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The Sequence Stratigraphy and Sandstone Play Fairways of the Late Jurassic Humber Group of the UK Central Graben

Non exclusive study

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TECHNICAL SUMMARY

This report provides stratigraphic analyses and interpretations of wells from the UK Central Graben over the Late Jurassic to Early Cretaceous Humber Group in order to construct a series of play fairway maps of potential and proven reservoir distribution. Stratigraphic interpretations and tops from 189 wells included in well releases 01 to 91 are included in the report (Table 1).

New biostratigraphic analyses provide a basis for lithostratigraphic and sequence stratigraphic interpretations, the latter comprised of genetic (J Sequences) and depositional sequence (DSB) picks that allow the generation of play fairway maps away from well control when integrated with a regional structure map (from the Millennium Atlas, 2003). Detailed, non-proprietary biostratigraphic analyses have been conducted by the authors on 95 of the 189 wells to provide stratigraphic control, although these data are not included in this report.

Sandstone fairway maps are provided for eight stratigraphic intervals defined mainly by a genetic sequence stratigraphic framework based on maximum flooding surfaces (MFS) but also based on depositional sequence boundaries (DSB) particularly within the Late Oxfordian J54 (LJ2) genetic sequence where the sequence stratigraphy is complex.

J Sequence	**GeoStrat Nomenclature**	**Age**
J46-J52;	LJ1 Sequence;	Early-Middle Oxfordian
J54;	LJ2 Sequence (LJ2 MFS – LJ2 DSB);	early Late Oxfordian
J54;	LJ2 Sequence (LJ2 DSB);	mid Late Oxfordian
J54;	LJ2 Sequence (LJ2 DSB – LJ3 MFS);	late Late Oxfordian
J56;	LJ3 Sequence (LJ3 MFS – *baylei* MFS);	latest Late Oxfordian to early Kimm
J62;	LJ3 Sequence (*baylei* MFS – LJ4 MFS);	early to mid Kimmeridgian
J63-J64;	LJ4 Sequence (LJ4 MFS – LJ5 MFS);	mid Kimm. to mid Early Volgian
J66-J73;	LJ5 Sequence (LJ5 MFS – LJ6 MFS);	mid Early to mid Late Volgian

Within each genetic sequence are depositional sequence boundaries which can be used to describe the sequence architecture, distinguishing highstand progradational sands, lowstand basin floor sands and transgressive, retrogradational sands.

GENETIC SEQUENCE J46 – J52; LJ1; EARLY to MIDDLE OXFORDIAN

This sequence is largely restricted to the axial part of the Central Graben and is comprised mainly of Heather Formation *sensu stricto* mudstones. The mudstones of the Heather Formation *sensu stricto* record the initial drowning of the graben in association with the J46 (LJ1) (*mariae*) MFS transgression and subsidence, resulting in a marine seaway. In many locations the Heather Formation *sensu stricto* may rest conformably on the underlying Pentland Formation.

Shallow marine sandstones of the Franklin Formation are present in wells from three areas: to the north east of the Puffin Fault Block in blocks 29/4d, 29/5b and 22/30b+c, flanking the southern part of the

Forties Montrose High in blocks 22/23b, 22/24b, 22/25b and 22/28a and in the southern part of the West Central Graben(22/27a).

The general lack of basin margin and intra-basinal faulting and wave energy (due to the narrow seaway) means that shoreface/shelf sands are not common although thicknesses may be significant. The extent of the Franklin Formation in this area is now well constrained by the presence of coeval mudstones of the Heather Formation *sensu stricto* and the sands are absent in wells from blocks 21/20b, 22/16a, 22/21, 22/22b, 22/25b, 22/27a, 22/29, 22/30a, 23/26a+b, 30/1c, 30/6, 30/8 and 30/13.

GENETIC SEQUENCE J54; LJ2; LATE OXFORDIAN

This sequence contains the greatest volume and most extensive distribution of sand within the Central Graben, represented by the Puffin Formation, including the Curlew Member and the Freshney Member of the Heather Formation. The Puffin Formation is a shoreface/shelf sand but in places contains an incised valley fill: the Curlew Member, which represents an estuarine to marginal marine facies above the LJ2 depositional sequence boundary. Situated above the depositional sequence boundary in distal locations are lowstand basin floor sands of the Freshney Member.

Sand generation is probably related to an intensification of rifting which provided the means to generate increased sand input into the developing basin from basin margin and footwall uplift. Widening of the basin, particularly across the Puffin Fault Block, may have allowed the development of high energy waves as a means of sediment transport.

The Puffin Formation has sufficient well density now to be mapped by systems tract. The typical bow shaped log profile of this unit reflects the high-stand/transgressive systems tract make-up of the section, with an interfluve sequence boundary/transgressive surface present in the medial part of the section, which is capped by a retrogradational system.

The lower part of the Puffin Formation is typified by a gamma profile, which records a cleaning upward, high-stand progradational succession. The slow rates of relative sea level rise allowed this part of the J54 / LJ2 sequence to remain in a shallow marine realm as accommodation was largely filled.

The main sand depocentre appears to be the Puffin Fault Block and to the north east of the Puffin Fault Block, prograding out to 23/26b block wells. Progradational shoreface/shelf sands of the Puffin Formation are recognised in wells from:

- the West Central Graben: blocks 21/20a+b, 22/16a.

- on the flanks of the Forties Montrose High: blocks 22/23b, 22/28a.

- on the Puffin Fault Block: blocks 22/27a, 22/28b, 29/1b, 29/2a+b, 29/3a+b, 29/4a, 29/5a, 29/8a, 29/9a+b, 29/10 and 29/15.

- to the northeast of the Puffin Fault Block: blocks 22/28a, 22/29, 22/30a+b+c, 29/4d, 29/5b and 23/26a+b.

- on the flanks of the Auk Ridge: block 30/11b.
- extending from the West Central Graben onto the West Central Shelf, possibly via a fault transfer ramp: blocks 21/24, 21/25, 21/30.

The areal distribution of the Puffin Formation on the West Central Shelf and in the West and East Central Graben is likely to be controlled by a pre-existing valley system created by the withdrawal of Zechstein salt and development of Triassic pods, drowned by the Oxfordian transgression.

The extent of the Puffin Formation is constrained by wells comprised of the Heather Formation *sensu lato* in the lower part of the J54 / LJ2 sequence in blocks 22/21, 22/22b, 22/24b, 22/25b, 22/27a, 22/29, 30/1c, 30/6 and 30/13.

Following a fall in relative sea level, fluvial transport was directed across the emergent Puffin Fault Block to supply sediment into the basins, where low-stand basin floor sands of the Freshney Member were deposited in the West Central Graben, blocks 22/21, 22/22b, 22/23b, 22/27a and 22/28a and blocks 30/6, 30/7a and 30/13 of the Central Graben.

A rise in relative seal level led to the backfilling of incised valleys on the Puffin Fault Block with estuarine/marginal marine sediments of the Curlew Member. The Curlew Member is identified in a sufficient number of wells to permit mapping the incised valley system. The Curlew Member is present in the following wells: 29/2a-2, 29/2a-3, 29/3a-5, 29/7-3, 29/7-4, 29/7-5, 29/7-6, 29/7-7, 29/8a-4, 29/8b-5 and 29/10-2. The location of the incised valley systems were probably structurally controlled with initial fluvial incision focused in areas of moderately high subsidence, eg. the hanging wall of the West Central Platform in block 29/7.

As the transgressive phase continued, retrogradational shoreface/shelf sands of the Puffin Formation accumulated above the Curlew Member or above the interfluve sequence boundary.

Retrogradational sands immediately above the LJ3 DSB are more widespread than the underlying progradational high-stand sands, particularly around the eastern margin of the Forties Montrose High, in West Central Platform block 21/24 and 21/25 and on the flank of the Auk Ridge. The Puffin Formation extended onto the flanks of the Forties Montrose High in block 22/24b+d and 22/19b, the West Central Platform in blocks 21/24, 21/25 and 21/30 and on the flanks of the Auk Ridge in block 30/11b. The Lower Fulmar Formation is present above the Puffin Formation in 30/11b and is also present above the base Late Jurassic unconformity to the southeast in block 30/12b.

In distal locations of the Puffin Fault Block, West Central Graben and the Central Graben, the Puffin Formation is succeeded by mudstones of the Heather Formation *sensu lato*, which contains the J56 (LJ3) (*rosenkrantzi*) MFS. In more proximal locations close to the West Central Platform and the Forties Montrose High in blocks 21/24, 21/25, 29/7, 30/11b, 30/12b, 22/23b and 22/28a, retrogradational followed by progradational/aggradational shoreface/shelf sands of the Puffin Formation and Lower Fulmar Formation accumulated through Late Oxfordian times, up to and beyond the J56 / LJ3 (*rosenkrantzi*) MFS.

More distal locations in the East Central Graben and the deeper part of the West Central Graben and Central Graben remained beyond the main Puffin Formation fairway.

GENETIC SEQUENCE J56; LJ3 (pars); latest LATE OXFORDIAN to early KIMMERIDGIAN

The transgression marked by the J56 / LJ3 (*rosenkrantzi*) MFS within the Heather Formation *sensu lato* reduced sand supply greatly into the Central Graben. Sands in the basin are restricted to low-stand basin floor sands, namely thin sands of the Shearwater Member which occur within the Heather Formation *sensu lato* above the LJ3i DSB. They are present in wells from blocks 22/30b, 23/26b, 23/21a and 30/2a and accumulated during latest Late Oxfordian times. The sands are probably sourced locally.

When high-stand progradation occurred it took place from localised sources of sand input on the margins of the West Central Platform and the Forties Montrose High. Four principal areas of high-stand sand input are recognised during latest Late Oxfordian to early Kimmeridgian times, up to the *baylei* ISF (J56):

- West Central Platform blocks 21/20a+b, 21/24 and 21/25 (Puffin Formation).

- on the flanks of the Forties Montrose High, blocks 22/23b to 22/28a (Puffin Formation).

- the 29/7 to 29/12 area (Puffin Formation).

- the Halley/Clyde/Fulmar area, blocks 30/11b, 30/12b, 30/16 and 30/17b (Lower Fulmar Formation).

Distribution of these sands is constrained by the coeval uppermost part of the Heather Formation *sensu lato*.

GENETIC SEQUENCE J62; LJ3(pars); early to mid KIMMERIDGIAN

The transgression marked by the J62 (*baylei)* MSF resulted in significant flooding of the West Central Platform and the Norwegian-Danish Platform and corresponds to the base of the Kimmeridge Clay Formation. High-stand progradation took place from localised sources of sand input on the margins of the Forth Approaches Platform and the Norwegian-Danish Platform. Five principal areas of high-stand sand input are present:

- West Central Platform blocks 21/19, 21/20a, 21/24 and 21/25 area (Ryton Member).

- blocks 29/1a, 29/6a+b and 29/11a (Ryton Member).

- blocks 29/9b and 29/14b (Leen Member).

- the Halley/Clyde/Fulmar area, blocks 30/11b, 30/12b, 30/16, 30/17a+b, 30/18 and 30/19a (Upper Fulmar Formation).

- the Jaeren High and Norwegian-Danish Platform (Ula Formation).

Distribution of these sands is constrained by the presence of the Trent Member of the Kimmeridge Clay Formation.

The areal distribution of the Ryton Member on the West Central Platform is likely to be controlled by a pre-existing valley system created by the withdrawal of Zechstein salt and development of Triassic pods, drowned by the early Kimmeridgian, *baylei* transgression.
In general these localised sand bodies show a progradational-retrogradational pattern. On the West Central Platform blocks 21/19, 21/20a, 21/24 and 21/25, the medial part of these cycles is marked by an interfluve lag deposit. Two examples of likely equivalent low-stand deposits have been penetrated in

wells from blocks 21/20a which contain forced regressive sands and 21/20b which penetrated low-stand basin floor sands assigned to the Christian Member.

GENETIC SEQUENCE J63-J64; LJ4; mid KIMMERIDGIAN to mid EARLY VOLGIAN

The drowning of the J62 Sequence was initiated by the J63/LJ4 (*eudoxus*) MFS. This represents a major condensed section. Due to ongoing tectonic activity the basin margins continued to drown, and four areas of shallow marine high-stand progradation are recorded:

- the Ula trend of the Norwegian-Danish platform.

- the Laver Member on the West Central Platform, blocks 21/29a+b, 21/30, 28/5, 28/10 and 29/6a.

- the Laver Member Equivalent in 22/18-6 (Wood field) on the crest of the Forties Montrose High.

- the Uppermost Fulmar Formation in block 30/17a.

The areal distribution of the Laver Member on the West Central Platform is likely to be controlled by a pre-existing valley system created by the withdrawal of Zechstein salt and development of Triassic pods, drowned by the Kimmeridgian, J63 (*eudoxus*) transgression.

Low-stand deposits are largely not penetrated over most of the area. Low-stand sands of the Selkirk Member are present in blocks 22/16a, 22/22b, 22/23b, 22/28a and 22/29 on the flanks of the Forties Montrose High. Sediment gravity flow and shallow marine deposits of the Ribble Member and its equivalents are also recognised in the Fulmar and Clyde Fields respectively. Enhanced input of fine-grained clastics during low-stand, may however be recorded by the Swale Member 'cool' shales which are coeval with the Selkirk Member.

GENETIC SEQUENCE J66-J7; LJ5 mid EARLY to mid LATE VOLGIAN)

This sequence records major mudrock blanketing across the basin and minimal sand development due to the retreat of shallow marine systems. The base of the sequence is marked by the J66 / LJ5 (*hudlestoni*) MFS. This event led to major flooding of the flanks and crest of the Forties Montrose High with intervening Triassic rafts/pods forming subaerial highs eg Marnock and Skua field, block 22/24.

The shallow marine Nidd Member and Equivalent represents shallow marine deposits fringing the basin, but the lack of well data and monotonous log character of these deposits means that their origin remains enigmatic. They are present in 29/20 and 29/23 and on the crest of the Forties Montrose High in 22/18-6 and 22/23b-4. The major cool shale of the Wharfe Member contained within this genetic sequence has been interpreted as a low-stand sequence which contains significant accumulations of sediment gravity flow deposits in other parts of the North Sea, such as the Witch Ground Graben and may record a global relative fall in sea level. In the Central Graben however, sand input is negligible as exposed source areas were increasingly distant.

1. INTRODUCTION

This report provides stratigraphic analyses and interpretations of wells from the UK Central Graben over the Late Jurassic to Early Cretaceous Humber Group in order to construct a series of play fairway maps of potential and proven reservoir distribution. Stratigraphic interpretations and tops from 189 wells included in well releases 01 to 91 are included in the report (Table 1).

New biostratigraphic analyses provide a basis for lithostratigraphic and sequence stratigraphic interpretations, the latter comprised of genetic (J Sequences) and depositional sequence (DSB) picks that allow the generation of play fairway maps away from well control when integrated with broader stratigraphic criteria and a regional structural elements map (from the Millennium Atlas, 2003). An account of the development of sequence stratigraphic schemes is provided in Chapter 2.3.

Detailed, non-proprietary biostratigraphic analyses have been conducted by the authors on 95 of the 189 wells to provide stratigraphic control, although these data are not included in this report.

The data and interpretations have been performed by GeoStrat stratigraphers Robin Dyer and Gwyd Williams during the past of 25 years with reviews every five years. More extensive versions of this report, including full biostratigraphy data and interpretations, have been purchased by 29 UKCS operators and partners since 1991. This interaction with numerous geoscientists with diverse knowledge and backgrounds has insured the veracity and integrity of the database. Internal GeoStrat audits of the data have been performed within an ODM/IC database, cross referencing well data through correlations and geo-referenced maps.

All stratigraphic tops, comprising formations, members, J sequences, depositional sequence boundaries and ages are tabulated in Appendix 1. OGA has been provided also with a set of csv's of tops for each category for import directly into stratigraphic databases such as Petrel.

The play fairway maps have been produced within ODM/IC and are geo-referenced. A set of polygons and an explanatory xls file has been provided to OGA for import into a GIS application such as ArcGis.

The following personnel have been involved in this study:

Robin Dyer	:	Micropalaeontology, stratigraphy and reservoir distribution
Gwyd Williams	:	Palynology and stratigraphy

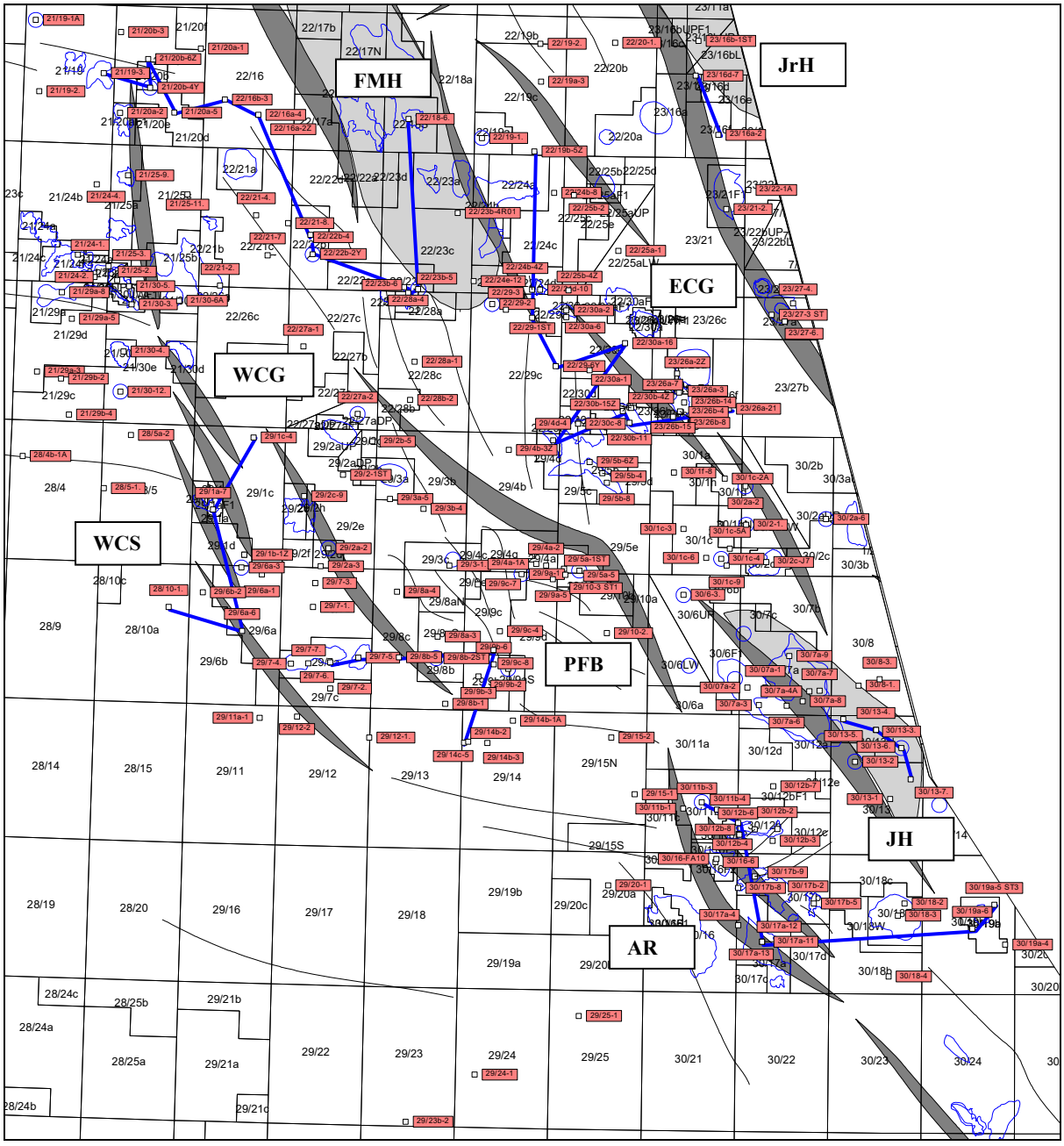

Figure 1.1 Well Location and Structural Elements Map

Blue lines = Chronostratigraphic well summaries
WCS = West Central Shelf
WCG = West Central Graben
FMH = Forties Montrose High
PFB = Puffin Fault Block
ECG = East Central Graben
JH = Josephine High
JrH = Jaeren High
AR = Auk Ridge

Table 1 UKCS Central Graben wells			
21/19-1A	22/28a-1*	29/2-1ST	30/12b-8
21/19-2*	22/28a-4*	29/23b-2	30/13-1X*
21/19-3	22/28b-2RE*	29/24-1	30/13-2X*
21/20a-1*	22/29-1ST*	29/25-1*	30/13-3
21/20a-2*	22/29-3*	29/2a-2*	30/13-4
21/20a-5	22/29-6S2*	29/2a-3*	30/13-5
21/20b-3*	22/30a-1*	29/2b-5	30/13-6*
21/20b-4 S2	22/30a-16*	29/2c-9	30/13-7
21/20b-6+6Z*	22/30a-2*	29/3-1*	30/16-6*
21/22-1	22/30a-6*	29/3a-5*	30/16-7*
21/24-1*	22/30b-11	29/3b-4*	30/16-FA10*
21/24-2	22/30b-15Z*	29/4a-1A*	30/17a-11
21/24-4	22/30b-4 RE	29/4a-2*	30/17a-12
21/25-2*	22/30c-8	29/4b-3 ST	30/17a-13+13RE*
21/25-3	23/16a-2	29/4d-4	30/17b-2
21/25-9	23/16b-1ST1*	29/5a-1ST*	30/17b-5
21/29a-3	23/16d-7	29/5a-5*	30/17b-8
21/29a-5*	23/21-2*	29/5b-4*	30/17b-9*
21/29a-8	23/22-1A	29/5b-8	30/18-3
21/29b-2*	23/26a-21	29/6a-1	30/18-4
21/29b-4*	23/26a-2Z*	29/6a-3	30/19a-4*
21/30-12*	23/26a-3*	29/6a-6	30/19a-5 ST3
21/30-3*	23/26a-7*	29/6b-2	30/19a-6*
21/30-4*	23/26b-14	29/7-1	30/1c-2A
21/30-5	23/26b-15	29/7-2*	30/1c-3*
21/30-6A	23/26b-4	29/7-3.*	30/1c-4
22/16a-2Z	23/26b-8	29/7-4.*	30/1c-5
22/16a-3	23/27-3	29/7-5.*	30/1c-6
22/16a-4	23/27-4*	29/7-6.	30/1f-8
22/18-6	23/27-6*	29/7-7.*	30/2-1
22/19-1	28/10-1*	29/8a-3*	30/2a-2*
22/19b-5Z*	28/4b-1A	29/8a-4*	30/6-3*
22/20-1	28/5-1.	29/8b-1*	30/7a-1
22/21-2	28/5a-2*	29/8b-2,2ST*	30/7a-2*
22/21-4*	29/10-2*	29/8b-5*	30/7a-3
22/21-7*	29/10-3ST1*	29/9a-1*	30/7a-4A
22/21-8	29/11a-1	29/9a-5*	30/7a-6
22/22b-2 ST2	29/12-1*	29/9b-2*	30/7a-8
22/22b-4	29/12-2.	29/9b-3*	30/8-1
22/23b-4RE*	29/14b-1A*	29/9b-6	
22/23b-5	29/14b-2	29/9c-7	
22/23b-6*	29/14b-3	29/9c-8	
22/24b-4ST1*	29/14c-5	30/11b-1*	
22/24b-8*	29/15-1*	30/11b-3	
22/24d-10	29/15-2*	30/11b-4	
22/25a-1*	29/1a-7*	30/12b-2*	
22/25b-2	29/1b-1*	30/12b-3*	
22/25b-4 S1	29/1b-1Z*	30/12b-4*	
22/27a-1	29/1c-4	30/12b-6	
22/27a-2*	29/20-1*	30/12b-7	
	Total wells: 189		
	* = Wells with new biostratigraphic analyses: 95		

2. STRATIGRAPHIC FRAMEWORK

An integrated stratigraphic framework, which includes biostratigraphy, lithostratigraphy and sequence stratigraphy, has been utilised in this study (Figures 2.1). The erection and use of this scheme is based on an exhaustive review of existing stratigraphic studies and on data generated from the well database of this study. This framework allows the development of a chronostratigraphic sequence model, which utilises the concepts of both genetic sequence and depositional sequence models in a pragmatic manner.

2.1 BIOSTRATIGRAPHY

This section discusses the application of biostratigraphic zonation schemes in the Central Graben covering nomenclature and terminology, zonal schemes. biofacies and problems and solutions, albeit there is no biostratigraphic data included in the report. The principal problems that have to be addressed in the Central Graben are related to depositional facies variation and poor recovery associated with depth of burial.

2.1.1 Nomenclature and Terminology

Zones and subzones

The biostratigraphic framework used in this study relies on the rigorous integration of palynological and micropalaeontological schemes. This approach improves resolution based on single disciplines and may overcome problems of relying on individual fossil groups.

The Late Jurassic interval is subdivided into:

- fourteen palynological zones (LJP1-14) and eighteen subzones.
- eleven micropalaeontological zones (LJM1-11) and eight subzones.

2.1.2 Zonal schemes and their application

Calibration between micropalaeontological and palynological zonal schemes (Figure 2.1) allows reliance on one alone, in the absence of dual data sets. In general, shallow-buried, shallow-marine sediments have been dated mainly by palynology and deeply-buried sequences mainly by micropalaeontology. Resolution to substage level has generally been achieved.

2.1.3 Biofacies

Interpretation of the depositional environment of Jurassic and Early Cretaceous sediments can be made from the nature, diversity and relative abundance of palynological and micropalaeontological taxa and assemblages. The main environmental categories and criteria used to define these are as follows:

- fluvio-deltaic environments (*eg.* Fladen Group) are indicated by the following features:
  - high abundance of terrestrially-derived spores and pollen.
  - absence of marine dinocysts, foraminifera, ostracods and radiolaria.
- estuarine to marginal-marine environments (*eg.* Curlew Member) are indicated by the following features:
  - high abundance of terrestrially-derived spores and pollen.
  - low diversity of marine dinocysts.

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U.K. Central Graben - Humber Group chronostratigraphy

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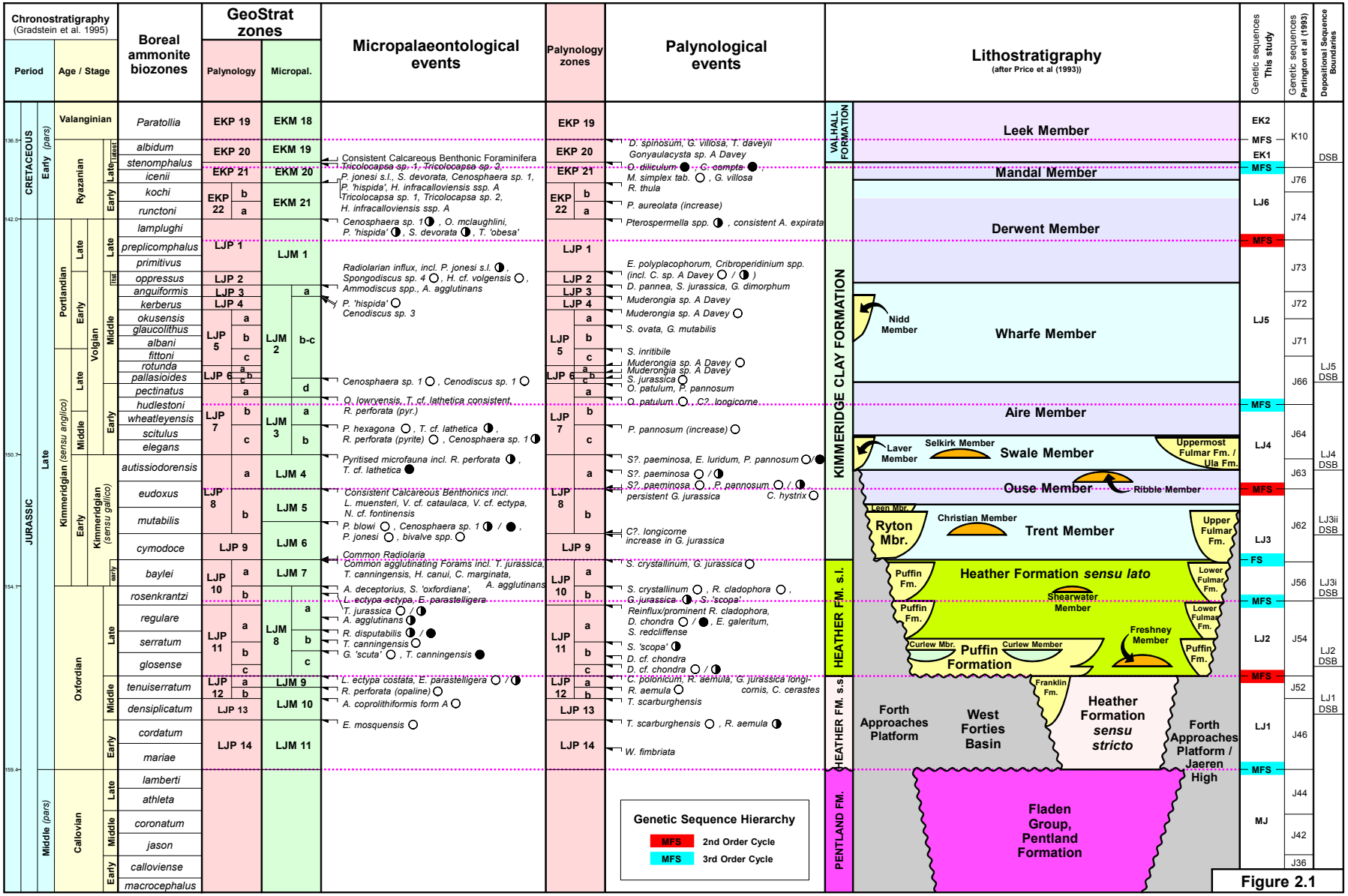

Figure 2.1

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U.K. Central Graben - Humber Group chronostratigraphy

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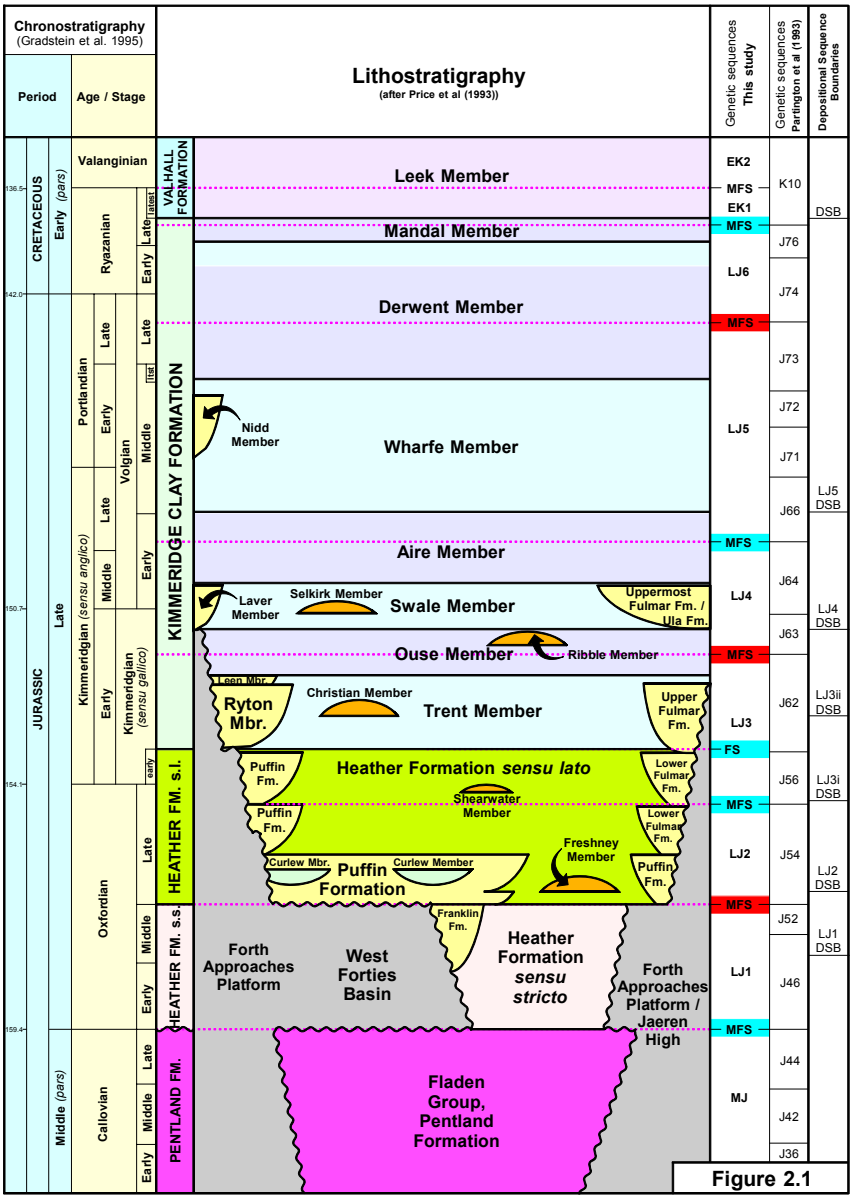

Figure 2.1

  - low diversity of agglutinating foraminifera, including *Glomospirella* spp. and *Glomospira* spp.
  - absence of calcareous foraminifera, ostracods and radiolaria.

- shallow-marine, inner shelf environments (*eg*. Heather Formation) are indicated by the following features:
  - high abundance and diversity of dinocysts.
  - high abundance and diversity of agglutinating foraminifera.
  - high abundance of sponge spicules.
  - low abundance of radiolaria.

- deep marine, outer shelf environments (*eg.* Kimmeridge Clay Formation) are indicated by the following features:
  - reduced abundance of diversity of dinocysts.
  - abundance of amorphous organic matter
  - absence of benthonic assemblages in anaerobic conditions due to the sea floor being below fair-weather storm-base.
  - high abundance of radiolaria.

These broad environmental categories invariably integrate to create mixed assemblages, although it is usually possible to interpret the most-likely environment of deposition because of the predominance of particular environmental indicators.

2.1.4 Problems of biostratigraphical analysis in the Central Graben

Two principal problems can be identified in the identification and application of biostratigraphic zonation schemes to the Central Graben.

Depositional/Facies Variation

Late Oxfordian sediments exist throughout the Central Graben. The sediments are predominantly shallow marine (Heather Formation *sensu lato* and Puffin Formation). However, within the Puffin Formation there may be developed estuarine/marginal marine sediments of the Curlew Member. Age diagnostic dinocysts are often present although some of the sediments may lack abundant marine index taxa and yield instead more long-ranging, terrestrially-derived spores and pollen and monospecific agglutinating foraminifera, namely, *Glomospirella 'scuta'*. Age interpretation and correlation of these assemblages with coeval marine sediments is relatively imprecise and is compounded by the fact that they typically form the fills to incised valleys, which correlate to surfaces (*i.e.* interfluve sequence boundaries) in nearby wells. While the log signature of the Curlew Member may be similar to that of the underlying Fladen Group, the biostratigraphic data may allow discrimination of these units, particularly by the presence of Late Oxfordian dinocysts and foraminifera.

Poor recovery

Biostratigraphical schemes for the Late Jurassic of the North Sea have relied traditionally on palynomorphs, particularly dinocysts. Planktonic dinoflagellates are very abundant in marine environments, are widespread in distribution and underwent rapid evolution. Fossilised dinocysts therefore provide an excellent basis for biostratigraphic zonation and correlation. The dinocyst zonation scheme for the Early Cretaceous and Late Jurassic potentially represents the most refined means of stratigraphic interpretation available to the industry. Recovery of dinocysts from deeply buried Jurassic sediments of the Central Graben is usually reduced however, due to post depositional destruction associated with high temperatures and pressures.

The problems of poor recovery associated with the destruction of palynomorphs at depths of burial below 14,000 ft. have been mitigated by the application of dual palynological and micropalaeontological zonation schemes.

The Kimmeridge Clay Formation is typically deeply-buried, thermally-mature and was deposited in conditions inimical to benthonic faunas. Radiolaria are planktonic, and because of their siliceous tests, were largely unaffected by burial. They are often abundant in assemblages recovered from the Kimmeridge Clay Formation. They are, therefore, important for providing dating within the deeply-buried Jurassic of the Central Graben (Dyer and Copestake 1989).

