

BioStrat Ltd.

BIOSTRATIGRAPHY OF NORWEGIAN WELL 15/9-F-1 (3270m-3632m), VOLVE FIELD.

Prepared by:

BioStrat Limited
1, Chapelstone Cottages
Backbarrow
Ulverston
Cumbria LA12 8PY
United Kingdom

BioStrat report no. 13/06-1
August 2014

Prepared for:

StatoilHydro
N-4035 Stavanger
Norway

Contents

	Page
1. INTRODUCTION & MAIN CONCLUSIONS	3
2. RESULTS	5
Figure 1 Stratigraphic summary	4
Figure 2 Palynological distribution chart	12
Figure 3 Palynomorph eco-groups (PEG)	13
Appendix 1 Mid Jurassic zonation	9
Appendix 2 Late Jurassic zonation	10
Appendix 3 Quad 15 zonation	11

1. Introduction

This report presents results of palynological analyses of Mid-Late Jurassic and Early Cretaceous sediments in well 15/9-F-1 (3270m-3632m). Results are summarised in Figure 1 and detailed in the range and abundance chart (Figure 2). These include all key bioevents, together with chronostratigraphic and biostratigraphic interpretations. Lithostratigraphic boundaries and wireline logs were provided by Statoil. Age interpretations are based on the recognition palynological biozones (Appendices 1-3).

Where recovery allows, the Statoil palynological counting procedure (PCP) includes two separate counts; Count 1 includes 100 identifiable palynomorphs, including pollen, spores, microplankton, acritarchs and miscellaneous forms. Count 2 is of 100 marine taxa, miscellaneous microplankton and acritarchs, with further scanning for rare taxa.

Several hot-shot samples were analysed upon the well reaching T.D., and the results of these analyses are incorporated here (hot-shot samples marked in Figure 1). Note however, that the standard PCP was not utilised for these samples, in which exclusively dinocysts were counted.

All sample depths are given in mBRT (drilled). The following abbreviations may be used in this report;

LO	last occurrence (top, extinction, first downhole occurrence)
LFO	last frequent occurrence
LCO	last common occurrence
LAO	last abundant occurrence
LSAO	last superabundant occurrence
FO	first occurrence (base, last downhole occurrence)
FFO	first frequent occurrence
FCO	first common occurrence
FAO	first abundant occurrence
FSAO	first superabundant occurrence
PRES	present
FREQ	frequent
CMN	common
ABNT	abundant
SA	superabundant

