Nature and timing of Late Mississippian to Mid Pennsylvanian glacio-eustatic sea-level changes of the Pennine Basin, UK

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Abstract: The Pennine Basin of northern England contains a comparatively complete Serpukhovian–Moscovian succession characterised by high-resolution ammonoid zonation and cyclic paralic sedimentation. Two new ID-TIMS zircon ages from a bentonite deposited during the Arnsbergian (mid-Serpukhovian) regional substage and tonstein of earliest Bolsovian (early Moscovian) regional substage, have been determined. The weighted mean $^{206}Pb/^{238}U$ ages of 328.34 ± 0.55 and 314.37 ± 0.53 Ma (total uncertainty), respectively, require modification of the timescale for the Western Europe regional chronostratigraphy.

The areal extent of acme ammonoid facies are used as a proxy for the magnitude of 47 discrete flooding events. Incised valleys (major sequence boundaries) are used as a proxy for the magnitude of sea-level falls. The frequency of these events, in the light of the new radiometric dating, indicates: (1) temporal coincidence between major glaciations in Gondwana and phases of increased frequency of sequence boundaries in the Pennine Basin; (2) high amplitude flooding surfaces have an average frequency of *c*. 400 ka; (3) average cycle durations during the Pendleian–early Arnsbergian and Chokierian–Bolsovian, of *c*.111 ka and *c*.150 ka, respectively, reflect short-duration eccentricities, and (4) multiple flooding surfaces with the same ammonoid assemblages may equate with sub-100 ka precession/obliquity frequencies.

Supplementary material: U-Pb method description and data, procedure for the calculation of the areal extent of marine bands and tables showing a full listing of biostratigraphical data used in the study are available at www.geolsoc.org.uk/SUPXXXXX.

Limited data exists for constraining the Carboniferous timescale (Davydov *et al*. 2004), representing a major limitation of our understanding of biological and environmental change, their linkages, and the rates at which change occurred during that interval. The current timescale for the Carboniferous (Davydov *et al*. 2004, modified by Ogg *et al*. 2008) is largely derived from dating of international stages, defined by a conodont-based stratigraphy. However many parts of the world, including the equatorial paralic basins of Western Europe and eastern USA, and regions located close to a palaeopole (e.g. Australia) cannot successfully use this scheme due to the lack of suitable fauna. The development of truly global geological 'timescales' requires the calibration, via radio-isotopic dating, and integration, of several different biostratigraphical schemes.

During the Carboniferous-Permian 'icehouse' global scale climate oscillations occurred at varying timescales. The Gondwanan glacial record suggests a series of distinct and 'short-lived' (1–4 Ma) glacial episodes (Fielding *et al*. 2008) whereas the equatorial 'Laurussia' records both 'long' and 'short' climate fluctuation. Outstanding issues for understanding Carboniferous-Permian environmental change include determination of the timing, duration and tempo of glaciation and the equatorial response to changes in polar regions.

This paper integrates bio- and litho-stratigraphic analyses of mid Carboniferous (Serpukhovian to Moscovian) strata of the Pennine Basin of central and northern England and North Wales (Fig. 1) combined with new U-Pb dating with the overarching aim of developing an integrated biostratigraphic, geochronologic and palaeoenvironmental dataset. There are two specific aims: (1) the high-precision calibration of mid-Carboniferous biostratigraphic zonation for Western Europe; (2) assessment of cyclic marine bands in relationship to known orbital forcings via glacio-eustatic sea-level fluctuation.

Previous attempts at estimating the duration of Namurian and Westphalian cyclicity have assumed a constant forcing mechanism during the entire interval. In this study we investigate that premise and present evidence for variations in the magnitude of flooding and regressive events which aid determination of a cyclostratigraphy for the succession.

Summary of existing radiometric dates

Hess & Lippolt (1986) and Berger *et al*. (1997) derived $^{40}Ar/^{39}Ar$ sanidine plateau dates from German and Czech tonsteins which suggested that the combined duration of the Namurian and Westphalian (broadly Serpukhovian to Moscovian) was about 21 Ma. The age determinations were largely for Stephanian, Bolsovian and early to mid Namurian tonsteins (Table 1) and provided no dates at the base of either the Namurian or Westphalian regional stages.

Recalibration of the MMHb-1 mineral standard, summarised in Davydov *et al*. (2004) results in revised ages which approximate to determinations using U−Pb TIMS (Table 1). Hess & Lippolt (1986) provided age uncertainties of 1.0 to 9.2 Ma (2σ); revised by Claoué-Long *et al*. (1995) to uncertainties of 7.4 to 10.0 Ma (2σ) based upon consideration of the uncertainties in the age of standard mineral against which the $^{40}Ar/^{39}Ar$ dates are calibrated. The limited biostratigraphical control in the German/Czech succession also limits the precise correlation of these dates globally.

$^{206}Pb/^{238}U$ zircon dates using the SHRIMP ion microprobe have provided Asbian (late Visean) dates of 334 ± 4 Ma (2σ) from Poland (Kryza *et al*. 2010), Arnsbergian (early Namurian) dates of 314.5 ± 4.6 Ma (2σ) for the Pennine Basin, UK (Riley *et al*. 1995), and Bolsovian (Westphalian) dates of 311.0 ± 3.4 Ma (2σ) from Germany (Claoué-Long *et al*. 1995). These suggest a *c*. 3.5 Ma duration for much of the Namurian and Westphalian, combined. The potential inaccuracies related to standardisation (Ireland & Williams 2003), in addition to the reported uncertainties, for the U-Pb SHRIMP dates discussed above do not permit a precise duration of the intervals required for the advancement of Carboniferous stratigraphy.

The U-Pb SHRIMP dates are at odds with recent timescales (Davydov *et al*. 2004, modified by Ogg *et al*. 2008) and high precision ID-TIMS U-Pb zircon ages for the Donetz Basin (Davydov *et al*. 2010). The latter work provides errors of about 100 ka, of sufficient resolution to be useful in determining the duration of marine band cyclicity. However, ammonoids are rare in the Donetz Basin and the main biostratigraphical correlations are based on foraminiferal zones. Although correlation at the substage level between the Pennine and Donetz basins is established, it is not possible to directly correlate the ages with specific marine bands in the UK. The work of Davydov *et al*. (2010) is significant in that it provides a 328.14 ± 0.11 Ma age for the early−mid Pendleian and a 314.40 ± 0.06 Ma age for the early Bolsovian, more than 3 Ma older than previous determinations using $^{40}Ar/^{39}Ar$ and $^{206}Pb/^{238}U$ SHRIMP techniques (Table 1), most likely reflecting errors in the standardisation of both the $^{40}Ar/^{39}Ar$ and $^{206}Pb/^{238}U$ SHRIMP dates. The Bolsovian would now appear to be in excess of 4 Ma in duration (Davydov *et al*. 2010). Two U-Pb ID-TIMS zircon ages from the Silesian Basin, 328.84 ± 0.38 Ma and 328.01 ± 0.36 Ma (total uncertainty) from early Pendleian and late Pendleian strata, respectively, have been determined (Gastaldo *et al*. 2009). These authors extrapolate cycle duration to produce an estimate of 329.7 Ma, rounded up to 330 Ma for the base of the Serpukhovian.

The U-Pb TIMS age of 326.8 ± 0.98 Ma of Trapp & Kaufmann (2002) from Germany is derived from a bentonite found within the ammonoid *Goniatites crenistria* (P1) Zone of late Asbian age (Waters *et al.* 2011).

U-Pb Geochronology

Sample localities

Bentonites found within Namurian strata comprise typically mixed-layer illite–smectite with subordinate kaolinite (i.e. K-bentonites). The trace element geochemistry is indicative of a rhyodacite-dacite composition for the late Pendleian to Arnsbergian ashfall deposits (Spears *et al*. 1999). Tonsteins are kaolinite aggregates, typically present in Westphalian strata in the Pennine Basin, interpreted as kaolinised volcanic ash-falls or reworked volcanic detritus, with both acid and basic tonsteins recognised geochemically (Spears & Kanaris-Sotiriou 1979). Bentonites and tonsteins most likely to contain primary zircons and with minimal siliciclastic contamination were selected. Eleven localities/boreholes were investigated with the aim of providing a broad range of dates for Brigantian (late Visean) to Bolsovian (late Westphalian) strata. However, following heavy mineral separation and age-screening using laser ablation inductively coupled plasma ionisation mass spectrometry (LA-ICP-MS) only two samples contained sufficient primary zircons to make dating chemical abrasion isotope-dilution thermal ionisation mass spectrometry (CA-ID-TIMS, see below) worthwhile.

The bentonite sample BLL1976 from the BGS Harewood Borehole (Fig. 1), West Yorkshire [BNG 43220 44410] at a depth of 304.10 m, were interpreted by Riley *et al*. (1995) as representing bentonite B6 of Trewin (1968). BLL1976 occurs within the upper part of the *Eumorphoceras yatesae* ($E_{2a}3$) Marine Band of early Arnsbergian age and is equivalent to the sample analysed by Riley *et al*. (1995) for which their SHRIMP U/Pb date of 314.4 ± 4.6 Ma was acquired using the SL13 zircon standard for U/Pb calibration.

Sample EH28155 from the Holme Pierrepont Borehole (Fig. 1), Nottinghamshire [BNG 46306 33933] at a depth of 181.8 m comes from the Sub-High Main tonstein, located 14 m above the Aegiranum Marine Band, the base of which marks the base of the Bolsovian regional substage. The stratigraphically nearest dated horizon is the Z1 tonstein from the Ruhr Coalfield, located just below the Aegiranum Marine Band. Hess & Lippolt (1986) provide a $^{40}Ar/^{39}Ar$ sanidine plateau date of 310.7 ± 2.6 Ma (2σ) relative to MMHb-1 mineral standard using an age of 519.5 Ma. Claoué-Long *et al*. (1995) determined 39 measurements of 37 zircons from the Z1 tonstein, with a mean U–Pb SHRIMP age of 311.0 ± 3.4 Ma (2σ).

Results

Zircons were analysed using CA-ID-TIMS methodologies employed at NERC Isotope Geoscience Laboratory (NIGL), details of which are outlined in an online supplemental material along with the tabulated results of the analytical programme. However, two important points are outlined here: (1) prior to dissolution zircons were subject to a modified chemical abrasion pre-treatement for the effective elimination of Pb-loss (Mattinson 2005); and (2) the accuracy of the ^{238}U/^{206}Pb dates presented herein are controlled by the gravimetric calibration of the EARTHTIME U-Pb tracer employed in this study and the determination of the ^{238}U decay constant (Condon *et al*. 2007; Jaffey *et al*. 1971). Zircons separated from both bentonite samples BLL1976 and EH28155 were small (<50 μm) with aspect ratios of ~1.5 to ~3. For sample BLL1976 seventeen fractions (single grains) were analysed, with the resulting data presented and their interpretation discussed in more detail in the online supplemental material. In brief, ^{206}Pb/^{238}U dates between 311 and 334 Ma (Fig. 2) with a distinct population (defined by 11 of the 17) of analyses yielding a weighted mean ^{206}Pb/^{238}U date of 328.34 ± 0.30(0.43)[0.55] [1] Ma (Mean square weighted deviation, MSWD = 2.2), which is interpreted as being the best estimate for the zircons of this sample and inferentially the age of bentonite at the sampled stratigraphic level. For sample EH28155 nine fractions (single grains) were analysed, and the resulting data are presented in Figure 2. Two of the nine analyses produced U-Pb dates older than the constraint imposed by sample BLL 1976 (see above). The remaining seven analyses yielded ^{206}Pb/^{238}U dates between 306 and 317 Ma (Fig. 2) with a distinct population (defined by 4 of the 7) of concordant anlyses yielding a weighted mean ^{206}Pb/^{238}U date of 314.37 ± 0.25(0.40)[0.53] [1] Ma (MSWD = 1.07) which is interpreted as being the best estimate for the zircons of this sample. In both samples the U/Pb dates that are older than the main population are interpeted as reflecting the analyses of zircon ante-/xeno-crysts, and grains that are younger as reflecting Pb-loss (Fig. 2) and interpretation that is supported by consideration of biostratigraphic and geochronologic constraints (e.g., Davydov *et al*. 2010).

[1]Errors presented in format ±X(Y)[Z]: X- internal or analytical uncertainty in absence of all systematic error (tracer calibration and decay constants); Y includes the quadratic addition of tracer calibration error (using a conservative estimate of the 2σ standard deviation of 0.1% for the Pb/U ratio in the tracer); Z includes the quadratic addition of both tracer calibration error and additional ^{238}U decay constant errors (see online supplemental information).

These two new ages for the early Arnsbergian and early Bolsovian are significantly older than existing published U-Pb SHRIMP and $^{40}Ar/^{39}Ar$ sanidine plateau dates for equivalent strata in Western Europe. Closer comparison with the $^{40}Ar/^{39}Ar$ ages is evident when recalibration of the mineral standard is taken into consideration, but the errors are too great to make the ages of any use in understanding basin evolution timing. The new ages align (within 2σ errors) with recent U-Pb ID-TIMS zircon ages from the Donetz Basin (Davydov *et al*. 2010).

Stratigraphic analyses

Marine band cyclicity referenced in the Pennine Basin

The 'cyclicity' of marine bands in the palaeo-equatorial Carboniferous Pennine Basin is considered by many (e.g. Holdsworth & Collinson 1988; Maynard & Leeder 1992; Martinsen *et al*. 1995; Hampson *et al*. 1997; Waters & Davies 2006) to be driven by eustatic sea-level fluctuations, a far-field response to polar environmental fluctuations in ice-sheet volume in the southern hemisphere (Veevers & Powell 1987; Isbell *et al*. 2003). Many of the marine bands recognised within the Pennine Basin can also be found in separate basins in Scotland, Ireland, northern France, Belgium, Holland and Germany (Ramsbottom 1979), indicating that sea-level rise, as opposed to regional subsidence, was the primary control of marine band formation. This marine band cyclicity is evident throughout strata of Pendleian (early Namurian) to Bolsovian (late Westphalian) age.

The marine bands occur at the base of marine to non-marine upward-coarsening cycles, equating to the parasequence of the Exxon sequence-stratigraphic model (Posamentier *et al.* 1988). The marine bands are taken to represent transgressive systems tracts and maximum flooding surfaces, with the acme marine facies coinciding with the maximum rate in rise of the sea-level curve (Posamentier *et al.* 1988). Alternatively, Martinsen *et al*. (1995) argue that due to the lengthy and sinuous nature of connections between the open sea and the basin, the condensed section represented by each of the ammonoid-bearing marine bands is likely to coincide with a maximum of the sea-level curve.

The periodicity of cyclicity has been estimated at 185 ka (Holdsworth & Collinson 1988), 120 ka (Maynard & Leeder 1992), or 65 ka based on SHRIMP U-Pb (zircon) dates (Riley *et al*. 1995). These values are consistent with eccentricity-forced modulation frequencies. The amplitude of sea-level variation has been estimated at about 42 m (Maynard & Leeder 1992) or 60 m (Church & Gawthorpe 1994), during the Namurian. The above estimated periodicities were based upon assumptions of a constant forcing during the entire interval and using time intervals for the Namurian which are shown in this study to lack required precision. For example, if we consider the 2σ *c*. 4 Ma uncertainties on the SHRIMP U-Pb (zircon) dates the total duration of this interval could range from ca. 0 to 11 Ma, or greater if SHRIMP U-Pb (zircon) dates are inaccurate, which has a great effect on the average cycle duration.

The existence of a superimposed higher-frequency obliquity or precession cyclicity, of lesser amplitude, has been proposed within the Pennine Basin (e.g. Brettle 2001; Waters *et al*. 2008; Tucker *et al*. 2009). In addition, Ramsbottom (1977) identified long-duration cyclic units, which he termed mesothems. He proposed eleven 'mesothemic' cycles for the British Namurian (Table 2), linked to the appearance of new ammonoid genera, and controlled by longer duration eustatic sea-level fluctuations, which he estimated to have an average duration of 1.1–1.35 Ma (Ramsbottom 1979). Similarly, Ramsbottom (1979) proposed the presence of ten mesothems within the Westphalian succession, of average duration of 1.66 Ma, with the lowermost coinciding with the uppermost Namurian mesothem (Table 3). Both Namurian and Westphalian mesothems were described as comprising pulsed marine transgressions in which each successive transgression is increasingly extensive, with the top of the mesothem marked by the most widespread marine band, commonly with a widely developed ammonoid facies (Ramsbottom 1979). The boundaries of the mesothems are marked by widespread disconformities in shelf areas. Sequence-stratigraphic terminology would consider the mesothems to broadly represent sequences (Posamentier *et al.* 1988), although the mesothem boundaries were taken at the top of major fluvial sandbodies and not at the sequence boundary at the base. The upper cycles of each Namurian mesothem were considered to be typically sandstone-dominated and associated with overall base-level fall and progressive progradation of fluvial systems further into the basin (Ramsbottom 1977). Holdsworth & Collinson (1988) provided a rigorous critique of the mesothemic concept, arguing that the linkage of sand-dominated cycles with regression and the major ammonoid turnover of taxa at mesothem boundaries could not be demonstrated. They also argued against the lateral extent of ammonoid-bearing marine bands being suitable as a means to deduce the form of major eustatic curves. Holdsworth & Collinson (1988) also considered that the example used by Ramsbottom (1977) of the transition between the Askrigg Block and Craven Basin (Fig. 1) is invalidated by the potential of tectonic uplift and subsidence influencing the areal extent of marine bands.

New observations on a Namurian-Westphalian marine band cyclostratigraphy

The areal extent of marine bands is primarily a function of the magnitude of eustatic sea-level rise, influenced by basin topography and subsidence/uplift rates. Hence, to use the areal extents of marine bands as a proxy of relative magnitude of sea-level rise it is important to understand the relative significance of these factors. The Southern Uplands High and Wales-Brabant Massif, bounding, respectively, the northern and southern margins of the Pennine Basin (Fig. 1), form topographical highs throughout the Carboniferous, and flooding events do not extend across them. The Namurian to early Westphalian interval covered by this study was a time of the onset of broad thermal subsidence between the Southern Uplands High and Wales-Brabant Massif (Leeder 1982). Waters *et al*. (1994) provided evidence that pulses of basin extension continued, though on a much reduced scale, during the thermal subsidence phase until Bolsovian times, at which time Variscan compressional structures became increasingly important, culminating in the end Carboniferous inversion of the entire basin. Deformation varied from growth folding within thick successions toward the basin depocentre to development of angular unconformities at the basin margin (Waters *et al*. 1994). Although such deformation may locally influence the absence of ammonoid fauna in the peripheral parts of the basin for some flooding events, by studying the basin as a whole it is considered that tectonism has no or only minimal influence on the extent of the majority of marine bands.

The ‘Block and Basin’ topography generated during Late Devonian to Mid Mississippian rifting (Leeder 1982) was gradually infilled by fluvio-deltaic sediments during Namurian times. However, this infilling was a diachronous process, starting in the north of the basin during the Pendleian, and the inherited basinal topography was only largely infilled by fluvio-deltaic sediments in the south by late Marsdenian times (Church & Gawthorpe 1994; Jones & Chisholm 1997; Waters & Davies 2006). Hence, flooding events, particularly during the early Namurian and in the south of the Pennine Basin, were in part constrained to the relict topographical lows associated with former half grabens and grabens, and only the highest sea-level maxima resulted in marine inundation of the block areas. By Westphalian times the fluvio-lacustrine sedimentation was associated with low-profile delta plains occupying the entire basin and in which flooding events were able to extend unconfined across the delta top. Subsidence rates were greatest in the basin depocentre around south Lancashire (Calver 1968), but this was not expressed as a topographical low (Rippon 1996). Hence, during Westphalian times, the marine band extent closely relates to the magnitude of sea-level rise.

The extents of Namurian marine bands within the Pennine Basin have been poorly delineated by previous workers, with the exception of the *Cancelloceras* (*Gastrioceras*) *cumbriense* Marine Band (Wignall 1987). During the current study, only the extent of the acme ammonoid facies was determined, as it is this that displays the diagnostic fauna which allows the unique identification of each marine band. The methodology by which the extents of the marine bands were defined is described in the online supplemental material. The extent of each of the Namurian ammonoid-bearing marine bands is shown in figures 3 and 4a–d. In contrast, marine bands within the Westphalian succession are well documented, with the extents of the various faunal phases shown for each flooding event (Calver 1968, 1969). Only eight of the 24 Westphalian marine bands include an acme ammonoid facies (Table 3) and only those marine bands are delineated in Figure 4e–f, again showing only the extent of the ammonoid facies. Westphalian marine bands with less diagnostic fauna, such as thin-shelled ammonoids (*Anthracoceras*), marine bivalves (*Dunbarella*), brachiopods (*Lingula*) and foraminifera, record a transition in salinity from marine to brackish environments, with four of the marine bands characterised by the presence of the branchiopod crustacean *Estheria*, interpreted as occurring within a transitional zone between swamp and marine environments (Calver 1968).

The early Namurian marine bands show compartmentalisation within small areas. This in part reflects the prominent basin topography at the time, with flooding events tending to be limited in extent to the unfilled Visean sub-basins. Also, the outcrop of these successions is relatively isolated, with successions of this age poorly known at depth within the central part of the basin. Furthermore, many of the early Namurian marine bands occur within mudstone-dominated successions lacking intervening deltaic intervals, making identification of the specific marine band at times difficult. As a result, fewer early Namurian exposures were included in the study compared with later Namurian marine bands. Consequently, comparisons between early Namurian and late Namurian magnitudes of sea-levels should be done with care, but within each of these intervals, comparison of individual flooding event extents was considered justifiable.

By Marsdenian times, the ammonoid facies components of marine bands appear to be more laterally extensive, centred upon the area of greatest magnitude of subsidence in south Lancashire (Fig. 4b–c). The pre-Namurian basin topography was largely infilled and accommodation space was the product of eustatic sea-level rises in combination with broad thermal subsidence of the Pennine Basin. This pattern continued into Langsettian and Duckmantian times (Fig. 4e–f). Bolsovian marine bands appear to show a slight shift of the focus of the ammonoid facies eastwards, towards the East Midlands, and are generally less extensive. The Cambriense Marine Band represents the final marine flooding event to affect the Pennine Basin (Guion *et al*. 1995; Aitkenhead *et al.* 2002; Waters *et al*. 2011).

Incised valley fills in the Pennine Basin and evidence for major regressive events

Discontinuities and unconformities are present within the Pennine Basin, though it is only within recent decades that their significance has been recognised. These major Type 1 unconformities, evident as incised palaeovalleys, represent sequence boundaries (Posamentier *et al.* 1988). Although many cycles include an upper fluvial-deltaic component, there has been a tendency to over interpret all boundaries with an overlying coarser grained succession to represent a Type 2 sequence boundary. The significance of these surfaces, whether they be the product of sea-level falls complementing sea-level rises indicated by the marine bands, or through deltaic avulsion during distinct flooding events, remains controversial (Waters *et al*. 2008) and, as a result, Type 2 sequence boundaries are not considered in this study. A number of Namurian and Westphalian thick, multi-storey fluvial complexes have been interpreted as sediments deposited in palaeovalleys generated by incision during significant sea-level fall.