The Heather Formation was deposited mainly in a shallow-marine setting and thus planktonic radiolaria are present in very low abundances. When buried to shallow depths (<12,000 ft.), and where lithologies are not predominantly well-sorted sands, precise dating using palynology can be achieved. Calcareous benthonic and agglutinating foraminifera can also be used for zonation in some shallow marine sediments, such as the Heather Formation and a scheme calibrated with the palynological scheme has been developed. It is possible to apply this scheme to deeply-buried shallow-marine sediments of the Heather Formation, which yield poor palynological assemblages.
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2.2 LITHOSTRATIGRAPHIC SCHEME

The lithostratigraphical scheme used in this study relies heavily on dating to constrain correlation between units of similar character yet differing ages. This is an alternative approach to the more dogmatic, but simplified method of assigning all shallow marine, shoreface sands to the Fulmar Formation, irrespective of age, geographic location and regional discontinuity.

The lithostratigraphic scheme is based on Price *et al.* (1993). Definitions are based mainly on wireline log features, but these are constrained by the biostratigraphic framework. While we recognised the potential for lithostratigraphic boundaries, particularly sand units, to be diachronous, it is essential to constrain lithostratigraphic units within a chronostratigraphic and sequence stratigraphic framework if we are to understand and predict the spatial and stratigraphic distribution of potential reservoirs, source and seal.

The Humber Group largely comprises the mudstones of the Heather Formation (*sensu stricto* and *sensu lato)* and the Kimmeridge Clay Formation. A series of seven alternating 'hot' and 'cool' mudstones comprise the Kimmeridge Clay Formation: the Trent, Ouse, Swale, Aire, Wharfe, Derwent and Mandal members.

Shallow-marine sandstones are grouped into four formations: the Franklin, Puffin, Fulmar and Ula formations, and also comprise four units of the Kimmeridge Clay Formation: the Ryton, Leen, Laver and Nidd members.

The Franklin Formation consists of sands of Early to Middle Oxfordian age and is coeval with the Heather Formation *sensu stricto,* present in the central part of the Central Graben.

The Puffin Formation consists of sands of Late Oxfordian age and is coeval with the Heather Formation *sensu lato* and is developed mainly between the main boundary faults of the Central Graben.

The Curlew Member occurs within the Puffin Formation and represents incised valley fill facies deposited in estuarine to marginal marine environments. This unit was informally proposed by Veldkamp *et al*. (1996) to accommodate an intermediate facies between the flood plain deposits of the Pentland Formation and the fully marine Puffin Formation. The Curlew

Member displays a large variety of lithologies indicative of an estuarine to marginal marine setting and contains Late Oxfordian dinocysts and foraminifera. Bioturbated and cross-bedded sands are interbedded with *in-situ* coals, rootlet horizons, sands, mudstones and oyster beds. This range of lithologies is well developed and illustrated in cores from wells 29/7-7, 29/8b-5 and 29/10-2. The Curlew Member is typically represented from wireline data by highly variable gamma and sonic signatures. The informal Curlew Member is recognised in several wells, including 29/3a-5, 29/7-4, 29/7-5, 29/7-6, 29/7-7, 29/8b-5 and 29/10-2.

The Fulmar Formation consists of sands of Late Oxfordian to Early Volgian age and is coeval with the Heather Formation *sensu lato* and the Trent, Ouse and Swale members of the Kimmeridge Clay Formation and is present in the southeast part of the West Central Shelf and south west Central Graben.

The Ula Formation is present on the Jaeren High and consists of sands of Kimmeridgian to Early Volgian age and is coeval with the Trent, Ouse and Swale members of the Kimmeridge Clay Formation.

The Ryton and Leen members are of Kimmeridgian age, present on the western parts of the West Central Shelf.

The Laver Member is of Kimmeridgian-Early Volgian age, present on the western parts of the West Central Shelf.

The Nidd Member is of Middle Volgian age, present on the southern parts of the West Central Shelf.

Equivalents to the Laver and Nidd members are present on the Forties-Montrose High in 22/18-6. This well indicates the development of shallow marine, shoreface sands of Kimmeridgian to Middle Volgian age near the crest of the Forties Montrose High, the first released well to penetrate Late Jurassic sands in this part of the study area. The units are named informally and are considered to be coeval with the shallow marine/shoreface sands of the Kimmeridgian-Early Volgian Laver Member and the Middle Volgian Nidd Member of the West Central Shelf.

Low-stand, mass flow basin-floor sandstones of the Freshney Member occur within the Heather Formation *sensu lato* and within the Puffin Formation in the axial part of the West Central Graben, adjacent to the Forties Montrose High and in the Central Graben adjacent to the Josephine High.

Additional low-stand, basin floor sands similar in character to the Freshney Member are present in younger intervals. The Shearwater Member is a thin sand of latest Late Oxfordian age and is developed within Genetic Sequence LJ3 of the Heather Formation *sensu lato*. The member is named after the Shearwater field, being present in 22/30b-11 as well as 22/29a-3, 23/26b-14, 23/26b-15 and 30/2a-2. The unit is highly argillaceous in 23/26a-21.

The Christian Member is of Kimmeridgian age and is developed within the Trent Member of the Kimmeridge Clay Formation, Genetic Sequence J62 in the West Central Graben. The member is named after Shell's Christian field well 21/20b-4 S2.

Mass flow sands of Kimmeridgian age - the Ribble Member - were recognized in blocks 30/16 and 30/17b.

The Selkirk Member is of Kimmeridgian-Early Volgian age and is coeval with the Swale Member of the Kimmeridge Clay Formation of Genetic Sequence J63-J64 in the West Central Graben. The member is named after Ranger's Selkirk field well 22/22b-2 ST2.

2.3 GENETIC SEQUENCE STRATIGRAPHY

The Late Jurassic and Early Cretaceous of the Central Graben represents deposition in a rift-basin with the added complication of mobile salt. Attempting to use sequence stratigraphy in this particular rift basin setting requires a pragmatic approach; one which uses the processes and principles that sequence stratigraphy provides, but which avoids model-driven assumptions which may have little validity in this type of setting.

There are currently two principal sequence stratigraphic approaches. The depositional sequence model (first developed by Vail *et al.* 1984) and the genetic sequence model (Galloway 1989). They differ in the importance placed on key stratal surfaces. Both have their merits in different situations and, as demonstrated in this study, are not mutually exclusive. The two single most important controls on stratal stacking patterns are likely to be accommodation and sediment supply.

The identification of key stratal surfaces is the first step to the development of a robust sequence stratigraphical framework. Stratal surfaces may be subdivided into three types:

- those developed as a response to a relative sea level fall (comprising depositional sequence boundaries and surfaces of forced regression)

- those developed as a response to a relative sea level rise (comprising transgressive surfaces and initial flooding surfaces).

- maximum flooding surfaces (MFS)

An ideal sequence stratigraphical framework aimed at recognising potential reservoir sandstones would divide the stratigraphy into the component systems tracts, separated by depositional sequence boundaries and maximum flooding surfaces. In this study a genetic sequence stratigraphic approach is used, largely to correlate from the mudrock sections to the sandstone sections (Figure 2.1, Price *et al.* 1993, Partington *et al.* 1993a, Carruthers *et al.* 1996, Underhill and Partington 1993). A depositional sequence stratigraphic approach is used to describe their architecture, where there are sufficient data.

Published genetic sequence stratigraphy schemes exists for the North Sea. The BP 'J' scheme papers (Partington *et al.* 1993a, b) represent a very significant release of data and ideas and rank as some of the most important publications of North Sea stratigraphy, although problems exist in applying the scheme consistently. We believe that the entire 'J' scheme is too detailed for regular application, except perhaps when applied to detailed appraisal and development scales. Many of the 'J' scheme surfaces are difficult to recognise or define and the scheme takes only limited account of the hierarchy of flooding surfaces present within the Upper Jurassic succession. The scheme has been accepted by many as an industry standard however and we have used a reduced version of the scheme that dispenses with some of the more contentious surfaces eg. J64, J71, J72, J73 and J76.

Jeremiah and Nicholson (1999) presented a scheme similar to that of Partington *et al.* (1993) but used dinocyst nomenclature rather than ammonites to label the events. MFS events in addition to those of the Partington scheme were recognised in the Kimmeridgian interval. This scheme represents the in-house scheme of Shell and Esso according to Jeremiah and Nicholson (1999).

Maximum flooding surfaces have been picked largely from the gamma maxima (taken as indicating the most condensed sections), however other logs, principally sonic, resistivity, density and neutron have been used to assist identification.

GeoStrat published a genetic scheme at the same time as the J scheme (Price et al. 1993), recognizing seven genetic sequences (LJ1-LJ6, EK1) in the Humber Group of the Central

Graben. There are corresponding surfaces recognized in the J scheme and we have used both schemes in this study.

2.3.1 Sequence Stratigraphic Scheme

Figure 2.1 illustrates the numbered genetic sequences identified in relation to the biozonal scheme and lithostratigraphy used in this report and gives a comparison with the BP 'J Scheme' of Partington *et al.* (1993a & b). The genetic sequences identified in this study are named after the corresponding basal maximum flooding surface (in ascending stratigraphic order).

Genetic sequence J46 to J52; LJ1 (mariae MFS); (Early to Middle Oxfordian)

This sequence represents the earliest Late Jurassic sequence identified in this study. It comprises the Early to Middle Oxfordian section and has been recognised mainly in the axial parts of the Central Graben (Heather Formation *sensu stricto* and Franklin Formation).

It is possible to identify the J52 MFS is some wells from the West Central Graben.

The sequence is characterised by the occurrence of *Wanaea fimbriata, Compositosphaeridium polonicum*, prominent *Rigaudella aemula*, common *Epistomina mosquensis*, prominant *Epistomina parastelligera* and *Lenticulina ectypa costata.*

Genetic sequence J54; LJ2 (glosense MFS); (Late Oxfordian)

This sequence corresponds to much of the Late Oxfordian interval. The base is marked by a basin wide maximum flooding surface/flooding surface at the base of the Late Oxfordian (which corresponds to the '*polonicum*' event of Jeremiah and Nicholson (1999)). This flooding event may have been induced by a regional acceleration in the rate of faulting in the Central Graben (often coincident with the base of the Puffin Formation).

This sequence can be characterised by abundant and diverse marine palynofloras and microfaunas, including common to abundant *Dichadogonyaulax chondra, Scriniodinium crystallinum, Rhynchodiniopsis cladophora, Gonyaulacysta jurassica, Systematophora 'scopa'*, *Recurvoides disputabilis* and *Ammobaculites deceptorius.*

Genetic sequence J56; LJ3 (pars) (rosenkrantzi MFS); (latest Late Oxfordian to early Kimmeridgian)

The base of this sequence is defined by the J56 (*rosenkrantzi*) MFS, which lies within the Heather Formation *sensu lato* (equivalent to the '*crystallinum*' MFS of Jeremiah and Nicholson (1999)). The J56 (*rosenkrantzi*) MFS occurs above the top range of common *Dichadogonyaulax chondra* and within the range of common *Scriniodinium crystallinum*, and common *Rhynchodiniopsis cladophora*.

Genetic sequence J62; LJ3 (pars) (baylei MFS); (early to mid Kimmeridgian)

The base of this sequence is defined by the J62 (*baylei*) MFS. This occurs above the top ranges of *Scriniodinium crystallinum* and *Textularia jurassica* and corresponds closely with the boundary between the Heather Formation *sensu lato* and the Kimmeridge Clay Formation.

There is a significant microflora/microfaunal turnover at the base Kimmeridge Clay Formation, which introduces common to prominent planktonic radiolaria and is associated with the elimination and extinction of agglutinating foraminifera and certain species of dinocysts. It is equivalent to the '*jurassica*' MFS of Jeremiah and Nicholson (1999).

Genetic sequence J63–J64; LJ4 (eudoxus MFS); (mid Kimmeridgian to mid Early Volgian)

The base of the sequence is defined by a gamma maximum, within the Kimmeridgian aged, 'hot' Ouse Member of the Kimmeridge Clay Formation. The J63 (*eudoxus*) MFS corresponds to major flooding and drowning of the platform areas surrounding the Central Graben and is associated with the top of the Ryton and Leen Member sands of the West Central Shelf and the initial marine transgression on to the Forties Montrose High. It corresponds to the '*pannosum*' MFS of Jeremiah and Nicholson (1999). Overlying this surface is a regional gamma log break, which marks the base of the 'cool' Swale Member. This break marks the base of the Laver Member of the West Central Shelf and the Laver Member Equivalent of the Forties Montrose High. Towards the upper part of the sequence a regional initial flooding surface is present. This break marks the base of the 'hot' Aire Member. It has no equivalent in the BP scheme unless there is a biostratigraphical miscalibration of their J64, *autissiodorensis* MFS.

This sequence is characterised by common to prominent *Subtilisphaera? paeminosa, Perisseiasphaeridium pannosum, Oligosphaeridium patulum, Cribroperidinium? longicorne* and significant numbers of *Rhaxella perforata* (pyritised).

Genetic sequence J66 – J73; LJ5 (hudlestoni MFS); (mid Early Volgian to mid Late Volgian)

The base of this sequence is defined by the J66 (*hudlestoni*) gamma maximum within the Early Volgian aged, 'hot' Aire Member of the Kimmeridge Clay Formation. This MFS corresponds to the '*compat*' MFS of Jeremiah and Nicholson (1999). Overlying this surface is a regional gamma log break, which marks the base of the 'cool' Wharfe Member. This contact may represent a correlative conformity marking the onset of a second-order sea relative level fall (Haq *et al.* 1988).

This genetic sequence contains the Nidd Member of the West Central Shelf, block 29/20 and the Nidd Member Equivalent of the Forties Montrose High.

Flooding surfaces occur within this interval, comprising the J71, J72 and J73. These are difficult to recognize consistently however and they have not been picked in this study. A significant regional flooding surface marks the base of the Derwent Member and probably equates to the J73 *anguiformis* MFS of the BP scheme.

This sequence is characterised by *Muderongia* sp. A, common to prominent *Cribroperidinium* spp. and common to prominent *Parvicingula jonesi.*

Genetic sequence J74 – J76; LJ6 (preplicomphalus MFS); (mid Late Volgian to Late Ryazanian)

The base of the sequence is defined by the J74 (*preplicomphalus*) gamma maximum within the Late Volgian to Ryazanian 'hot' Derwent Member of the Kimmeridge Clay Formation.

This sequence is characterised by common to prominent *Pterospermella* spp., *Amphorula expirata* and common to prominent *Stichocapsa devorata* and *Praeconocaryomma 'hispida'.*

Genetic sequence K10; EKM1 (stenomphalus MFS); (Late Ryazanian to Early Valanginian)

The base is defined by the gamma maximum within the Late Ryazanian Mandal Member of the Kimmeridge Clay Formation.

The lower part of the sequence is characterised by common to prominent *Tricolocapsa* sp. 1, *Haplophragmoides infracalloviensis* ssp. A, *Oligosphaeridium diluculum* and *Circulodinium compta.*

The Kimmeridge Clay/ Valhall Formation contact marks a fundamental facies boundary between organic rich mudstones, which accumulated under anaerobic/dysaerobic sea floor conditions, to organic-poor argillaceous limestones, and calcareous mudstones, which accumulated under aerobic conditions. This change has been ascribed to a regional transgression during *stenomphalus* ammonite Zone times (Rawson and Riley 1982) and resulted in a major microfaunal and floral turnover.

The uppermost part of the sequence is represented by the base of the Leek Member (Valhall Unit V1) of the Cromer Knoll Group, Valhall Formation.

Overview and Sequence Hierarchy

The genetic sequence scheme can be placed into a sequence stratigraphic hierarchy. Five major transgressive events in the Central Graben culminated in the J54 (*glosense*), J62 (*baylei*) J63 (*eudoxus*), J66 (*hudlestoni*) and J74 (*preplicomphalus*) MFS, which we interpret as 3rd order cycles. The other MFS may be considered as 4th order events. Within each genetic sequence, a depositional sequence stratigraphic approach is used to describe the architecture of the sandstone intervals. An example of the identification of J sequences in well 29/12-1 is illustrated in Figure 2.2.

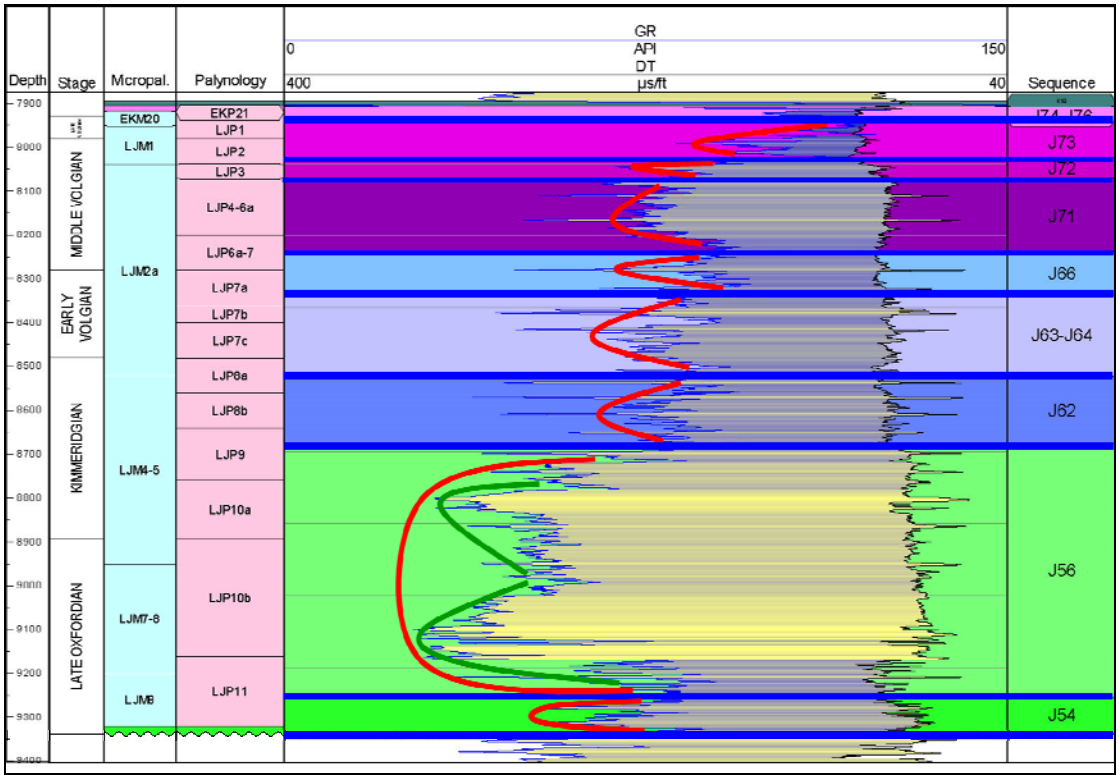

Figure 2.2 Identification of J Sequences in 29/12-1.

The J sequences are most readily picked using expanded horizontal and compressed vertical scales which highlight the gamma maxima that represent maximum flooding surfaces (marked by red cycles). Correct identification of each MFS requires a refined biostratigraphic framework as illustrated.
Blue line thickness may represent cycle hierarchy: thick = 3rd order; thinner = 4th order
Lower order cycles, eg within J56 may be marked by green cycles

3. DEPOSITIONAL SEQUENCE STRATIGRAPHY

3.1 INTRODUCTION

This section outlines the basis for the recognition of the depositional sequence boundaries (DSB) in the Humber Group. The key to such a framework is the Genetic Sequence framework based on maximum flooding surfaces, which in the Humber Group are commonly expressed as gamma maxima within biostratigraphically constrained hot shale facies (Figure 2.1). These record the condensation of shelf and basinal muds during the maximum rate of relative sea level rise. Between these are recorded the products of sea level falls. However, the active extensional tectonics and salt withdrawal during the Late Jurassic implies that whilst depositional sequence boundaries might be recognised, the idealised models in the literature require extensive modification to account for the rugged basin physiography and aerially variable rates in accommodation space creation (Posamentier and Allen 1993, Gawthorpe *et al.* 1994, Howell and Flint 1996). The main expressions of depositional sequence boundaries within the Humber Group can be summarised as comprising:

- estuarine deposits encased in more marine facies (*eg*. Curlew Member) record the transgressive filling of incised valleys cut during low-stand exposure of the shelf. These deposits provide the clearest evidence of relative falls in sea level and fluvial erosion of the shelf, and provide a context (and supporting evidence) for the much more difficult task of identifying interfluve sequence boundaries, particularly where cores are unavailable.

- the interfluve areas flanking incised valleys are a common expression of sequence boundaries in the Central Graben. However, they rarely contain clear evidence of subareal exposure due to erosional transgressive reworking. The typical expression of such surfaces occurs at the boundary between regressive and transgressive deposits (bounded by maximum flooding surfaces) and shows three significant features:

    - a granule/pebble lag, which represents the erosional remnants of the former fluvial or paralic, pebble bearing deposits, which have been transgressively reworked.

    - major calcite cementation/hardground. This represents a sustained submarine hiatus during erosional transgression and may be characterised by a major shift in Δt indicated on sonic logs.

    - sharply-based shoreface deposits (*sensu* Plint 1988) represent the juxtaposition of nearshore shallow marine deposits on offshore sands or mudrocks without the intervening facies which would have been present had normal progradation occurred. This is marked by a sharp decrease in gamma response.

- in more basinal settings the stratigraphic restriction of sediment gravity flow deposits to discrete stratigraphic intervals within mudstone dominated successions is interpreted to reflect the sudden increase in sediments into basinal areas brought about by low-stand conditions as sources of sand grade sediments were brought closer to the basin centre (Carruthers *et al.* 1996).

- the alternations of ‘hot’ and ‘cool’ shales in basinal mudrock successions are similarly interpreted to be the product of relative sea level changes causing variations in sediment flux and degree of oxygenation. The ‘cool’ shales, which almost exclusively contain the sediment gravity flow deposits, are interpreted to largely represent low-stand conditions. Locally, where sediment gravity flow deposits are present within a ‘cool shale’ package, the base of the ‘cool’ shale unit occurs below the base of the sediment gravity flow package.

The above discussion outlines the methodology used to recognise type 1 sequence boundaries within the Humber Group. However, given the potential for locally high subsidence rates within this basin, type 2 sequence boundaries might be expected to occur. Whilst this is likely to be the case, several factors conspire to make the recognition of these extremely difficult and in this report boundaries are assumed to be type 1 until proven otherwise.

The recognition of maximum flooding surfaces and depositional sequence boundaries provides a basis for discriminating high-stand, progradational sands, low-stand basin floor sands and transgressive, retrogradational sands.

3.2 STRATIGRAPHIC DISTRIBUTION OF DEPOSITIONAL SEQUENCE BOUNDARIES

Six depositional sequence boundaries are identified throughout the Early Oxfordian to Middle Volgian intervals of the Humber Group. We have adopted a nomenclature that relates the depositional sequence boundaries to within the corresponding Genetic Sequence (Figure 2.1). The depositional sequence boundaries are considered conceptually as unconformities although missing section cannot be usually demonstrated.

3.2.1 LJ1 Depositional Sequence Boundary (DSB) – within J46.

This event is of early Middle Oxfordian age and is associated with the base of the Franklin Formation or the base of a coarsening upwards trend within the Heather Formation *sensu stricto.*

3.2.2 LJ2 Depositional Sequence Boundary (DSB) – within J54

This event is of Late Oxfordian age. The boundary is associated with the base of the Freshney Member within the Heather Formation *sensu lato* and within the Puffin Formation, marked by an interfluve boundary or the base of the Curlew Member. This sequence boundary equates to the SJU300 DSB of Jeremiah and Nicholson (1999).

Figure 3.1 illustrates the stratigraphy of the Late Oxfordian across the Puffin Fault Block (after Carruthers *et al.* 1996). The LJ2 depositional sequence boundary is marked by an interfluve granule lag in 29/4a-1A, the base of the Curlew Member in 29/10-2 and the base of the Freshney Member in 30/6-3.

3.2.3 LJ3i Depositional Sequence Boundary (DSB) – within J56

This event is of Late Oxfordian age. The boundary is associated with the base of coarsening upwards trends within the Heather Formation (below the Shearwater Member), the Puffin Formation and the Lower Fulmar Formation. This sequence boundary equates to the SJU400 DSB of Jeremiah and Nicholson (1999).

3.2.4 LJ3ii Depositional Sequence Boundary (DSB) – within J62

This event is of Kimmeridgian age. The boundary is associated with the base of a coarsening upwards trend within the Trent Member (below the Christian Member) and within the Ryton Member, marked by an interfluve boundary. This sequence boundary equates to the SJU450 DSB of Jeremiah and Nicholson (1999).

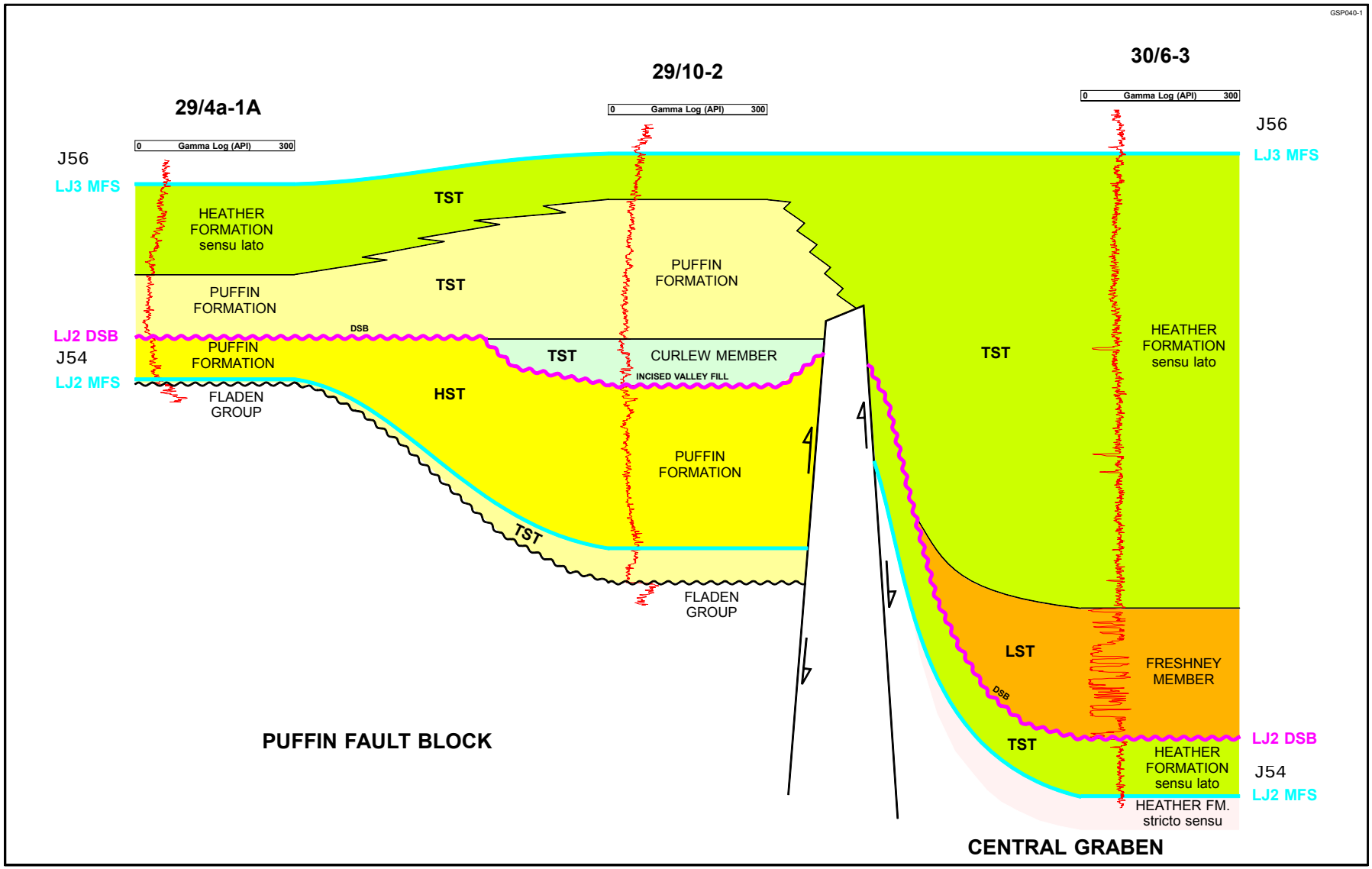

Figure 3.1 LJ2 Depositional Sequence Boundary, Puffin Fault Block

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Figure 3.2 illustrates the stratigraphy of the Kimmeridgian from the West Central Shelf to the West Central Graben. The LJ3ii depositional sequence boundary is marked by an interfluve surface within the Ryton Member in 21/24-4 and 21/25-9 and the base of the cool shale beneath the Christian Member in 21/20b-4 S2.

3.2.5 LJ4 Depositional Sequence Boundary (DSB) – within J63-J64

This event is of Kimmeridgian age. The boundary is marked by the base of the Swale Member 'cool' shale and the base of the Laver Member. The event occurs below the Selkirk Member.

Figure 3.3 illustrates the stratigraphy of the Kimmeridgian to Middle Volgian from the Forties Montrose High to the West Central Graben. The LJ4 depositional sequence boundary is marked by a surface of non-deposition below sands of the shallow marine Laver Member Equivalent in 22/18-6 and the base of the mass flow, basin floor sands of the Selkirk Member in 22/23b-5.

3.2.6 LJ5 Depositional Sequence Boundary (DSB) – within J66-J73

This event occurs at the Early/Middle Volgian boundary. The event is marked by the base of the Wharfe Member 'cool' shale. This contact may represent a correlative conformity marking the onset of a second-order sea relative level fall (Haq *et al.* 1988). This sequence boundary equates to the SJU600 DSB of Jeremiah and Nicholson (1999).

Figure 3.3 illustrates the stratigraphy of the Kimmeridgian to Middle Volgian from the Forties Montrose High to the West Central Graben. The LJ5 depositional sequence boundary is marked by the base of shallow marine sands of the Nidd Member Equivalent in 22/18-6 and the base of the Wharfe Member in 22/23b-5.

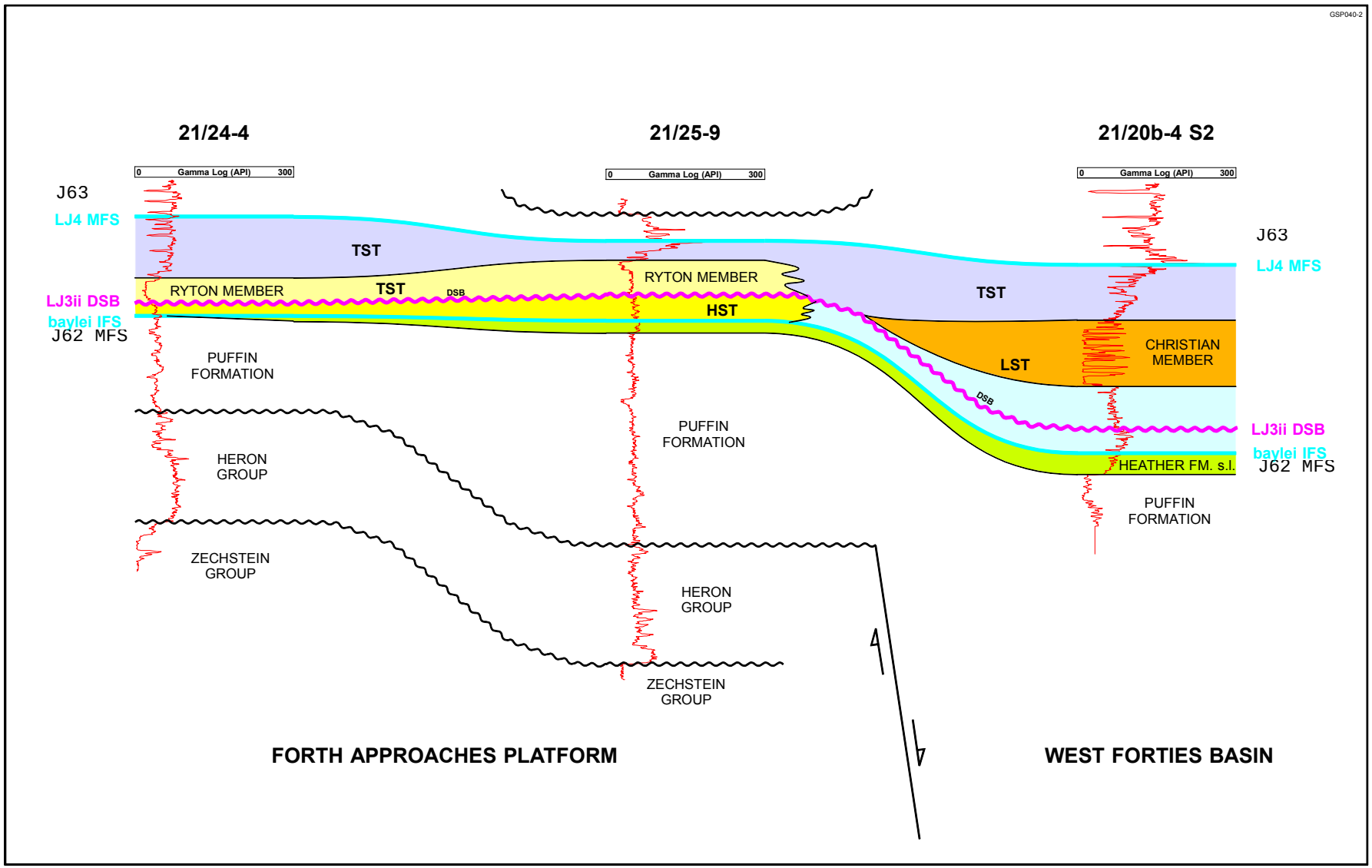

Figure 3.2 LJ3ii Depositional Sequence Boundary, Forth Approaches Platform - West Forties Basin

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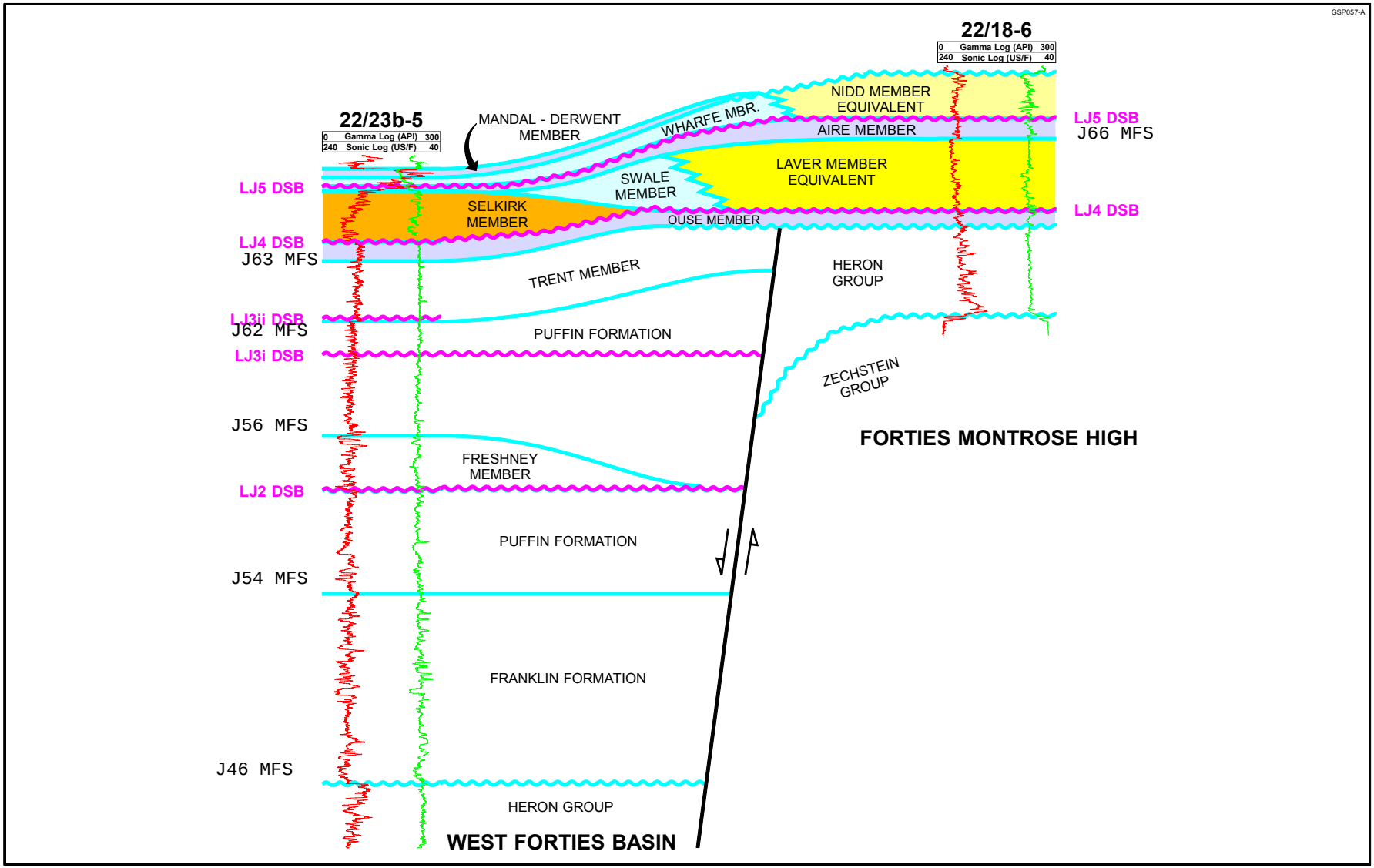

Figure 3.3 LJ4 and LJ5 Depositional Sequence Boundary, West Forties Basin - Forties Montrose High

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4. CENTRAL GRABEN STRUCTURAL ELEMENTS

Mapping the distribution of reservoir sands through Late Jurassic time is a primary objective of this study. Palaeogeographic reconstruction requires a regional structural elements map to constrain the depositional fairways and to aid the prediction of sandstone development away from well control.

