The Ravenscar Group: a coeval analogue for the Middle Jurassic reservoirs of the North Sea and offshore Mid-Norway

N. BUTLER[1], M. A. CHARNOCK[2], K. O. HAGER[2,3] & C. A. WATKINS[1]
[1]*Robertson Research International Ltd., Llanrhos, Llandudno LL30 1SA, UK*
(e-mail nb@robresint.co.uk)
[2]*Norsk Hydro AS, Research Centre, N-5020, Bergen, Norway*
[3]*Norsk Hydro AS, N-0246, Oslo, Norway*

Abstract: A palynostratigraphical study of the Middle Jurassic Ravenscar Group, Cleveland Basin, northern England involving the integration of miospore and microplankton data with sedimentary facies data has resulted in improvements in the stratigraphical resolution of offshore hydrocarbon-bearing strata in the North Viking Graben and Mid-Norway. The Dogger Formation is of 'earliest' Aalenian age and is correlative with the uppermost Dunlin Group, Drake Formation and Båt Group, Ror Formation. The overlying Aalenian Saltwick and Eller Beck formations correlate with the Brent Group, Broom–Rannoch–Etive–Ness and the Fangst Group, Ile–Not–'lower' Garn genetic packages. The Cloughton Formation is either unrepresented or condensed in the Brent Province and Mid-Norway due to a regional unconformity, which truncates lower Bajocian sediments. The Scarborough Formation is of 'latest' early to 'earliest' late Bajocian age and correlative with the older part of the Tarbert–Heather and the 'upper' Garn–Melke genetic packages. These interpretations contrast markedly with the majority of those published.

Despite their maturity of exploration and development, Middle Jurassic sandstones of the North Sea and offshore Mid-Norway still represent some of the most prolific hydrocarbon reservoirs in northwest Europe. Of these, the Brent and Fangst Groups (Deegan & Scull 1977; Dalland *et al.* 1988) are particularly important and, despite the vast number of wells, the published chronostratigraphic schemes are poorly calibrated with confidently dated, onshore sections. The Ravenscar Group of the Cleveland Basin, Yorkshire (Fig. 1) consists of five formations (Rawson & Wright 1995; Fig. 2). This group comprises similar facies to those encountered in the Brent Province and Mid-Norway with sandstones, siltstones, mudstones and coals of Aalenian to Bathonian age deposited in a coastal/delta plain to shelfal environment. A palynostratigraphical scheme has been developed from quantitative palynological analyses of 114 field samples taken from Ravenscar Group outcrops. This has allowed a chronostratigraphical subdivision of the Ravenscar Group and enabled regional correlation of the constituent formations with coeval sediments of similar facies of the North Viking Graben (Brent Group) and offshore Mid-Norway (Fangst Group).

Methodology and techniques

The analyses were concentrated on three key sections near Whitby, Ravenscar and Scarborough (Fig. 1). Additionally, some of these sections were logged sedimentologically to place the samples in a sedimentary facies context. Samples were selected from mudstones, siltstones and argillaceous sandstones as previous experience has demonstrated these lithologies to be most productive for palynology. Palynological preparations were made using a standard acid maceration and oxidation process with the residue strewn onto a permanent glass slide and analysed under the light microscope. For each sample, a split count technique was undertaken where 200 specimens were counted in the 10 μm fraction. An additional count was made where 100 dinoflagellate cysts were counted, wherever practical, concurrent to the first count, providing a high-resolution, quantitative database. Additionally, each slide was thoroughly scanned to ensure that all minor occurrences were recorded and that the abundance data were representative of the entire slide. A combination of numerical abundance changes in conjunction with evolutionary tops and bases of key palynomorph taxa (mainly dinoflagellate cysts; Williams *et al.* 1998 provide a comprehensive index for all dinoflagellate cyst

From: POWELL, A. J. & RIDING, J. B. (eds) 2005. *Recent Developments in Applied Biostratigraphy*.
The Micropalaeontological Society, Special Publications, 43–53. 1747-602X/$15.00

