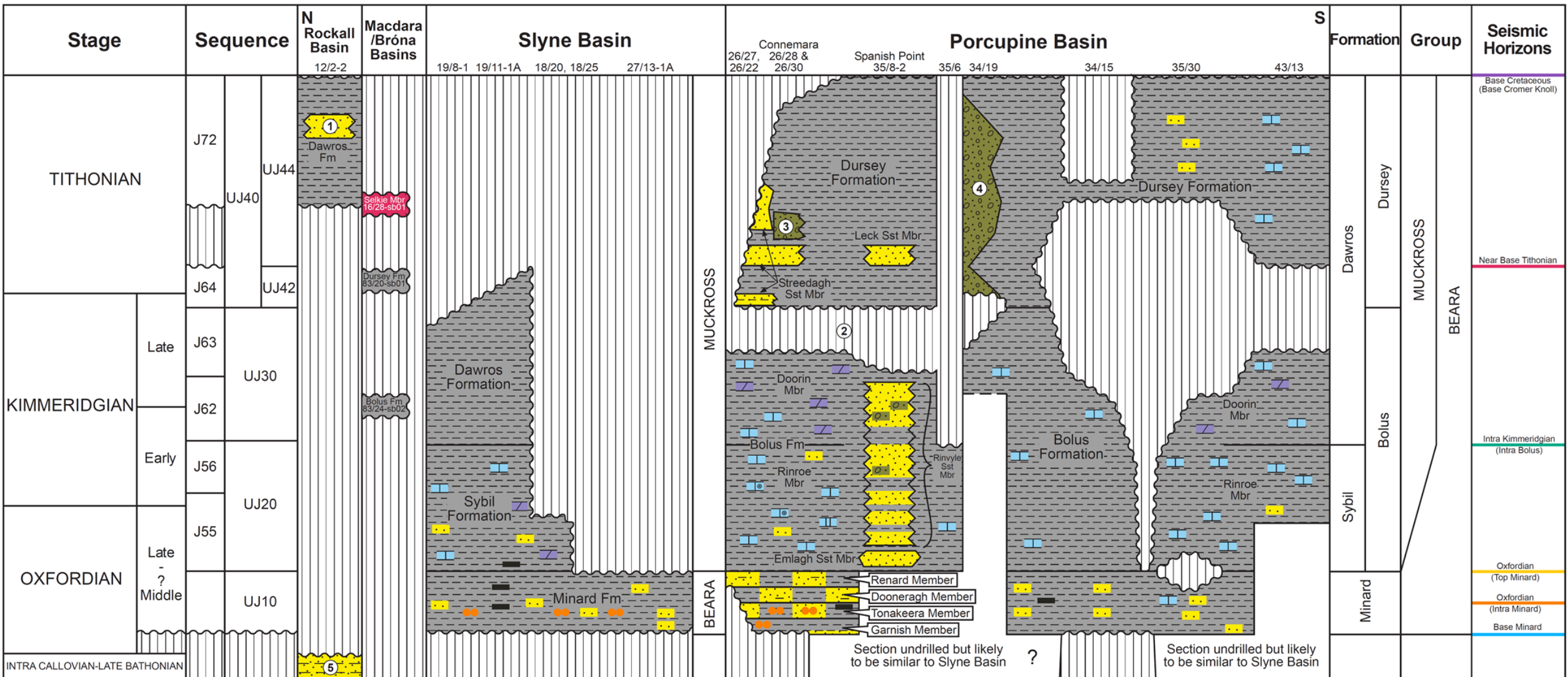
* Bown & Cooper in Bown (1998)

* Rockall Basin (12/2-2)

* J sequences recognisable in Sybil & Dawros Fms in Slyne & Erris basins only. UJ sequences recognisable elsewhere

Merlin (2020)

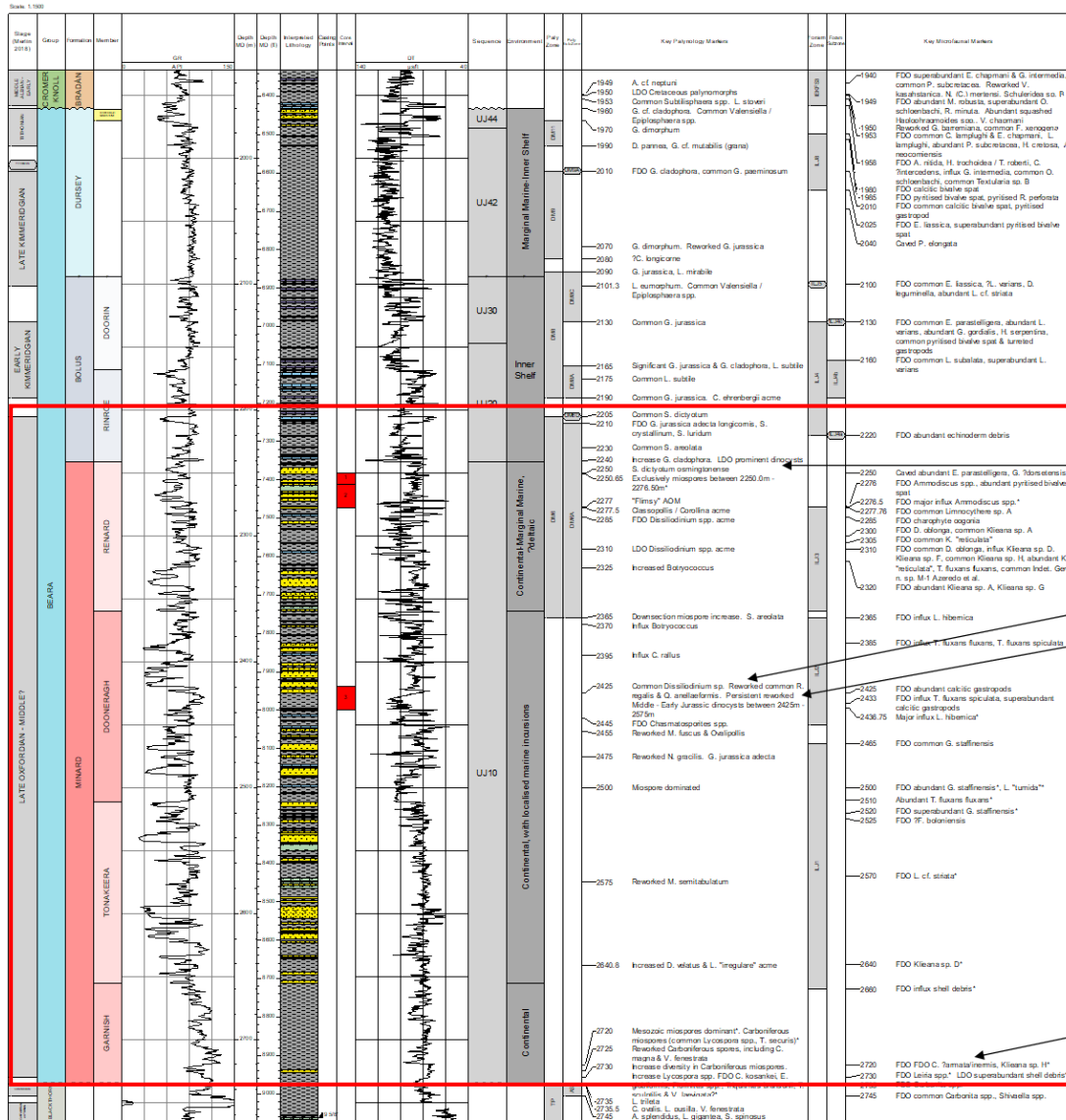
Late Jurassic stratigraphic scheme west of Ireland (Porcupine, Slyne & Rockall Basins)



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Use of biostratigraphy in reservoir zonation; e.g. Connemara Discovery reservoir section

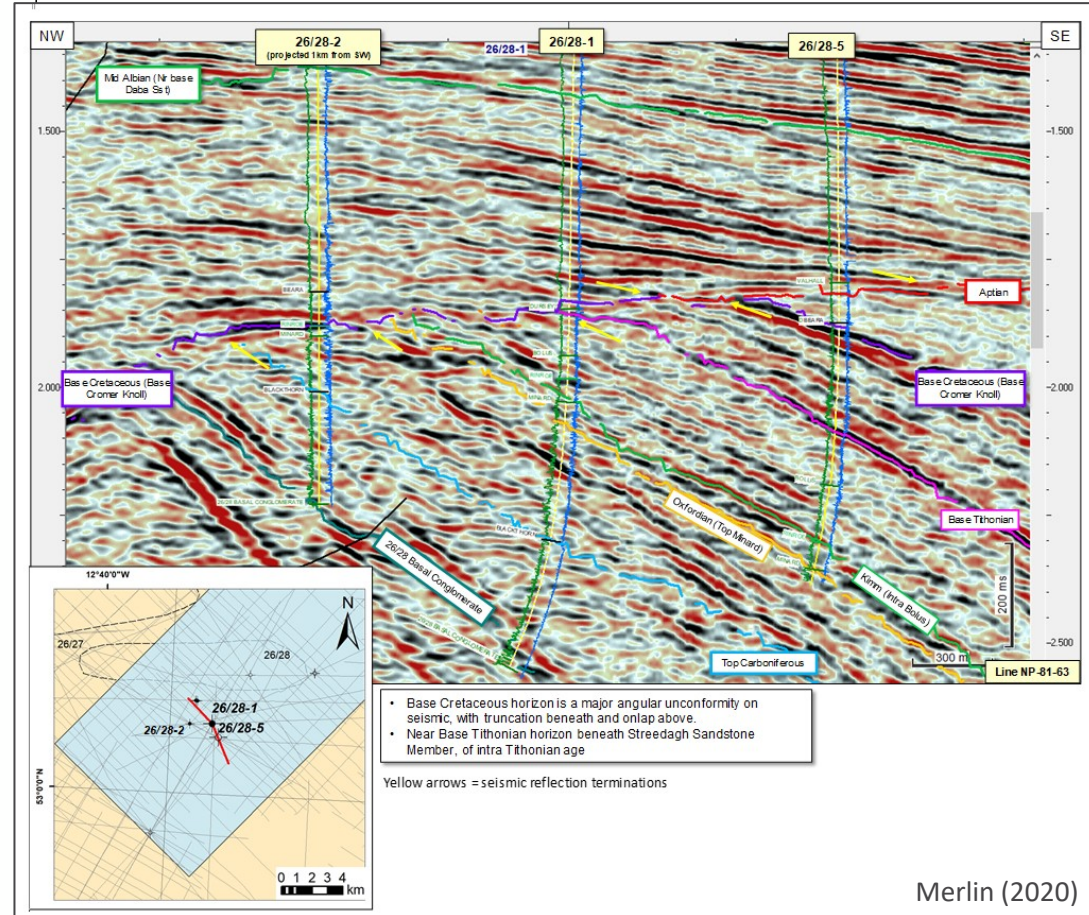
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- Upwards shift from marginal/non-marine to marine palynofloras and microfossils; indicative of major flooding (base UJ20 sequence)
- Late Oxfordian in age