A structural elements map should illustrate those faults that are considered to be influential during Late Jurassic times, controlling extension and salt withdrawal and therefore depositional fairways and accommodation space for reservoir sands.

Structural interpretations of the Central Graben are presented in the following publications: Erratt *et al.* (1999), Evans *et al.* (1999), Lasocki *et al.* (1999), Penge *et al.* (1993), Penge *et al.* (1999) and Stewart and Clark. (1999).

The work of Penge et al (1993, 1999) and Stewart and Clark (1999) is particularly relevant to the structural history and marine flooding of the Forties Montrose High during the Late Jurassic.

Erratt *et al.* (1999) considered the sequential development of Triassic, Jurassic and Cretaceous rifting across the UK, Norwegian and Danish North Sea, using regional 3D sequence coverage, particularly for the UK section. They describe the North Sea rift system as a faulted rift of Triassic-Jurassic age formed on a basement transected by Palaeozoic lines of weakness developed principally along northeast-southwest 'Caledonide' and northwest-southeast 'Trans European Fault Zone' trends.

The Triassic-Early Cretaceous history records a westward migration of the rift axis in an 'en echelon' fashion due to the effect of the Palaeozoic lineaments. The Jurassic polyphase rifting history is explained by a variation of the 'vector triangle' model of Roberts *et al.* (1990). Structural geometries within the Central North Sea, including the Central Graben, are primarily attributable to basin extension via normal faulting and salt tectonics/withdrawal.

Erratt *et al.* (1999) present a structural elements map for the Central North Sea, which includes the Central Graben of this report, illustrating those faults that influenced Late Jurassic palaeogeography.

Evans *et al.* (1999) published an account of the Banff field in block 29/2a and 22/28a. The field is a steeply dipping raft of fractured Late Cretaceous and Danian chalk on the flank of a salt diapir. The authors included a detailed structural elements map for the West Central Shelf across the West Central Graben, Forties Montrose High and East Forties Basin from the southern parts of Quadrant 21, 22 and 23 and the northern half of Quadrants 28, 29 and 30 to illustrate the relationship between major faults and diapirs. The paper does not include a detailed discussion of the regional structural processes and development, however.

Lasocki *et al.* (1999) described the petroleum geology of the Late Jurassic Elgin and Franklin fields in blocks 22/30c, 22/30b and 29/5b. The authors recognise two phases of extension in the Central Graben during the Triassic and Late Jurassic/Early Cretaceous and emphasise the importance of the marked structural detachment above the ductile salt, which influences the transfer of the extension in the basement to the overlying Triassic 'pod' complex.

Lasocki *et al.* (1999) published a regional structural elements map for the entire UK Central North Sea, including the Central Graben although discussion of the structural history is restricted to the vicinity of the Elgin and Franklin fields.
A detailed comparison of the structural elements maps published by Erratt *et al.* (1999), Evans *et al.* (1999) and Lasocki *et al.* (1999) for the Central Graben indicates that there is general agreement of the nature and trends of the principal structural elements. This

consensus possibly reflects an acceptance that normal fault extension and salt tectonics superimposed on Palaeozoic structural grain were the main structural processes.

The structural interpretations vary mainly according to the detailed, block scale faults and the precise location of the principal structural elements. A significant variation in the structural interpretations concerns the relationship between the north eastern boundary fault of the Puffin Fault Block and the faults bounding the Forties Montrose High.

Erratt *et al.* (1999) propose a continuous element linking the north east fault of the Puffin Fault Block with the northeast boundary fault of the Forties Montrose High. Lasocki *et al.* (1999) and Evans *et al.* (1999) however, propose that the bounding fault of the Puffin Fault Block is offset in an 'en echelon' style to the south west of the Forties Montrose High.

A detailed structural elements map for the entire northern North Sea was published in the Millennium Atlas (Zanella and Coward (2003)). This map embraces the interpretations of previous work outlined above and has been used in this study (see Figure 1.1).

The presence or not of a continuous structural feature linking the Puffin Fault Block with the Forties Montrose High has important implications concerning depositional continuity between the East Central Graben and the West Central Graben during Oxfordian and Kimmeridgian times.

Stratigraphic comparison of wells from the West Central Graben with those to the east of the Puffin Fault in the East Central Graben eg.Elgin/Franklin/Shearwater/Erskine field wells, indicates significant similarity in the Middle Oxfordian, Late Oxfordian and Kimmeridgian stratigraphy. This suggests that a single depositional fairway existed and faults did not act as depositional barriers, supporting the structural map of Lasocki *et al*. (1999) and Zanella and Coward (2003) rather than Erratt *et al.* (1999).

The names assigned to the discrete elements in Figure 1.1 follow Zanella and Coward (2003) and include the West Central Shelf, Puffin Fault Block, West Central Graben, Forties Montrose High, Josephine High and East Central Graben.

Forties Montrose High

The release of well 22/18-6 raises significant issues regarding the structural configuration, structural history and Late Jurassic prospectivity of the Forties Montrose High, particularly in relation to the palaeogeography and flooding history during Late Jurassic times and potential marine links to the Central Graben to the south and east or the Fisher Bank Basin to the north.

Well 22/18-6 was drilled on a crestal position of the Forties Montrose High and penetrated over 400' of sand dominated sediments of Kimmeridgian to Middle Volgian age (released well database). The well has been declared a commercial discovery (Wood field). The Late Jurassic sediments overlay 251' of Triassic Heron Group and the well TD is in the Zechstein Group.

The nearest released wells containing Late Jurassic sediments are some significant distance to the east or south. The Kimmeridge Clay Formation onlaps the Triassic to the east and south on the flanks of the Forties Montrose High eg. 22/19-1, 22/19-2 and 22/19a-3. The Kimmeridge Clay Formation is highly condensed in these wells and ranges in age from Late Ryazanian to no older than Early Volgian. Well 22/19b-5Z is located further off the Forties Montrose High flank and penetrated condensed Early Volgian Kimmeridge Clay Formation above Late Oxfordian Heather Formation and the Puffin Formation.

Kate field wells further to the south of 22/23b-4RE, namely 22/23b-5, 22/23b-6 and 22/28a-4, contain a more complete and very thick (> 1,500') Humber Group section of Late Ryazanian to Middle Oxfordian age.

If a palaeogeographic link i.e. a Late Jurassic seaway, can be made between wells on the southern or eastern flanks of the Forties Montrose High with 22/18-6 on the crest of the high, it may highlight potential Late Jurassic prospectivity in the intervening areas.

The internal structural complexity of the Forties Montrose High is not illustrated in published maps although a cross section including the 22/18-6 location is available. Crawford et al. (1991) provided a line drawing cross section of the Forties Montrose High to illustrate the Late Palaeocene Arbroath field. The cross section linked wells 22/18-1 and 22/18-4. Well 22/18-6 had not been drilled in 1991 but is located directly along the line of cross section between 22/18-1 and 22/18-4. The cross section illustrated structural complexity of the Forties Montrose High below the base Cretaceous, with a series of fault blocks between the main bounding faults of the Forties Montrose High. Wells drilled at the time of publication had not penetrated Jurassic sediments and none were envisaged on the cross section, which featured Triassic below the base Cretaceous unconformity. The location of 22/18-6 can be inferred within a hanging wall, mini graben to the east of 22/18-1, however.

The structural history and palaeogeography of the Forties Montrose High has been considered by Penge *et al.* (1993, 1999) and Stewart and Clark (1999). These authors were concerned primarily with the controls on Triassic stratigraphy and structural evolution by underlying salt mobility and tectonic extension. Penge *et al.* (1993,1999) proposed a post-depositional (Late Triassic) 'rift/raft' model for the Triassic of the East Forties Basin and Forties Montrose High while Stewart and Clark (1999) suggested an alternative syn-depositional 'pod' model.

Penge et al. (1993, 1999) proposed some rafts occurring as contra-rotated pairs, each separated by a mini-rift and salt swell. Significantly, Late Jurassic sediments are absent or highly condensed on Triassic rafts but are present within the rifts eg. 22/23b-4RE, 22/24b-4ST1. 'Rift/raft' structures were identified on the Forties Montrose High and to the east in the East Central Graben. Four pairs of contra-rotational rafts were identified adjacent and parallel to the Forties Montrose High, the western raft of each pair being drilled by 22/18-3, 22/18-5, 22/19-1 and 22/24d-10. The fifth pair, perpendicular to this trend, comprise the Marnock and Skua fields in block 22/24.

Penge *et al.* (1993) illustrated a seismic cross section across the Forties Montrose High in block 22/23 showing well 22/23-1 penetrating the western Triassic raft of a contra-rotational pair. This has been reproduced in the Millennium Atlas (Figure 9.10, Section 6) and included in this report - Figure 4.1. A Jurassic sequence is interpreted in the mini-rift between the contra-rotational pair on the crest of the high, buoyed up by a salt wall.

This southwest – northeast cross section is located to the south of 22/18-6 and to the north of the Kate field wells 22/23b-5, 22/23b-6 and 22/28a-4 and may illustrate a linear mini-rift system parallel to the main bounding faults of the Forties Montrose High. This mini-rift may have acted as a conduit for a marine connection between 22/18-6 and the Central Graben to the south from Kimmeridgian to Middle Volgian times.

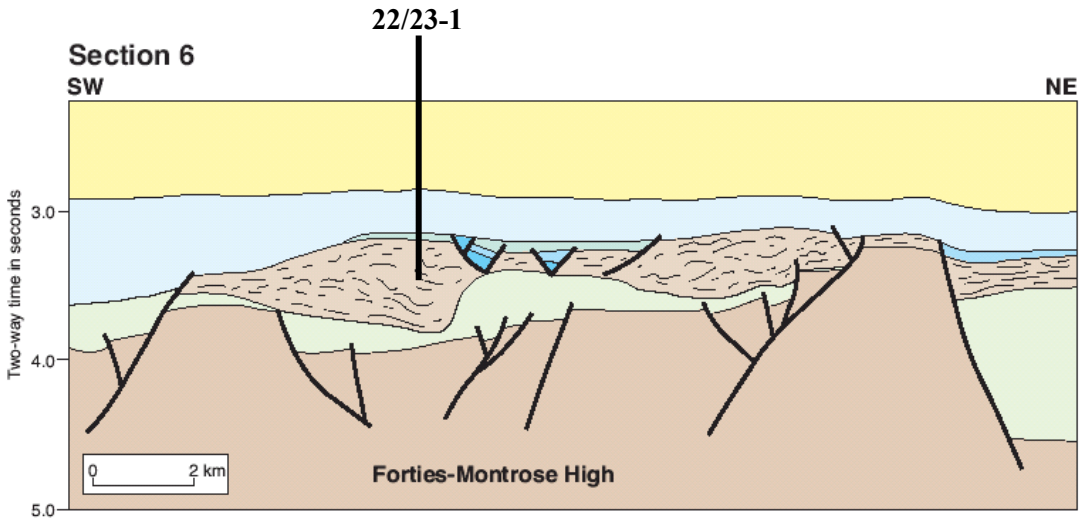

Figure 4.1 Cross section of the Forties Montrose High showing a pair of contra-rotational rafts of Smith Bank Formation separated by a Jurassic mini-rift above a salt wall, Block 22/23 (from Millennium Atlas and Penge et al., 1993).

Stewart and Clark (1999) published a series of regional sections across the Central Graben and Forties Montrose High to illustrate basin evolution from end Permian to Oligocene times. The cross sections propose a Triassic mini-rift on the crest of the Forties Montrose High. Late Jurassic tectonism uplifted the crest, but while the Triassic 'pods' on each side of the rift were subaerial, the crestal 'rift' was drowned by the Late Jurassic sea, allowing marine sediments to accumulate in the accommodation space (Figure 4.2). The cross sections suggest significant variation in water depths between the Jurassic sea on the Forties Montrose High crestal mini-rift and the adjacent West Central Graben. This view is supported by well evidence with Kimmeridgian to Middle Volgian shallow marine, shoreface sands in 22/18-6 compared to coeval, mid to outer shelf mudstones and mass flow sands in wells from the West Central Graben.

Data and interpretations provided by Penge et al. (1993, 1999) and Stewart and Clark (1999) support the view that the crestal part of the Forties Montrose High at 22/18-6 was drowned during the Kimmeridgian to Middle Volgian. The Late Jurassic sea encroached the high from the south along a south – north 'mini-rift' between pairs of contra-rotational Triassic 'rafts' or 'pods'. The existence of the 'mini-rift' may explain the thick succession of Middle and Late Oxfordian sands on the margins of the Forties Montrose High in 22/23b-5, 22/23b-6 and 22/28a-4 because it may have served as a conduit for fluvial systems feeding sand into the Oxfordian sea. This may have implications for Late Jurassic prospectivity on the Forties Montrose High if reservoir sands are present in the 'mini-rift' system to the south of 22/18-6.

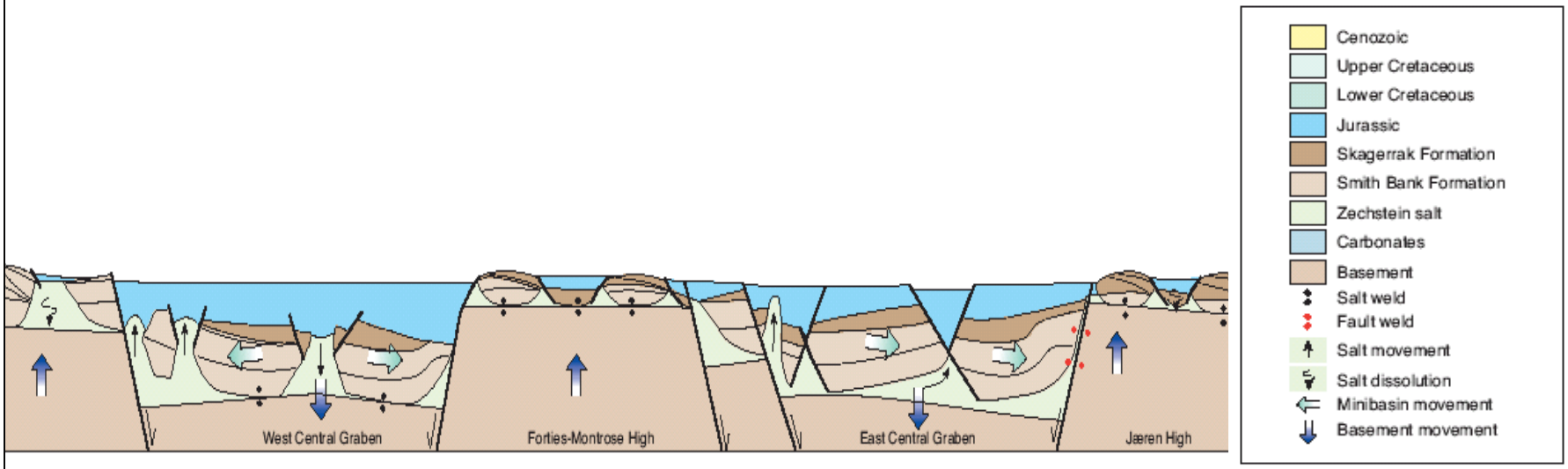

Figure 4.2 Regional schematic east – west section across the Central Graben providing a simplified reconstruction of the structural and stratigraphic evolution of the basin during the Late Jurassic, illustrating:

- sinking and grounding of Triassic pods
- development of accommodation space within interpod areas as a result of salt dissolution on the emergent Forth Approaches Platform and intrabasinal Forties Montrose High and Jaeren High
- formation of secondary rim synclines and early salt diaperic structures within graben areas
- active extensional fault growth along basin margin and intrabasinal highs.

Taken from Millennium Atlas, after Stewart and Clark (1999)

5. CHRONOSTRATIGRAPHIC WELL SUMMARIES

Figures 5.1 to 5.8 provide eight chronostratigraphic well summary correlations of selected, representative wells to illustrate the variable stratigraphy across the study area.

The chronostratigraphic summaries illustrate lithostratigraphic successions and correlations contrained by sequence stratigraphy and hung on a linear chronostratigraphic scale. This means that lithostratigraphic thicknesses are not represented although they are noted in the text where significant variation is apparent.

5.1 CHRONOSTRATIGRAPHIC WELL SUMMARY: FIGURE 5.1.

This chronostratigraphic well summary includes wells from the West Central Shelf (21/19-3) and the West Central Graben (21/20b-4S2, 21/20b-6+6Z, 21/20a-5, 22/16b-3, 22/16a-4 and 22/22b-4).

The oldest Late Jurassic sediments are Early? to Middle Oxfordian mudstones of the Heather Formation *sensu stricto* present in 21/20b-6+6Z, which may rest conformably on the Fladen Group. These are succeeded in this well by Late Oxfordian mudstones of the Heather Formation *sensu lato* following the J54 (*glosense*) MFS. A thick succession of progradational sands of the Puffin Formation are present in 21/20b-6+6Z. Coeval sands in 21/20a-5 are thin, probably condensed and lay unconformably on the Fladen Group. This variation in thickness may reflect underlying salt withdrawal.

The LJ2 DSB is represented by an interfluve within the Puffin Formation of 21/20a-5. The entire Puffin Formation in 21/20b-6+6Z is strongly progradational with a very sharp top and this is thought to mark the LJ2 DSB. Retrogradational shoreface/shelf sands of the Puffin Formation are present above the LJ2 DSB in 21/20a-5, whereas the 21/20b-5+5Z well location was by-passed by these sediments, possibly due to a lack of accommodation space as local salt withdrawal may have slowed.

The Heather Formation *sensu lato* is present in 21/20b-4S2, 21/20b-6+6Z, 21/20a-5, 22/16b-3, and 22/16a-4 in the West Central Graben, although the latter two wells reach TD in the uppermost part of the formation. A complete succession is present in 21/20a-5 and 21/20b-6+6Z including the J56 (*rosenkrantzi*) MFS. The lower part of the Heather Formation *sensu lato* is absent in 21/20b-4S2 and the J56 (*rosenkrantzi*) MFS onlaps the Heron Group. Young Puffin Formation sands are present above the LJ3 DSB in 21/20b-4S2, shaling out to mudstones in 21/20a-5 and 21/20b-6+6Z.

The oldest Late Jurassic sediments in West Central Shelf well 21/19-3 are shoreface/shelf sands of the Ryton Member above the J62 *baylei* flooding surface. In the West Central Graben this event marks the boundary of the Heather Formation *sensu lato* and the Trent Member of the Kimmeridge Clay Formation.

The LJ3ii DSB is considered to be developed as an interfluve surface in 21/19-3, marked by a sharp coarsening up log boundary. This is supported by interpretations present in cores in wells 21/18-3 and 21/19-1A. Low-stand basin floor sands of the Christian Member are present above the LJ3ii DSB in West Central Graben well 21/20b-4S2. The Christian Member has limited lateral extend and is constrained by coeval mudstones of the Trent Member in 21/20a-5 and 21/20b-6+6Z. Retrogradational shoreface/shelf sands of the Ryton Member are present above the LJ3ii DSB in 21/19-3.

Low-stand basin floor sands of the Selkirk Member, which are coeval with the Swale Member, are present above the LJ4 DSB in 22/16a-4 and 22/22b-4.

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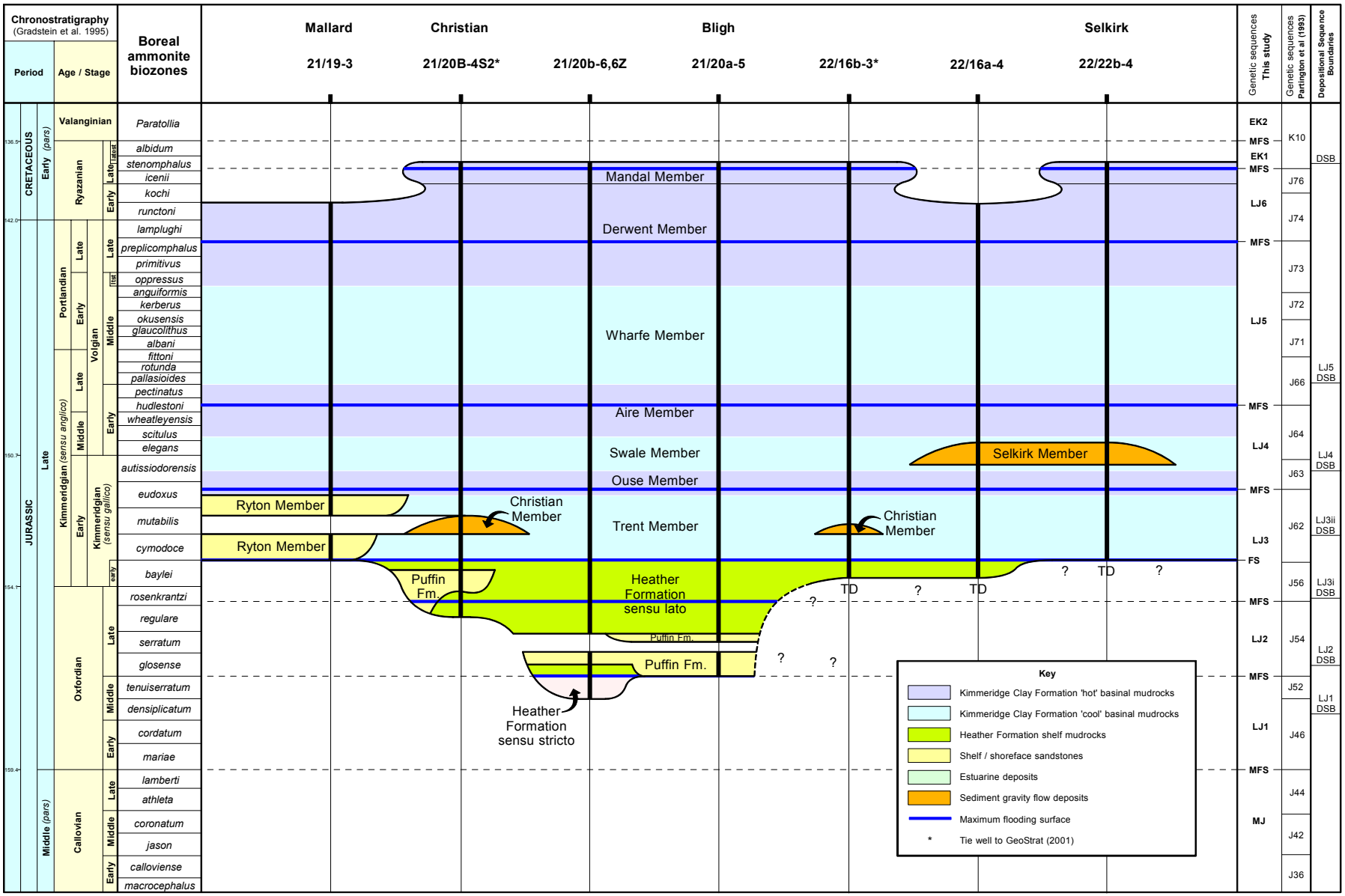

Figure 5.1 Chronostratigraphic summary diagram : Forth Approaches Platform to West Forties Basin Wells

5.2 CHRONOSTRATIGRAPHIC WELL SUMMARY: FIGURE 5.2.

This chronostratigraphic well summary includes wells in the West Central Graben (22/22b-4 and 22/22b-2 ST2), on the flanks of the Forties Montrose High (22/23b-6, 22/28a-4, 22/23b-5) and on the crest of the Forties Montrose High (22/18-6).

The Humber Group in the West Central Graben and Forties Montrose High flanking wells include thick Oxfordian to Early Volgian sequences and condensed or absent Middle Volgian to Late Ryazanian sequences. This probably relects salt withdrawal and the creation of accommodation space until the end of Early Volgian times, when subsidence rates slowed considerably.

Well 22/18-6 on the crest of the Forties Montrose High lacks Oxfordian sediments and contains a less condensed Early Volgian to Middle Volgian succession comprised of shoreface sands bounded by large unconformities that reflect the structural location of the well.

The oldest Late Jurassic sediments are Early Oxfordian mudstones of the Heather Formation *sensu stricto* present in 22/22b-2ST2 associated with the J46 (*mariae*) MFS. These sediments may have overlain conformably the Fladen Group as subsidence and transgression introduced a marine seaway into the West Central Graben from the southeast. Mudstones continued to be deposited in this basin centre location during Middle Oxfordian times although a thick succession of shoreface sands were deposited in the more proximal locations of 22/23b-5, 22/23b-6 and 22/28a-4.

Progradational, shoreface sands of the Puffin Formation accumulated in the proximal locations of 22/23b-6 and 22/28a-4 during 'early' Late Oxfordian times following the J54 (*glosense*) MFS. Coeval sediments in basinal well 22/22b-2ST2 are mudstones of the Heather Formation *sensu lato.*

Mass flow sands of the Freshney Member were deposited in 22/22b-2ST2 , 22/23b-5, 22/23b-6 and 22/28a-4 above the LJ2 DSB, although there is significant thickening towards 22/22b-2ST2 and 22/23b-5. These are succeeded by retrogradational, shoreface sands of the Puffin Formation in 22/23b-5, 22/23b-6 and 22/28a-4 and more distal mudstones of the Heather Formation *sensu lato* in 22/22b-2ST2.

The Puffin Formation extends to a younger age (post J56 (*rosenkrantzi*) MFS) at 22/23b-5, 22/23b-6 and 22/28a-4 compared to more distal areas of the Central Graben. This is due to retrogradational sand deposition continuing in more proximal areas close to the emergent Forties Montrose High. .

Localised deposition of low-stand sands of the Christian Member are present above the LJ3ii DSB in 22/23b-6.

Well 22/18-6 records the drowning of the Forties Montrose High by the J63 (*eudoxus*) MFS event during Kimmeridgian times. The oldest sediments in 22/18-6 are coeval with the Ouse Member in the West Central Graben wells. The LJ4 DSB resulted in the deposition low-stand, mass flow sands of the Selkirk Member in 22/22b-4, 22/22b-2ST2, 22/23b-6, 22/28a-4 and 22/23b-5, with considerable thickening of the unit to the northwest in 22/22b-4 and 22/22b-2 ST2.

Shoreface sands of the Laver Member Equivalent accumulated in 22/18-6 on the crest of the Forties Montrose High during Early Volgian times, coeval in part to the Swale Member mudstones of the basin.

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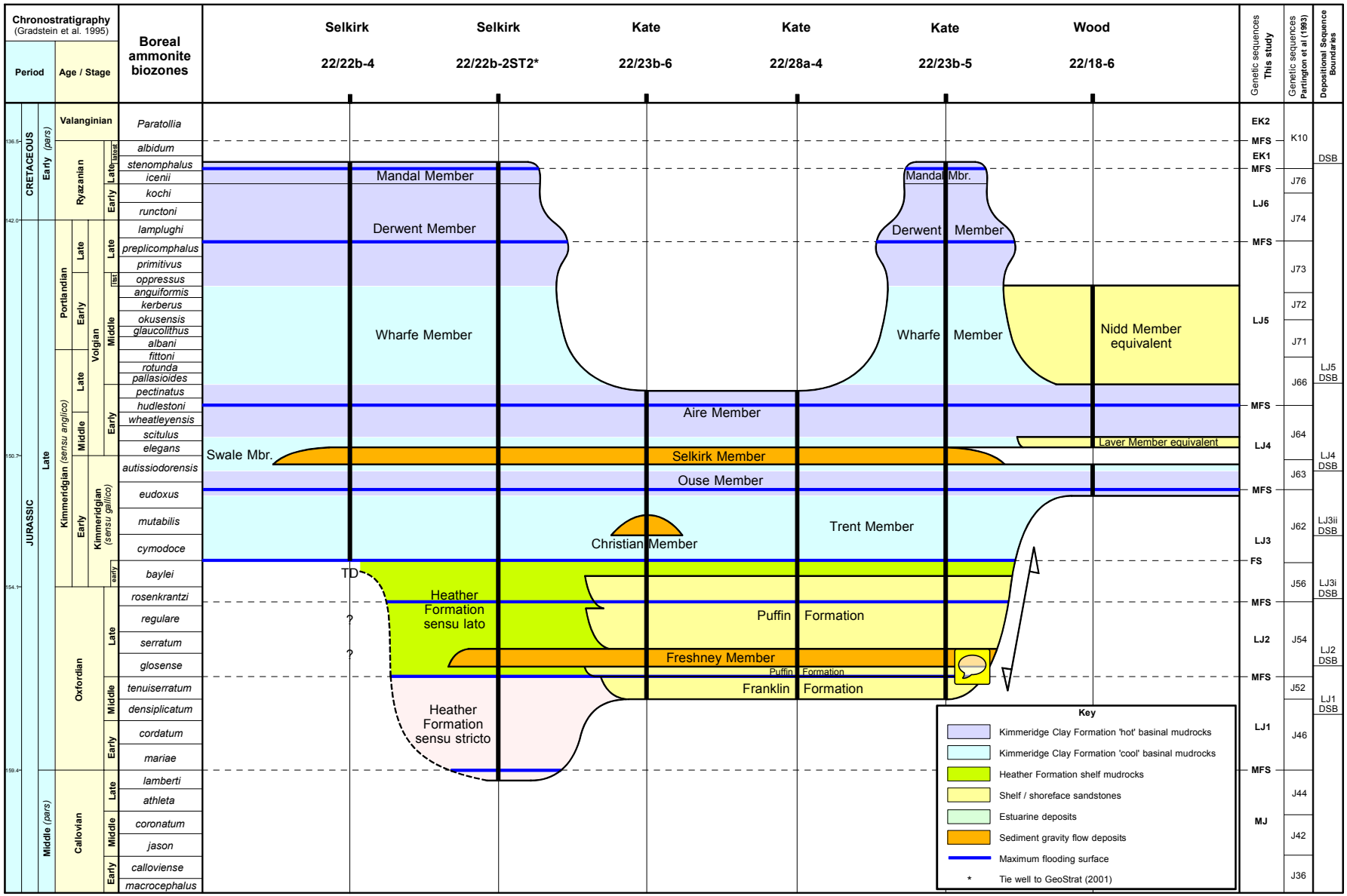

Figure 5.2 Chronostratigraphic summary diagram : West Forties Basin to Forties Montrose High Wells

Sand deposition in 22/18-6 was inhibited by the J66 (*hudlestoni*) MFS but resumed during Middle Volgian times above the LJ6 DSB with shoreface sands of the Nidd Member Equivalent. Coeval sediments in the basin are highly condensed mudstones of the Wharfe Member.

5.3 CHRONOSTRATIGRAPHIC WELL SUMMARY: FIGURE 5.3.

This chronostratigraphic well summary includes wells from the flanks of the Forties Montrose High into the Central Graben (22/19b-5Z, 22/29-1ST, 22/29-6S2, 22/30a-16, 29/4d-4, 22/30b-15Z, 22/30b-11, 23/26b-15 and 23/26a-21).

There is a significant contrast between wells on the flanks of the Forties Montrose High compared to more basinal wells to the south. The Humber Group sequences in wells flanking the high are condensed and bounded by large unconformities. The Oxfordian sequences in basinal wells to the south are relatively thick, reflecting high subsidence and sedimentation rates associated with active rifting.

The oldest Late Jurassic sediments are Middle Oxfordian mudstones and sandstones. Mudstones of the Heather Formation *sensu stricto* are present in 22/29-1ST, 22/29-6S2, 22/30a-16, 22/30b-15Z, 22/30b-11, 23/26b-15 and 23/26a-21. Thin shoreface/shelf sands of the Franklin Formation are present within the Heather Formation *sensu stricto* in 22/30b-11 and 22/30b-15Z.

A thick succession of Middle Oxfordian Franklin Formation sands is present in well 29/4d-4. Similar sands in block 29/5b are interpreted as restricted marine, mouth bar, distributary channel and bay fill sediments by Lasocki *et al.* (1999). The Franklin Formation grades into interbedded sands and mudstones as seen in surrounding wells.

Progradational, shoreface sands of the Puffin Formation in 29/4d-4 or mudstones of the Heather Formation *sensu lato* accumulated in all wells except 22/19b-5Z during early Late Oxfordian times following the J54 (*glosense*) MFS. The Puffin Formation gradually prograded over the Heather Formation mudstones in all wells to the north and east of 29/4d-4, except 22/29-1ST.

A regional interfluve surface is identified within the Puffin Formation in 22/29-6S2, 22/30a-16, 29/4d-4, 22/30b-15Z, 22/30b-11, 23/26b-15 and 23/26a-21, marking the LJ2 DSB. This surface is marked by a pronounced decrease in Δt in these wells. The sedimentology core report in the DTI released well database for 29/4d-4 indicates possible carbonaceous rootlets or bioturbation at 19,107ft., associated with the carbonate cemented zone below the depositional sequence boundary. Jeremiah and Nicholson (1999) referred to this surface in 22/30b-11 and 23/26b-15 as the SJU300 sequence boundary and consider it the product of a forced regression. Lasocki *et al.* (1999) use this event to mark the top of Unit A within the Puffin Formation in 22/30c-8 and 29/5b-8.

The product of forced regression in basinal settings are low-stand sands of the Freshney Member, eg. block 22/21, 22/22, 22/27, 30/6, 30/13 wells.

Retrogradational shoreface/shelf sands of the Puffin Formation are present above the interfluve surface in all wells, including 22/29-1ST and 22/19b-5Z as the Late Oxfordian sediments transgressed the flanks of the Forties Montrose High. Well 29/4d-4 illustrates well defined progradational log features in the upper part of the Puffin Formation and these may represent a younger sequence compared to adjacent wells.

The overlying Heather Formation *sensu lato* is widespread, and includes the J56 (*rosenkrantzi*) MFS.