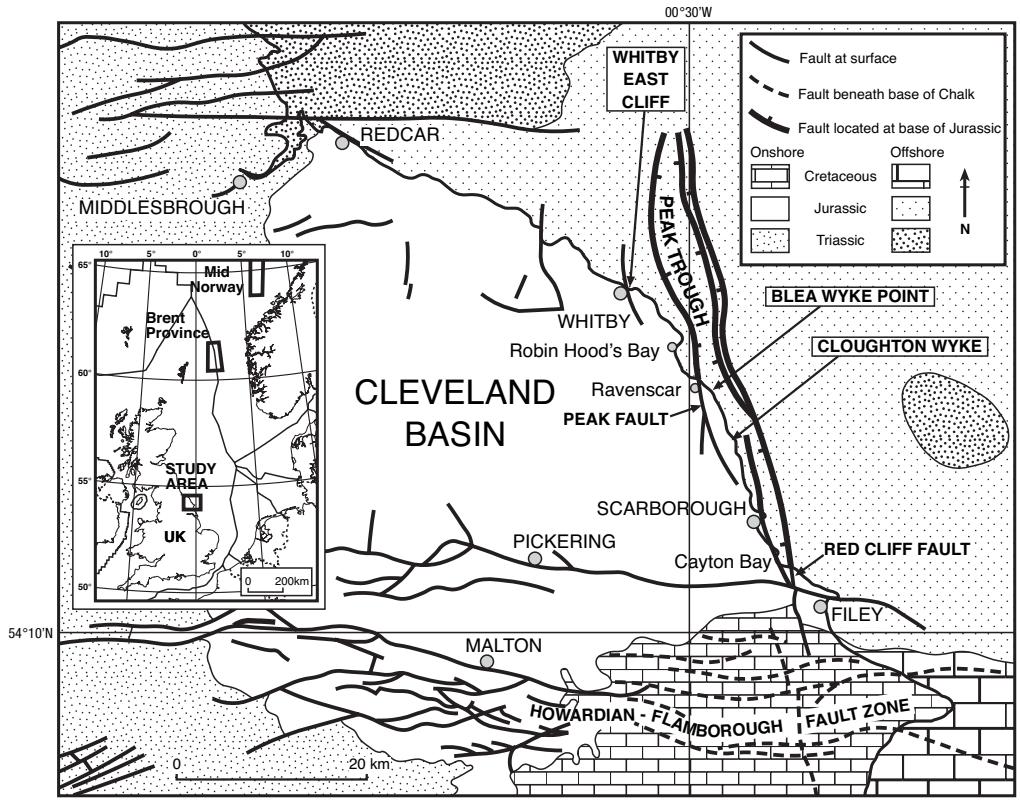

Fig. 1. Location map for the Cleveland Basin and its geographical relationship with the Brent Province and Mid-Norway (after Rawson & Wright 1992).

taxa discussed herein) have been used to constrain the gross stratigraphy. This approach has proven instrumental in many studies particularly of the Lower–Middle Jurassic of the Mid-Norway Heidrun Field (Pedersen *et al*. 1989) and in the Viking Graben to the south (Mitchener *et al*. 1992; Whitaker *et al*. 1992; Bray *et al*. 1995). The abundance events may be manifested as top increases, acmes or base increases of a specific taxon or group of taxa. A number of significant events are established herein and summarized in Figure 3. These are regionally correlative with the Brent and Fangst groups, which has facilitated a refined stratigraphy for these areas.

Previous palynostratigraphical work

Little has been published on the palynology of the Middle Jurassic of Yorkshire. The earliest palynological work was a comprehensive evaluation of miospores from the entire Ravenscar Group concentrating on taxonomy by Couper (1958). However, some stratigraphical data are of interest, particularly regarding the distribution of *Classopollis* spp. that broadly concurs with the distribution recorded herein. Hancock & Fisher (1981) documented the palynofacies of selected parts of the Saltwick, Eller Beck, Cloughton and 'lower' Scarborough formations. Although this information is useful, it provides little foundation for stratigraphical interpretation and correlation. Woollam & Riding (1983) published a palynostratigraphical account on a limited number of field samples. Riding (1984) documented dinoflagellate cyst assemblages from the mid-Toarcian to Aalenian of Blea Wyke Point, Ravenscar. Palynofloral composition compares closely with that recorded herein. The Scarborough Formation was documented by Gowland & Riding (1991) and although a useful sedimentary log was produced (and utilized herein), only eight palynological analyses were undertaken from the entire formation. Hogg (1993) produced a comprehensive account of the largely non-marine Scalby

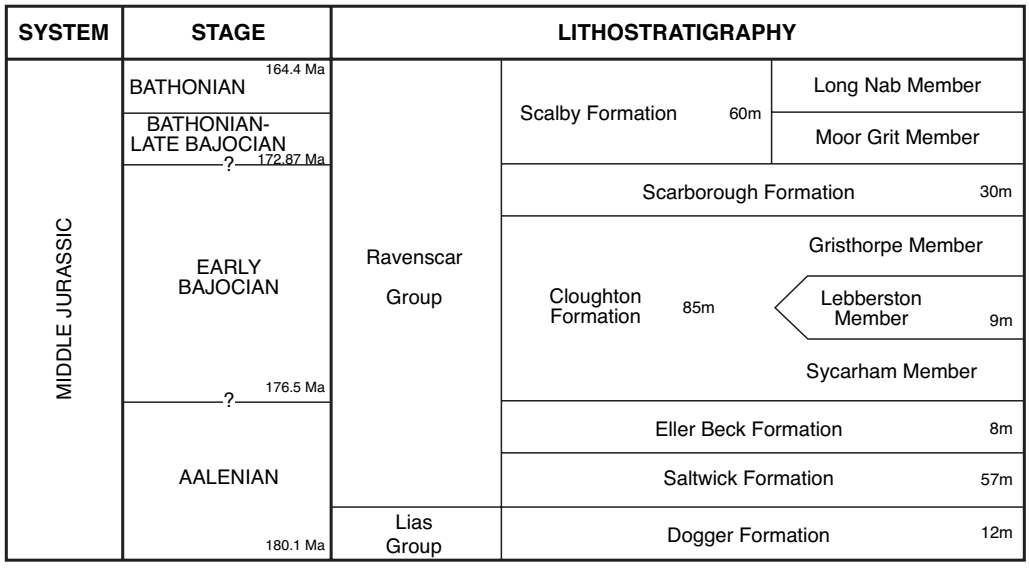

Fig. 2. Subdivision of the Middle Jurassic (Aalenian–Bathonian) succession (modified after Rawson & Wright 1992).

