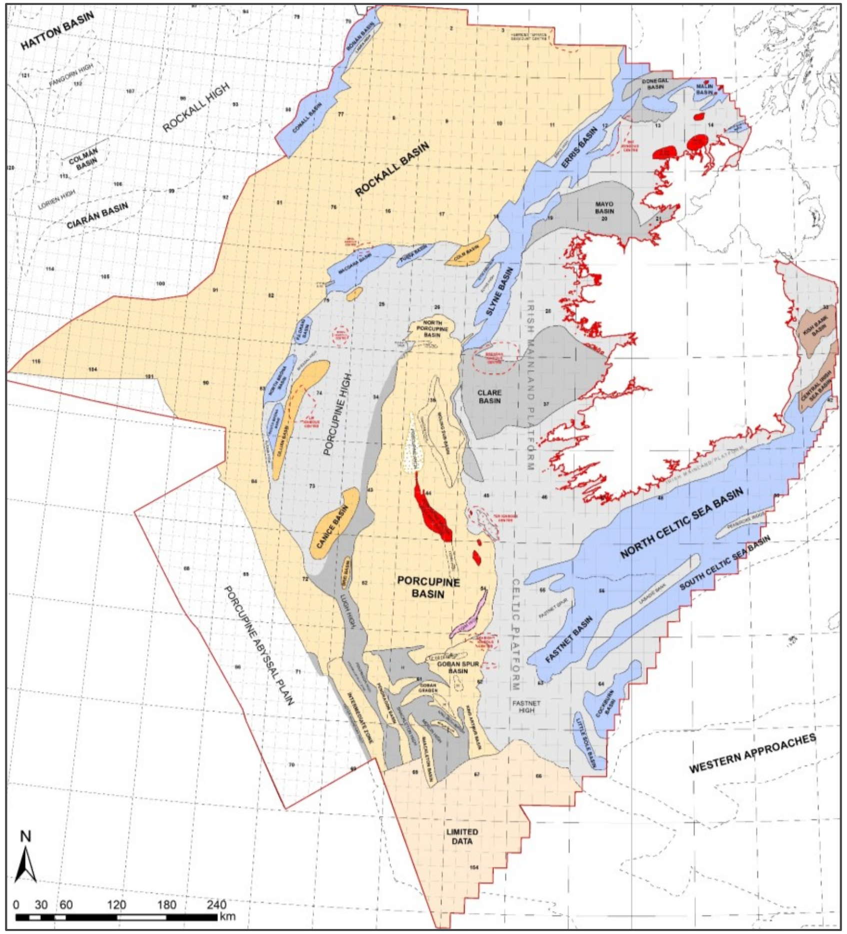
Offshore Ireland: a whole new story

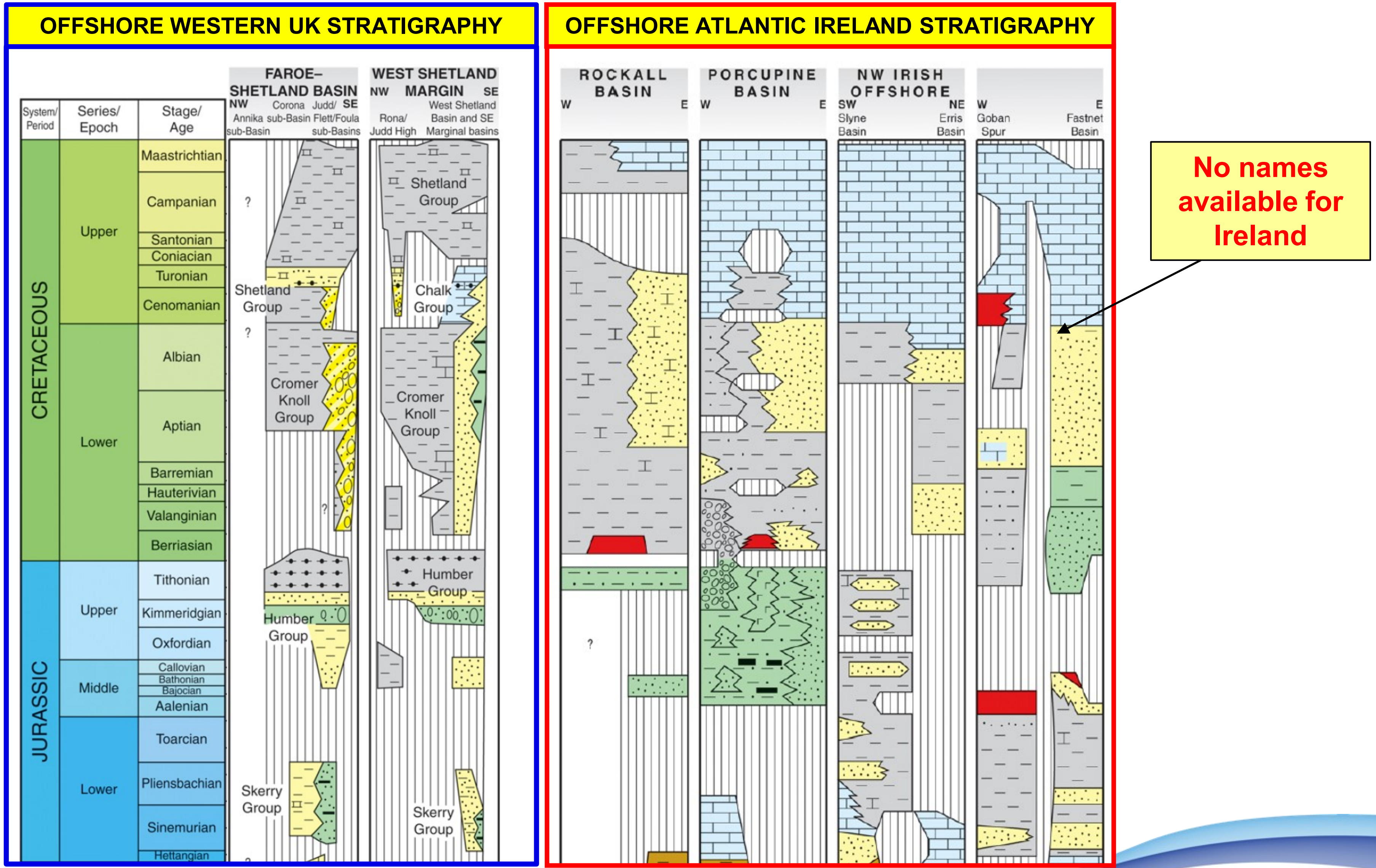
Ainsworth, N. R.[2], Gallagher, L. T.[3], Hampton, M.[3], **Copestake, P.**[1]

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



Background

- Prior to 2016, no standard stratigraphy scheme has ever been previously defined for offshore Ireland
- Despite the long history of hydrocarbon exploration in Ireland (the first offshore well was drilled in 1970)
- Including gas production (Kinsale Head) since 1971



Stoker *et al.* (2016)

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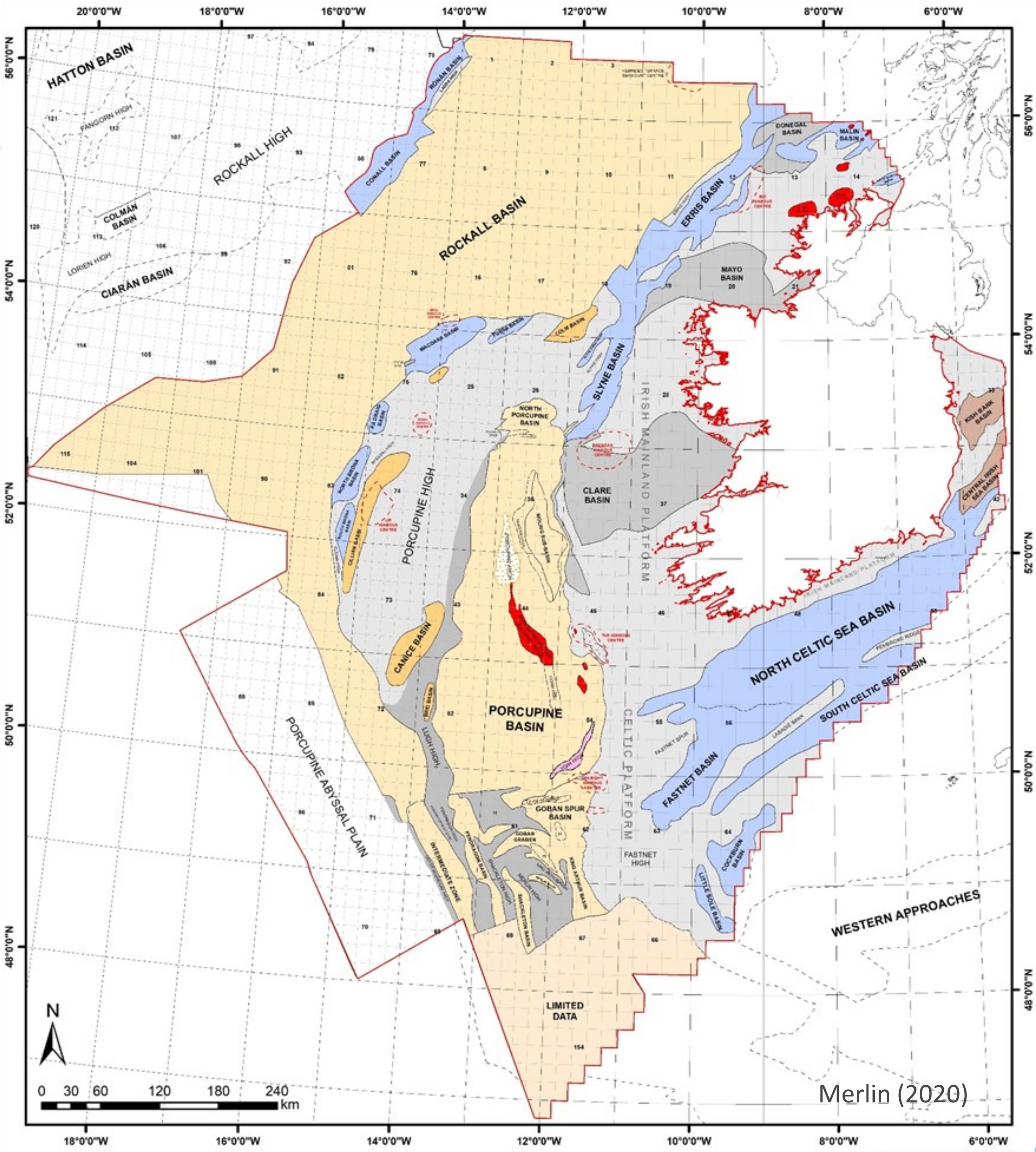
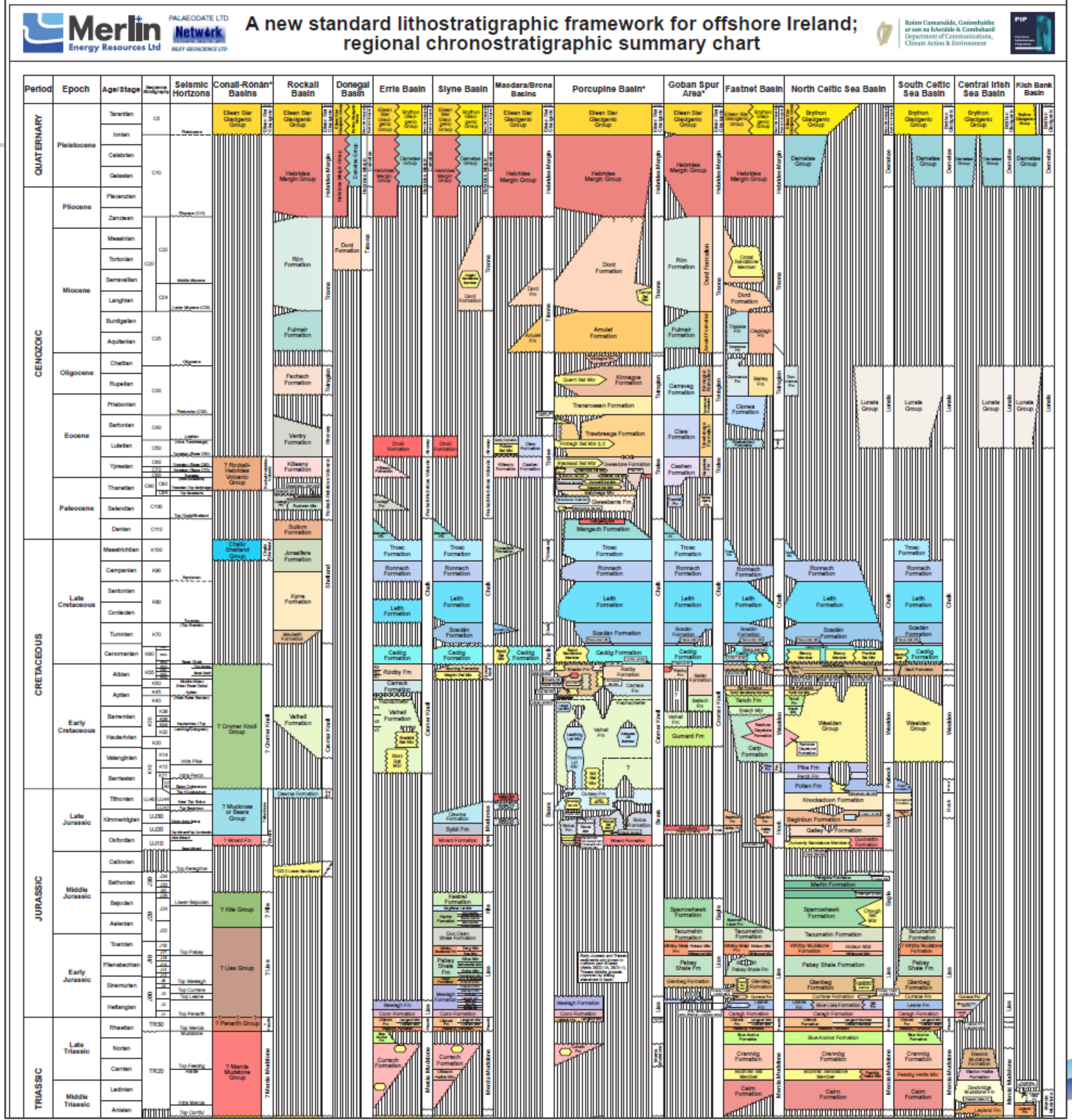
Background & Presentation Aims

- 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



Merlin (2020)

New lithostratigraphic framework for offshore Ireland



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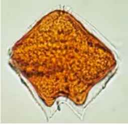
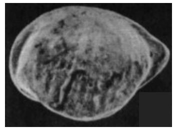
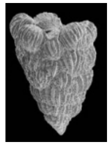
Merlin Consortium Members

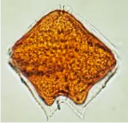
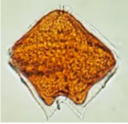
The Biostratigraphic Team

Merlin Energy Resources Ltd ……………………………..Phil Copestake  , Tony Loy 

PALAEODATE LTD ……………………..Nigel Ainsworth  

Network Stratigraphic Consulting Limited ……………………………..Liam Gallagher  , Matt Hampton  ,

Haydon Bailey 

RILEY GEOSCIENCE LTD……………………Les Riley , Keith Gueinn 

IGI Integrated Geochemical Interpretation

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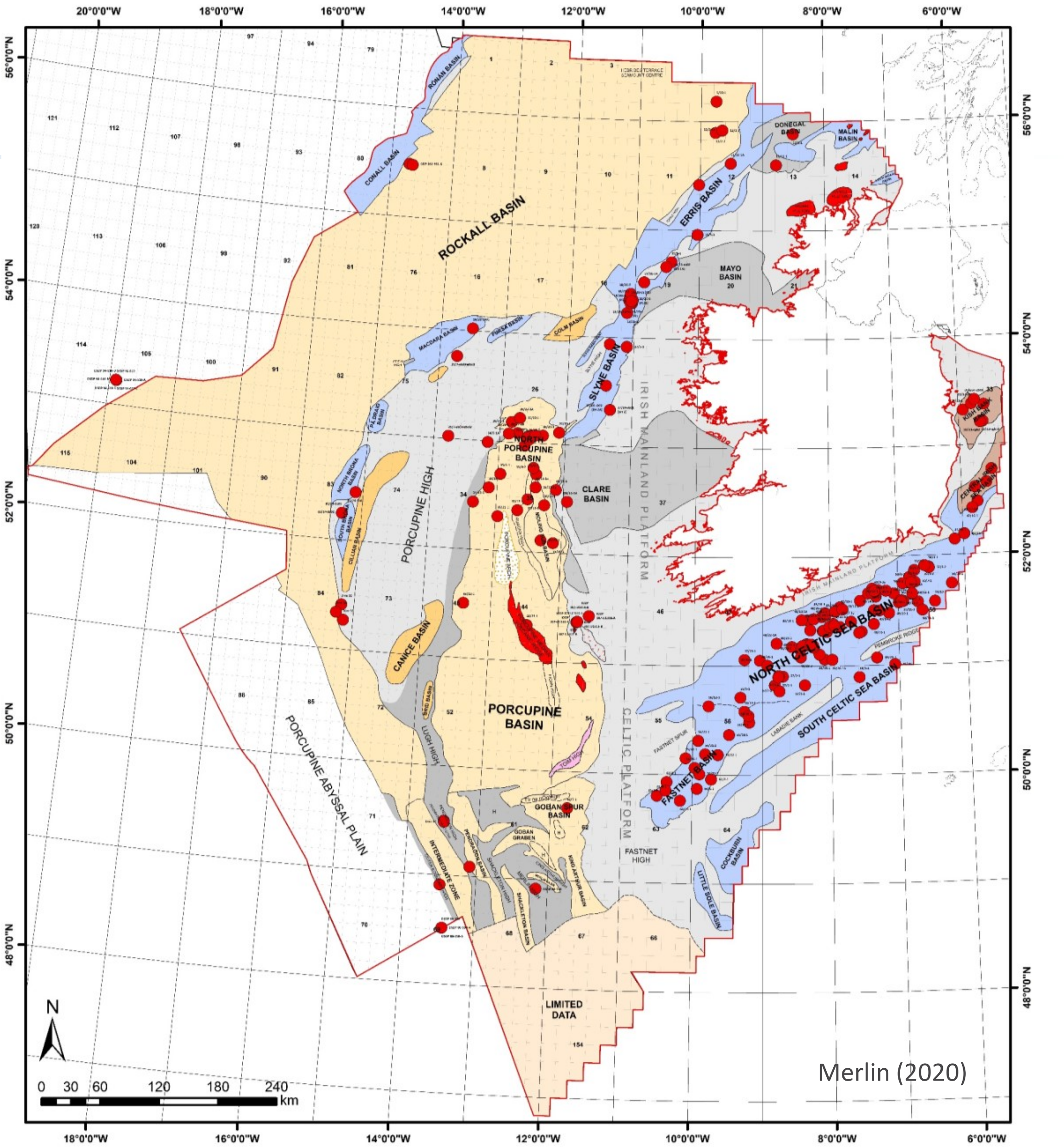
Well & borehole database