2. Main conclusions

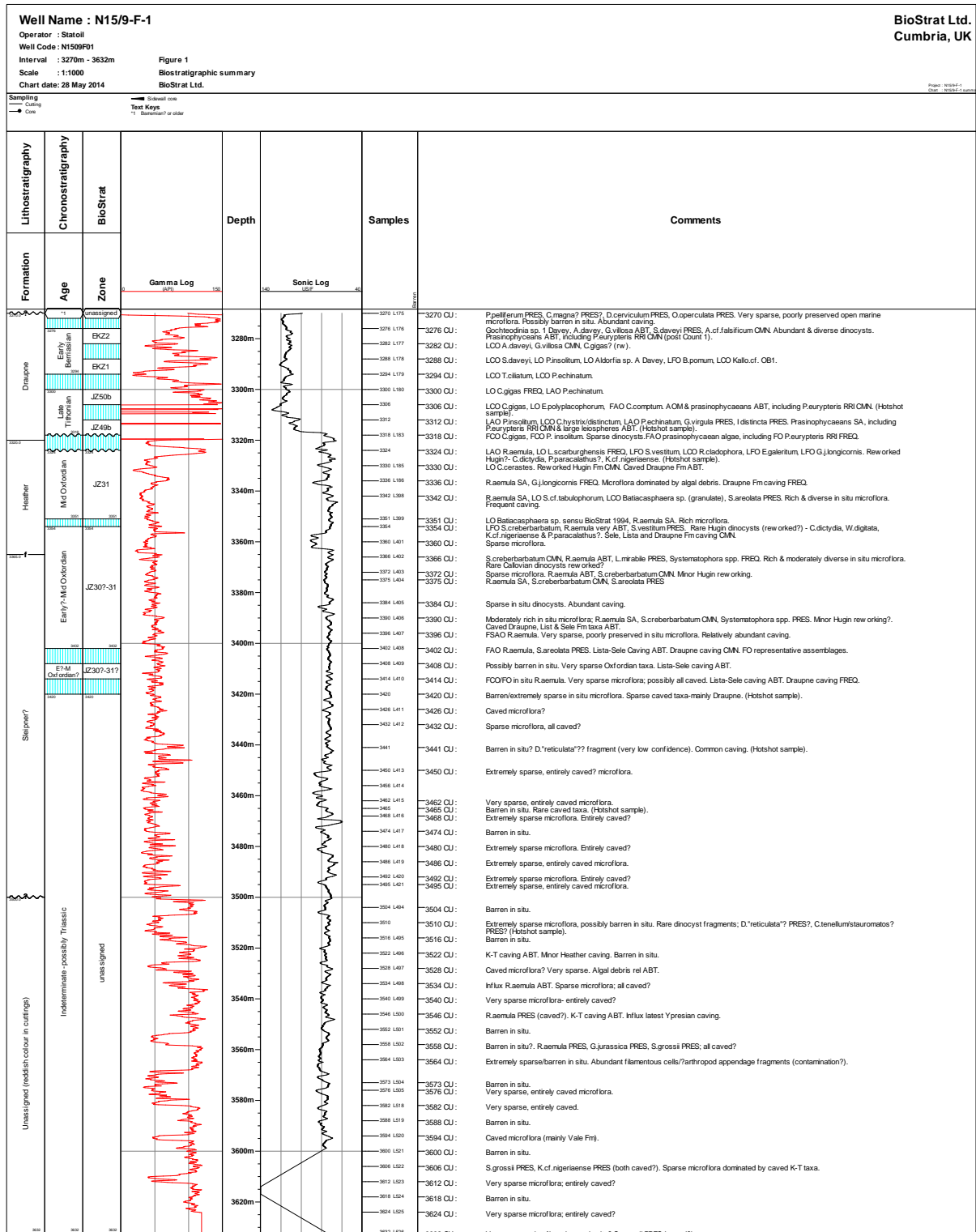
The entire lower half of the interval of study remain of indeterminate age, though a possible Triassic age is suggested.

There is no reliable palynological evidence for the presence of the Hugin Formation and none at all for the Sleipner Formation.

The Heather Sandstone Formation is probably no older than Mid Oxfordian at this location. It was deposited above a significant unconformity in a near-shore, open marine environment. The time-span represented in the hiatus is uncertain as the ages of the underlying units are unknown. Representative *in situ* assemblages are associated with frequent reworked Callovian taxa.

The upper boundary of the Heather Sandstone Formation is also represented by a significant hiatus, with the oldest Draupne Formation being of latest Tithonian age. Early Berriasian microfloras are present above, and indicate deposition in an open marine, periodically anoxic environment. No Late Berriasian assemblages are recorded, suggesting that the uppermost Draupne Formation was eroded at BCU, or not deposited.

Figure 1. Stratigraphic Summary, 15/9-F-1



2. RESULTS

Barremian? or older 3270m

The age assignment is based on the presence of *Pseudoceratium pelliferum*, *Dingodinium cerviculum* and *Odontochitina operculata* at 3270m. The sample yielded an extremely sparse, poorly preserved marine microflora, also including a questionable record of *Cassiculosphaeridia magna* (fragment), *Hystrichodinium pulchrum* and *Cribroperidinium edwardsii*. The assemblage is not representative and no biozone assignment is possible.