Formation. It is apparent that very few palynostratigraphical data have been produced for the more proximal facies of the Saltwick Formation, Sycarham Member and Gristhorpe Member or the marine Eller Beck Formation.

There is considerably more published palynological information regarding the Brent Group. Authors including Graue *et al.* (1987), Mitchener *et al.* (1992), Whitaker *et al.* (1992), Helland-Hansen *et al.* (1992) and Husmo *et al.* (2002) have published stratigraphical schemes, the main conclusion being that the Broom Formation is Aalenian in age, the Rannoch, Etive and Ness formations are Bajocian and the Tarbert Formation is 'latest' Bajocian or Bathonian in age. This interpretation contrasts markedly with the new data presented herein.

Palynostratigraphy of the Ravenscar Group and correlation with the Brent and Fangst Groups

The Lias Group and Dogger Formation were sampled at two locations, namely at Blea Wyke Point where it is 12 m thick and Whitby East Cliff where it is condensed to less than 1 m thick. The Dogger Formation generally comprises argillaceous shelfal sandstones and siltstones that rest unconformably on either the Blea Wyke Sandstone Formation (at Blea Wyke Point) or the older Whitby Mudstone Formation (at Whitby East Cliff). These sediments yield high numbers and a high diversity of dinoflagellate cysts assigned to the Family Phallocystaceae (including *Parvocysta nasuta, Susadinium scrofoides, Susadinium faustum, Ovalicysta hiata, Moesiodinium raileanui, Phallocysta eumekes,* and *P. elongata)*. It is possible that these records in the Dogger Formation at Whitby East Cliff may represent reworked occurrences since reworked mud-clasts derived from the Whitby Mudstone Formation are present. However, a diverse and abundant suite of Phallocystaceae (dominated by *Susadinium scrofoides* and *Ovalicysta hiata* with low but consistent numbers of *Phallocysta* and *Parvocysta* spp.) are present in the much thicker Dogger sequence at Blea Wyke Point. The abundance and diversity of this group however decreases sharply in the uppermost part of the formation, a feature that has also been identified in the uppermost Drake Formation (Dunlin Group) in the North Viking Graben (Bray *et al.* 1995) and uppermost Ror Formation (Båt Group) in Mid-Norway (Butler, personal observation). It is possible that these events are a coeval response to a regional regressive phase, which resulted from uplift at the triple junction between the Viking Graben, Moray Firth and Central Graben. However, the top of diverse Phallocystaceae is also identified within the Opalinum ammonite zone in the Bearreraig Sandstone Formation of Skye, Scotland (Riding *et al.* 1991) and consequently