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



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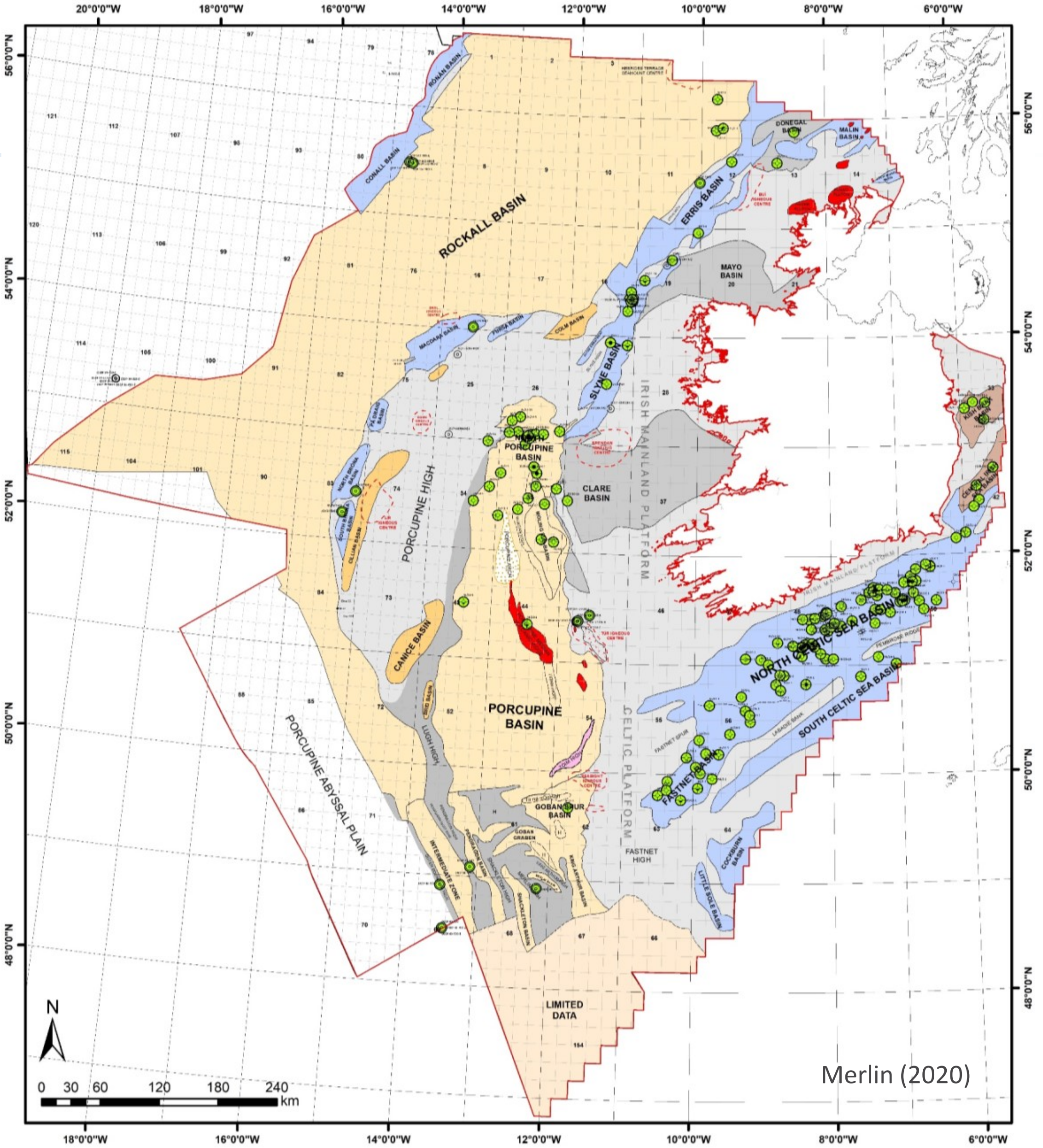
Wells & boreholes with legacy biostratigraphic data

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



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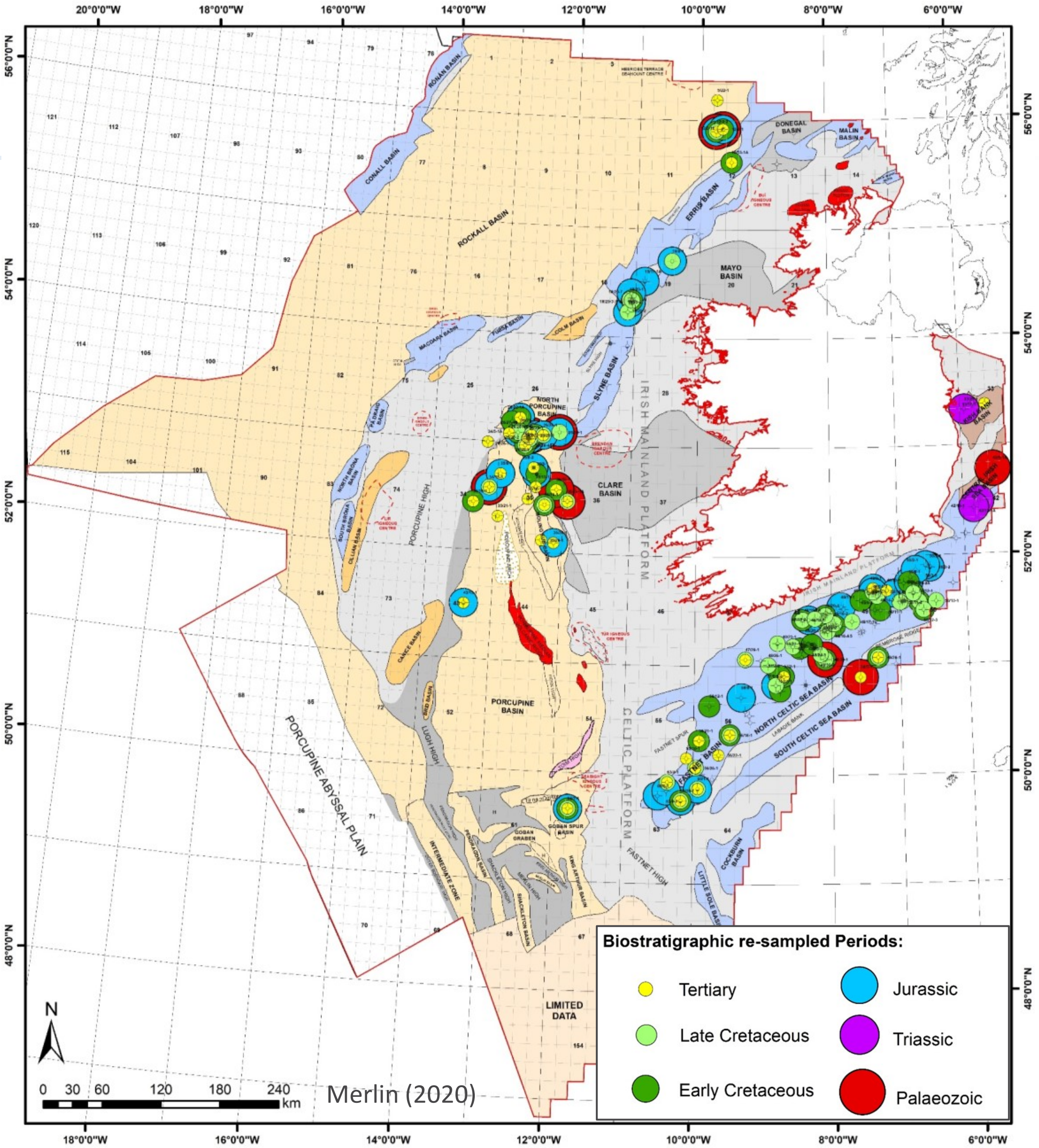
New biostratigraphic analysis

- 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

StrataBugs
Biostratigraphic Computing



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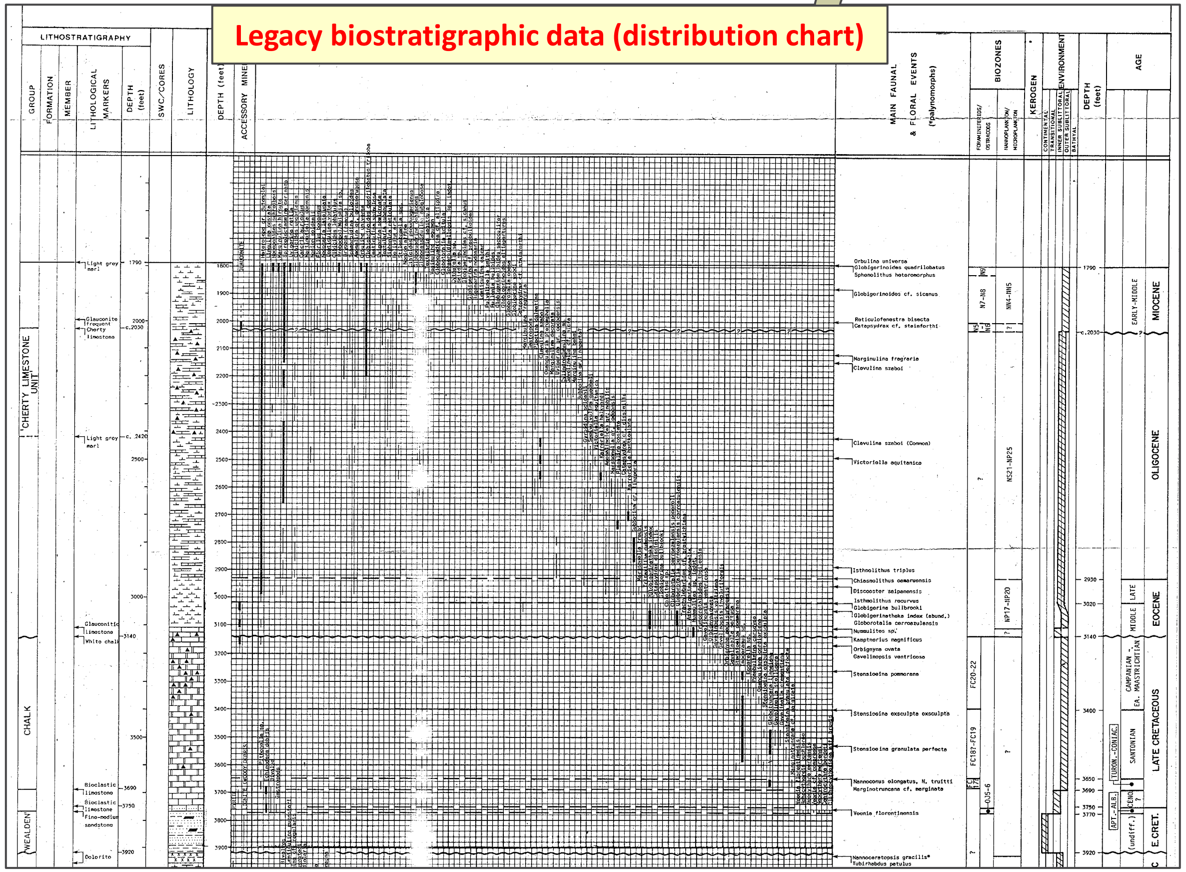
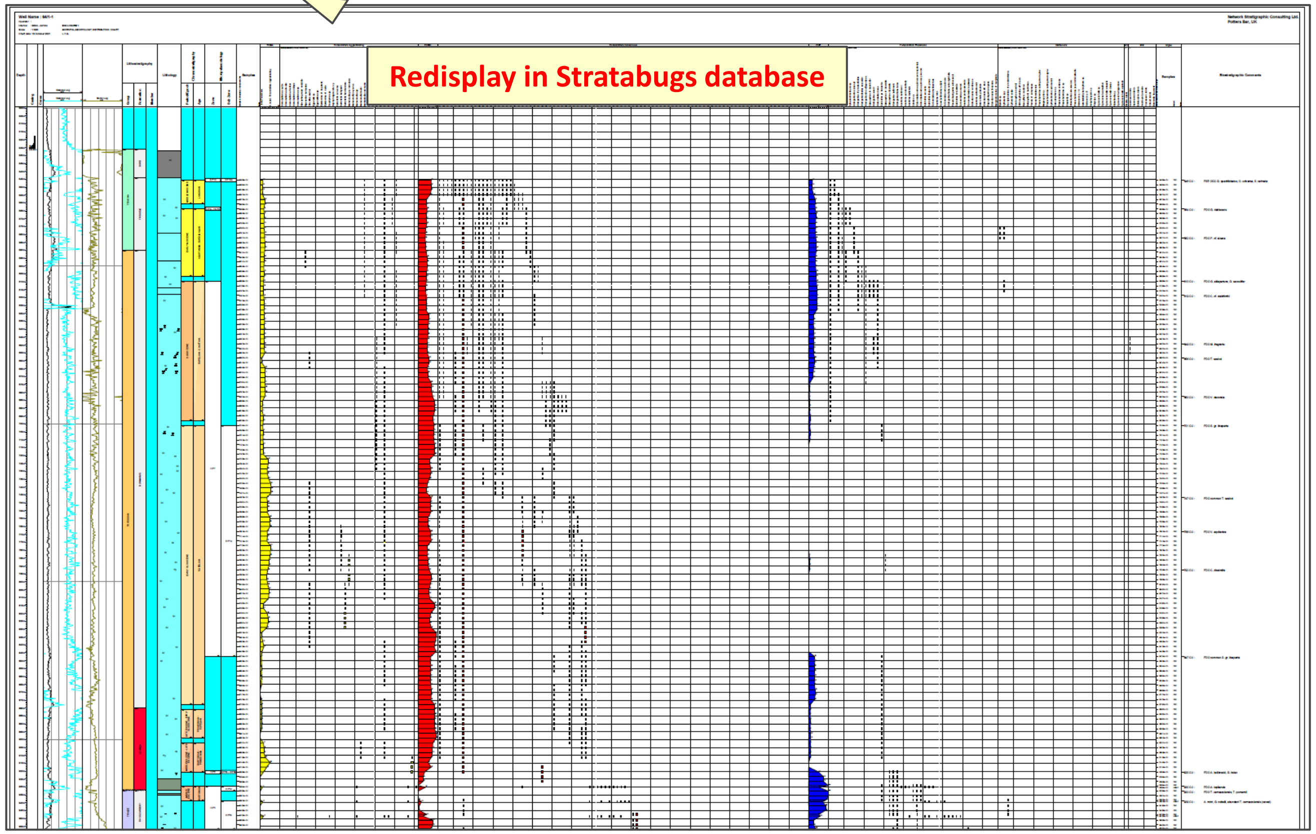
Biostratigraphic databases created; *StrataBugs*

StrataBugs
Biostratigraphic Computing

- All legacy biostratigraphic data (inc. distribution charts) incorporated into newly created *StrataBugs* database





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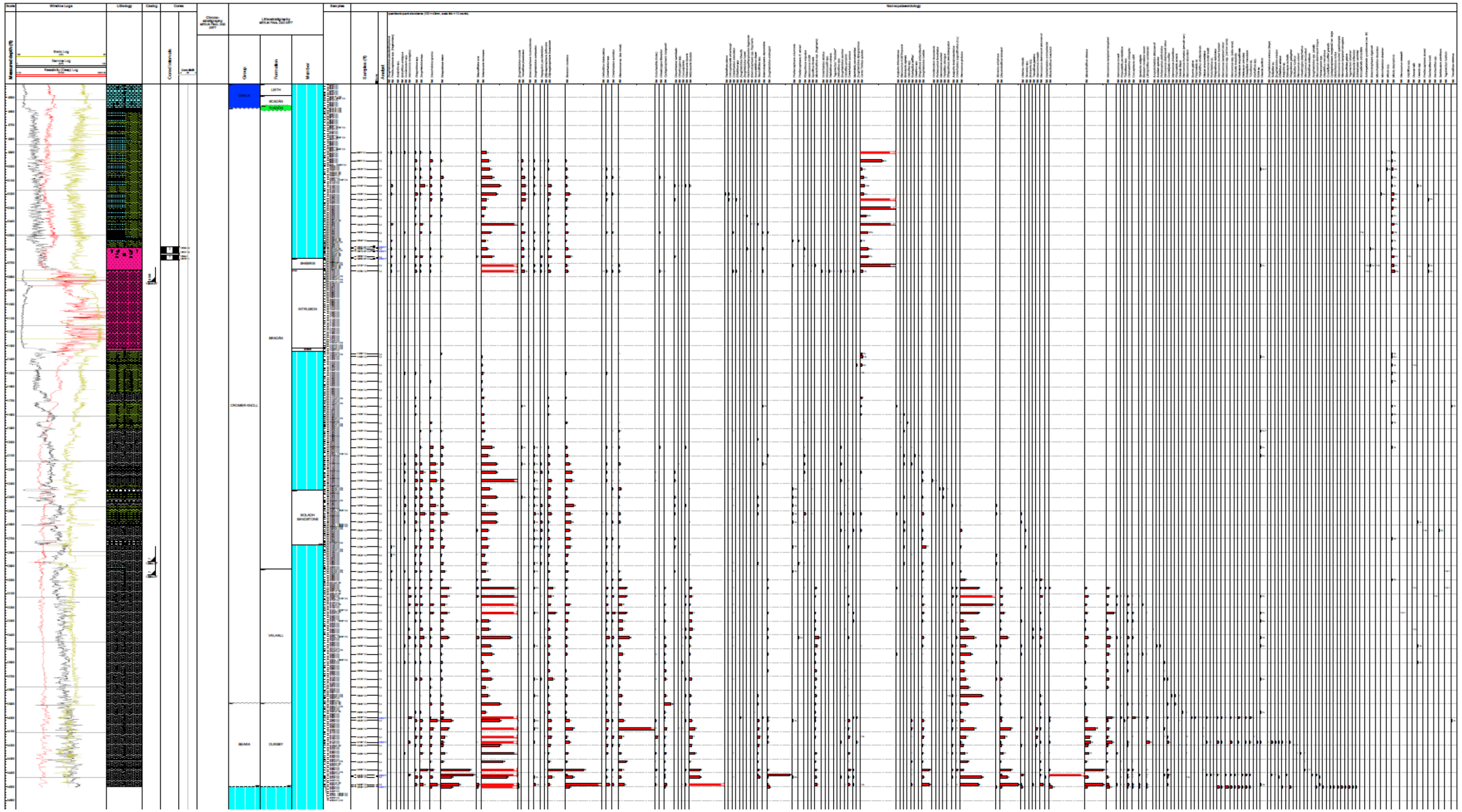
Biostratigraphic databases created; *StrataBugs*