Early Berriasian 3276m-3294m

Age and biozone assignments are based on;

LO *Systematophora daveyi*, LO *Gochteodinia* sp. 1 Davey 1982 at 3276m (**EKZ2**).

LCO *Apteodinium daveyi* & at 3282m (**EKZ2**).

LCO *S.daveyi* and LO *Perisseiasphaeridium insolitum* at 3288m (**EKZ1**).

LCO *Pilosidinium echinatum* at 3294m (**EKZ1**).

A major palynofacies change is observed at 3276m, associated with the upper boundary of the Draupne Formation at 3270.0m (log). Samples from this interval yielded moderately rich and diverse open marine assemblages. These include diverse dinocysts, together with abundant prasinophycean algae, the latter indicating predominantly anoxic conditions. In particular there are significant numbers of *Pterospermella eurypteris* RRI, which are characteristic of the upper Draupne Formation.

Of the dinocysts, *Circulodinium comptum* is the most abundant species, especially in EKZ2. Whilst it was also abundant during EKZ1 times, *Pilosidinium echinatum* was more predominant.

The EKZ1 microfloras also include significant numbers of *Trichodinium ciliatum*, *S.daveyi* and *Gonyaulacysta cretacea*. In the following EKZ2 interval, *Gochteodinia villosa*, *Sirmiodinium grossi* and *Avellodinium cf. falsificum* are common or abundant. The occurrence of frequent *Batioladinium pomum* at 3288m represents the minor acme of this species in lower EKZ2 and are probably caved from the overlying sample gap.

A fragment, possibly of *Cribroperidinium gigas* was observed at 3282m, though is not considered to be *in situ* even if the tentative identification is correct.

Regionally, deposition of the Draupne Formation continued until the Late Berriasian (EKZ4) times. However, sediments of EKZ 3-4 age were not deposited, or were subsequently eroded to BCU, which occurs at 3270.0m (log).

Late Tithonian 3300m-3318m

Age and biozone assignments are based on;

LFO *Cribroperidinium gigas* at 3306m (**JZ50b**).

LCO *C.gigas* and FAO *C. comptum* at 3306m (**JZ50b**).

LAO *P. insolitum* and LCO *Circulodinium hystrix/distinctum* at 3312m (**JZ49b**).

Microfloras include rich and diverse dinocysts, together with abundant prasinophycean algae and amorphous organic material (AOM). This association is characteristic of the upper Draupne Formation and indicates deposition in an open marine environment under predominantly anoxic conditions.

The diverse dinocyst assemblages also include *Cribroperidinium gigas*, *Gochteodinia virgula*, *Gochteodinia* sp. 1 Davey 1982, *Leptodinium cf. subtile*, *Epiplosphaera gochtii*, *Isthmocystis distincta*, *Egmontodinium expiratum*, *Rotosphaeropsis thula*, *Kallosphaeridium cf. OB1* and *Apteodinium daveyi*.

Also of note is the LO of *Egmontodinium polyplacophorum* at 3306m. Historically, the extinction datum of this generally rare species has been used to mark the upper limit of the old "Mid Volgian" (top *opressus* ammonite zone). In this area however, *E.polyplacophorum* appears to persist, and is often seen above or close to the LCO *C.gigas* event.

The LAO of *Pilosidinium echinatum* is also recorded at 3306m. This form is often superabundant in Late Jurassic sediments, but numbers declined rapidly at the onset of the Cretaceous Period, Berriasian Stage.

Significant unconformities are present at both the upper and lower boundaries of the Draupne Formation. The top of the Heather Formation is within the underlying sample gap at 3320.0m (log), and the palynological evidence indicates that the entire Late Oxfordian, Kimmeridgian and Early Tithonian, together with a substantial part of the Late Tithonian are omitted.