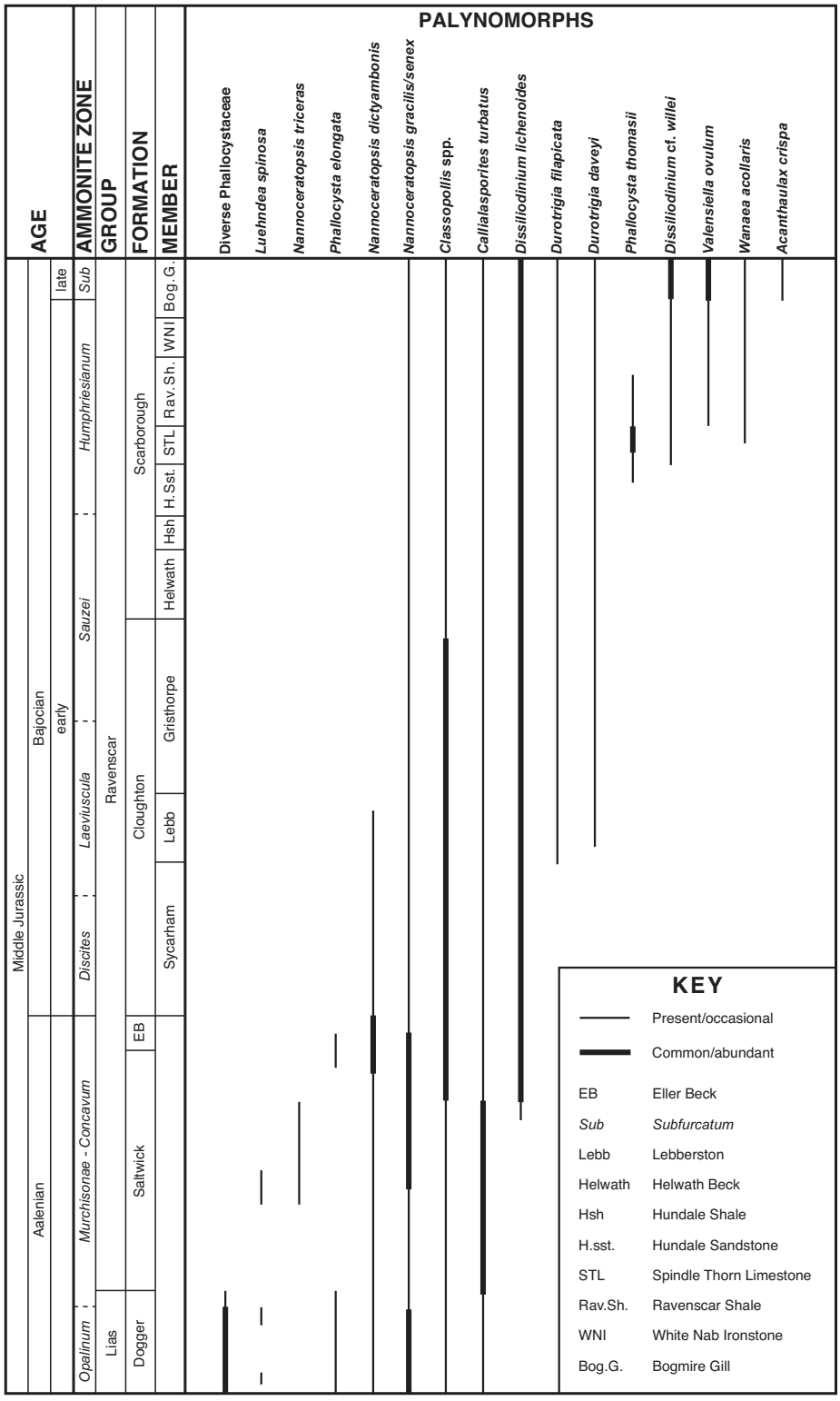

Fig. 3. Ranges of selected taxa in the Ravenscar Group.

its true evolutionary top may also be manifested in the Cleveland Basin. The Dogger Formation is age dated as earliest Aalenian Opalinum ammonite zone on the basis of ammonite faunas recovered from Blea Wyke Point (Cope *et al.* 1980; Riding 1984).

The Saltwick Formation is characterized by sandstones, siltstones, mudstones and coals deposited in a paralic to non-marine environment. This was logged sedimentologically and sampled for biostratigraphy at Whitby East Cliff where it comprises a 33 m thick mudstone-dominated succession (Fig. 4). Although no ammonite faunas have been recovered, the age of the formation is considered to be Aalenian (Murchisonae to Concavum ammonite zones) in age (Cope *et al.* 1980). A major basinward shift in facies is inferred at the base of the formation by the absence of dinoflagellate cysts and the proliferation of pteridophyte spores in conjunction with lacustrine or overbank sedimentary facies. This non-marine aspect persists throughout the lower 10 m of the Saltwick Formation.

The middle to upper interval of the formation is characterised by an increase in dinoflagellate cysts that comprise approximately 1–2% of the total palynoflora; principally *Nannoceratopsis gracilis*, *N. senex*, *N. triceras*, *Mancodinium semitabulatum* and *Mendicodinium morgenrothii*. This assemblage, which broadly substantiates an Aalenian age, has also been identified in the Brent Group, Ness Formation. (The extinction of *Nannoceratopsis triceras* is ammonite constrained as 'earliest' Bajocian, intra-Discites ammonite zone in the UK according to Woollam & Riding 1983.)

Luehndea spinosa has been identified from marine intervals in the 'middle' Saltwick Formation as well as consistently occurring in lower delta plain facies of the Ness Formation. This taxon has an accepted range top (extinction) in the early Toarcian (Woollam & Riding 1983) and its reappearance in these formations is somewhat controversial. In the Brent Province, the event was originally considered to represent reworking of late Pliensbachian to early Toarcian sediments. However, the occurrences of *Luehndea spinosa* in these Aalenian sediments are associated with appropriate ichnofaunas and sedimentary structures that are consistent with a marginal marine, distal environment as opposed to a non-marine, proximate environment. Additionally, increases in other dinoflagellate cyst taxa such as *Mancodinium semitabulatum* and *Nannoceratopsis* spp., in conjunction with gymnosperm pollen associations and lower numbers of pteridophyte spores are noted. If *Luehndea spinosa* was reworked then it would be reasonable to encounter other indigenous late Pliensbachian to early Toarcian taxa such as *Scriniocassis weberi*, *Comparodinium* spp., *Valvaeodinium* spp. and *Maturodinium inornatum* as reworking. This is not the case in either the Saltwick or Ness formations and consequently *Luehndea spinosa* is considered to be *in situ* in these formations. One possible interpretation for the disappearance then reappearance of this taxon could be that the motile stage responsible for *Luehndea spinosa* stopped producing fossilizable cysts at the end of the early Toarcian. Subsequently, during the Aalenian, the motile forms (still present in the water column) had become adapted to life in stressed salinities and had recommenced producing fossilizable cysts. Alternatively, the forms identified as *Luehndea spinosa* in the Saltwick and Ness Formations may be subtly different from these older forms, which became extinct in the early Toarcian. Improved taxonomic work incorporating scanning and transmission electronic microscopy would be necessary to clarify this hypothesis.

Miospores are generally characterized by high numbers of pteridophyte spores throughout. An up-section increase in the xerophytic pollen genus *Classopollis* may be correlative with a similar base increase identified in the Ness Formation (associated with the base of the 'mid-Ness shale'; Bray *et al.* 1995). This increase may be the result of climatic change with an increase in aridity (Vakrameev 1981; Abbink 1998) which commenced in the 'mid' Aalenian. The effects of this increased aridity could be manifested to the north and south of the Mid-North Sea High, affecting both the Cleveland Basin and the North Viking Graben.