StrataBugs
Biostratigraphic Computing

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



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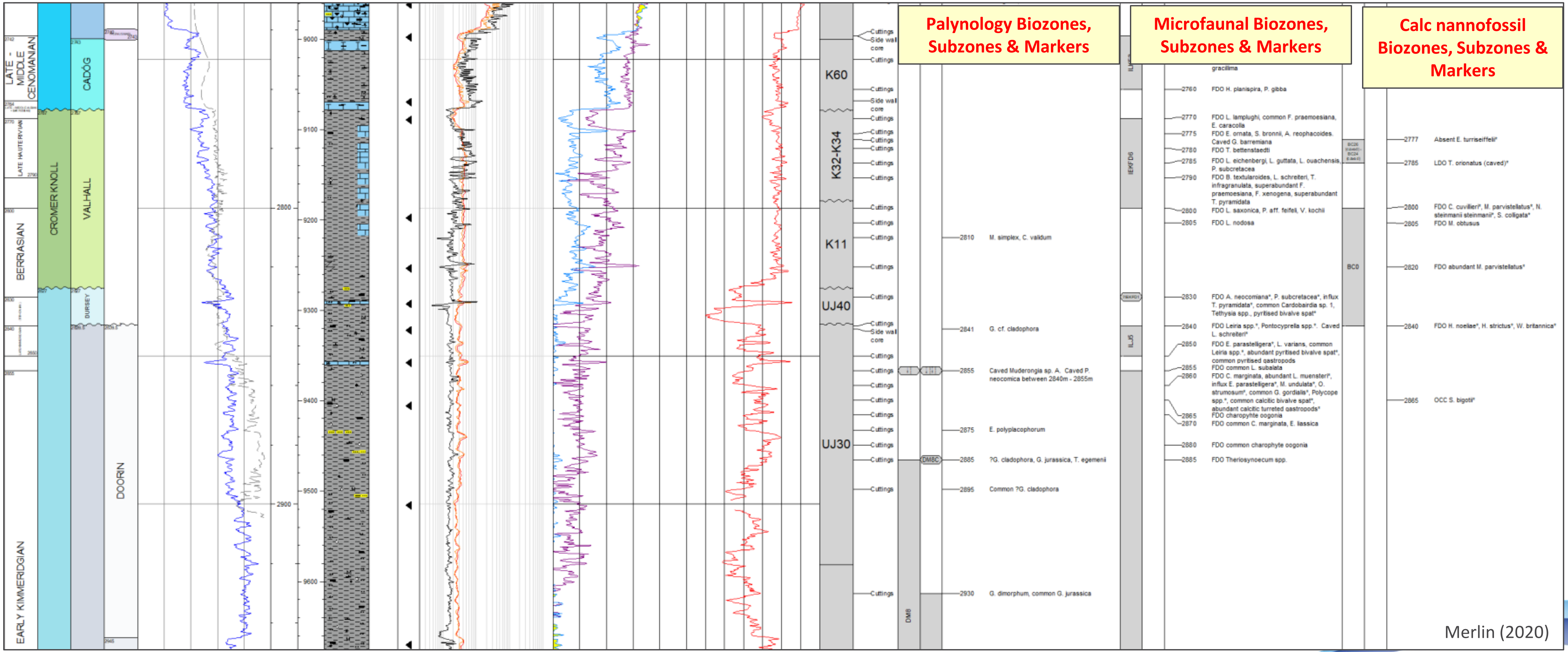
Biostratigraphic databases created; IC

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 biostratrigraphy 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 int Late Oxfordian, age, which lies in the lower half of the Muckross Group, within the Slyne Basin. These sediments may al extend into the Conall, Rónán and Rockall basins. This formation is the lower formation of the Muckross Group. It is overla 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 Ternan (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 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 a dolomite stringers. Rare sandstones 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 sil or sandy, grains clear, very fine to fine grained, subrounded, non to slightly calcareous, subblocky to subfissile, and gradi into siltstones. The thin limestones and dolomites are pale yellowish grey, greyish orange to dark yellowish orange, mudstor microcrystalline, and well indurated. The thin interbedded sandstones are transparent, pale brown, olive grey, locally lig 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 19/1 1A well.

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

Upper boundary. The upper boundary is marked by a downsection lithological change from the organic-rich non-calcareo 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.

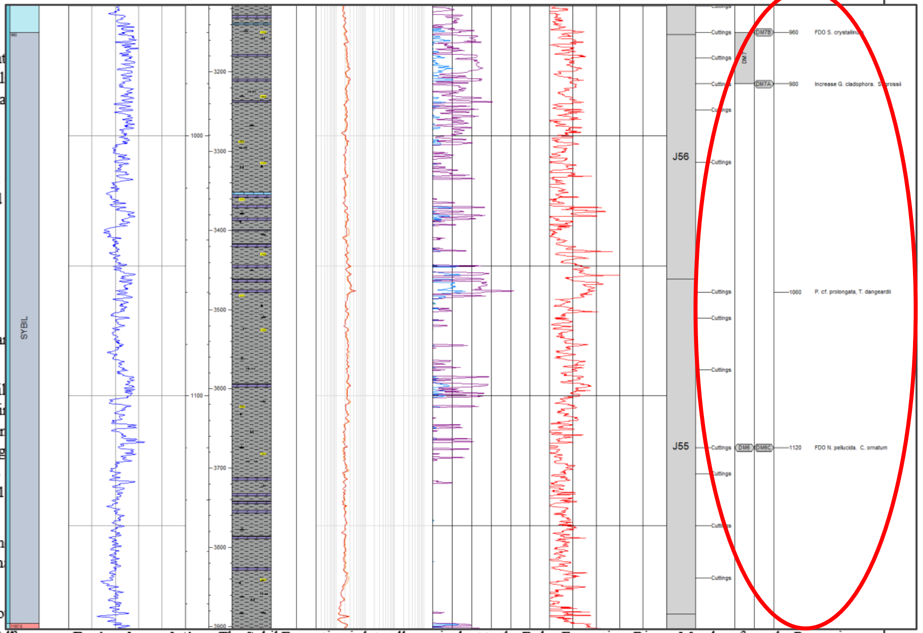
Subdivision. No subdivision is recognised.

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 Ampthill 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.

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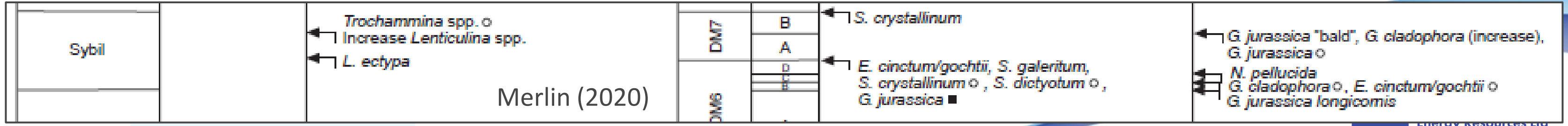

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How has the biostratrigraphy been used in the offshore Ireland area?

- Fossil assemblages used to indicate depositional environments

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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 deepening trend; initially a number of shallow water foraminiferal taxa (including *Palaeomiliolina* 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.

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 Ampthill 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.

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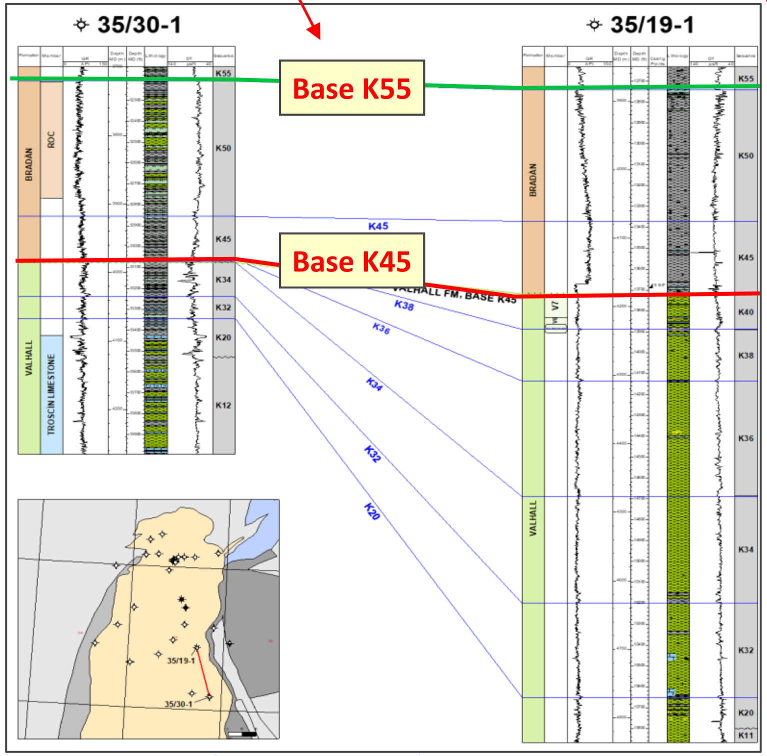
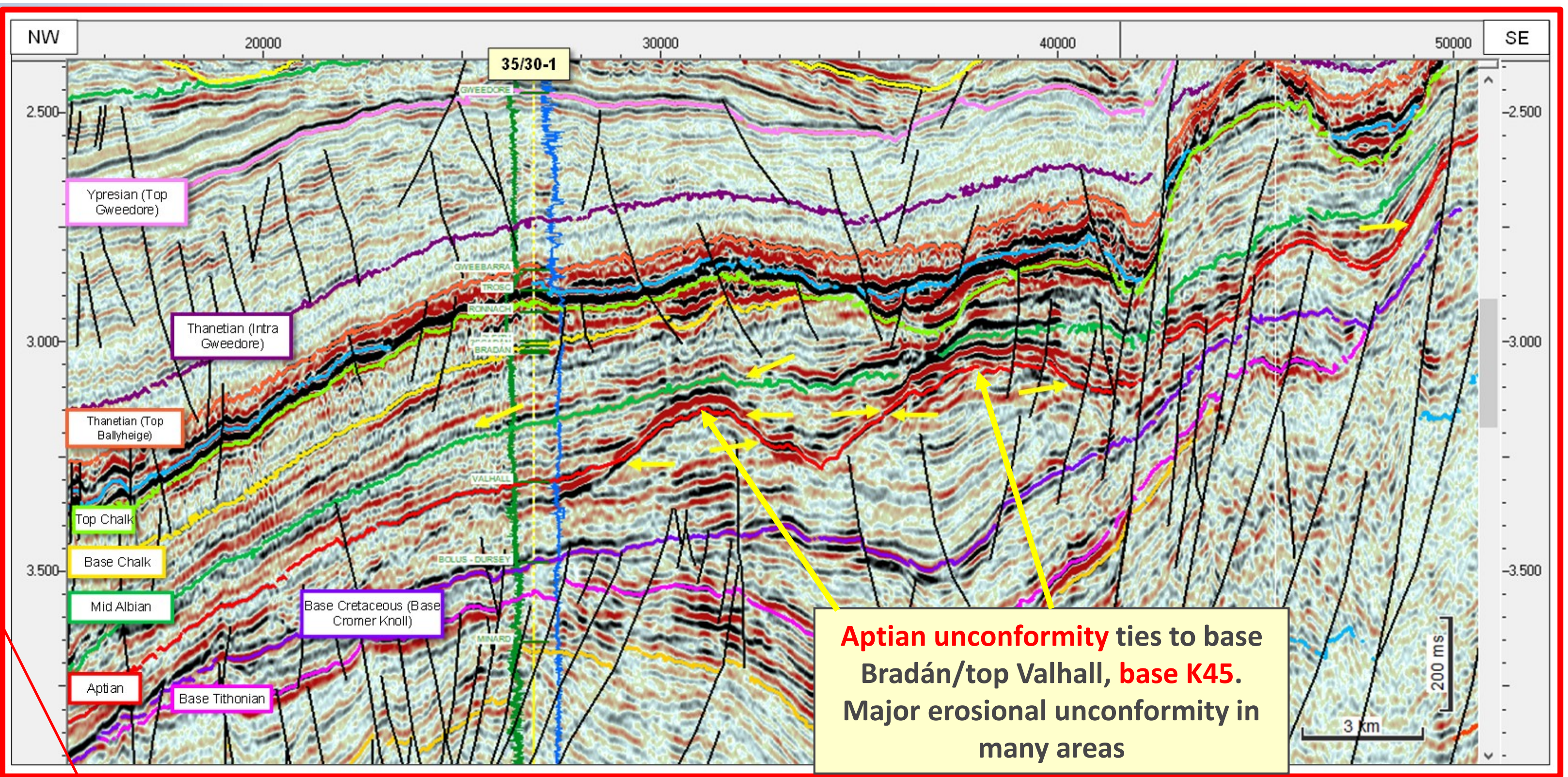
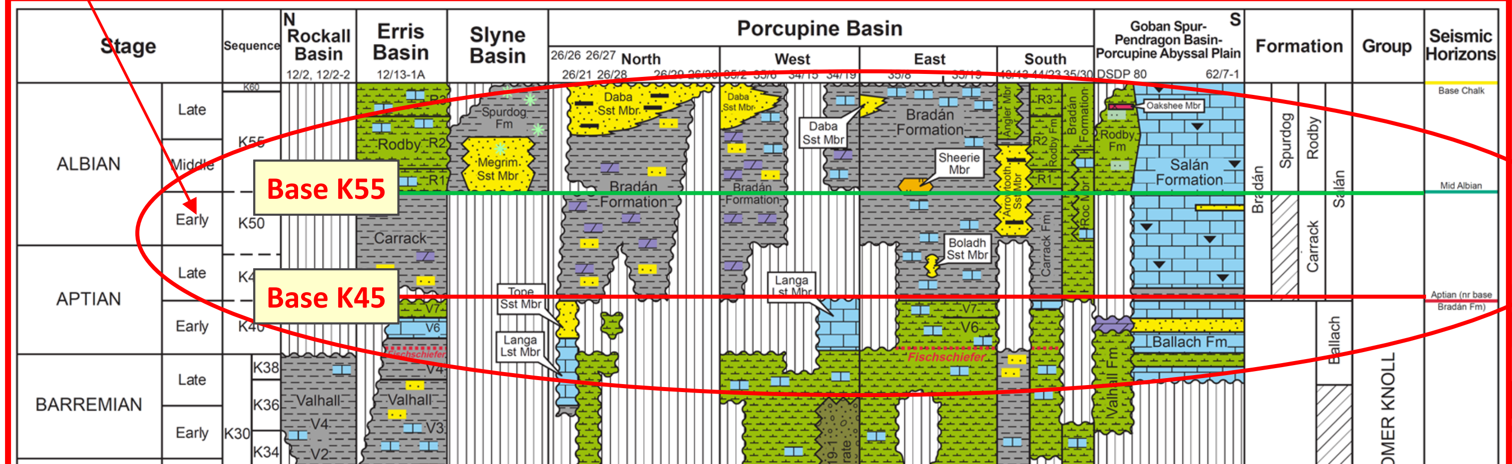
How has the biostratrigraphy been used in the offshore Ireland area?

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







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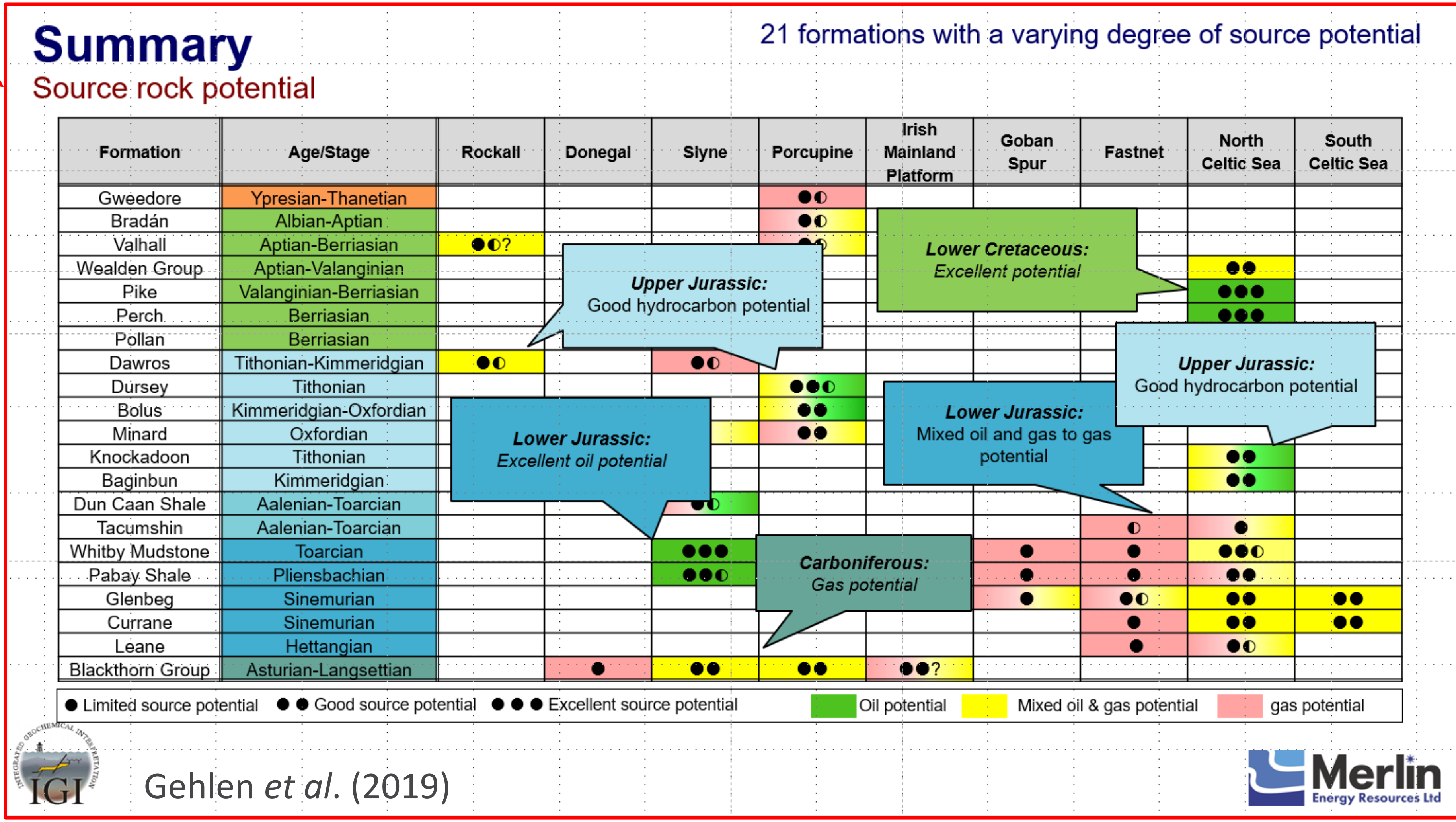
How has the biostratrigraphy been used in the offshore Ireland area?

- Age dating of source rock units



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	●◐?			●◐					
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-Langsettian		●	●●	●●	●●?				