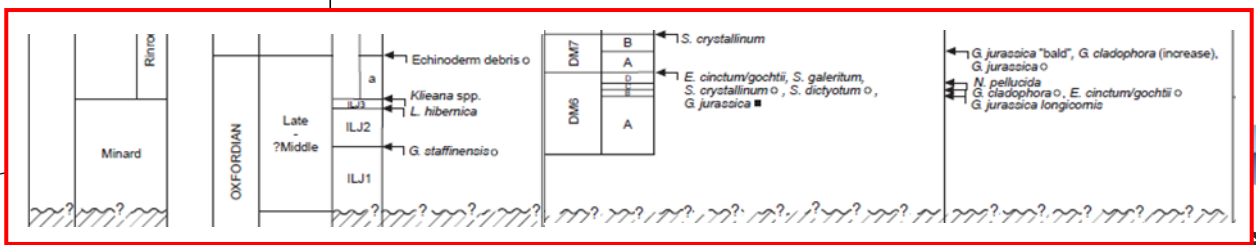
Beginning of marine influence; *Dissiliodinium* spp. present

Middle Jurassic dinocysts present; interpreted as reworked. Previously interpreted as in situ Middle Jurassic



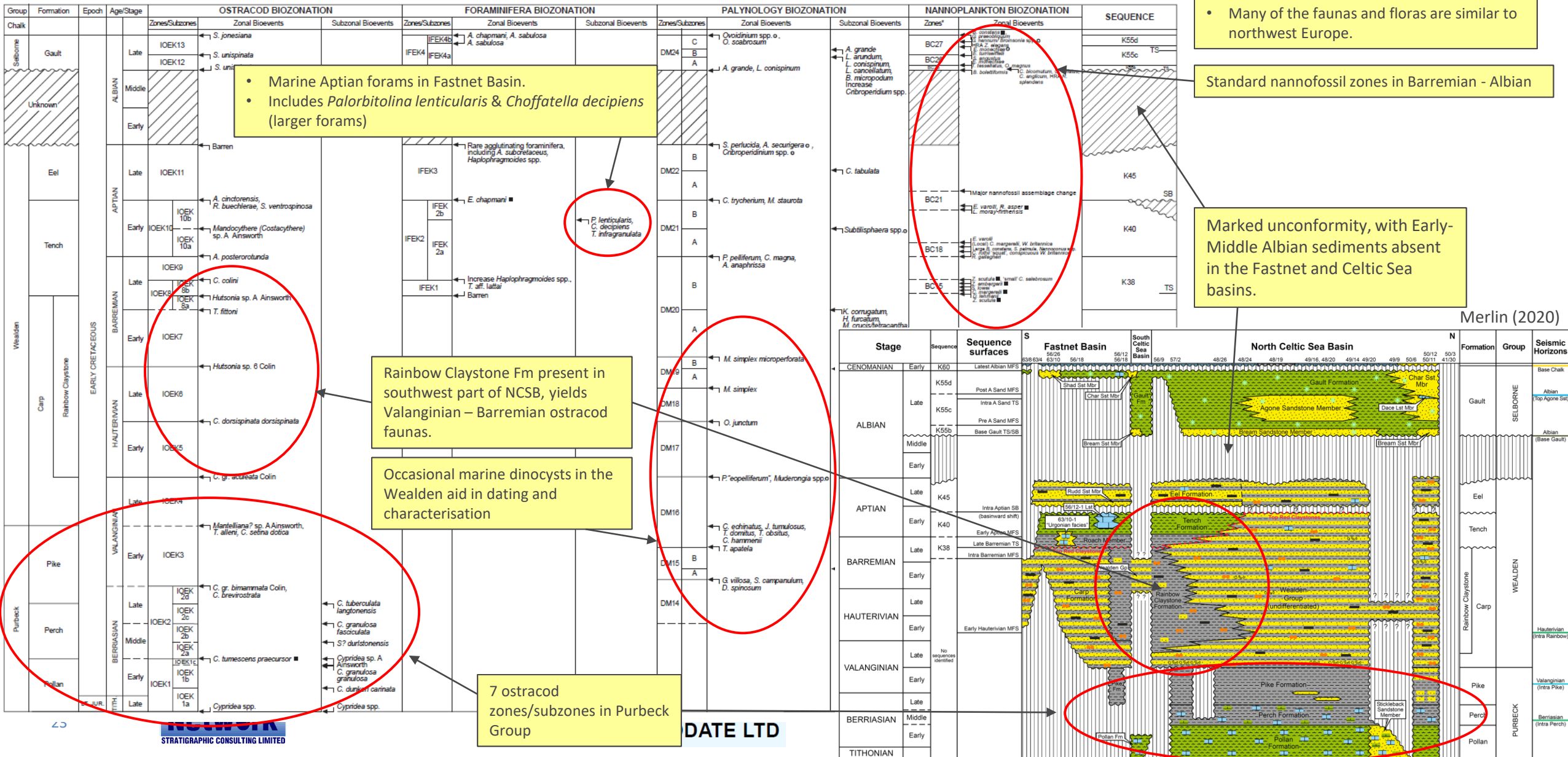
- Base Cretaceous horizon is a major angular unconformity on seismic, with truncation beneath and onlap above.
- Near Base Tithonian horizon beneath Streedagh Sandstone Member, of intra Tithonian age

Yellow arrows = seismic reflection terminations



Merlin (2020)

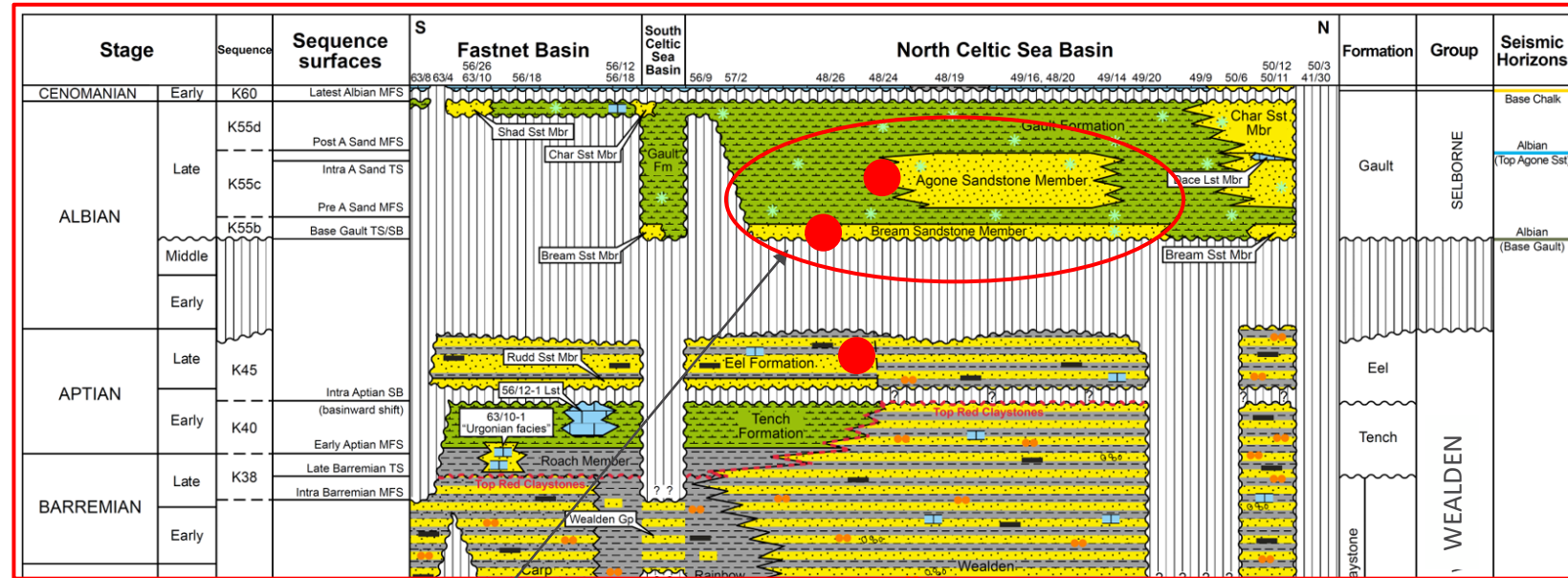
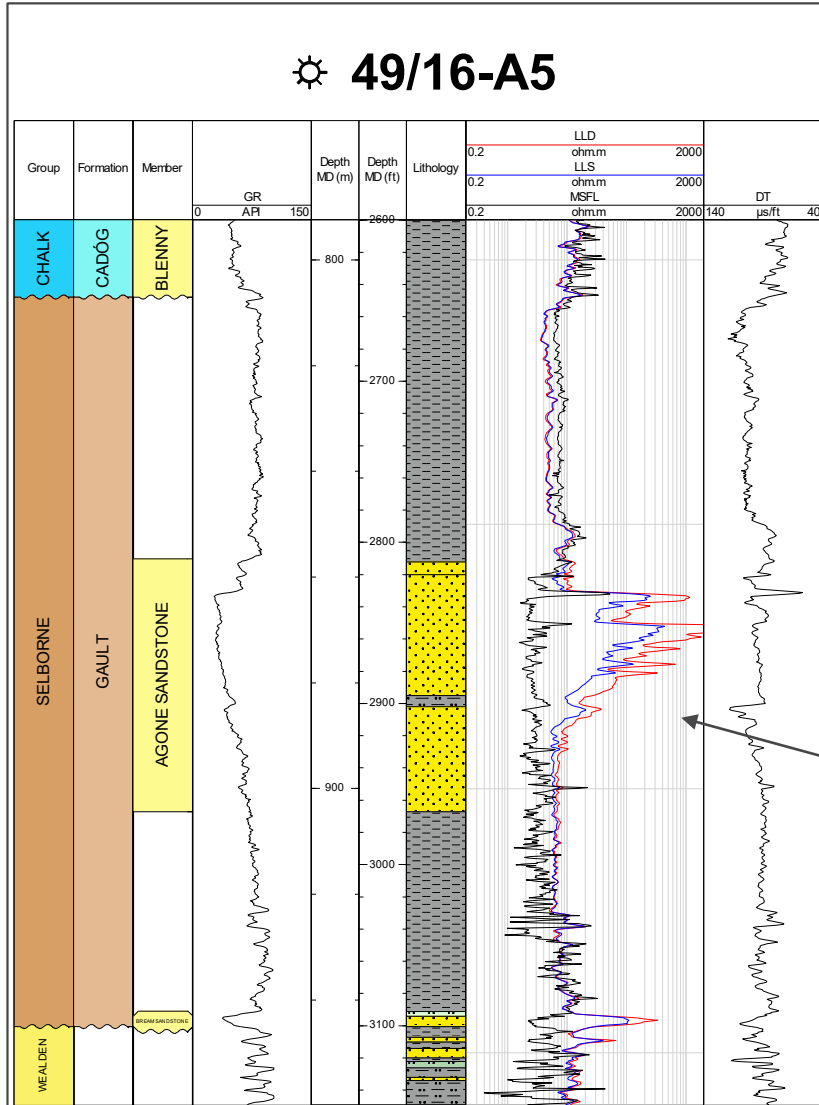
Early Cretaceous biozonation scheme North Celtic Sea – Fastnet Basins