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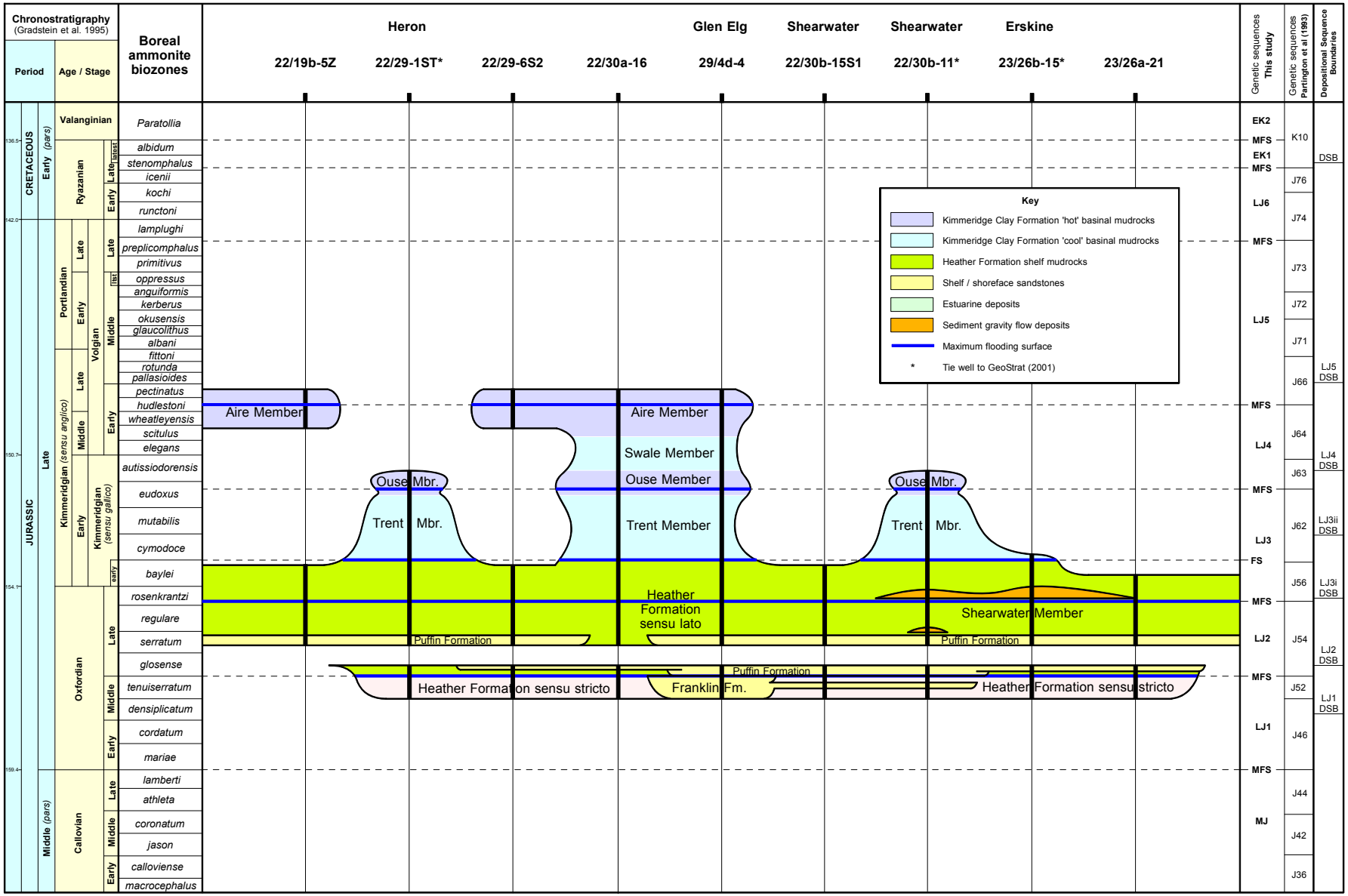

Figure 5.3 Chronostratigraphic summary diagram : Forties Montrose High to Central Graben Wells

Low-stand basin floor sands of the Shearwater Member accumulated above the LJ3i DSB in wells 22/30b-11, 23/26b-15, 23/26a-21, although the unit is more argillaceous in the latter well.

No sediments younger than the Early Volgian Aire Member are preserved in the wells. This may reflect decreased subsidence rates associated with reduced salt withdrawal.

5.4 CHRONOSTRATIGRAPHIC WELL SUMMARY: FIGURE 5.4.

This chronostratigraphic well summary includes wells situated on the Jaeren High (23/16d-7 and 23/16a-2).

This correlation contrasts 23/16d-7, which penetrated Kimmeridgian to Early Volgian aged Ula Formation shoreface sands overlain by the Aire Member, including the J66 (*hudlestoni*) MFS, with 23/16a-2, where the Aire Member overlies unconformably the Heron Group.

5.5 CHRONOSTRATIGRAPHIC WELL SUMMARY: FIGURE 5.5.

This chronostratigraphic well summary includes wells situated on the West Central Shelf and the Puffin Fault Block (28/10-1, 29/6a-6, 29/1a-7 and 29/1c-4).

This correlation demonstrates the gradual back-stepping of Kimmeridgian and Early Volgian sands from the western edge of the Puffin Fault Block on to the West Central Shelf.

The oldest Late Jurassic sediments are mudstones of the Heather Formation *sensu lato* in Puffin Fault Block well 29/1c-4. These are succeeded by mudstones of the Kimmeridge Clay Formation, Trent Member following the J62 MFS. The LJ3ii DSB within the Trent Member is picked also near base of the Ryton Member in 29/1a-7. The Ryton and Trent members are coeval and demonstrate the shale out of Ryton Member shoreface sands to the east of the West Central Shelf.

The deposition of Ryton Member sands is terminated by the J63 (*eudoxus*) MFS associated with the Ouse Member mudstones. The succeeding LJ4 DSB marks the base of the Laver Member shoreface sands. These are present in West Central Shelf wells 28/10-1 and 29/6a-6 above the Triassic Heron Group and prograde above the Ouse Member in 29/1a-7. This well is unique amongst released wells from the margins of the West Central Shelf by penetrating a stacked sequence of Laver Member sands of Early Volgian to Kimmeridgian age overlying Ryton Member sands of Kimmeridgian age. The deposition of the Laver and Ryton sands do not overlap at other released well locations.

The deposition of Laver Member sands is terminated by the J66 (*hudlestoni*) MFS associated with the Aire Member mudstones. The Kimmeridge Clay Formation is complete above the J66 (*hudlestoni*) MFS in all wells.

5.6 CHRONOSTRATIGRAPHIC WELL SUMMARY: FIGURE 5.6.

This chronostratigraphic well summary includes wells situated on the Puffin Fault Block (29/7-7, 29/7-5, 29/8b-5, 29/9b-6 and 29/14c-5).

The oldest sediments present are estuarine and marginal marine sediments of the Puffin Formation, Curlew Member of Late Oxfordian age in 29/7-7, 29/7-5 and 29/8b-5. The LJ2 DSB is picked at the base of the Curlew Member in these wells. This unit is interpreted as an

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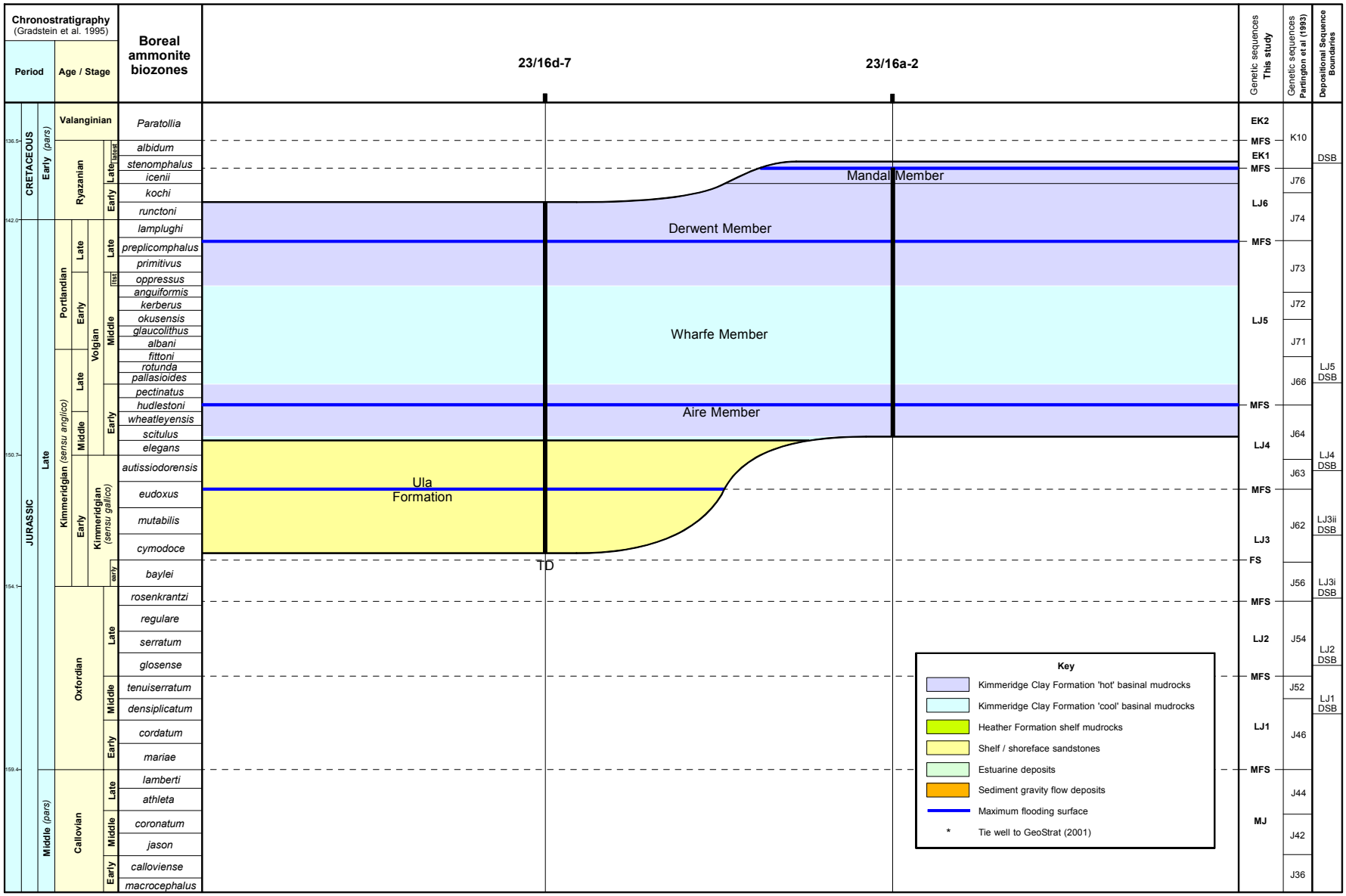

Figure 5.4 Chronostratigraphic summary diagram : Jaeren High Wells

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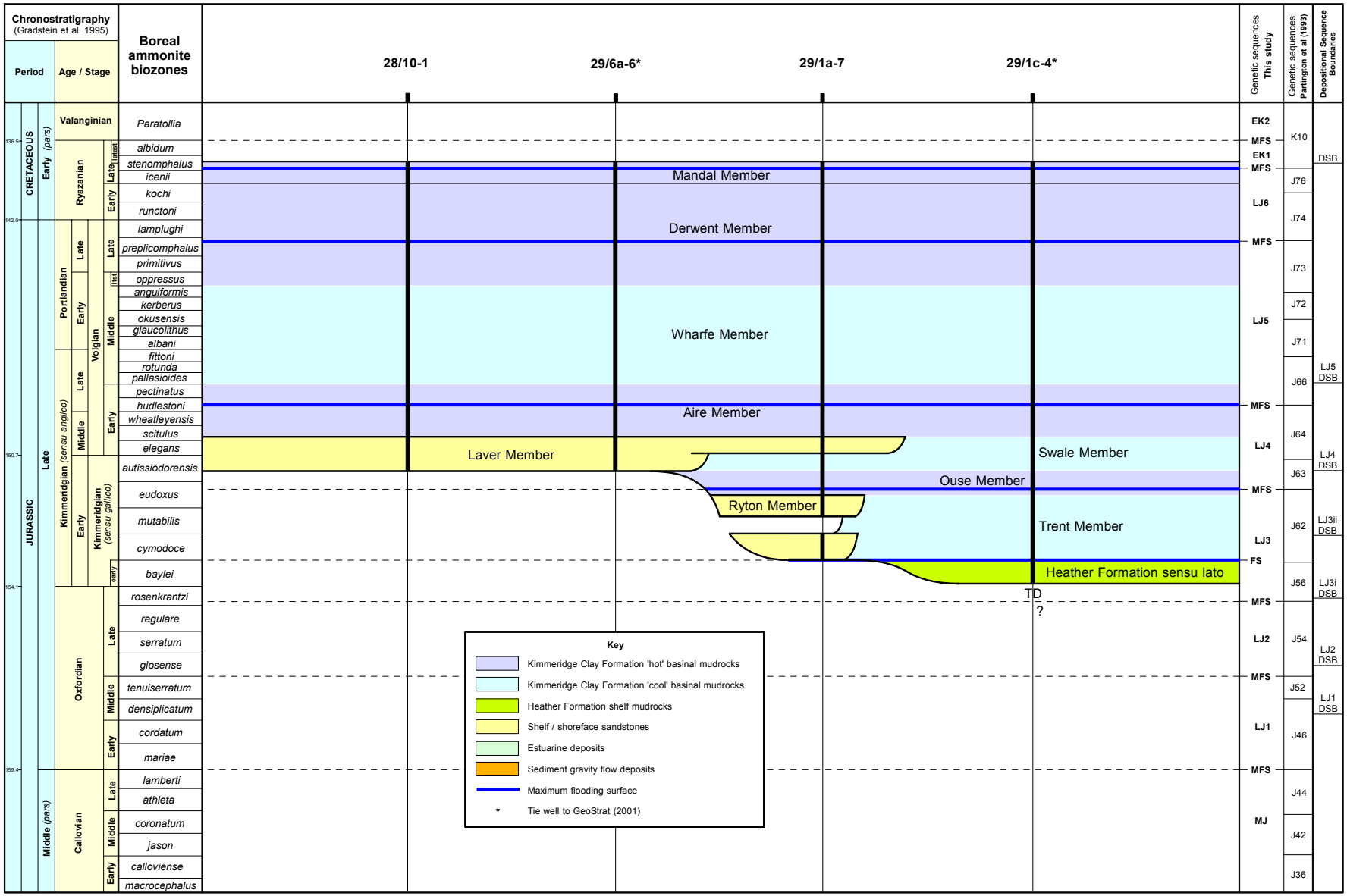

Figure 5.5 Chronostratigraphic summary diagram : Forth Approaches Platform to Puffin Terrace Wells

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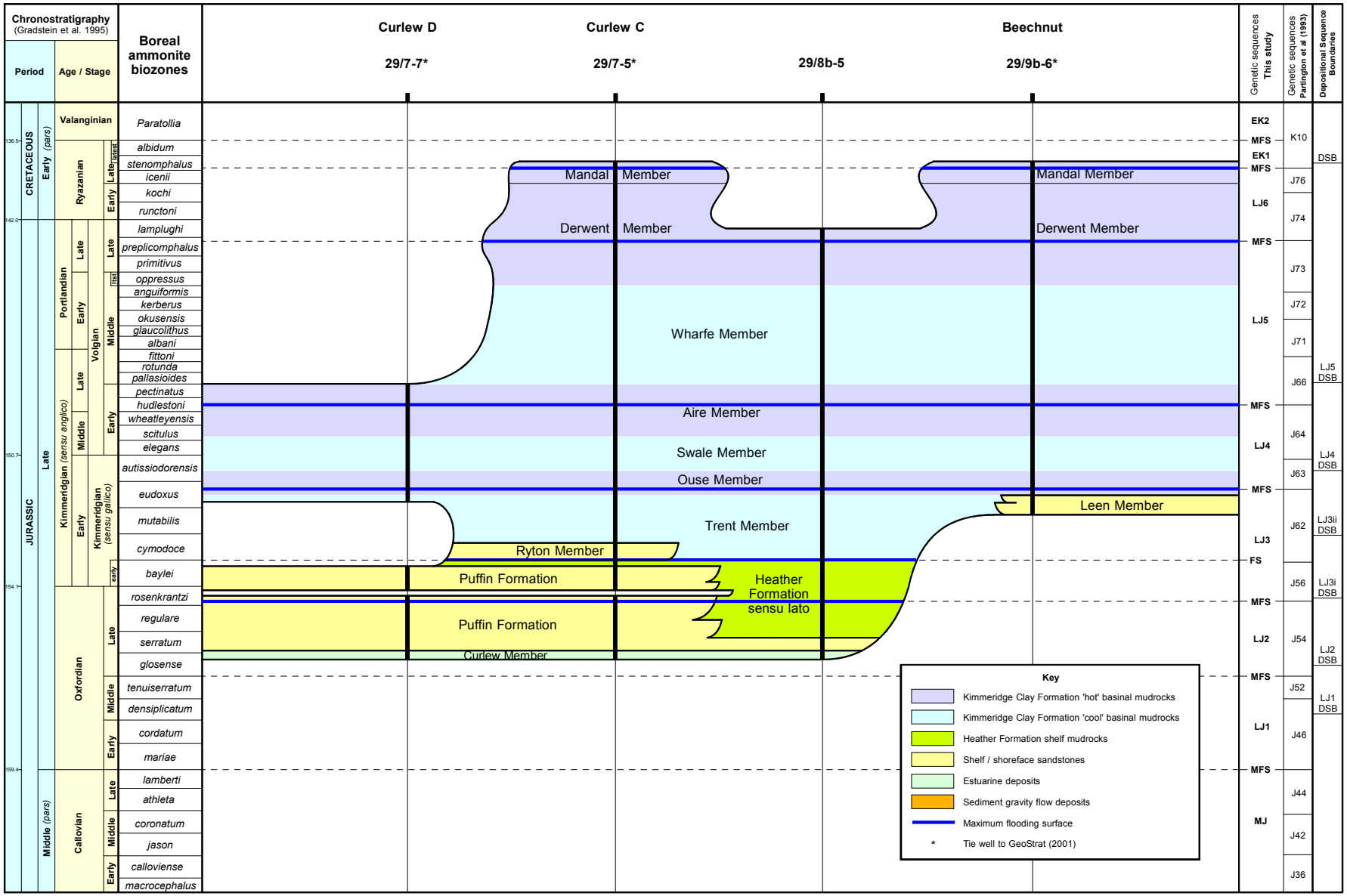

Figure 5.6 Chronostratigraphic summary diagram : Puffin Terrace

incised valley fill deposited in an estuarine to marginal marine environment as a transgressive phase started to drown the Puffin Fault Block following the LJ3 DSB. This area may have lacked older Late Oxfordian sediments although the presence of the Curlew Member directly above the Fladen Group may be due to erosion below the incised valley.

Continued transgression resulted in retrogradational, shoreface/shelf sands of the Puffin Formation in 29/7-7, 29/7-5 and 29/8b-5. In distal locations of the Puffin Fault Block and the Central Graben, the Puffin Formation is succeeded by mudstones of the Heather Formation *sensu lato*, which contains the J56 (*rosenkrantzi*) MFS eg. 29/8b-5. In more proximal locations close to the West Central Shelf, retrogradational followed by progradational/aggradational shoreface/shelf sands of the Puffin Formation accumulated through Late Oxfordian to early Kimmeridgian times, including 29/7-7 and 29/7-5.

The J56 (*rosenkrantzi*) MFS is identified within the Puffin Formation of wells 29/7-7 and 29/7-5. Jeremiah and Nicholson (1999, Figure 20) also identify this event (named the *crystallinum* MFS) in 29/7-7 and 29/7-5. The LJ3i DSB is also present within the Puffin Formation of these wells.

Ryton Member sands are present at the base of the Trent Member in 29/7-5.

The oldest Late Jurassic sediments in Puffin Fault Block well 29/9b-6 are shoreface/shelf sands of the Leen Member, situated above the LJ3ii DSB surface of Kimmeridgian age. This is equivalent to the distal Trent Member in 29/8b-5. Sand deposition was eventually terminated by the J63 (*eudoxus*) MFS associated with the Ouse Member.

Well 29/14c-5 records the drowning of a Triassic high during the Late Volgian.

The Kimmeridge Clay Formation is complete above the J63 (*eudoxus*) MFS in well 29/9b-6. Unconformities at the top of the Kimmeridge Clay Formation in 29/7-7, 29/7-5 and 29/8b-5 may be due to reduced subsidence rates associated with salt withdrawal.

5.7 CHRONOSTRATIGRAPHIC WELL SUMMARY: FIGURE 5.7.

This chronostratigraphic well summary includes wells situated in the Central Graben adjacent of the Auk Ridge and West Central Shelf (30/11b-4, 30/12b-8, 30/17a-12, 30/17a-13+13RE, 30/17a-11, 30/19a-6 and 30/19a-5.

The oldest Late Jurassic sediments are retrogradational and progradational shoreface/shelf sands of the Lower Fulmar Formation that accumulated during Late Oxfordian times in 30/11b-4 and 30/12b-8. The J56 (*rosenkrantzi*) MFS event is located within the Lower Fulmar Formation in these wells. The LJ3i DSB is present within the Lower Fulmar Formation. The J62 *baylei* flooding surface separates the Lower/Upper Fulmar Formation. Sands accumulated through early Kimmeridgian to Kimmeridgian times and an interfluve boundary is picked near the base of the Upper Fulmar Formation, associated with the LJ3ii DSB.

The Upper Fulmar Formation in 30/11b-4 and 30/12b-8 is succeeded by the Ouse Member, including the J63 (*eudoxus*) MFS event.

The oldest Late Jurassic sediments in Janice field wells 30/17a-12, 30/17a-13+RE and 30/17a-11 are predominantly aggradational shoreface sands of the Kimmeridgian Upper Fulmar Formation, following the J62 flooding of this area. Deposition of the Upper Fulmar Formation was terminated by the J63 (*eudoxus*) MFS. Sands are also present above the Upper Fulmar Formation; these are assigned to the Uppermost Fulmar Formation of latest Kimmeridgian – Early Volgian age and the base is related to the LJ4 DSB.

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U.K. Central Graben - Humber Group chronostratigraphy

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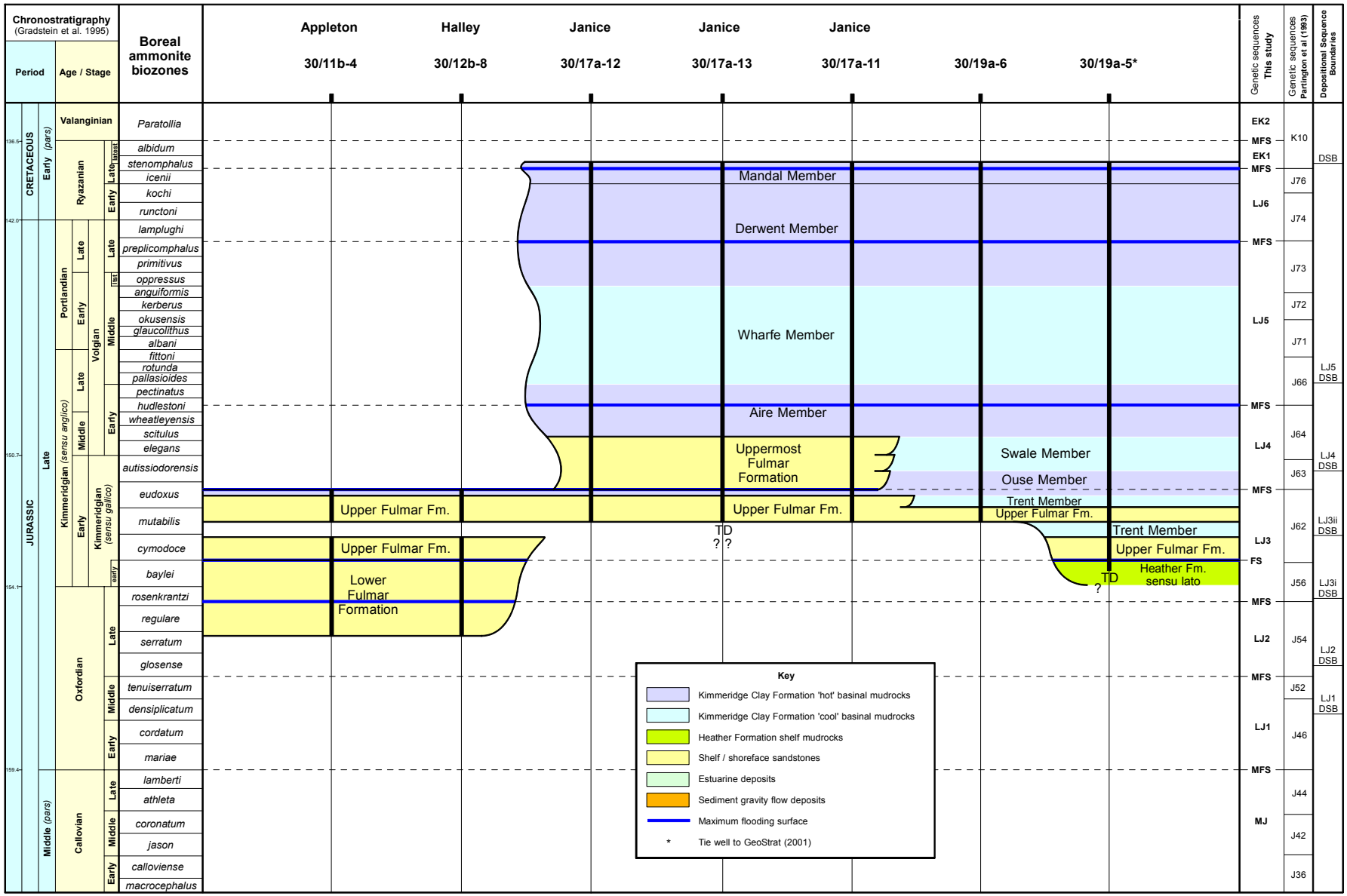

Figure 5.7 Chronostratigraphic summary diagram : Fulmar Terrace to Central Graben Wells

The Uppermost Fulmar Formation in 30/17a-12, 30/17a-13+RE and 30/17a-11 is younger (Early Volgian) than the youngest Fulmar Formation (Kimmeridgian) present to the north at Fulmar, Clyde and Halley fields in blocks 30/16, 30/17b, 30/11b and 30/12b. This is due to the overall retrogradational deposition and onlap of Fulmar Formation sands, transgressing and being gradually restricted to the flooded basin margins during the Kimmeridgian to Early Volgian transgressive/subsidence phases. The Uppermost Fulmar Formation and the 'older' Fulmar Formation are separated stratigraphically by the J63 (*eudoxus*) MFS event. The older Lower Fulmar Formation of Late Oxfordian – early Kimmeridgian age that is developed to the north in the Fulmar, Clyde and Halley fields is absent at 30/17a-12, 30/17a-13+RE and 30/17a-11 because the area was emergent at this time and was transgressed only after the J62 event.

Wells 30/17a-12, 30/17a-13+RE and 30/17a-11 illustrate the diachroneity at base and top Fulmar Formation surfaces between the Janice field and the Fulmar, Clyde and Halley fields to the north.

The Upper Fulmar Formation is developed above the Heather Formation in 30/19a-5, indicating that the Lower Fulmar Formation has probably shaled-out at this location. The Upper Fulmar Formation rests directly on the Heron Group in 30/19a-6. The uppermost part of the Upper Fulmar Formation has shaled-out relative to wells to the west in blocks 30/11, 30/12, 30/16 and 30/17, indicated by the presence of the Trent Member.

5.8 CHRONOSTRATIGRAPHIC WELL SUMMARY: FIGURE 5.8.

This chronostratigraphic well summary includes five wells situated in the Central Graben to the east of the Josephine High (30/13-5, 30/13-4, 30/13-6, 30/13-3 and 30/13-7).

The oldest Late Oxfordian sediments are Middle Oxfordian mudstones of the Heather Formation *sensu stricto* present in 30/13-3, 30/13-4 and 30/13-6. The base of the Heather Formation *sensu lato* is marked by the J54 (*glosense*) MFS. Low-stand basin floor sands of the Late Oxfordian, Freshney Member are well developed in 30/13-3, 30/13-4, 30/13-6 and 30/13-7 above the LJ2 DSB within the Heather Formation *sensu lato.* The Heather Formation *sensu lato* includes the J56 (*rosenkrantzi*) MFS.

Late Oxfordian sediments older than the J56 (*rosenkrantzi*) MFS are absent in 30/13-5. Mudstones associated with the J56 (*rosenkrantzi*) MFS of the Heather Formation *sensu lato* unconformably overlie the Triassic Heron Group in this well.

There is an unconformity of variable extent at the top of the Kimmeridge Clay Formation, possibly due to reduced subsidence associated with a reduction in salt withdrawal. The Heather Formation *sensu lato* is succeeded by the Kimmeridge Clay Formation, Trent and Ouse Members in 30/13-3 and 30/13-4, below the base Cretaceous unconformity. The Kimmeridge Clay Formation is more complete in 30/13-6 and 30/13-7 while a complete succession is indicated in 30/13-5.

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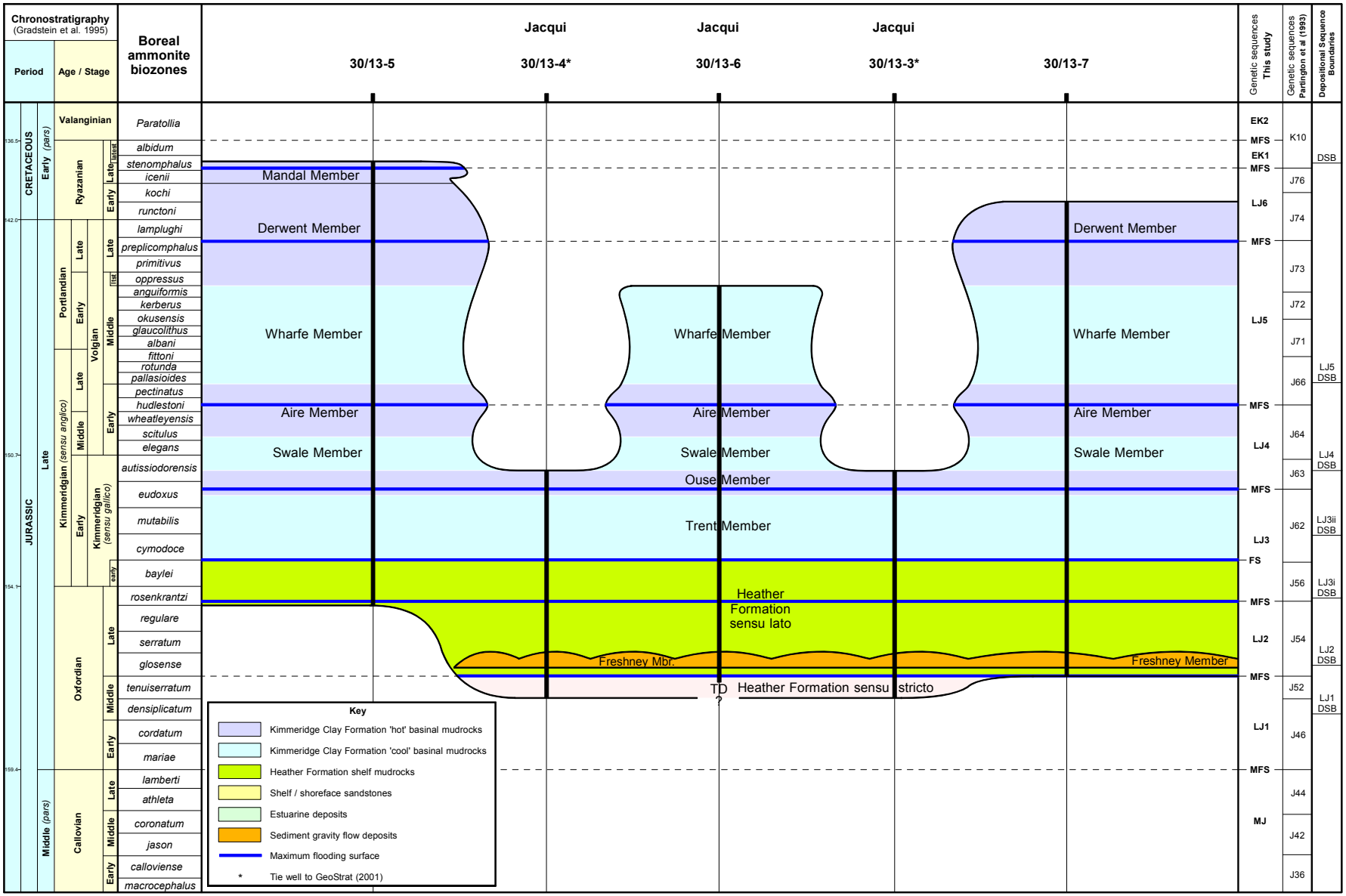

Figure 5.8 Chronostratigraphic summary diagram : Central Graben Wells

6. PLAY FAIRWAY MAPS

The distribution of sandstones within the Humber Group is discussed within the context of evolving paleogeographies linked to relative sea level changes (driven by eustacy and tectonics). Genetic sequences, bounded by the maximum flooding surfaces described in Chapter 2 are used for mapping because they form readily identifiable wireline log and biostratigraphic markers, they are less contentious in areas of poor core coverage than depositional sequence boundaries and are therefore a more reliable method of subdividing the Humber Group on a regional basis. This approach only goes partly towards understanding the architecture of the Humber Group and where possible depositional sequence boundaries have been used to delineate systems tracts and improve the level of detail incorporated.

The play fairway maps present a simplified facies scheme used within a more sophisticated sequence framework. Sediment distribution away from well control is constrained by the regional Late Jurassic structural elements map. Local, block scale structure maps based on more detailed 3D seismic data have not been used to constrain sandstone distribution.

6.1 GENETIC SEQUENCE J46 – J52; LJ1; (EARLY TO MIDDLE OXFORDIAN)

The palaeogeography of the J46-J52 Genetic Sequence is illustrated in Figure 6.1. This sequence is largely restricted to the axial part of the Central Graben and is comprised mainly of Heather Formation *sensu stricto* mudstones eg. 22/22b-2 ST2. The mudstones of the Heather Formation *sensu stricto* record the initial drowning of the graben in association with the J46 (*mariae*) MFS transgression and subsidence, resulting in a marine seaway. In many locations the Heather Formation *sensu stricto* may rest conformably on the underlying Pentland Formation eg. 21/20b-6+6Z, 22/22b-2 ST2.

Shallow marine sandstones of the Franklin Formation are present in three areas: to the north east of the Puffin Fault Block in blocks 29/4d, 29/5b and 22/30b+c (29/4d-4, 29/5b-8, 22/30b-8, 22/30b-11, 22/30b-15Z), flanking the southern part of the Forties Montrose High in blocks 22/23b, 22/24b, 22/25b and 22/28a (22/23b-5, 22/23b-6, 22/28a-4, 22/24b-4ST, 22/25b-4S1) and in the southern part of the West Central Graben (22/27a-2).

The general lack of faulting and wave energy (due to the narrow seaway) means that shoreface/shelf sands are not common although thicknesses may be significant. The Franklin Formation in 29/5b-8 and 22/30c-8 is considered by Lasocki *at al.* (1999) to represent marginal marine, mouth bar, distributary channel and bay fill sands. These sands thin to 22/30b-11 and 22/30b-15Z and are considered in this report to be derived most likely from the emergent Puffin Fault Block. The extent of the Franklin Formation in this area is now well constrained and the sands are absent in wells from blocks 21/20b, 22/16a, 22/21, 22/22b, 22/25b, 22/27a, 22/29, 22/30a, 23/26a+b, 30/1c, 30/6, 30/8 and 30/13.

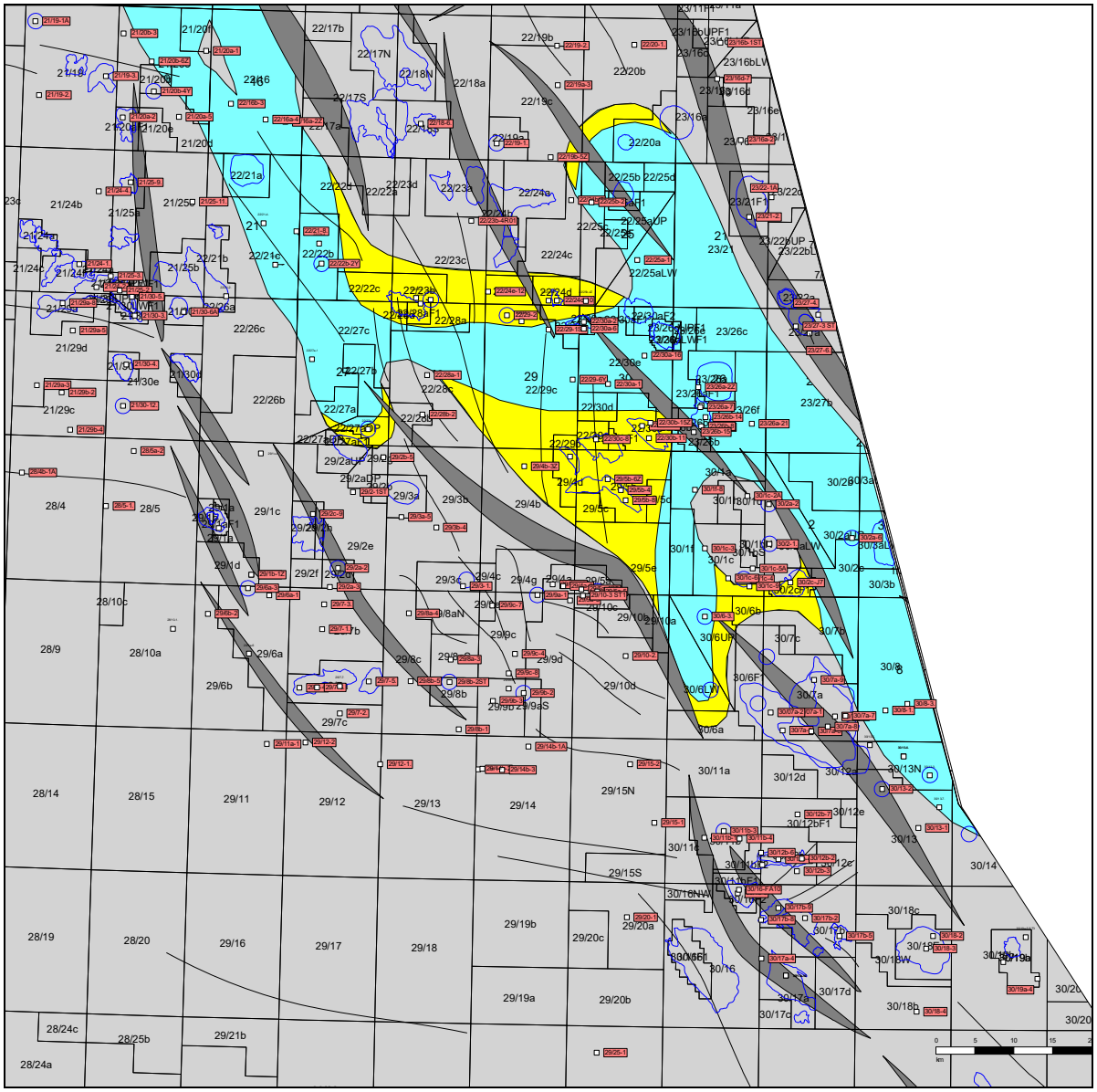

Figure 6.1 Play fairway map for the J46-J52 Genetic Sequence (Early to Middle Oxfordian)

Grey = emergent land
Blue = marine mudstones
Yellow = Shallow marine / shoreface sands (Franklin Formation)
NB. The distribution of sands within the mapped fairway will be controlled significantly by underlying Triassic pods and intervening salt walls.