The uppermost part of the Saltwick Formation yields a base and up-section increase in *Dissiliodinium lichenoides*. The inception of this dinoflagellate cyst was reported in the uppermost part of the Murchisonae ammonite zone of southwest Germany by Feist-Burkhardt & Monteil (2001). A similar base and base increase is also well documented in the uppermost Ness Formation, where preserved (Butler, personal observation). This event is absent from the Not and 'lower' Garn formations, which are interpreted to predate it.

The Eller Beck Formation was sedimentologically logged and sampled near Cloughton Wyke and is probably latest Aalenian in age based on a lithostratigraphical correlation with the Hydraulic Limestone in South Humberside (Cope *et al.* 1980). It represents a significant marine incursion and is characterized by the

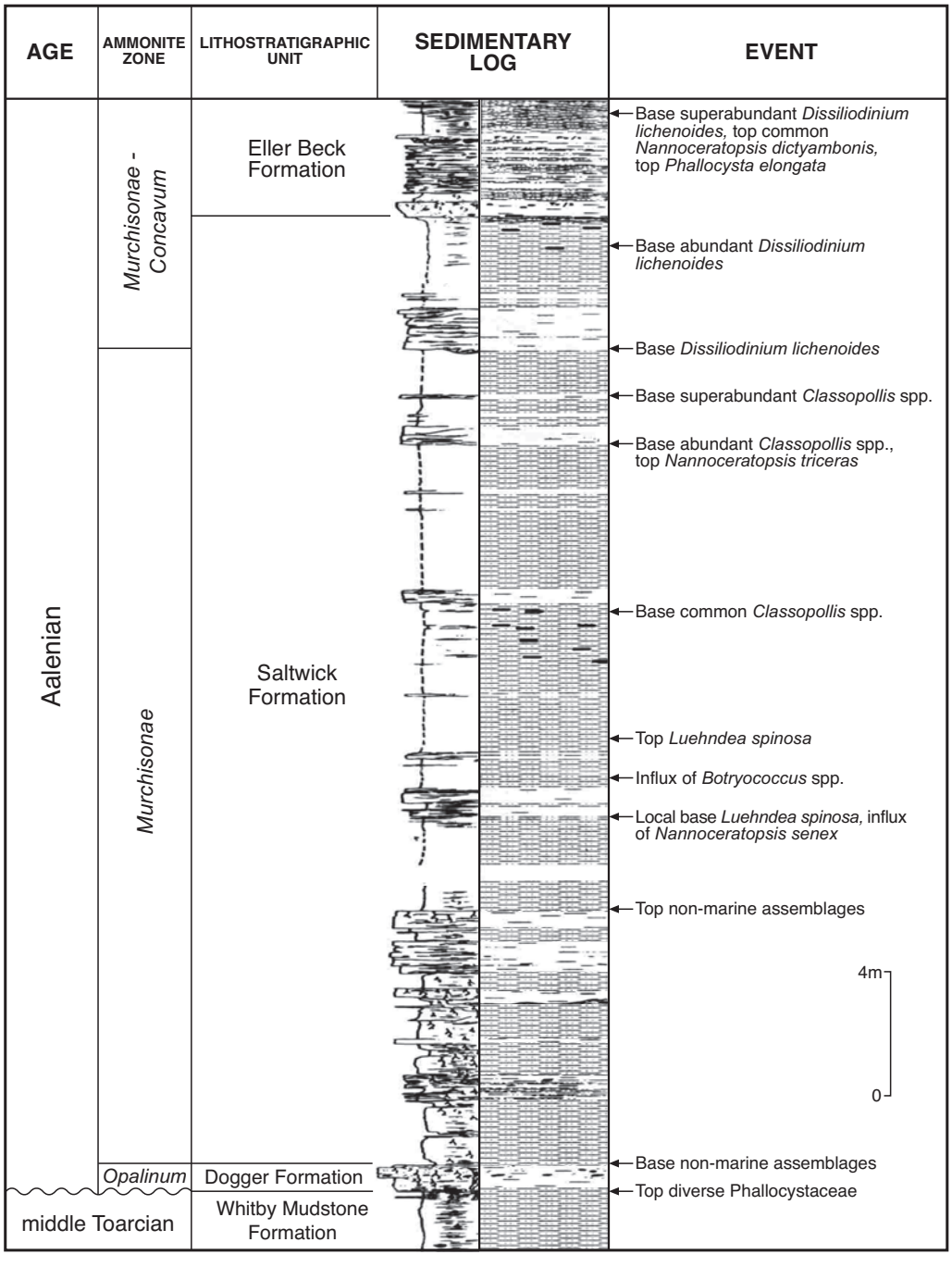

Fig. 4. Stratigraphy of the Saltwick Formation at Whitby East Cliff.

persistence of *Dissiliodinium lichenoides*, in conjunction with *Nannoceratopsis dictyambonis* and *Dissiliodinium psilatum*, all in high relative abundances. Although the formation is considered correlative with the 'uppermost' Ness Formation (where preserved in the North Viking Graben), it post-dates the Not/'lower' Garn Formations which lack these taxa.