Mid Oxfordian 3324m-3351m

Age and biozone assignments are based on;

LAO *Rigaudella aemula*, LFO *Leisbergia scarburghensis* 3324m (**JZ31**).

LO *Chytroeisphaeridia cerastes* at 3330m (**JZ31**).

LO *Stepanelytron cf. tabulophorum* & LCO *Batiacasphaera* sp. (granulate) at 3342m (**JZ31**).

LO *Batiacasphaera* sp. *sensu* BioStrat1994 at 3351m (**JZ31**).

A major palynofacies change is seen at 3324m, associated with the upper boundary of the Heather Sandstone Formation at 3320.0m (log). The microfloras recovered from this interval are typical of those observed regionally in the Heather Formation, though they are sparser and include significant quantities of reworked taxa. They also differ from Heather Fm s.s. assemblages by exhibiting 3D preservation (though the overall state of preservation is generally poor).

The sporadic records of *Polystephanophorus paracalathus*, *Kallosphaeridium cf. nigeriaense*, *Cassiculosphaeridia dictydia*, *Mendicodinium groenlandicum*, *Durotrigia "reticulata"* and *Surculosphaeridium vestitum* from throughout this interval are considered to be reworked. This interpretation is based not only on comparison with nearby wells, but by the overall composition of the assemblages, which is very characteristic of the lower Mid Oxfordian.

Typical species include *Gonyaulacysta jurassica*, *G. jurassica longicornis*, *Stephanelytron redcliffense*, *Nannoceratopsis pellucida*, *Batiacasphaera* sp. (granulate), *Scriniodinium crystallinum*, *Tubotuberella eisenackii*, *Endoscrinium galeritum* and *Rhynchodiniopsis cladophora* ABT. The interpretation is further substantiated by common and consistent records of *Systematophora* spp., mostly *S. areolata* and *S. fasciculigera*, together with the presence of *Leptodinium mirabile*.

Early?-Mid Oxfordian 3354m-3402m

Age and biozone assignments are based on;

LFO *Sentusidinium creberbarbatum* at 3354m (**JZ30?-31**).

FO *Systematophora fasciculigera* at 3366m (**JZ31** or younger).

FO *Systematophora areolata* at 3402m (**JZ31** or younger).

Evidence for penetration of Early Oxfordian sediments is very minor, based on a small downhole increase of *S. creberbarbatum*, which occurs close to the Early-Mid Oxfordian boundary.

Although modified by variable degrees of caving and/or reworking, most samples yielded representative assemblages typical of the lower Mid Oxfordian (lower JZ31). Characteristic species include *R. aemula* SA, *Systematophora* spp., *G. jurassica longicornis*, *Batiacasphaera* sp. (granulate) **FREQ**, *Stephanelytron redcliffense*, *Sentusidinium creberbarbatum* **FREQ** and *Endoscrinium galeritum*. In particular, the consistent, or common occurrence of *Systematophora* spp. throughout the interval suggests a Mid Oxfordian age is most probable.

Early?-Mid Oxfordian? 3408m-3414m

The age and biozonal interpretation is based on the age of the overlying interval, together with the consistent, though sparse Heather Formation dinocysts. Clearly these may be caved, and the assignment should be considered as very tentative.

Indeterminate interval, possibly Triassic? 3420m-3649m

A confident age, or biozonal assignment is not possible for the entire lower half of the interval studied from the well due to the absence of palynological evidence. Most samples are significantly contaminated by caved taxa, especially from the Lista, Sele and Draupne formations. By implication, it is also likely that sporadic occurrences of Callovian-Oxfordian taxa encountered are also caved. No representative microfloras were observed and we consider that the majority, or all of the samples are probably barren of *in situ* palynomorphs.

The only lithostratigraphic units in the area that is consistently barren, or yield severely impoverished microfloras are the Skagerrak and Smith Bank formations. This is the only basis on which to suggest a possible Triassic age for the interval.