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

Gehlen *et al*. (2019)

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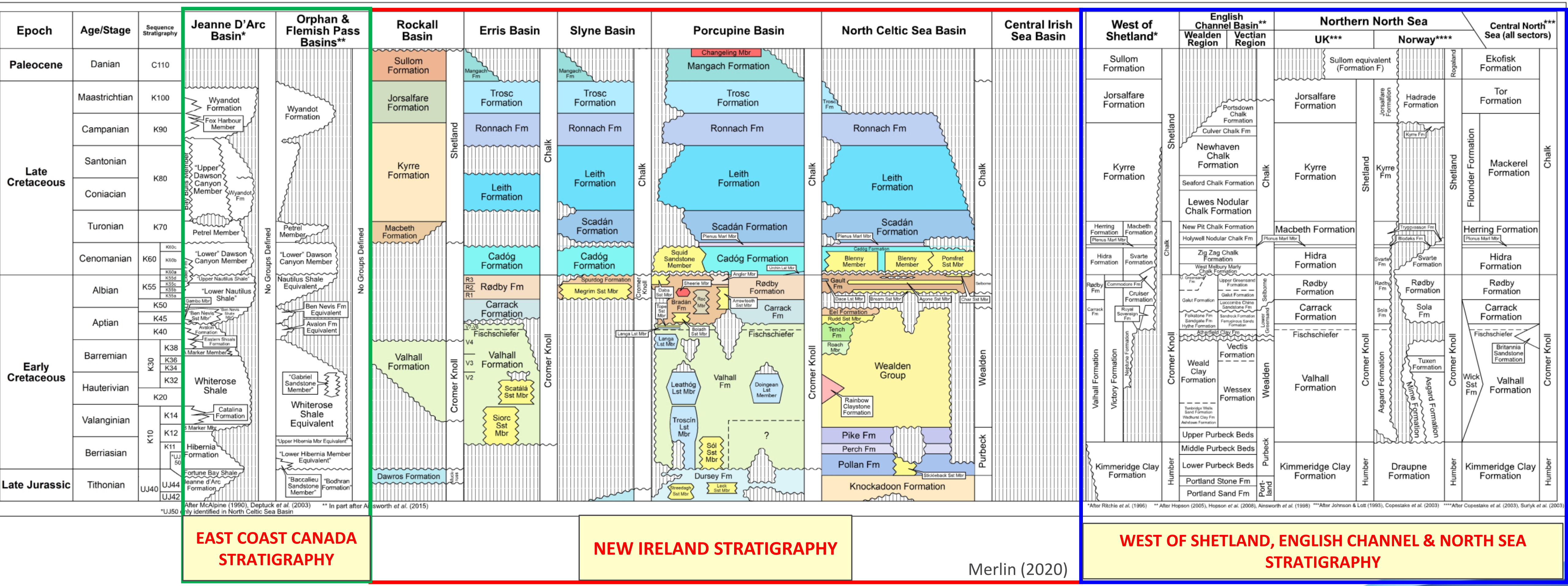
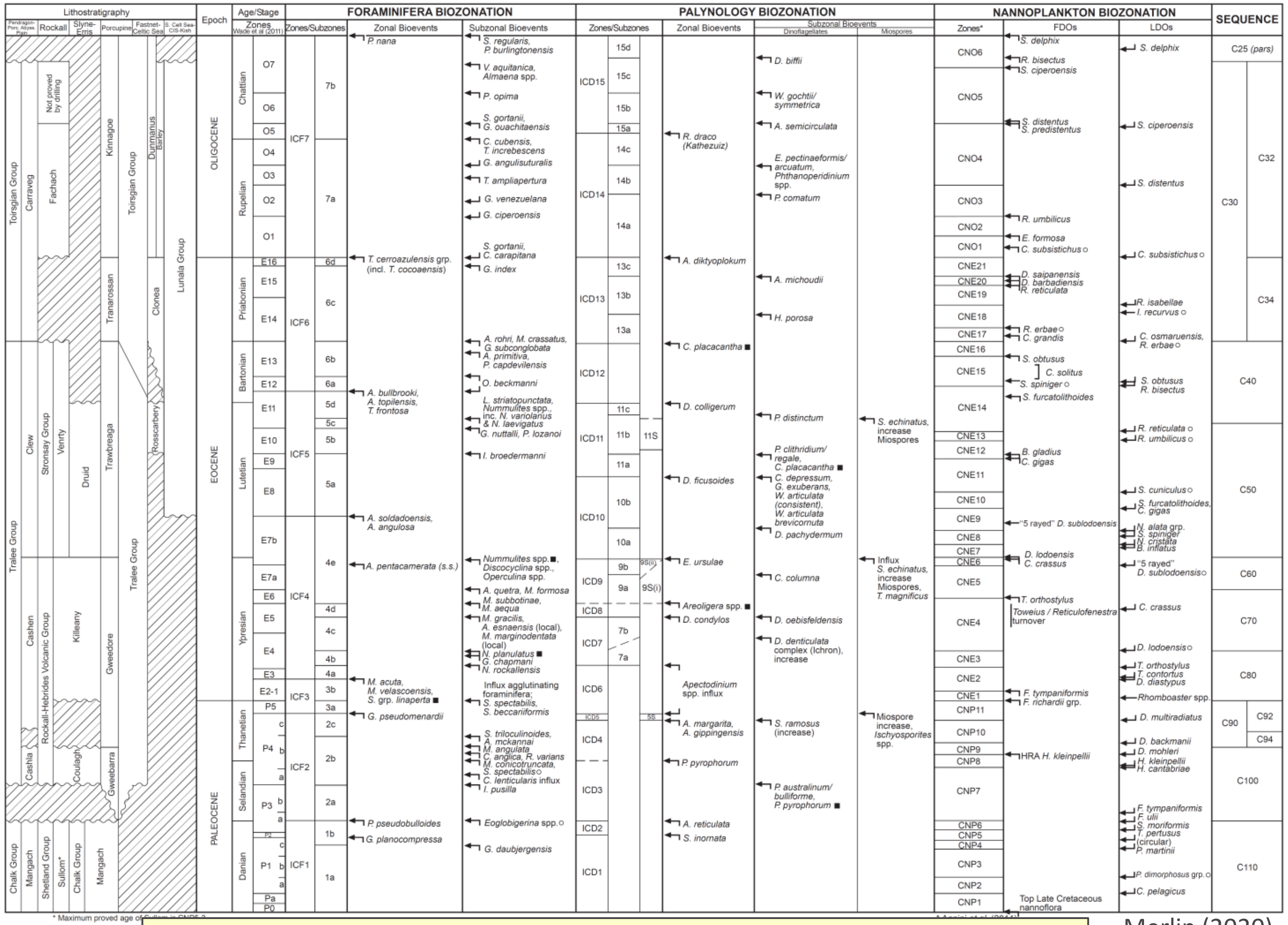
Biostratigraphy used as basis for regional correlation

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



Biozonation schemes

- New biozonation schemes defined for
  - Early – Middle Jurassic (palynology, foraminifera, ostracods)
  - Late Jurassic (palynology, foraminifera, ostracods, occasional radiolaria)
  - Early Cretaceous (palynology, foraminifera, ostracods)
  - Late Cretaceous (palynology, microfauna)
  - Cenozoic (palynology, microfauna)
- Existing biozonation schemes used in
  - Carboniferous
  - Triassic
  - Jurassic – Cenozoic for calcareous nannofossils



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Example; newly defined Cenozoic biozonation scheme for offshore Ireland

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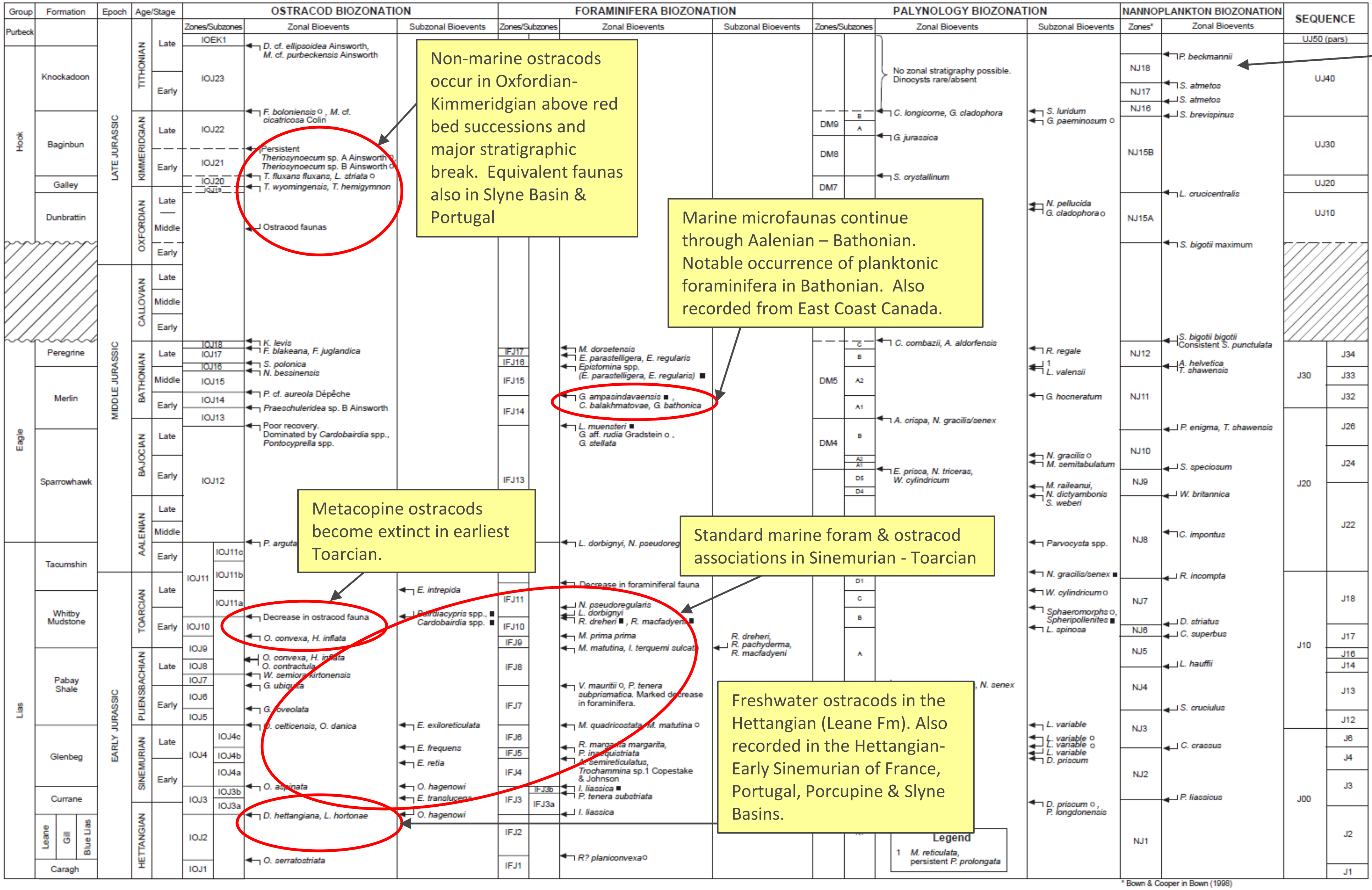
Jurassic biozonation scheme (Fastnet – North Celtic Sea Basins)



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

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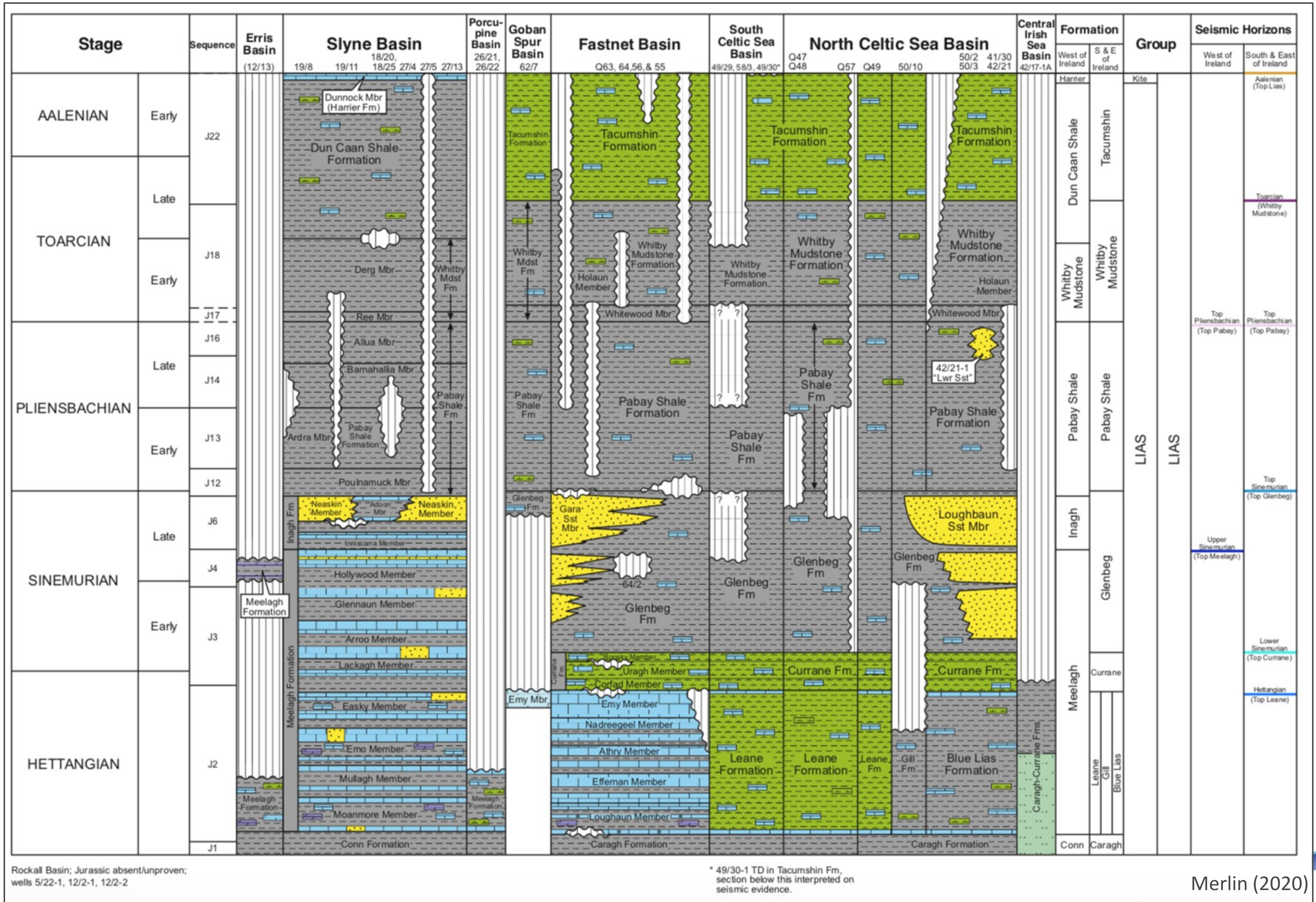
Stratigraphic scheme for Hettangian – Aalenian of offshore Ireland



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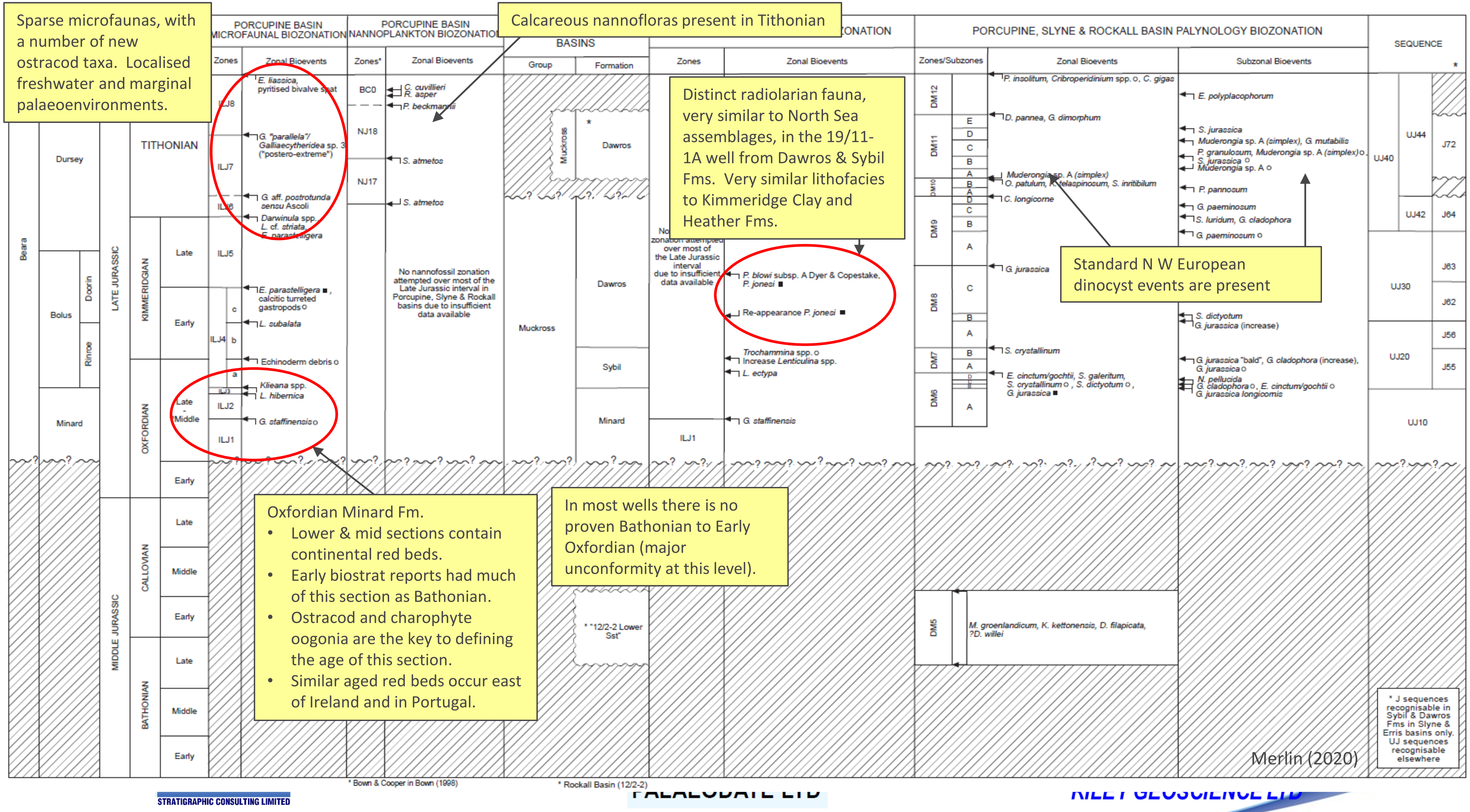
Late Jurassic biozonation scheme west of Ireland (Porcupine, Slyne & Rockall Basins)