6.2 GENETIC SEQUENCE J54: LJ2 (LATE OXFORDIAN)

This sequence is considered in three maps:

- from the J54 (*glosense*) MFS to the LJ2 depositional sequence boundary (Figure 6.2).
- at the LJ2 depositional sequence boundary (Figure 6.3).
- above the LJ2 depositional sequence boundary to the J56 (*rosenkrantzi*) MFS (Figure 6.4).

The J54 sequence contains the greatest volume and geographical extent of sand within the Central Graben, represented by the Puffin Formation, including the Curlew Member and the Freshney Member of the Heather Formation. The Puffin Formation is a shoreface/shelf sand but in places contains an incised valley fill: the Curlew Member which represents an estuarine to marginal marine facies above the LJ2 depositional sequence boundary. Situated above the depositional sequence boundary in distal locations are lowstand basin floor sands of the Freshney Member.

Sand generation is probably related to an intensification of rifting which provided the means to generate increased sand input into the developing basin from basin margin uplift. Widening of the basin, particularly across the Puffin Fault Block, may have allowed the development of high energy waves as a means of sediment transport.

The Puffin Formation has sufficient well density now to be mapped by systems tract. The typical bow shaped log profile of this unit reflects the high-stand/transgressive systems tract make-up of the section, with an interfluve sequence boundary/transgressive surface present in the medial part of the section, which is capped by a retrogradational system.

6.2.1 early Late Oxfordian: J54 (*glosense*) MFS to the LJ2 DSB (figure 6.2)

The slow rates of relative sea level rise allowed this part of the J54 sequence to remain in a shallow marine realm as accommodation was largely filled. The lower part of the Puffin Formation is typified by a gamma profile, which records a cleaning upward, high-stand progradational succession.

The main sand depocentre appears to be the Puffin Fault Block and to the north east of the Puffin Fault Block, prograding out to 23/26b block wells. Progradational shoreface/shelf sands of the Puffin Formation are recognised in wells from:

- the West Central Graben: blocks 21/20a+b, 22/16a.
- on the flanks of the Forties Montrose High: blocks 22/23b, 22/28a.
- on the Puffin Fault Block: blocks 22/27a, 22/28b, 29/1b, 29/2a+b, 29/3a+b, 29/4a, 29/5a, 29/8a, 29/9a+b, 29/10 and 29/15.
- to the northeast of the Puffin Fault Block: blocks 22/28a, 22/29, 22/30a+b+c, 29/4d, 29/5b and 23/26a+b.
- on the flanks of the Auk Ridge: block 30/11b.
- extending from the West Central Graben onto the West Central Shelf possibly via a fault transfer ramp: blocks 21/24, 21/25, 21/30.

The areal distribution of the Puffin Formation on the West Central Shelf and graben areas is likely to be controlled by a pre-existing valley system created by the withdrawal of Zechstein salt and development of Triassic pods and drowned by the Oxfordian transgression (see Wakefield *et al*., 1993; Fraser et al. 2003 (for the Puffin Field)).

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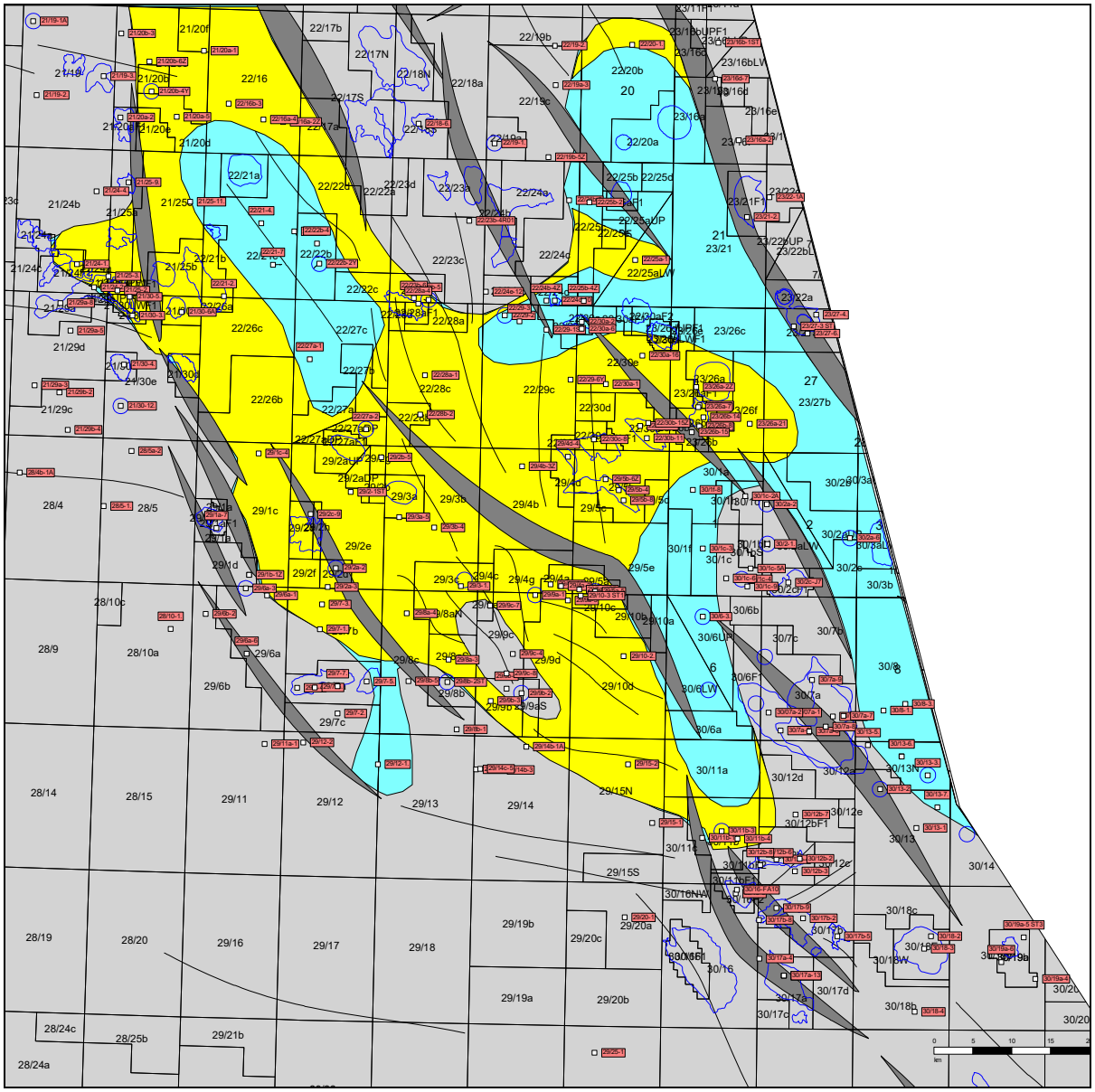

Figure 6.2 Play fairway map for the J54 Genetic Sequence (up to the LJ2 depositional sequence boundary) (early Late Oxfordian)

Grey = emergent land
Blue = marine mudstones
Yellow = Shallow marine / shoreface sands (Puffin Formation)
NB. The distribution of sands within the mapped fairway will be controlled significantly by underlying Triassic pods and intervening salt walls.

The extent of the Puffin Formation is constrained by wells comprised of the Heather Formation *sensu lato* in the lower part of the J54 sequence (22/21-7, 22/21-4, 22/21-8,

22/22b-2 ST2, 22/24b-4ST, 22/24b-8, 22/25b-2, 22/25b-4S1, 22/27a-1, 22/29-1ST, 22/29-3, 30/1c-3, 30/6-3 and 30/13-3, 4, 6, 7).

On the margins of the Forth Approach Platform, in 29/12-1, this part of the sequence is represented also by mudstones. Equivalent sediments are absent in 29/7-4, 29/7-5, 29/7-6, 29/7-7 and 29/8b-5, either because the locations were emergent at the time or possibly because of down-cutting of the overlying incised valley fill which was subsequently filled with the Curlew Member.

6.2.2 'mid' Late Oxfordian: LJ2 Depositional Sequence Boundary (Figure 6.3)

A significant sequence boundary, LJ2 DSB, is well recognised within the Puffin Formation. The sequence boundary is represented by:

- an interfluve lag deposit/hardground within the Puffin Formation marked in core or by a fast sonic response or a sharp decrease in gamma response, eg. 29/4a-1A, 22/30c-8.
- the base of the Curlew Member above shoreface/shelf sands of the Puffin Formation, representing subaerial erosion and estuarine/marginal marine backfilling of incised valleys eg. 29/10-2.
- sharp contacts between shoreface/shelf sands of the Puffin Formation above mudstones of the Heather Formation *sensu lato*, recording a basinward shift in facies, eg. 22/29-1 ST.
- the base of the Freshney Member above mudstones of the Heather Formation *sensu lato* eg. 30/13-3.

Following a fall in relative sea level, fluvial transport was directed across the emergent Puffin Fault Block to supply sediment into the basins, where low-stand basin floor sands of the Freshney Member were deposited in the West Central Graben, blocks 22/21, 22/22b, 22/23b, 22/27a and 22/28a and blocks 30/6, 30/7a and 30/13 of the Central Graben.

Additional volumes of sediment may have been transported along the axis of the Puffin Fault Block fault, to be deposited as low-stand deposits to the north west of 30/6-3. Wells are sparse in this area however. In 29/4b-3 ST, a major unconformity exists between the Kimmeridge Clay Formation and the Fladen Group. Low-stand basin floor sands of the Freshney Member are well developed in the West Central Graben, represented by 22/21-7 (1,265 ft. gross), 22/22b-2 ST2 (503 ft. gross) and 22/27a-1 (1,331 ft. gross). These sands are constrained by 22/21-4 (19 ft. gross) and by 22/21-8, which was by-passed.

Low-stand basin floor sands of the Freshney Member are present within the Puffin Formation in 22/23b-5 (723 ft. gross), 22/23b-6 (54 ft. gross) and 22/28a-4 (68 ft. gross) and possibly represent the eastern edge of the depositional system in the West Central Graben.

Sands were probably shed off the Josephine High, resulting in low-stand deposits of the Freshney Member in 30/7a-4A, 30/13-3, 30/13-4, 30/13-6 and 30/13-7. The extent of these sands is poorly understood due to the lack of released well control, although well 30/8-1 is comprised of mudstones of the Heather Formation *sensu lato*.

A rise in relative seal level led to the backfilling of incised valleys on the Puffin Fault Block with estuarine/marginal marine sediments of the Curlew Member. The Curlew Member is identified in a sufficient number of wells to permit mapping the incised valley system. The Curlew Member is present in the following wells: 29/2a-2, 29/2a-3, 29/3a-5, 29/7-3, 29/7-4, 29/7-5, 29/7-6, 29/7-7, 29/8a-4, 29/8b-5 and 29/10-2. The location of the incised valley systems were probably structurally controlled with initial fluvial incision focused in areas of moderately high subsidence, eg. the hanging wall of the West Central Shelf in block 29/7.

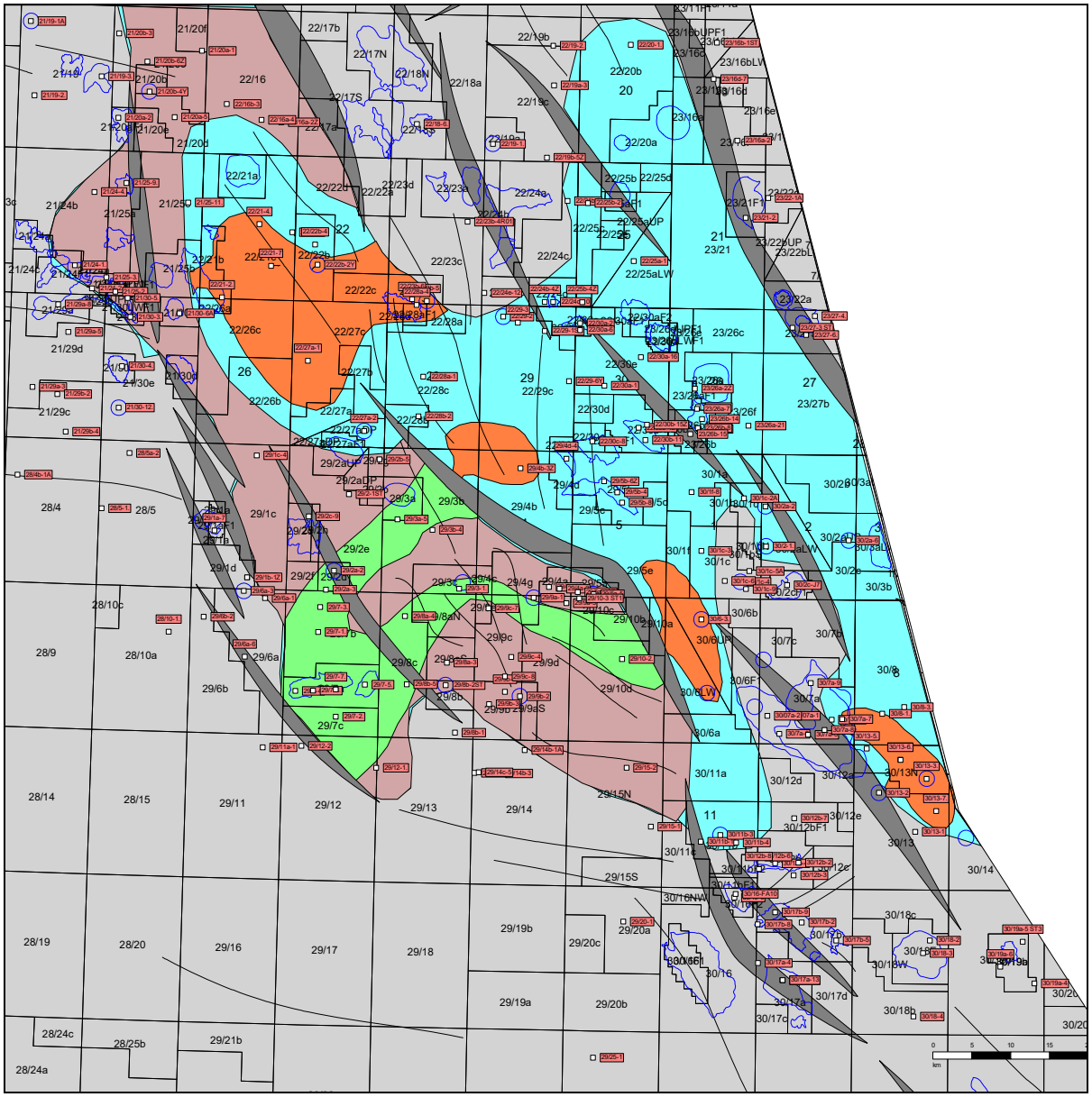

Figure 6.3 Play fairway map for the J54 Genetic Sequence (at the LJ2 depositional sequence boundary) (mid Late Oxfordian)

Grey = emergent land
Blue = marine mudstones
Brown = newly emergent land
Orange = mass-flow basinal sands (Freshney Member)
Green = estuarine, incised valley transgressive fill (Curlew Member)
NB. The distribution of sands within the mapped fairway will be controlled significantly by underlying Triassic pods and intervening salt walls.

6.2.3 late Late Oxfordian: Above the LJ2 DSB to the J56 (*rosenkrantzi*) MFS (Figure 6.4)

As the transgressive phase continued, retrogradational shoreface/shelf sands of the Puffin Formation accumulated above the Curlew Member or above the interfluve sequence boundary.

Retrogradational sands above the LJ2 DSB are more widespread than the underlying progradational high-stand sands, particularly around the eastern margin of the Forties Montrose High, in West Central Shelf block 21/24 and 21/25 and on the flank of the Auk Ridge (compare Figures 6.2 - 6.4). The Puffin Formation extended onto the flanks of the Forties Montrose High in block 22/24b+d and 22/19b, the West Central Shelf in blocks 21/24, 21/25 and 21/30 and on the flanks of the Auk Ridge in block 30/11b. The Lower Fulmar Formation is present above the Puffin Formation in 30/11b-3 and is also present above the base Late Jurassic unconformity to the southeast in block 30/12b.

In distal locations of the Puffin Fault Block, West Central Graben and the East Central Graben, the Puffin Formation is succeeded by mudstones of the Heather Formation *sensu lato*, which contains the J56 (*rosenkrantzi*) MFS. In more proximal locations close to the West Central Shelf and the Forties Montrose High in blocks 21/24, 21/25, 29/7, 30/11b, 30/12b, 22/23b and 22/28a, retrogradational followed by progradational/aggradational shoreface/shelf sands of the Puffin Formation and Lower Fulmar Formation accumulated through Late Oxfordian times, up to and beyond the J56 (*rosenkrantzi*) MFS.

More distal locations in the East Central Graben and the deeper part of the West Central Graben and Central Graben remained beyond the main Puffin Formation fairway.

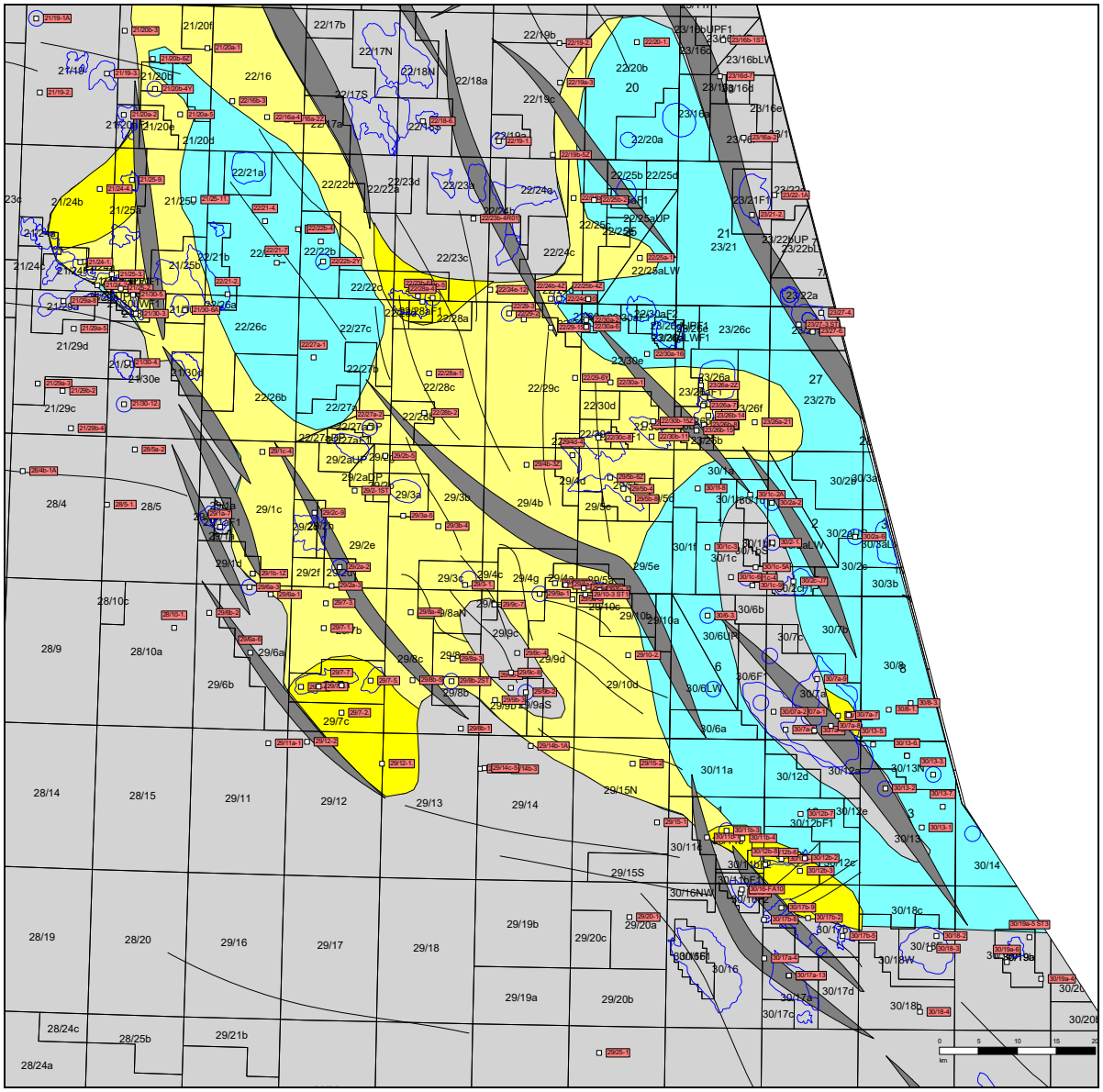

Figure 6.4 Play fairway map for the J54 Genetic Sequence (above the LJ2 depositional sequence boundary) (late Late Oxfordian)

Grey = emergent land
Blue = marine mudstones
Yellow = shallow marine/shoreface sands (Puffin Formation)
NB. The distribution of sands within the mapped fairway will be controlled significantly by underlying Triassic pods and intervening salt walls.

6.3 GENETIC SEQUENCE J56; LJ3 (pars) (latest LATE OXFORDIAN TO early KIMMERIDGIAN)

Figure 6.5 illustrates the palaeogeography from the J56 (*rosenkrantzi*) MFS to the early Kimmeridgian J62 (*baylei)* MSF. The transgression marked by the J56 (*rosenkrantzi*) MFS within the Heather Formation *sensu lato* reduced sand supply greatly into the Central Graben. Sands in the basin are restricted to low-stand basin floor sands, namely thin sands of the Shearwater Member which occur within the Heather Formation *sensu lato* above the LJ3i DSB. They are present in 22/29-3, 22/30b-11, 23/26b-14, 23/26b-15, 23/21a-21 and 30/2a-2 and accumulated during latest Late Oxfordian times. The sands are probably sourced locally.

When high-stand progradation occurred it took place from localised sources of sand input on the margins of the West Central Shelf and the Forties Montrose High. Four principal areas of high-stand sand input are present:

- blocks 21/20a+b, 21/24 and 21/25 during Late Oxfordian to early Kimmeridgian times (Puffin Formation).
- on the flanks of the Forties Montrose High, 22/23b to 22/28 during Late Oxfordian to early Kimmeridgian times (Puffin Formation).
- the 29/7 to 29/12 area during Late Oxfordian times (Puffin Formation).
- the Halley/Clyde/Fulmar area, blocks 30/11b, 30/12b, 30/16 and 30/17b during Late Oxfordian to early Kimmeridgian times (Lower Fulmar Formation).

Distribution of these sands is constrained by the coeval uppermost part of the Heather Formation *sensu lato*, which are distal equivalents, eg. the basinward extent of the Puffin Formation in 29/7-4, 29/7-5, 29/7-6 and 29/7-7 is constrained by the presence of the Heather Formation distal equivalent in 29/7-3.

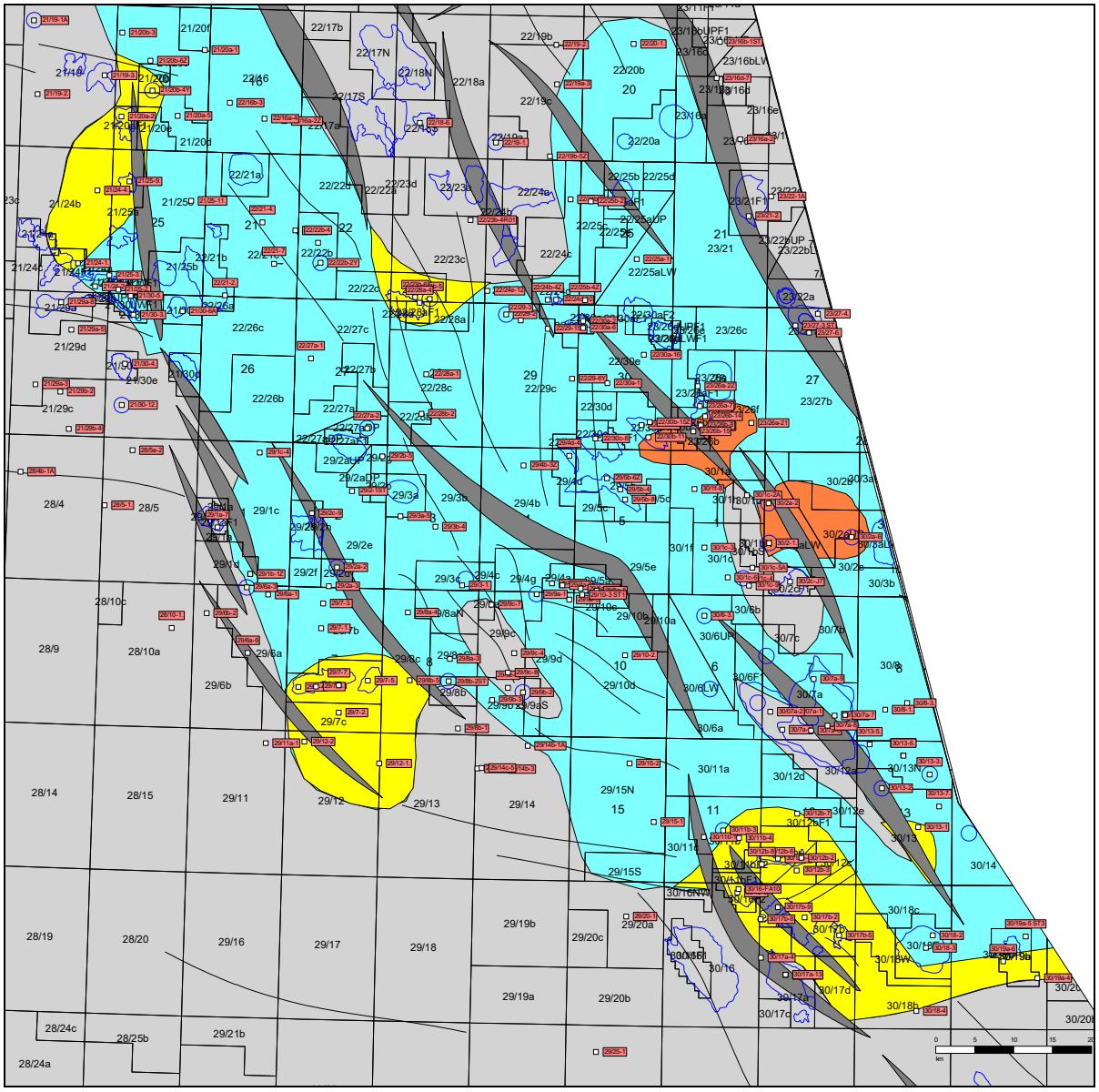

Figure 6.5 Play fairway map for the J56 Genetic Sequence (latest Late Oxfordian to early Kimmeridgian)

Grey = emergent land
Blue = marine mudstones
Yellow = shallow marine/shoreface sands (Puffin Formation or Lower Fulmar Formation)
Orange = mass-flow basinal sands (Shearwater Member)
NB. The distribution of sands within the mapped fairway will be controlled significantly by underlying Triassic pods and intervening salt walls.

6.4 GENETIC SEQUENCE J62; LJ3 (pars) (early to mid KIMMERIDGIAN)

Figure 6.6 illustrates the palaeogeography from the early Kimmeridgian J62 (*baylei*) MSF to the J63 (*eudoxus*) MFS. The transgression marked by the J62 MFS resulted in significant flooding of the West Central Shelf and the Norwegian-Danish Platform and corresponds to the base of the Kimmeridge Clay Formation. High-stand progradation took place from localised sources of sand input on the margins of the West Central Shelf and the Norwegian-Danish Platform. Five principal areas of high-stand sand input are present:

- blocks 21/19, 21/20a, 21/24 and 21/25 area (Ryton Member).
- blocks 29/1a, 29/6a+b and 29/11a (Ryton Member).
- blocks 29/9b and 29/14b (Leen Member in 29/9b-6).
- Clyde/Fulmar area, blocks 30/11b, 30/12b, 30/16, 30/17a+b, 30/18 and 30/19a (Upper Fulmar Formation).
- the Jaeren High and Norwegian-Danish Platform (Ula Formation).

Distribution of these sands is constrained by the presence of the Trent Member of the Kimmeridge Clay Formation.

The areal distribution of the Ryton Member on the West Central Shelf is likely to be controlled by a pre-existing valley system created by the withdrawal of Zechstein salt and development of Triassic pods and drowned by the early Kimmeridgian, J62 transgression (see Wakefield *et al*., 1993).

In general these localised sand bodies show a progradational-retrogradational pattern. On the West Central Shelf blocks 21/19, 21/20a, 21/24 and 21/25, the medial part of these cycles is marked by an interfluve lag deposit. Two examples of likely equivalent low-stand deposits have been penetrated:

- 21/20a-2 shows the thick development of burrowed shallow marine sandstones resting sharply on shelf mudrocks and these are interpreted as forced regressive deposits.
- 21/20b-4S2 penetrated low-stand basin floor sands assigned to the Christian Member. Coeval sediments are also present locally in 22/23b-6.

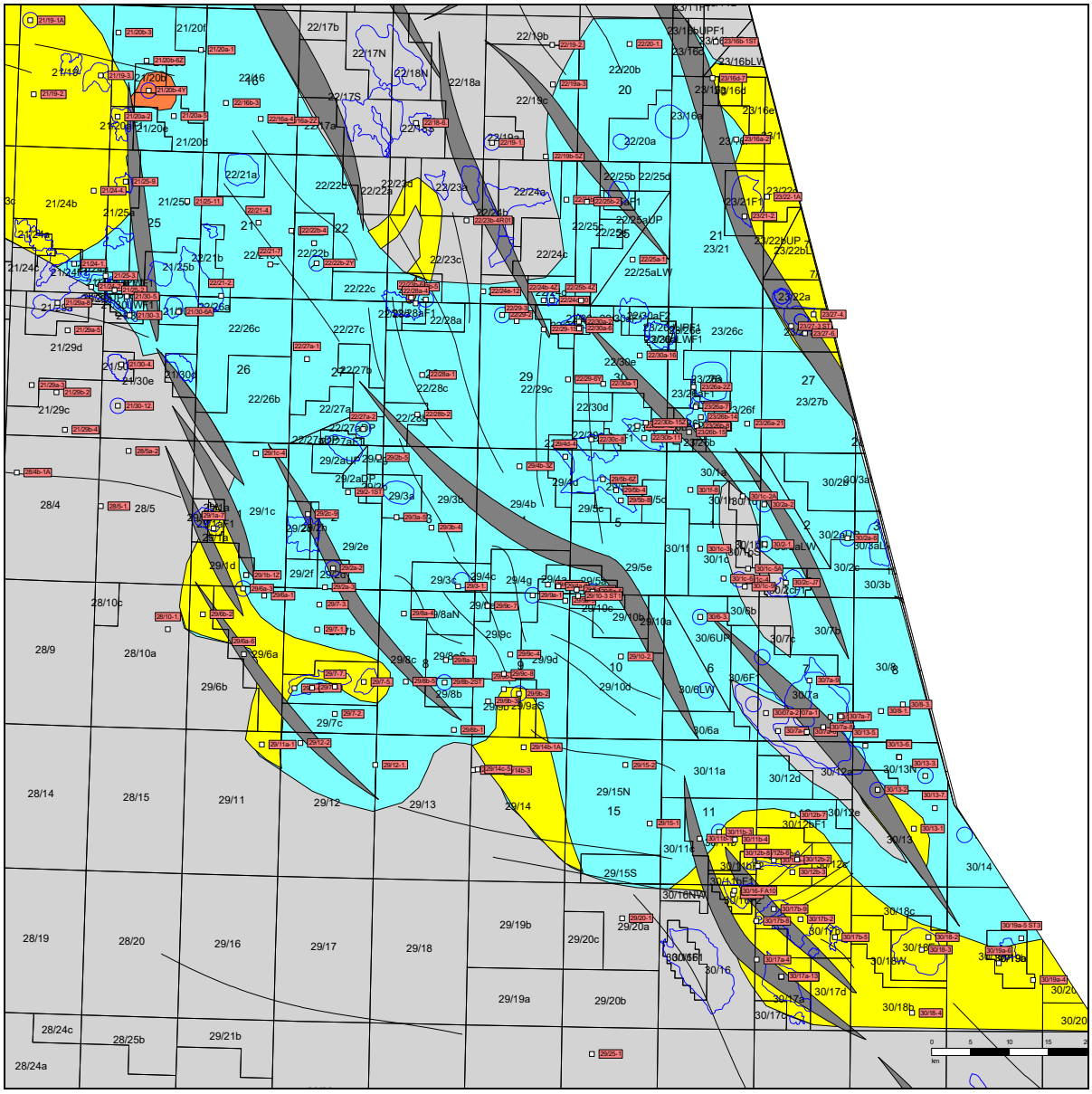

Figure 6.6 Play fairway map for the J62 Genetic Sequence (early to mid Kimmeridgian)

Grey = emergent land
Blue = marine mudstones
Yellow = shallow marine/shoreface sands (Ryton Member, Leen Member, Upper Fulmar Formation, Ula Formation)
Orange = mass-flow basinal sands (Christian Member)
NB. The distribution of sands within the mapped fairway will be controlled significantly by underlying Triassic pods and intervening salt walls.

6.5 GENETIC SEQUENCE J63-J64; LJ4; (mid KIMMERIDGIAN TO mid EARLY VOLGIAN)

Figure 6.7 illustrates the palaeogeography of the J63-J64 Genetic Sequence (mid Kimmeridgian to Early Volgian times). The drowning of the J62 sequence was initiated by the J63 (*eudoxus*) maximum flooding surface. This represents a major condensed section. Due to ongoing tectonic activity the basin margins continued to drown, and four areas of shallow marine high-stand progradation are recorded:

- the Ula trend on the Norwegian-Danish Platform.
- the Laver Member on the West Central Shelf, blocks 21/29a+b, 21/30, 28/5, 28/10 and 29/6a.
- the Laver Member Equivalent in 22/18-6 (Wood field) on the crest of the Forties Montrose High. This are considered to be linked via a mini-rift to the main Central Graben seaway to the south which may have acted as a feeder channel for Selkirk Member low-stand sands (see below and Chapter 4).
- the Uppermost Fulmar Formation in block 30/17a.

The areal distribution of the Laver Member on the West Central Shelf is likely to be controlled by a pre-existing valley system created by the withdrawal of Zechstein salt and development of Triassic pods and drowned by the Kimmeridgian, J63 (*eudoxus*) transgression (see Wakefield *et al*., 1993).

Low-stand deposits are largely not penetrated over most of the area. Low-stand sands of the Selkirk Member are present in 22/16a-4, 22/22b-2 ST2, 22/22b-4, 22/23b-5, 22/23b-6 and 22/28a-4 on the flanks of the Forties Montrose High. Sediment gravity flow and shallow marine deposits of the Ribble Member and its equivalents are also recognised in the Fulmar and Clyde Fields respectively. Enhanced input of fine-grained clastics during low-stand, may however be recorded by the Swale Member ‘cool’ shales which are coeval with the Selkirk Member.