MID JURASSIC ZONATION			AMMONITE CHRONOZONE	ZONE	BIOEVENTS
Age	Stage	Substage			
165	Callovian	Lt.	lamberti	JZ28	M. groenlandicum CMN, C. dictydia, P. paracalathus L.jurassica, L.cristi/caytonensis, L.callovianum R.gochtii E.evittii W.fimbriata S.vesitum CMN
			athleta	JZ27	W. acollaris, D. filapicata, L. spongiosa, C. ectotabulata, K. hypornatum
			coronatum	JZ26	C. dictydia CMN, A.cf.teichophora, C.pachydermum
		M.	jason	JZ25	b N. pellicuda CMN, C.cf."edentulum" C.pachydermum CMN N.pellicuda CMN C.cf."edentulum"
			calloviense	JZ24	a K.hypornatum CMN, C.varisposum C.hyalina CMN, P.calloviensis/retiphragmata C.polygonicum
			koenigi		K.hypornatum ssp. A G.pectinigera, D.asketa
	E.	herveyi	JZ23	A.aldorfensis, Polystephanophorus sp. A A.aldorfensis ACME Poly.sp. A ACME	
	Bathonian	Lt.	discus	JZ22	G. pectinigera CMN, Q. anellaformis V.ampulla Poly.sp. A, C.varisposum
			orbis	JZ21	E."inflata", C.gochtii, V.ampulla CMN Crussolia? sp. A, V.spinusum, V.vermicylindratum E."inflata" ACME Crussolia? sp. A ACME
		M.	hodsoni	JZ20	d N.pellicuda Late Bathonian ACME C."edentulum" DOM N.pellicuda, T."horridus" D.aspera T."acquirruccatus", I."latimurus", K."cycalus"
			morrissi		c D.aspera D.aspera CMN D.aspera ACME
			subcontractus		b D.aspera D.aspera CMN D.aspera ACME
progracilis		a D.daveyi, C.perireticulata CMN D.willei CMN, D.daveyi CMN S.grossii			
E.	zigzag	JZ19	D. omentifera CMN, B. "murchisoni", C. cf. dictydia		
Bajocian	Lt.	parkinsoni	JZ17	b D. psilatam CMN, B. "murchisoni" CMN D. psilatam CMN	
		garantiana	JZ16	a P. thomasii, N. gracilis/senex, B. asymmetra CMN B. laevigata CMN, B. pelionense DOM, E. granochagrinata B. "murchisoni" CMN D. omentifera CMN R.gochtii, P. thomasii CMN	
		niortense		b V. brevipellitum, V. vermicypellitum, E. spongogramulata E. granochagrinata/"granulosa" ACME	
	E.	humphriesianum	JZ15	N. gracilis/senex CMN, S. scrofoides, N. raunggardii CMN, S. priscus, V. armatum N. raunggardii CMN (=N.spiculata sensu BioStrat)	
		propinquans	JZ14	L. cf. spinosa, K. distincta Classopolis ACME	
		laeviuscula	JZ13	N. ambonis, N. diktyambonis, M. semitabulatum N. truncata	
Aalenian	Lt.	concovum	JZ12	N. tricerias, F. senilis, E. eschachensis, D. willei ABT (local) D. willei CMN (local)	
		bradfordensis		S. weberi, K. praussii, N. gracilis/senex ABT, N. plegas, O. pseudochyroides E. granochagrinata CMN E. eschachensis	
	M.	murchinsonae		S. priscus CMN Evansia/Caddisphaera ACME	
		opalinum	JZ11	P. bululla, P. nasuta, P. nasuta sensu Riding et al., P. racens, S. knertene, R. cardobarbata, R. holotabulata (cons) S. priscus ACME	
	E.			P. frommernensis	