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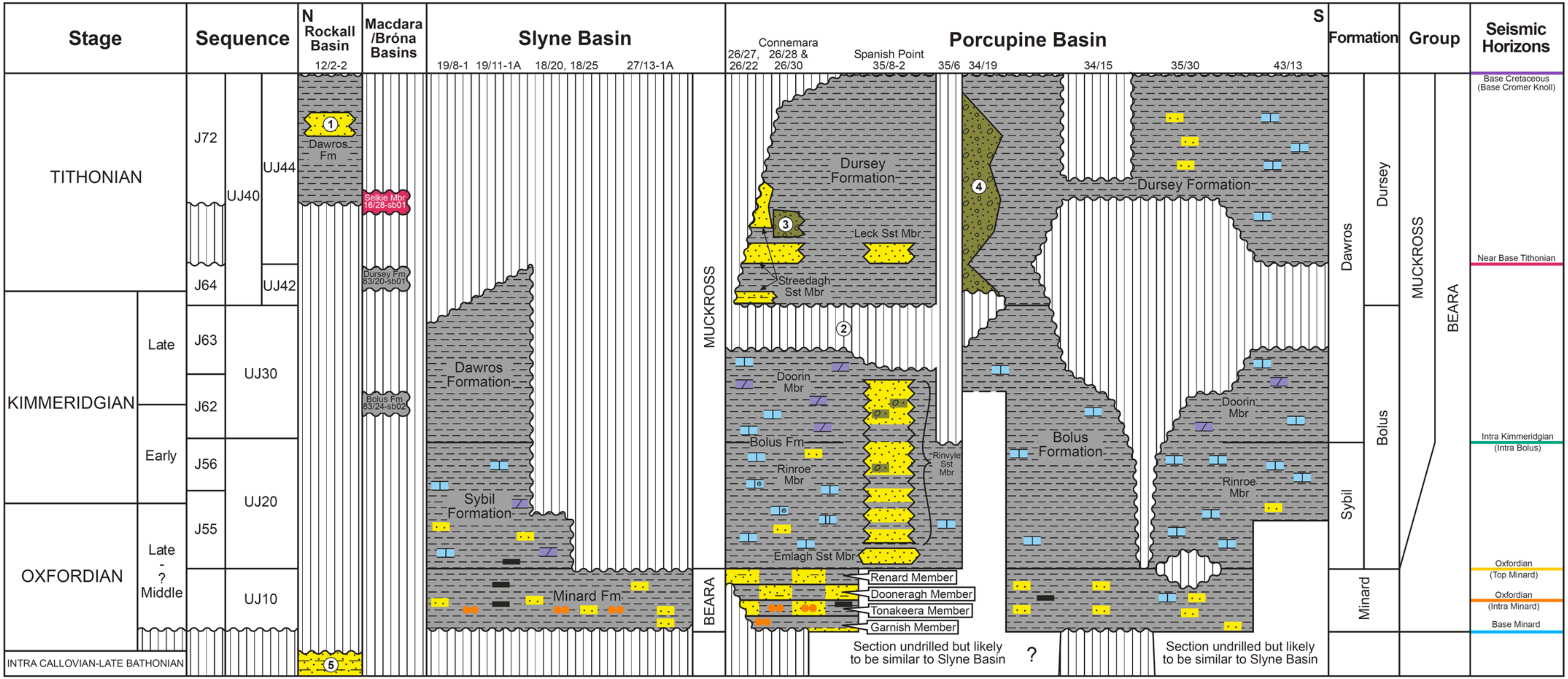

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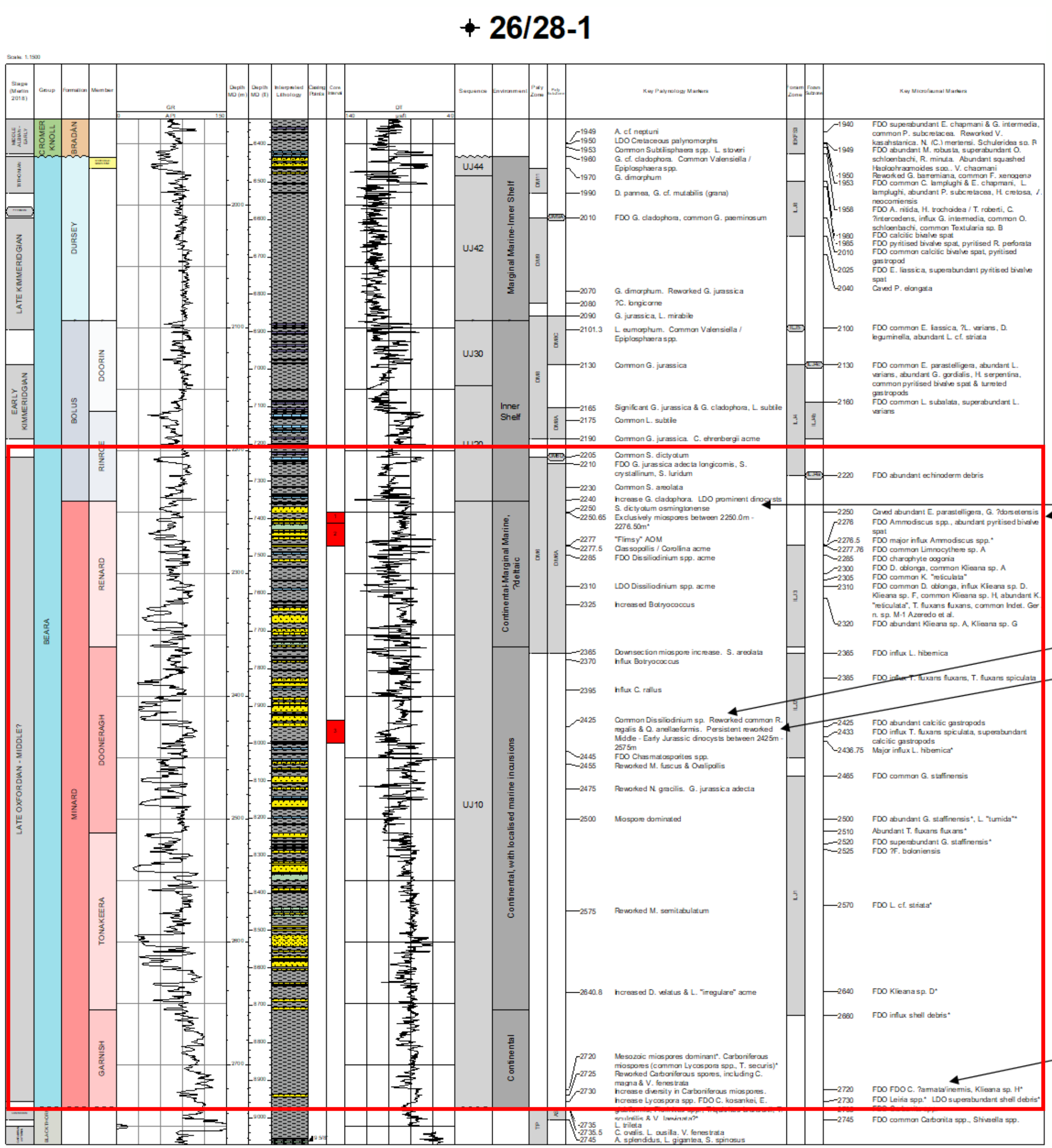
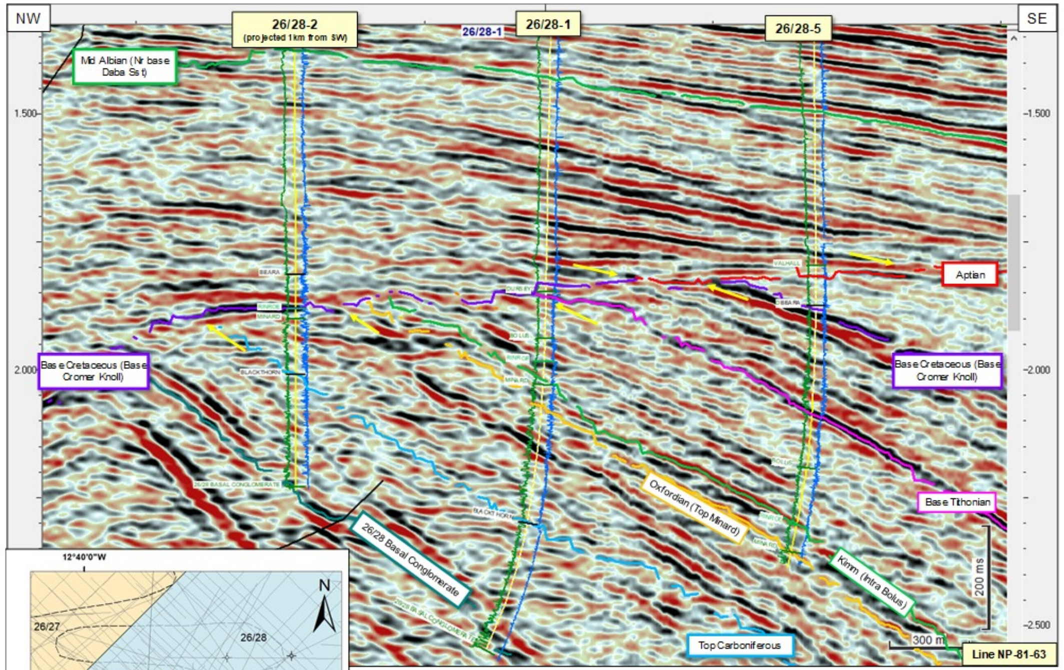
Use of biostratigraphy in reservoir zonation; e.g. Connemara Discovery reservoir section

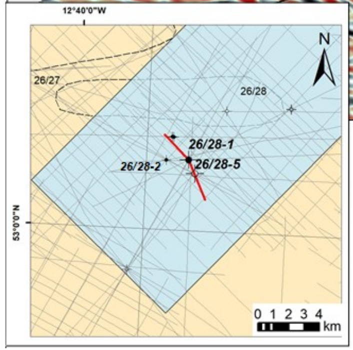


- Upwards shift from marginal/non-marine to marine palynofloras and microfaunas; indicative of major flooding (base UJ20 sequence)
- Late Oxfordian in age

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

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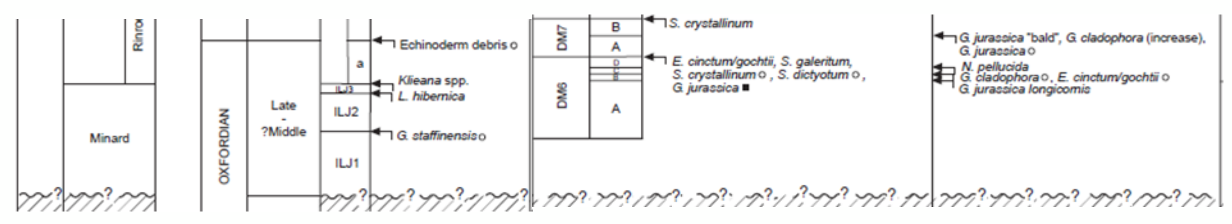

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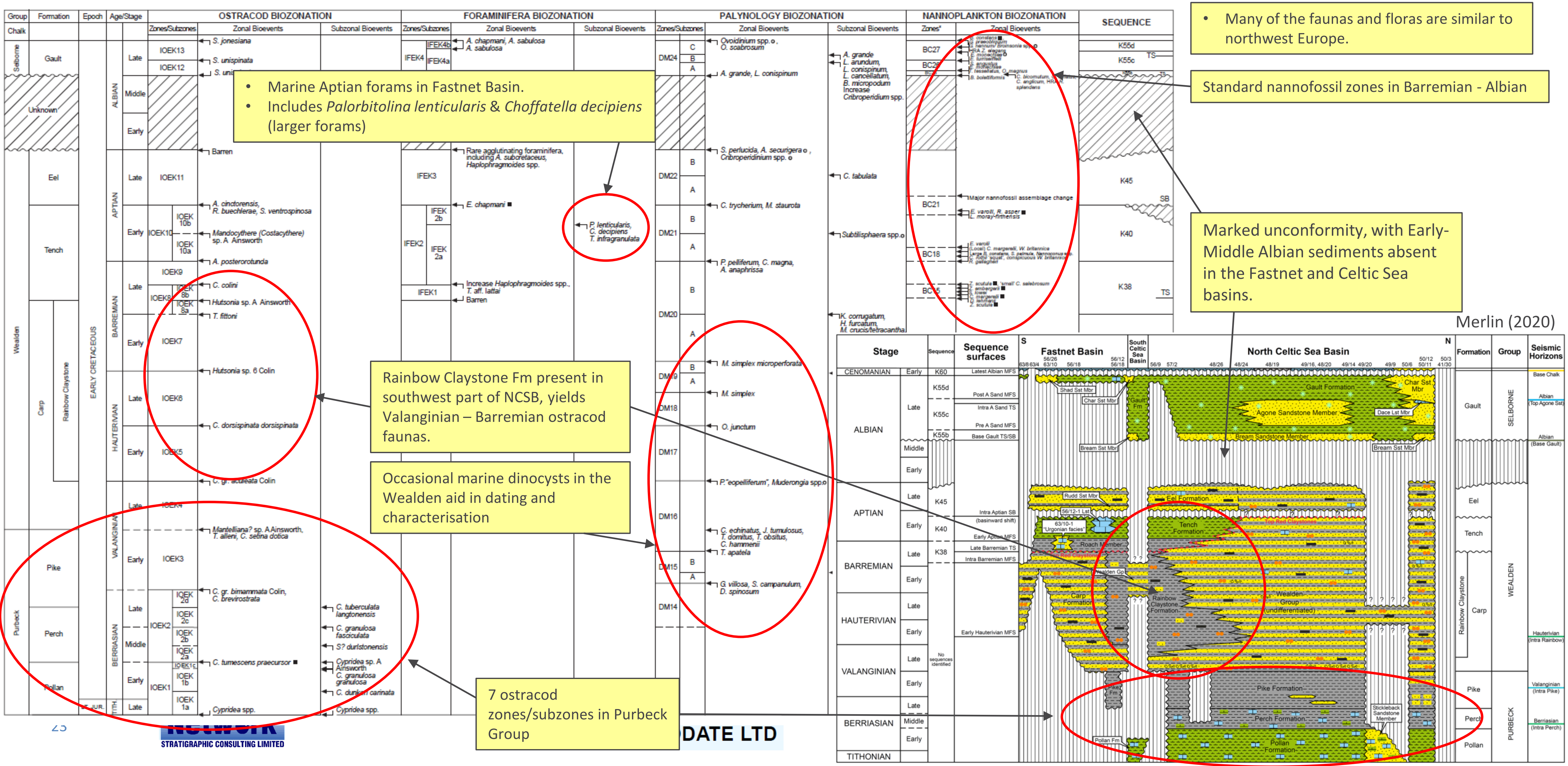
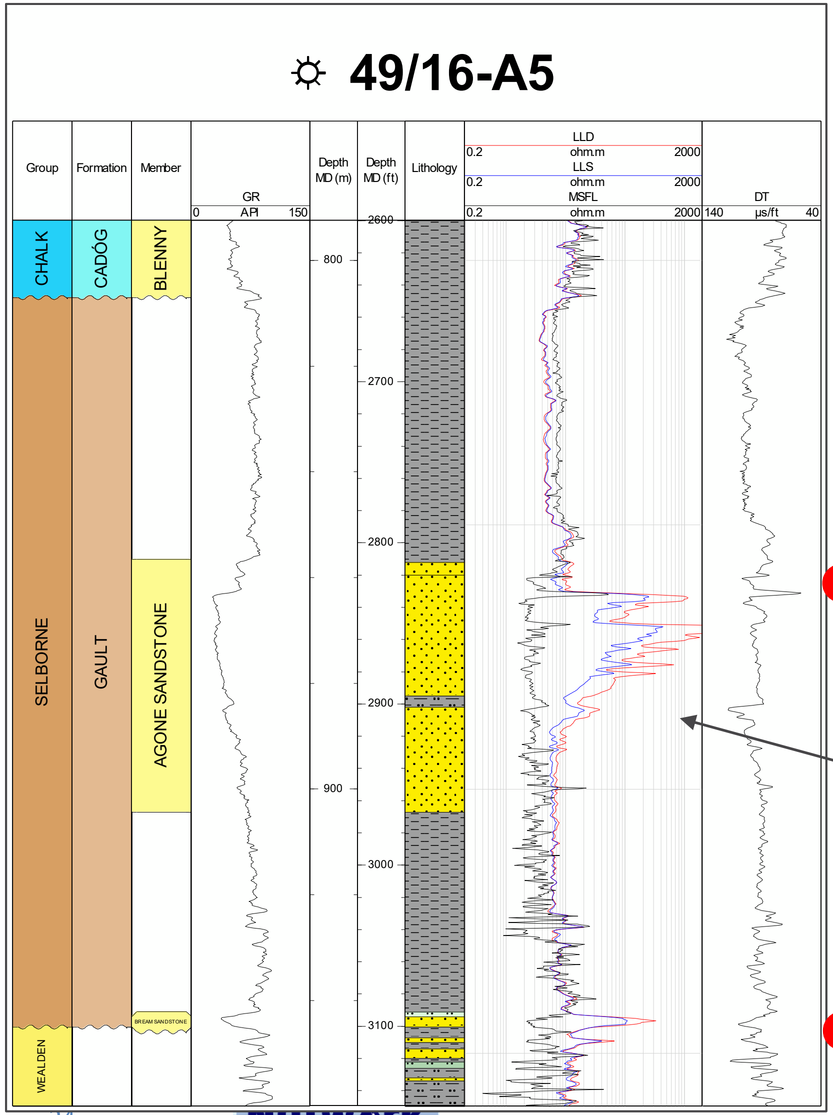
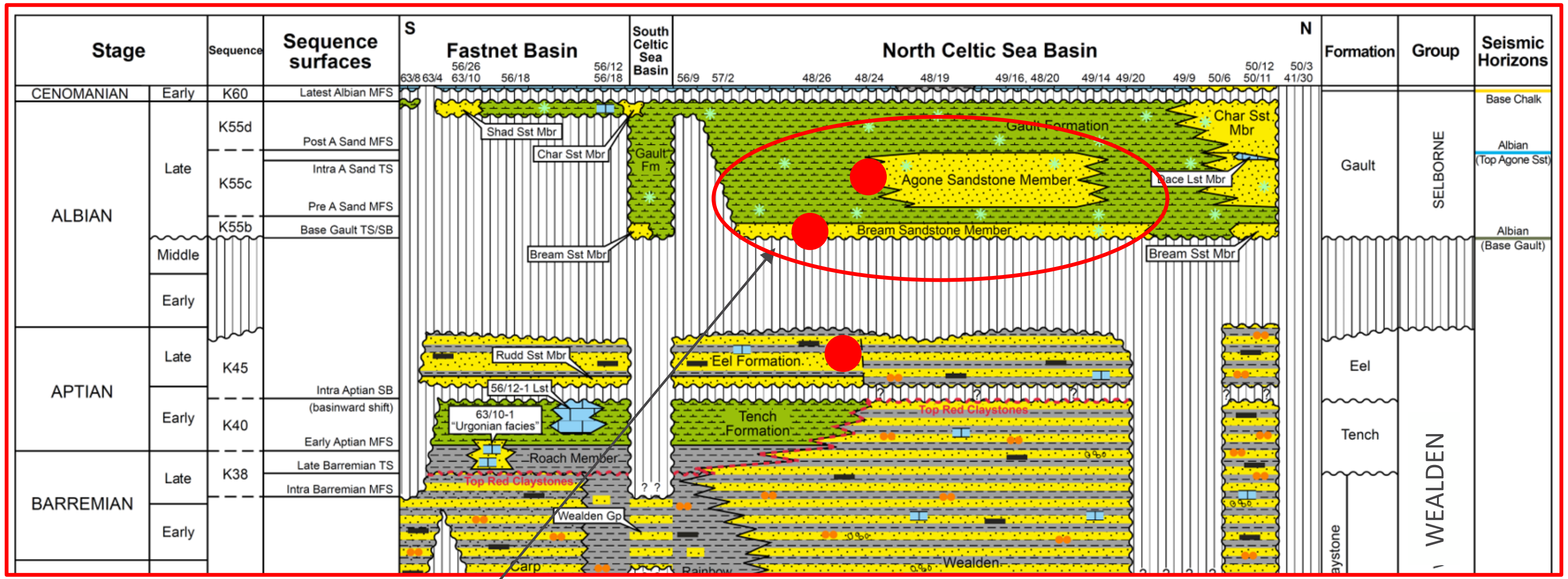
Early Cretaceous biozonation scheme North Celtic Sea – Fastnet Basins