Most Namurian-aged multi-storey sandstone bodies are 10-30 km wide and the preserved thickness is 25-35 m (Davies *et al*. 1999). Much of the evidence for low base levels and fluvial incision during the early Namurian comes from the comparatively condensed successions above the Alston and Askrigg Blocks (Fig. 1). Above the Alston Block, the Rogerley Channel (Fig. 3a), of north-south orientation, is up to 4 km wide and is associated with up to 30-40 m of erosional relief, including localised removal of the marine Knucton Shell Bed (Dunham 1990). The incised valley formed at approximately the same time as a major intra-E_{1c} angular unconformity, associated with the northward tilting and subsequent erosion of the Askrigg Block (Brandon *et al*. 1995). Within the lowermost Arnsbergian $E_{2a}1$ cycle of the western part of the Askrigg Block (Fig. 3b), a lowstand erosion surface is recognised below the Upper Howgate Edge Grit (Martinsen 1993; Martinsen *et al*. 1995), though with insufficient erosion to remove the underlying *Cravenoceras cowlingense* Marine Band (Table 2). A younger Arnsbergian succession on the Askrigg Block (Fig. 3b) includes a prominent intra-$E_{2a}3$ unconformity below the Red Scar Grit (and equivalent sandstones). An erosional relief of up to 100 m, associated with the removal of four marine bands may in part coincide with tectonic activity (Brandon *et al*. 1995). An intra-$E_{2c}2$ erosion surface at the base of the Lower Follifoot Grit in the southeast of the Askrigg Block (Fig. 3c) is associated with complete removal of the $E_{2c}1$ cycle, with the unconformity resting upon the $E_{2b}3$ marine band (Martinsen 1993; Martinsen *et al*. 1995). An unconformity is demonstrated in the northern part of the Craven Basin, occurring immediately beneath the $H_{1a}3$ marine band, with spores of $E_{2c}4$ present beneath the erosive surface, but no incised valley fill sandbody is recorded (Owens *et al*. 1990). In the southeastern part of the Askrigg Block (Fig. 3d), the markedly erosive base of the fluvial channel of the Upper Follifoot Grit, with pedogenically modified interfluves, suggest base level fall within the $H_{1b}2$ subzone (Martinsen 1993).

Kinderscoutian to Yeadonian sandbodies have been subject to the most scrutiny within the central part of the Pennine Basin, with two distinct settings for development of incision. Some valley fills show a marked increase in thickness towards, and immediately upstream of the mouth of the incised valley, developed in association with turbidite-fronted deltas within steep submarine slopes. These sandbodies thicken from 20–30 m to 50–80 m over a distance of 2-5 km and are filled with giant foresets (Hampson *et al*. 1999). These valley fills occur within the earliest deltaic infill of the Pennine Basin, ranging from Kinderscoutian within the central part of the basin, to Yeadonian in the south. In contrast, extensive sheet-like sandstones, up to 45 m thick and up to 70 km wide (Hampson *et al*. 1999), develop mainly within Marsdenian to Yeadonian successions and are associated with little basinal topography.

The Kinderscoutian Lower Kinderscout Grit (Hampson 1997) and associated basal turbidite channel of the Todmorden Grit (Fig. 4a), of probable $R_{1c}3$ age, display local erosion of two R_{1c} marine bands. The uppermost Kinderscoutian cycle includes a marked erosive surface at the base of the Upper Kinderscout Grit (Fig. 4a), which locally erodes through the Butterly ($R_{1c}5$) Marine Band (Hampson 1997). The extensive sheet-like Marsdenian Midgley Grit (Fig. 4b) shows incision of the underlying $R_{2b}3$ marine band (Brettle 2001). The erosive base of the Marsdenian Roaches Grit/Ashover Grit is associated with a palaeovalley up to 80 m deep (Jones & Chisholm 1997), which removes the underlying $R_{2b}5$ marine band within the eastern part of the Widmerpool Gulf (Fig. 4b; Church & Gawthorpe 1994). The east-west palaeochannel of Chatsworth Grit (Fig. 4c) is 25 km wide with a steep 50 m high northern flank, though the incision has not removed underlying marine bands (Waters *et al*. 2008). The late Yeadonian Rough Rock is typically a low-sinuousity broad sheet-like fluvial sandbody. However, within the Widmerpool Gulf and East Midlands Shelf a north-south incised valley in excess of 11 km width (Fig. 4d) incises up to 5 marine bands, down to and including the $R_{2c}2$ Marine Band (Church & Gawthorpe 1994; Hampson *et al*. 1997).

The early Langsettian Crawshaw Sandstone of the East Midlands Shelf is less than 70 km wide (Fig. 4e) and has well defined margins with identifiable interfluves and removes up to three marine bands including the Subcrenatum and $G_{1b}1$ marine bands (Hampson *et al.* 1997). This is the last representative of this style of fluvial deposition within the Pennine Basin. Subsequent fluvial systems are characterised by less laterally extensive sandstone bodies, typically up to 20 km wide, with a maximum of 30 km, and 8-20 m thick with a maximum of 100 m (Guion *et al.* 1995; Aitken *et al.* 1999). The presence of incised valley fills within this Westphalian succession remains controversial. Regionally developed well-drained palaeosols, considered to form on the interfluve, are not common, and major fluvial sandbodies show only limited basal incision of up to 5 m, exceptionally up to 8 m (Rippon 1996). This may reflect distance from the sea, with incision of river channels having insufficient time to work upstream from the coast before the next flooding event (Aitkenhead *et al.* 2002). Alternatively, it may relate to the enclosed nature of the basin. Only the highest global sea-level rises would result in a rapid base-level rise within the basin, with the subsequent fall in sea-level leaving an isolated basin for which base levels may fall comparatively slowly as it continues to be fed by rivers (Waters & Davies 2006).

Westphalian multi-storey sandbodies commonly show a relationship with their adjacent strata. This may include high ash contents in coals adjacent to the sandbodies, coal splitting towards channels and an increase in interbedded sandstone layers in proximity to the channel bodies (Aitken et al. 1999; Guion et al. 1995). These observations imply that overbank flooding events from the channels occurred during peat accumulation and leads these authors to believe that many of the channel systems were aggradational, as opposed to having filled previously incised valley systems.

The Duckmantian and Bolsovian succession includes a number of multistorey sandstone bodies with local basal erosional relief that represent candidate incised valley fills (Fig. 4f). The basal Duckmantian Thornhill Rock cuts through the Vanderbeckei Marine Band (Lake 1999) and reaches thicknesses of 37-45 m. The Woolley Edge Rock is distinctly coarser grained and pebbly compared with earlier Westphalian sandbodies. The channel fill, about 23 km wide, shows palaeocurrents to the west or WNW and has up to 60 m of erosional truncation (Aitken *et al*. 1999), including removal of the Manton Estheria Band. The Oaks Rock, up to 40 m thick, is similarly associated with the absence of the Haughton and Sutton marine bands (Lake 1999). The early Bolsovian Mexborough Rock is the fill of an east-west channel, 30-40 m thick (locally up to 80 m) and 15-30 km wide (Aitken et al. 1999) and may be associated with erosion of the Main Estheria Band and Edmondia Band.

Discussion

The recognition of cyclic sedimentation offers the potential to develop high-resolution time-thickness models for sedimentary successions, in which the resolution is determined by the dominant forcing mechanism. This approach is routinely applied to Cenozoic strata and the current Neogene Timescale (Gradstein *et al*. 2004) is based entirely upon astronomical calibration. Milankovitch orbital forcing during the Carboniferous is thought to be 413 ka and 112 ka for long- and short-duration eccentricity periodicities, respectively, 34 ka for obliquity and 21 ka and 17 ka for precession frequencies (Maynard & Leeder 1992).

The late Mississippian to Pennsylvanian is a time of high frequency-high amplitude sea-level oscillations during icehouse conditions. The presence of cyclic stratigraphy in the Pennine Basin, evidenced by the presence of cyclothems and periodic development of marine bands, has lead many workers to suggest these can be used to generate high-resolution age-models for parts of the

Carboniferous (Ramsbottom 1977; Maynard & Leeder 1992; Brettle 2001; Waters *et al*. 2008; Tucker *et al*. 2009). Recent developments in high-precision U-Pb geochronology means that it is now possible to test some of these hypotheses and develop more accurate models for the evolution of a Carboniferous cyclostratigraphy.

Most attempts at estimating the duration of the Namurian and Westphalian cyclicity have assumed a constant forcing mechanism during the entire interval; simply duration divided by the number of marine bands (fossiliferous carbonaceous mudstones or impure limestones). The new radiometric ages from this study combined with the most recent and accurate estimates of 330 Ma and 322.8 Ma for the base of the Serpukhovian and Bashkirian, respectively (Davydov *et al*., 2010), permit the detailed analysis of cyclicity duration over specific time intervals.

There are 15 marine bands in the 1.66 Ma interval between the base of the Pendleian to the dated bentonite (BLL1976) of early Arnsbergian age (Table 2; Fig. 5). The average duration of ca. 111 ka represents a possible short-duration eccentricity modulation. Four peak flooding events are recognised ($E_{1a}1$, $E_{1c}1$, $E_{2a}1$ and $E_{2a}3$), which are equated with the 400 ka long-duration eccentricity frequency and identified as the orbital cycles S1 to S4.

The mid to late Arnsbergian interval between the dated bentonite (BLL1976) and the base of the Bashkirian Stage, which occurs above the $H_{1a}1$ marine band (Riley *et al*. 1995), there are 13 marine bands over a duration of 5.54 Ma (Table 2; Fig. 5). The average of ca. 426 ka may suggest that only the long-duration eccentricity frequency is observed. However, the marine bands $E_{2b}1$a-c, $E_{2b}2$a-c, $E_{2c}2$-4 and $H_{1a}1$-3 occur as triple short-duration flooding events associated with the same ammonoid fauna (see below), and are considered to represent only four 400 ka flooding events. If these four, along with the $E_{2b}3$ and $E_{2c}1$ are taken to represent peak flooding events, it requires that eight 400 ka cycles are not represented in the geological record by marine flooding events (Fig. 5). It is possible that these missing cycles may be distributed evenly throughout the mid to late Arnsbergian interval. However, the very marked change in ammonoid genera between the $E_{2c}4$ and $H_{1a}1$ flooding events is here interpreted as indicative of a long period without marine flooding of the basin. During the Pendleian and Arnsbergian the dominant genera are *Cravenoceras*, *Eumorphoceras* and *Cravenoceratoides*, but these genera are absent from Chokierian and younger strata (Table 2).

Between the base of the Bashkirian Stage and the dated early Bolsovian tonstein (EH28155) there are 56 marine bands in the Pennine Basin (Tables 2 & 3; Fig. 5) over an interval of 8.43 Ma. This results in an average marine band cycle of ca. 150 ka, a possible short-duration eccentricity modulation. However, these high-frequency events appear to be less common during the early to mid Kinderscoutian and late Marsdenian to Yeadonian. Twenty one peak flooding events are recognised between the $H_{1b}1$ to Aegiranum marine bands, which are equated with the 400 ka long-duration eccentricity frequency and identified as the orbital cycles B2 to M2 (Fig. 5). Eight out of the 24 Westphalian marine bands are associated with ammonoid assemblages (Table 3), of which seven of these marine bands, along with the brachiopod-bearing Haughton Marine Band, are recognised as representing the 400 ka peak flooding events.

A common feature of many of the Namurian marine bands is the presence of two or three distinct beds with marine fauna, separated by non-marine barren mudstones. In many cases the separation between these bands is only a few tens of centimetres to metres scale, e.g. $E_{1a}1$ (a-c) or $E_{2a}1$ (a-c), but in other cases they are separated by tens of metres of succession, including prograding deltaic lobes, e.g. $R_{1c}1$-3 or $R_{2b}1$-3. Importantly, these distinct "leaves" show the same ammonoid assemblages and cannot be readily distinguished, unless all "leaves" are evident in a single section or through correlation of intervening deltaic sandbodies. If one assumes a constancy of rate of evolution of ammonoid species through the Namurian it would suggest that these multiple marine bands occur at higher frequencies than between marine bands with distinct ammonoid taxa. This would suggest shorter frequencies than the 111 ka or 150 ka periodicities recognised above, and may indicate evidence of precession or obliquity components of too short a duration to be determined through current radiometric dating techniques.

Throughout the Namurian and Westphalian, 17 major base-level falls are recognised, at a frequency of about 1 Ma (Fig. 5). This long-duration cyclicity broadly approximates to the periodicity of the "mesothems" of Ramsbottom (1977; 1979). These major regressive events occur at greatest frequency during late Pendleian to late Arnsbergian, Chokierian, late Kinderscoutian to early Langsettian and Duckmantian to early Bolsovian times, but appear to be absent throughout much of the late Arnsbergian, Alportian to mid Kinderscoutian and Langsettian.

The variations in development of unconformities within the Pennine Basin may be a far-field response to the record of alternating glacial and non-glacial climatic regimes proposed for Gondwana. The onset of the main phase of glaciation began in the early Namurian and peaked in the late Westphalian and Stephanian (Gonzalez-Bonorino & Eyles 1995). Isbell *et al*. (2003) recognised an early Visean alpine glaciation event, but considered the main continental glaciation to persist across Gondwana from early Serpukhovian to Permian times, with a phase of minimal ice during latest Bashkirian to early Moscovian times. Fielding *et al*. (2008) indicate that eastern Australia was affected by four major glaciations during the Carboniferous, each separated by non-glacial periods of similar duration. Their estimates for the ages of these glaciations are based upon U-Pb SHRIMP dates (e.g. Claoué-Long *et al*. 1995, Roberts *et al*. 1995), now considered unsuitable (see summary of existing dates above). Within the Paganzo Basin of Argentina, three glacial pulses during the mid Visean, early Bashkirian (*c*. 323–319.57 ± 0.09 Ma) and latest Bashkirian to early Moscovian (315.46 ± 0.07–312.82 ± 0.11 Ma) are well constrained by U-Pb ID-TIMS dates from zircons (Gulbranson *et al*., 2010). The timing and duration of glaciations remain problematic and until redating occurs in Eastern Australia, the far-field response to these glaciations may provide the most suitable method for estimating their ages.

Glaciation C1 of earliest Namurian age, proposed by Fielding *et al*. (2008) to represent the initiation of the Late Palaeozoic Ice Age, is of limited extent and short-duration. In the study area, Type 1 unconformities are developed during the late Pendleian to early Arnsbergian and tend to be limited to the basin margin (Fig. 3). These unconformities follow after three of the four peak flooding events described earlier (Fig. 5), suggesting linkage to the ~400 ka eccentricity frequency. This early Serukhovian glaciation is considered to range from orbital cycles S1 to S9, approximately 330.0 to 326.5 Ma (Fig. 5). The start of Cycle S1 coincides with the sudden cessation of platform carbonate deposition and Cycles S2 to S5, between the $E_{1c}1$ and $E_{2a}3$ marine bands, is marked by the first phase of thick fluvio-deltaic siliciclastic sandbodies entering the basin (Aitkenhead *et al*. 2002; Waters & Davies 2006).

An absence of Type 1 unconformities and inferred absence of eight 400 ka cycle flooding events during the mid to late Arnsbergian may represent the interval between the C1 and C2 glaciations. Isbell *et al*. (2003) considered there to be evidence of glaciations in South America and Tibet in this interval. However, Stephenson *et al*. (2010) have demonstrated using $\delta^{18}O$ and $\delta^{13}C$ from the Pennine Basin that widespread ice-caps were absent throughout mid Serpukhovian times. This interval is considered to range from orbital cycles S10 to S17, approximately 326.5 to 323.0 Ma (Fig. 5). Few large sandbodies prograded into the Pennine Basin during this time interval (Aitkenhead *et al*. 2002; Waters & Davies 2006).

The Glaciation C2 of mid-Namurian age, estimated to range from 322.5–319.5 Ma by Fielding *et al*. (2008) is coincident with the second glacigenic phase in Argentina (Gulbranson *et al*., 2010). It broadly aligns with the phase of Chokierian to Alportian increased frequency of unconformities and marine flooding events. This early Bashkirian glaciation is considered in this study to range from orbital cycles B1 to B4, approximately 323.0 to 321.5 Ma (Fig. 5). This was a time when the Pennine Basin was dominated by slow hemipelagic deposition with comparatively few large sandbodies prograding into the basin (Waters & Davies 2006).

The early to mid Kinderscoutian within the Pennine Basin is marked by low magnitude variations in sea-level, no major incision events and no multiple (high-frequency) marine bands. Deposition at this time was dominated by slow accumulation of hemipelagic and distal turbidite deposits (Waters & Davies 2006). It is suggested that this may equate with the interval between Glaciations C2 and C3, during which eustatic sea-level fluctuations are more subdued, but suggests not completely free of ice-sheet development. As with the C1–C2 interglacial, this interval is associated with a marked turnover of ammonoid genera, most notably marked by the appearance of *Reticuloceras* (Table 2). This interval is considered to range from orbital cycles B5 to B9, approximately 321.5 to 319.5 Ma (Fig. 5).

The latest Namurian to earliest Westphalian Glaciation C3, estimated by Fielding *et al*. (2008) to range of 317–315 Ma, was considered to have a comparable areal extent to Glaciation C2. No equivalent of this glaciation is recorded in the Paganzo Basin of Argentina (Gulbranson *et al.*, 2010). This broadly coincides with the late Kinderscoutian to early Langsettian phase in the Pennine Basin of highest magnitude sea-level flooding events and most numerous incision surfaces, almost on a ~400 ka cyclicity, with a return to common multiple (high-frequency) marine bands. In contrast to the early Namurian event, these unconformities commonly follow trends of decreasing amplitude flooding events. The onset of this glaciation is evident through a rapid and almost basinwide progradation of coarse, pebbly and commonly sheet-like fluvio-deltaic sandbodies, with this style of deposition persisting throughout this interval (Waters & Davies 2006). This glaciation is considered to range from orbital cycles B10 to B18, approximately 319.5 to 316.0 Ma (Fig. 5).

The short-lived interglacial interval between C3 and C4 equates with the mid- to late-Langsettian succession, possibly representing an interval of up to two orbital cycles (B18 to B20). The interval follows the Listeri Marine Band, the most extensive of all of the flooding events (Fig. 5), after which sea-level fluctuations are diminished and major incision surfaces are not recorded. The interval also records a marked dimunition of sandbody dimension and grainsize (Guion *et al*. 1995; Waters & Davies 2006). As for the C2–C3 interglacial, this interval appears not to be completely free of ice-sheet development.

The youngest mid-Westphalian Glaciation C4, estimated by Fielding *et al*. (2008) to range from 313–308 Ma, is thought to be in part coincident with the third glacigenic phase in Argentina (Gulbranson *et al.*, 2010). It may equate with the Duckmantian to early Bolsovian phase of high-frequency major flooding and incision events (Fig. 5). The expression of this glaciation in the Pennine Basin is considered to range from orbital cycles B20 to M3, approximately 315.2 to 314.0 Ma (Fig. 5).

Conclusions

This study provides two new high-precision U/Pb ages of 328.34 ± 0.55 Ma (total uncertainty) for the Arnsbergian regional substage (mid-Serpukhovian stage) and 314.37 ± 0.53 Ma (total uncertainty) for the earliest Bolsovian regional substage (early Moscovian stage). These ages are somewhat older than existing published ages for these successions and require modification of the current timescale for the Western Europe regional chronostratigraphy, but align with recent dates provided by Davydov *et al*. (2010) for the Donetz Basin.

The extent of acme ammonoid facies within discrete marine intervals is used as a proxy of the magnitude of these marine flooding events. The recognition of candidate incised valleys, and the number of cycles locally removed by these major sequence boundaries, is used as a proxy of the magnitude of sea-level falls. The frequency of these events, when considered in the light of the new radiometric dating indicates the following relationships:

1) The interval between major sequence boundaries within the Namurian and Westphalian is approximately 1 Ma. This cyclicity may be a far-field response to the record of alternating glacial and non-glacial climatic regimes proposed for Gondwana. The four major glaciations proposed for Gondwana may equate with phases of increased numbers of sequence boundaries in the Pennine Basin. It is suggested that the main glaciations occurred during the late Pendleian to late Arnsbergian (approximately 330.0 to 326.5 Ma), Chokierian to Alportian (approximately 323.0 to 321.5 Ma), late Kinderscoutian to early Langsettian age (approximately 319.5 to 316.0 Ma) and Duckmantian to early Bolsovian (approximately 315.2 to 314.0 Ma).

2) The interglacial intervals are associated with no development of incised valleys, no or reduced frequency of flooding events and marked turnover of ammonoid genera, considered to mark long time durations between successive flooding events.

3) Distinct peak flooding surfaces within Namurian strata, associated with ammonoid-bearing marine bands in the Westphalian succession, have an average frequency of 400 ka, equating with the long-duration eccentricity component described in mid- to late-Pennsylvanian strata in the USA.

4) Average durations of marine band cycles during the Pendleian to early Arnsbergian and Chokierian to Bolsovian, of 111 ka and 150 ka, respectively, may reflect a short-duration eccentricity component. These flooding events are associated with non-ammonoid marine fauna in the Westphalian succession.

5) Multiple flooding surfaces associated with the same ammonoid assemblages in the Namurian may equate with sub-100 ka precession or obliquity frequencies.

The interaction of cyclicities associated with long-duration switching from glacial and non-glacial climatic regimes and long- and short-duration eccentricity cycles offers the opportunity of trans-continental cyclostratigraphical correlations within late Mississippian to Pennsylvanian successions.

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Figure captions

Fig. 1. Map showing the approximate extent of Namurian and Westphalian strata at crop, the subcrop of Westphalian strata and the main pre-Namurian structural features of the Pennine Basin, derived from Waters *et al*. (2011). The location of the Harewood and Holme Pierrepont boreholes, from which new dates have been acquired during this study, are shown. DH- Derbyshire High, WG- Widmerpool Gulf.

Fig. 2. U-Pb data for samples BLL1976 and EH28155. A, conventional U-Pb concordia plot of zircons analysed from samples BLL1976 and EH28155. The grey band reflects the uncertainty in the ^{238}U and ^{235}U decay constants (Jaffey *et al*. 1971). B, plot of ^{238}U/^{206}Pb dates for single zircon crystals analyses (same data as in Figure 2a). Dashed ellipses/bars represent analyses of zircon that are considered to be xenocrysts and/or inherited crystals that are disregarded in calculation of final date, whereas as undashed ellipses/bars represent the analyses used for calculation of the weighted mean final date (see text for discussion). Data point error ellipses/bars are 2σ.