Appendix 1. Middle Jurassic zonation

CHRONOSTRAT			AMMONITE CHRONOZONE	BIOZONE BioStrat Ltd	BIOEVENTS	
Age	Stage	Substage				
145	Berriasian	RYAZANIAN (pars)	stenomphalus	EKZ4	O. diluculum CMN, D. boresphaera, E. sarjantii, S. arbusatum, C. comptum CMN, AOM ABT	
			iceni		B. radiculatum, S. dictyophorum, K. porospinum CMN	
			kochi		R. thula, C. comptum ABT	
			runctoni		S. daveyi, E. expiratum, A. daveyi	
			lampughi		C. gigas, G. virgula, Aldorfia sp. A Davey, Gochtedinia sp. 1 Davey, L. cf. subtile Group, Cribroperidinium spp. CMN, E. gochtii, Kalliosphaeridium cf. OB1	
		VOLGIAN	Lt	preplicomphalus	EKZ1	S. daveyi CMN, W. krutschii CMN, P. insolitum
				primitivus		E. polyplacophorum (rare)
				oppressus		C. gigas CMN
				anguliformis		P. insolitum CMN, G. virgula, Gochtedinia sp. 1 Davey, E. polyplacophorum (cons.), C. hystrix/distinctum CMN, A. haromense (cons.)
				kerberus		G. dimorphum, C. paneum, S. jurassica, M. simplex, Rhynchodiniopsis sp. G, S. jurassica FREQ, M. simplex CMN, E. cf. gochtii CMN, S. clavellii
	Tithonian	M	glaucolithus	JZ45	G. mutabilis, E. ovatum	
			albani		P. granulatum, S. inriabile, O. balia, R. martonense, A. "volgensis"	
			fittoni		O. patulum (rare) K. telaspinum, A. staffinensis, C. chyroides	
			rotunda		A. "volgensis" FREQ, O. patulum (consistent)	
			pallasioides		Cassicosphaeridia sp. VFR ABT	
		E	pectinatus	JZ44	C. copei	
			hudlestoni		P. ingeerdiae, C. copei CMN, S. jurassica CMN	
			wheatlevis		O. patulum CMN, Kalliosphaeridium OB1	
			scitulus		C. longicorne, O. patulum ABT	
			elegans		P. pannosum, C. longicorne FREQ, T. egemii	
150	Kimmeridgian	autissiodorensis	JZ41	S. paemiosa, S. inaffecta, C. longicorne ACME, E. luridum, G. jurassica, C. crassinervum, C. complexum		
		eudoxus		"Parahystrichodinium" ACME		
		mutabilis		P. pannosum CMN, H. ornata, K. suevicum, S. paemiosa CMN		
		cymodoce		S. scarburghensis, L. mirabile, T. unctispina		
		baylei		D. jurassicum FREQ		
	Oxfordian	Lt	rosenkrantzi	JZ36	A. staffinensis CMN, R. cladophora CMN, S. crystallinum CMN	
			regulare		S. redcliffense, E. galerium, L. mirabile CMN, S. "magnusense", B. "periphragmata"	
			serratum		E. galerium CMN, T. eisenackii, N. jubilaea, B. "microreticulata"	
		M	glosense	JZ33	C. polonicum, N. pellucida, G. jurassica longicornis	
			tenuiserratum		R. aemula, C. cerastes	
E	densiplicatum	JZ31	R. aemula CMN, L. scarburghensis			
	cordatum		R. aemula CMN, W. fimbriata CMN, P. prolungata, C. continuum			
	mariae		N. pellucida E. Oxfordian ACME			
155	Kimmeridgian	eudoxus	JZ40	S. paemiosa CMN, P. pannosum CMN, K. suevicum, P. pannosum, S. paemiosa, S. inaffecta		
		mutabilis		D. jurassicum FREQ		
		cymodoce		G. jurassica FREQ		
		baylei		S. crystallinum, G. jurassica CMN		
		rosenkrantzi		A. staffinensis CMN, R. cladophora CMN, S. crystallinum CMN		
	Oxfordian	Lt	regulare	JZ35	S. redcliffense, E. galerium, L. mirabile CMN, S. "magnusense", B. "periphragmata"	
			serratum		E. galerium CMN, T. eisenackii, N. jubilaea, B. "microreticulata"	
			glosense		C. polonicum, N. pellucida, G. jurassica longicornis	
		M	tenuiserratum	JZ32	R. aemula, C. cerastes	
			densiplicatum		R. aemula CMN, L. scarburghensis	
E	cordatum	JZ30	R. aemula CMN, W. fimbriata CMN, P. prolungata, C. continuum			
	mariae		N. pellucida E. Oxfordian ACME			
	cordatum		S. vestitum CMN, W. fimbriata CMN, P. prolungata, C. continuum			
160	Oxfordian	cordatum	JZ30	S. vestitum CMN, W. fimbriata CMN, P. prolungata, C. continuum		
		mariae		N. pellucida E. Oxfordian ACME		
		cordatum		S. vestitum CMN, W. fimbriata CMN, P. prolungata, C. continuum		
		mariae		N. pellucida E. Oxfordian ACME		
		cordatum		S. vestitum CMN, W. fimbriata CMN, P. prolungata, C. continuum		
	Tithonian	E	scitulus	JZ42	S. paemiosa, S. inaffecta, C. longicorne ACME, E. luridum, G. jurassica, C. crassinervum, C. complexum	
			scitulus		S. paemiosa, S. inaffecta, C. longicorne ACME, E. luridum, G. jurassica, C. crassinervum, C. complexum	
			scitulus		S. paemiosa, S. inaffecta, C. longicorne ACME, E. luridum, G. jurassica, C. crassinervum, C. complexum	
			scitulus		S. paemiosa, S. inaffecta, C. longicorne ACME, E. luridum, G. jurassica, C. crassinervum, C. complexum	
			scitulus		S. paemiosa, S. inaffecta, C. longicorne ACME, E. luridum, G. jurassica, C. crassinervum, C. complexum	