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

Kinsale Head Field

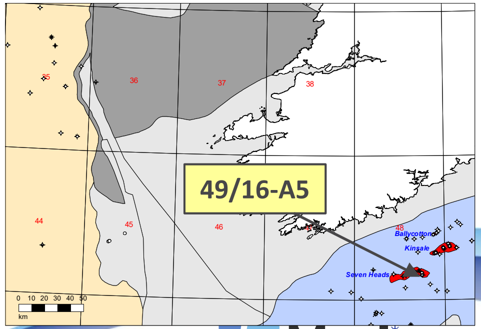




Proven hydrocarbons

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, Midleton, Carrigaline, Galley Head, Schull & Ballycotton
- Late Aptian Eel Formation is hydrocarbon reservoir in Seven Heads (48/24), 57/9-1 Discovery



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

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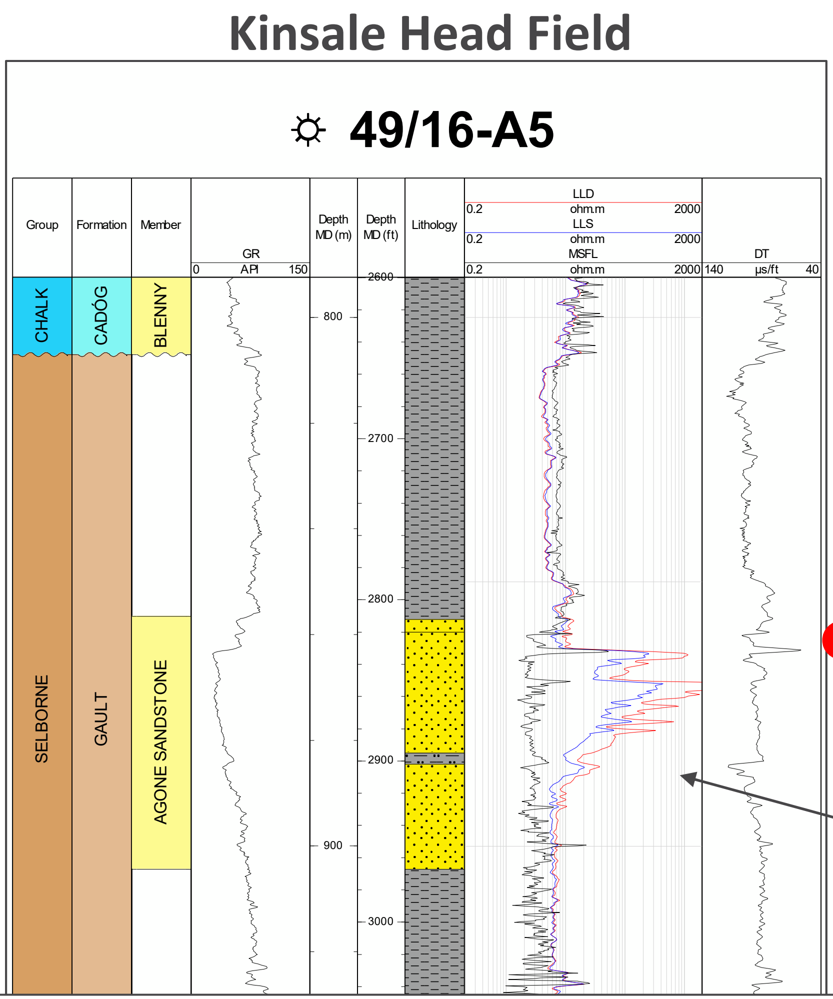

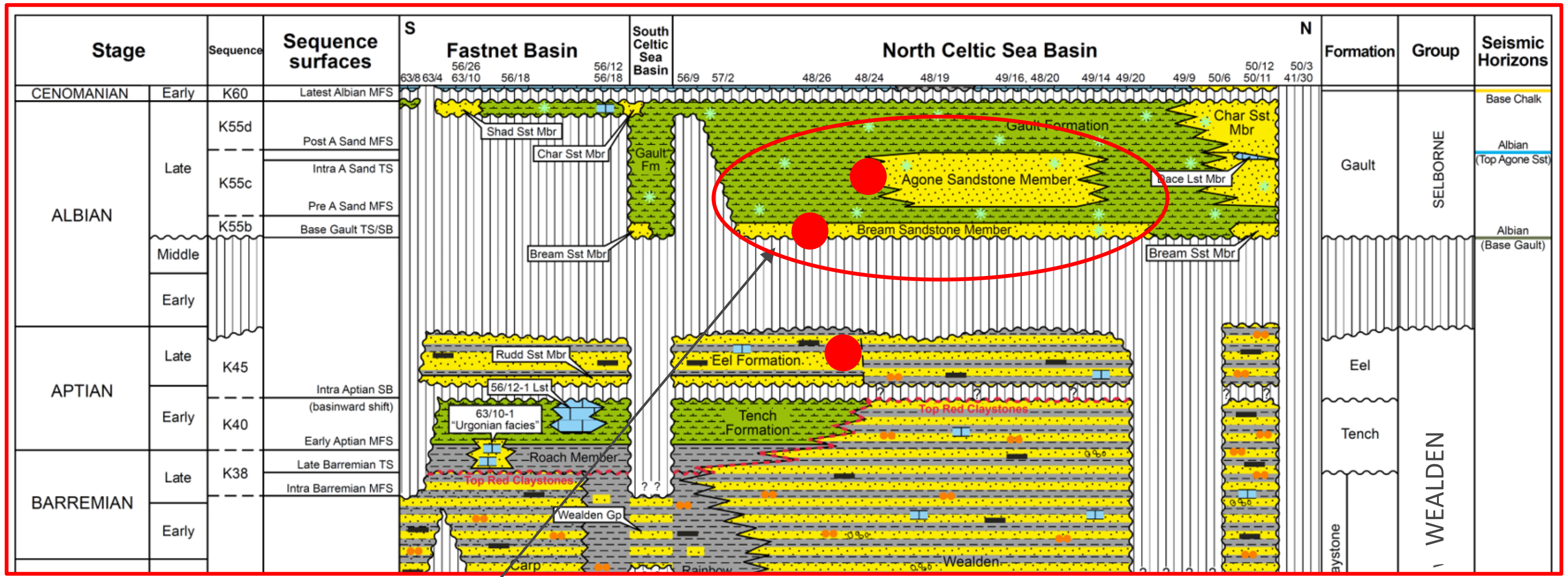

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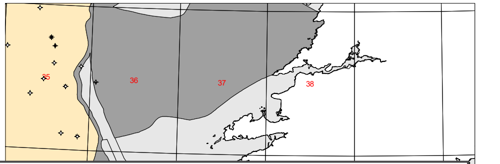
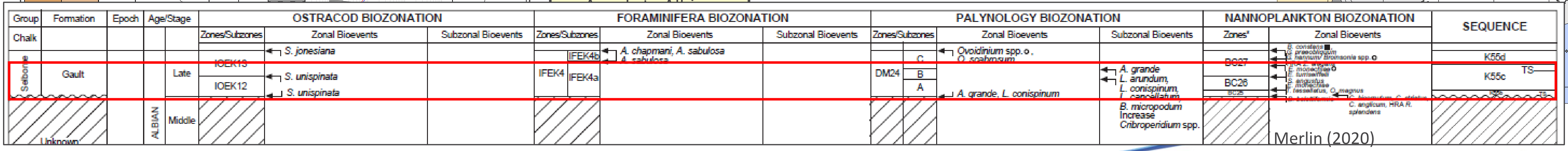
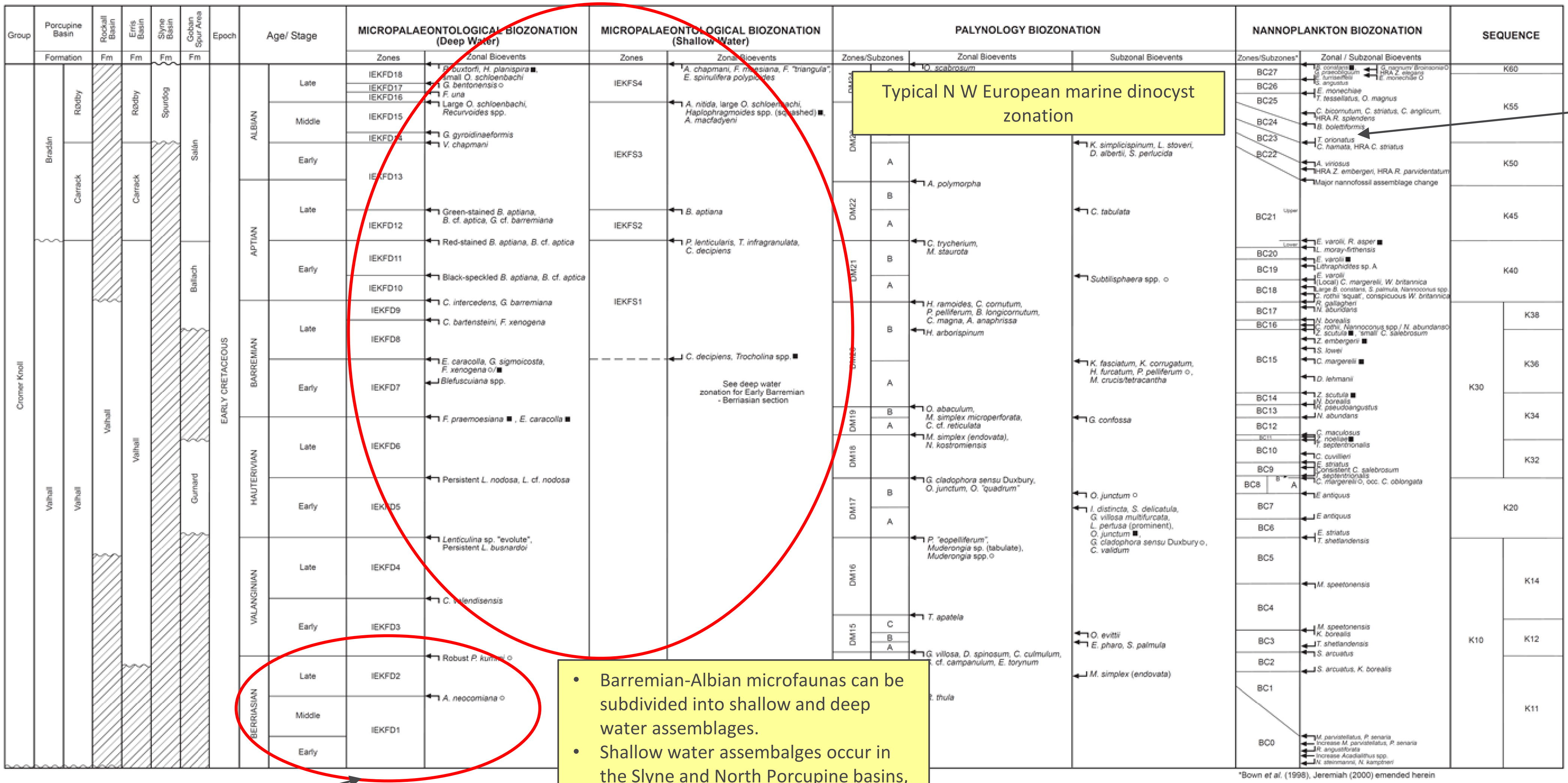




Early Cretaceous biozonation scheme Goban Spur, Porcupine, Slyne, Erris & Rockall basins



Typical N W European marine dinocyst zonation

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

- Barremian-Albian microfaunas can be subdivided into shallow and deep water assemblages.
- Shallow water assembalges 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

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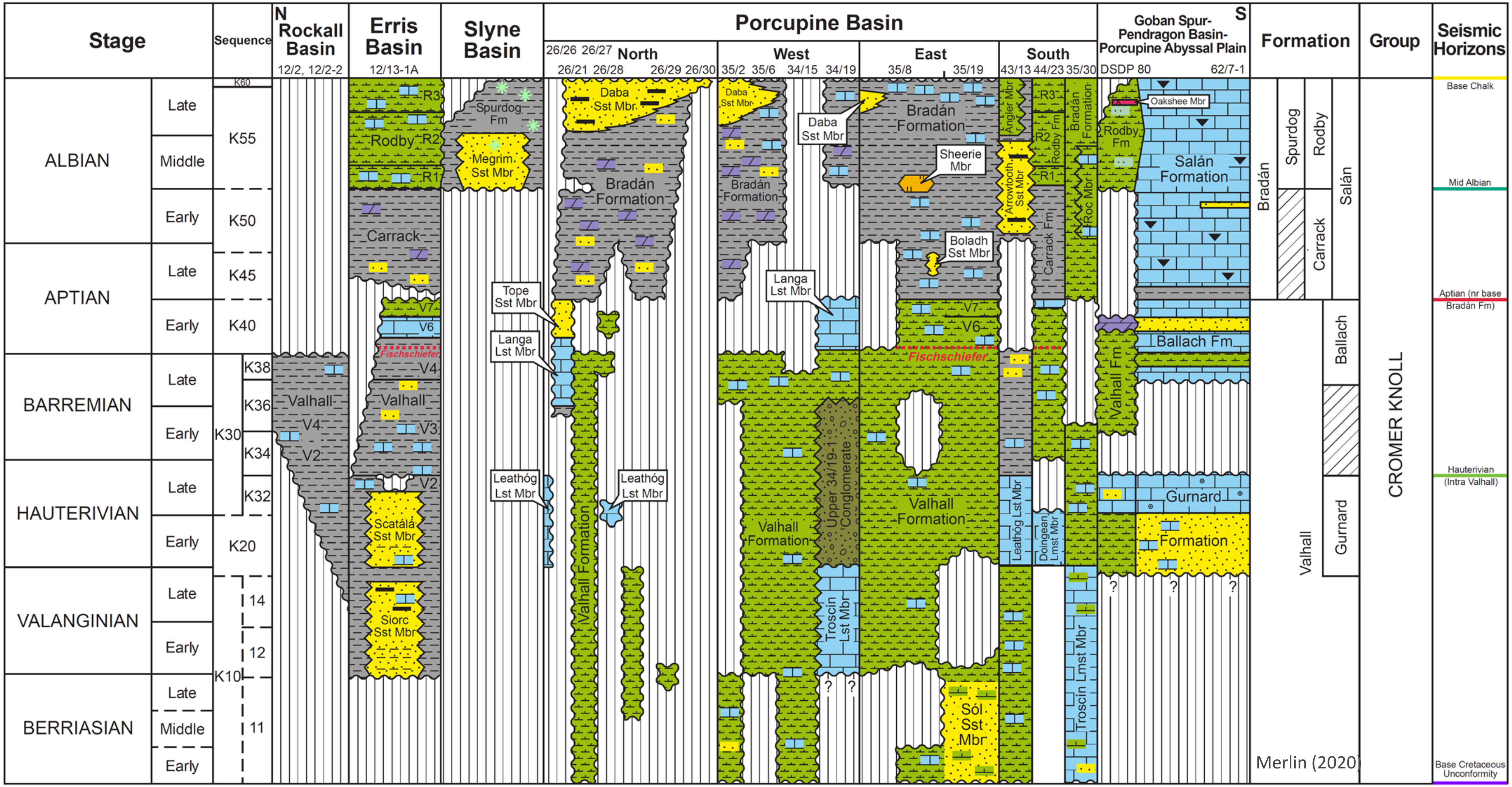
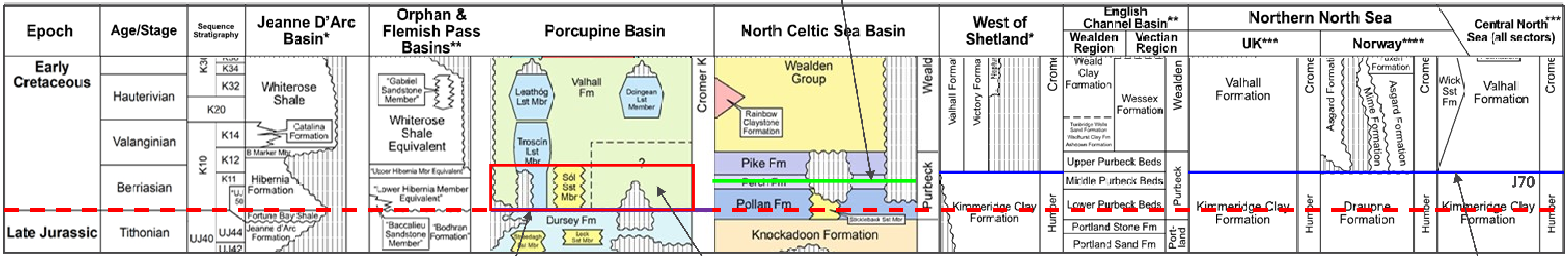
Early Cretaceous stratigraphic scheme Goban Spur, Porcupine, Slyne, Erris & Rockall basins



Jurassic/Cretaceous boundary

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



Base Cretaceous seismic horizon (Porcupine Basin)