Fig. 3. Distribution of ammonoid acme facies in early Namurian marine bands: a) Pendleian; b) early Arnsbergian; c) mid to late Arnsbergian; d) Chokierian; e) Alportian; f) early Kinderscoutian. Grey tone denotes marine band with maximum areal extent for each interval. Key for Incised Valleys, as for Figure 5.

Fig. 4. Distribution of ammonoid acme facies in late Namurian–Westphalian marine bands: a) mid to late Kinderscoutian; b) early Marsdenian; c) late Marsdenian; d) Yeadonian- $G_{1b}1$ modified from Wignall (1987); e) Langsettian and f) Duckmantian–Bolsovian, in part based upon Calver (1968, 1969). Grey tone denotes marine band with maximum areal extent for each interval. Key for Incised Valleys, as for Figure 5.

Fig. 5. Magnitude and duration of sea-level oscillations. Sea-level maxima are estimated through the determination of maximum areal extent of acme ammonoid facies. Abbreviations for Westphalian marine bands: SMB Subcrenatum Marine Band; LMB Listeri Marine Band; AmMB Amaliae Marine Band; VMB Vanderbeckei Marine Band; HMB Haughton Marine Band; AMB Aegiranum Marine Band; CMB Cambriense Marine Band. For marine bands lacking ammonoid fauna the magnitude of sea-level is determined through the acme marine fauna, ranging from *Estheria* to brachiopod-bivalve facies. Sea-level minima are determined through the presence of incised valleys, with the magnitude recorded by the number of underlying marine bands removed beneath the sequence boundary. Sources for incised valleys are as follows: a) Rogerley Channel (Dunham 1990); b) Upper Howgate Edge channel (Martinsen *et al*. 1995); c) Red Scar Grit

(Brandon *et al*. 1995); d) Lower Follifoot Grit (Martinsen 1993); e) Intra-H_{1a} unconformity (Owens *et al*. 1990); f) Upper Follifoot Grit (Martinsen 1993); g) Todmorden Grit/Kinderscout Grit (Hampson 1997); h) Upper Kinderscout Grit (Hampson 1997); i) Midgley Grit (Brettle 2001); j) Ashover Grit/Roaches Grit (Jones & Chisholm 1997; Church & Gawthorpe 1994); k) Chatsworth Grit (Waters *et al*. 2008); l) Rough Rock (Church & Gawthorpe 1994); m) Crawshaw Sandstone (Hampson *et al.* 1997); n) Thornhill Rock (Lake 1999); o) Woolley Edge Rock (Aitken *et al*. 1999); p) Oaks Rock (Lake 1999); q) Mexborough Rock (Aitken *et al*. 1999). Radiometric dates are from this study and estimated ages of stage boundaries are from Davydov *et al*. (2010), with an imposed 400 ka long-duration eccentricity oscillation numbered sequentially for each international stage: S Serpukhovian; B Bashkirian; M Moscovian. The proposed four main glaciations are highlighted as grey bands.

Nature and timing of Late Mississippian to Mid Pennsylvanian glacio-eustatic sea-level changes of the Pennine Basin, UK

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Online Supplemental Information

Zircon U-Pb ID-TIMS Methods

Zircons were isolated from ca. 100 grams of bentonite layer (sample BLL1976) from the BGS Harewood Borehole section and ca. 100 grams of bentonite layer (sample EH28155) from the Holme Pierrepont Borehole section, using conventional mineral separation techniques. Prior to isotope dilution thermal ionization mass spectrometry (ID-TIMS) analyses zircons were subject to a modified version of the chemical abrasion technique (Mattinson 2005). For details of sample pre-treatment, dissolution and anion exchange chemistry see Sláma *et al*. (2008). U-Pb ID-TIMS analyses herein utilized the EARTHTIME ^{205}Pb-^{233}U-^{235}U (ET535) tracer solution. Measurements at the NERC Isotope Geosciences Laboratory were performed on a Thermo Triton TIMS. Pb analyses were measured in dynamic mode on a MassCom SEM detector and corrected for 0.14 ±0.04%/u. mass fractionation. Linearity and dead-time corrections on the SEM were monitored using repeated analyses of NBS 982, NBS 981 and U500. Uranium was measured in static Faraday mode on 10^{11} ohm resistors or for signal intensities < 15 mV, in dynamic mode on the SEM detector. Uranium was run as the oxide and corrected for isobaric interferences with an ^{18}O/^{16}O composition of 0.00205 (IUPAC value and determined through direct measurement at NIGL). U-Pb dates and uncertainties were calculated using the algorithms of Schmitz & Schoene (2007) and a ^{235}U/^{205}Pb ratio for ET535 of 100.18 ±0.1%. All common Pb in the analyses was attributed to the blank and subtracted based on the isotopic composition and associated uncertainties analysed over time. The ^{206}Pb/^{238}U ratios and dates were corrected for initial ^{230}Th disequilibrium using a Th/U[magma] of 4 ±1 applying the algorithms of Schärer (1984) resulting in an increase in the ^{206}Pb/^{238}U dates of ~100 kyr. Errors for U-Pb dates are reported in the following format: ±X(Y)[Z], where X is the internal or analytical uncertainty in the absence of all systematic error (tracer calibration and decay constants), Y includes the quadratic addition of tracer calibration error (using a conservative estimate of the 2σ standard deviation of 0.1% for the Pb/U ratio in the tracer), and Z includes the quadratic addition of both the tracer calibration error and additional ^{238}U decay constant errors of Jaffey *et al*. (1971). All analytical uncertainties are calculated at the 95% confidence interval. These ^{238}U/^{206}Pb dates are traceable back to SI units via the gravimetric calibration of the EARTHTIME U-Pb tracer and the determination of the ^{238}U decay constant (Condon *et al*. 2007; Jaffey *et al*. 1971). The results for the analyses of samples BLL1976 and EH28155 are shown in Table 1.

Zircon U-Pb ID-TIMS Results and Discussion

Zircons separated from both bentonite samples BLL1976 and EH28155 were small (<50 μm) with aspect ratios of ~1.5 to ~3. For sample BLL1976 seventeen fractions (single grains) were analysed. Relatively large uncertainties on ^{207}Pb/^{206}Pb dates (~5 to 50 Ma) limit the usefulness of concordance for assessing the accuracy of ^{206}Pb/^{238}U and the potential for subtle Pb-loss and/or incorporation of minor amounts of older material. ^{206}Pb/^{238}U dates for sample BLL1976 between 311 and 334 Ma with a distinct population (defined by 11 of the 17) of concordant analyses yielding a weighted mean ^{206}Pb/^{238}U date of 328.34 ± 0.30(0.43)[0.55] Ma (Mean square weighted deviation (95% confidence level, MSWD = 2.2). ^{206}Pb/^{238}U dates that are older than the main population are interpeted as reflecting the analyses of zircon ante-/xeno-crysts, and grains that are younger as reflecting Pb-loss (see below). The MSWD for this sample exceeds that expected for a single population (Wendt & Carl 1991) indicating excess scatter. There are two possible explanations for this scatter: (1) residual Pb-loss in younger zircons (e.g., z6, z15 and z12); or (2) older zircon U/Pb dates (e.g., z4, z19, z22, zA2) reflect pre-eruptive crystalisation of zircon (i.e., ante-/xeno-crysts). The alternative interpretations, based upon statistically cohernt populations, result in weighted mean ^{206}Pb/^{238}U dates that are ~200 ka older/youger than the weighted mean ^{206}Pb/^{238}U date of 328.34 ± 0.30 Ma, in part as the 95% confidence error of the weighted average multiplies the '2σ internal' error by the square root of the MSWD therefore using the actual scatter of the data rather than the predicted scatter based upon the main population

(Ludwig 1991). Thus, in the absence of any independent criteria for the exclusion of data points from the main population we interpret the weighted mean $^{206}Pb/^{238}U$ date of 328.34 ± 0.30(0.43)[0.55] Ma as being the best estimate for the zircons of this sample and inferentially the age of bentonite at the sampled stratigraphic level. For sample EH28155 nine fractions (single grains) were analysed, and the resulting data are presented in Figure 2 of the paper. Two of the nine analyses produced U-Pb dates older than the constraint imposed by sample BLL 1976 (see above). The remaining seven analyses yielded $^{206}Pb/^{238}U$ dates between 306 and 317 Ma with a distinct population (defined by 4 of the 7) of anlyses yielding a weighted mean $^{206}Pb/^{238}U$ date of 314.37 ± 0.25(0.40)[0.53] [1] Ma (MSWD = 1.07) which is interpreted as being the best estimate for the zircons of this sample. In both samples the U/Pb dates that are older than the main population are interpeted as reflecting the analyses of zircon ante-/xeno-crysts, and grains that are younger as reflecting Pb-loss. This interpretation is supported by consideration of biostratigraphical and geochronological constraints (e.g., Davydov *et al*. 2010) for this time interval and is typical for moderate-*n* high-precision U-Pb (zircon) data sets obtained on primary air-fall ash beds (e.g., Davydov *et al*., 2010; Schoene *et al*. 2010).

Ammonoid biostratigraphy

Ammonoid biozones in the Namurian succession are defined by the first appearance of ammonoid taxa, with the base of the biozones coinciding with the bases of specific marine bands. Ammonoid evolution rates reached an acme during the Namurian, such that the majority of marine bands comprise a distinct ammonoid fauna. The Namurian ammonoid biostratigraphy was developed largely from studies within the Central Pennine Basin by Bisat (1924; 1928) and Bisat & Hudson (1943), and later refined by Ramsbottom (1969; 1971). The scheme used for the Namurian in this study is derived from Riley *et al*. (1995). An ammonoid biozonation scheme has not been developed for the Westphalian, but key ammonoid-bearing marine bands have been used as marker beds to divide the cyclical Coal Measures lithofacies. The key marine bands, identified by Ramsbottom *et al*. (1978), are named after the diagnostic ammonoid species, replacing a plethora of local geographical names used historically. Correlation in the Westphalian is enhanced by the presence of an additional framework of marker marine bands that contain less diagnostic fauna, such as thin-shelled ammonoids (*Anthracoceras*), marine bivalves (*Dunbarella*), brachiopods (*Lingula*) and crustacea (Ostracodes, *Estheria*). Few such marine marker bands, entirely devoid of ammonoid fauna across the basin, are recognized in the Namurian succession.

Calculation of areal extent of marine bands

Ammonoid-bearing marine band locations, either from surface exposures or borehole samples, were determined by a comprehensive trawl of BGS palaeontological registers, BGS memoirs and technical reports and scientific publications, too many to reference individually. Marine band locations were used in the study only where ammonoids were described, representing the acme fauna, and for which the marine band attribution was unequivocal. It was decided that the recognition of marine faunal facies within the Namurian succession, as carried out for the Westphalian by Calver (1968, 1969), was beyond the scope of this study. Table 2 shows the location and ammonoid assemblages used to compile the distribution maps. The described location is that given in registers or publications, presented without modification to show the basis by which locations were determined. Borehole locations and logs, available from the BGS Single Onshore Borehole Index (SOBI) database, were used to check the attribution of the marine bands. The British National Grid of surface locations was determined in the majority of cases by comparing the description of the locality to BGS fieldslips and published 1:10,560- or 1:10,000-scale maps which showed the location of the fossil locality. This also provided a means of confirming or determining from which marine band the sample was collected. If marine band identification was equivocal it was not included in the study. This is in particular relevant to marine bands present in great thicknesses of mudstone, for example in the Bowland Shale Formation, where correlation of distinct marine bands can be more uncertain. As the identification of marine band nomenclature is dependent on recognition of the first incoming of certain taxa, it can be difficult to confirm the first appearance unless a sequential succession of several marine bands are studied in a single section, which is relatively unusual in surface sections. Within the Millstone Grit Group, the cyclic nature of sedimentation means that marine bands commonly rest upon sandstones, with significant thicknesses between flooding events. This makes correlation of individual marine bands over large distances comparatively easy, with the relationship of specific marine bands to named sandstones well established. As a consequence of this study it has been possible to compile typical ammonoid assemblage lists for each marine band, something not previously published systematically. In Table 2 the faunal list is that which appears in the source register or literature. A modern reinterpretation of these faunal lists appears in Tables 2 to 3 in the publication. However, it is important to realize that none of the specimens, many of which will be stored at BGS Keyworth, were examined during this study to confirm the original identifications.

The distribution of the ammonoid facies in the Westphalian succession were previously constrained by Calver (1968, 1969) and these envelopes were used in this study, with modification where samples listed in Table 2 indicated the need to extend the extent of the envelope. In many cases this resulted from borehole data from the eastern part of the basin, acquired after Calver's studies.

For each marine band, the position of the ammonoid localities were presented using ArcGIS software, an envelope was drawn around the locations and the areal extent of the envelope calculated. To some extent, an understanding of the geology of the basin was required to determine the extent that the area between locations could be assumed to still be ammonoid-bearing. In particular, envelopes were not extrapolated across areas where no data were available, either through the marine band being too deeply buried to be proved by boreholes, or absent through removal by erosion.

Production of the cyclostratigraphical model

The regional chronostratigraphy was initially scaled against absolute time using the two dates acquired during this study and the additional constraints for the age of the base of the Serpukhovian and Bashkirian, derived from Davydov *et al*. (2010). By dividing each of the age ranges (base Pendleian to early Arnbergian, early Arnbergian to Chokierian and Chokierian to early Bolsovian) by the number of recognized flooding surfaces within each interval it was possible to recognize the average cycle duration. However, consideration of just peak flooding events and Type 1 unconformities suggested that a ~400 kyr eccentricity frequency persisted throughout the study interval, a duration consistent with findings from other international studies. On this basis the Serpukhovian, Bashkirian and lower part of the Moscovian stages were subdivided into ~400 kyr cycles, numbered S1 to S17, B1 to B20 and M1 to M3, respectively. Peak flooding events were then aligned to each of the cycles. Where this proved not possible for the Mid to Late Arnsbergian succession because of too few flooding events, it was decided to take an arbitrary position of spacing equally the $E_{2b}3$ and $E_{2c}1$ flooding events.

The magnitude of sea-level oscillations is presented using three distinct scales. The areal extent of ammonoid facies is presented as a linear scale of 1000's Km^2. Non-ammonoid bearing flooding events were incorporated into the analysis by indicating the acme marine facies described within the Pennine Basin. The order presented of *Estheria*, Foraminifera, *Lingula* and brachiopod-bivalve facies, indicates increasing marine influence (Calver 1968). The absolute magnitude of sea-level fall associated with many of the Type 1 unconformities is unrecorded, whereas the number of cycles removed by erosion was determinable from publications describing these erosional surfaces. Again, this does not provide absolute magnitudes of sea-level falls, but is indicative of the relative significance of these events. It is important to realize that the resultant figure, using three different scales provides a means to visualize relative magnitudes of sea-level fluctuation but cannot be used to an oscillatory sea-level curve.

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Table 1. U-Th-Pb isotopic data

Sample (a)	Compositional Parameters: $\frac{Th}{U}$ (b)	$^{206}Pb^*$ $x10^{-13}$ mol (c)	mol % $^{206}Pb^*$ (c)	$\frac{Pb^*}{Pb_c}$ (c)	Pb_c (pg) (c)	$\frac{^{206}Pb}{^{204}Pb}$ (d)	Radiogenic Isotope Ratios: $\frac{^{208}Pb}{^{206}Pb}$ (e)	$\frac{^{207}Pb}{^{206}Pb}$ (e)	% err (f)	$\frac{^{207}Pb}{^{235}U}$ (e)	% err (f)	$\frac{^{206}Pb}{^{238}U}$ (e)	% err (f)	corr. coef.	Isotopic Ages: $\frac{^{207}Pb}{^{206}Pb}$ (g)	± (f)	$\frac{^{207}Pb}{^{235}U}$ (g)	± (f)	$\frac{^{206}Pb}{^{238}U}$ (g, h)	± (f)
EH-28155																				
z2	0.407	0.4794	98.68%	22	0.53	1378	0.128	0.05276	0.27	0.3666	0.34	0.05040	0.10	0.740	317.6	6.2	317.14	0.92	317.07	0.31
z3	0.379	0.4504	98.43%	18	0.60	1159	0.120	0.05271	0.66	0.3634	0.70	0.05000	0.17	0.315	315.7	15.1	314.73	1.88	**314.60**	**0.52**
z4	0.213	0.3503	97.99%	14	0.60	904	0.067	0.05254	0.38	0.3606	0.45	0.04977	0.12	0.650	308.3	8.7	312.63	1.21	313.22	0.38
z5	0.362	0.5413	98.74%	23	0.57	1446	0.115	0.05272	0.26	0.3629	0.33	0.04993	0.12	0.708	316.0	6.0	314.39	0.90	**314.17**	**0.36**
z6	0.319	0.1435	97.09%	10	0.36	625	0.100	0.05287	0.62	0.3863	0.70	0.05300	0.18	0.545	322.6	14.1	331.69	1.97	333.00	0.57
zA6	0.357	0.2455	95.99%	7	0.85	454	0.112	0.05222	0.82	0.3601	0.91	0.05001	0.20	0.514	294.5	18.7	312.30	2.43	**314.69**	**0.62**
zA7	0.470	0.1401	90.22%	3	1.26	186	0.145	0.05120	2.57	0.3525	2.72	0.04994	0.32	0.498	249.2	59.2	306.63	7.20	**314.23**	**0.99**
zA8	0.345	0.5371	91.46%	3	4.16	213	0.109	0.05346	1.04	0.3958	1.14	0.05370	0.24	0.534	347.7	23.4	338.59	3.29	337.27	0.78
zA9	0.261	0.1667	90.37%	3	1.47	189	0.081	0.05171	1.85	0.3475	1.99	0.04874	0.20	0.704	271.7	42.4	302.82	5.21	306.87	0.61
BLL 1976																				
z2	1.464	0.3195	98.10%	20	0.51	960	0.463	0.05305	0.39	0.3821	0.45	0.05225	0.12	0.638	330.4	8.8	328.61	1.28	**328.35**	**0.38**
z4	1.771	0.1298	94.23%	7	0.66	315	0.555	0.05255	1.40	0.3793	1.51	0.05235	0.21	0.564	309.1	32.0	326.51	4.22	**328.96**	**0.67**
z5	1.482	0.3720	94.55%	7	1.78	334	0.463	0.05239	1.18	0.3759	1.28	0.05204	0.17	0.630	302.0	26.9	324.01	3.55	327.08	0.54
z6	1.457	0.7789	98.34%	22	1.09	1093	0.460	0.05296	0.36	0.3807	0.43	0.05213	0.13	0.618	326.8	8.2	327.55	1.19	**327.65**	**0.42**
z12	1.542	0.0831	94.72%	7	0.38	345	0.488	0.05316	1.13	0.3826	1.24	0.05221	0.23	0.530	335.3	25.7	328.98	3.48	**328.10**	**0.73**
z14	1.355	0.0874	92.38%	4	0.60	239	0.430	0.05326	1.67	0.3838	1.80	0.05227	0.26	0.552	339.5	37.7	329.85	5.06	**328.48**	**0.84**
z15	1.319	0.4603	99.04%	38	0.37	1896	0.417	0.05300	0.24	0.3810	0.58	0.05214	0.51	0.915	328.3	5.3	327.79	1.63	**327.71**	**1.63**
z16	0.104	0.2838	98.46%	17	0.37	1179	0.033	0.05302	0.33	0.3820	0.40	0.05226	0.12	0.651	328.8	7.5	328.49	1.11	**328.45**	**0.39**
z17	1.267	0.1359	93.68%	5	0.76	288	0.398	0.05254	1.28	0.3748	1.39	0.05173	0.20	0.593	308.8	29.1	323.19	3.84	325.19	0.65
z18	1.447	0.1733	97.58%	15	0.36	754	0.454	0.05262	0.55	0.3805	0.62	0.05244	0.15	0.573	311.9	12.5	327.37	1.73	329.56	0.48
z19	1.145	0.1573	97.23%	12	0.37	658	0.359	0.05259	0.56	0.3793	0.64	0.05231	0.18	0.571	310.6	12.8	326.54	1.80	**328.78**	**0.58**
z21	1.472	0.1358	95.68%	8	0.51	421	0.464	0.05289	0.97	0.3830	1.05	0.05253	0.18	0.541	323.5	21.9	329.24	2.96	330.06	0.59
z22	1.552	0.2240	94.98%	7	0.98	363	0.488	0.05274	0.95	0.3805	1.06	0.05233	0.26	0.516	317.2	21.6	327.42	2.96	**328.86**	**0.85**
zA1	1.515	0.1162	96.44%	10	0.36	511	0.478	0.05303	0.69	0.3886	0.77	0.05315	0.15	0.608	329.9	15.8	333.38	2.20	333.89	0.48
zA2	1.535	0.0427	93.65%	6	0.24	287	0.486	0.05265	2.45	0.3591	2.56	0.04946	0.34	0.387	313.4	55.7	311.51	6.87	311.25	1.05
zA3	1.372	0.0706	96.95%	12	0.18	596	0.435	0.05325	0.73	0.3845	0.83	0.05236	0.26	0.524	339.1	16.5	330.31	2.33	**329.06**	**0.82**
zA4	1.404	0.0423	93.74%	6	0.23	291	0.444	0.05313	1.35	0.3830	1.47	0.05228	0.32	0.480	334.0	30.6	329.23	4.15	**328.56**	**1.04**

(a) z1, z2 etc. are labels for fractions composed of single zircon grains or fragments; all fractions annealed and chemically abraded after Mattinson (2005).
(b) Model Th/U ratio calculated from radiogenic $^{208}Pb/^{206}Pb$ ratio and $^{207}Pb/^{235}U$ age.
(c) Pb* and Pbc represent radiogenic and common Pb, respectively; mol % $^{206}Pb^*$ with respect to radiogenic, blank and initial common Pb.
(d) Measured ratio corrected for spike and fractionation only.
(e) Corrected for fractionation, spike, and common Pb; up to 2 pg of common Pb was assumed to be procedural blank: $^{206}Pb/^{204}Pb = 18.60 \pm 0.80\%$; $^{207}Pb/^{204}Pb = 15.69 \pm 0.32\%$; $^{208}Pb/^{204}Pb = 38.51 \pm 0.74\%$ (all uncertainties 1-sigma). Excess over blank was assigned to initial common Pb.
(f) Errors are 2-sigma, propagated using the algorithms of Schmitz & Schoene (2007).
(g) Calculations are based on the decay constants of Jaffey et al. (1971). $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages corrected for initial disequilibrium in $^{230}Th/^{238}U$ using Th/U [magma] = 3 using the algorithms of Schärer (1984).
(h) dates in bold are those included in weighted mean calculations. See text for discussion.