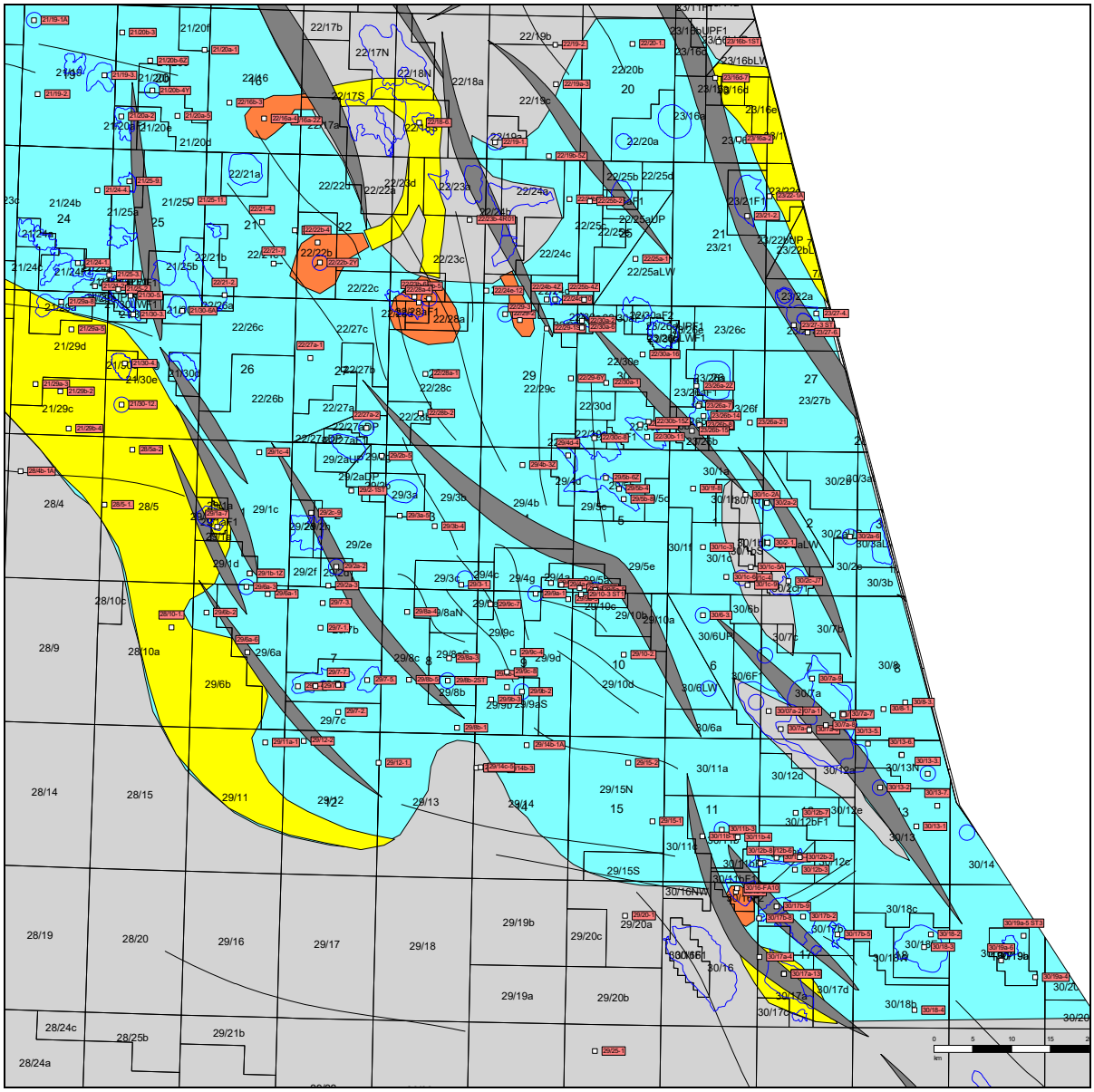

Figure 6.7 Play fairway map for the J63-J64 Genetic Sequence (mid Kimmeridgian to mid Early Volgian)

Grey = emergent land
Blue = marine mudstones
Yellow = shallow marine/shoreface sands (Laver Member, Upper Fulmar Formation, Ula Formation)
Orange = mass-flow basinal sands (Selkirk Member, Ribble Member)
NB. The distribution of sands within the mapped fairway will be controlled significantly by underlying Triassic pods and intervening salt walls.

6.5 GENETIC SEQUENCE J66-J73; LJ5; (mid EARLY TO mid LATE VOLGIAN)

Figure 6.8 illustrates the palaeogeography of the J66-J73 Genetic Sequences (mid Early to mid Late Volgian times).

This sequence records major mudrock blanketing across the basin and minimal sand development due to the retreat of shallow marine systems. The base of the sequence is marked by the J66 (*hudlestoni*) MFS. This event led to major flooding of the flanks and crest of the Forties Montrose High with intervening Triassic rafts/pods forming subaerial highs eg Marnock and Skua field, block 22/24.

The shallow marine Nidd Member and Equivalent represents shallow marine deposits fringing the basin, but the lack of well data and monotonous log character of these deposits means that their origin remains enigmatic. They are present in 29/20 and 29/23 and on the crest of the Forties Montrose High in 22/18-6. The major cool shale of the Wharfe Member contained within this genetic sequence has been interpreted as a low-stand sequence which contains significant accumulations of sediment gravity flow deposits in other parts of the North Sea, such as the Witch Ground Graben and may record a global relative fall in sea level. In the Central Graben however, sand input is negligible as exposed source areas were increasingly distant.

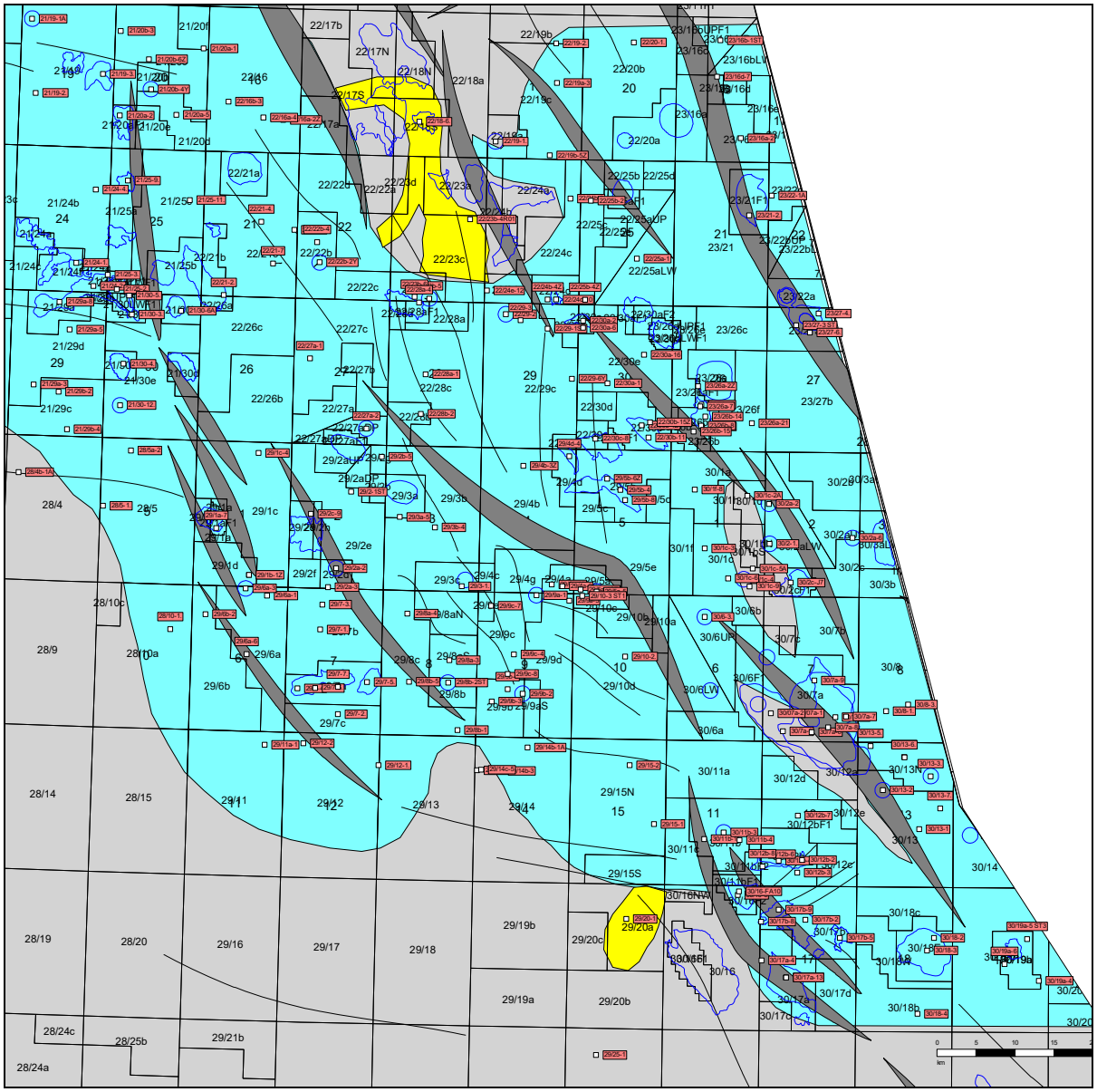

Figure 6.8 Play fairway map for the J66-J73 Genetic Sequence (mid Early Volgian to mid Late Volgian)

Grey = emergent land
Blue = marine mudstones
Yellow = shallow marine/shoreface sands (Nidd Member)
NB. The distribution of sands within the mapped fairway will be controlled significantly by underlying Triassic pods and intervening salt walls.

7. REFERENCES

CARRUTHERS, R.A., McKIE, T., PRICE, J., DYER, R., WILLIAMS, G. and WATSON, P.

1996 The application of sequence stratigraphy to the understanding of Late Jurassic turbidite plays in the Central North Sea, UKCS. *In:* Hurst, A. *et al.* (eds.). **Geology of the Humber Group: Central Graben and Moray Firth, UKCS.** Geological Society Special Publication. 114, p.29-45.

CRAWFORD, R., LITTLEFAIR, R.W. and AFFLECK, L.G.

1991 The Arbroath and Montrose Fields, Blocks 22/17, 18, UK North Sea. *In:* Abbotts, I, L. (ed.). **United Kingdom Oil and Gas Fields 25 years commemorative volume.** Geological Society Memoir. 14, p.211-217.

DYER, R. AND COPESTAKE, P.

1989 A review of Late Jurassic to earliest Cretaceous radiolaria and their biostratigraphic potential to petroleum exploration in the North Sea. In Batten, D and Keen, M. (eds.). **Northwest European Micropaleontology and Palynology**, Ellis Horwood, p. 214-235.

ERRATT, D., THOMAS, G.M. and WALL, G.R.T.

1999 The evolution of the Central North Sea Rift. *In*: Fleet, A.J. & Boldy, S.A.R. (eds) **Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference**. Geological Society, London, p.63-82.

EVANS, N., RORISON, P. and SYKES, G.

1999 Banff Field, UK Central Graben - evaluation of a steeply dipping, fractured chalk reservoir. *In*: Fleet, A.J. & Boldy, S.A.R. (eds) **Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference.** Geological Society, London, p.975-988.

FRASER, S., ROBINSON, A., JOHNSON, H., UNDERHILL, J., KADOLSKY, D., CONNELL, R., JOHANNESSEN, P. and RAVNAS, R.

2003 Upper Jurassic. In: Evans, D., Graham, C., Armour, A. and Bathurst, P. (eds) **The Millennium Atlas: Petroleum geology of the Central and Northern North Sea.** Geological Society, London, p.157-189.

GALLOWAY, W.E.

1989 Genetic Stratigraphic Sequences in Basin Analysis I: Architecture and Genesis of Flooding-Surface Bounded Depositional Units. **A.A.P.G. Bull.,** v.73/2, p.125-142.

GAWKTHORPE, R.L. FRASER, A.J. and COLLIER, R.E.

1994 Sequence stratigraphy in active extensional basins: implications for the interpretation of ancient basin-fills. **Marine and Petroleum Geology** 11, p.642-658.

HAQ, B.U., HARDENBOL, J. and VAIL, P.R.

1988 Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. *In:* Wilgus, C.K., Hastings, B.S., Kendall, C.G. St. C., Posamentier, H.W., Ross C.A. & Van Wagoner, J.C. (eds). **Sea Level Changes; an Integrated Approach.** Society of Economic Paleontologists and Mineralogists Special Publication, 42, 71-108.

HOWELL, J.A. & FLINT, S.S.

1996 A model for high-resolution sequence stratigraphy within extensional basins. *In*: Howell, J.A. & Aitken, J.F. (eds). **High Resolution Sequence stratigraphy; Innovations and Applications.** Geological Society Special Publication, 104, p.129-138.

JEREMIAH. M. and NICHOLSON, P.H.

1999 Middle Oxfordian to Volgian sequence stratigraphy of the Greater Shearwater area. *In*: Fleet, A.J. & Boldy, S.A.R. (eds) **Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference.** p.153-170 Geological Society, London.

JERVEY, M. T.

1988 Quantitative geological modelling of siliciclastic rock sequences and their seismic expression. *In:* Wilgus, C.K., Hastings, B.S., Kendall, C.G. St. C., Posamentier, H.W., Ross, C.A. & van Wagoner, J.C. (eds). **Sea Level Changes; an Integrated Approach.** Society of Economic Paleontologists and Mineralogists Special Publication, 42, p.48-69.

LASOCKI, J., GUEMENE, J.M., HEDAYATI, A., LEGORJUS, C. and PAGE, W.M.

1999 The Elgin and Franklin fields: U.K. Blocks 22/30c, 22/30b and 29/5b. In: Fleet, A.J. & Boldy, S.A.R. (eds) **Petroleum Geology of Northwest Europe:** Proceedings of the 5th Conference. Geological Society, London, p.1007-1020.

PARTINGTON, M.A., MITCHENER, B.C., MILTON, N.J. & FRASER, A.J.

1993a Genetic sequence stratigraphy for the North Sea Late Jurassic and Early Cretaceous: distribution and prediction of Kimmeridgian-Late Ryazanian reservoirs in the North Sea and adjacent areas. **Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference** (Edited by J.R. Parker). The Geological Society, London. pp.347-370.

PARTINGTON, M.A., COPESTAKE, P., MITCHENER, C. and UNDERHILL, J.R.

1993b Biostratigraphic calibration of genetic stratigraphic sequences in the Jurassic-lowermost Cretaceous (Hettangian to Ryazanian) of the North Sea and adjacent areas. **Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference** (Edited by J.R. Parker). The Geological Society, London. pp.371-386.

PENGE, J., TAYLOR, B., HUCKERBY, J.A. and MUNNS, J.W.

1993 Extension and salt tectonics in the East Central Graben. **Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference** (Edited by J.R. Parker). The Geological Society, London. pp.1197-1209.

PENGE, J., MUNNS, J.W., TAYLOR, B. and WINDLE, T.M.F.

1999 Rift-raft tectonics: examples of gravitational tectonics from the Zechstein basins of northwest Europe. In: Fleet, A.J. & Boldy, S.A.R. (eds) **Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference.** Geological Society, London, p.201 - 213.

PLINT, A.G.

1988 Sharp-based shoreface sequences and 'offshore bars' in the Cardium Formation of Alberta: their relationship to relative changes in sea level. *In:* Wilgus, C.K. *et al.* (eds). **Sea level changes: an integrated approach.** SEPM Special Publication, 42, p.357-376.

POSAMENTIER, H.W. AND ALLEN, G.P.

1993 Siliclastic sequence stratigraphic patterns in foreland ramp-type basins. **Geology** 21, 455-458.

PRICE, J., DYER., R., GOODALL, I., McKIE, T., WATSON, D.P. and WILLIAMS, G.

1993 Effective Stratigraphical Subdivision of the Humber Group and the Late Jurassic Evolution of the UK Central Graben. **Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference** (Edited by J.R. Parker). The Geological Society, London. pp.443-458.

RAWSON, P.F. and RILEY, L.A.

1982 Latest Jurassic - Early Cretaceous events and the 'Late Cimmerian Unconformity' in the North Sea area. **American Association of Petroleum Geologists Bulletin**., vol. 66, no. 12, p.2628-2648.

STEWART, S.A. and CLARK, J.A.

1999 Impact of salt on the structure of the Central North Sea hydrocarbon fairways.. In: Fleet, A.J. & Boldy, S.A.R. (eds) **Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference.** Geological Society, London, p.179-200.

UNDERHILL, J.R. & PARTINGTON, M.A.

1993 Jurassic thermal doming deflation in the North Sea: implications of the sequence stratigraphic evidence. *In:* Parker, J.R. (ed.). **Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference.** Geological Society, London, 337-345.

VAIL, P.R., HARDENBOL, J. and TODD, R.G.

1984 Jurassic unconformities, chronostratigraphy and sea-level changes from seismic stratigraphy and biostratigraphy. In: Interregional unconformities and hydrocarbon accumulation. **A.A.P.G. Geol. Memoir** 36, pp.129-144.

VELDKAMP, J.J., GAILLARD, M.G. JONKERS, H.A. and LEVELL, B.K.

1996 A Kimmeridgian time-slice through the Humber Group of the Central North Sea: a test of sequence stratigraphic methods. *In*: Hurst, A. *et al*. (eds.). **Geology of the Humber Group: Central Graben and Moray Firth, UKCS.** Geology Society Special Publication, 114. p.1-28.

WAKEFIELD, L.L., DROSTE, H., GILES, M.R. and JANSSEN, R.

1993 Late Jurassic plays along the western margin of the Central Graben. **Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference** (Edited by J.R. Parker). The Geological Society, London. pp.459-468.

ZANELLA, E. and COWARD, M.P.

2003 Structural framework. In: Evans, D., Graham, C., Armour, A. and Bathurst, P. (eds) **The Millennium Atlas: Petroleum geology of the Central and Northern North Sea.** Geological Society, London, p.45-59.

APPENDIX 1

STRATIGRAPHIC PICKS

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	21/19-1A			21/19-2				21/19-3			21/20a-1				21/20a-2			
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Age
Kimmeridge Clay Formation				10910			10220				12385			13092				11856			
Mandal Member				10910			10220							13092				11856			
			Late - Early Ryazanian							10220							13100				11860
	EK1 MFS / K10				10914			10221							13100				11867		
Derwent Member				10918																	
			Late Volgian																		
	LJ6 MFS / J74				10936																
			latest Middle Volgian																		
Wharfe Member				10942			10223				12441										
Nidd Member																					
			Middle Volgian							10240											
		LJ5 DSB				10985			10246				12545								
Aire Member				10985			10246				12545			13103				11870			
			Early Volgian							10240							13130				11900
	LJ5 MFS / J66				10990			10250				12568			13122				11877		
Swale Member				10995			10253				12572			13125				11879			
Laver Member																					
Uppermost Fulmar Formation																					
top Selkirk Member																					
base Selkirk Member																					
			Kimmeridgian							10280							13238				11900
		LJ4 DSB				11020			10278				12592			13180				11918	
un-named conglomerate																					
Ouse Member				11020			10278				12592			13180				11918			
	LJ4 MFS / J63				11029			10305				12596			13261				11930		
Leen Member																					
Ribble Member																					
Trent Member				11036			10323							13360							
Ula Formation																					
Ryton Member				11064			10338				12632							11942			
Upper Fulmar Formation																					
top Christian Member																					
base Christian Member																					
		LJ3ii DSB				11123			10429				12814			13546				12289	
	baylei IFS / J62				11165			10456			12946				13784				12394		
Lower Fulmar Formation																					
Heather Formation *sensu lato*														13803				12402			
			early Kimmeridgian														13770				
			early Kimm. - Lt Oxfordian																		12440
			Late Oxfordian														13860				
Puffin Formation																		12497			
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB														14152				12712	
	LJ3 MFS / J56														14311						
Puffin Formation														14353							
top Curlew Member																					
base Curlew Member																					
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB														14428					
base Puffin Formation																					
	LJ2 MFS / J54																				
Franklin Formation																					
Heather Formation *sensu stricto*																					
			Middle Oxfordian																		
		LJ1 DSB																			
			Early Oxfordian																		
	J52																				
	LJ1 MFS / J46																				
Fladen Group														14524							
			Middle Jurassic														14524				
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group				11166			10457				12948							12712			
			Triassic							10457											12712
Zechstein Group			Late Permian	11344			10550				13225										

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	21/20b-3				21/20b-4 S2			21/20a-5			21/20b-6Z				21/22-1		
				Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				13123				12920			12842			13566				6254		
Mandal Member				13123				12920			12842			13566				6254		
			Late - Early Ryazanian				13140										13566			
	EK1 MFS / K10				13129				12929			12850			13576				6281	
Derwent Member								12930			12852			13578				6291		
			Late Volgian																	
	LJ6 MFS / J74								12960			12862			13603				6337	
			latest Middle Volgian																	
Wharfe Member								12999			12898			13613				6409		
Nidd Member																				
			Middle Volgian														13650			
		LJ5 DSB								13105			13051			13631				6521
Aire Member								13105			13051			13631				6521		
			Early Volgian														13650			
	LJ5 MFS / J66								13172			13067			13639				6553	
Swale Member				13134				13293			13155			13677						
Laver Member																		6618		
Uppermost Fulmar Formation																				
top Selkirk Member																				
base Selkirk Member																				
			Kimmeridgian				13140										13770			
		LJ4 DSB				13145				13356			13235			13740				
un-named conglomerate																				
Ouse Member				13145				13356			13235			13740						
	LJ4 MFS / J63				13163				13378			13268			13780					
Leen Member																				
Ribble Member																				
Trent Member				13180				13450			13460			13909						
Ula Formation																				
Ryton Member																				
Upper Fulmar Formation																				
top Christian Member								13485												
base Christian Member								13629												
		LJ3ii DSB				13354				13715			13647			13940				
	baylei IFS / J62				13376				13769			13705			13944					
Lower Fulmar Formation																				
Heather Formation *sensu lato*				13377				13770			13741			13949						
			early Kimmeridgian																	
			early Kimm. - Lt Oxfordian				13400										14020			
			Late Oxfordian				13460										14070			
Puffin Formation								13809												
base Puffin Formation								13863												
top Shearwater Member																				
base Shearwater Member																				
		LJ3i DSB				13435				13863			14120			14076				
	LJ3 MFS / J56				13443				13900			14220			14113					
Puffin Formation											14335			14190						
top Curlew Member																				
base Curlew Member																				
top Freshney Member																				
base Freshney Member																				
		LJ2 DSB											14419			14190				
base Puffin Formation											14435			14526						
	LJ2 MFS / J54											14435			14610					
Franklin Formation																				
Heather Formation *sensu stricto*														14627						
			Middle Oxfordian														14640			
		LJ1 DSB														14690				
			Early Oxfordian																	
	J52																			
	LJ1 MFS / J46														14700					
Fladen Group											14435			14704						
			Middle Jurassic														14704			
Ron Volcanic Member																				
Indeterminate																				
Lias Group																				
			Early Jurassic																	
Heron Group				13496				13950			14965			14864				6652		
			Triassic				13496										14864			
Zechstein Group			Late Permian															6787		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	21/24-1				21/24-2			21/24-4			21/25-2				21/25-3			21/25-9		
				Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				6716				8000			11325			7367				9380			10432		
Mandal Member				6716				8000			11325			7367				9380			10432		
			Late - Early Ryazanian				6720										7360						
	EK1 MFS / K10				6724				8007			11331			7377				9382			10440	
Derwent Member				6725							11340			7385				9383					
			Late Volgian				6720										7400						
	LJ6 MFS / J74				6750							11350			7412				9420				
			latest Middle Volgian														7440						
Wharfe Member				6755							11370			7475				9483			10442		
Nidd Member																							
			Middle Volgian				6760										7480						
		LJ5 DSB				6767							11477			7584				9596			10462
Aire Member				6767							11477			7584				9596			10462		
			Early Volgian				6810										7640						
	LJ5 MFS / J66				6786							11502			7657				9624			10465	
Swale Member											11530			7675				9657			10466		
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member																							
base Selkirk Member																							
			Kimmeridgian														7920						
		LJ4 DSB											11612			7748				9740			10489
un-named conglomerate																							
Ouse Member											11612			7748				9740			10489		
	LJ4 MFS / J63											11662			7780				9770			10490	
Leen Member																							
Ribble Member																							
Trent Member											11747			7809				9797			10509		
Ula Formation																							
Ryton Member											11792										10530		
Upper Fulmar Formation																							
top Christian Member																							
base Christian Member																							
		LJ3ii DSB											11850			7952				9900			10600
	baylei IFS / J62											11870			7984				9900			10660	
Lower Fulmar Formation																							
Heather Formation *sensu lato*														7992				9905					
			early Kimmeridgian																				
			early Kimm. - Lt Oxfordian				6865										8080						
			Late Oxfordian														8325						
Puffin Formation											11872										11678		
base Puffin Formation																							
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB											11975			8064				9981			11010
	LJ3 MFS / J56											11980			8095				10042			11016	
Puffin Formation				6794										8165				10164					
top Curlew Member																							
base Curlew Member																							
top Freshney Member																							
base Freshney Member																							
		LJ2 DSB				6852							12070			8274				10255			11112
base Puffin Formation																							
	LJ2 MFS / J54														8375				10288				
Franklin Formation																							
Heather Formation *sensu stricto*																							
			Middle Oxfordian																				
		LJ1 DSB																					
			Early Oxfordian																				
	J52																						
	LJ1 MFS / J46																						
Fladen Group																							
			Middle Jurassic																				
Ron Volcanic Member																							
Indeterminate																							
Lias Group																							
			Early Jurassic																				
Heron Group				6898				8008			12070			8375				10288			11112		
			Triassic				6898										8375						
Zechstein Group			Late Permian	6970							12296			8702				10913			11362		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	21/29b-2				21/29a-3			21/29b-4				21/29a-5				21/29a-8		
				Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				6518				5964			7260				7192				7122		
Mandal Member				6518				5964			7260				7192				7122		
			Late - Early Ryazanian											7280				7200			
	EK1 MFS / K10				6520				5970			7277				7193				7125	
Derwent Member				6523				5975			7283				7198				7128		
			Late Volgian				6540							7280				7200			
	LJ6 MFS / J74				6527				5978			7291				7245				7169	
			latest Middle Volgian											7320				7280			
Wharfe Member				6539				5999			7340				7324				7222		
Nidd Member																					
			Middle Volgian											7360				7320			
		LJ5 DSB				6672				6160			7408				7355				7246
Aire Member				6672				6160			7408				7355				7246		
			Early Volgian				6570							7440				7480			
	LJ5 MFS / J66				6714				6199			7453				7393				7255	
Swale Member																					
Laver Member				6771				6241			7545				7473						
Uppermost Fulmar Formation																					
top Selkirk Member																					
base Selkirk Member																					
			Kimmeridgian																		
		LJ4 DSB																			
un-named conglomerate																					
Ouse Member																					
	LJ4 MFS / J63																				
Leen Member																					
Ribble Member																					
Trent Member																					
Ula Formation																					
Ryton Member																					
Upper Fulmar Formation																					
top Christian Member																					
base Christian Member																					
		LJ3ii DSB																			
	baylei IFS / J62																				
Lower Fulmar Formation																					
Heather Formation *sensu lato*																					
			early Kimmeridgian																		
			early Kimm. - Lt Oxfordian																		
			Late Oxfordian																		
Puffin Formation																					
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB																			
	LJ3 MFS / J56																				
Puffin Formation																					
top Curlew Member																					
base Curlew Member																					
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB																			
base Puffin Formation																					
	LJ2 MFS / J54																				
Franklin Formation																					
Heather Formation *sensu stricto*																					
			Middle Oxfordian																		
		LJ1 DSB																			
			Early Oxfordian																		
	J52																				
	LJ1 MFS / J46																				
Fladen Group																					
			Middle Jurassic																		
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group								6261			7653				7558				7256		
			Triassic											7653				7558			
Zechstein Group			Late Permian	6810				6293			7750				7573						

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	21/30-3				21/30-4				21/30-5			21/30-6A			21/30-12			
				Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Age	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Age
Kimmeridge Clay Formation				7538				7401				8032			8960			7600			
Mandal Member				7538				7401				8032			8960			7600			
			Late - Early Ryazanian				7550				7400										
	EK1 MFS / K10				7545				7409				8033			8961			7605		
Derwent Member				7750				7433				8037			8963			7610			
			Late Volgian																		
	LJ6 MFS / J74				7576				7465				8057			8970			7670		
			latest Middle Volgian				7578.5				7440										
Wharfe Member				7646				7578				8120						7781			
Nidd Member																					
			Middle Volgian				7640				7560										
		LJ5 DSB				7720				7880				8186						7858	
Aire Member				7720				7880				8186						7858			
			Early Volgian				7700				7920										7994.8
	LJ5 MFS / J66				7781				7970				8238						7930		
Swale Member				7848								8300									
Laver Member								8073										7979			
Uppermost Fulmar Formation																					
top Selkirk Member																					
base Selkirk Member																					
			Kimmeridgian				7970				8120										
		LJ4 DSB				7964								8394							
un-named conglomerate																					
Ouse Member				7964								8394									
	LJ4 MFS / J63				7992								8431								
Leen Member																					
Ribble Member																					
Trent Member				8055								8466			8987						
Ula Formation																					
Ryton Member																					
Upper Fulmar Formation																					
top Christian Member																					
base Christian Member																					
		LJ3ii DSB				8219								8601							
	baylei IFS / J62				8255								8620			9002					
Lower Fulmar Formation																					
Heather Formation *sensu lato*				8262								8625			9010						
			early Kimmeridgian																		
			early Kimm. - Lt Oxfordian				8270														
			Late Oxfordian				8495.25														
Puffin Formation																					
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB				8350								8720			9032				
	LJ3 MFS / J56				8392								8755			9035					
Puffin Formation				8465								8792			9040						
top Curlew Member																					
base Curlew Member																					
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB				8615								8917			9162				
base Puffin Formation																					
	LJ2 MFS / J54				8738								8995			9303					
Franklin Formation																					
Heather Formation *sensu stricto*																					
			Middle Oxfordian																		
		LJ1 DSB																			
			Early Oxfordian																		
	J52																				
	LJ1 MFS / J46																				
Fladen Group																					
			Middle Jurassic																		
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group				8738				8145				8995			9334			8069			
			Triassic				8738				8145										8069
Zechstein Group			Late Permian	9396				8212				9340						8122			

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	22/16a-2Z			22/16b-3			22/16a-4			22/18-6			22/19-1			22/19-2.		
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				13662			14492			13662			10321			11432			13413		
Mandal Member				13662			14492									11432			13413		
			Late - Early Ryazanian																		
	EK1 MFS / K10				13666			14502									11434			13414	
Derwent Member							14509			13662									13415		
			Late Volgian																		
	LJ6 MFS / J74							14553												13435	
			latest Middle Volgian																		
Wharfe Member							14682			13705											
Nidd Member													10321								
			Middle Volgian																		
		LJ5 DSB							14842			13762			10450						
Aire Member							14842			13762			10450								
			Early Volgian																		
	LJ5 MFS / J66							14890			13785			10469							
Swale Member							14964														
Laver Member													10503								
Uppermost Fulmar Formation																					
top Selkirk Member										13864											
base Selkirk Member										14191											
			Kimmeridgian																		
		LJ4 DSB							15052			14191			10702						
un-named conglomerate																					
Ouse Member				13668			15052			14191			10702								
	LJ4 MFS / J63				13675			15081			14205			10744							
Leen Member																					
Ribble Member																					
Trent Member				13767			15216			14258											
Ula Formation																					
Ryton Member																					
Upper Fulmar Formation																					
top Christian Member							15169														
base Christian Member							15180														
		LJ3ii DSB				13956			15395			14333									
	baylei IFS / J62				14130			15428			14382										
Lower Fulmar Formation																					
Heather Formation *sensu lato*				14138			15449			14395											
			early Kimmeridgian																		
			early Kimm. - Lt Oxfordian																		
			Late Oxfordian																		
Puffin Formation																					
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB				14478															
	LJ3 MFS / J56				14640																
Puffin Formation				14738																	
top Curlew Member																					
base Curlew Member																					
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB				14915															
base Puffin Formation				14915																	
	LJ2 MFS / J54				14918																
Franklin Formation																					
Heather Formation *sensu stricto*				14924																	
			Middle Oxfordian																		
		LJ1 DSB				14975															
			Early Oxfordian																		
	J52																				
	LJ1 MFS / J46				14990																
Fladen Group				15000																	
			Middle Jurassic																		
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group				15248									10745			11436			13441		
			Triassic																		
Zechstein Group			Late Permian										10996								

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	22/19a-3			22/19b-5				22/20-1			22/21-2			22/21-4			
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				13510			13337				15621			11693			12683			
Mandal Member				13510							15621			11693			12683			
			Late - Early Ryazanian																	12693.5
	EK1 MFS / K10				13520							15624			11700			12685		
Derwent Member				13521							15625			11717						
			Late Volgian																	
	LJ6 MFS / J74				13550							15653			11725			12694		
			latest Middle Volgian																	
Wharfe Member				13589							15707			11762						
Nidd Member																				
			Middle Volgian																	
		LJ5 DSB											15835			11844				
Aire Member				13636			13337				15835			11844			12693			
			Early Volgian							13337										12700
	LJ5 MFS / J66				13641			13350				15858			11883			12695		
Swale Member											15859			12003			12717			
Laver Member																				
Uppermost Fulmar Formation																				
top Selkirk Member																				
base Selkirk Member																				
			Kimmeridgian																	12760
		LJ4 DSB											15878			12062			12743	
un-named conglomerate																				
Ouse Member											15878			12062			12743			
	LJ4 MFS / J63											15882			12110			12750		
Leen Member																				
Ribble Member																				
Trent Member											15891			12174			12774			
Ula Formation																				
Ryton Member																				
Upper Fulmar Formation																				
top Christian Member																				
base Christian Member																				
		LJ3ii DSB											15997			12787			12918	
	baylei IFS / J62											16009			13005			12948		
Lower Fulmar Formation																				
Heather Formation *sensu lato*							13352				16019			13037			12967			
			early Kimmeridgian																	12970
			early Kimm. - Lt Oxfordian							13370										
			Late Oxfordian							13435.4										13060
Puffin Formation																				
base Puffin Formation																				
top Shearwater Member																				
base Shearwater Member																				
		LJ3i DSB							13372				16052			14124			13166	
	LJ3 MFS / J56							13378				16087			14324			13260		
Puffin Formation							13409													
top Curlew Member																				
base Curlew Member																				
top Freshney Member														14700			13532			
base Freshney Member														14719 TD			13556			
		LJ2 DSB							13438										13556	
base Puffin Formation																				
	LJ2 MFS / J54																	13860		
Franklin Formation																				
Heather Formation *sensu stricto*																	13862			
			Middle Oxfordian																	13880
		LJ1 DSB																	13958	
			Early Oxfordian																	14000
	J52																	13989		
	LJ1 MFS / J46																	14039		
Fladen Group							13438				16144						14039			
			Middle Jurassic							13439.5										14039
Ron Volcanic Member																				
Indeterminate																				
Lias Group																				
			Early Jurassic																	
Heron Group				13646			13800				16753						14486			
			Triassic							13840										14486
Zechstein Group			Late Permian	13708																