Lowermost Cretaceous in calcareous, open marine facies

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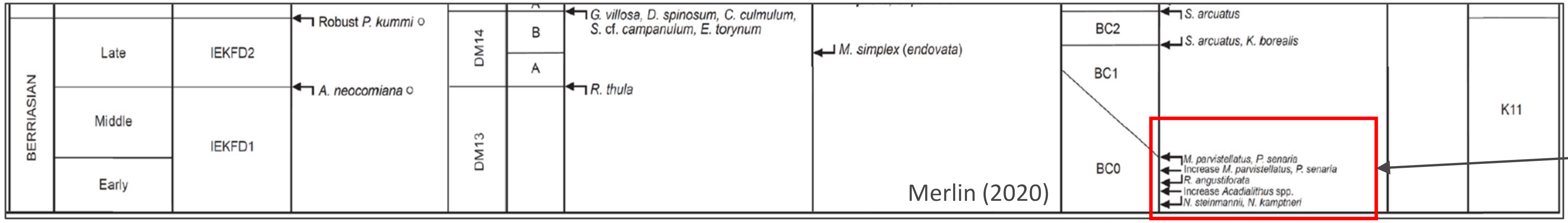
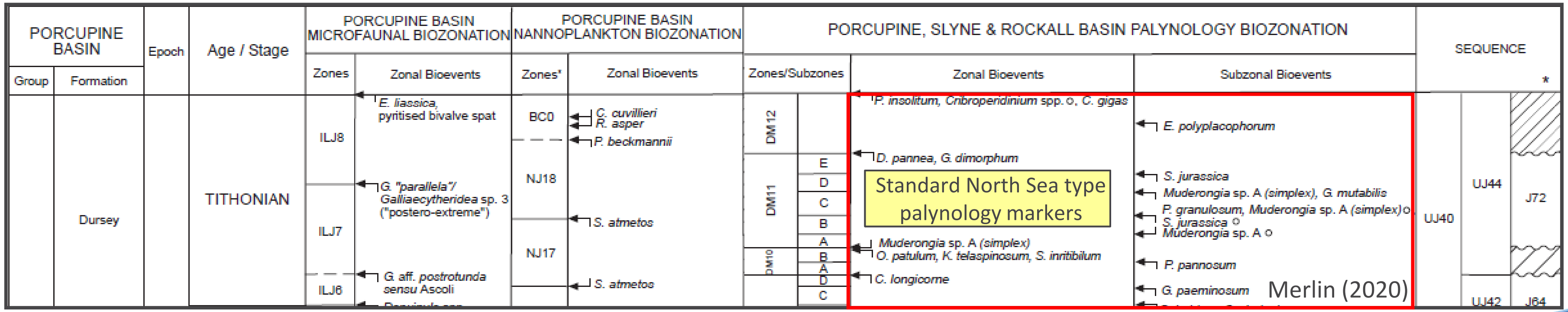
Base Cretaceous seismic horizon (North Sea & West of Shetland)





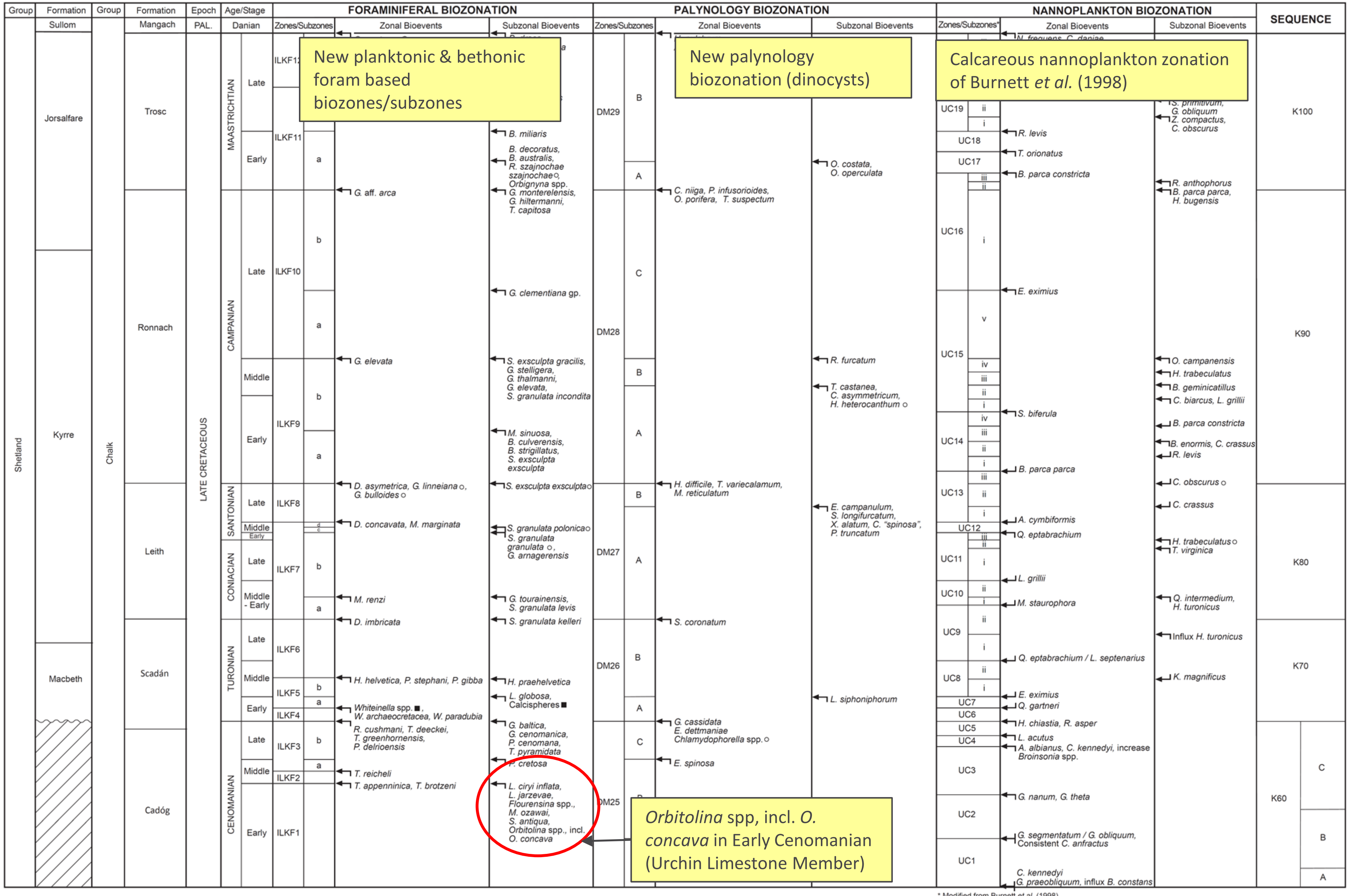
- Additional nannofossil stratigraphy in the 'Earliest' Cretaceous relative to the North Sea.
- The uppermost Kimmeridge Clay Formation in North Sea does not yield these events due to the facies change at the boundary between the Cromer Knoll and Humber Groups.
- These taxa are known from offshore Canada (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.

M. parvistellatus

P. senaria

Late Cretaceous biozonation scheme for offshore Ireland

integrated multi proxy biozonations; foraminifera, calcareous nannoplankton, dinocysts



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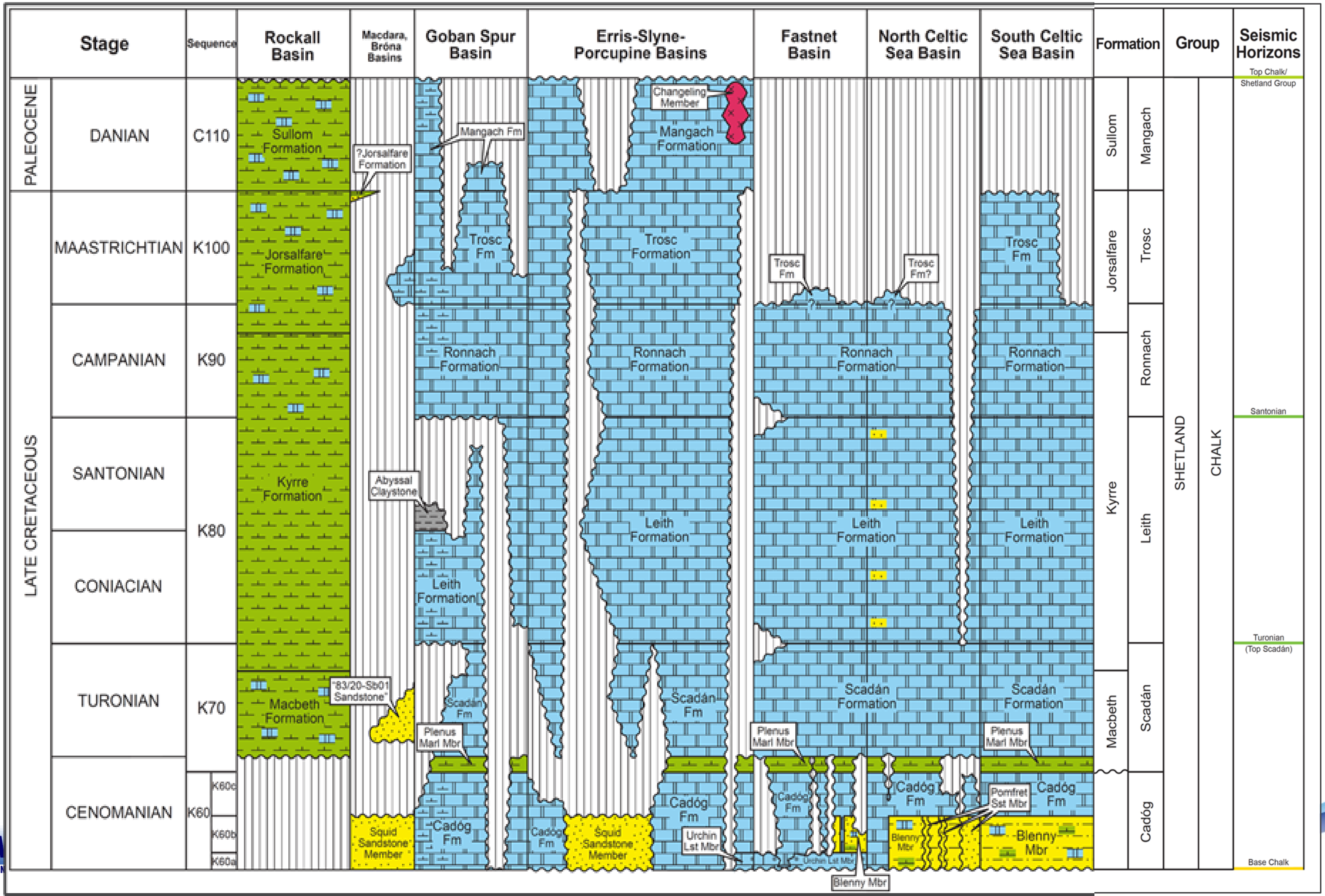
Late Cretaceous stratigraphic scheme for offshore Ireland



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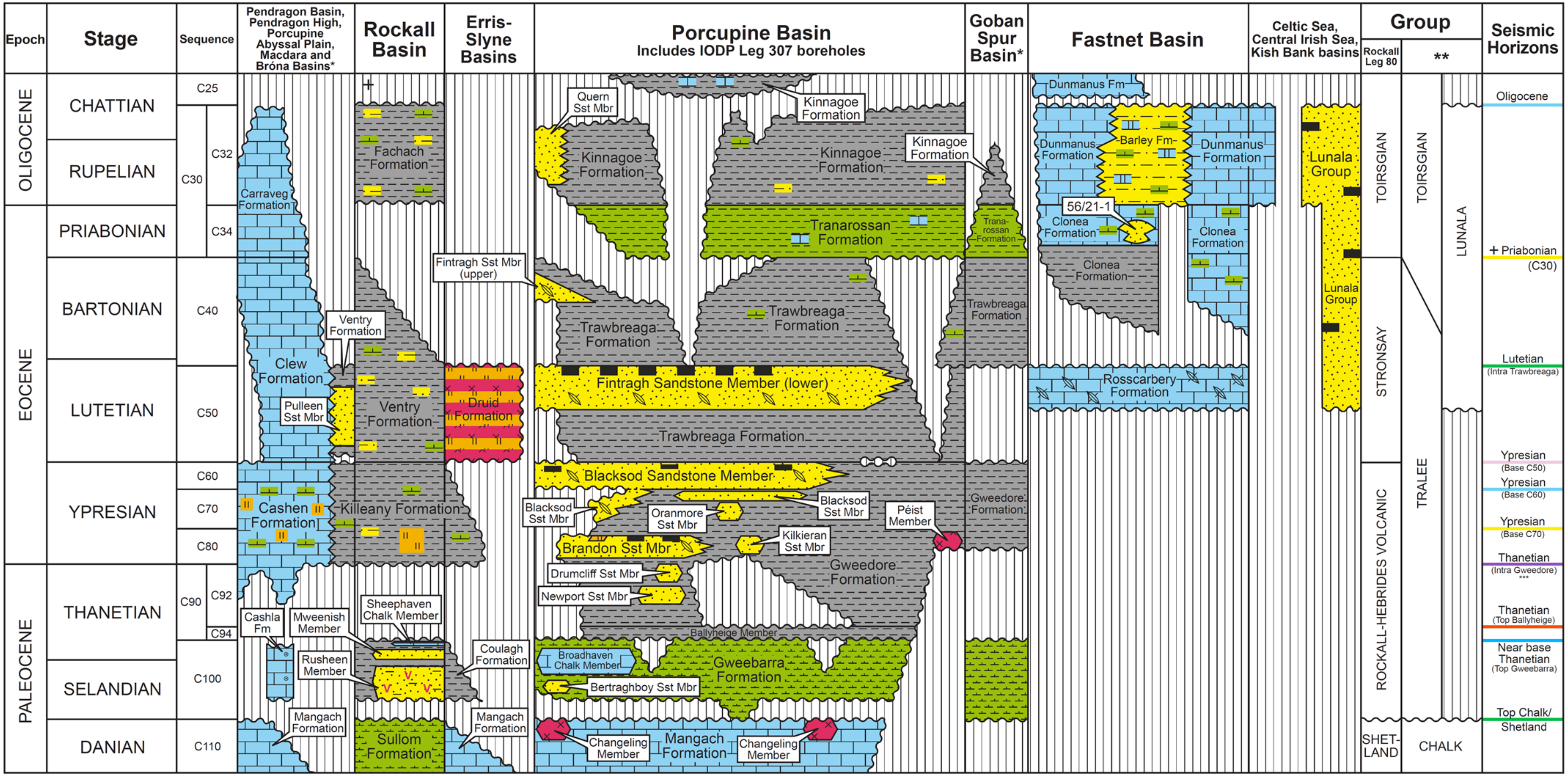
Paleogene stratigraphy of offshore Ireland



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* 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)

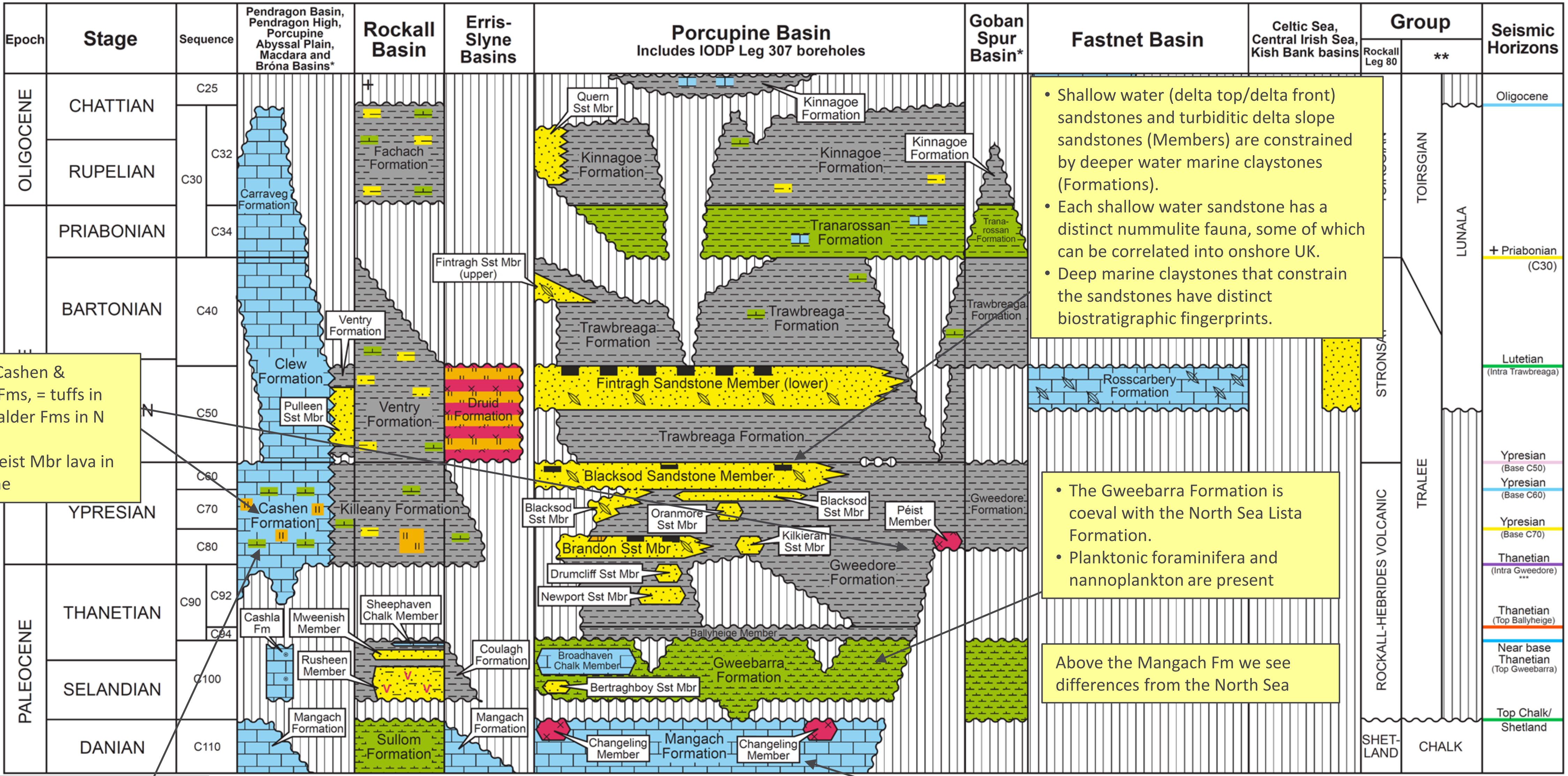
** Erris, Slyne, Porcupine, Goban Spur, Fastnet, Celtic Sea, Central Irish Sea, Kish Bank basins