Use of biostratigraphy in reservoir zonation; e.g. Lower Cretaceous reservoirs, North Celtic Sea Basin

Kinsale Head Field

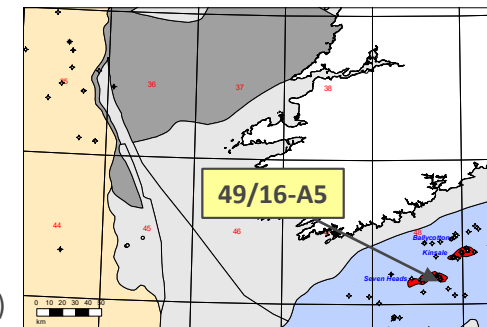
☀ 49/16-A5



Proven hydrocarbons

Agone Sandstone & Bream Sandstone members, Gault Formation. Formerly known as A Sand and B Sand Age; Late Albian

- Late Albian Agone & Bream sandstones are reservoirs in several fields & discoveries in the basin, e.g. Kinsale, SW Kinsale, Old Head of Kinsale, Middleton, Carrigaline, Galley Head, Schull & Ballycotton
- Late Aptian Eel Formation is hydrocarbon reservoir in Seven Heads (48/24), 57/9-1 Discovery

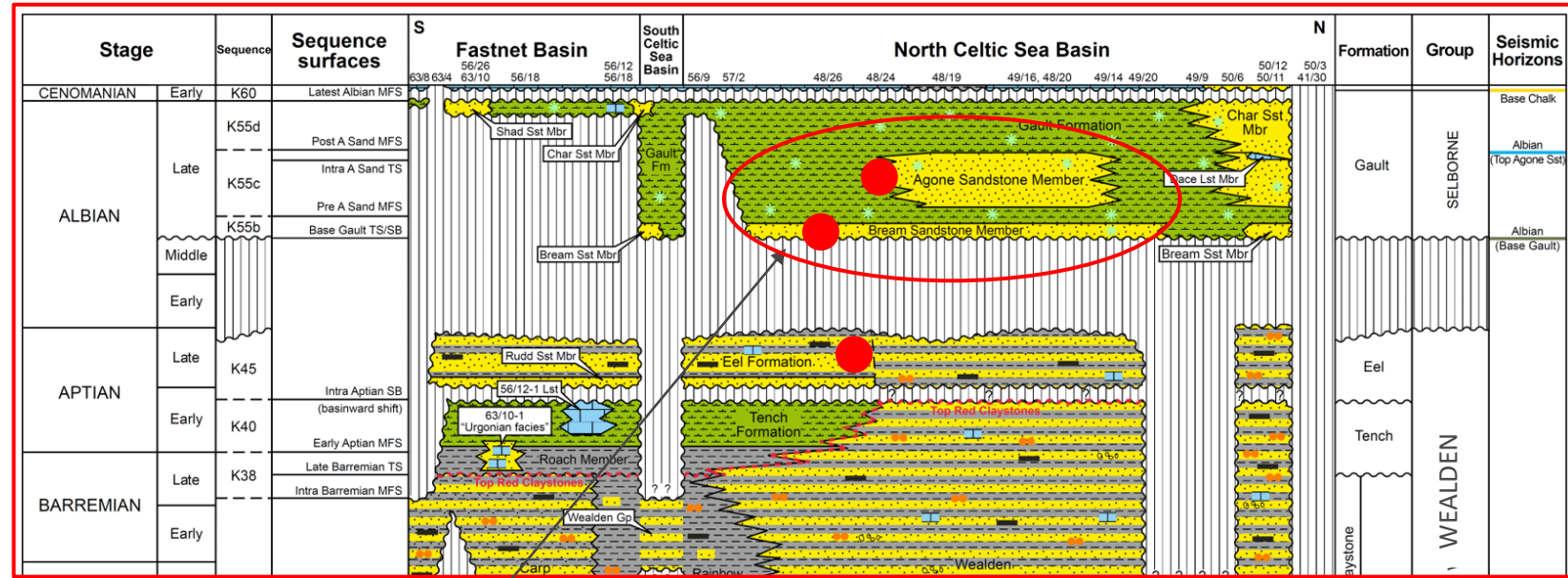
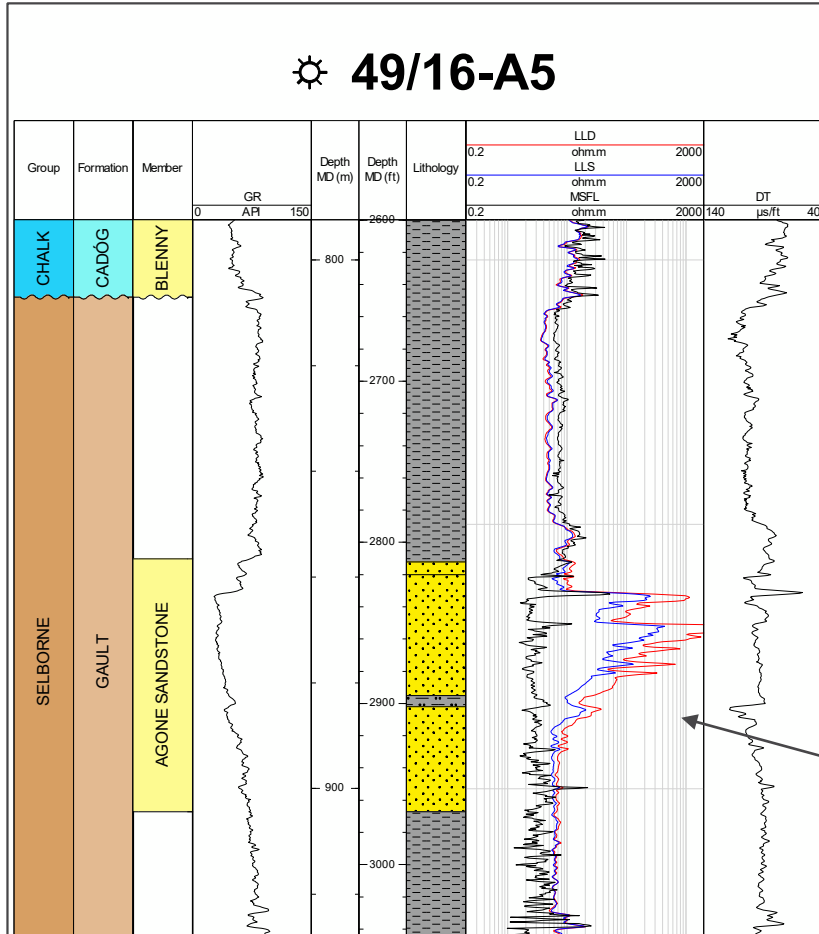


Merlin (2020)

Use of biostratigraphy in reservoir zonation; e.g. Lower Cretaceous reservoirs, North Celtic Sea Basin

Kinsale Head Field

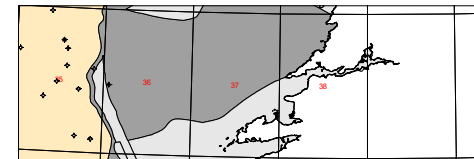
☀ 49/16-A5



Proven hydrocarbons

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- Late Albian Agone & Bream sandstones are reservoirs in several fields & discoveries in the basin, e.g. Kinsale, SW Kinsale, Old Head of Kinsale, Midleton, Carrigaline, Galley Head, Schull & Ballycotton
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Group	Formation	Epoch	Age/Stage	OSTRACOD BIOZONATION			FORAMINIFERA BIOZONATION			PALYNOLOGY BIOZONATION			NANNOPLANKTON BIOZONATION			SEQUENCE
				Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones	Zonal Bioevents	Subzonal Bioevents	
Selborne	Gault		Late	IOEK13	← S. jonesiana		IFEK4b	← A. chapmani, A. sabulosa A. sabulosa		C	← Ovoidinium spp. o. O. scaberrimum		BC27	← L. conispinum L. arundum L. conispinum L. conispinum L. conispinum		K55d
				IOEK12	← S. unispinata S. unispinata		DM24 B A	← A. grande, L. conispinum		BC28 BC25	← B. micropodium Increase Cribropidium spp.		K55c			
Unknown			ALBIAN Middle													

Merlin (2020)

Early Cretaceous biozonation scheme Goban Spur, Porcupine, Slyne, Erris & Rockall basins