The Cloughton Formation was also logged and sampled near Cloughton Wyke and comprises the Sycarham, Lebberston and Gristhorpe members, which are of early Bajocian age (Cope *et al.* 1980). Sediments of this age are significantly truncated or may be condensed in the Brent Province and Mid-Norway.

The inceptions of *Durotrigia filapicata* and *Sentusidinium granulatum* were identified within the Lebberston Member in the Cleveland Basin sections. The true inception is not encountered in the North Viking Graben due to the interpreted stratigraphical break or condensing, with these taxa first appearing in the Tarbert Formation. The co-occurrences of *Durotrigia daveyi* and *Nannoceratopsis dictyambonis*, also within the Lebberston Member (Butler, personal observation), suggests a Laeviuscula ammonite zone age for this unit (Penn *et al.* 1980). These latter two taxa are not encountered in the Brent Province or Mid-Norway.

The top of superabundant *Classopollis* spp. is identified in the uppermost part of the Gristhorpe Member and possibly represents the end of an arid climatic phase during the later part of the early Bajocian. High abundances of this xerophytic pollen genus are also encountered throughout the Aalenian Ness Formation with the true elimination event not identified due to the interpreted truncation at the Ness/Tarbert formational boundary. High numbers of *Classopollis* spp. are generally absent from the Tarbert Formation except in UK Block 211/23 and 211/18 wells where potentially older Tarbert Formation is present (Butler, personal observation).

The Scarborough Formation comprises mudstones, sandstones and silicious carbonates deposited in a progressively deepening environment (Gowland & Riding 1991) and was sampled at Hundale Point to the south of Cloughton Wyke. The distribution of *Phallocysta thomasii* has been carefully documented in the Hundale Point section. Its stratigraphical first and last occurrences have been identified in the middle parts of the Humphriesianum ammonite zone dated Hundale Sandstone and Ravenscar Shale members, respectively, with maximum numbers noted within the upper part of the Spindle Thorn Limestone Member (Fig. 5). This is considered significant for the calibration of similar distributions of *Phallocysta thomasii* within the 'upper' Garn and Melke Formations of the Norwegian Sea and in the Tarbert and Heather formations of the North Viking Graben, the implication being that these formations are, in part, Humphriesianum ammonite zone and therefore 'latest' early Bajocian in age.

The inception of *Dissiliodinium* cf. *willei* has been noted from the uppermost Scarborough Formation, Spindle Thorn Limestone Member, with maximum numbers identified in the Bogmire Gill Member at Hundale Point. This form morphographically resembles *Dissiliodinium willei sensu stricto*, differing in possessing smaller, isolated but hyaline grana, and is perhaps the immediate precursor to *Dissiliodinium willei*. Although the Bogmire Gill Member has been dated in the literature as Humphriesianum ammonite zone by inference (Parsons 1977; Gowland & Riding 1991), marker ammonites are absent. The overall dinoflagellate cyst assemblage is more consistent with the 'earliest' late Bajocian Subfurcatum ammonite zone as described by Feist-Burkhardt & Wille (1992) from Germany (as the Niortense ammonite zone). The absence of *Dissiliodinium willei sensu stricto* from the Hundale Point section is probably due to truncation at the top of the Scarborough Formation with the late Bajocian Garantiana and Parkinsoni zones being absent. The acme of *Dissiliodinium willei sensu stricto* is encountered in Heather and coeval Tarbert formation assemblages in the North Viking Graben, and the Melke Formation in Mid-Norway (Fig. 6). The event is calibrated to the boreal Pompeckji Zone from ammonite-dated core (Regnouf de Vains 1980). This zone is considered to be equivalent to the Parkinsoni and Garantiana ammonite zones in the UK (Callomon 1993).

A stratigraphical break is tentatively identified at the Scarborough Formation, Bogmire Gill Member/Scalby Formation, Moor Grit Member boundary (Leeder & Nami 1979; Riding & Wright 1989) although biostratigraphical control within the Moor Grit Member is lacking. The overlying Long Nab Member yields a similar palynomorph assemblage to the Pentland Group, 'lower' Bryne Formation in the Central Graben which is interpreted as Bathonian in age due to the presence of such miospore taxa as *Verrureticulisporis giganteus*, *Couperisporites jurassicus* and *Quadraeculina anellaeformis* (Butler, personal observation.). The formation is considered age equivalent to the Bathonian Heather and Melke formations of the northern North Sea and Mid-Norway, respectively (post-*Dissiliodinium willei* acme and pre-*Chytroeisphaeridia hyalina* acme).

Conclusions

The correlation of palynoevents identified in the Ravenscar Group with coeval sediments in the North Viking Graben and Mid-Norway is