*** 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.

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

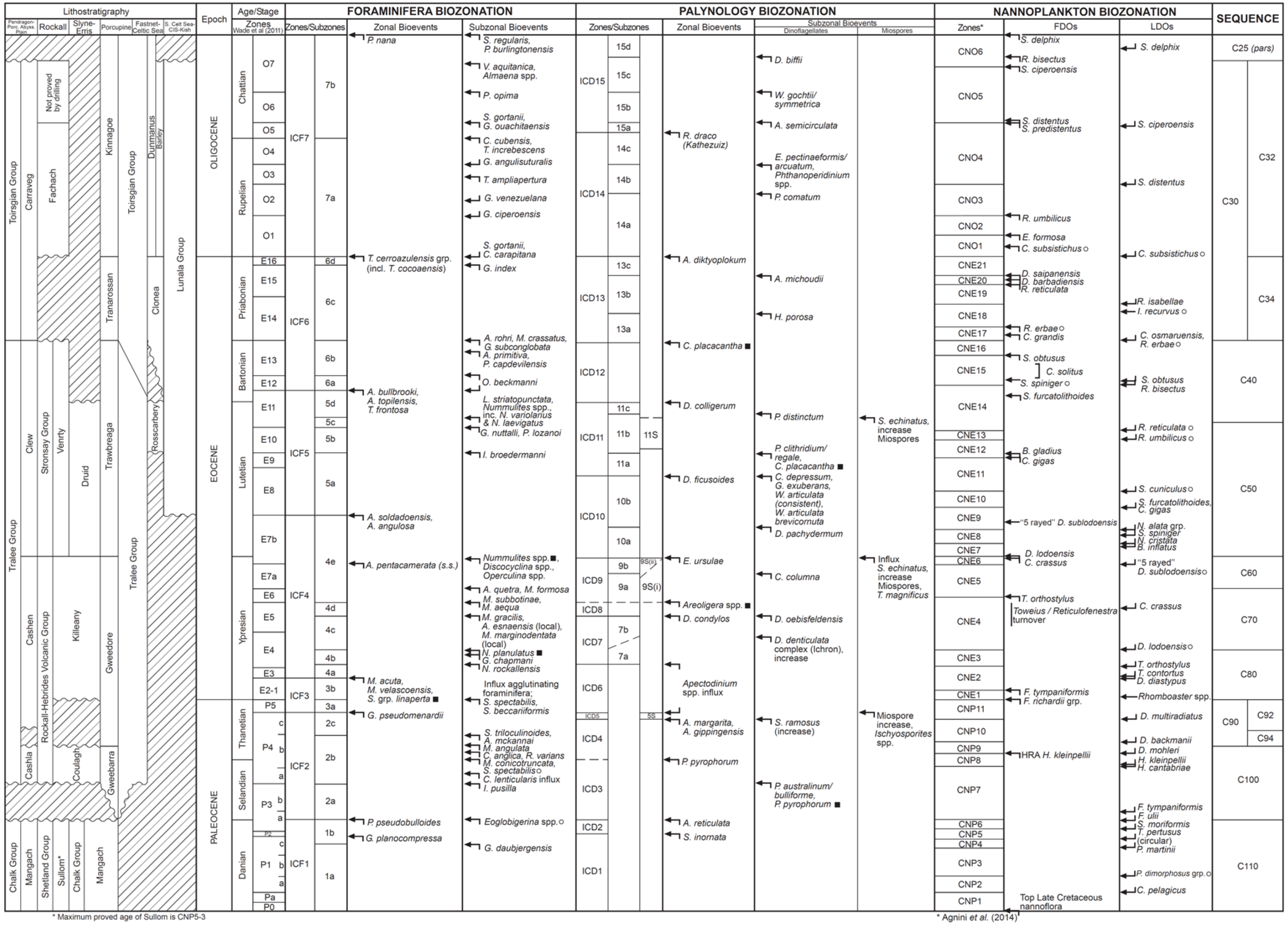
- The Gweebarra Formation is coeval with the North Sea Lista Formation.
- Planktonic foraminifera and nannoplankton are present

Above the Mangach Fm we see differences from the North Sea

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

Paleogene biozonation scheme



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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

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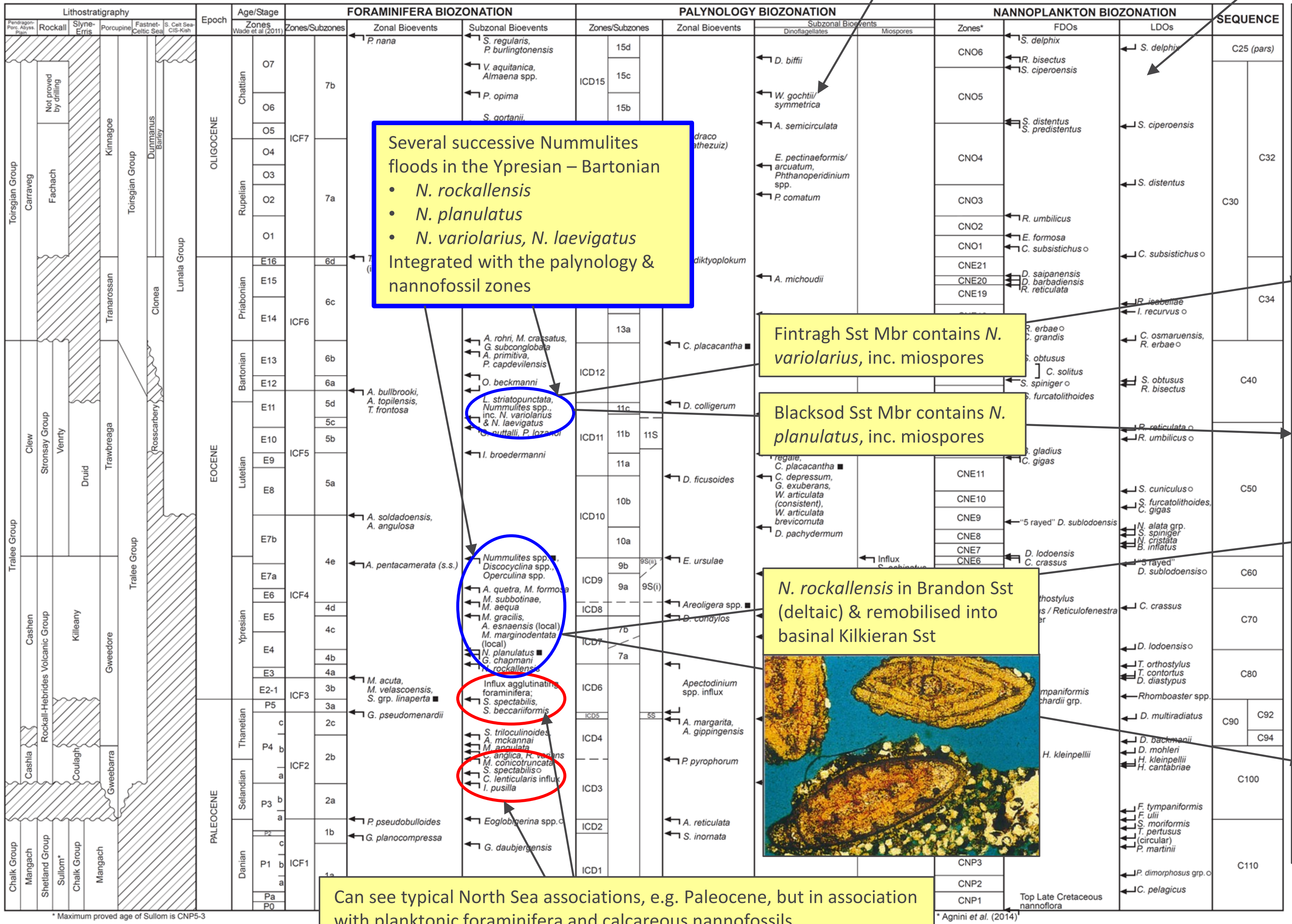


Several successive Nummulites floods in the Ypresian – Bartonian
- *N. rockallensis*
- *N. planulatus*
- *N. variolarius, N. laevigatus*

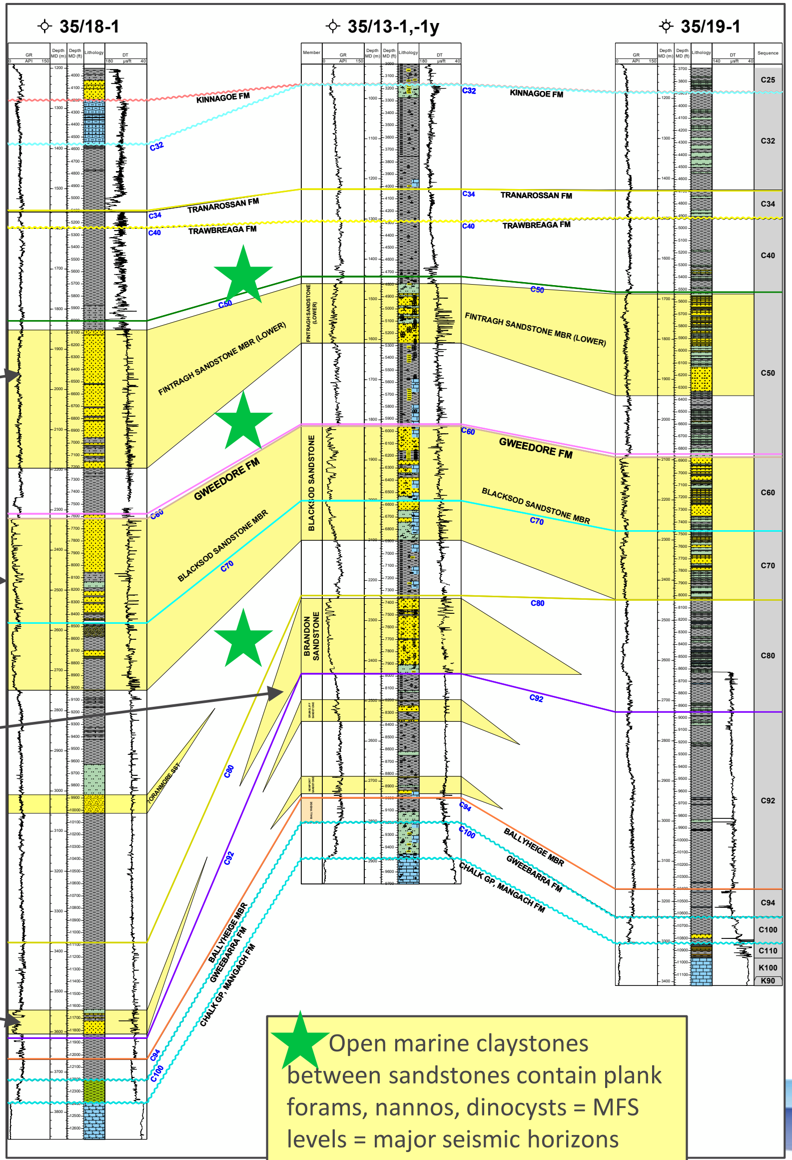
Integrated with the palynology & nannofossil zones

Fintragh Sst Mbr contains *N. variolarius*, inc. miospores

Blacksod Sst Mbr contains *N. planulatus*, inc. miospores

N. rockallensis in Brandon Sst (deltaic) & remobilised into basinal Kilkieran Sst

Can see typical North Sea associations, e.g. Paleocene, but in association with planktonic foraminifera and calcareous nannofossils



Open marine claystones between sandstones contain plank forams, nannos, dinocysts = MFS levels = major seismic horizons

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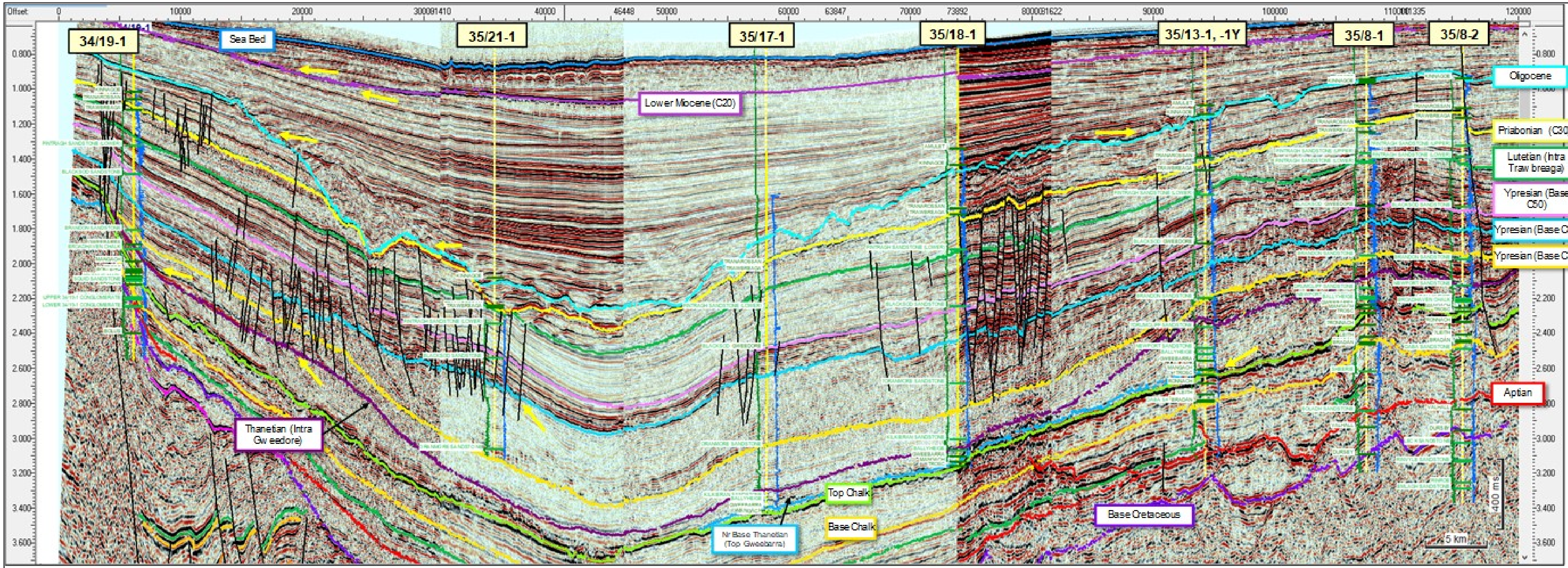
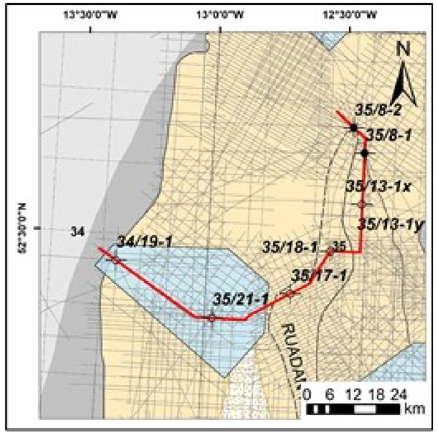
Seismic line across Porcupine Basin showing complexity of Tertiary seismic sequences



2D data

Arbitrary line across several surveys

Yellow arrows=seismic reflection terminations



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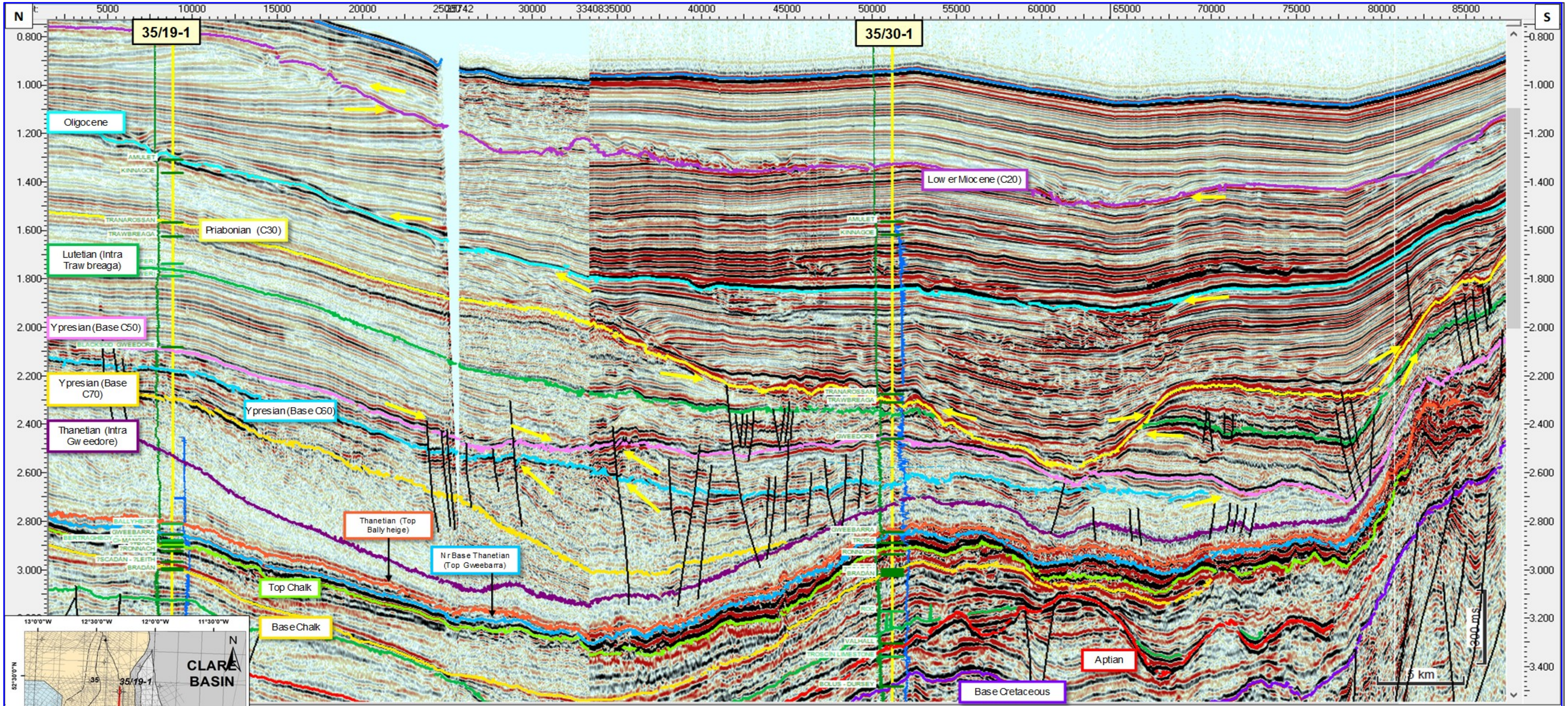

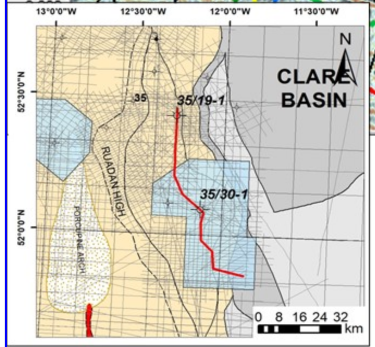

Arbitrary line across several surveys

Yellow arrows=seismic reflection terminations

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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.

Acknowledgements

- We thank the Petroleum Affairs Division (PAD) (of the Department of Communications, Climate Action & Environment), and the Petroleum Infrastructure Programme (PIP) for their support throughout this project

Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

PIP
Petroleum Infrastructure Programme

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  AzEire Petroleum, BP, Cairn Energy, Chevron, ENI, Equinor, Europa Oil & Gas, ExxonMobil, Maersk Oil, Nexen Petroleum, DCCAE/PAD, Providence Resources, Repsol, San Leon Energy, Serica Energy, Shell, Sosina Exploration, Tullow Oil & Woodside Energy.

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