Group	Basins					Epoch	Age/ Stage	MICROPALAEONTOLOGICAL BIOZONATION		MICROPALAEONTOLOGICAL BIOZONATION		PALYNOLOGY BIOZONATION		NANNOPLANKTON BIOZONATION		SEQUENCE		
	Porcupine Basin	Rockall Basin	Erris Basin	Slyne Basin	Goban Spur Area			MICROPALAEONTOLOGICAL BIOZONATION (Deep Water)		MICROPALAEONTOLOGICAL BIOZONATION (Shallow Water)		PALYNOLOGY BIOZONATION		NANNOPLANKTON BIOZONATION		SEQUENCE		
	Formation	Fm	Fm	Fm	Fm			Zones	Zonal Bioevents	Zones	Zonal Bioevents	Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones/Subzones	Zonal / Subzonal Bioevents	SEQUENCE	
Cromer Knoll	Broadland	Robby	Robby	Spurdog	Salin	ALBIAN	Late	IEKFD18	← <i>F. austrofl.</i> , <i>H. planispira</i> , <i>I. small</i> , <i>O. schloenbachi</i> , <i>T. bentonensis</i> , <i>T. una</i>	IEKFS4	← <i>A. chapmani</i> , <i>F. rossiana</i> , <i>F. "triangula"</i> , <i>E. spinulifera</i> , <i>polyphoides</i>	DM24	A	← <i>A. polymorpha</i>	BC27	← <i>S. constrictus</i> , <i>S. regium</i> , <i>B. concolor</i> , <i>B. furcata</i> , <i>B. angustifolia</i> , <i>B. angustifolia</i> , <i>B. angustifolia</i>	K60	
							Middle	IEKFD15	← Large <i>O. schloenbachi</i> , <i>Recurvoides</i> spp.	← <i>A. nitida</i> , large <i>O. schloenbachi</i> , <i>Haplophragmoides</i> spp. (scashed), <i>A. macfadanyi</i>	BC26					← <i>E. monochlae</i>		K55
							IEKFD13	← <i>G. gyrodinaeformis</i> , <i>V. chapmani</i>	← <i>K. simplicispinum</i> , <i>L. stoveri</i> , <i>D. alberti</i> , <i>S. perficata</i>	BC25	← <i>C. bicoloratum</i> , <i>C. striatus</i> , <i>C. anglicum</i> , <i>HRA R. splendens</i>							
	Carnock	Carnock	Spartan	Salin	Aptian	Late	IEKFD12	← Green-stained <i>B. aptiana</i> , <i>B. cf. aptica</i> , <i>G. cf. barremiana</i>	IEKFS2	← <i>B. aptiana</i>	DM22	B	← <i>C. tabulata</i>	BC24	← <i>A. vinosus</i>	K50		
						IEKFD11	← Red-stained <i>B. aptiana</i> , <i>B. cf. aptica</i>	IEKFS1	← <i>P. lenticularis</i> , <i>T. infragranulata</i> , <i>C. decipiens</i>	BC23					← <i>HRA Z. embergeri</i> , <i>HRA R. parvidentatum</i>			
						IEKFD10	← Black-speckled <i>B. aptiana</i> , <i>B. cf. aptica</i>	← <i>C. decipiens</i> , <i>Trocholina</i> spp. ■	BC22	← Major nannofossil assemblage change								
	Vahall	Vahall	Vahall	Gomard	Barremian	Early	IEKFD9	← <i>C. intercedens</i> , <i>G. barremiana</i>	DM21	A	← <i>C. trycherium</i> , <i>M. staurota</i>	BC21	← <i>E. varoli</i> , <i>R. asper</i> ■	K45				
						IEKFD8	← <i>C. bartensteini</i> , <i>F. xenogena</i>	← <i>H. ramoides</i> , <i>C. cornutum</i> , <i>P. peliferum</i> , <i>B. longicornutum</i> , <i>C. magna</i> , <i>A. anapiripisa</i>					BC20		← <i>E. varoli</i> ■			
						IEKFD7	← <i>E. caracolla</i> , <i>G. sigmaicosta</i> , <i>F. xenogena</i> ○ ■	← <i>M. simplex (endovata)</i> , <i>N. kostromiensis</i>					BC19		← <i>L. subtilisphaera</i> spp. ○			
	Vahall	Vahall	Vahall	Gomard	Hautervian	Late	IEKFD6	← <i>F. praemiosiana</i> ■, <i>E. caracolla</i> ■	DM19	B	← <i>O. abaculum</i> , <i>M. simplex microperforata</i> , <i>C. cf. reticulata</i>	BC18	← <i>E. varoli</i> ■	K40				
						IEKFD5	← Persistent <i>L. nodosa</i> , <i>L. cf. nodosa</i>	← <i>H. borealis</i> , <i>C. cornutum</i> , <i>N. abundans</i>					BC17		← <i>L. (Local) C. margereli</i> , <i>W. britannica</i>			
						IEKFD4	← Lenticulina sp. "evolute", Persistent <i>L. busnardo</i>	← <i>K. fasciatum</i> , <i>K. comugatum</i> , <i>H. furcatum</i> , <i>P. peliferum</i> ○, <i>M. cruciata</i> , <i>tetracantha</i>					BC16		← <i>E. varoli</i> ■			
	Vahall	Vahall	Vahall	Gomard	Valanginian	Early	IEKFD3	← <i>C. valandensis</i>	DM18	A	← <i>G. confossa</i>	BC15	← <i>D. lehmani</i> ■	K38				
						IEKFD2	← Robust <i>P. kumeli</i> ○	← <i>N. borealis</i> , <i>P. suboblongatus</i> , <i>N. abundans</i>					BC14		← <i>Z. scutella</i> ■			
						IEKFD1	← <i>A. neocomiana</i> ○	← <i>M. simplex (endovata)</i> , <i>N. kostromiensis</i>					BC13		← <i>N. borealis</i> ■			
	Vahall	Vahall	Vahall	Gomard	Berriasian	Late	IEKFD2	← Robust <i>P. kumeli</i> ○	DM17	B	← <i>O. junctum</i> ○	BC12	← <i>C. maculosus</i> ■	K36				
						Middle	IEKFD1	← <i>A. neocomiana</i> ○					← <i>G. cladophora</i> sensu Duxbury, <i>O. junctum</i> , <i>O. "quadrum"</i>		BC11	← <i>F. septentrionalis</i> ■		
						IEKFD1	← <i>A. neocomiana</i> ○	← <i>P. "neopelliferum"</i> , <i>Muderongia</i> sp. (tabulate), <i>Muderongia</i> spp. ○					BC10		← <i>C. ovaliter</i> ■			
Vahall	Vahall	Vahall	Gomard	Valanginian	Early	IEKFD3	← <i>C. valandensis</i>	DM16	A	← <i>I. distincta</i> , <i>S. delicatula</i> , <i>G. villosa multifurcata</i> , <i>L. perflua</i> (prominent), <i>O. junctum</i> ■	BC9	← <i>E. striatus</i> ■	K34					
					IEKFD2	← Robust <i>P. kumeli</i> ○	← <i>C. cladophora</i> sensu Duxbury ○, <i>C. validum</i>					BC8		← <i>P. constanti</i> , <i>C. salebrosum</i>				
					IEKFD1	← <i>A. neocomiana</i> ○	← <i>P. "neopelliferum"</i> , <i>Muderongia</i> sp. (tabulate), <i>Muderongia</i> spp. ○					BC7		← <i>C. septentrionalis</i> ■				
Vahall	Vahall	Vahall	Gomard	Valanginian	Early	IEKFD3	← <i>C. valandensis</i>	DM15	C	← <i>T. apatele</i>	BC6	← <i>E. antiquus</i> ■	K32					
					IEKFD2	← Robust <i>P. kumeli</i> ○	← <i>O. evittii</i>					BC5		← <i>E. striatus</i> ■				
					IEKFD1	← <i>A. neocomiana</i> ○	← <i>E. pharo</i> , <i>S. palmula</i>					BC4		← <i>T. sheldandensis</i>				
Vahall	Vahall	Vahall	Gomard	Valanginian	Early	IEKFD3	← <i>C. valandensis</i>	DM15	A	← <i>G. villosa</i> , <i>D. spinosum</i> , <i>C. culmulum</i> , <i>cf. campanulum</i> , <i>E. torynum</i>	BC3	← <i>S. arcuatus</i>	K20					
					IEKFD2	← Robust <i>P. kumeli</i> ○	← <i>M. speetonensis</i>					BC2		← <i>S. arcuatus</i> , <i>K. borealis</i>				
					IEKFD1	← <i>A. neocomiana</i> ○	← <i>M. speetonensis</i>					BC1		← <i>S. arcuatus</i> , <i>K. borealis</i>				
Vahall	Vahall	Vahall	Gomard	Valanginian	Early	IEKFD3	← <i>C. valandensis</i>	DM15	A	← <i>G. villosa</i> , <i>D. spinosum</i> , <i>C. culmulum</i> , <i>cf. campanulum</i> , <i>E. torynum</i>	BC0	← <i>M. parvitolitatus</i> , <i>P. senaria</i>	K14					
					IEKFD2	← Robust <i>P. kumeli</i> ○	← <i>M. speetonensis</i> , <i>K. borealis</i>					← <i>M. parvitolitatus</i> , <i>P. senaria</i>						
					IEKFD1	← <i>A. neocomiana</i> ○	← <i>T. sheldandensis</i>					← <i>R. angustifolia</i>						

Typical N W European marine dinocyst zonation

High resolution nannofossil biozonation (Bown *et al.*, 1998; Jeremiah, 2000; emended)