Appendix 2. Late Jurassic zonation

Mid Oxfordian	JZ32		R.aemula, C.cerastes
	JZ31		R.aemula ABT L.scarburghensis, G. j. longicornis C.cerastes CMN G.j.longicornis CMN L.mirabile
Early Oxfordian	JZ30		L.scarburghensis ABT, W.fimbriata, W.thysanota S.vestitum ABT, W.fimbriata CMN P.prolongata, C.continuum R.aemula ACME
	JZ29	b a	N.pellucida CMN M.groenlandicum CMN, L.scarburghensis ABT C.dictydia, P. paracalathus
Late Callovian	JZ28	b a	P.ceratophora ACME W.fimbriata, W. thysanota, S. vestitum ABT E. evittii E.galeritum W.acollaris, D.filipicatum, K.hypornatum L.scarburghensis S.crystallinum
	JZ27		C.dictydia ABT
	JZ26		R.aemula, B.asaphum
Mid Callovian	JZ25	b a	Kdiceras CMN, C. pachydermum CMN N.pellucida CMN W.digitata L.spongiosa CMN, C.thulium L. planoseptata CMN, C.torosus CMN C.varispin., K.hyporn CMN G.j.longicornis C.hyalina ABT, S.redcliff., S.creberbarbatum
	JZ24		C.policum D.cf.willei ABT, K.hypornatum ssp.A C.varispinosum CMN G. pectinigera
Early Callovian	JZ23		A.altdorfensis C.varispinosum CMN Polysteph. sp.A Q.anellaeformis, G.pectinigera CMN
	JZ22		C.varispinosum Poly sp. A E."inflata", C.gochtii, Crussolia sp.A
Late Bathonian	JZ21		N.pellucida CMN Tuberositriletes spp, K."cyclus" C."edentulum" ABT I."latimurus"

Appendix 3. Quad 15 zonation.