Table 2 Biostratigraphical data used to compile the distribution of marine bands

LOCALITY	EASTING	NORTHING	AMMONOIDS
Emstites (Cravenoceras) leion Marine Band (E1a1)			
Whinney Gill Reservoir,Skipton,Yorkshire	399900	451000	*Cravenoceras leion*
River Ribble,Dinckley,Lancs	368640	436520	*Cravenoceras leion*
Harry Wall Gill - in stream bed W of Station - Bolton Abbey.	405830	452740	*Cravenoceras leion*
Bramley Farm - Bleaklow - Derbys.	424300	373400	*Cravenoceras leion*
Carla Beck - S of Rectory Carleton - Skipton - Yorks.	397600	448100	*Cravenoceras leion*
Audley Beck - Pendleton - nr Clitheroe - Lancs.	376100	438500	*Cravenoceras leion*
Croasdale Beck - NNW of Slaidburn	369680	455510	*Cravenoceras leion*
Whinney Hill Brickpits,Skipton	400100	451100	*Cravenoceras leion*
Longstone Station - disused Railway cutting West of Longstone Station.	419530	371120	*Cravenoceras leion*
Greenleighton Quarry,9miles NNW of Belsay	403400	591700	*Cravenoceras leion*
Bleaklow Mining Company - Exposure.	423000	373420	*Cravenoceras leion*
Alport Boring,near Alport	413610	391050	*Cravenoceras leion*
Hind Clough, Forest of Bowland	364400	453300	*Cravenoceras leion*
Southwest of The Hill	406400	357300	*Cravenoceras leion*
Railway cutting near Thornbridge Hall	419530	371130	*Cravenoceras leion*
Raper Mine	421690	365230	*Cravenoceras leion*
Bowers Hall BH SK26SW/46	423490	364560	*Cravenoceras leion*
Mootlaw Quarry, Matfen	402400	575000	*Cravenoceras* aff. *lineolatum*
Light Clough, Pendle Hill	375160	437640	*Cravenoceras leion*
Downs Gill, Coverhead	399000	476500	?*Cravenoceras* sp.
Roosecote BH	323040	468660	*Cravenoceras* sp.
Darnbrook Beck	387420	471710	*Cravenoceras leion*
Cominco Borehole S3	386010	463500	*Cravenoceras leion, Euomorphoceras tornquisti*
Eshton Beck	394220	455730	*Cravenoceras* cf. *leion*
Cowside Beck	385650	466370	*Cravenoceras* cf. *leion*
Daw Haw Beck	385100	466460	*Cravenoceras leion*
NE of Lower House, near Scotch Green, Inglewhite	353640	440780	*Cravenoceras* cf. *leion*
Inglewhite	354550	439030	*Cravenoceras* sp.
East of Hall Trees Farm, west of Chipping	360710	442200	*Cravenoceras leion*
200 m north of Higher Core, Bowland Fells	359240	444370	*Cravenoceras leion*
White Fold, near Longridge Fold	362180	439340	*Cravenoceras* sp.
Little Mearley Clough	377900	441400	*Cravenoceras leion*
Higher Laithe Plantation	386000	445300	*Cravenoceras leion*
Edale BH	410780	384930	*Cravenoceras leion, Eumorphoceras tornquisti*
Castleton BH	414100	382930	*Cravenoceras leion, Eumorphoceras sp.*
Hope cement works BH, Salter Barn	416780	382280	*Cravenoceras leion, Eumorphoceras sp.*
Calow No 1 BH	440860	370410	*Cravenoceras cf. leion, Eumorphoceras sp.*
Disused railway cutting near Waterhouses	407530	349560	8 bands
Bullclough	406030	355020	*Cravenoceras* sp.
Ford, R. Hamps	406600	353700	*Cravenoceras leion*
SW of Parwich	417680	354060	*Cravenoceras leion*
Lees Farm BH	418180	350160	*Cravenoceras leion*, *C.* sp., *Eumorphoceras involutum*
Farnah House, Duffield	432430	343280	*Cravenoceras* cf. *leion*
Duffield BH	434280	342170	*Cravenoceras*. Sp., *C. leion*
Widmerpool No. 1 BH SK62NW/1	463660	329580	?*Cravenoceras*. sp., *C*. cf. *leion*, *C*. cf. *malhamense, Eumorphoceras* sp., *E. pseudobilingue, Girtyoceras*
Cravenoceras brandoni Marine Band (E1b1)			
Burn Fell	367800	453100	*Cravenoceras brandoni*
Tumulites pseudobilinguis Marine Band (E1b2)			
Ramshaw Beck - Skipton	397500	448600	aff Eumorphoceras pseudobilingue
Little Mearley Clough, Pendle, Lancs	378500	441100	Eumorphoceras pseudobilingue

Cow Close Sike, Malham	390810	462100	Eumorphoceras pseudobilingue
Alport BH, Alport Castle's Farm, Glossop	413612	391055	Eumorphoceras pseudobilingue
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Tumulites pseudobilinguis Marine Band (E1b2) Continued			
Studforth Gill - Tosside - SW of Settle	377340	457500	Eumorphoceras pseudobilingue C
Croasdale Beck - NNW of Slaidburn - Yorks	369680	455510	Eumorphoceras pseudobilingue
Jenny Gill, 30yds from bottom fence, Skipton.	400440	451110	Eumorphoceras pseudobilingue
Whinney Gill Quarry - Skipton	399900	451000	Eumorphoceras pseudobilingue
Swarth Beck, Kellet Park Wood	353060	470770	*Tumulites pseudobilinguis*
Burn Fell	367800	453100	*Tumulites pseudobilinguis*
Skibeden Beck, Bullion 840' OD, Parkers Hull - Skipton	402200	451500	*Eumorphoceras pseudobilingue*
Southwest of Warslow Hall	408620	359250	*Eumorphoceras pseudobilingue*
Isingdale Beck, east of Linton	401000	463000	*Eumorphoceras pseudobilingue*
North bank of R. Wharfe, opposite Linton church	400500	463028	*Eumorphoceras pseudobilingue*
Grimwith Reservoir	406000	464000	*Eumorphoceras pseudobilingue*
Roosecote BH	323040	468660	*Eumorphoceras pseudobilingue*
Hare Clough Beck, Catlow	370470	457150	*Eumorphoceras pseudobilingue*
Hollow Gill Wood, south of Rathmell	380040	458510	*Eumorphoceras pseudobilingue*
Tranlands Beck SW of Malham	389460	462360	*Eumorphoceras pseudobilingue*
Tributary of Tranlands Beck	388460	462350	*Eumorphoceras pseudobilingue*
Crimple Beck BH	427280	451860	*Tumulites pseudobilinguis*
River Brock, Walmsley Bridge to Brock Bottom	353720	441660	*Tumulites cf. pseudobilinguis*
Right bank Fiendsdale Water	359630	449350	*Tumulites pseudobilinguis*
White Fold, near Longridge Fold	362180	439340	*Tumulites sp.*
R. Ribble west of Dinckley Hall	368640	436520	*Eumorphoceras pseudobilingue*
Butler Clough	372600	435400	*Eumorphoceras pseudobilingue*
Light Clough	375108	437708	*Eumorphoceras pseudobilingue*
Deep Clough	380900	440300	*Eumorphoceras pseudobilingue*
Weets Hollow	385900	445100	*Eumorphoceras pseudobilingue*
Castleton BH	414100	382930	*Eumorphoceras pseudobilingue* & C
River Noe, 700 yds N38W of Manor House	410630	384950	*Eumorphoceras pseudobilingue*
Calow No 1 BH	440860	370410	*Eumorphoceras pseudobilingue* ss. & C
WSW of Knockerdown	422810	352010	*Eumorphoceras pseudobilingue*
N of Bradley Nook Farm	423320	347570	*Eumorphoceras pseudobilingue*
Duffield BH	434280	342170	*Eumorphoceras pseudobilingue, E.* sp (2 leaves)
Upholland No 2 BH	350443	402870	*Eumorphoceras pseudobilingue*
Cravenoceras malhamense Marine Band (E1c1)			
Moor Close Gill - near Malham	393330	463940	*Cravenoceras malhamense*
Swinhope Mine, from shale above Little Limestone	382600	546600	*Cravenoceras aff. malhamense*
Roosecote BH	323040	468660	*Cravenoceras malhamense*
Burn Side	368800	454370	*Cravenoceras malhamense*
Copped Hill Clough	371140	457210	*Cravenoceras malhamense*
Hollow Gill Wood, south of Rathmell	379900	458570	*Cravenoceras cf. malhamense*
Out Gang	390760	461510	*Cravenoceras malhamense*
South of Stockdale Beck	384550	463100	*Cravenoceras malhamense*
Cominco Borehole S9 40.5-45.4m depth	383090	463300	*Cravenoceras malhamense*
Daw Haw Beck	385100	466460	*Cravenoceras malhamense*
Crimple Beck	425460	451780	*Cravenoceras malhamense*
Woodfold, Beacon Fell	356790	442190	*Cravenoceras malhamense*
Duckey Leach BH From 294-324 ft depth	373800	446800	*Cravenoceras sp.*
Railway cutting north of Wilpshire Tunnel	368700	432900	*Cravenoceras malhamense*
Butler Clough	372600	435400	*Cravenoceras malhamense*
Light Clough	375200	437500	*Cravenoceras malhamense*
Little Mearley Clough	378500	441100	*Cravenoceras malhamense*
Deep Clough	380900	440300	*Cravenoceras malhamense*
310 yards N50E from Firber House	383400	443000	*Cravenoceras malhamense*
Weets Hollow	385900	445100	*Cravenoceras malhamense*
Thornton Wood	392000	448000	*Cravenoceras malhamense*
300 yards S70W of Smearber	393600	449200	*Cravenoceras malhamense*
Carla Beck, 300 yards upstream from The Grange	397800	449400	*Cravenoceras malhamense*
Town Edge, south of Lothersdale	395800	445800	*Cravenoceras malhamense*
	403500	451600	*Cravenoceras cf. malhamense*

570 yards N5W of Ramsgreave Hall	367740	432010	*Cravenoceras malhamense*
Castleton BH	414100	382930	*Cravenoceras malhamense*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Cravenoceras malhamense Marine Band (E1c1) Continued			
Hope cement works BH, Salter Barn	416780	382280	*Cravenoceras malhamense*
Abbey Mills BH 4	319490	377470	*Cravenoceras* sp., *Eumorphoceras* sp.
Horton, 450 yds E by N of The Rails	391900	358550	*Cravenoceras*
Calow No 1 BH	440860	370410	*Cravenoceras malhamense*
Near Moorside	404140	354570	*Cravenoceras* sp.
Duffield BH	434280	342170	*Cravenoceras malhamense, Cravenoceras* sp.
Upholland No 2 BH	350443	402870	Cravenoceras sp.
Cravenoceras cowlingense Marine Band (E2a1)			
Cockhill - Bewerley	411200	464400	*Cravenoceras cowlingense*
Crook Dyke - Upper Nidderdale	402570	476400	*Cravenoceras cowlingense*
Brigstsone Gill - Upper Swaledale - Yorks	383900	501900	*Cravenoceras cowlingense*
Screes End, Tarnbrook	360300	455400	*Cravenoceras cowlingense*
Great Ugly Clough, Quernmore	351190	461120	*Cravenoceras cowlingense, E. grassingtonense*
Croft House Borehole, Newton-le-Wilows	419820	488830	*Cravenoceras* sp.
Black Scar, Penhill	404200	486900	*Cravenoceras cowlingense*
Gate Up Gill	405700	467400	*Cravenoceras cowlingense*
Burn Gill, Nidderdale	412800	468200	*Cravenoceras cowlingense*
Mirk Fell Gill	391000	507000	*Cravenoceras cowlingense*
Oak Beck, Oakdale temporary exposure	427450	454640	*Cravenoceras cowlingense*
Left bank, Grizedale Brook	351170	447820	*Cravenoceras cowlingense*
North of Warley Wise Farm	394400	443600	*Eumorphoceras bisulcatum*
50 yards east of Owl Cotes, 500 yards ESE of Mire Close	396700	445000	*Eumorphoceras bisulcatum*
Cononley Beck	398590	446910	*Eumorphoceras grassingtonense, Cravenoceras cowlingense*
Eller Beck	400500	448800	*Eumorphoceras bisulcatum*
Edge	402500	450000	*Eumorphoceras grassingtonense*
Bradley Gill	400800	449300	*Eumorphoceras grassingtonense*
350 yards NE of Kildwick Hall	401400	446500	*Cravenoceras cowlingense*
River Noe, 20 yds downstream of roadbridge to Upper Booth	410370	385120	*Cravenoceras cowlingense*
Alport Boring,near Alport,Derbyshire	413612	391055	*Cravenoceras cowlingense, Eumorphoceras bisulcatum* sl.
R. Hamps near Ironpits	406620	352040	*Cravenoceras cowlingense*
Lea Brook, near Cauldon	407330	349690	*Eumorphoceras grassingtonense*
Moorside	404380	354100	*Cravenoceras cowlingense*
Duffield BH	434280	342170	*Cravenoceras cowlingense, Cravenoceras* sp.
Upholland No 2 BH	350443	402870	*Cravenoceras* sp.
Eumorphoceras ferrimontanum Marine Band (E2a2)			
Tarnbrook Wyre, Abbeystead	356800	454400	*Eumorphoceras ferrimontanum*
East of Ward's Stone	359900	459100	*Eumorphoceras ferrimontanum*
Sapling Clough	362600	456300	*Eumorphoceras ferrimontanum*
Upper Dove Valley	406940	367250	*Eumorphoceras ferrimontanum*
Cogill Seave Bead, Lovely Seat	388600	494800	*Cravenoceras* aff. *cowlingense*
Croft House Borehole, Newton-le-Wilows	419820	488830	*Cravenoceras ?*
Hookstone Beck	431300	454190	*Eumorphoceras* cf. *ferrimontanum*
Stone Rings Beck	430510	452750	Cravenoceras sp., *Eumorphoceras erinense*
Barnacre Lodge	351580	446380	Cravenoceras sp., *Eumorphoceras* cf. *ferrimontanum, E. erinense*
Holbeck	419800	447000	*Eumorphoceras erinense, E. ferrimontanum, Cravenoceras* sp.
River Washburn	422900	447000	*Eumorphoceras erinense, E. ferrimontanum, Cravenoceras sp. nov,*
775 yards N of Leathley Hall	423700	447500	AMMONOIDEA *Eumorphoceras erinense, Cravenoceras* sp. nov, *E. ferrimontanum*
R. Hamps near Crowtrees, Waterhouses	407370	350250	*Cravenoceras gairense, Eumorphoceras bisulcatum & Kazakhoceras scaliger*
Hulland	424600	346220	*Eumorphoceras bisulcatum*
0.75 mile SW of Wirksworth Church	428020	353050	*Eumorphoceras bisulcatum*

Alport Boring,near Alport,Derbyshire	413612	391055	*Eumorphoceras bisulcatum*

LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Eumorphoceras ferrimontanum Marine Band (E2a2) Continued			
Duffield BH	434280	342170	*Eumorphoceras bisulcatum, Cravenoceras* sp., *Kazakhoceras scaliger*
Upholland No 2 BH	350443	402870	*Eumorphoceras bisulcatum* cf. *erinense & ferrimontanum*
Cravenoceras gressinghamense Marine Band (E2a2a)			
Gressingham Beck	356440	469960	*Cravenoceras gressinghamense*
Hunt's Gill	360560	467020	*Cravenoceras gressinghamense*
Badger Ford Beck	369270	469808	*Cravenoceras gressinghamense*
Duffield BH	434280	342170	*Eumorphoceras* sp.
Eumorphoceras yatesae Marine Band (E2a3)			
Mill Dam Beck - E of New Bridge - Weston - Burley in Wharfdale	417900	447900	*Eumorphoceras yatesae*
Croker Hill - N of Dawsons - Cheshire	392710	367380	*Eumorphoceras yatesae*
Throstle Nest - Silsden - Yorkshire	403800	446800	*Eumorphoceras yatesae*
Artle Beck	355200	462470	*Eumorphoceras yatesae*
Coppice Beck, Harrogate	430000	456200	*Eumorphoceras yatesae*
Sales Wheel, Samlesbury Hall	367560	435850	*Eumorphoceras yatesae*
Duffield BH	434280	342170	*Eumorphoceras yatesae* , *E.* sp.
Harewood BH SE34SW/37	432200	444100	*Cravenoceras*
Cravenoceratoides edalensis Marine Band (E2b1)			
River Noe, right bank, W of Edale Mill	412850	385120	*Cravenoceratoides edalense* (type)
Bosley, stream W of Higher Minnend, E of Hug Bridge	393730	364590	*Cravenoceratoides edalense*
Throstle Nest - Silsden - Yorkshire	403800	446800	*Cravenoceratoides aff. edalense*
Goodber Beck	363920	460780	*Cravenoceratoides edalensis, C.* cf. *subplicatum*
Bowers Hall BH	423490	364560	*Cravenoceratoides edalensis*
Knott Copy BH	376980	464490	*Cravenoceratoides edalensis*
Coppice Beck, Harrogate	430000	456200	*Cravenoceratoides edalensis*
Sales Wheel, Salesbury Hall	367460	435850	*Cravenoceratoides edalensis;* underlying *C. subplicatum* bed
Alport Boring,near Alport,Derbyshire	413612	391055	*Cravenoceratoides edalensis*
Ladywash crosscut	422620	376930	*Cravenoceratoides edalensis*
R. Hamps near Winkhill	406870	350410	*Cravenoceratoides edalensis*
SW of Shiningford	424200	352360	*Cravenoceratoides edalensis*
Duffield BH	434280	342170	*Cravenoceratoides edalensis, Cravenoceras* sp. nov, *C. sublicatum*
Harewood BH	432200	444100	*Cravenoceratoides*
Cravenoceras nitidus Marine Band (E2b2)			
River Ribble - Dinckley - Lancs.	368640	436520	*Cravenoceratoides nitidum*
Keasden (or Keasdon) Beck - 0.25ml above Tunnerford Bridge - Clapham	372440	465460	*Cravenoceratoides cf. nitidum*
Goodber Beck	363920	460780	*Cravenoceratoides nitidum*
Greenholes Beck	356480	463040	*Eumorphoceras leitrimense*
Branstone Beck	367830	467860	*Eumorphoceras leitrimense*
Crag Hall BH, Ellel Grange	348390	453450	*Cravenoceratoides cf. nitidus*
Wiggenstall	409020	360780	*Cravenoceratoides nitidus*
Pow Gill, 130 yards N of bridge at Powbank	325360	542300	*Anthrococeras glabrum*
Old Quarry, Wath, Nidderdale	414600	468400	*Cravenoceratoides nitidus*
Cross Gill, Nidderdale	404200	470800	*Cravenoceratoides nitidus*
NW slope of Great Whernside	400200	476000	*Cravenoceratoides nitidus*
Stand Sike, Upper Nidderdale	405100	477900	*Cravenoceratoides nitidus*
Thorny Crane Gill, Colsterdale	411200	479600	*Cravenoceratoides nitidus*
Spruce Gill, Colsterdale	413500	480300	*Cravenoceratoides nitidus*
Ulfers Gill, Colsterdale	409300	482700	*Cravenoceratoides nitidus*
Knott Copy BH 3	376980	464490	*Cravenoceratoides nitidus (lower), Glaphyrites (middle), Gl. kettlesingense (upper)*
Former brick pit at Stonefall	433100	454800	*Cravenoceratoides nitidus*
Crimple Beck between Pannal Bridge & Almsford Bridge	430740	451660	*Cravenoceratoides* sp., *Cravenoceras* sp., *Eumorphoceras* sp.

Left bank, Grizedale Brook	350740	447260	*Cravenoceratoides nitidus, C. holmesi*
Stubbing Beck	396600	443800	*Cravenoceratoides* sp., *E. bisulcatum*
Harewood BH	432200	444100	*Eumorphoceras*
Worthington BH	440450	321040	*Cravenoceras subplicatum*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Cravenoceras nitidus Marine Band (E2b2) Continued			
Hope cement works BH, Salter Barn	416780	382280	*Cravenoceratoides* cf., *nitidus, Cravenoceras* cf. *holmesi, Eumorphoceras* sp.
Duffield BH	434280	342170	*Cravenoceratoides nitidus, Eumorphoceras leitrimense*, *Cravenoceras* sp.
Alport Boring,near Alport,Derbyshire	413612	391055	*Cravenoceratoides nitidus*, *Eumorphoceras bisulcatum* var.
Upholland No 2 BH	350443	402870	*Eumorphoceras bisulcatum* cf. *leitrimense*
Cravenoceras nititoides Marine Band (E2b3)			
North of Endon	392190	354140	*Cravenoceras* sp.
E. bank of R. Crowden, 10-20 yds above confluence with R. Noe	410220	385260	*Cravenoceras*?, *Eumorphoceras* cf. *rostratum*
Alport Boring, near Alport, Derbyshire	413612	391055	*Cravenoceratoides nititoides*, *Eumorphoceras* cf. *rostratum*
Hope cement works BH, Salter Barn	416780	382280	*Cravenoceratoides nititoides*
River Terrig	323380	356970	*Cravenoceratoides nititoides*
Combes Brook, S of Ballfields	400770	352920	*Eumorphoceras rostratum*
River Ecclesbourne	431370	345550	*Cravenoceratoides nititoides, Eumorphoceras rostratum*
Duffield BH	434280	342170	*Cravenoceratoides nititoides, Eumorphoceras rostratum*, *Cravenoceras* sp.
Harewood BH	432200	444100	*Cravenoceras*
Nuculoceras stellarum Marine Band (E2c1)			
Gill Beck - Cowling – N. Yorks	395800	443600	*Cravenoceratoides stellarum*
Westfield Farm - Gill Beck - Cowling - Yorks.	395800	443600	*Cravenoceratoides stellarum*
Black Scars Beck, Cowling,SSW of Skipton Station	394100	443000	*Cravenoceratoides stellarum*
Cheddleton Paper Mills BH.	397680	352470	*Nuculoceras stellarum*
River Wharfe, right bank, 200 yards SE of Netherby	433300	446700	*Cravenoceratoides stellarum*
Right bank of Gill Beck,10yds SSE of Westfield 1230yds W 30degs N of Holy Trinity Church, Cowling	395800	443600	*Cravenoceratoides stellarum*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Carsington Reservoir BH CR10	424460	350200	*Nuculoceras stellarum*
Holehouse Lane	392020	354830	*Nuculoceras stellarum*
Castleberg Scar, 30 ft below Nesfield Sst	409100	449600	*Nuculoceras stellarum*
Hole Brook	360500	429400	Cravenoceras *stellarum, C. holmesi*
E. bank of R. Crowden, 10-20 yds above confluence with R. Noe	410220	385260	Nuculoceras stellarum
Alport Boring, near Alport, Derbyshire	413612	391055	*Nuculoceras* stellarum
Combes Brook	401880	353330	*Nuculoceras* stellarum
River Ecclesbourne	431370	345550	*Nuculoceras* stellarum
Duffield BH	434280	342170	*Nuculoceras* cf. stellarum
Harewood BH	432200	444100	*Nuculoceras* stellarum
Nuculoceras nuculum Marine Band (E2c2-4)			
Tansley Bore - Derbyshire	433126	359604	*Nuculoceras nuculum*
Sutton - 240yds E by N of Crag & SW of St Thomas's Church - Sutton.	400000	443500	*Nuculoceras nuculum*
R. Darwen, Samlesbury Bottoms,Blackburn	361720	429360	*Nuculoceras nuculum*
Gill Beck - Cowling - N Yorks	394730	443300	*Nuculoceras nuculum* (upper 2 bands)
Bentend Farm - in stream 450yds SSW of farm - near Dane Bridge - Staffs	396420	363280	*Nuculoceras nuculum*
Owl Head Wood - Kearby - Yorks	434500	446600	*Nuculoceras nuculum, Cravenoceras fragile (type)*
Oakhill Clough - 250yds NNW of Stansfield Hall Station - Todmorden	393790	424870	*Nuculoceras nuculum* (2 bands)
Mam Tor - 0.75ml NW of Castleton	413150	383450	*Nuculoceras nuculum*