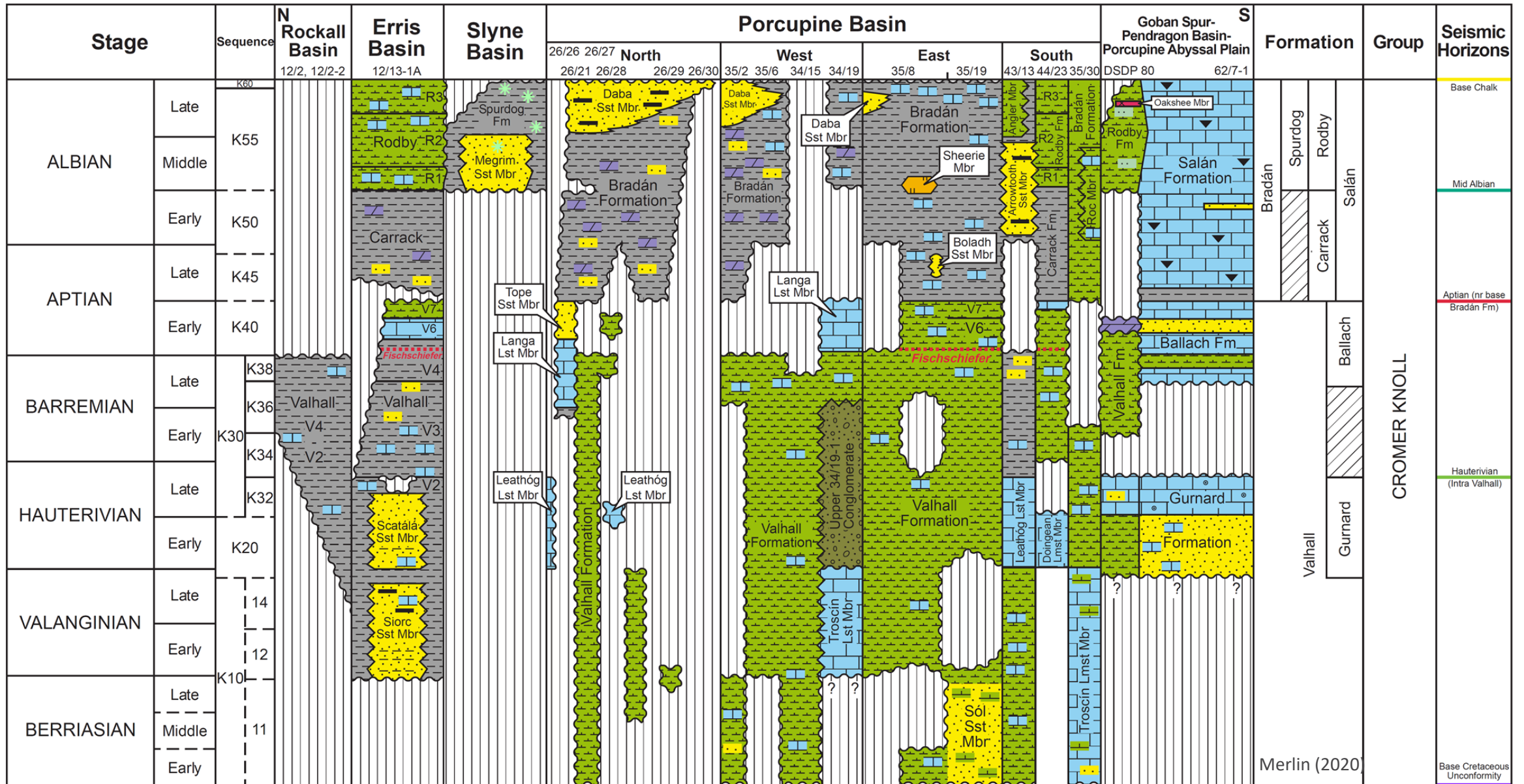
- Berriasian-Albian microfaunas can be subdivided into shallow and deep water assemblages.
- Shallow water assemblages occur in the Slyne and North Porcupine basins, while the deep faunas occur in the Main Porcupine Basin.
- Assemblages are v. similar to northwest Europe and Canada.
- Valanginian-Hautervian faunas similar to northwest Europe.

Berriasian faunas similar to Canada, not seen in the North Sea

*Bown *et al.* (1998), Jeremiah (2000) emended herein

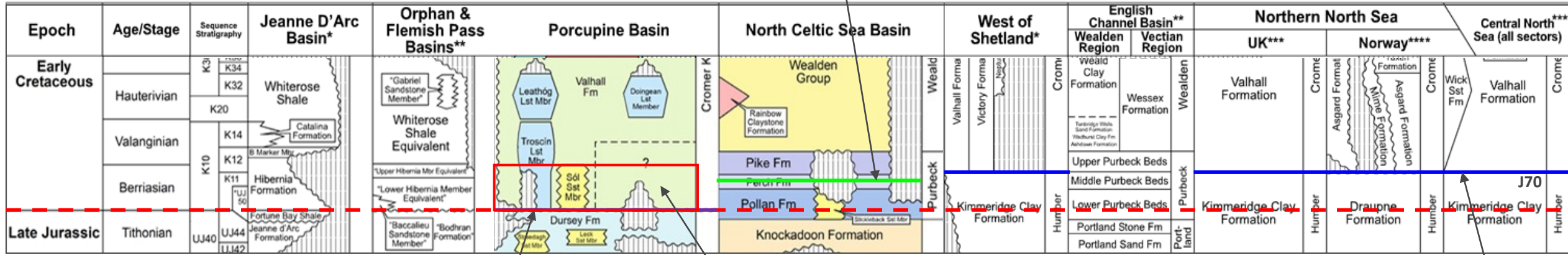
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Early Cretaceous stratigraphic scheme Goban Spur, Porcupine, Slyne, Erris & Rockall basins



Jurassic/Cretaceous boundary

"Intra Perch" seismic horizon (N. Celtic Sea Basin)



Base Cretaceous seismic horizon (Porcupine Basin)

Lowermost Cretaceous in calcareous, open marine facies

Base Cretaceous seismic horizon (North Sea & West of Shetland)

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BERRIASIAN	Late	IEKFD2	← Robust <i>P. kummi</i> ◦	DM14	B	← <i>G. villosa</i> , <i>D. spinosum</i> , <i>C. culmulum</i> , <i>S. cf. campanulum</i> , <i>E. torynum</i>	BC2	← <i>S. arcuatus</i>	K11
	Middle	IEKFD1	← <i>A. neocomiana</i> ◦		A	← <i>R. thula</i>		BC1	
	Early					BC0	← <i>M. parvistellatus</i> , <i>P. senaria</i> ← Increase <i>M. parvistellatus</i> , <i>P. senaria</i> ← <i>R. angustiflora</i> ← Increase <i>Acadialtitus</i> spp. ← <i>N. steinmanni</i> , <i>N. kamptrii</i>		

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- Additional nannofossil stratigraphy in the 'Earliest' Cretaceous relative to the North Sea.
- The uppermost Kimmeridge Clay Formation in North Sea does not yield these events due to the facies change at the boundary between the Cromer Knoll and Humber Groups.
- These taxa are known from offshore Canada (Howe 2017), offshore USA (Varol & Bowman 2019) and North Atlantic DSDP Leg 76.
- Currently only recorded from offshore boreholes – therefore imprecise calibration with chronostratigraphy/macrofossil stratigraphy.

PORCUPINE BASIN		Epoch	Age / Stage	PORCUPINE BASIN MICROFAUNAL BIOZONATION		PORCUPINE BASIN NANNOPLANKTON BIOZONATION		PORCUPINE, SLYNE & ROCKALL BASIN PALYNOLOGY BIOZONATION			SEQUENCE	
Group	Formation			Zones	Zonal Bioevents	Zones*	Zonal Bioevents	Zones/Subzones	Zonal Bioevents	Subzonal Bioevents		*
				ILJ8	← <i>E. liassica</i> , pyritised bivalve spat	BC0	← <i>C. cuvillieri</i> ← <i>R. asper</i> ← <i>P. beckmannii</i>	DM12	← <i>P. insolitum</i> , <i>Cnbroperidium</i> spp. ◦, <i>C. gigas</i>	← <i>E. polyplacophorum</i>	UJ44	J72
				ILJ7	← <i>G. "parallela"/ Galliaecytheridea</i> sp. 3 ("postero-extreme")	NJ18	← <i>S. atmetos</i>	DM11	← <i>D. pannea</i> , <i>G. dimorphum</i>	← <i>S. jurassica</i> ← <i>Muderongia</i> sp. A (<i>simplex</i>), <i>G. mutabilis</i> ← <i>P. granuloseum</i> , <i>Muderongia</i> sp. A (<i>simplex</i>) ◦ ← <i>S. jurassica</i> ◦ ← <i>Muderongia</i> sp. A ◦	UJ40	J70
	Dursey		TITHONIAN	ILJ6	← <i>G. aff. postrotunda sensu Ascoli</i>	NJ17	← <i>J.S. atmetos</i>	DM10	← <i>Muderongia</i> sp. A (<i>simplex</i>) ← <i>O. patulum</i> , <i>K. telaspinosum</i> , <i>S. innitibulum</i> ← <i>C. longicorne</i>	← <i>P. pannosum</i> ← <i>G. paemosum</i>	UJ42	J64

Standard North Sea type palyнологy markers

Merlin (2020)



Late Cretaceous biozonation scheme for offshore Ireland

integrated multi proxy biozonations; foraminifera, calcareous nannoplankton, dinocysts