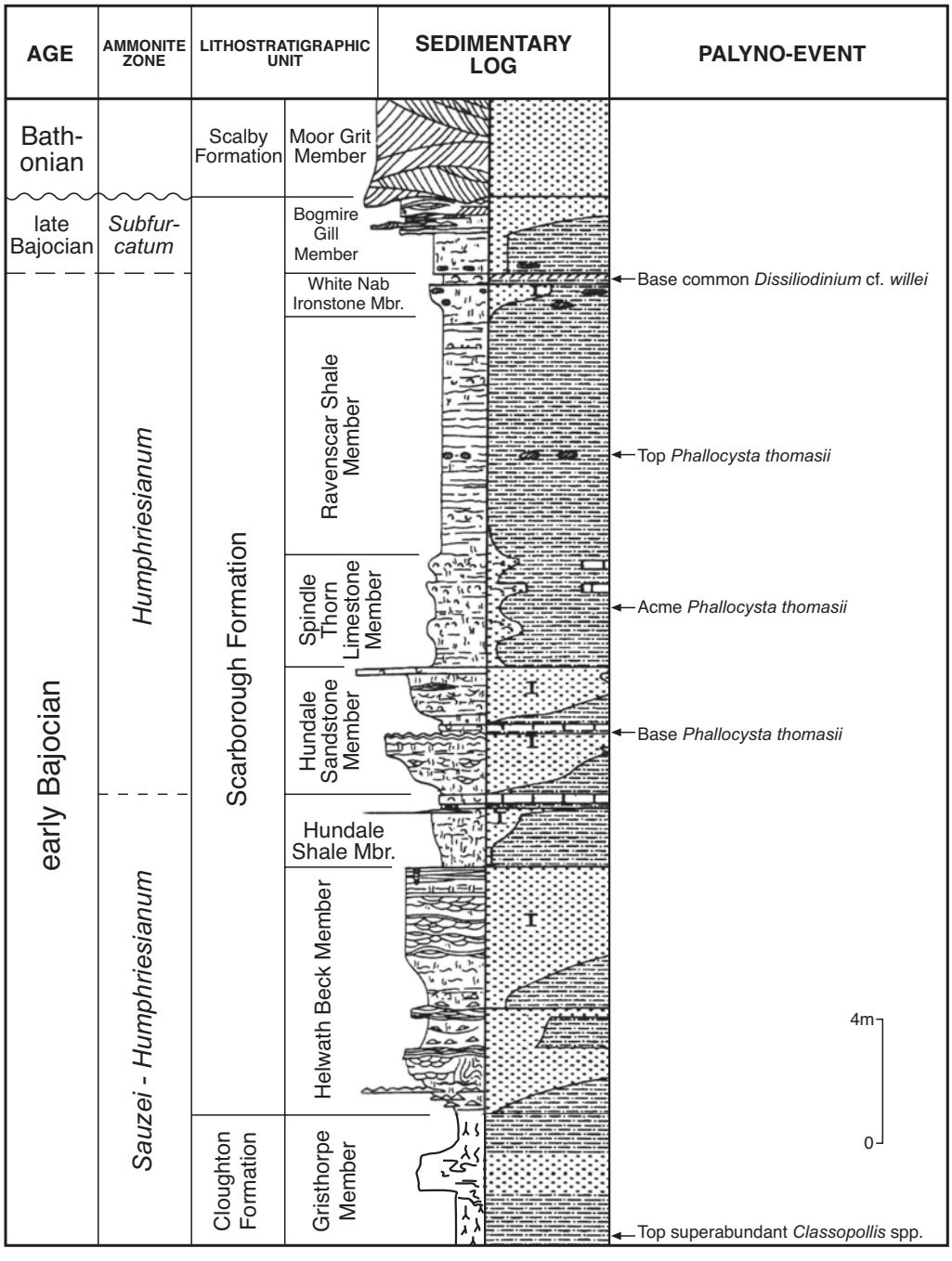

Fig. 5. Stratigraphy of the Scarborough Formation (modified after Gowland & Riding 1991).

summarized in Figure 6 and contrasts markedly with those previously published (e.g. Graue *et al*. 1987; Mitchener *et al*. 1992; Whitaker *et al*. 1992; Helland-Hansen *et al*. 1992; Husmo *et al*. 2002). The shelfal marine Dogger Formation is of 'earliest' Aalenian age and correlative with uppermost Dunlin Group, Drake Formation and Båt Group, Ror Formation. The Aalenian