Tittesworth Reservoir - SW corner - Staffs.	399220	358830	*Nuculoceras nuculum*
Sutton-on-Trent Well No.3	479900	364900	*Nuculoceras nuculum*
Shellag Point BH RTZ 1	245650	499650	*Nuculoceras nuculum*
Moor Hall, Bagnall	394910	351180	*Nuculoceras nuculum*
Stoop Farm BH	406500	368220	*Nuculoceras nuculum* (upper band)
Bowers Hall BH	423490	364560	*Nuculoceras nuculum*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Nuculoceras nuculum Marine Band (E2c2-4) Continued			
Field House	412360	358390	*Nuculoceras nuculum*
Old Park Wood	365220	434350	*Nuculoceras nuculum*
R. Ribble near Balderstone Hall	361310	433300	*Nuculoceras nuculum* (upper band)
Shawhead Beck SSE of Shaw Gate (2 bands)	392300	441500	*Nuculoceras nuculum. E. bisulcatum, Cravenoceratoides fragilis (middle), Cravenoceras darwenense (middle), Kazakhoceras hawkinsi (middle band)*
Black Scars	394100	443000	*Nuculoceras nuculum* (lower band)
340 yards E17N of Nesfield Church	409600	449700	*Nuculoceras nuculum, E. bisulcatum, Cravenoceratoides fragilis?* (lower band)
160 yards S 30E of Gildersber	407100	448800	*Nuculoceras nuculum, E. bisulcatum, Cravenoceratoides fragilis?* (lower band)
Crowden Brook	410250	385400	*Nuculoceras nuculum*
Grinds Brook, 0.25 miles N15W of Edale church	412210	386160	*Nuculoceras nuculum*
Alport Boring, near Alport, Derbyshire	413612	391055	*Nuculoceras nuculum, Eumorphoceras bisulcatum (3 horizons)*
Dove Holes, railway cutting	407610	379330	*Nuculoceras nuculum, Eumorphoceras bisulcatum*
R. Derwent, 660 yds N84W of St Helen's Church, Churchtown	426070	363040	*Nuculoceras nuculum*
Cromford Station	430340	357440	*Nuculoceras nuculum, Eumorphoceras bisulcatum*
Combes Brook	400660	352920	*Nuculoceras nuculum* (3 bands)
Middle Cliff	400020	354770	*Nuculoceras nuculum*, *Eumorphoceras bisulcatum* (highest band)
Ipstones Edge BH	402580	351090	*Nuculoceras nuculum*, (two bands)
Biggin Brook	425760	347770	*Nuculoceras nuculum*, *Eumorphoceras bisulcatum (lower band*)
Franker Brook	430810	347290	*Nuculoceras* nuculum (lower band)
Duffield BH	434280	342170	*Nuculoceras* nuculum (3 bands)
Isohomoceras subglobosum Marine Band (H1a1-3)			
Brunthwaite Beck - E of Brunthwaite & S of Parish Church - Silsden	405200	446200	*Homoceras subglobosum*
Rowley Wood, W of Low House & S of Station - Ben Rhydding	414500	447100	*Homoceras cf subglobosum*
Ilkley, NE of Pomona/SW of Middleton, Ilkley	412100	449000	*Homoceras cf subglobosum*
Stone Head Beck/Gill Beck - East of Colne	394730	443300	*Homoceras subglobosum* (3 bands)
Stream - between Ford of Meerbrook & NW of New Grange Farm - Staffs.	399290	360330	*Homoceras subglobosum*
River Noe - below Edale Mill - Derbyshire	413700	385450	*Homoceras subglobosum*
River Darwen 1500 yards W of chapel at Nab's Head	360890	429270	*Homoceras subglobosum (3 bands)*
Alport Boring, Derbyshire	413612	391055	*Homoceras subglobosum*
Black Scars Beck - Cowling - 5.25mls SSW of Skipton Station	394100	443000	*Homoceras subglobosum*
River Noe - left bank - 270yds S & 77deg W of Harrop Farm	416660	385370	*Homoceras subglobosum* (2 bands)
Tunnel Entrance - 1100yds N & 12deg E of Doveholes Station	407700	479010	*Homoceras subglobosum*
Tittesworth Reservoir, 2mls North of Leek	399210	358960	*Isohomoceras subglobosum*
Stream section at Cocker Clough Wood, north of Dolphinholme	350780	455900	*Isohomoceras subglobosum*
Well Beck, near Summersgill	363980	463600	*Isohomoceras subglobosum* (upper band)
Field House	412360	358390	*Isohomoceras subglobosum*
Haddon Park Farm	423020	367580	*Isohomoceras subglobosum*
R. Ribble near Balderstone Hall	361330	433250	*Isohomoceras subglobosum* (lower/middle band)
Lumb Clough Beck	400600	443600	*Isohomoceras subglobosum*

Swartha Wood	405380	446560	*Isohomoceras subglobosum*
Grinds Brook, 0.25 miles N15W of Edale church	412210	386160	*Isohomoceras subglobosum*
Crowden Brook, Upper Booth	410270	385520	*Isohomoceras subglobosum*
R. Noe, 710 yds S15E of Clough Farm	414750	385970	*Homoceras subglobosum* (3 bands)
Dove Holes, railway cutting	407610	379330	*Homoceras subglobosum* (lower band)
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Isohomoceras subglobosum Marine Band (H1a1-3) Continued			
Quarry, Coed Llwybr-y-bi	319280	375200	*Isohomoceras subglobosum* (lower band)
Rushton, Dingle Brook, 230 yds SSE of Harper's Farm	392070	361750	*Homoceras subglobosum*
Horton, 160 yds NNE of Porter's Farm	392600	359390	*Homoceras subglobosum*
Carsington Reservoir R11 BH	424700	349860	*Isohomoceras subglobosum* (3 bands)
Ashcombe Park	397710	351070	*Isohomoceras subglobosum* (1 band seen)
Boosemoor Brook	437380	340530	*Homoceras subglobosum*
Mill Plantation	437590	339550	*Homoceras subglobosum*
Duffield BH	434280	342170	*Homoceras subglobosum* (3 bands)
Homoceras beyrichianum Marine Band (H1b1)			
Old Wives Gill, NE of Tivoli, 600yds WNW of Myddleton Lodge, Ilkley	410600	449500	*Homoceras beyrichianum*
Swartha Gill, Silsden	405300	471000	*Homoceras beyrichianum*
Ilkley, right bank Hebers Gill, 1275yds E & 3deg N of Netherwood House & W of Station	410120	447790	*Homoceras beyrichianum*
Brunthwaite Beck, 220yds N & 27deg E of Brunthwaite, Silsden	405300	446500	*Homoceras beyrichianum*
Lumb Beck, 350yds SE of Throstle Nest, Addingham	408100	448600	*Homoceras beyrichianum*
Alport Boring, near Alport, Derbyshire	413612	391055	*Homoceras beyrichianum*
Lowgill, 170 m downstream of road bridge, Crossdale Beck	365620	465240	*Homoceras beyrichianum, H.* cf. *diadema, Isohomoceras* sp.
Well Beck, near Summersgill	365110	465460	*Homoceras beyrichianum, H.* cf. *diadema, Isohomoceras* sp.
Wiggenstall	408750	360970	*Homoceras beyrichianum*
Stoop Farm BH	406500	368220	*Homoceras beyrichianum*
Field House	412360	358390	*Homoceras* cf. *beyrichianum*
Haddon Park Farm	423020	367580	*Homoceras beyrichianum*
Gill Beck - Cowling - N Yorks.	394730	443300	*Homoceras beyrichianum*
Knott Copy BH – nonsequence immediately above marine band	376980	464490	*Homoceras beyrichianum*
400 yards S80E from Shaw Gate, Shawhead Beck	392500	441800	*Homoceras beyrichianum*
River Darwen	361720	429360	*Homoceras beyrichianum*
River Noe, left bank, 270yds S & 77deg W of Harrop Farm	416590	385540	*Homoceras beyrichianum*
Franker Brook	430590	347610	*Homoceras beyrichianum, H.* cf. *subglobosum*
Ing Gill - Primrose Hill - Middleton - Ilkley	411160	449710	*Homoceras* aff. *subglobosum*
Isohomoceras sp. nov. Marine Band (H1b2)			
Lowgill, 170 m downstream of road bridge, Crossdale Beck	365620	465240	*Isohomoceras* sp. nov.
Franker Brook	430570	347740	*Homoceras* sp. aff. *beyrichianum, H.* sp. of the *subglobosum* group
Hudsonoceras proteum Marine Band (H2a1)			
River Noe - Edale - Derbyshire	409570	385540	*Hudsonoceras proteum, Homoceras cf. smithi* (3 bands)
Congleton Edge - Staffordshire	387680	360570	*Hudsonoceras proteum*
Mam Tor - Castleton - Derbyshire	412900	383400	*Hudsonoceras proteum*
Wiggenstall	408990	360800	*Hudsonoceras proteum*
Blake Brook, Longnor	406250	361190	*Hudsonoceras proteum*
Pendle Water, east of the inn at Roughlee	384600	440400	*Hudsonoceras proteum*
R. Darwen, N of Samlesbury Bottoms	361810	429090	*Hudsonoceras proteus, Homoceras smithi*
Crowden Brook, 640 yds N3E of Highfield	410250	385630	*Hudsonoceras proteus, Homoceras smithi*
Grinds Brook, Grindsbrook Booth	412220	386260	*Hudsonoceras proteus (upper), Homoceras smithi* (lower)

Harden Clough	412240	384460	
Alport Boring,near Alport,Derbyshire	413612	391055	*Hudsonoceras proteus*
1010 yds S32E of Alport Castles Farm	414010	390290	*Hudsonoceras proteus, Homoceras smithi*
Potbank Quarry, Newbold Astbury	386910	359220	*Hudsonoceras proteus*
R. Derwent, 750 yds N89W of Stancliffe Hall	426030	364010	*Hudsonoceras proteus*
Scow Brook	424970	350930	*Hudsonoceras proteus*

LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Homoceras undulatum Marine Band (H2b1)			
Ladywash Mine - Eyam - Derbyshire	422500	376800	*Homoceras* aff. *undulatum*
Brunthwaite Beck - 220yds N & 27deg E of Brunthwaite - Silsden	405300	446500	*Homoceras* aff. *undulatum, H. beyrichianum*
Lumb Clough Beck - 735yds S & 13deg W of Sutton Church - Yorks.	400700	443500	*? Homoceras undulatum*
Samlesbury - River Darwen	361830	429160	*Homoceras undulatum*
Shell Brook - Greasley Hollow	394700	366130	*Homoceras* aff. *undulatum*
Roughlee - Right bank - immediately downstream for Stepping Stones	384600	440400	*Homoceras undulatum*
Eskew Beck, Bentham	364890	468330	*Homoceras undulatum, H.* cf. *smithi*
Tittesworth Reservoir Water Treatment Plant- N of Leek	399500	358500	*Homoceras undulatum*
Right bank of stream, 350 yards SW of Lower Jack Field	399400	443400	*Homoceras* cf. *undulatum, H.* cf. *smithi*
Alport Boring, near Alport, Derbyshire	413612	391055	*Homoceratoides* cf. *undulatum,*
1010 yds S32E of Alport Castles Farm	414010	390290	*Homoceras* cf. *undulatum*
Stream section	322680	371130	*Homoceras undulatum*
Coed-y-cra	327540	370590	*Homoceras undulatum*
Rushton, Dingle Brook, 370 yds SW by W of Fold Farm	392750	361280	*Homoceras undulatum*
Franker Brook	430550	347820	*Homoceras* cf. *undulatum*
Vallites eostriolatus Marine Band (H2c1)			
Right bank of River Darwen, 100yds NW of bridge, Samlesbury Bottoms, Blackburn	361830	429160	*Vallites eostriolatus*
Pendle Water, east of the inn at Roughlee	384600	440400	*Homoceras eostriolatum*
Hillside Section - 450yds E & 13deg S of Knot House - Eastburn - Sutton	402100	444200	*Homoceras* aff. *undulatum, H.* cf. *striolatum*
Alport Boring,near Alport, Derbyshire	413612	391055	*Homoceras eostriolatum*
Homoceratoides prereticulatus Marine Band (H2c2)			
Roughlee - 10yds downstream from Stepping Stones	384600	440400	*Homoceratoides prereticulatus*
Mam Tor - Castleton - Derbyshire.	410440	384300	*Homoceratoides prereticulatum*
Holden Beck, Silsden (Holotype)	405940	445470	*Homoceratoides prereticulatum*
River Darwen NW of Samlesbury Bridge,near Blackburn Lancs	361830	429160	*Homoceratoides* cf. *prereticulatum*
Blake Brook, Longnor	406250	361190	*Homoceratoides prereticulatum*
River Noe - at junction with Grains Clough - Edale	409530	385510	*Homoceratoides prereticulatum*
Harden Clough	412240	384460	*Homoceratoides* aff. *prereticulatum*, *Homoceras* sp.
Alport Boring,near Alport,Derbyshire	413612	391055	*Homoceratoides* aff. *prereticulatum*
Alport, ENE of Hayridge Farm	414120	389690	*Homoceratoides prereticulatum*
R. Noe, 200 yds W-WNW of Fulwood Holmes	416700	385000	*Homoceratoides prereticulatum*
Horton, 210 yds N by E of Bentend	396600	363890	*Homoceratoides prereticulatus* , *H.* sp.
Biddulph, 420 yds E by N of Heath Hay	390900	359310	*Homoceratoides prereticulatus*
Johannesburg No 6 BH	430370	359010	*Homoceratoides prereticulatus*
Hodsonites magistrorum Marine Band (R1a1)			
Backstone Beck,SE of Ilkley Station Yorks	412500	447200	*Homoceras* [sp. nov. A] *magistrorum*
Blake Brook, Longnor	406250	361190	*Homoceras magistrorum*
Right bank of River Darwen 100yds NW of Bridge,Samlesbury Bottoms,near Blackburn	361830	429160	*Homoceras magistrorum*
Alport, ENE of Hayridge Farm	414120	389690	*Homoceras* sp.
Maplebeck Well	470520	360090	*Homoceras* cf. *magistrorum*
Reticuloceras circumplicatile Marine Band (R1a2)			
Pendle Water - Rough Lee - Nelson	384500	440300	*Reticuloceras circumplicatile*
Blake Brook, Longnor	406250	361190	*Reticuloceras circumplicatile*
Right bank of River Darwen 100yds NW of	361830	429160	*Reticuloceras circumplicatile*

Bridge,Samlesbury Bottoms, near Blackburn			
Mousegill Beck, Stainmore	383520	512490	*Vallites henkei*
Franker Brook	430560	347880	*Reticuloceras circumplicatile, Vallites. henkei, Homoceratoides* sp.
Ferriby Brook	437870	339660	*Reticuloceras circumplicatile, Vallites henkei*
Reticuloceras subreticulatum Marine Band (R1a3)			
Grinds Brook, 25 yds E of Grindslow House	412140	386350	*Homoceratoides* sp., *Reticuloceras* cf. *pulchellum*, *R.* cf. *subreticulatum*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Reticuloceras subreticulatum Marine Band (R1a3) Continued			
Franker Brook	430590	347960	*Reticuloceras subreticulatum*
Ferriby Brook	437970	339720	*Reticuloceras* cf. subreticulatum
Reticuloceras todmordenense Marine Band (R1a4)			
Lumbutts Clough, Woodhouse, Todmorden	395030	424220	*Reticuloceras todmordenense*
Roughlee - Pendle	384600	440400	*Reticuloceras todmordenense*
Brund BHs, Manifold valley	408920	361530	*Reticuloceras* cf. *todmordenense*
Knott Copy BH	376980	464490	*Reticuloceras todmordenense* , *R. paucicrenulatum, R.* aff. *adpressum*
Farnham BH	434690	459960	*Reticuloceras paucicrenulatum*
Grinds Brook, 25 yds E of Grindslow House	412140	386350	*Homoceras* sp., *Reticuloceras* sp., *R. ?todmordense*
Reticuloceras dubium Marine Band (R1a5)			
Holden Beck - N of Holden Bridge - S of Silsden Parish Church	405900	445500	*Reticuloceras* cf. *dubium*
Knott Copy BH	376980	464490	*Reticuloceras dubium*
533yds SSW of Haggs Rd Farm, Spofforth Haggs - North Yorkshire	433740	450700	*Reticuloceras dubium*
Reticuloceras dubium Marine Band (R1a5) Continued			
Greenway Hall Golf Course	391860	351270	*Reticuloceras* cf. *dubium, R.* sp.
Bentham Station BH	366590	468930	*Reticuloceras dubium*
Blackwood End Farm, Quernmore	351270	457810	*Reticuloceras dubium*
Samlesbury - River Darwen	361830	429160	*Reticuloceras dubium*
Reticuloceras eoreticulatum Marine Band (R1b1)			
Mam Tor - Castleton - Derbyshire	412990	383460	*Reticuloceras eoreticulatum*
Black Bank Syke	376370	465270	*Reticuloceras* sp.
Roughlee (type specimen) large scar on right bank 65 yards upstream of stepping stones	384300	440200	*Reticuloceras eoreticulatum*
Reticuloceras nodosum Marine Band (R1b2)			
Swint Clough - Alport Valley	413470	391060	*Reticuloceras nodosum, Homoceras spiraloides, H. striolatum*
Spofforth Haggs - North Yorkshire	433740	450700	*Reticuloceras nodosum* group
Porters Farm - 420yds East + 3deg South of Porters Farm - Horton	392930	359140	*Reticuloceras* cf. *nodosum*
Brund BHs, Manifold valley	408920	361530	*Reticuloceras* aff. *nodosum*
Mam Tor - Castleton - Derbyshire	412990	383460	*Reticuloceras* cf. *nodosum*
Reticuloceras stubblefieldi Marine Band (R1b3)			
River Noe - Edale - Derbyshire	417640	383170	*Reticuloceras stubblefieldi*
1000m ENE of Bull Bank	362880	472060	*Reticuloceras* cf. *stubblefieldi*
Brund BHs, Manifold valley	408920	361530	*Reticuloceras* cf. *stubblefieldi*
Acton Burn, north of Derwent Reservoir	398300	552880	*Reticuloceras* cf. *stubblefieldi* (juv)
Crag Gill, near White House	402680	523620	*Reticuloceras stubblefieldi*
Black Bank Syke	376370	465270	*Reticuloceras stubblefieldi*
Swint Clough - Alport Valley - Derbyshire	413470	391060	*Reticuloceras* cf. *stubblefieldi, Hudsonoceras ornatum, R.* aff. *Moorei, R.* cf. *regularum*
Franker Brook	430600	348050	*Reticuloceras stubblefieldi* , *H.* cf. *striolatum*
Upper part of shale quarry, Earle's cement works, southern slope of the Folly, Hope	417000	382600	*Reticuloceras stubblefieldi* (type specimen)
Reticuloceras reticulatum Marine Band (R1c1-3)			
Eccup - 4.5mls NNW of Leeds - Yorkshire	428000	442000	*Reticuloceras reticulatum*
Stanbury, adit spoil, Sladen Bridge, Stanbury	401800	437200	*Reticuloceras reticulatum* (type form)
Woodfold Park Nab's Head	363720	428840	*Reticuloceras* cf. *reticulatum*
Clough - W of Ewood Hall - 1100yds NW of Todmorden Station	392730	424720	*Reticuloceras* cf. *reticulatum*
Black Scout, Crimsworth Dean, Hebden Bridge	3988170	429820	*Reticuloceras reticulatum*

Shewboard (or Shrewbroad) Clough, Todmorden	393590	423700	*Reticuloceras reticulatum*
Shell Brook - Mareknowles - Staffordshire	394770	365640	*Reticuloceras reticulatum*
Quarmby Clough Mills BH SE11NW/8	411453	4167370	*Reticuloceras reticulatum*
Greenway Hall Golf Course	391860	351270	*Reticuloceras reticulatum*
Grange Brickworks, Killinghall	428650	457700	*Reticuloceras reticulatum, Vallites* sp., *V. striolatus*
Stockeld BH SE34NE/16	438030	449450	*Reticuloceras reticulatum, Vallites. striolatus*
Sabden Brook	374600	434500	*Reticuloceras reticulatum, R. davisi*
LOCALITY	EASTING	NORTHING	AMMONOIDS
Reticuloceras reticulatum Marine Band (R1c1-3) Continued			
Westfield Mills BH,Yeadon SE24SW/1	420450	440940	*Reticuloceras* cf. *reticulatum reticulatum*
Co-operative Laundry SE04SE 6 BH 49.99-51.51m depth	405800	441200	*Reticuloceras* cf. *reticulatum reticulatum*
Samlesbury - River Darwen	361830	429160	*Reticuloceras reticulatum*
Samlesbury - River Darwen	362410	428640	*Reticuloceras reticulatum, R. davisi, Homoceras striolatum*
Samlesbury - River Darwen 300 yards W of Beardwood Hall	365960	428840	*Reticuloceras* cf. *reticulatum, R.* cf. *regularum, Homoceras striolatum*
Stream below Wimberry Stone	401500	402500	*Reticuloceras reticulatum* type
River Noe	409250	385760	*Reticuloceras reticulatum*
Swint Clough - Alport Valley - Derbyshire	413470	391060	*Reticuloceras reticulatum* ss.
Eyam View	421420	377190	*Reticuloceras reticulatum* ss.
South Leverton No 1 BH	479330	380400	*Reticuloceras cf. reticulatum*
Biddulph, 265 yds E of Heath Hay	390770	359280	*Homoceratoides prereticulatus*
Franker Brook	430510	348120	*Reticuloceras* cf. *reticulatum*
Reticuloceras coreticulatum Marine Band (R1c4)			
Pendle Water, right bank, Rough Lee, Forest of Pendle	384000	437000	*Reticuloceras coreticulatum*
Sabden Brook - 1250' N of confluence with River Calder	374600	434400	*Reticuloceras* aff. *coreticulatum*
Ponden Clough - 550yds upstream from Ponden Reservoir - Stanbury	398700	436700	*Reticuloceras coreticulatum* , R. reticulatum
Heysham Power Station BH SD45NW/229	340450	459890	*Reticuloceras coreticulatum, Homoceratoides divaricatus, R. reticulatum*
Co-operative Laundry BH SE04SE/6 49.99-51.51m depth	405800	441200	*Reticuloceras coreticulatum, R. reticulatum, Hudsonoceras ornatum,*
Bradup BH SE04SE/774 97.85-99.85m	409140	444170	*Reticuloceras coreticulatum*
Westfield Mills BH - Yeadon SE24SW/1	420450	440940	*Reticuloceras reticulatum* late form
Clough Hole	401800	436800	*Reticuloceras reticulatum*
Wike Whin 1.25 miles WSW of Bardsey church	434500	442200	*Reticuloceras coreticulatum, R. reticulatum*
Callow BH	426650	352820	*Reticuloceras* spp., *R. coreticulatum*
Bilinguites gracilis Marine Band (R2a1)			
Bankfield Mills BH, Mold Green SE11NE/11	414660	416270	*Reticuloceras gracile*
Foster Clough - Mytholmroyd Station	401880	427210	*Reticuloceras gracile*
Mount Road,Pule Hill,400yds E by N of Gilberts Farm, Marsden	403160	410120	*Reticuloceras gracile*
Birchover Borehole, Buxton SK26SW/16	424130	362330	*Bilinguites gracile*
Yeadon Waterworks BH - SE24SW/14	422410	442470	*Reticuloceras gracile* late mut. alpha
Holme Woods Dike - 130yds S of Holme Woods - 1mile S of Holme	410460	404450	*Reticuloceras gracile*
Grinding Stone Hole - Rag Clough - W of Church - Oxenhope	401400	433800	*Reticuloceras gracile*
Alum Crag - NNE of Alum Scar - 1.1/8ml SE of Chapel - Nabs Head	363680	428050	*Reticuloceras gracile* late mut.
Butts Clough - 100yds NE of Rishworth Mills	403750	418020	*Reticuloceras gracile, R.reticulatum*
Rake Dike - Holme - Holmfirth - Yorkshire	409980	405210	*Reticuloceras gracile*
Sun Hill Clough - Oxenhope	400600	434000	*Reticuloceras gracile*
Long Ridge - 630yds SSE of North Grain with Howels Head Clough	404940	403940	*Reticuloceras reticulatum* mut. gracile
Star Wood, 1ml NE of Oakamoor	406120	346080	*Reticuloceras gracile* (2 bands)
Bank of Salter's Brook,550 SSW of Salter's Brook Bridge, Woodhead	413510	399660	*Reticuloceras reticulatum* mut. alpha
Greenway Hall Golf Course	391860	351270	*Bilinguites gracilis*
Heysham Power Station BH SD45NW/229	340450	459890	*Bilinguites gracilis*