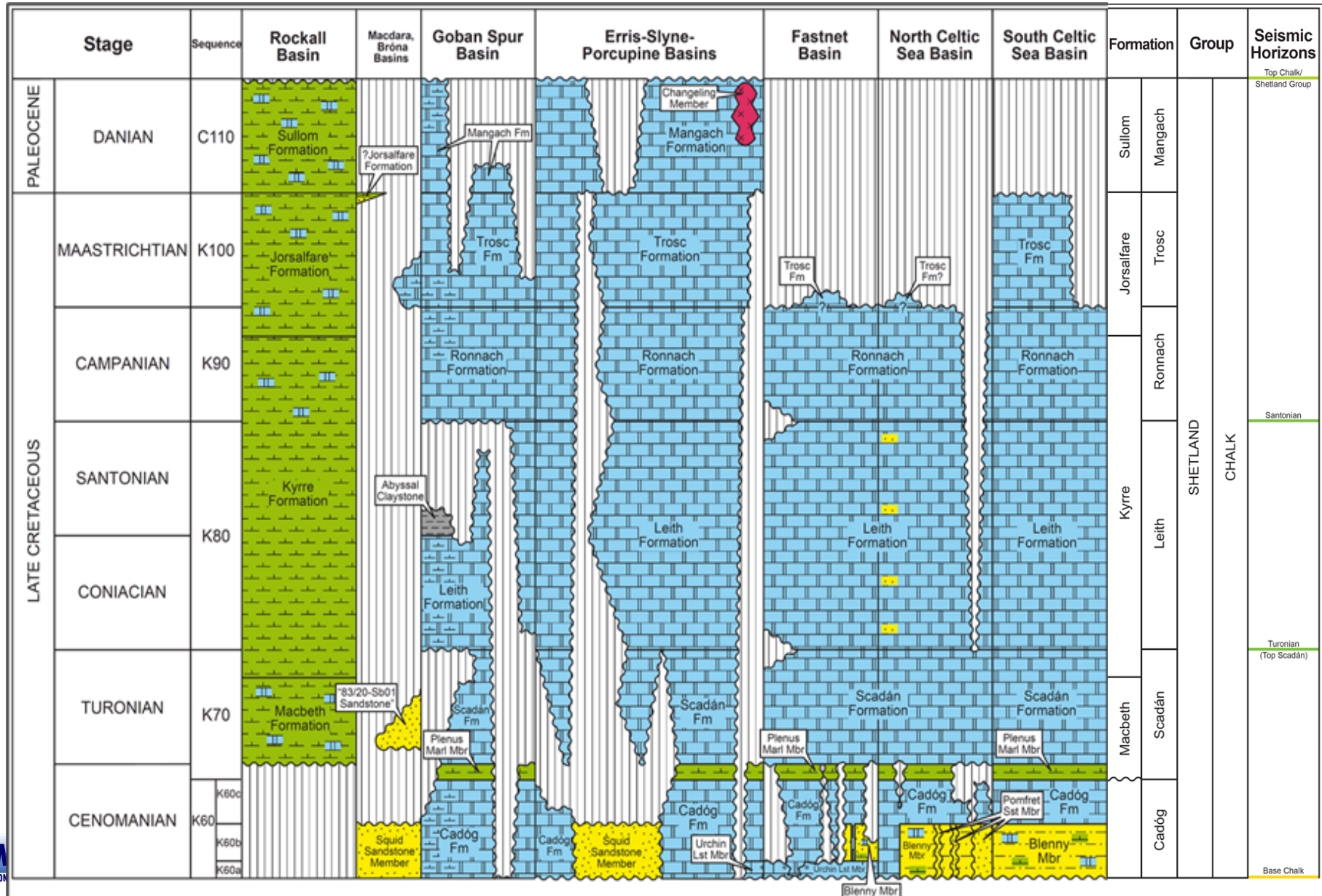
Group	Formation	Group	Formation	Epoch	Age/Stage	FORAMINIFERAL BIOZONATION			PALYNOLOGY BIOZONATION			NANNOPLANKTON BIOZONATION			SEQUENCE
						Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	Zones/Subzones	Zonal Bioevents	Subzonal Bioevents	
Shetland	Jorsalfare	Chalk	Mangach	PAL.	Danian	FORAMINIFERAL BIOZONATION			PALYNOLOGY BIOZONATION			NANNOPLANKTON BIOZONATION			K100
						ILKF12	New planktonic & benthonic foram based biozones/subzones		DM29	B	New palynology biozonation (dinocysts)		UC19	Calcareous nannoplankton zonation of Burnett <i>et al.</i> (1998)	
	Kyrre	Ronnach	LATE CRETACEOUS	MAASTRICHTIAN	Late	ILKF11	a	← <i>B. miliaris</i> <i>B. decoratus</i> , <i>B. australis</i> , <i>R. szajnochae</i> , <i>Orbigryna</i> spp., <i>G. monterelensis</i> , <i>G. hiltermanni</i> , <i>T. capitosa</i>	← <i>O. costata</i> , <i>O. operculata</i>	UC18	← <i>R. levis</i>	← <i>S. primivium</i> , <i>G. obliquum</i> , <i>Z. compactus</i> , <i>C. obscurus</i>	K90		
					Early	ILKF10	b	← <i>G. aff. arca</i>	← <i>C. niiga</i> , <i>P. infusoroides</i> , <i>O. porifera</i> , <i>T. suspectum</i>	UC17	← <i>T. orionatus</i>	← <i>R. anthophorus</i> , <i>B. parca parca</i> , <i>H. bugensis</i>			
			Late	ILKF10	a	← <i>G. clementiana</i> sp.	← <i>R. furcatum</i>	UC16	← <i>B. parca constricta</i>	← <i>E. eximius</i>					
			Middle	ILKF9	b	← <i>G. elevata</i>	← <i>S. exsculpta gracilis</i> , <i>G. stelligera</i> , <i>G. thalmanni</i> , <i>G. elevata</i> , <i>S. granulata incondita</i>	← <i>T. castanea</i> , <i>C. asymmetricum</i> , <i>H. heterocanthum</i> o	UC15	← <i>S. biferula</i>	← <i>O. campanensis</i> , <i>H. trabeculatus</i> , <i>A. geminacanthus</i> , <i>C. biarcus</i> , <i>L. grillii</i>				
		Early	ILKF9	a	← <i>M. sinuosa</i> , <i>B. culverensis</i> , <i>B. strigillatus</i> , <i>S. exsculpta exsculpta</i>	← <i>H. difficile</i> , <i>T. variecalamum</i> , <i>M. reticulatum</i>	← <i>E. campanulum</i> , <i>S. longifurcatum</i> , <i>X. alatum</i> , <i>C. "spinosa"</i> , <i>P. truncatum</i>	UC14	← <i>B. parca parca</i>	← <i>B. parca constricta</i> , <i>B. enormis</i> , <i>C. crassus</i> , <i>J. R. levis</i>					
		Late	ILKF8	b	← <i>D. asymmetrica</i> , <i>G. linneiana</i> o, <i>G. bulloides</i> o	← <i>S. exsculpta exsculpta</i> o	← <i>L. siphoniphorum</i>	UC13	← <i>B. parca parca</i>	← <i>C. obscurus</i> o, <i>C. crassus</i>					
		Middle	ILKF8	a	← <i>D. concavata</i> , <i>M. marginata</i>	← <i>S. granulata polonica</i> o, <i>S. granulata granulata</i> o, <i>G. amagerensis</i>	← <i>A. cymbiformis</i> , <i>Q. eptabrachium</i>	UC12	← <i>A. cymbiformis</i> , <i>Q. eptabrachium</i>	← <i>H. trabeculatus</i> o, <i>T. virginica</i>					
		Early	ILKF7	b	← <i>M. renzi</i>	← <i>G. fourainensis</i> , <i>S. granulata levis</i>	← <i>S. coronatum</i>	UC11	← <i>L. grillii</i>	← <i>Q. intermedium</i> , <i>H. turonicus</i>					
Macbeth	Scadán	LATE CRETACEOUS	TURONIAN	Late	ILKF6	a	← <i>D. imbricata</i>	← <i>S. granulata kelleri</i>	← <i>S. coronatum</i>	UC10	← <i>M. staurophora</i>	← <i>Influx H. turonicus</i>	K70		
				Middle	ILKF6	b	← <i>H. helvetica</i> , <i>P. stephani</i> , <i>P. gibba</i>	← <i>H. prae-helvetica</i>	← <i>L. siphoniphorum</i>	UC9	← <i>Q. eptabrachium / L. septenarius</i>	← <i>K. magnificus</i>			
				Early	ILKF5	a	← <i>Whiteinella</i> spp. ■, <i>W. archaeocretacea</i> , <i>W. paradubia</i>	← <i>L. globosa</i> , <i>Calcispheres</i> ■	← <i>L. siphoniphorum</i>	UC8	← <i>E. eximius</i> , <i>Q. gartneri</i>				
				Early	ILKF4	b	← <i>R. cushmani</i> , <i>T. deeckei</i> , <i>T. greenhornensis</i> , <i>P. delrioensis</i>	← <i>G. ballica</i> , <i>G. cenomanica</i> , <i>P. cenomana</i> , <i>T. pyramidata</i> , <i>T. cretosa</i>	← <i>G. cassidata</i> , <i>E. dettmaniae</i> , <i>Chlamydothorella</i> spp. o	UC7	← <i>H. chiastia</i> , <i>R. asper</i>				
				Late	ILKF3	a	← <i>T. reicheli</i>	← <i>E. spinosa</i>	← <i>E. spinosa</i>	UC6	← <i>L. acutus</i>				
				Middle	ILKF2	b	← <i>T. appenninica</i> , <i>T. brotzeni</i>	← <i>L. ciryi infata</i> , <i>L. jarzevae</i> , <i>Flourensina</i> spp., <i>M. ozavai</i> , <i>S. antiqua</i> , <i>Orbitolina</i> spp., incl <i>O. concava</i>	← <i>O. concava</i> in Early Cenomanian (Urchin Limestone Member)	UC5	← <i>A. albianus</i> , <i>C. kennedyi</i> , increase <i>Broinsonia</i> spp.				
Cadóg	CENOMANIAN	Early	ILKF1	a	← <i>T. appenninica</i> , <i>T. brotzeni</i>	← <i>O. concava</i> in Early Cenomanian (Urchin Limestone Member)	UC4	← <i>G. nanum</i> , <i>G. theta</i>							
		UC3	← <i>G. segmentatum / G. obliquum</i> , Consistent <i>C. anfractus</i>												
							UC2	← <i>C. kennedyi</i> , <i>G. praeboliquum</i> , <i>influx B. constans</i>							
							UC1								



Merlin (2020)