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	22/21-7				22/21-8			22/22b-2 ST2			22/22b-4			22/23b-4RE				22/23b-5		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				13423				13161			13320			13639			11555				14439		
Mandal Member											13320			13639			11555				14439		
			Late - Early Ryazanian																	11570			
	EK1 MFS / K10											13323			13642			11561				14440	
Derwent Member											13326			13646			11562				14442		
			Late Volgian																	11590			
	LJ6 MFS / J74											13357			13670			11589				14450	
			latest Middle Volgian																	11650			
Wharfe Member											13366			13685							14460		
Nidd Member																	11659						
			Middle Volgian																				
		LJ5 DSB											13425			13888							14485
Aire Member								13161			13425			13888							14485		
			Early Volgian																				
	LJ5 MFS / J66								13181			13490			14008							14486	
Swale Member								13239			13488												
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member											13676			14229							14500		
base Selkirk Member											13740			14949							14640		
			Kimmeridgian				13460																
		LJ4 DSB								13460			13822			14949							14640
un-named conglomerate																							
Ouse Member				13423				13460			13822			14996							14640		
	LJ4 MFS / J63								13503			14112			15158							14665	
Leen Member																							
Ribble Member																							
Trent Member				13445				13550			14186										14694		
Ula Formation																							
Ryton Member																							
Upper Fulmar Formation																							
top Christian Member																							
base Christian Member																							
		LJ3ii DSB				13541				13584			14314										14855
	baylei IFS / J62				13598				13590			14360										14858	
Lower Fulmar Formation																							
Heather Formation *sensu lato*				13604				13599			14362												
			early Kimmeridgian																				
			early Kimm. - Lt Oxfordian				13520																
			Late Oxfordian				13950																
Puffin Formation																					14863		
base Puffin Formation																							
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB				14200				13723			14608										14955
	LJ3 MFS / J56				14229				13740			14760										14962	
Puffin Formation																							
top Curlew Member																							
base Curlew Member																							
top Freshney Member				14543							14968										15182		
base Freshney Member				15808							15472										15905		
		LJ2 DSB				15808				13770			15472										15905
base Puffin Formation																							
	LJ2 MFS / J54				15914				13795			15853										15905	
Franklin Formation																					15905		
Heather Formation *sensu stricto*				15915				13798			15870												
			Middle Oxfordian				15950																
		LJ1 DSB											16280										16134
			Early Oxfordian																				
	J52				15991				13857			16177										16036	
	LJ1 MFS / J46											16335										16152	
Fladen Group				15991							16335												
			Middle Jurassic				15991																
Ron Volcanic Member																							
Indeterminate																							
Lias Group																							
			Early Jurassic																				
Heron Group																	11682				16152		
			Triassic																	11682			
Zechstein Group			Late Permian																		17107		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	22/23b-6				22/24b-4ST				22/24b-8				22/24d-10			22/25a-1			
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				14103				14150				12943				14002			15046			
Mandal Member																						
			Late - Early Ryazanian																			15046
	EK1 MFS / K10																					
Derwent Member																						
			Late Volgian																			
	LJ6 MFS / J74																					
			latest Middle Volgian																			
Wharfe Member																						
Nidd Member																						
			Middle Volgian																			15046
		LJ5 DSB																				
Aire Member				14103																		
			Early Volgian																			15144
	LJ5 MFS / J66				14118																	
Swale Member																						
Laver Member																						
Uppermost Fulmar Formation																						
top Selkirk Member				14129																		
base Selkirk Member				14187																		
			Kimmeridgian				14375.5				14150				12940							
		LJ4 DSB				14187																
un-named conglomerate																						
Ouse Member				14187				14150				12943				14002						
	LJ4 MFS / J63				14256				14163				12949				14006					
Leen Member																						
Ribble Member																						
Trent Member								14163														
Ula Formation																						
Ryton Member																						
Upper Fulmar Formation																						
top Christian Member				14361																		
base Christian Member				14507																		
		LJ3ii DSB				14507				14323												
	baylei IFS / J62				14571				14355													
Lower Fulmar Formation																						
Heather Formation *sensu lato*								14360				12950				14014			15194			
			early Kimmeridgian								14390											15193
			early Kimm. - Lt Oxfordian																			
			Late Oxfordian				14857				14430				12942							15371
Puffin Formation				14591																		
base Puffin Formation																						
top Shearwater Member																						
base Shearwater Member																						
		LJ3i DSB				14671				14458				13970				14076				
	LJ3 MFS / J56				14701				14607				12972				14110					
Puffin Formation								14728				12979							?15545			
top Curlew Member																						
base Curlew Member																						
top Freshney Member				14833																		
base Freshney Member				14891																		
		LJ2 DSB				14891				14853				13020								
base Puffin Formation								14853				13020										
	LJ2 MFS / J54				15329				14898				13046									
Franklin Formation				15361				14927														
Heather Formation *sensu stricto*								14910														
			Middle Oxfordian								15000											
		LJ1 DSB								14943												
			Early Oxfordian																			
	J52				15671																	
	LJ1 MFS / J46																					
Fladen Group								14975				13046				14120			15925			
			Middle Jurassic								14975				13046							15925
Ron Volcanic Member																						
Indeterminate																						
Lias Group																						
			Early Jurassic																			
Heron Group								15276				13256				14189						
			Triassic								15276				13256							
Zechstein Group			Late Permian					16811														

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	22/25b-2			22/25b-4 S1			22/27a-1			22/27a-2				22/28a-1			
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				13940			14809						15009				15650			
Mandal Member																	15650			
			Late - Early Ryazanian																	15651
	EK1 MFS / K10																	15654		
Derwent Member																				
			Late Volgian																	
	LJ6 MFS / J74																			
			latest Middle Volgian																	
Wharfe Member																				
Nidd Member																				
			Middle Volgian																	
		LJ5 DSB																		
Aire Member							14809						15009				15665			
			Early Volgian													15040				15666
	LJ5 MFS / J66							14838						15023				15677		
Swale Member							14850						15052				15691			
Laver Member																				
Uppermost Fulmar Formation																				
top Selkirk Member																				
base Selkirk Member																				
			Kimmeridgian													15080				15760
		LJ4 DSB							14883						15106				15749	
un-named conglomerate																				
Ouse Member							14883						15106				15749			
	LJ4 MFS / J63							14898						15133				15752		
Leen Member																				
Ribble Member																				
Trent Member							14900						15163				15766			
Ula Formation																				
Ryton Member																				
Upper Fulmar Formation																				
top Christian Member																				
base Christian Member																				
		LJ3ii DSB							15153						15327				15990	
	baylei IFS / J62							15303						15362				16015		
Lower Fulmar Formation																				
Heather Formation *sensu lato*				13972			15310			14265			15383				16019			
			early Kimmeridgian													15400				
			early Kimm. - Lt Oxfordian																	16030
			Late Oxfordian													15520				16200
Puffin Formation																				
base Puffin Formation																				
top Shearwater Member																				
base Shearwater Member																				
		LJ3i DSB				14000			15470			14314			15667				16184	
	LJ3 MFS / J56				14028			15545			14521			15684				16241		
Puffin Formation													16222				16359			
top Curlew Member																				
base Curlew Member																				
top Freshney Member										14747										
base Freshney Member										16078										
		LJ2 DSB							15650			16078			16311				16417	
base Puffin Formation																				
	LJ2 MFS / J54				14049			15666			16190			16387				16522		
Franklin Formation							15680						16390							
Heather Formation *sensu stricto*				14050			15688			16190										
			Middle Oxfordian													16400				
		LJ1 DSB				14105			15698						16669					
			Early Oxfordian																	
	J52													16605						
	LJ1 MFS / J46				14108						16432			16710						
Fladen Group							15730			16432			16710							
			Middle Jurassic													16710				
Ron Volcanic Member																				
Indeterminate																				
Lias Group																				
			Early Jurassic																	
Heron Group				14112			16022						16843							
			Triassic													16843				
Zechstein Group			Late Permian														16522			

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	22/28b-2RE				22/28a-4				22/29-1ST				22/29-3				22/29-6S2			
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				16441				14278				14540				13555				15466			
Mandal Member																							
			Late - Early Ryazanian																				
	EK1 MFS / K10																						
Derwent Member																							
			Late Volgian																				
	LJ6 MFS / J74																						
			latest Middle Volgian																				
Wharfe Member																							
Nidd Member																							
			Middle Volgian																				
		LJ5 DSB																					
Aire Member								14278								13555				15466			
			Early Volgian								14362.8												15470
	LJ5 MFS / J66								14283								13561				15477		
Swale Member																							
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member								14306								13563							
base Selkirk Member								14348								13600							
			Kimmeridgian				16444								14540				13560				
		LJ4 DSB								14348								13600					
un-named conglomerate																							
Ouse Member				16441				14348				14540											
	LJ4 MFS / J63				16449				14385				14545				13600						
Leen Member																							
Ribble Member																							
Trent Member				16454				14482				14550											
Ula Formation																							
Ryton Member																							
Upper Fulmar Formation																							
top Christian Member																							
base Christian Member																							
		LJ3ii DSB				16504				14577				14619									
	baylei IFS / J62				16549				14592				14630										
Lower Fulmar Formation																							
Heather Formation *sensu lato*				16550								14640				13600				15501			
			early Kimmeridgian				16562								14630								
			early Kimm. - Lt Oxfordian								14795.5												
			Late Oxfordian				16621								14690				13601				15510
Puffin Formation								14638															
base Puffin Formation																							
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB				16709				14720				14739								15563	
	LJ3 MFS / J56				16825				14728				14759								15576		
Puffin Formation				16950								14862								15641			
top Curlew Member																							
base Curlew Member																							
top Freshney Member								14902															
base Freshney Member								14970															
		LJ2 DSB				16983				14970				14907								15709	
base Puffin Formation												14907								15795			
	LJ2 MFS / J54				17103				15185				14984				13623				15805		
Franklin Formation								15190								13624							
Heather Formation *sensu stricto*												14985								15806			
			Middle Oxfordian								15190				15030				13624				15800
		LJ1 DSB								15791													
			Early Oxfordian																				
	J52								15614								13642						
	LJ1 MFS / J46								15922														
Fladen Group				17103								15053				13642				15836			
			Middle Jurassic				17103								15053				13639				15836
Ron Volcanic Member																							
Indeterminate																							
Lias Group																							
			Early Jurassic																				
Heron Group				17634				15922				15415				13703				16342			
			Triassic				17634				15922				15415				13703				16342
Zechstein Group			Late Permian																				

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	22/30a-1				22/30a-2				22/30b-4 RE		22/30a-6				22/30c-8			22/30b-11		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				14847										14888				16814			15830		
Mandal Member																							
			Late - Early Ryazanian																				
	EK1 MFS / K10																						
Derwent Member																							
			Late Volgian																				
	LJ6 MFS / J74																						
			latest Middle Volgian																				
Wharfe Member																							
Nidd Member																							
			Middle Volgian																				
		LJ5 DSB																					
Aire Member																							
			Early Volgian																				
	LJ5 MFS / J66																						
Swale Member																							
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member																							
base Selkirk Member																							
			Kimmeridgian				14840																	
		LJ4 DSB																					
un-named conglomerate																							
Ouse Member														14888				16804			15830		
	LJ4 MFS / J63														14889				16825			15839	
Leen Member																							
Ribble Member																							
Trent Member				14847														16847			15840		
Ula Formation																							
Ryton Member																							
Upper Fulmar Formation																							
top Christian Member																							
base Christian Member																							
		LJ3ii DSB																		17079			15851
	baylei IFS / J62				14872														17084			15861	
Lower Fulmar Formation																							
Heather Formation *sensu lato*				14876				14280				15451		14891				17090			15864		
			early Kimmeridgian				14900										14900						
			early Kimm. - Lt Oxfordian																				
			Late Oxfordian				14920				14280						14940						
Puffin Formation																							
base Puffin Formation																							
top Shearwater Member																					15970		
base Shearwater Member																					16011		
		LJ3i DSB				14980										15033				17167			16150
	LJ3 MFS / J56				15000				14324						15065				17242			16235	
Puffin Formation				15150								15457						17405			16440		
top Curlew Member																							
base Curlew Member																							
top Freshney Member																							
base Freshney Member																							
		LJ2 DSB				15363														17950			16720
base Puffin Formation				15474																	17113		
	LJ2 MFS / J54				15509														18290			17160	
Franklin Formation																		18297			17170		
Heather Formation *sensu stricto*												16160									17204		
			Middle Oxfordian																				
		LJ1 DSB																		18530			17280
			Early Oxfordian																				
	J52																						
	LJ1 MFS / J46																						
Fladen Group				15520				14327				16280		15076				18530			17310		
			Middle Jurassic				15520				14327						15076						
Ron Volcanic Member																							
Indeterminate																							
Lias Group																							
			Early Jurassic																				
Heron Group								14530						15446									
			Triassic								14530						15446						
Zechstein Group			Late Permian																				

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	22/30b-15Z				22/30a-16				23/16b-1ST1				23/16a-2			23/16d-7		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation												13094				12758			13247		
Mandal Member												13094				12758					
			Late - Early Ryazanian												13100						
	EK1 MFS / K10												13099				12775				
Derwent Member												13103				12780			13247		
			Late Volgian												13130						
	LJ6 MFS / J74												13169				12810			13291	
			latest Middle Volgian												13220						
Wharfe Member												13255				12825			13306		
Nidd Member																					
			Middle Volgian												13310						
		LJ5 DSB																12960			13480
Aire Member								17000								12960			13480		
			Early Volgian																		
	LJ5 MFS / J66								17019								13011			13522	
Swale Member								17023													
Laver Member																					
Uppermost Fulmar Formation																					
top Selkirk Member																					
base Selkirk Member																					
			Kimmeridgian								17020										
		LJ4 DSB								17052											13882
un-named conglomerate																					
Ouse Member								17052													
	LJ4 MFS / J63								17067											13907	
Leen Member																					
Ribble Member																					
Trent Member								17099													
Ula Formation																			13581		
Ryton Member																					
Upper Fulmar Formation																					
top Christian Member																					
base Christian Member																					
		LJ3ii DSB								17256											
	baylei IFS / J62				18091				17272												
Lower Fulmar Formation																					
Heather Formation *sensu lato*				18089				17285													
			early Kimmeridgian				18120				17260										
			early Kimm. - Lt Oxfordian																		
			Late Oxfordian				18240				17350										
Puffin Formation																					
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB				18294				17561											
	LJ3 MFS / J56				18321				17724												
Puffin Formation				18506				17818													
top Curlew Member																					
base Curlew Member																					
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB				18697				17889											
base Puffin Formation				19140				18008													
	LJ2 MFS / J54				19165				18047												
Franklin Formation				19172																	
Heather Formation *sensu stricto*				19246				18049													
			Middle Oxfordian				19180				18010										
		LJ1 DSB																			
			Early Oxfordian																		
	J52																				
	LJ1 MFS / J46																				
Fladen Group				19321				18089													
			Middle Jurassic				19321				18089										
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group												13348				13015					
			Triassic												13348						
Zechstein Group			Late Permian									13568									

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	23/21-2				23/22-1A		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				11248				13534		
Mandal Member				11248				13534		
			Late - Early Ryazanian				11270			
	EK1 MFS / K10				11256				13546	
Derwent Member								13550		
			Late Volgian				11270			
	LJ6 MFS / J74				11294				13574	
			latest Middle Volgian							
Wharfe Member				11262				13580		
Nidd Member										
			Middle Volgian				11300			
		LJ5 DSB				11290				13695
Aire Member				11290				13695		
			Early Volgian				11330			
	LJ5 MFS / J66				11338				13724	
Swale Member				11307						
Laver Member										
Uppermost Fulmar Formation										
top Selkirk Member										
base Selkirk Member										
			Kimmeridgian							
		LJ4 DSB				11320				
un-named conglomerate										
Ouse Member				11320						
	LJ4 MFS / J63									
Leen Member										
Ribble Member										
Trent Member				11351						
Ula Formation				11380				13726		
Ryton Member										
Upper Fulmar Formation										
top Christian Member										
base Christian Member										
		LJ3ii DSB				11484				13780
	baylei IFS / J62									
Lower Fulmar Formation										
Heather Formation *sensu lato*										
			early Kimmeridgian							
			early Kimm. - Lt Oxfordian							
			Late Oxfordian							
Puffin Formation										
base Puffin Formation										
top Shearwater Member										
base Shearwater Member										
		LJ3i DSB								
	LJ3 MFS / J56									
Puffin Formation										
top Curlew Member										
base Curlew Member										
top Freshney Member										
base Freshney Member										
		LJ2 DSB								
base Puffin Formation										
	LJ2 MFS / J54									
Franklin Formation										
Heather Formation *sensu stricto*										
			Middle Oxfordian							
		LJ1 DSB								
			Early Oxfordian							
	J52									
	LJ1 MFS / J46									
Fladen Group				11484						
			Middle Jurassic				11484			
Ron Volcanic Member										
Indeterminate										
Lias Group										
			Early Jurassic							
Heron Group								13780		
			Triassic							
Zechstein Group			Late Permian							

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	23/26a-2Z				23/26a-3				23/26b-4			23/26a-7				23/26b-8		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				16051																	
Mandal Member																					
			Late - Early Ryazanian																		
	EK1 MFS / K10																				
Derwent Member																					
			Late Volgian																		
	LJ6 MFS / J74																				
			latest Middle Volgian																		
Wharfe Member																					
Nidd Member																					
			Middle Volgian																		
		LJ5 DSB																			
Aire Member				16051																	
			Early Volgian				16109														
	LJ5 MFS / J66				16092																
Swale Member				16132																	
Laver Member																					
Uppermost Fulmar Formation																					
top Selkirk Member																					
base Selkirk Member																					
			Kimmeridgian				16207														
		LJ4 DSB				16219															
un-named conglomerate																					
Ouse Member				16219																	
	LJ4 MFS / J63				16256																
Leen Member																					
Ribble Member																					
Trent Member				16442																	
Ula Formation																					
Ryton Member																					
Upper Fulmar Formation																					
top Christian Member																					
base Christian Member																					
		LJ3ii DSB				16588															
	baylei IFS / J62				16772																
Lower Fulmar Formation																					
Heather Formation *sensu lato*								15230				14878			15141				14892		
			early Kimmeridgian								15256										
			early Kimm. - Lt Oxfordian																		
			Late Oxfordian								15322							15174			
Puffin Formation																					
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB								15296				14944			15172				14919
	LJ3 MFS / J56								15297				14953			15279				15000	
Puffin Formation								15367				15050			15440				15091		
top Curlew Member																					
base Curlew Member																					
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB															15561				15142
base Puffin Formation								15669				15128			15738				15360		
	LJ2 MFS / J54								15732							15804				15444	
Franklin Formation																					
Heather Formation *sensu stricto*								15735							15805				15444		
			Middle Oxfordian								15735							15804			
		LJ1 DSB																			
			Early Oxfordian															15833			
	J52																				
	LJ1 MFS / J46															15853				15481	
Fladen Group				16778				15792							15853				15481		
			Middle Jurassic				16778				15792							15853			
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group																					
			Triassic																		
Zechstein Group			Late Permian																		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	23/26b-14			23/26b-15			23/26a-21			23/27-3			23/27-4			23/27-6			
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation							15342						12152			10183			12096			
Mandal Member													12152			10183						
			Late - Early Ryazanian																			
	EK1 MFS / K10													12159			10190					
Derwent Member													12158			10199						
			Late Volgian																			
	LJ6 MFS / J74													12180			10236					
			latest Middle Volgian																			
Wharfe Member													12200			10300			12096			
Nidd Member																						
			Middle Volgian																			12120
		LJ5 DSB													12458			10640			12311	
Aire Member													12458			10640			12311			
			Early Volgian																			12340
	LJ5 MFS / J66													12512			10694			12339		
Swale Member													12618			10764			12394			
Laver Member																						
Uppermost Fulmar Formation																						
top Selkirk Member																						
base Selkirk Member																						
			Kimmeridgian																			12670
		LJ4 DSB													12795			10862			12505	
un-named conglomerate																						
Ouse Member													12795			10862			12505			
	LJ4 MFS / J63													12948			10942			12556		
Leen Member																						
Ribble Member																						
Trent Member																10970						
Ula Formation													12980			11020			12584			
Ryton Member																						
Upper Fulmar Formation																						
top Christian Member																						
base Christian Member																						
		LJ3ii DSB													13535			11891				
	baylei IFS / J62							15342														
Lower Fulmar Formation																						
Heather Formation *sensu lato*				14805			15360			15740												
			early Kimmeridgian																			
			early Kimm. - Lt Oxfordian																			
			Late Oxfordian																			
Puffin Formation																						
base Puffin Formation																						
top Shearwater Member				14830			15409			15970												
base Shearwater Member				14841			15570			16059												
		LJ3i DSB				14901			15660			16059										
	LJ3 MFS / J56				15065			15863			16067											
Puffin Formation				15162			16032			16144												
top Curlew Member																						
base Curlew Member																						
top Freshney Member																						
base Freshney Member																						
		LJ2 DSB				15259			16112			16242										
base Puffin Formation				15450			16342			16456												
	LJ2 MFS / J54				15490			16390			16593											
Franklin Formation																						
Heather Formation *sensu stricto*				15510			16402			16610												
			Middle Oxfordian																			
		LJ1 DSB																				
			Early Oxfordian																			
	J52																					
	LJ1 MFS / J46																					
Fladen Group				15550			16423			16677						11891						
			Middle Jurassic																			
Ron Volcanic Member																						
Indeterminate																						
Lias Group																						
			Early Jurassic																			
Heron Group													13535			11990						
			Triassic																			
Zechstein Group			Late Permian																			

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	28/4b-1A			28/5-1			28/5a-2				28/10-1.				29/1b-1			
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				5935			6422			7726				7056				12360			
Mandal Member				5935			6422			7726				7056				12360			
			Late - Early Ryazanian										7740				7058				12370
	EK1 MFS / K10				5945			6437			7740				7058				12368		
Derwent Member				5954			6449			7750				7075				12370			
			Late Volgian										7770				7108				12380
	LJ6 MFS / J74				5963			6459			7800				7096				12398		
			latest Middle Volgian										7890								12398
Wharfe Member				5970			6459			8015				7118				12415			
Nidd Member																					
			Middle Volgian										8074				7120				12414
		LJ5 DSB				6152			6680			8220				7142					
Aire Member				6152			6680			8220				7142							
			Early Volgian										8190				7144				
	LJ5 MFS / J66				6156			6698			8232				7145						
Swale Member																					
Laver Member							6744			8275				7146							
Uppermost Fulmar Formation																					
top Selkirk Member																					
base Selkirk Member																					
			Kimmeridgian										8360.6								
		LJ4 DSB																			
un-named conglomerate																					
Ouse Member																					
	LJ4 MFS / J63																				
Leen Member																					
Ribble Member																					
Trent Member																					
Ula Formation																					
Ryton Member																					
Upper Fulmar Formation																					
top Christian Member																					
base Christian Member																					
		LJ3ii DSB																			
	baylei IFS / J62																				
Lower Fulmar Formation																					
Heather Formation *sensu lato*																					
			early Kimmeridgian																		
			early Kimm. - Lt Oxfordian																		
			Late Oxfordian																		
Puffin Formation																					
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB																			
	LJ3 MFS / J56																				
Puffin Formation																					
top Curlew Member																					
base Curlew Member																					
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB																			
base Puffin Formation																					
	LJ2 MFS / J54																				
Franklin Formation																					
Heather Formation *sensu stricto*																					
			Middle Oxfordian																		
		LJ1 DSB																			
			Early Oxfordian																		
	J52																				
	LJ1 MFS / J46																				
Fladen Group																					
			Middle Jurassic																		
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group							6840							7205				12462			
			Triassic														7205				12462
Zechstein Group			Late Permian	6190						8376				7256			7256				

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/1b-1Z				29/1c-4			29/1a-7				29/2-1ST			29/2a-2		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				13125				14072			9053				13560			11815		
Mandal Member				13125				14072			9053				13560			11815		
			Late - Early Ryazanian				13130							9060						
	EK1 MFS / K10				13148				14100			9056				13566			11818	
Derwent Member				13160				14102			9058				13600					
			Late Volgian				13170													
	LJ6 MFS / J74								14149			9085				13660				
			latest Middle Volgian																	
Wharfe Member								14269			9170				13735					
Nidd Member																				
			Middle Volgian																	
		LJ5 DSB				13250				14670			9235				13870			
Aire Member				13250				14670			9235				13870					
			Early Volgian				13250							9180						
	LJ5 MFS / J66								14795			9320				13937				
Swale Member								14825							14038			11830		
Laver Member											9332									
Uppermost Fulmar Formation																				
top Selkirk Member																				
base Selkirk Member																				
			Kimmeridgian				13270							9425						
		LJ4 DSB								14919			9489				14110			11840
un-named conglomerate																				
Ouse Member								14919			9489				14110			11840		
	LJ4 MFS / J63								14970			9521				14124			11860	
Leen Member																				
Ribble Member																				
Trent Member								15000							14156			11925		
Ula Formation																				
Ryton Member											9544									
Upper Fulmar Formation																				
top Christian Member																				
base Christian Member																				
		LJ3ii DSB								15328			9761				14527			12040
	baylei IFS / J62								15373			9780				14599			12084	
Lower Fulmar Formation																				
Heather Formation *sensu lato*				13513				15395							14619			12085		
			early Kimmeridgian																	
			early Kimm. - Lt Oxfordian				13560													
			Late Oxfordian				13680													
Puffin Formation																				
base Puffin Formation																				
top Shearwater Member																				
base Shearwater Member																				
		LJ3i DSB																		12289
	LJ3 MFS / J56				13684														12361	
Puffin Formation				13650														12649		
top Curlew Member																		12649		
base Curlew Member																		12843		
top Freshney Member																				
base Freshney Member																				
		LJ2 DSB				13714														12971
base Puffin Formation																		13170		
	LJ2 MFS / J54																		13170	
Franklin Formation																				
Heather Formation *sensu stricto*																				
			Middle Oxfordian																	
		LJ1 DSB																		
			Early Oxfordian																	
	J52																			
	LJ1 MFS / J46																			
Fladen Group																		13170		
			Middle Jurassic																	
Ron Volcanic Member																				
Indeterminate																				
Lias Group																				
			Early Jurassic																	
Heron Group				13759							9789							13471		
			Triassic				13759							9789						
Zechstein Group			Late Permian																	

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/2a-3				29/2b-5			29/2c-9			29/3-1.				29/3b-4			
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				11840				14535			12261			12660				14708			
Mandal Member				11840				14535			12261			12660				14708			
			Late - Early Ryazanian														12670				14730
	EK1 MFS / K10				11840										12665				14710		
Derwent Member											12264							14712			
			Late Volgian																		14730
	LJ6 MFS / J74											12274							14744		
			latest Middle Volgian																		
Wharfe Member											12290			12670				14795			
Nidd Member																					
			Middle Volgian														12680				14820
		LJ5 DSB											12327			12693				14844	
Aire Member								14545			12327			12693				14844			
			Early Volgian														12720				14844
	LJ5 MFS / J66								14559			12380			12769				14851		
Swale Member								14560			12417							14852			
Laver Member																					
Uppermost Fulmar Formation																					
top Selkirk Member																					
base Selkirk Member																					
			Kimmeridgian				11900										12910				
		LJ4 DSB								14583			12447							14862	
un-named conglomerate																					
Ouse Member				11850				14583			12447							14862			
	LJ4 MFS / J63				11861				14591			12471							14865		
Leen Member																					
Ribble Member																					
Trent Member				11873				14668			12490										
Ula Formation																					
Ryton Member																					
Upper Fulmar Formation																					
top Christian Member																					
base Christian Member																					
		LJ3ii DSB				12031				14729			12731								
	baylei IFS / J62				12045				14761			12882									
Lower Fulmar Formation																					
Heather Formation *sensu lato*				12046				14769			12883							14874			
			early Kimmeridgian																		
			early Kimm. - Lt Oxfordian				12080										13140				
			Late Oxfordian				12800														14869
Puffin Formation																					
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB				12380				15155			13376							14901	
	LJ3 MFS / J56				12610				15252			13743							14911		
Puffin Formation				12870				15680			14335			13095				14936			
top Curlew Member				13120																	
base Curlew Member				13230																	
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB				13230				15918			14612							14955	
base Puffin Formation				13343										13394							
	LJ2 MFS / J54				13343				16036			14893									
Franklin Formation																					
Heather Formation *sensu stricto*																					
			Middle Oxfordian																		
		LJ1 DSB																			
			Early Oxfordian																		
	J52																				
	LJ1 MFS / J46																				
Fladen Group				13343				16036			14893										
			Middle Jurassic				13343														
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group				13795														14955			
			Triassic				13795														14955
Zechstein Group			Late Permian																		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/3a-5				29/4a-1A			29/4a-2				29/4b-3 ST			29/4d-4		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				14180				14362			14012				18720			17831		
Mandal Member				14180				14362							18720					
			Late - Early Ryazanian				14210													
	EK1 MFS / K10				14190				14363							18727				
Derwent Member				14190				14369							18728					
			Late Volgian				14210													
	LJ6 MFS / J74				14200				14379							18736				
			latest Middle Volgian																	
Wharfe Member				14230				14387							18740					
Nidd Member																				
			Middle Volgian				14230													
		LJ5 DSB				14280				14450							18763			
Aire Member				14280				14450							18763			17831		
			Early Volgian				14270													
	LJ5 MFS / J66				14329				14456							18805			17841	
Swale Member				14341				14492							18820			17858		
Laver Member																				
Uppermost Fulmar Formation																				
top Selkirk Member																				
base Selkirk Member																				
			Kimmeridgian				14390							14020						
		LJ4 DSB				14359				14518							18843			17880
un-named conglomerate																				
Ouse Member				14359				14518			14012				18843			17880		
	LJ4 MFS / J63				14360				14520			14015				18863			17888	
Leen Member																				
Ribble Member																				
Trent Member				14430				14543			14015				18893			17949		
Ula Formation																				
Ryton Member																				
Upper Fulmar Formation																				
top Christian Member																				
base Christian Member																				
		LJ3ii DSB				14480				14640			14066				18937			17981
	baylei IFS / J62				14490				14689			14070				18950			17982	
Lower Fulmar Formation																				
Heather Formation *sensu lato*				14495				14690			14075							17989		
			early Kimmeridgian											14080						
			early Kimm. - Lt Oxfordian				14540													
			Late Oxfordian				14630							14100						
Puffin Formation																				
base Puffin Formation																				
top Shearwater Member																				
base Shearwater Member																				
		LJ3i DSB				14652				14742			14127							18229
	LJ3 MFS / J56				14750				14802			14164							18249	
Puffin Formation				15013				14895			14225							18350		
top Curlew Member				15160																
base Curlew Member				15305																
top Freshney Member																				
base Freshney Member																				
		LJ2 DSB				15305				15110			14300							19112
base Puffin Formation				15324																
	LJ2 MFS / J54				15324				15202			14528							19344	
Franklin Formation																		19357		
Heather Formation *sensu stricto*																				
			Middle Oxfordian																	
		LJ1 DSB																		19740
			Early Oxfordian																	
	J52																			
	LJ1 MFS / J46																		19747	
Fladen Group				15324				15212			14543				18953			19757		
			Middle Jurassic				15324							14543						
Ron Volcanic Member																				
Indeterminate																				
Lias Group																				
			Early Jurassic																	
Heron Group				15350							15229									
			Triassic				15350							15229						
Zechstein Group			Late Permian																	

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/5a-1ST				29/5b-4				29/5a-5				29/5b-6, 6Z			29/5b-8		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				14250				16360				14330				16767			16690		
Mandal Member																					
			Late - Early Ryazanian																		
	EK1 MFS / K10																				
Derwent Member																					
			Late Volgian																		
	LJ6 MFS / J74																				
			latest Middle Volgian																		
Wharfe Member																					
Nidd Member																					
			Middle Volgian																		
		LJ5 DSB																			
Aire Member				14250																	
			Early Volgian				14320														
	LJ5 MFS / J66				14265																
Swale Member				14282																	
Laver Member																					
Uppermost Fulmar Formation																					
top Selkirk Member																					
base Selkirk Member																					
			Kimmeridgian				14350				16380				14330						
		LJ4 DSB				14305															
un-named conglomerate																					
Ouse Member				14305												16767			16690		
	LJ4 MFS / J63				14317												16768			16691	
Leen Member																					
Ribble Member																					
Trent Member				14341				16360				14330				16772			16696		
Ula Formation																					
Ryton Member																					
Upper Fulmar Formation																					
top Christian Member																					
base Christian Member																					
		LJ3ii DSB				14368												16798			16873
	baylei IFS / J62				14370				16383								16801			16873	
Lower Fulmar Formation																					
Heather Formation *sensu lato*				14371				16402								16804			16930		
			early Kimmeridgian								16460										
			early Kimm. - Lt Oxfordian				14430														
			Late Oxfordian								16540				14419.6						
Puffin Formation																					
base Puffin Formation																					
top Shearwater Member																					
base Shearwater Member																					
		LJ3i DSB								16534								16903			17330
	LJ3 MFS / J56								16699								16929			17380	
Puffin Formation				14376				17078				14361				17182			17850		
top Curlew Member																					
base Curlew Member																					
top Freshney Member																					
base Freshney Member																					
		LJ2 DSB				14509				17788				14426				17743			18680
base Puffin Formation								17930													
	LJ2 MFS / J54																17913			18940	
Franklin Formation																17933			18955		
Heather Formation *sensu stricto*																					
			Middle Oxfordian																		
		LJ1 DSB																18097			19202
			Early Oxfordian																		
	J52																				
	LJ1 MFS / J46																				
Fladen Group				14692								14480				18097			19202		
			Middle Jurassic				14692														
Ron Volcanic Member																					
Indeterminate																					
Lias Group																					
			Early Jurassic																		
Heron Group				15124								15043									
			Triassic				15124								15043						
Zechstein Group			Late Permian	15354								15110									

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/6a-1			29/6b-2			29/6a-3			29/6a-6			29/7-1.		
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				10982			7333			10870			7270			10790		
Mandal Member				10982			7333			10870			7270			10790		
			Late - Early Ryazanian															
	EK1 MFS / K10				10990			7334			10879			7271			10809	
Derwent Member				11000			7338						7274			10814		
			Late Volgian															
	LJ6 MFS / J74				11028			7348						7290			10830	
			latest Middle Volgian															
Wharfe Member							7358			10880			7313			10848		
Nidd Member																		
			Middle Volgian															
		LJ5 DSB							7374			10880			7358			10930
Aire Member							7374			10891						10930		
			Early Volgian															
	LJ5 MFS / J66							7387			10905			7358			11064	
Swale Member							7398			10910						11115		
Laver Member													7359					
Uppermost Fulmar Formation																		
top Selkirk Member																		
base Selkirk Member																		
			Kimmeridgian															
		LJ4 DSB							7409			10983						11166
un-named conglomerate																		
Ouse Member							7409			10983						11166		
	LJ4 MFS / J63							7416			11015						11268	
Leen Member																		
Ribble Member																		
Trent Member																11283		
Ula Formation																		
Ryton Member							7446			11058								
Upper Fulmar Formation																		
top Christian Member																		
base Christian Member																		
		LJ3ii DSB							7605			11109						11380
	baylei IFS / J62																11410	
Lower Fulmar Formation																		
Heather Formation *sensu lato*																11418		
			early Kimmeridgian															
			early Kimm. - Lt Oxfordian															
			Late Oxfordian															
Puffin Formation																		
base Puffin Formation																		
top Shearwater Member																		
base Shearwater Member																		
		LJ3i DSB																11610
	LJ3 MFS / J56																11677	
Puffin Formation																		
top Curlew Member																		
base Curlew Member																		
top Freshney Member																		
base Freshney Member																		
		LJ2 DSB																
base Puffin Formation																		
	LJ2 MFS / J54																	
Franklin Formation																		
Heather Formation *sensu stricto*																		
			Middle Oxfordian															
		LJ1 DSB																
			Early Oxfordian															
	J52																	
	LJ1 MFS / J46																	
Fladen Group																11705		
			Middle Jurassic															
Ron Volcanic Member																		
Indeterminate																		
Lias Group																		
			Early Jurassic															
Heron Group				11035			7721			11151			7420					
			Triassic															
Zechstein Group			Late Permian													12129		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/7-2.				29/7-3.				29/7-4				29/7-5				29/7-6		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				8730				11210				10570				9207				10530		
Mandal Member				8730								10570				9207				10530		
			Late - Early Ryazanian				8760												9230			
	EK1 MFS / K10				8733								10573								10547	
Derwent Member				8738								10575								10550		
			Late Volgian				8760												9230			
	LJ6 MFS / J74				8800								10581								10660	
			latest Middle Volgian																9260			
Wharfe Member				8850								10585				9343				10684		
Nidd Member																						
			Middle Volgian				8900								10590				9350			
		LJ5 DSB				8956								10611				9459				10780
Aire Member				8956								10611				9459				10780		
			Early Volgian				8960								10630				9500			
	LJ5 MFS / J66				8999								10678				9576				10790	
Swale Member				9041								10716				9630				10820		
Laver Member																						
Uppermost Fulmar Formation																						
top Selkirk Member																						
base Selkirk Member																						
			Kimmeridgian				9080				11210				10720				9680			
		LJ4 DSB				9082								10747				9710				10855
un-named conglomerate																						
Ouse Member				9082								10747				9710				10855		
	LJ4 MFS / J63				9089								10749				9770				10937	
Leen Member																						
Ribble Member																						
Trent Member				9131				11210								9883						
Ula Formation																						
Ryton Member																10013						
Upper Fulmar Formation																						
top Christian Member																						
base Christian Member																						
		LJ3ii DSB				9414												10054				
	baylei IFS / J62				9440				11260								10055					
Lower Fulmar Formation																						
Heather Formation *sensu lato*								11261														
			early Kimmeridgian								11330											
			early Kimm. - Lt Oxfordian																10200			
			Late Oxfordian								11530				10804.9				10430			
Puffin Formation												10770				10064				11034		
base Puffin Formation																						
top Shearwater Member																						
base Shearwater Member																						
		LJ3i DSB								11555				10896				10157				11170
	LJ3 MFS / J56								11844				10939				10228				11232	
Puffin Formation								12220														
top Curlew Member								12339				10995				10371				11291		
base Curlew Member								12566				11450				10810				11784		
top Freshney Member																						
base Freshney Member																						
		LJ2 DSB								12566								10810				
base Puffin Formation								12566				11450				10810				11784		
	LJ2 MFS / J54																					
Franklin Formation																						
Heather Formation *sensu stricto*																						
			Middle Oxfordian																			
		LJ1 DSB																				
			Early Oxfordian																			
	J52																					
	LJ1 MFS / J46																					
Fladen Group								12566				11450				10810						
			Middle Jurassic								12566				11450				10810			
Ron Volcanic Member																						
Indeterminate																						
Lias Group																						
			Early Jurassic																			
Heron Group								12875								11360						
			Triassic								12875								11360			
Zechstein Group			Late Permian	9480																		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/7-7				29/8b-1				29/8b-2ST				29/8a-3				29/8a-4			
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				10350								12285				12581				12780			
Mandal Member												12285				12581				12780			
			Late - Early Ryazanian												12300				12600				12780
	EK1 MFS / K10												12286				12582				12789		
Derwent Member												12297				12586							
			Late Volgian												12310				12600				
	LJ6 MFS / J74												12325				12616						
			latest Middle Volgian																				
Wharfe Member												12380				12634				12795			
Nidd Member																							
			Middle Volgian												12390				12660				
		LJ5 DSB												12443				12688				12839	
Aire Member				10350								12443				12688				12839			
			Early Volgian				10380								12470				12720				12840
	LJ5 MFS / J66				10416								12478				12710				12920		
Swale Member				10485								12560				12779				13019			
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member																							
base Selkirk Member																							
			Kimmeridgian				10500								12600				12780				13020
		LJ4 DSB				10511								12608				12821				13064	
un-named conglomerate																							
Ouse Member				10511								12608				12821				13066			
	LJ4 MFS / J63				10525								12635				12834				13090		
Leen Member																							
Ribble Member																							
Trent Member												12700								13140			
Ula Formation																							
Ryton Member																							
Upper Fulmar Formation																							
top Christian Member																							
base Christian Member																							
		LJ3ii DSB												13133								13152	
	baylei IFS / J62												13140								13172		
Lower Fulmar Formation																							
Heather Formation *sensu lato*																12834				13182			
			early Kimmeridgian																				13200
			early Kimm. - Lt Oxfordian																12870				
			Late Oxfordian				10612																13340
Puffin Formation				10580																			
base Puffin Formation																							
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB				10690												12866				13304	
	LJ3 MFS / J56				10723												12879				13454		
Puffin Formation																				13586			
top Curlew Member				10889																13611			
base Curlew Member				11359																13710			
top Freshney Member																							
base Freshney Member																							
		LJ2 DSB				11359																13710	
base Puffin Formation				11359																13795			
	LJ2 MFS / J54																						
Franklin Formation																							
Heather Formation *sensu stricto*																							
			Middle Oxfordian																				
		LJ1 DSB																					
			Early Oxfordian																				
	J52																						
	LJ1 MFS / J46																						
Fladen Group				11359								13142											
			Middle Jurassic				11359								13142								
Ron Volcanic Member																							
Indeterminate								10946															
Lias Group																							
			Early Jurassic																				
Heron Group								10997								12942				13795			
			Triassic								10997								12942				13795
Zechstein Group			Late Permian					12260															