Seat Hall BH SD66NE/2	366030	469820	*Bilinguites gracilis*
Tittesworth Farm	400040	358740	*Bilinguites gracilis* (Lower and both middle bands of Marine Band)
River Churnet north of Swainsmoor	402410	361900	*Bilinguites gracilis* (Both middle bands of Marine Band)
Boreholes near Brund	409630	361780	*Bilinguites gracilis* (3 bands of Marine Band: *Reticuloceras* sp. nov, in Upper and lower Middle band)
NE of Pilsley	423260	371750	*Bilinguites gracilis* late form
Newton Bank BH	395820	395060	*Bilinguites gracilis* late form
Park Clough, Hey Green, Marsden	402990	412460	*Bilinguites gracilis*
Farnham BH SE35NE 27	434690	459960	*Bilinguites gracilis*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Bilinguites gracilis Marine Band (R2a1) Continued			
Sabden Brook	374600	434300	*Reticuloceras gracile* late form
Rams Clough	391000	432100	*Reticuloceras gracile* late form
Bradup BH SE04SE/774 23.05-24.49m (upper band); 26.15-28.48m (lower band)	409140	444170	*Reticuloceras gracile* type & late form (lower band) and early (upper band)
Aire Valley BH 29 SE04SE/17 35.5-37.0m	408990	440570	*Reticuloceras gracile* early form
Westfield Mills BH - Yeadon SE24SW/1	420450	440940	*Reticuloceras gracile* late mut. alpha
Kirk Lane Dye Works BH SE24SW/4a	420350	441020	*Reticuloceras gracile* late mut. alpha
Horsforth Water Works BH SE24SW/7a	423370	441160	*Reticuloceras gracile* late mut. alpha
Junction of Bent & Middle Moor cloughs 800 yards N of High Greave	399200	433600	*Reticuloceras reticulatum* early mut. alpha
Paul Clough 640 yards SE of Aberdeen	403100	433900	*Reticuloceras reticulatum* late mut. alpha & mut. alpha
Sough Hole 330 yards NW of Two Laws	397400	438300	*Reticuloceras reticulatum* mut. alpha
Victoria Hospital, Keighley 1040 yards SW of Cliffe Castle	405300	441500	*Reticuloceras reticulatum* late mut. alpha
Brickpit (Park Wood Brick co) 530yds S 6degs S of station, Keighley	406600	440700	*Reticuloceras reticulatum* cf. late mut alpha, *R. reticulatum* (2 bands)
Snail Green BH	411800	442500	*Reticuloceras gracile* mut. alpha
Banksfield Dye Works BH	420700	441500	*Reticuloceras gracile aff. mut alpha*
Corringham No 3 BH	489050	393520	*Bilinguites gracilis*
Trumfleet No 1 BH SE51SE/1	460520	412640	*Bilinguites gracilis*
Moss Oil BH SE51SE/19	459980	413900	*Bilinguites gracilis, B. gracilis* (early form)
W bank of Long Clough, c 400yds W of bridge on Glossop-Hayfield road	403020	390730	*Reticuloceras gracile*
The Heys	404390	385540	*Reticuloceras gracile*
Whitehall Works BH	403550	382020	*Reticuloceras gracile*
Forge Works No. 3 BH	404170	382190	*Reticuloceras gracile*
Clough, 0.25 miles NNE of Ridge Hall	405950	379250	*Reticuloceras* cf. *gracile*
300 yds NW of Cowlow Farm	406620	378780	*Reticuloceras gracile* [evolute form]
Stream near Dunge Farm	398900	377690	*Reticuloceras gracile*
S bank of stream 1 mile NW of Hallfield	423300	392890	*Reticuloceras gracile*
E bank of stream, W of Bole Edge Plantation	422590	392000	*Reticuloceras* cf. *gracile* and late form
N side of Raddlepit Rushes in Strines Dike	421040	389740	*Reticuloceras gracile* late form
Moscar Moor	422230	387360	*Reticuloceras gracile* late form
210 yds NNE of Mitchell Field, E of Hathersage	424870	381920	*Reticuloceras gracile*
Leeswood Old Hall BH	326360	361800	*Bilinguites gracilis*
Coed-y-felin stream section	322370	371500	*Bilinguites gracilis*
North Rode, N bank of R. Dane, 760 yds S by E of Ladderstile	390240	365310	*Reticuloceras gracile* early and late forms
Rushton, Dingle Brook, 350 yds SE by E of Harper’s Farm	392250	361760	*Reticuloceras gracile* early and late forms
Biddulph, 250 yds E by S of Heath Hay	390740	359220	*Reticuloceras gracile* early form
Abbey Mills BH 4	319490	377470	*Reticuloceras gracile* late form
Ashover, 1033 yds S20E of Raven House	435570	360270	*Reticuloceras gracile* late form
Tansley BH - Derbyshire	433126	359604	*Reticuloceras gracile,* and early form
Bothamsall No 1 BH	465860	373675	*Reticuloceras gracile*
Kelham Hills No 51 BH	476480	357500	*Reticuloceras gracile*
Kelham Hills No 1 BH	475940	357620	*Reticuloceras gracile* late form
Eakring No 1 BH	467600	361330	*Reticuloceras gracile* late form
Eakring No 3 BH	467710	361450	*Reticuloceras gracile*
Felthouse Wood	397900	350200	*Reticuloceras gracile*
Rotherwood BH	434580	315590	*Bilinguites cf. gracilis*

Callow BH	426650	352820	*Reticuloceras gracilis*
Shottlegate	431370	347410	*Reticuloceras gracilis*
Load Clough, 700yds S by E of Luddenden Parish Church	404400	425590	*Reticuloceras reticulatum*
Clark Bridge Mills - Halifax	409846	425166	*Reticuloceras reticulatum*
Butterley Clough - W bank of Gorge at top of Clough - Swellands Reservoir - Marsden	404080	409010	*Reticuloceras reticulatum* mut alpha
Worthington BH SK24SW/204	440450	321040	*Bilinguites gracilis*
Asfordby Hydro BH SK72SW/71	472520	320610	*Bilinguites* sp.
Bilinguites bilinguis Marine Band (R2b1-3)			
Dry Clough,Warm Withens, Rishworth Moor,W of Rishworth	399030	417750	*Reticuloceras reticulatum* late mut alpha, *Bilinguites bilinguis* (R2b1-2)
Netherend's Beck - right bank - Sowerby	404110	422270	*Reticuloceras bilingue* (R2b1-2)
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Bilinguites bilinguis Marine Band (R2b1-3) Continued			
Phoenix Mills BH Huddersfield	414940	417500	*Reticuloceras reticulatum* mut. *bilingue* (R2b1-2)
W bank of Long Clough,c 400yds W of bridge on Glossop-Hayfield road	403020	390730	*Reticuloceras bilingue* early form (R2b1-2)
Section in cut of bank 150yds N 31degs of High Cote, Riddlesden	406800	443000	*Reticuloceras reticulatum* mut. *bilingue* (R2b1-2)
High Marcroft Fold - Near Rochdale	384100	414800	*Reticuloceras bilingue* (R2b1-2)
March Hill - N of Dobcross	400800	413270	*Bilinguites bilinguis* (R2b1-2)
Brickpit (Park Wood Brick co) 530yds S 6degs S of station, Keighley	406600	440700	*Reticuloceras reticulatum* mut. *bilingue* (R2b1-2)
Rake Dyke @ 12000' OD 1mile SW of Holme	409670	404980	*Reticuloceras bilingue* (R2b1-2)
Kitchen Clough - Slaithwaite	408150	413470	*Reticuloceras bilingue* (R2b1-2)
Bank of R Dane W of Swythanley Hall Church	396320	364520	*Reticuloceras bilingue* (R2b1-2)
Bankfield Mills BH - Mold Green - Huddersfield	414660	416270	*Reticuloceras bilingue* (R2b1-2)
Shale scar above right bank of River Derwent about 0.5ml SW of Beeley	425760	367010	*Reticuloceras bilingue* (R2b1-2)
Fairweather Green, Four Lane Ends, Bradford	413410	433350	*Reticuloceras bilingue* (R2b1-2)
Saltaire BH - NW of Bradford	414100	438000	*Reticuloceras bilingue* (R2b1-2)
350yds SW of Lench House, Blackwood Rishworth	400700	417600	*Reticuloceras reticulatum* mut. Beta (R2b1-2)
Pike Clough,300yds ENE of Pike Farm Rishworth	403210	417570	*Bilinguites bilinguis* (R2b1-2)
Upper Deanhead Clough, Scammonden	402630	414540	*Reticuloceras reticulatum* mut. Beta (R2b1-2)
Hard Head Clough - Shot Scar - ENE of March Haigh Reservoir - Marsden	402440	413250	*Reticuloceras reticulatum* mut. Beta (R2b1-2)
Old quarry,E side of Valley Road Slaithwaite	408150	413470	*Reticuloceras reticulatum* mut. Beta (R2b1-2)
Slaithwaite Railway Station	408160	415140	*Reticuloceras reticulatum* mut. Beta (R2b1-2)
600yds S 23degs W of Hooley Hey Farm, 3 and 1/3rd miles SW of Taxal Church Cheshire	397300	374810	*Reticuloceras bilingue* early form (R2b1-2)
Borehole at Phoenix Mills Huddersfield	414940	417500	*Reticuloceras reticulatum* mut. *bilingue* (R2b1-2)
Black Sike 0.5ml SW of Upperthong,1ml W of Holmfirth	412170	408080	*Reticuloceras reticulatum* mut. Beta (R2b1-2)
SW end of Pule Hill,1150ft OD, 400yds NE of Gilberts Farm W of Marsden	403240	410160	*Reticuloceras bilingue; R. reticulatum* mut. early Beta (R2b1-2)
Kirk Lane Dyeworks BH	420350	441020	*Reticuloceras reticulatum* early mut. Beta (R2b1-2)
Wittonstall Clough, 500yds NE Cornholme Station	391480	426670	*Reticuloceras reticulatum* mut. Beta (R2b1-2)
Paul Clough - Stiperden House - NE Portsmouth Station	390960	427920	*Reticuloceras reticulatum* mut. Beta (R2b2)
Bagnall	393740	359230	*Bilinguites bilinguis* ss. (R2b2)
Greenway Hall Golf Course	391860	351270	*Bilinguites bilinguis* (R2b1)
Middleton Towers	340940	458660	*Bilinguites* sp. juv. *(ex. gr. bilinguis)* (R2b1)
Birchover Borehole,Buxton	424130	362330	*Bilinguites bilinguis* early form (R2b1)
River Churnet north of Swainsmoor	402410	361900	*Bilinguites bilinguis* early and type (R2b1)
Boreholes near Brund	409630	361780	*Bilinguites bilinguis* early form and type (R2b1&2)

NE of Pilsley	423260	371750	*Bilinguites bilinguis* early form, *Hudsonoceras ornatum, Reticuloceras sp.* (R2b1)
Newton Bank BH	395820	395060	*Bilinguites bilinguis*
Park Clough, Hey Green, Marsden	402990	412460	*Bilinguites bilinguis* early form (R2b1)
NW of Black Bank	375750	464800	*Bilinguites bilinguis*
Sabden Brook	374600	434300	*Reticuloceras bilingue*
Aire Valley BH 26	410190	439500	*Bilinguites bilinguis*
Snail Green BH	411800	442500	*Reticuloceras bilingue*
Horsforth Water Works BH SE24SW/7a	423370	441160	*Reticuloceras bilingue*
Red Brook 914m WNW of Lydgate Mill	396160	416650	*Bilinguites bilinguis, B.* cf. *circumplicatile*

LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Bilinguites bilinguis Marine Band (R2b1-3) Continued			
Moorley Clough 183m S of Rough Stones Farm	394070	420490	*Bilinguites bilinguis, B.* cf. *circumplicatile*
557m S31E of Cowall, Cowall Manor	390690	355160	*Bilinguites bilinguis* (R2b1-2)
Broomhead Reservoir dam trench	426880	396000	*Reticuloceras reticulatum mut. Beta* (R2b1-2)
Trumfleet No 2 BH	460330	412460	Bilinguites bilinguis
Whitehall Works BH	403550	382020	*Reticuloceras bilingue* early form (R2b1)
Forge Works No. 3 BH	404170	382190	*Reticuloceras bilingue* early form (R2b1)
Blackedge Reservoir	406730	376550	*Reticuloceras bilingue* (R2b1)
Hogshaw Brook	405990	374230	*Reticuloceras bilingue* early form & *bilingue* (R2b1&2)
Stream 0.25 miles ESE of Longhill Farm	403790	374830	*Reticuloceras bilingue* (R2b1)
Stream near Dunge Farm	398930	377680	*Reticuloceras bilingue* early form (R2b1)
Broughton Brook waterfall	331970	361590	*Bilinguites* cf. *bilinguis* (R2b2)
Heaton, 300 yds N by E Bearda	396320	364510	*Reticuloceras bilingue* (R2b2)
Heaton, S bank of R. Deane, 350 yds W by N Hollinhall	395380	363880	*Reticuloceras bilingue* (R2b2)
Heaton, S bank of R. Deane, 450 yds NE by E Wormhill	394120	363490	*Reticuloceras bilingue* early form (R2b1)
Rushton, Dingle Brook, 500 yds W by S Fold Farm	392610	361330	*Reticuloceras bilingue* early form (R2b1)
Heaton, 500 yds NE by N Fairboroughs	396020	361270	*Reticuloceras bilingue*
Horton, 320 yds SE Endon Hays	393100	360470	*Reticuloceras bilingue* early form (R2b1)
Biddulph, 240 yds ESE Heath Hay	390720	359180	*Reticuloceras bilingue*
Beeley Brook, 570 yds S66E of St Anne's Church, Beeley	426980	367450	*Reticuloceras bilingue* (R2b2)
Lindup Wood, 1050 yds S48W of St Anne's Church, Beeley	425790	367000	*Reticuloceras bilingue* (R2b2)
Ravensnest Wood, 770 yds N82W of Raven House	434530	361270	*Reticuloceras bilingue* (R2b2)
Hole Wood, 530 yds S9W of Raven House	435160	360670	*Reticuloceras bilingue* (R2b2)
Tansley BH - Derbyshire	433126	359604	*Reticuloceras bilingue* early form (R2b1)
Uppertown BH - Derbyshire	432370	364250	*Reticuloceras bilingue* early form (R2b1)
South of Cheddleton	397980	350230	*Reticuloceras bilingue* early form (R2b1)
Cotton Dell	406120	346080	*Reticuloceras bilingue* ss. (R2b2)
Lumb Grange	433140	346750	*Reticuloceras bilinguis*
Croxteth Park BH	340300	394300	*Reticuloceras bilingue* (R2b2)
Head of Doe Holes Clough,200yds above Deanhead Clough, Scammonden	402910	414930	*Reticuloceras reticulatum mut. Beta*
Crimble Clough - Slaithwaite - Yorkshire	408160	415110	*Reticuloceras reticulatum* (R2b2)
Clark Bridge Mills BH - Halifax	409846	425166	*Reticuloceras reticulatum*
Old quarry - Varley Road/Mansergh House - Slaithwaite	408150	413470	*Reticuloceras reticulatum*
Stream - 0.5ml NE of Warders Tower - Knypersley Reservoir - Crowborough Wood	390670	355180	*Reticuloceras reticulatum*
Worthington BH SK24SW/204	440450	321040	*Bilinguites* sp., *B. bilinguis* (R2b1)
Asfordby Hydro BH SK72SW/71	472520	320610	*Bilinguites* cf. *bilingue*
Bilinguites eometabilinguis Marine Band (R2b4)			
South of Stake Gutter	402430	362980	*Bilinguites eometabilinguis*
Birchover Borehole, Buxton SK26SW/16	424130	362330	*Bilinguites eometabilinguis*
Nan Scar Beck - Sunny Bank - Yorkshire	403400	433300	*Reticuloceras reticulatum* late mut. Beta

Gingerbread Clough	406100	439500	*Reticuloceras reticulatum*
Cullingworth, Hewenden Valley	407820	436120	*Reticuloceras reticulatum* late mut. Beta
Stream, 500 yds SE Lion's Paw Farm, Knypersley	390300	355600	*Bilinguites eometabilinguis*, *B. bilinguis* late form
Cotton Dell	406120	345770	*Reticuloceras eometabilingue, R. metabilingue*
Carsington Aquaduct BH M8 SK25SE/62	425390	350190	*Reticuloceras eometabilingue, R. bilingue*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Bilinguites eometabilinguis Marine Band (R2b4) Continued			
Asfordby Hydro BH SK72SW/71	472520	320610	*Bilinguites* cf. *eometabilingue*
Bilinguites metabilinguis Marine Band (R2b5)			
Phoenix Mills BH Huddersfield	414940	317500	*Reticuloceras reticulatum* cf. mut. *metabilingue*
300yds NE of Higher Hempshaws - 2mls W of Belmont	365000	416500	*Reticuloceras eometabilingue, Reticuloceras reticulatum metabilingue*
Fairweather Green BH, Four Lane Ends, Bradford	413380	433300	*Reticuloceras bilingue* late form
Horsforth UD Waterworks BH - N of Horsforth	423370	441160	*Reticuloceras reticulatum* late mut. Beta
Bagnall	393640	350530	*Bilinguites* cf. *metabilinguis Verneulites sigma*
Birchover Borehole, Buxton SK26SW/16	424130	362330	*Bilinguites metabilinguis*
Brownsett	399250	363690	*Bilinguites metabilinguis*
Aire Valley BH P22 SE03NE/9	409850	439750	*Bilinguites bilinguis* late form
Aire Valley BH A4 SE04SE/15	408920	440560	*Bilinguites bilinguis* late form
Aire Valley BH A1 SE04SE/12	408820	440360	*Bilinguites bilinguis* late form, cf. *B. metabilinguis*
200 yards ESE of Mould Greave, Marsh, near Oxenhope	402700	435400	*Reticuloceras reticulatum* late mut. Beta
Lees Moor BH, 230 yards W of Lower Height Bingley	406100	438000	*Reticuloceras reticulatum* late mut. Beta
Kirk Lane Dyeworks BH SE24SW/4a	420350	441020	*Reticuloceras reticulatum* late mut Beta
Old lead mines 0.5 miles E of Leicester Mill Quarry	362830	416360	*Reticuloceras metabilingue, Gastrioceras sigma*
Ryal Fold, W of Darwen Hill 280 yards SSE of the SE end of Higher Roddlesworth Reservoir	366200	421520	*Reticuloceras metabilingue*
Wiggins Teape No2 BH	361460	423440	*Reticuloceras metabilingue*
Star Paper Mills B BH	364700	424950	*Reticuloceras metabilingue*
400 yds N16W of Ladymon (?Ladymoor) Gate	390300	355800	*Bilinguites metabilinguis, B. bilinguis* late form
South end of tunnel, Scout, Scout Mill	397280	401230	*Reticuloceras reticulatum* late mut. B & gamma
Stream 140 yds WNW of Carr Meadow, Derbyshire	403320	389510	*Reticuloceras metabilingue*
Stream W of Marl House, Derbyshire	403090	388800	*Reticuloceras* cf. *bilingue* late form*, R. metabilingue*
Blackedge Reservoir	406730	376550	*Reticuloceras metabilingue*
Rocher End Brook, 420yds at N50W from Bradfield Church	426000	392000	*Reticuloceras bilingue* late form, *Homoceras?*
Rivelin valley close to Wolf Wheel 1160 yds S83E of Rails	430200	387500	*Reticuloceras bilingue* late form
Macclesfield Forest, S bank of reservoir, 1400 yds NE Thickwithers	396570	371300	*Reticuloceras metabilingue*
Rushton, 350 yds NE Oulton	396570	371300	*Reticuloceras metabilingue*
Lindup Wood, 1050 yds S48W of St Anne's Church, Beeley	425790	367000	*Reticuloceras bilingue* late form
370 yds S75E of Cromford station	430650	357280	*Reticuloceras bilingue* late form
South of Cheddleton	398130	350430	*Reticuloceras bilingue* late form
Combes Valley	400360	351450	*Reticuloceras metabilingue* and *R. bilingue* early form
Duffield railway cutting	434290	343640	*Reticuloceras bilinguis* late form
Ferriby Brook	438080	339780	*Reticuloceras bilinguis* late form
Butts Clough - 220yds SW Clough Head Farm - Rishworth	404300	417810	*Reticuloceras reticulatum* mut. Beta
Blake Clough - Blake Clough Farm - Slaithwaite Moors	405200	413610	*Reticuloceras reticulatum* mut. Beta
Worthington BH SK24SW/204	440450	321040	*Bilinguites* sp., *B. bilinguis, B. metabilinguis*