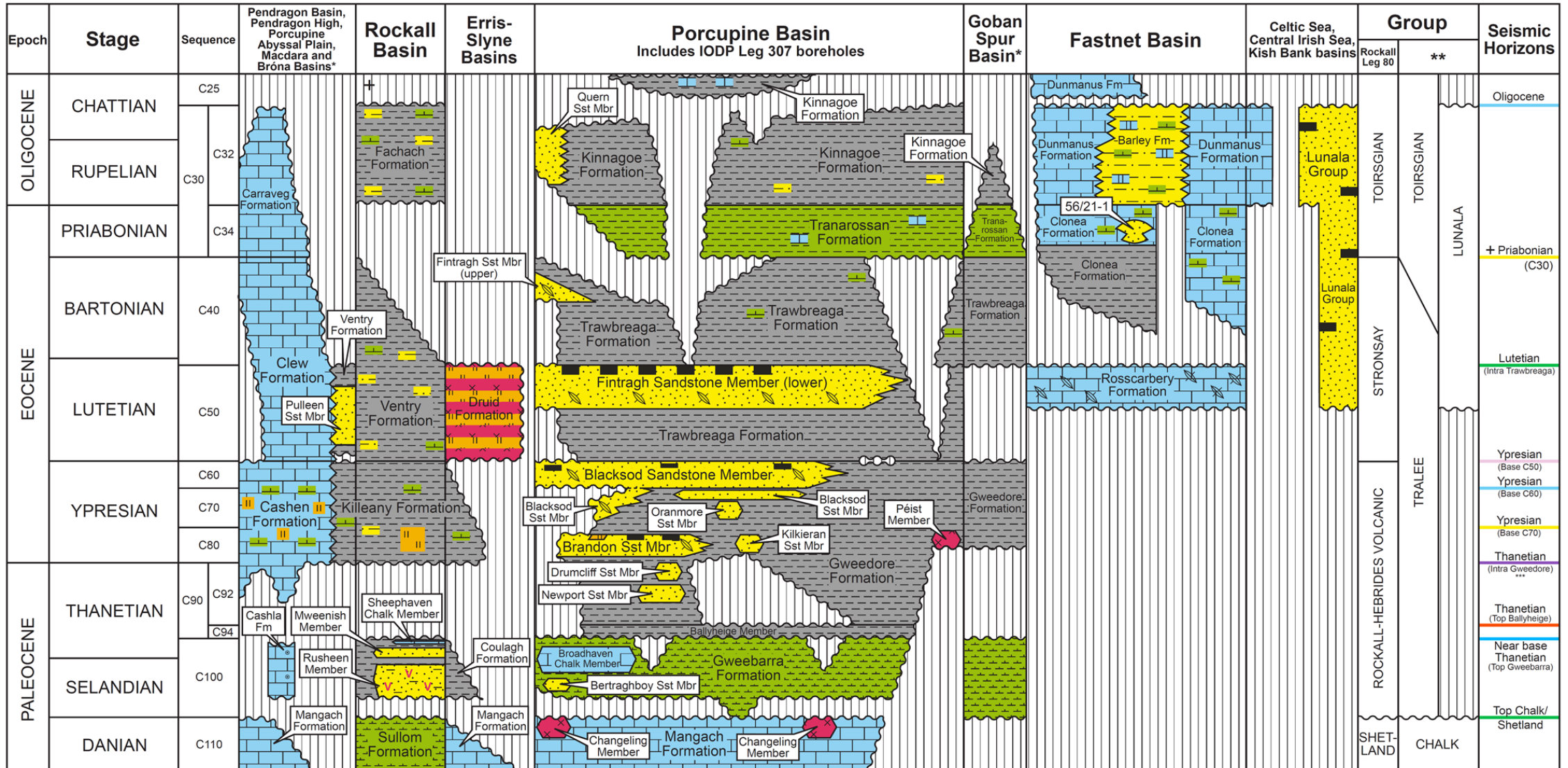


Late Cretaceous stratigraphic scheme for offshore Ireland



Merlin (2020)

Paleogene stratigraphy of offshore Ireland



Merlin (2020)

* Leg 80 boreholes, 83/20 & 16/28 shallow boreholes

+Upper age limit of Fachach Formation based on seismic interpretation. Top not seen in 5/22-1 Well

* All section above the pink seismic horizon is based on seismic data alone (no returns in 62/7-1 well)

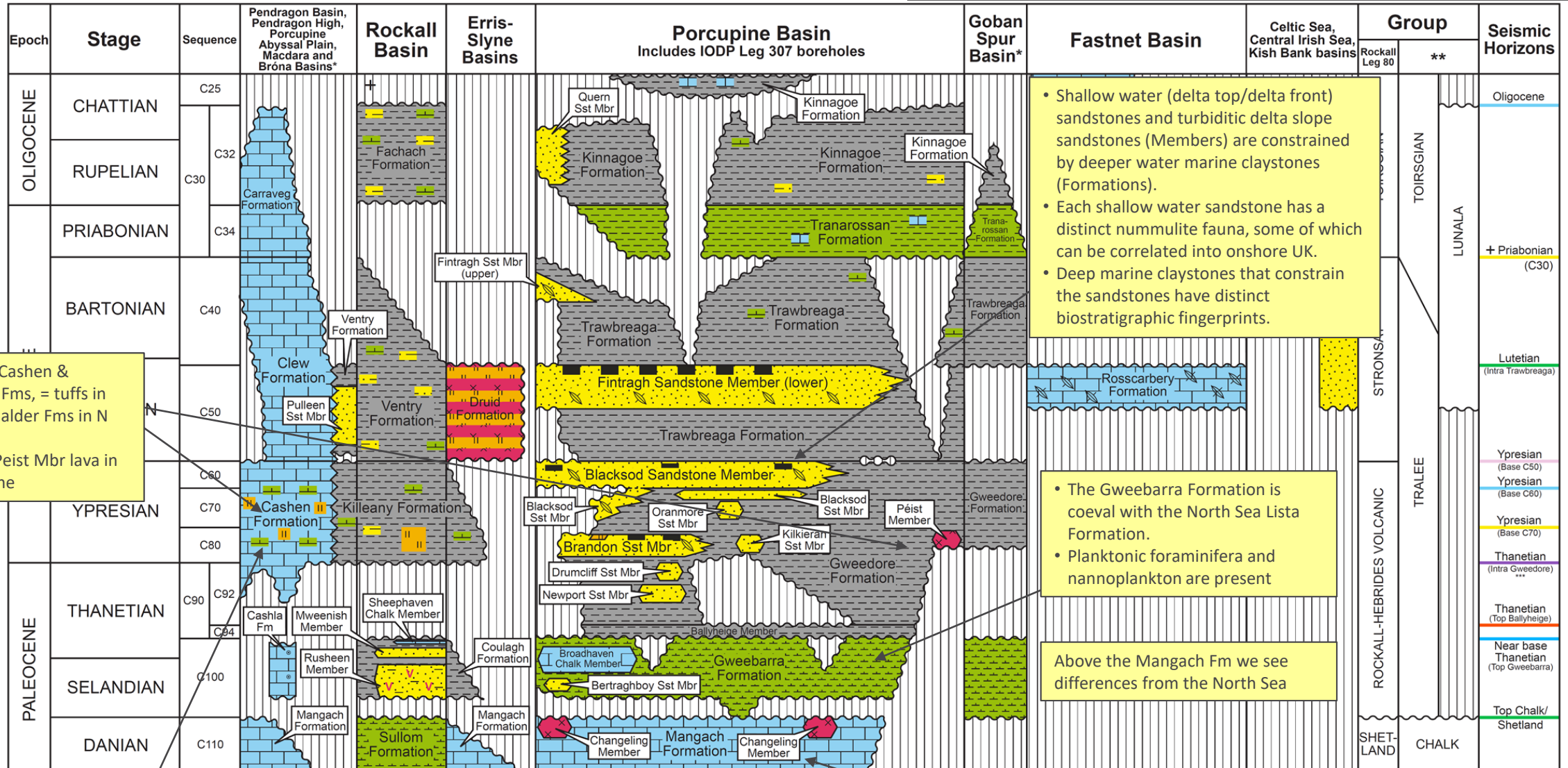
** Erris, Slyne, Porcupine, Goban Spur, Fastnet, Celtic Sea, Central Irish Sea, Kish Bank basins

*** Thanetian (Top Coulagh) (Rockall Basin)
+Priabonian seismic horizon variable in its tie to Clonea Fm

Paleogene stratigraphy of offshore Ireland

THE MOST DETAILED STRATIGRAPHY OF ALL INTERVALS HAS BEEN DEFINED FOR THE TERTIARY

- Good biostratigraphy (on the whole)
- Complex lithostratigraphy (including lateral variations)
- Good seismic data quality (especially west of Ireland)
- Complex sequence stratigraphy & unconformity development



• Shallow water (delta top/delta front) sandstones and turbiditic delta slope sandstones (Members) are constrained by deeper water marine claystones (Formations).
 • Each shallow water sandstone has a distinct nummulite fauna, some of which can be correlated into onshore UK.
 • Deep marine claystones that constrain the sandstones have distinct biostratigraphic fingerprints.

• The Gweedarra Formation is coeval with the North Sea Lista Formation.
 • Planktonic foraminifera and nannoplankton are present

Above the Mangach Fm we see differences from the North Sea

• Tuffs in Cashen & Killeany Fms, = tuffs in Sele & Balder Fms in N Sea.
 • Coeval Peist Mbr lava in Porcupine

DSDP leg 80 Boreholes: Deep marine biogenic chalks rich in plank forams & calc nannos.

Danian age Mangach Formation comparable (but not contiguous) with the Ekofisk Formation in the North Sea. Contains volcanic Changeling Member

** Erris, Slyne, Porcupine, Goban Spur, Fastnet, Celtic Sea, Central Irish Sea, Kish Bank basins

Merlin (2020)