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/8b-5				29/9a-1				29/9b-2				29/9b-3				29/9a-5			
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				11489				14492				13042				13010				14423			
Mandal Member								14492				13042											
			Late - Early Ryazanian								14500				13050								
	EK1 MFS / K10								14499				13050										
Derwent Member				11489												13010							
			Late Volgian																13020				
	LJ6 MFS / J74				11495												13025						
			latest Middle Volgian				11510																
Wharfe Member				11500								13056				13032							
Nidd Member																							
			Middle Volgian				11540								13070				13102				
		LJ5 DSB				11560								13281				13120					
Aire Member				11560								13081				13120							
			Early Volgian				11560								13110				13260				
	LJ5 MFS / J66				11630								13118				13139						
Swale Member				11734				14507				13130				13240							
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member																							
base Selkirk Member																							
			Kimmeridgian				11840				14580				13130				13422				14430
		LJ4 DSB				11853				14525				13262				13325					
un-named conglomerate																							
Ouse Member				11853				14525				13262				13325				14423			
	LJ4 MFS / J63				11885				14552				13272				13349				14423		
Leen Member												13310											
Ribble Member																							
Trent Member				11910				14604								13460				14425			
Ula Formation																							
Ryton Member																							
Upper Fulmar Formation																							
top Christian Member																							
base Christian Member																							
		LJ3ii DSB																13764				14542	
	baylei IFS / J62				11944												13803				14571		
Lower Fulmar Formation																							
Heather Formation *sensu lato*				11945												13821				14574			
			early Kimmeridgian																				
			early Kimm. - Lt Oxfordian				11945												13821				14650
			Late Oxfordian				12016																
Puffin Formation																							
base Puffin Formation																							
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB				11980												13872				14643	
	LJ3 MFS / J56				11989												13900				14666		
Puffin Formation				11990												13970				14774			
top Curlew Member				12022																			
base Curlew Member				12097																			
top Freshney Member																							
base Freshney Member																							
		LJ2 DSB				12097												13999				14956	
base Puffin Formation				12097																			
	LJ2 MFS / J54																						
Franklin Formation																							
Heather Formation *sensu stricto*																							
			Middle Oxfordian																				
		LJ1 DSB																					
			Early Oxfordian																				
	J52																						
	LJ1 MFS / J46																						
Fladen Group				12097								13388				14038				15212			
			Middle Jurassic				12097								13388				14038				15212
Ron Volcanic Member												13388				14038							
Indeterminate																							
Lias Group																							
			Early Jurassic																				
Heron Group				12638				14622				14080											
			Triassic				12638				14622				14080								
Zechstein Group			Late Permian									14216								15330			

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/9b-6			29/9c-7			29/9c-8			29/10-2.				29/10-3ST				29/11a-1		
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				13129			14179			14325			13254				14470				6676		
Mandal Member				13129									13254				14470				6676		
			Late - Early Ryazanian													13290				14470			
	EK1 MFS / K10				13135									13260				14473				6678	
Derwent Member				13138																	6679		
			Late Volgian																				
	LJ6 MFS / J74				13174																	6681	
			latest Middle Volgian																				
Wharfe Member				13205			14179			14325											6755		
Nidd Member																							
			Middle Volgian																				
		LJ5 DSB				13249			14238			14415											6948
Aire Member				13249			14238			14415											6948		
			Early Volgian													13320							
	LJ5 MFS / J66				13262			14245			14449											6972	
Swale Member				13270			14276			14450			13264								6989		
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member																							
base Selkirk Member																							
			Kimmeridgian													13350							
		LJ4 DSB				13309			14300			14550			13298								7142
un-named conglomerate																							
Ouse Member				13309			14300			14550			13298								7142		
	LJ4 MFS / J63				13318			14309			14574			13299								7144	
Leen Member				13333																			
Ribble Member																							
Trent Member							14358			14596			13362										
Ula Formation																							
Ryton Member																					7150		
Upper Fulmar Formation																							
top Christian Member																							
base Christian Member																							
		LJ3ii DSB				13420			14465			14760			13457								7258
	baylei IFS / J62													13528								7345	
Lower Fulmar Formation																							
Heather Formation *sensu lato*													13530										
			early Kimmeridgian																				
			early Kimm. - Lt Oxfordian													13500							
			Late Oxfordian													13740							
Puffin Formation																							
base Puffin Formation																							
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB													13563								
	LJ3 MFS / J56													13580									
Puffin Formation													13660										
top Curlew Member													13947										
base Curlew Member													14067										
top Freshney Member																							
base Freshney Member																							
		LJ2 DSB													14067								
base Puffin Formation													14458										
	LJ2 MFS / J54													14383									
Franklin Formation																							
Heather Formation *sensu stricto*																							
			Middle Oxfordian																				
		LJ1 DSB																					
			Early Oxfordian																				
	J52																						
	LJ1 MFS / J46																						
Fladen Group				13420									14458				14474				7345		
			Middle Jurassic													14458				14474			
Ron Volcanic Member				13420			14465																
Indeterminate																							
Lias Group																							
			Early Jurassic																				
Heron Group										14760			15818				14552				7470		
			Triassic													15818				14552			
Zechstein Group			Late Permian																		7987		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/12-1				29/12-2			29/14b-1a				29/14b-2			29/14b-3			29/14c-5		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				7897				9579			11829				9200			10062			9535		
Mandal Member				7897				9579			11829				9200			10062					
			Late - Early Ryazanian				7920							11850									
	EK1 MFS / K10				7908				9580			11840				9202			10067				
Derwent Member				7910				9580			11850				9205			10068			9535		
			Late Volgian				7920							11850									
	LJ6 MFS / J74				7940				9591			11856				9210			10078			9540	
			latest Middle Volgian				7980																
Wharfe Member				8030				9592			11866							10083					
Nidd Member																							
			Middle Volgian				8040																
		LJ5 DSB				8208				9635			11899							10125			
Aire Member				8208				9635			11899							10125					
			Early Volgian				8280							11940									
	LJ5 MFS / J66				8337				9671			11917							10150				
Swale Member				8405				9710			11940							10159					
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member																							
base Selkirk Member																							
			Kimmeridgian				8480							12024									
		LJ4 DSB				8491				9820			12043							10170			
un-named conglomerate																							
Ouse Member				8491				9820			12043							10170					
	LJ4 MFS / J63				8523				9826			12049							10173				
Leen Member											12064							10196					
Ribble Member																							
Trent Member				8570				9869															
Ula Formation																							
Ryton Member																							
Upper Fulmar Formation																							
top Christian Member																							
base Christian Member																							
		LJ3ii DSB				8675				10050													
	baylei IFS / J62				8717				10080														
Lower Fulmar Formation																							
Heather Formation *sensu lato*				8721																			
			early Kimmeridgian																				
			early Kimm. - Lt Oxfordian				8760																
			Late Oxfordian				9160																
Puffin Formation				8780				10088															
base Puffin Formation				8837																			
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB				8837				10170													
	LJ3 MFS / J56				8993																		
Puffin Formation				9023																			
top Curlew Member																							
base Curlew Member																							
top Freshney Member																							
base Freshney Member																							
		LJ2 DSB				9170																	
base Puffin Formation				9170																			
	LJ2 MFS / J54				9338																		
Franklin Formation																							
Heather Formation *sensu stricto*																							
			Middle Oxfordian																				
		LJ1 DSB				9170																	
			Early Oxfordian																				
	J52																						
	LJ1 MFS / J46																						
Fladen Group				9339							12174				9214			10240					
			Middle Jurassic				9339							12174									
Ron Volcanic Member											12174				9214			10240					
Indeterminate																							
Lias Group																							
			Early Jurassic																				
Heron Group				10103				10170			13080										9567		
			Triassic				10103							13080									9567
Zechstein Group			Late Permian																				

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/15-1				29/15-2				29/20-1			
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				12675				15012				7563			
Mandal Member				12675				15012							
			Late - Early Ryazanian				12670				15040				
	EK1 MFS / K10				12678				15022						
Derwent Member				12680				15023							
			Late Volgian				12690				15040				
	LJ6 MFS / J74				12690				15051						
			latest Middle Volgian				12710								7620
Wharfe Member				12739				15075							
Nidd Member												7563			
			Middle Volgian				12770				15100				7650
		LJ5 DSB				12832				15250					
Aire Member				12832				15250							
			Early Volgian				12870				15250				
	LJ5 MFS / J66				12837				15254						
Swale Member				12860				15260							
Laver Member															
Uppermost Fulmar Formation															
top Selkirk Member															
base Selkirk Member															
			Kimmeridgian												
		LJ4 DSB				12892				15275					
un-named conglomerate															
Ouse Member				12892				15275							
	LJ4 MFS / J63				12898				15288						
Leen Member															
Ribble Member															
Trent Member				12901				15307							
Ula Formation															
Ryton Member															
Upper Fulmar Formation															
top Christian Member															
base Christian Member															
		LJ3ii DSB				12954				15317					
	baylei IFS / J62				12993				15331						
Lower Fulmar Formation															
Heather Formation *sensu lato*				12998				15334							
			early Kimmeridgian												
			early Kimm. - Lt Oxfordian				13010				15360				
			Late Oxfordian								15390				
Puffin Formation															
base Puffin Formation															
top Shearwater Member															
base Shearwater Member															
		LJ3i DSB								15500					
	LJ3 MFS / J56								15514						
Puffin Formation								15680							
top Curlew Member															
base Curlew Member															
top Freshney Member															
base Freshney Member															
		LJ2 DSB								15736					
base Puffin Formation															
	LJ2 MFS / J54								15785						
Franklin Formation															
Heather Formation *sensu stricto*															
			Middle Oxfordian												
		LJ1 DSB													
			Early Oxfordian												
	J52														
	LJ1 MFS / J46														
Fladen Group								15785							
			Middle Jurassic								15785				
Ron Volcanic Member															
Indeterminate															
Lias Group															
			Early Jurassic												
Heron Group				13050				16140				7859			
			Triassic				13050				16140				7859
Zechstein Group			Late Permian	14564								8112			

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	29/23b-2			29/24-1			29/25-1			30/1c-2a			30/1c-3				30/1c-4		
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				5235			5690															
Mandal Member				5235																		
			Late - Early Ryazanian																			
	EK1 MFS / K10				5241																	
Derwent Member				5242																		
			Late Volgian																			
	LJ6 MFS / J74				5287																	
			latest Middle Volgian																			
Wharfe Member																						
Nidd Member				5300			5690															
			Middle Volgian																			
		LJ5 DSB				5745																
Aire Member																						
			Early Volgian																			
	LJ5 MFS / J66																					
Swale Member																						
Laver Member																						
Uppermost Fulmar Formation																						
top Selkirk Member																						
base Selkirk Member																						
			Kimmeridgian																			
		LJ4 DSB																				
un-named conglomerate																						
Ouse Member																						
	LJ4 MFS / J63																					
Leen Member																						
Ribble Member																						
Trent Member																						
Ula Formation																						
Ryton Member																						
Upper Fulmar Formation																						
top Christian Member																						
base Christian Member																						
		LJ3ii DSB																				
	baylei IFS / J62																					
Lower Fulmar Formation																						
Heather Formation *sensu lato*																13825						
			early Kimmeridgian																13862			
			early Kimm. - Lt Oxfordian																			
			Late Oxfordian																13927			
Puffin Formation																						
base Puffin Formation																						
top Shearwater Member																						
base Shearwater Member																						
		LJ3i DSB																14126				
	LJ3 MFS / J56																14226					
Puffin Formation																						
top Curlew Member																						
base Curlew Member																						
top Freshney Member																						
base Freshney Member																						
		LJ2 DSB																14488				
base Puffin Formation																						
	LJ2 MFS / J54																14511					
Franklin Formation																						
Heather Formation *sensu stricto*																14514						
			Middle Oxfordian																14518			
		LJ1 DSB																				
			Early Oxfordian																			
	J52																					
	LJ1 MFS / J46																14543					
Fladen Group													13476			14543				13878		
			Middle Jurassic																14543			
Ron Volcanic Member																						
Indeterminate																						
Lias Group																						
			Early Jurassic																			
Heron Group				5745			6000			8149			14202			15462				14330		
			Triassic																15462			
Zechstein Group				6768			7694			8385												

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	30/1c-5			30/1c-6			30/1f-8			30/2-1.			30/2a-2				30/6-3.		
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB
Kimmeridge Clay Formation							14275			15405			14590							12890		
Mandal Member													14590							12890		
			Late - Early Ryazanian																			
	EK1 MFS / K10													14596							12890	
Derwent Member													14600							12900		
			Late Volgian																			
	LJ6 MFS / J74													14620							12910	
			latest Middle Volgian																			
Wharfe Member													14667							12920		
Nidd Member																						
			Middle Volgian																			
		LJ5 DSB													14930							12952
Aire Member													14930							12952		
			Early Volgian																			
	LJ5 MFS / J66													14956							13055	
Swale Member													14975							13059		
Laver Member																						
Uppermost Fulmar Formation																						
top Selkirk Member																						
base Selkirk Member																						
			Kimmeridgian																			
		LJ4 DSB													15055							13186
un-named conglomerate																						
Ouse Member							14275			15405			15055							13186		
	LJ4 MFS / J63							14278			15410			15094							13278	
Leen Member																						
Ribble Member																						
Trent Member										15412			15170							13282		
Ula Formation																						
Ryton Member																						
Upper Fulmar Formation																						
top Christian Member																						
base Christian Member																						
		LJ3ii DSB										15439			15210							14021
	baylei IFS / J62										15470										14099	
Lower Fulmar Formation																						
Heather Formation *sensu lato*							14288			15477			15220			13950				14110		
			early Kimmeridgian																			
			early Kimm. - Lt Oxfordian																			
			Late Oxfordian																13967			
Puffin Formation																						
base Puffin Formation																						
top Shearwater Member																13997						
base Shearwater Member																14060						
		LJ3i DSB							14370			15526						14144				14578
	LJ3 MFS / J56							14406			15540			15225			14191				14642	
Puffin Formation													15240									
top Curlew Member																						
base Curlew Member																						
top Freshney Member																				15583		
base Freshney Member																				15858		
		LJ2 DSB										15643						14284				15858
base Puffin Formation																						
	LJ2 MFS / J54										15730										15932	
Franklin Formation																						
Heather Formation *sensu stricto*																				15932		
			Middle Oxfordian																			
		LJ1 DSB																				
			Early Oxfordian																			
	J52																					
	LJ1 MFS / J46																					
Fladen Group				13678			14406			15750						14284				16401		
			Middle Jurassic																14284			
Ron Volcanic Member																						
Indeterminate																						
Lias Group																						
			Early Jurassic																			
Heron Group				13756			14792						15286									
			Triassic																			
Zechstein Group													15306									

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	30/7a-1			30/7a-2				30/7a-3			30/7a-4A			30/7a-6			30/7a-8		
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				12784			13067				13009						12125					
Mandal Member							13067															
			Late - Early Ryazanian							13080												
	EK1 MFS / K10							13069														
Derwent Member																						
			Late Volgian																			
	LJ6 MFS / J74																					
			latest Middle Volgian																			
Wharfe Member				12784																		
Nidd Member																						
			Middle Volgian																			
		LJ5 DSB																				
Aire Member				12793			13070				13009											
			Early Volgian																			
	LJ5 MFS / J66				12822			13084				13015										
Swale Member				12871			13095				13028											
Laver Member																						
Uppermost Fulmar Formation																						
top Selkirk Member																						
base Selkirk Member																						
			Kimmeridgian							13140												
		LJ4 DSB				12893			13117				13043									
un-named conglomerate																				11390		
Ouse Member				12893			13117				13043									11493		
	LJ4 MFS / J63				12907			13125				13054									11400	
Leen Member																						
Ribble Member																						
Trent Member							13130															
Ula Formation																						
Ryton Member																						
Upper Fulmar Formation																						
top Christian Member																						
base Christian Member																						
		LJ3ii DSB							13144													
	baylei IFS / J62							13147														
Lower Fulmar Formation																						
Heather Formation *sensu lato*				12913			13154				13064			10942						11509		
			early Kimmeridgian																			
			early Kimm. - Lt Oxfordian							13160												
			Late Oxfordian																			
Puffin Formation																						
base Puffin Formation																						
top Shearwater Member																						
base Shearwater Member																						
		LJ3i DSB							13168													11556
	LJ3 MFS / J56							13170							11094						11603	
Puffin Formation																						
top Curlew Member																						
base Curlew Member																						
top Freshney Member														11109								
base Freshney Member														11176								
		LJ2 DSB																				
base Puffin Formation																						
	LJ2 MFS / J54																					
Franklin Formation																						
Heather Formation *sensu stricto*																						
			Middle Oxfordian																			
		LJ1 DSB																				
			Early Oxfordian																			
	J52																					
	LJ1 MFS / J46																					
Fladen Group																						
			Middle Jurassic																			
Ron Volcanic Member																						
Indeterminate																						
Lias Group																						
			Early Jurassic																			
Heron Group				12968			13180				13154			11176			12200			11617		
			Triassic							13180												
Zechstein Group				13046			13218															

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	30/8-1			30/11b-1				30/11b-3			30/11b-4			30/12b-2				30/12b-3			
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				12137			13860				14360			14268			13198				13026			
Mandal Member				12137							14360										13026			
			Late - Early Ryazanian																					
	EK1 MFS / K10				12138							14367										13030		
Derwent Member				12147							14368													
			Late Volgian																					
	LJ6 MFS / J74				12163							14380												
			latest Middle Volgian																					
Wharfe Member				12164							14385										13033			
Nidd Member																								
			Middle Volgian																					
		LJ5 DSB				12201							14423										13059	
Aire Member				12201			13860				14423										13059			
			Early Volgian							14156														13094.7
	LJ5 MFS / J66				12215			13957				14515										13081		
Swale Member				12235							14590										13092			
Laver Member																								
Uppermost Fulmar Formation																								
top Selkirk Member																								
base Selkirk Member																								
			Kimmeridgian																	13240				
		LJ4 DSB				12238							14662										13115	
un-named conglomerate							14010																	
Ouse Member				12238							14662			14268			13198				13115			
	LJ4 MFS / J63				12398							14724			14272			13214				13130		
Leen Member																								
Ribble Member																								
Trent Member				12444																				
Ula Formation																								
Ryton Member																								
Upper Fulmar Formation											14820			14280			13216				13160			
top Christian Member																								
base Christian Member																								
		LJ3ii DSB				12900							15133			14467			13310				13345	
	baylei IFS / J62				12962							15150			14495			13317				13355		
Lower Fulmar Formation											15150			14495			13317				13355			
Heather Formation *sensu lato*				13090																				
			early Kimmeridgian																					
			early Kimm. - Lt Oxfordian																	13320				13356.4
			Late Oxfordian																					
Puffin Formation																								
base Puffin Formation																								
top Shearwater Member																								
base Shearwater Member																								
		LJ3i DSB				14207							15360			14575			13424				13447	
	LJ3 MFS / J56				14294							15397			14600			13430				13470		
Puffin Formation											15740													
top Curlew Member																								
base Curlew Member																								
top Freshney Member																								
base Freshney Member																								
		LJ2 DSB											15838											
base Puffin Formation																								
	LJ2 MFS / J54				14704							15872												
Franklin Formation																								
Heather Formation *sensu stricto*				14743																				
			Middle Oxfordian																					
		LJ1 DSB				14886																		
			Early Oxfordian																					
	J52																							
	LJ1 MFS / J46				14903																			
Fladen Group				14904																				
			Middle Jurassic																					
Ron Volcanic Member																								
Indeterminate																								
Lias Group																								
			Early Jurassic																					
Heron Group							14283				15872			14781			13431				13597			
			Triassic							14283										13431				13597
Zechstein Group							14573																	

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	30/12b-4				30/12b-6			30/12b-7			30/12b-8			30/13-1X				30/13-2X			
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				12838				13420			15160			12343			11986				12274			
Mandal Member								13420			15160													
			Late - Early Ryazanian																					
	EK1 MFS / K10								13423			15168												
Derwent Member								13426			15170													
			Late Volgian																					
	LJ6 MFS / J74								13446			15193												
			latest Middle Volgian																					
Wharfe Member								13470			15207													
Nidd Member																								
			Middle Volgian																					
		LJ5 DSB								13559			15265											
Aire Member				12838				13559			15265						11986				12274			
			Early Volgian																					12340
	LJ5 MFS / J66				12844				13571			15280						11996				12305		
Swale Member				12851				13587			15288						12005				12376			
Laver Member																								
Uppermost Fulmar Formation																								
top Selkirk Member																								
base Selkirk Member																								
			Kimmeridgian				12921																		
		LJ4 DSB				12870				13673			15349						12045				12504	
un-named conglomerate																								
Ouse Member				12870				13673			15349			12343			12045				12504			
	LJ4 MFS / J63				12873				13709			15366			12349			12050				12560		
Leen Member																								
Ribble Member																								
Trent Member																					12670			
Ula Formation																								
Ryton Member																								
Upper Fulmar Formation				12881				13715			15367			12384			12053				13065			
top Christian Member																								
base Christian Member																								
		LJ3ii DSB				13040				13880			15483			12602			12108				13113	
	baylei IFS / J62				13040				13887			15500			12610			12109				13125		
Lower Fulmar Formation				13040				13887			15500			12610			12109							
Heather Formation *sensu lato*																	12196				13141			
			early Kimmeridgian																					
			early Kimm. - Lt Oxfordian				13042																	13120
			Late Oxfordian																	12109				13710
Puffin Formation																								
base Puffin Formation																								
top Shearwater Member																								
base Shearwater Member																								
		LJ3i DSB				13154				13967			15520			12739			12196				13315	
	LJ3 MFS / J56				13157				13984			15530			12766			12220				13638		
Puffin Formation																								
top Curlew Member																								
base Curlew Member																								
top Freshney Member																								
base Freshney Member																								
		LJ2 DSB																						
base Puffin Formation																								
	LJ2 MFS / J54																							
Franklin Formation																								
Heather Formation *sensu stricto*																								
			Middle Oxfordian																					
		LJ1 DSB																						
			Early Oxfordian																					
	J52																							
	LJ1 MFS / J46																							
Fladen Group																								
			Middle Jurassic																					
Ron Volcanic Member																								
Indeterminate																								
Lias Group																								
			Early Jurassic																					
Heron Group				13270				14088			15533			13008			12270				13765			
			Triassic				13270													12270				13765
Zechstein Group																					13910			

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	30/13-3			30/13-4			30/13-5			30/13-6				30/13-7			30/16-6			
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages
Kimmeridge Clay Formation				12711			11696			11744			12854				12510			9833			
Mandal Member										11744													
			Late - Early Ryazanian																				
	EK1 MFS / K10										11750												
Derwent Member										11750							12510						
			Late Volgian																				
	LJ6 MFS / J74										1773							12511					
			latest Middle Volgian																				
Wharfe Member										11800			12854				12522						
Nidd Member																							
			Middle Volgian													12880							
		LJ5 DSB										11864			12869								
Aire Member										11864			12869				12689			9833			
			Early Volgian													12880							9860
	LJ5 MFS / J66										11921			12880				12720			9884		
Swale Member										11950			12898				12790			10026			
Laver Member																							
Uppermost Fulmar Formation																							
top Selkirk Member																							
base Selkirk Member																							
			Kimmeridgian													13030							10180
		LJ4 DSB										11980			13035						10158		
un-named conglomerate																							
Ouse Member				12711			11696			11980			13035				12899			10158			
	LJ4 MFS / J63				12732			11712			12032			13135				12930			10320		
Leen Member																							
Ribble Member																				10240			
Trent Member				12737			11740			12136			13218				12994						
Ula Formation																							
Ryton Member																							
Upper Fulmar Formation																				10327			
top Christian Member																							
base Christian Member																							
		LJ3ii DSB				12927			11887			12308			13440							11165		
	baylei IFS / J62				13099			12063			12349			13482				13294			11190		
Lower Fulmar Formation																				11190			
Heather Formation *sensu lato*				13130			12076			12372			13529				13306						
			early Kimmeridgian													13560							
			early Kimm. - Lt Oxfordian																				
			Late Oxfordian													13600							
Puffin Formation																							
base Puffin Formation																							
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB				13405			12666			12888			14095									
	LJ3 MFS / J56				13556			12913			12900			14293				14051					
Puffin Formation																							
top Curlew Member																							
base Curlew Member																							
top Freshney Member				13660			13173						14449				14229						
base Freshney Member				13877			13400						14700				14638						
		LJ2 DSB				13970			13529						14818								
base Puffin Formation																							
	LJ2 MFS / J54				14130			13750						15000				14686					
Franklin Formation																							
Heather Formation *sensu stricto*				14143			13762						15032										
			Middle Oxfordian													15032							
		LJ1 DSB																					
			Early Oxfordian																				
	J52																						
	LJ1 MFS / J46																						
Fladen Group				14178			13830										14703						
			Middle Jurassic																				
Ron Volcanic Member																							
Indeterminate																							
Lias Group																							
			Early Jurassic																				
Heron Group							14800			12905							15315			11230			
			Triassic																				11230
Zechstein Group																							

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	30/16-7				30/16-FA10				30/17b-2			30/17b-5			30/17b-8		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				9950								11910			13288			11860		
Mandal Member				9950								11910			13288					
			Late - Early Ryazanian				9960													
	EK1 MFS / K10				9958								11920			13290				
Derwent Member												11921			13294					
			Late Volgian																	
	LJ6 MFS / J74												11943			13325				
			latest Middle Volgian																	
Wharfe Member												11970			13332					
Nidd Member																				
			Middle Volgian																	
		LJ5 DSB												12035			13370			
Aire Member				9959								12035			13370			11860		
			Early Volgian				9960													
	LJ5 MFS / J66				9975								12038			13392			11866	
Swale Member				10199								12040			13400			12170		
Laver Member																				
Uppermost Fulmar Formation																				
top Selkirk Member																				
base Selkirk Member																				
			Kimmeridgian				10470				11749.3									
		LJ4 DSB				10438								12090			13440			12353
un-named conglomerate																				
Ouse Member				10438								12090			13440			12353		
	LJ4 MFS / J63				10917								12113			13445			12580	
Leen Member																				
Ribble Member				10702														12491		
Trent Member																				
Ula Formation																				
Ryton Member																				
Upper Fulmar Formation				10942				11619				12175			13481			12604		
top Christian Member																				
base Christian Member																				
		LJ3ii DSB				11593				12119				12635			13776			13090
	baylei IFS / J62				11597				12129				12660			13789			13020	
Lower Fulmar Formation				11597				12129				12660			13789			13020		
Heather Formation *sensu lato*																				
			early Kimmeridgian								12115.3									
			early Kimm. - Lt Oxfordian																	
			Late Oxfordian								12143									
Puffin Formation																				
base Puffin Formation																				
top Shearwater Member																				
base Shearwater Member																				
		LJ3i DSB								12265				12785			13815			13276
	LJ3 MFS / J56								12294				12838			13831				
Puffin Formation																				
top Curlew Member																				
base Curlew Member																				
top Freshney Member																				
base Freshney Member																				
		LJ2 DSB																		
base Puffin Formation																				
	LJ2 MFS / J54																			
Franklin Formation																				
Heather Formation *sensu stricto*																				
			Middle Oxfordian																	
		LJ1 DSB																		
			Early Oxfordian																	
	J52																			
	LJ1 MFS / J46																			
Fladen Group																				
			Middle Jurassic																	
Ron Volcanic Member																				
Indeterminate																				
Lias Group																				
			Early Jurassic																	
Heron Group				11615				12298				12845			13850			13288		
			Triassic				11615				12298									
Zechstein Group																				

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	30/17b-9, ST2				30/17a-11			30/17a-12			30/17a-13+RE				30/18-2			30/18-3		
				Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				12100				11780			11537			11270				14238			13890		
Mandal Member								11780			11537			11270				14238			13890		
			Late - Early Ryazanian																				
	EK1 MFS / K10								11789			11541			11274				14257			13910	
Derwent Member								11800			11546			11279				14262			13922		
			Late Volgian																				
	LJ6 MFS / J74								11808			11569			11318				14334			14019	
			latest Middle Volgian																				
Wharfe Member								11844			11570			11340				14420			14115		
Nidd Member																							
			Middle Volgian																				
		LJ5 DSB								11861			11587			11354				14580			14207
Aire Member								11861			11587			11354				14580			14207		
			Early Volgian														11660.3						
	LJ5 MFS / J66								11869			11591			11379				14600			14208	
Swale Member				12100														14605			14218		
Laver Member																							
Uppermost Fulmar Formation								11930			11700			11568									
top Selkirk Member																							
base Selkirk Member																							
			Kimmeridgian				12110										11851.5						
		LJ4 DSB				12150				12338			12115			11869				14636			14249
un-named conglomerate																							
Ouse Member				12150														14636			14249		
	LJ4 MFS / J63				12207				12342			12115			11895				14669			14252	
Leen Member																							
Ribble Member				12198																			
Trent Member																		14800			14285		
Ula Formation																							
Ryton Member																							
Upper Fulmar Formation				12216				12350			12116			11909				14880			14322		
top Christian Member																							
base Christian Member																							
		LJ3ii DSB				12682				12717			12457										14398
	baylei IFS / J62				12700																	14398	
Lower Fulmar Formation				12700				12717															
Heather Formation *sensu lato*																					14398		
			early Kimmeridgian																				
			early Kimm. - Lt Oxfordian				12740																
			Late Oxfordian				12960																
Puffin Formation																							
base Puffin Formation																							
top Shearwater Member																							
base Shearwater Member																							
		LJ3i DSB				12889																	
	LJ3 MFS / J56				12950																		
Puffin Formation																							
top Curlew Member																							
base Curlew Member																							
top Freshney Member																							
base Freshney Member																							
		LJ2 DSB																					
base Puffin Formation																							
	LJ2 MFS / J54																						
Franklin Formation																							
Heather Formation *sensu stricto*																							
			Middle Oxfordian																				
		LJ1 DSB																					
			Early Oxfordian																				
	J52																						
	LJ1 MFS / J46																						
Fladen Group																							
			Middle Jurassic																				
Ron Volcanic Member																							
Indeterminate																							
Lias Group				12995																			
			Early Jurassic				12995																
Heron Group				13115				12735			12457												
			Triassic				13115																
Zechstein Group				13338				12760			12700										14421		

Appendix 1 Stratigraphic Picks

Lithostratigraphy	MFS	DSB	Age	30/18-4			30/19a-4				30/19a-5			30/19a-6				N1/3-3 (metres)				N7/12-6 (metres)		
				Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB	Ages	Lithostrat	MFS	DSB
Kimmeridge Clay Formation				15782			15368				14553			14375				4042				3292		
Mandal Member				15782			15368				14553			14375				4042				3292		
			Late - Early Ryazanian							15360							14400				4045			
	EK1 MFS / K10				15792			15832				14563			14380				4046				3294	
Derwent Member				15800			15385				14569			14385				4049				3295		
			Late Volgian							15440							14400							
	LJ6 MFS / J74				15847			15885				14575			14401				4064				3300	
			latest Middle Volgian														4045							
Wharfe Member				15870			15788				14580			14442				4077.5				3305		
Nidd Member																								
			Middle Volgian							15790							14490							
		LJ5 DSB							16040				14750			14675				4163.5				3388
Aire Member							16040				14750			14675				4163.5				3388		
			Early Volgian							16060							14670				4138			
	LJ5 MFS / J66							16134				14760			14714				4171				3392	
Swale Member							16178				14792			14752										
Laver Member																								
Uppermost Fulmar Formation																								
top Selkirk Member																								
base Selkirk Member																								
			Kimmeridgian														15030							
		LJ4 DSB											14825			14779				4344				3521`
un-named conglomerate																								
Ouse Member											14825			14779										
	LJ4 MFS / J63											14838			14801				4356					
Leen Member																								
Ribble Member																								
Trent Member											14916			14972										
Ula Formation																		4179				3406		
Ryton Member																								
Upper Fulmar Formation											15069			15186										
top Christian Member																								
base Christian Member																								
		LJ3ii DSB											15439			15283				4483				
	baylei IFS / J62											16129							4497					
Lower Fulmar Formation																								
Heather Formation *sensu lato*											16130							4498						
			early Kimmeridgian																					
			early Kimm. - Lt Oxfordian																		4506			
			Late Oxfordian																					
Puffin Formation																								
base Puffin Formation																								
top Shearwater Member																								
base Shearwater Member																								
		LJ3i DSB																		4515				
	LJ3 MFS / J56																		4515					
Puffin Formation																								
top Curlew Member																								
base Curlew Member																								
top Freshney Member																								
base Freshney Member																								
		LJ2 DSB																						
base Puffin Formation																								
	LJ2 MFS / J54																		4542.5					
Franklin Formation																								
Heather Formation *sensu stricto*																								
			Middle Oxfordian																					
		LJ1 DSB																						
			Early Oxfordian																					
	J52																							
	LJ1 MFS / J46																							
Fladen Group																		4542.5						
			Middle Jurassic																		4542.5			
Ron Volcanic Member																								
Indeterminate																								
Lias Group																								
			Early Jurassic																					
Heron Group														15283				4620				3521.5		
			Triassic														15283				4620			
Zechstein Group				15900			16206							15390			15390	4820						