Asfordby Hydro BH SK72SW/71	472520	320610	*Bilinguites* sp.
Bilinguites superbilinguis Marine Band (R2c1)			
Pears House Clough, 850yds S of Strines Public House - Derbyshire	422520	389890	*Reticuloceras superbilingue*
Eagle Stone - site 825yds from at S5W- 8mls NNW of Chesterfield	426000	373000	*Reticuloceras reticulatum* mut. *superbilingue*
Rocher End Brook,530yds at 344degs from Bradfield Church, Yorkshire	426000	392000	*Reticuloceras superbilinguis, Gastrioceras* sp. nov., *G.* cf. *lineatum, Homoceratoides* cf. *divaricatus, H,* sp. nov.
LOCALITY	EASTING	NORTHING	AMMONOIDS
Bilinguites superbilinguis Marine Band (R2c1) Continued			
Newton Bank BH	395820	395060	*Bilinguites superbilinguis*
Will Moor Clough, 240 yards S of Antley Gate	391900	436300	*Reticuloceras superbilingue*
Trawden Brook, below Lumb Spout Waterfall	392000	437200	*Reticuloceras superbilingue*
Aire Valley BH A1SE04SE/12	408820	440360	*Bilinguites* ghosts
Horsforth Water Works BH SE24SW/7a	423370	441160	*Reticuloceras superbilingue*
Haworth Moor at Near Fosse Intake 170 yards ESE of Withins	398300	435400	*Reticuloceras reticulatum* mut. gamma
Blue Scar Beck 550 yards NNE of Clough Hey	400000	439900	*Reticuloceras reticulatum* mut. gamma
Baildon Holmes 1100 yards S67E of Baildon Green church	415400	438200	*Reticuloceras reticulatum* mut. gamma
Sydney Works BH, Fairweather Green	413400	433300	*Reticuloceras superbilingue*
Sandoz Chemical Co. BH	416300	434300	*Reticuloceras superbilingue*
New Lane Mills BH Laisterdyke	419100	432700	*Reticuloceras superbilingue*
River Yarrow 300 yards NE of Hempshaws	365000	416500	*Reticuloceras superbilingue, Gastrioceras sigma*
Ryal Fold, west of Darwen Hill	366260	421700	*Reticuloceras superbilingue*
Wiggins Teape No2 BH Withnell Fold	361460	423440	*Reticuloceras superbilingue*
Mossley Sewage Works 450 yards S of Scout	397200	400800	*Reticuloceras reticulatum* mut. gamma
Askern Oil BH SE51NE/1	456520	415020	*Bilinguites superbilinguis*
Moss Oil BH SE51SE/19	459980	413900	*Bilinguites superbilinguis*
Trumfleet No 1 BH	460520	412640	*Bilinguites superbilinguis*
Trumfleet No 2 BH	460330	412460	*Bilinguites superbilinguis, Verneulites sigma*
Tributary of Long Clough, Derbyshire	402710	390980	*Reticuloceras superbilingue, Donetzoceras* cf. *sigma, Gastrioceras, Homoceratoides* cf. *divaricatus*
Heylee, Spire Hollins	403200	378300	*Reticuloceras superbilingue, Gastrioceras* spp., *Homoceratoides divaricatus*
Pyegreave Brook	404880	378060	*Reticuloceras superbilingue*
Castle Naze	404820	378570	*Reticuloceras superbilingue, Gastrioceras spp., Homoceratoides fortelirifer*
Lightwood Reservoir	405470	375290	*Reticuloceras* sp.
Yarncliff Wood	425140	379100	*Donetzoceras sigma, Reticuloceras superbilinguis*
Hallam Head BH	430091	389123	*Donetzoceras sigma, Reticuloceras superbilinguis*
Broughton Brook, SE of Corn Mill	331640	365410	*Bilinguites superbilinguis*
Sutton, 500 yds NE by N of Langley Print Works	394350	371740	*Reticuloceras superbilingue*
Uppertown BH - Derbyshire	432370	364250	*Reticuloceras bilingue* early form
3050 yds N5E of Chatsworth House	426510	373030	*Reticuloceras superbilingue, Gastrioceras* spp. *Homoceratoides fortelirifer*
Jumbel (or Jumble) Coppice - Baslow; 2230 yds N25E of Chatsworth House	426830	372090	*Reticuloceras superbilingue, Gastrioceras* spp. *Homoceratoides fortelirifer*
Bassetbarn Farm BH	435540	364160	*Reticuloceras superbilingue*
Bothamsall No 1 BH	465860	373675	*Reticuloceras* cf. *superbilingue*
Shirley Hollow	403790	348090	*Reticuloceras superbilingue*
Rotherwood BH	434580	315590	*Bilinguites superbilinguis*
W. of Hankin Farm	432140	354480	*Reticuloceras superbilingue*
Ambergate railway cutting	434670	350800	*Reticuloceras superbilingue*
Blackfordby No. 1 BH	432250	318270	*Reticuloceras reticulatum* mut. gamma
Bottonley Clough - 140yds E of Bottoms Farm	406340	419190	*Reticuloceras reticulatum*

- Barkisland			
Junction of Streams - Heath House Wood - 150yds N of Heath House - Golcar	408990	415810	*Reticuloceras reticulatum*
Stream bank below Haslingden-Helmshore Road - 850yds NW of Helmshore Sation	377760	421680	*Reticuloceras reticulatum*
Worthington BH SK24SW/204	440450	321040	*Bilinguites superbilinguis, Gastrioceras* sp.
Asfordby Hydro BH SK72SW/71	472520	320610	*Bilinguites superbilinguis,* cf.*Gastrioceras* sp.
Verneulites sigma Marine Band (R2c2)			
Oxspring Borehole, SE of Oxspring SE20SE/6	427870	401360	*Gastrioceras ? sigma, Reticuloceras reticulatum* mut. *superbilingue*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Verneulites sigma Marine Band (R2c2) Continued			
Stream bank, NNW of Bromiley, Belmont	365780	417920	*Gastrioceras sigma*
NE of Higher Hempshaws, W of Belmont	365000	416500	*Gastrioceras ? sigma*
Burbage Brook, Grindleford Station, Derbys.	425030	378690	*Gastrioceras ? sigma*
100yds N of Chatsworth House	426210	371180	*Gastrioceras ? sigma*
Anglezarke Reservoir, Lancashire	362200	415900	*Gastrioceras sigma, Homoceratoides*
Ryal Fold, west of Darwen Hill	366300	421490	*Pygmaeoceras sigma*
Wiggins Teape No2 BH	361460	423440	*Gastrioceras* sp.
200 yards SE of Canyards	425900	395100	*Reticuloceras reticulatum* early mut. gamma
Raynor Clough 800 yds E25N of White Lea	427500	395500	*Reticuloceras reticulatum* early mut. gamma*, Gastrioceras ? sigma*
More Hall (or Hull) Reservoir - trial hole for wing trench - 900yds NW of Brightholmlee	428390	395570	*Gastrioceras* cf. *cumbriense, G.* cf. *crenulatum, G. spp, Reticuloceras reticulatum* mut. gamma*, Gastrioceras ? sigma*
Stream N of Bankvale Mill	403110	387660	*Donetzoceras sigma, Reticuloceras superbilingue*
River between Strines & Dale Dike reservoirs	423360	390660	*Donetzoceras sigma*
Pear House Clough	422830	388960	*Donetzoceras sigma*
Callow Bank	425190	382290	*Donetzoceras sigma*
Yarncliff Wood	425140	379100	*Donetzoceras sigma*
Wincle, 1300 yds SE Sutton End	396630	367980	*Donetzoceras sigma*
Rushton, 810 yds SE by E of The Cloud	391060	363200	*Donetzoceras sigma*
Biddulph, 180 yds S by W of Heath Hay	390480	359110	*Donetzoceras sigma*
Biddulph, 400 yds NNW of Cowall	390250	356030	*Donetzoceras sigma*
3050 yds N5E of Chatsworth House	426150	373030	*Pygmaeoceras sigma*
2230 yds N25E of Chatsworth House	426830	372090	*Pygmaeoceras sigma, Gastrioceras* sp.
Bassetbarn Farm BH	435540	364160	*Pygmaeoceras sigma, Gastrioceras* sp., *Reticuloceras superbilingue*
Combes Valley	401350	351010	*Donetzoceras sigma*
Shirley Hollow	403790	348090	*Donetzoceras sigma*
Blackfordby No. 1 BH	432350	318270	*Gastrioceras ?sigma*
Cancelloceras cancellatum Marine Band (G1a1)			
Royshaw Brick Works, Blackburn Station	368250	429500	*Gastrioceras cancellatum* var. *crencellatum; Reticuloceras reticulatum*
Section in Dean brook,150yds S of Higher House, 2 miles W of Belmont	364350	415380	*Gastrioceras cancellatum, G.* cf. *crencellatum, R. superbilingue*
Crowborough Wood Warders Tower,Staffs.	390100	355520	*Gastrioceras* cf. *cancellatum*
Nant Figillt Farm - Rhosesmor - Flints	320910	368000	Cancell*oceras cancellatum, C. crencellatum, C.* sp., *Homoceratoides divaricatum, Reticuloceras reticulatum mut alpha*
Wall Grange Brick Pit – Staffs.	396440	353220	*Gastrioceras cancellatum*
Bowsey Wood BH SJ74NE/9	376950	346430	*Gastrioceras* cf. *cancellatum*
Heysham Power Station BH SD45NW/87	340260	459940	*Cancelloceras cancellatum, C. crencellatum, C.* sp., *Homoceratoides divaricatum, Reticuloceras reticulatum mut alpha*
Seat Hall BH SD66NE/2	366030	469820	*Cancelloceras cancellatum, C.branneroides*
River Greta	361700	472230	*Gastrioceras* cf. *cancellatum, C. crencellatum*
Newton Bank BH	395820	395060	*Gastrioceras crencellatum*
Harrop Brook	395990	378460	*Gastrioceras crencellatum*

Bollington Print Works BH	393980	377970	*Gastrioceras cancellatum*
Orchard Farm	402260	369030	*Cancelloceras cancellatum*
Waters Farm BH	375370	467630	*Cancelloceras cancellatum, Gastrioceras crencellatum, G. branneroides*
Farnham BH SE35NE/27	434690	459960	*Cancelloceras* cf. *cancellatum, C. crencellatum*
Monkroyd Beck, NNE of Monkroyd	393400	441400	*Gastrioceras* crencellatum
Aire Valley BH 28 SE13NW/22	410400	439110	*Cancelloceras cancellatum, C. crencellatum*
Aire Valley BH B52 SE13NE/29	415010	437880	*Cancelloceras cancellatum, C. crencellatum*
Aire Valley BH A2 SE04SE/13	408870	440450	*Cancelloceras* crencellatum
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Cancelloceras cancellatum Marine Band (G1a1) Continued			
Horsforth Water Works BH SE04SE/13	423370	441160	*Cancelloceras cancellatum*
Middle Moor Clough 600 yards SW of Upper Ponden	397600	436000	*Cancelloceras cancellatum, Gastrioceras crencellatum, R. superbilinguis*
Bingley Brick Pit	411200	441200	*Cancelloceras cancellatum, R. superbilinguis*
Saltaire Mills	414100	438000	*Cancelloceras cancellatum, R. superbilinguis*
Yeadon Brick & Tile Works	419400	440900	*Cancelloceras cancellatum, R. superbilinguis*
West View, 330 yards N of Apperley Bridge Station	419600	438700	*Cancelloceras cancellatum, R. superbilinguis*
Sydney Works BH, Fairweather Green	413400	433300	*Cancelloceras cancellatum, Gastrioceras crencellatum, ? G. sigma*
New Lane Mills Laisterdyke	419100	432700	*Gastrioceras crencellatum, G.* cf. *cumbriense*
Summit Brickworks	394850	418730	*Gastrioceras crencellatum, Cancelloceras cancellatum*
Ring road cutting N of Meanwood Hall	428300	438600	*Gastrioceras cancellatum type*
60 yds WNW of Hollinshead Hall 3 miles N of Belmont	366230	419920	*Gastrioceras crencellatum* (upper fauna)
400 yds N10W of Wheelton crossroads	359990	421510	*Gastrioceras branneroides* (Bed A)*, G. cancellatum, R. superbilingue* (Bed B-C)*, G. crencellatum* (Bed D)
Howe Brook, SW of Chorley 1560 yds NNW of Wrightington Church	352030	414860	*Gastrioceras crencellatum* (upper fauna)
Acres Brook	397000	397800	*Gastrioceras cancellatum, R. reticulatum* mut. gamma
Oxspring BH, SE of Oxspring SE20SE/6	427870	401360	*Gastrioceras cancelloceras, Reticuloceras reticulatum* mut. gamma
Trumfleet No 1 BH SE51SE/1	460520	412640	*Cancelloceras cancellatum, C. crencellatum*
Askern Oil BH SE51NE/1	456520	415020	*Cancelloceras crencellatum*
Belton Oil BH	477710	408460	*Cancelloceras crencellatum*
Fernilee No. 1 BH	401240	378230	*Cancelloceras cancellatum, C. crencellatum, R. superbilingue*
Mather Clough	397700	382130	*Cancelloceras cancellatum, C.* cf. *crencellatum*
Mill Clough	400240	378070	*Cancelloceras crencellatum*
Shooter's Clough	400570	374670	*Cancelloceras cancellatum, R. superbilingue*
Damflask Reservoir	427400	391100	*Gastrioceras cancellatum, G.* cf. *crencellatum, Reticuloceras superbilinguis*
Rod Moor No 3 BH	426780	389160	*Gastrioceras crencellatum, Reticuloceras superbilinguis*
Carr Brook, 1490 yds N79E of Bassett, W of Fulwood	429700	384800	*Gastrioceras crencellatum, G. rurae*
Limb Brook, 1250 yds N88E of Barberfields Farm	430800	382900	*Gastrioceras* cf. *cancellatum, G. rurae?*
Smeekley No 3 BH	429690	376498	*Gastrioceras cancellatum, G. crencellatum*
Tickhill No 1 BH	457730	392970	*Gastrioceras cancellatum*
Walkeringham No 1 BH	475550	391900	*Gastrioceras crencellatum*

Morton No 1 BH	479320	392410	*Gastrioceras crencellatum*
Apleyhead No 1 BH	465510	376310	*Gastrioceras* cf. *crencellatum*
Apleyhead No 2 BH	465770	376630	*Gastrioceras* cf. *crencellatum*
Bothamsall No 2 BH	465566	373917	*Gastrioceras crencellatum*
Bothamsall No 4 BH	466193	374022	*Gastrioceras crencellatum*
Fishpond Wood, stream section	332600	364310	*Cancelloceras cancellatum*
Warren Dingle	331790	362340	Cancell*oceras cancellatum, Ca. branneroides, Ca.* sp., *Bilinguites superbilinguis*
Congleton, 660 yds NE by E of Timbersbrook crossroads	390030	362980	Cancell*oceras cancellatum, Bilinguites superbilinguis, Homoceratoides* sp.
Biddulph, 300 yds WSW of Heath Hay	390260	359140	*Gastrioceras crencellatum*
Biddulph, W bank of R. Trent, 320 yds SW by W of Cowall	390110	355510	*Cancelloceras cancellatum, Bilinguites superbilinguis*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Cancelloceras cancellatum Marine Band (G1a1) Continued			
Harewood Grange, N side of R. Hipper	431280	368080	*Gastrioceras crencellatum*
Walnut Opencast C11 BH, N bank of Carr Brook, 1970 yds N86E of Butterley Reservoir	436360	360130	Gastrioceras *cf.* crencellatum, G. *cf. rurae, G.* sp.
Calow No 1 BH	440860	370410	*Gastrioceras crencellatum*
Bothamsall No 5 BH	466595	373440	*Gastrioceras* cf. *crencellatum*
Farley's Wood No 2 BH	470969	369997	*Gastrioceras crencellatum*, G. *crencellatum, G.* cf. *cumbriense*, cf. *Agastrioceras carinatum*
Eakring No 1 BH	467600	361330	*Gastrioceras crencellatum*
Eakring No 3 BH	467710	361450	*Gastrioceras crencellatum*
Ruelow Wood BH SK04NW/5	402050	347520	*Gastrioceras crencellatum* (2 bands)
Rugeley (Trent Valley) BH	405080	319020	*Gastrioceras crencellatum*, with *G. cancellatum & Reticuloceras superbilingue* in base
Whittington Heath BH	414780	308000	*Gastrioceras cancellatum, Reticuloceras superbilingue*
Blackfordby No. 1 BH	432350	318270	?*Gastrioceras cancellatum*
Sandoz Chemical Co.	416300	434300	*Gastrioceras crencellatum*, with *G. rurae* in lower bed & *G.* cf. *carinatum* in upper
Winksley BH	425070	471510	*Gastrioceras cancellatum*
Cancelloceras cumbriense Marine Band (G1b1)			
N side of Willow railway cutting - NNE of Chorley Station	359520	419250	*Gastrioceras cumbriense. G. crenulatum*
Bigrigg - Cumberland	300100	513050	*Gastrioceras cumbriense*
Mousegill - 120yds W + 20deg S of Swinestone House - Westmorland	383680	512420	*Gastrioceras* cf. *cumbriense*
Horsforth UD Waterworks BH - 2mls N of Horsforth SE24SW/7a	423370	441160	*Gastrioceras cumbriense*
River Greta	361700	472230	Cancell*oceras* cf. *cumbriense, Homoceratoides* sp.
Newton Bank BH	395820	395060	*Gastrioceras cumbriense*
Harrop Brook	395830	378450	*Gastrioceras cumbriense, G. crenulatum, Homoceratoides* aff. *divaricatus*
Orchard Farm	402260	369030	*Cancelloceras cumbriense*
Waters Farm BH	375370	467630	*Cancelloceras cumbriense, Gastrioceras crenulatum*
Goat Gap Syke	371630	469970	*Cancelloceras cumbriense, Gastrioceras crenulatum*
Farnham BH SE35NE/27	434690	459960	*Cancelloceras cumbriense, Gastrioceras crenulatum*
High Lea Farm, Lower Trap	377200	435400	*Cancelloceras cumbriense, Ca. crenulatum, Homoceratoides divaricatus*
Monkroyd Beck, NNE of Monkroyd	393400	441400	*Gastrioceras* cumbriense
North bank of Swinden Water	390600	433000	*Gastrioceras* cumbriense
Brook east of Combe Hill Cross	395800	438500	*Gastrioceras* cumbriense
Aire Valley BH 43 SE13NW/23	410270	439040	*Cancelloceras cumbriense, Ca. crenulatum*
Aire Valley BH 29 SE13NE/29	415010	437880	*Cancelloceras cumbriense*
Oaks Farm, Yeadon	424040	441200	*Cancelloceras cumbriense, Ca. crenulatum*
Middle Moor Clough 600 yards SW of Upper	397500	435900	*Cancelloceras cumbriense,*

Ponden			*Gastrioceras crenulatum, R. superbilinguis*
Gill Beck 400 yards N14E of Ash House Farm	414600	441800	*Cancelloceras cumbriense, Gastrioceras crenulatum*
Yeadon Brick & Tile Works	419400	440900	*Cancelloceras cancellatum, Gastrioceras crenulatum*
Sydney Works BH, Fairweather Green	413400	433300	*Cancelloceras cumbriense, Gastrioceras crenulatum*
New Lane Mills Laisterdyke	419100	432700	*Cancelloceras cancellatum, Gastrioceras crenulatum*
Great Heads Wood, Roundhay Park	433600	438500	Gastrioceras *cumbriense*
Shore Brook 320 yds SE of Higher House, 2 miles W of Belmont	364520	415300	*Gastrioceras cumbriense, G. crenulatum*
LOCALITY	EASTING	NORTHING	AMMONOIDS
Cancelloceras cumbriense Marine Band (G1b1) Continued			
Yarrow valley 900 yds W40S of Euxton Hall	354730	417950	*Gastrioceras cumbriense, G. crenulatum*
Booth's Farm BH	354220	417310	*Gastrioceras cumbriense*
Oxspring Borehole, SE of Oxspring SE20SE/6	427870	401360	*Gastrioceras* cf. *crenulatum, G.* cf. *cumbriense*
Moss Oil BH	459980	413900	Cancelloceras crenulatum, *Ca. cumbriense*
Trumfleet No 1 BH	460520	412640	*Cancelloceras crenulatum, Ca. cumbriense*
Askern Oil BH	456520	415020	*Cancelloceras cumbriense*
N of Rowarth	401610	389840	*Gastrioceras cumbriense*
Fernilee No. 1 BH	401240	378230	*Gastrioceras cumbriense* , *G. crenulatum*
Mather Clough	397740	382250	*Gastrioceras cumbriense* , G. crenulatum
Stream, 0.5 miles W by S of Handley Fold	397400	380540	*Gastrioceras cumbriense* , G. crenulatum
Mill Clough	400240	378070	*Gastrioceras cumbriense*
Shooter's Clough	400570	374670	*Gastrioceras cumbriense, Homoceratoides* aff. *divaricatus*
Holes Clough	423830	390380	*Gastrioceras cumbriense, G. crenulatum, Homoceratoides* aff. *divaricatus*
Ughill Brook, 160 yds N7W of Corker Walls	426100	390100	*Gastrioceras cumbriense, G. crenulatum*
Rod Moor No 3 BH	426780	389160	*Gastrioceras cumbriense, G. crenulatum*
Stream 633 yds N33E of Norfolk Arms, Ringinglow	429400	384200	*Gastrioceras cumbriense, G. crenulatum*
Stream 130 yds N of chapel at Longshaw Lodge	426400	380000	*Gastrioceras cumbriense, G. crenulatum*
Barr Brook, 30 ft below Rough Rock	427900	375000	*Gastrioceras cumbriense, G. crenulatum*
Smeekley No 3 BH SK27NE/2	429690	376498	*Gastrioceras cumbriense, G. crenulatum*
Tickhill No 1 BH	457730	392970	*Gastrioceras cumbriense*
Warren Dingle	332270	362320	Cancell*oceras cumbriense, Ca. crenulatum*
Leeswood Old Hall	326410	361300	Cancell*oceras cumbriense, Ca. crenulatum*
Congleton, E bank of gully, 560 yds ENE of Timbersbrook crossroads	389990	362860	Cancell*oceras* cf. *cumbriense, Ca. crenulatum*
Biddulph, W bank of stream, 640 yds SW by S of Bridestones	390310	361760	Cancell*oceras* cf. *cumbriense*
Biddulph, SE bank of R. Trent, 390 yds SW of Cowall	390110	355420	Cancell*oceras cumbriense, Ca.* cf. *crenulatum*
Abbey Mills BH 4	319490	377470	*Gastrioceras cumbriense*
Harewood Grange, N side of R. Hipper	431250	368110	*Gastrioceras cumbriense*
220 yds SE of Lea Hall	433530	357370	*Gastrioceras cumbriense, G. crenulatum, Homoceratoides* aff. *divaricatus*
Calow No 1 BH	440860	370410	*Gastrioceras cumbriense*, *G. crenulatum*
Ruelow Wood BH	402050	347520	*Gastrioceras cumbriense* (2 bands)
Beelow Hill	406620	345060	*Gastrioceras cumbriense*
Rugeley (Trent Valley) BH	405080	319020	*Gastrioceras cumbriense*
Blackfordby No. 1 BH	432350	318270	*Gastrioceras cumbriense*