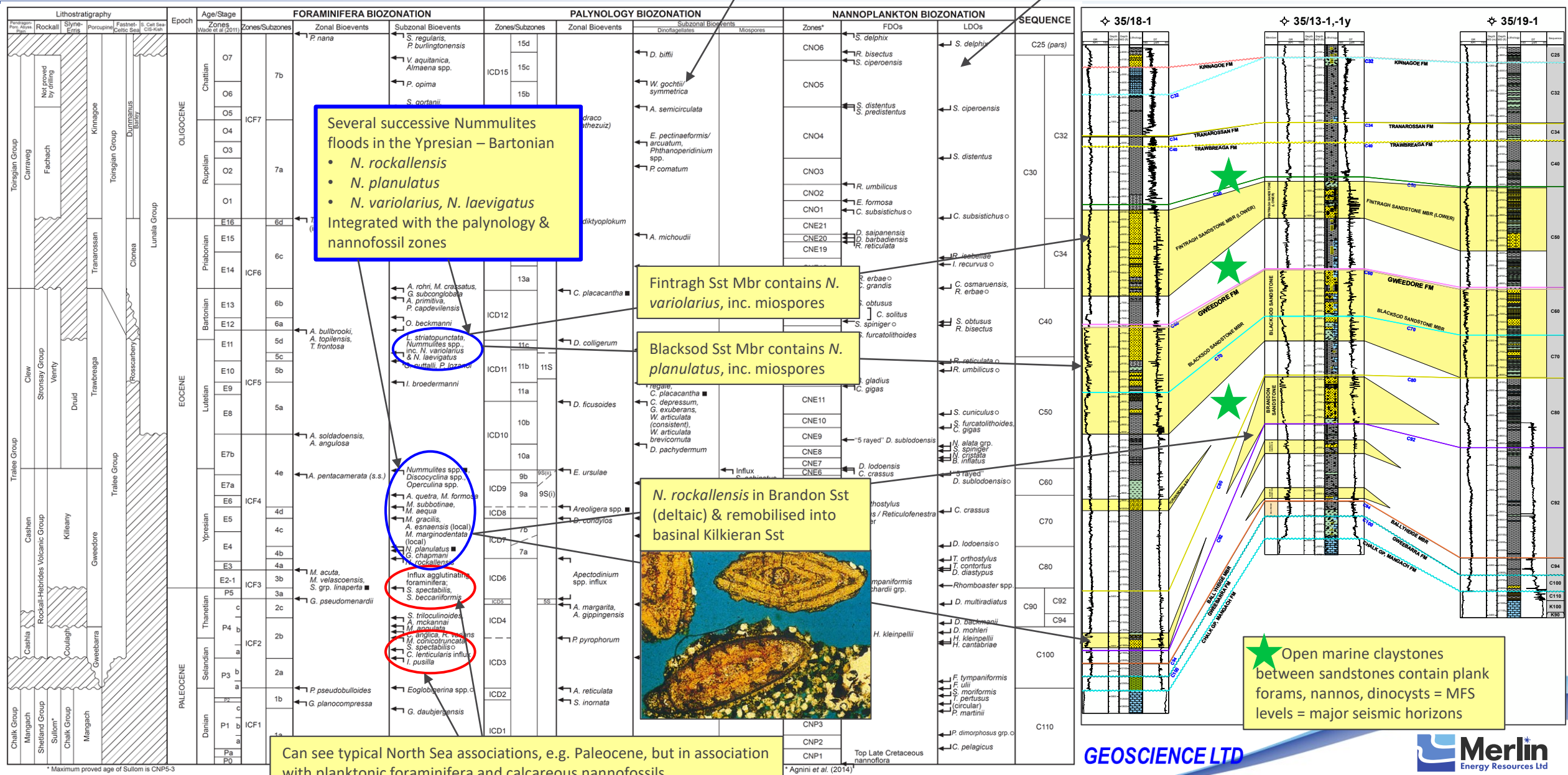


Paleogene biozonation schemes

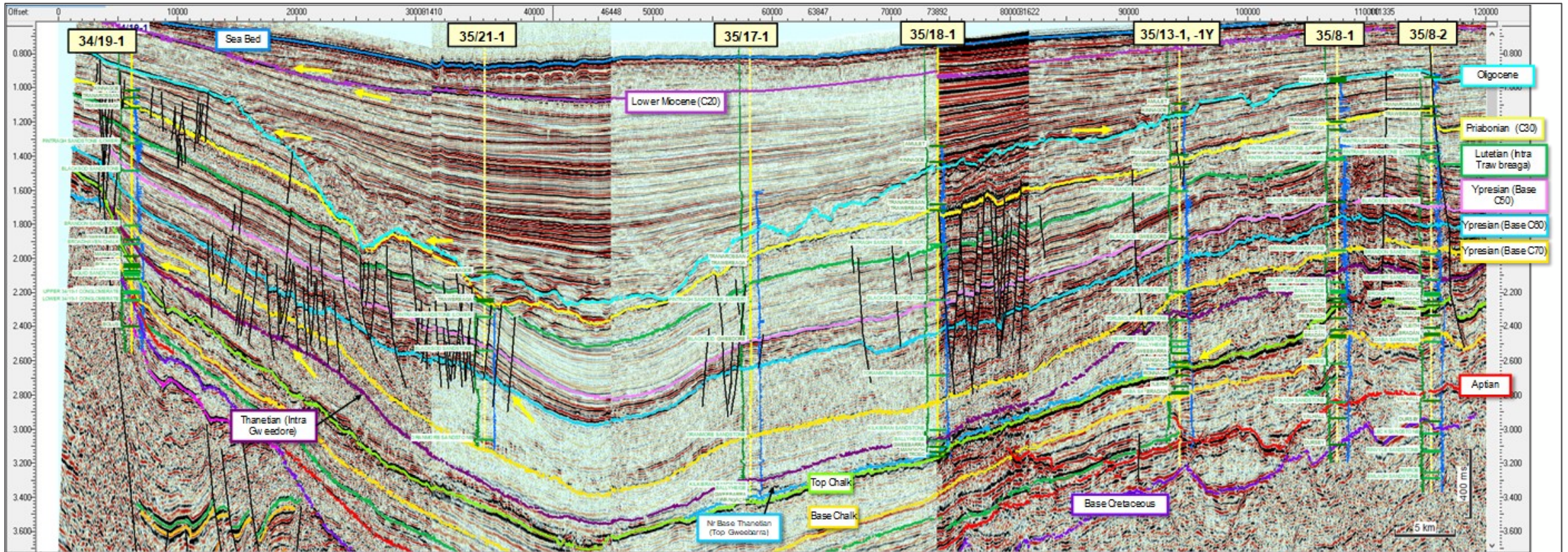
- Detailed palynology biozonation throughout the Tertiary.
- Compares with North Sea

- Detailed calcareous nannofossil biozonation throughout the Tertiary.
- Generally not seen in North Sea

Merlin (2020)



Seismic line across Porcupine Basin showing complexity of Tertiary seismic sequences



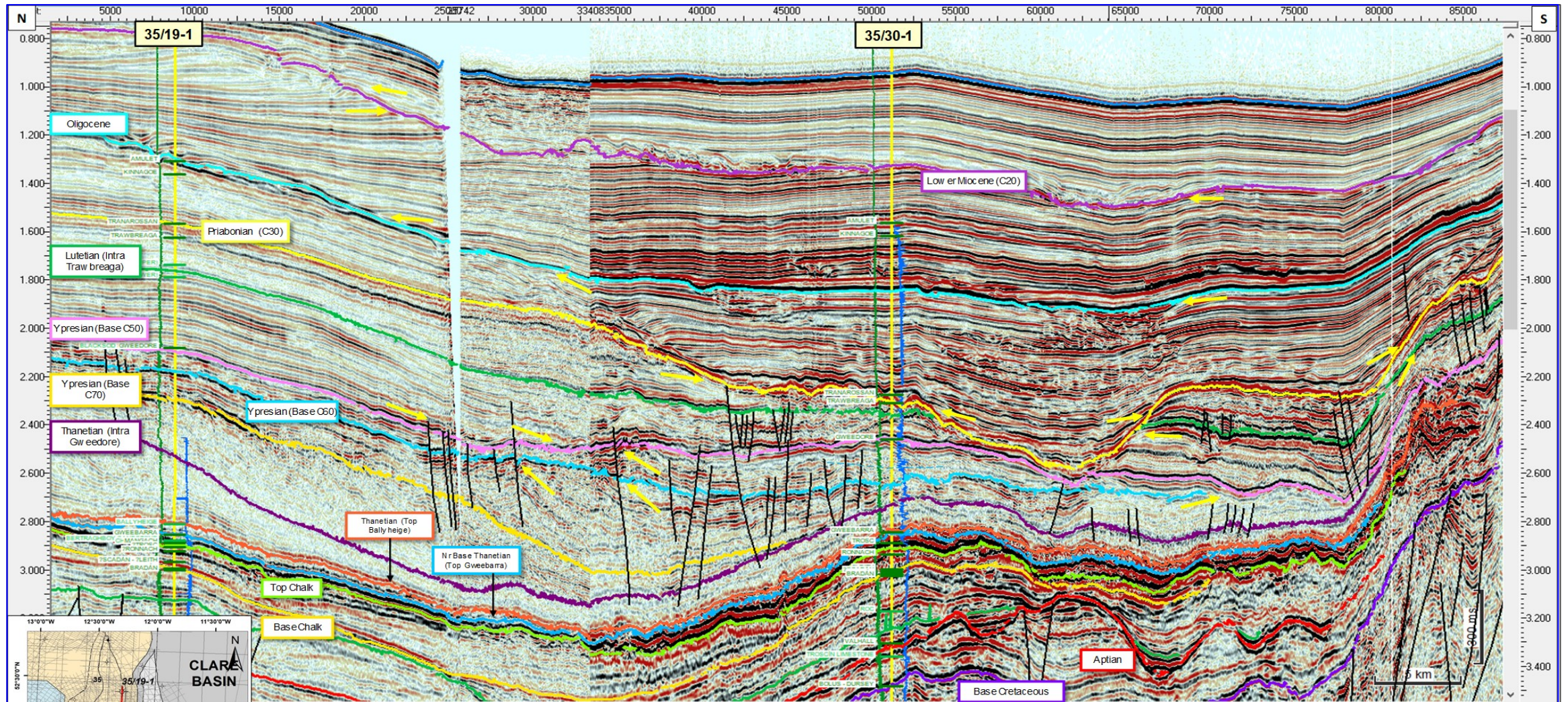
2D data

Arbitrary line across several surveys

Yellow arrows=seismic reflection terminations



Seismic line across Porcupine Basin showing complexity of Tertiary seismic sequences



Arbitrary line across several surveys

Yellow arrows=seismic reflection terminations

In conclusion

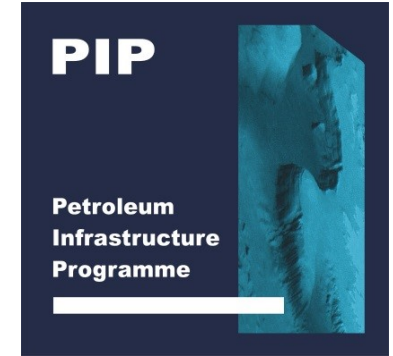
- Study represents a unique (to our knowledge), whole country, highly detailed stratigraphic data set
 - much more detail than any of the released OGA studies in the UKCS
 - Irish authorities and the sponsoring companies are to be commended for releasing this data publicly
- Good example of multiproxy stratigraphic approach to the evaluation of a whole country
- Will provide a foundation for all future geoscience work in the offshore Ireland area
 - oil & gas, carbon capture, utilisation & storage, geothermal, geohazard, academia etc
- Key comparative data set for the wider North Atlantic region
- Is this a possible model for other offshore country jurisdictions to follow?
- Today we have only been able to touch on certain aspects of the study. We would be pleased to discuss any other aspects of the study separately.

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Department of Communications,
Climate Action & Environment



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