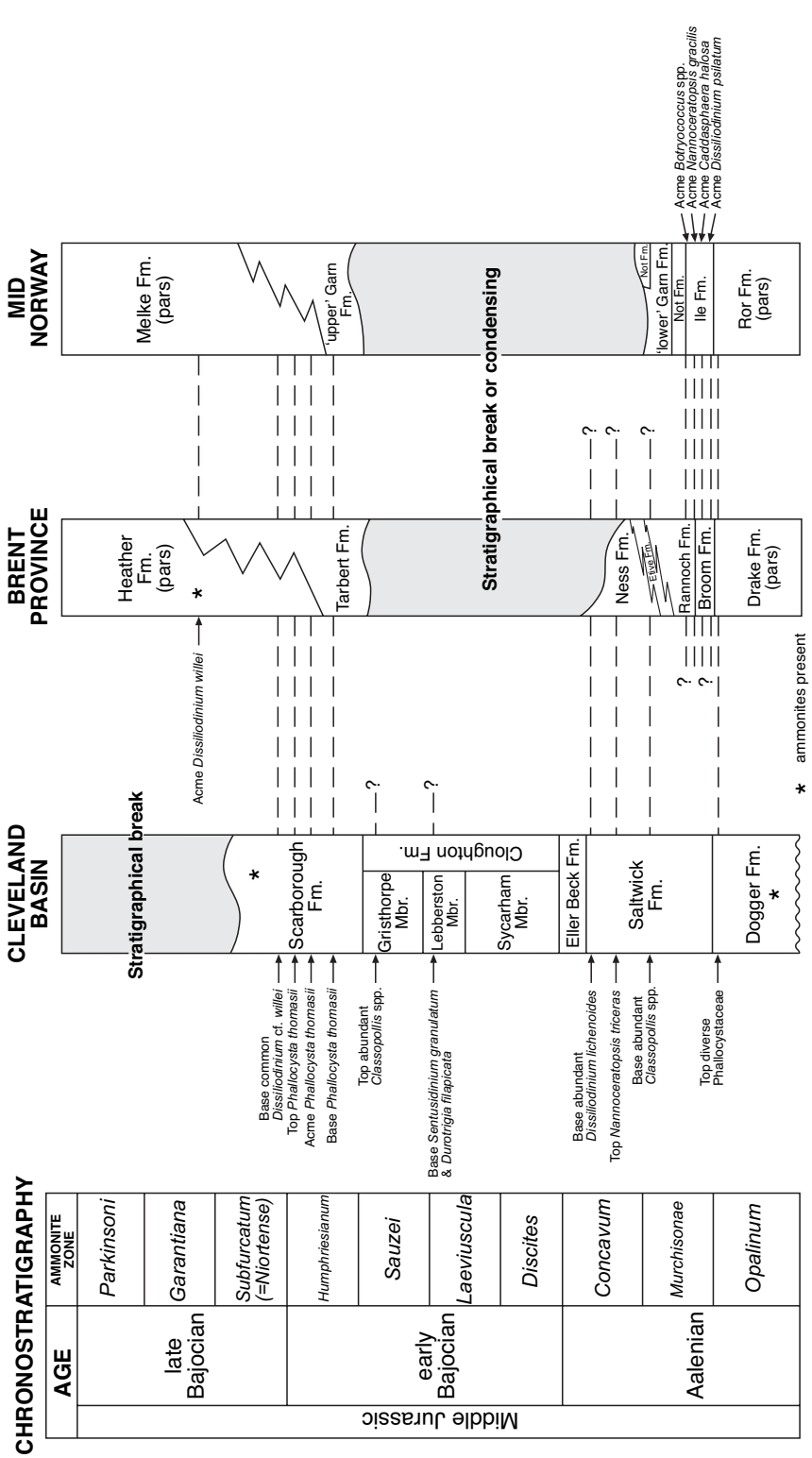

Fig. 6. Correlation of the Cleveland Basin with the Brent province and Mid-Norway.

Saltwick Formation (non-marine/brackish coastal plain/deltaic sediments) and Eller Beck Formation (marine incursion) correlate with the Brent Group, Broom–Rannoch–Etive–Ness and the Fangst Group, Ile–Not–'lower' Garn genetic packages. The variably non-marine to shelfal sediments of the Cloughton Formation are either unrepresented or condensed in the Brent Province and Mid-Norway due to a regional unconformity, which truncates early Bajocian sediments. The Scarborough Formation is a retrogradational package, which was deposited in a shelfal environment and is of 'latest' early to 'earliest' late Bajocian age. This formation is correlative with the older part of the Tarbert–Heather and the 'upper' Garn–Melke genetic packages.

Our thanks are due to the directors of Norsk Hydro a.s. and Robertson Research International Ltd for the use of their technical facilities and permission to publish this paper. We are particularly grateful to J. P. G. Fenton for critically reading the manuscript.

Appendix: list of palynomorph taxa

Dinoflagellate cysts

Chytroeisphaeridia hyalina (Raynaud 1978) Lentin & Williams 1981
Comparodinium spp. Morbey 1975
Dissiliodinium lichenoides Feist-Burkhardt & Monteil 2001
Dissiliodinium psilatum Prauss 1989
Dissiliodinium willei Bailey & Partington 1991
Durotrigia daveyii Bailey 1986
Durotrigia filapicata (Gocht 1970) Riding & Bailey 1991
Luehndea spinosa Morgenroth 1970
Mancodinium semitabulatum Morgenroth 1970
Maturodinium inornatum Morgenroth 1970
Mendicodinium morgenrothii Butler 1995
Moesiodinium raileanui Antonesçu 1974
Nannoceratopsis dictyambonis Riding 1984
Nannoceratopsis gracilis Alberti 1961
Nannoceratopsis senex Van Helden 1977
Nannoceratopsis triceras Drugg 1978
Ovalicysta hiata Bjaerke 1980
Parvocysta nasuta Bjaerke 1980
Phallocysta elongata (Beju 1971) Riding 1994
Phallocysta eumekes Dörhöfer & Davies 1980
Phallocysta thomasii Smelror 1991
Scriniocassis weberi Gocht 1964
Sentusidinium granulatum (Courtinat & Gaillard, 1980) Brenner 1988
Susadinium faustum (Bjaerke 1980) Lentin & Williams, 1985
Susadinium scrofoides Dorhofer & Davies, 1980
Valvaeodinium spp. Morgenroth 1970

Spores

Couperisporites jurassicus Pocock 1970
Verrureticulisporis giganteus Danzé-Corsin & Laveine 1963

Pollen

Classopollis spp. Pflug 1953
Quadraeculina anellaeformis Maljavkina 1949

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