Sandoz Chemical Co. BH	416300	434300	*Gastrioceras cumbriense*, *Homoceratoides divaricatum*; *G.* sp., *G. carbonarium* in upper part
Asfordby Hydro BH SK72SW 71	472520	320610	*Gastrioceras* cf. *crenulatum*
Gastrioceras subcrenatum Marine Band (G2a1)			
Ballavarish Bh, Shellag north Bh	246250	500700	*Gastrioceras subcrenatum*
Ridgeway Bh	389220	353810	*Gastrioceras subcrenatum*
River Greta	364360	472040	*Gastrioceras subcrenatum*
Stake Clough, NW of Goyt's Moss	400660	372910	*Gastrioceras subcrenatum*
400 yds SW of Arnold Hill reservoir, Gee Cross	395000	393000	*Gastrioceras subcrenatum*
LOCALITY	EASTING	NORTHING	AMMONOIDS
Gastrioceras subcrenatum Marine Band (G2a1) Continued			
Bakestonedale BH	395940	379510	*Gastrioceras* sp.
Mere Burn	408860	554850	*Gastrioceras subcrenatum*
River Little Don, 1km E of Langsett (type section)	422150	400410	*Gastrioceras subcrenatum*
Harrington No. 19 BH	299500	521000	*Gastrioceras subcrenatum*
St. Bees No. 4 BH	295000	512700	*Gastrioceras subcrenatum*
Whitehaven Laundry BH	297600	516800	*Gastrioceras subcrenatum*
Waters Farm BH	375370	467630	*Gastrioceras subcrenatum*
South of Blackwood Head, Wheatley Lane	383200	438200	*Gastrioceras subcrenatum, Reticuloceras superbilingue*
South bank of Colne Water, 450 yards east of Carry Bridge	390000	439800	Gastrioceras cf. s*ubcrenatum*
Horsforth Water Works BH SE24SW/7a	423370	441160	Gastrioceras *subcrenatum*
Thornton Moor	405300	432600	Gastrioceras *subcrenatum*
Cottingley Moor Bridge	411200	436200	Gastrioceras *subcrenatum*
Thackley Tunnel, NW of Apperley Bridge	418400	438700	Gastrioceras *subcrenatum*
Newlay cutting	423200	436800	Gastrioceras *subcrenatum*
Top Mill BH, 400 yards NW of Alerton	411800	434400	Gastrioceras *subcrenatum, G. listeri*
Sydney Works BH, Fairweather Green	413400	433300	Gastrioceras carbonarium
Horsforth UD Waterworks BH - N of Horsforth	423370	441160	*Gastrioceras subcrenatum*
Union Mills	418600	435600	*Gastrioceras* cf. *subcrenatum*
Alston Works BH	414600	433400	*Gastrioceras subcrenatum*
Britannia Mills BH	416400	432500	*Gastrioceras subcrenatum*
Sandoz Chemical Co. BH	416300	434300	*Gastrioceras carbonarium*
Globe Mills BH, Leeds, 400 yards S of City station SE23SE/7	4297990	4327870	*Gastrioceras* spp.*, G. retrorsum, R. reticuloceras*
North bank R. Darwen, 120 yds SE of Old Hall, Feniscowles	363780	425720	*Gastrioceras subcrenatum*
Stepback Brook, W of Darwen Hill, 1300 yds S42E of the inn at Ryal Fold	367310	420650	*Gastrioceras subcrenatum*
560 yds NNW of St Stephen's Church, Chapel	365760	424000	*Gastrioceras subcrenatum*
Howe Brook, S of Brook House	352280	413980	*Gastrioceras subcrenatum, G.* sp.
Heskin BH	353890	414500	*Gastrioceras subcrenatum, G.* sp.
Oughtibridge, 200 yds W of station	431000	393500	*Gastrioceras subcrenatum*
Moss Oil BH SE51SE/19	459980	413900	*Gastrioceras subcrenatum*
Fernilee No. 2 BH	401190	378630	*Gastrioceras subcrenatum*
E of Fernilee	401910	378510	*Gastrioceras subcrenatum*
Shaw Farm BH, 0.5 miles NW of Eaves Knoll	399050	386610	*Gastrioceras subcrenatum, Homoceratoides* sp. *G.* sp.
Knowle Wood	398160	388660	*Gastrioceras subcrenatum, G.* sp.
S of Sugworth Road, near Moscar	424000	389500	*Gastrioceras subcrenatum, G.* sp., *G.* sp. nov.
Smeekley No 3 BH SK27NE/2	429690	376498	*Gastrioceras subcrenatum*
Tickhill No 1 BH	457730	392970	*Gastrioceras subcrenatum, Homoceratoides* aff. *divaricatus*
Ranskill No 1 BH	464230	388140	*Gastrioceras subcrenatum*
Oakenholt Paper Mill BH	326280	375120	*Gastrioceras subcrenatum*, *G.* cf. *rertrorsum*
Alders Farm BH	389540	362080	*Gastrioceras subcrenatum*
R. Hipper, 360 yds up from Harewood Grange bridge	431110	368350	*Gastrioceras subcrenatum, G.* sp. nov., *G.* sp., *Homoceratoides* sp.
760 yds N33W of Stonehay Farm	432800	368080	*Gastrioceras subcrenatum*
Opencast workings SW of Alton	436070	364200	*Gastrioceras subcrenatum*
Clattercotes Wood, 400 yds N15E of Whitecarr	436120	360140	*Gastrioceras subcrenatum, G.* sp. nov., *Homoceratoides* sp.

Egmanton No 62 BH	474440	367770	*Gastrioceras subcrenatum*
Ruelow Wood BH	402050	347520	*Gastrioceras subcrenatum*
Wetley Rocks	396640	349440	*Gastrioceras subcrenatum*
Consall New Lock	400420	348360	*Gastrioceras subcrenatum*
Newhouse Wood, Ipstones	401770	348850	*Gastrioceras subcrenatum*
Crowtrees No. 8 BH SK04NW/19	404980	345590	*Gastrioceras subcrenatum*
Rugeley (Trent Valley) BH 100 yds ESE of Railway Inn, Rugeley	405080	319020	*Gastrioceras subcrenatum*
Osbaston Hollow BH	441660	306350	*Gastrioceras*
Park Brook BH, Horsley	438300	343850	*Gastrioceras subcrenatum*
Nether Heage BH	435990	351190	*Gastrioceras subcrenatum*
Beechdale Rd (Robins Wood) BH	453610	341130	*Gastrioceras subcrenatum*
LOCALITY	EASTING	NORTHIN G	AMMONOIDS
Gastrioceras subcrenatum Marine Band (G2a1) Continued			
Wilds Bridge BH SK63SE/30	467380	332480	*Gastrioceras subcrenatum*
Blackfordby No. 1 BH	432350	318270	*Gastrioceras subcrenatum*
Road cut	437640	324860	*Gastrioceras subcrenatum, G.* sp
Worthington BH SK24SW/204	440450	321040	*Gastrioceras sp., Gastrioceras subcrenatum*
Honley Marine Band			
Ridgeway Bh SJ85SE/14	389220	353810	*Gastrioceras sp.*
Charnock Old Hall BH	354730	416560	*Gastrioceras sp.*
Cheshire Brook	389030	361430	*Gastrioceras sp.*
Listeri Marine Band			
Ridgeway Bh SJ85SE/14	389220	353810	*Gastrioceras listeri*
Robin's Clough near Knar	400420	367630	*Gastrioceras listeri*
Waters Farm BH	375370	467630	Gastrioceras *listeri* , *G. circumnodosum*
Valley Mills BH	386700	437200	Gastrioceras *listeri*
Cockden Bridge BH	387600	434400	Gastrioceras *listeri*
Globe Mills BH, Leeds, 400 yards S of City station SE23SE/7	429799	432787	Gastrioceras *listeri*
Stepback Brook, 900 yds S35W of Darwen Tower	367410	420920	Gastrioceras *listeri*
Tan House Farm BH	355420	416920	Gastrioceras *listeri*
Heskin BH	353010	401360	Gastrioceras *listeri*
Oxspring Borehole,SE of Oxspring Yorks SE20SE/6	427870	401360	*Gastrioceras listeri*
Moss Oil BH SE51SE/19	459980	413900	*Gastrioceras listeri*
Ringstone Clough	400080	382210	*Gastrioceras listeri*
Furness Vale Colliery	400380	383390	Gastrioceras *listeri, Homoceratoides* aff. *divaricatus*
Pingot Clough	401640	385320	*Gastrioceras listeri*
Stirrup, west of Chisworth	398350	391870	*Gastrioceras listeri*
Chew	399400	392030	*Gastrioceras listeri*
Smeekley No 3 BH SK27NE/2	429690	376498	*Gastrioceras listeri*
Connah's Quay, trial pit	328170	369160	*Gastrioceras listeri*
Biddulph Grange	389210	359610	*Gastrioceras circumnodosum*
Cheshire Brook	388970	361330	*Gastrioceras circumnodosum, G. listeri*
Clattercotes Wood, 480 yds N53E of Whitecarr	436380	360050	*Gastrioceras listeri*
Key Wood BH SK04NW/1	403910	345360	*Gastrioceras listeri*
Out Wood, Consall valley	398050	347810	*Gastrioceras listeri*
SE of Ipstones	402980	349000	*Gastrioceras circumnodosum*
Whittington Heath BH	414780	308000	*Gastrioceras* cf. *listeri*
Ellistown Colliery BH	443900	310560	*Gastrioceras listeri*
Wilds Bridge BH SK63SE/30	467380	332480	*Gastrioceras listeri*
Marriott Wood Brickpit	429800	380300	*Gastrioceras listeri*
Little Stubbin Opencast, Stubbinedge	436300	361900	*Gastrioceras listeri, G. coronatum, G. retrorsum*
Sandoz Chemical Co	416300	434300	*Gastrioceras listeri*
Amaliae Marine Band			
Disused quarry, 720 yds E14S of Charnock Green	355980	416640	*Gastrioceras* cf. *amaliae*
Crook Fold BH	354700	415870	*Gastrioceras* cf. *amaliae*
Vanderbeckei Marine Band			
Wiggins Teape No 2 BH, Withnell Fold Chorley	361460	423440	*Anthracoceras* cf. *vanderbeckei*

Bankfield Mills BH - Mold Green - SE11NE/11	414660	416270	*Anthracoceras* aff. *vanderbeckei*
Bowsey Wood BH SJ74NE/9	376950	346430	*Anthracoceras vanderbeckei*
Railway cutting, 1615 yds N of Holy Cross Church, Morton (Clay Cross type locality)	440730	361600	*Anthracoceras* cf. *vanderbeckei*
Scaftworth BH	467610	391670	*Anthracoceras vanderbeckei*
Disused railway cutting, Duckmanton	442370	370400	*Anthracoceras vanderbeckei*
Manton Colliery No 7 UG BH	463786	376334	*Anthracoceras vanderbeckei*
Carbank BH	463969	355793	*Anthracoceras vanderbeckei*
Haughton Hall BH	468595	373305	*Anthracoceras vanderbeckei*
Clipstone Colliery No. 1 BH	459530	363290	*Anthracoceras vanderbeckei*
Kirton BH	469880	369130	*Anthracoceras vanderbeckei*
Kneesall BH	471353	364380	*Anthracoceras vanderbeckei*
Mansfield Colliery BH	457020	361450	*Anthracoceras vanderbeckei*
Ompton BH	469000	366100	*Anthracoceras vanderbeckei*
LOCALITY	EASTING	NORTHING	AMMONOIDS
Vanderbeckei Marine Band Continued			
Foxfield No8 BH SJ94SE/8	398880	343220	*Anthracoceras vanderbeckei*
Manchester Woods BH SK44SW/3	441600	344170	*Anthracoceras vanderbeckei*
Digby Clay Pit	448600	345000	*Anthracoceras vanderbeckei*
Jockey House BH SK67NE/18	468971	376839	*Anthracoceras vanderbeckei*
Aegiranum Marine Band			
Wentbridge No. 2 BH SE41NE/18	447560	417570	*Donetzoceras aegiranum*
Bowsey Wood BH SJ74NE/9	376950	346430	*Donetzoceras aegiranum*
Nettlebank Colliery	388500	350300	*Donetzoceras aegiranum*
Pow Gill, 130 yards N of bridge at Powbank	325090	544320	*Donetzoceras aegiranum* , *Anthracoceras hindi*
Stairfoot Brickworks, 3km ESE of Barnsley	438030	404980	*Donetzoceras aegiranum*
Manvers Main Brickworks, 1650 yds E6S of Bolton upon Dearne church	445300	400980	Gastrioceras sp.
Doles Lane BH	453594	3774910	Homoceratoides politus
Whitwell Rectory	452480	376670	Homoceratoides?
Elmton Green BH	450560	373170	*Gastrioceras cf. depressum*
Red Hill BH, 2140 yds W of St James' church Longdon SK01SE/9	406230	314110	Homoceratoides politus
Albion Clay Pit, 300 yds SSE Dordon church	426300	300100	Gastrioceras depressum
Robinson & Dowler's Pit, 300 yds SSE of Dordon church	429600	316100	Anthracoceras cf aegiranum-hindi
Donington Pit, 250 yds 106 of Swainspark	429900	317100	Anthracoceras cf aegiranum-hindi
Caldwell No. 1 BH, 250 yds 106 of Swainspark	425990	317340	Gastrioceras sp.
Eymore Farm railway cutting, Upper Arley	376900	279000	*Donetzoceras aegiranum*
Shafton Marine Band			
Maltby Main Colliery No 2 shaft	455120	392460	*Anthracoceras hindi*
Cambriense Marine Band			
Wentbridge No. 2 BH SE41NE/18	447560	417570	*Donetzoceras cambriense*

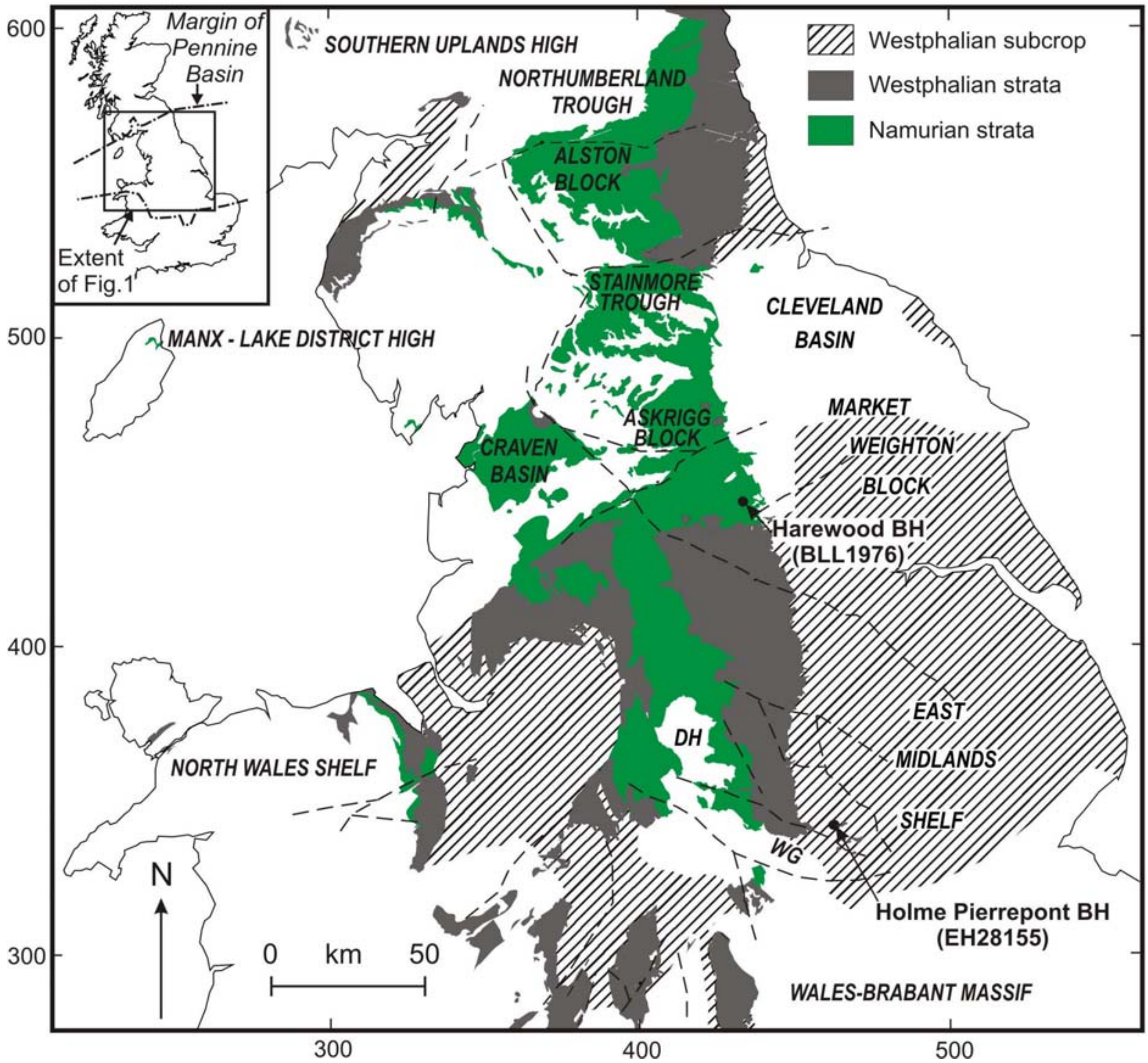
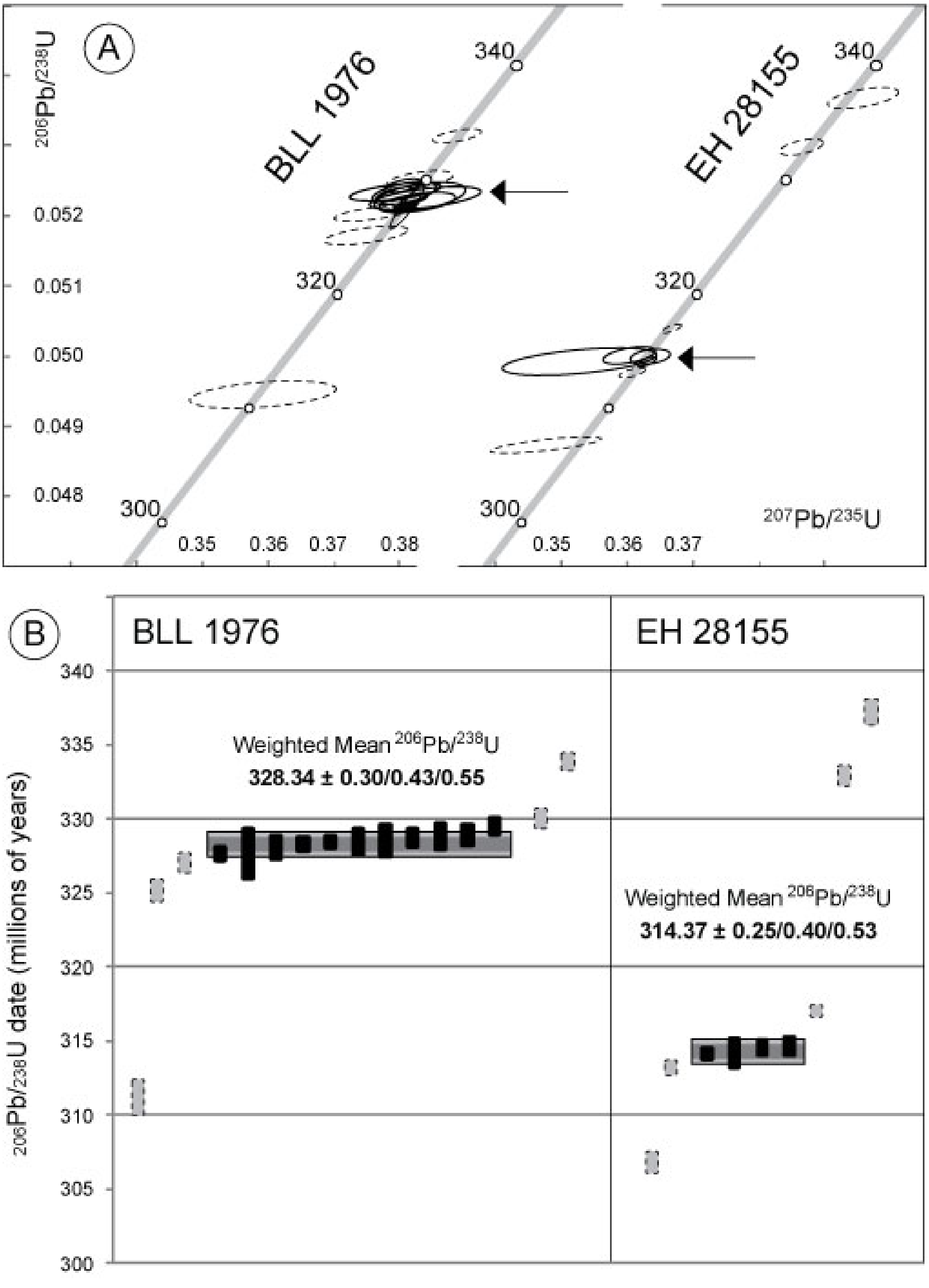


Fig. 1. Map showing the approximate extent of Namurian and Westphalian strata at crop, the subcrop of Westphalian strata and the main pre-Namurian structural features of the Pennine Basin, derived from Waters *et al*. (2011). The location of the Harewood and Holme Pierrepont boreholes, from which new dates have been acquired during this study, are shown. DH- Derbyshire High, WG- Widmerpool Gulf.

Fig. 2. U-Pb data for samples BLL1976 and EH28155. A, conventional U-Pb concordia plot of zircons analysed from samples BLL1976 and EH28155. The grey band reflects the uncertainty in the ^{238}U and ^{235}U decay constants (Jaffey *et al*. 1971). B, plot of $^{238}U/^{206}Pb$ dates for single zircon crystals analyses (same data as in Figure 2a). Dashed ellipses/bars represent analyses of zircon that are considered to be xenocrysts and/or inherited crystals that are disregarded in calculation of final date, whereas as undashed ellipses/bars represent the analyses used for calculation of the weighted mean final date (see text for discussion). Data point error ellipses/bars are 2σ.



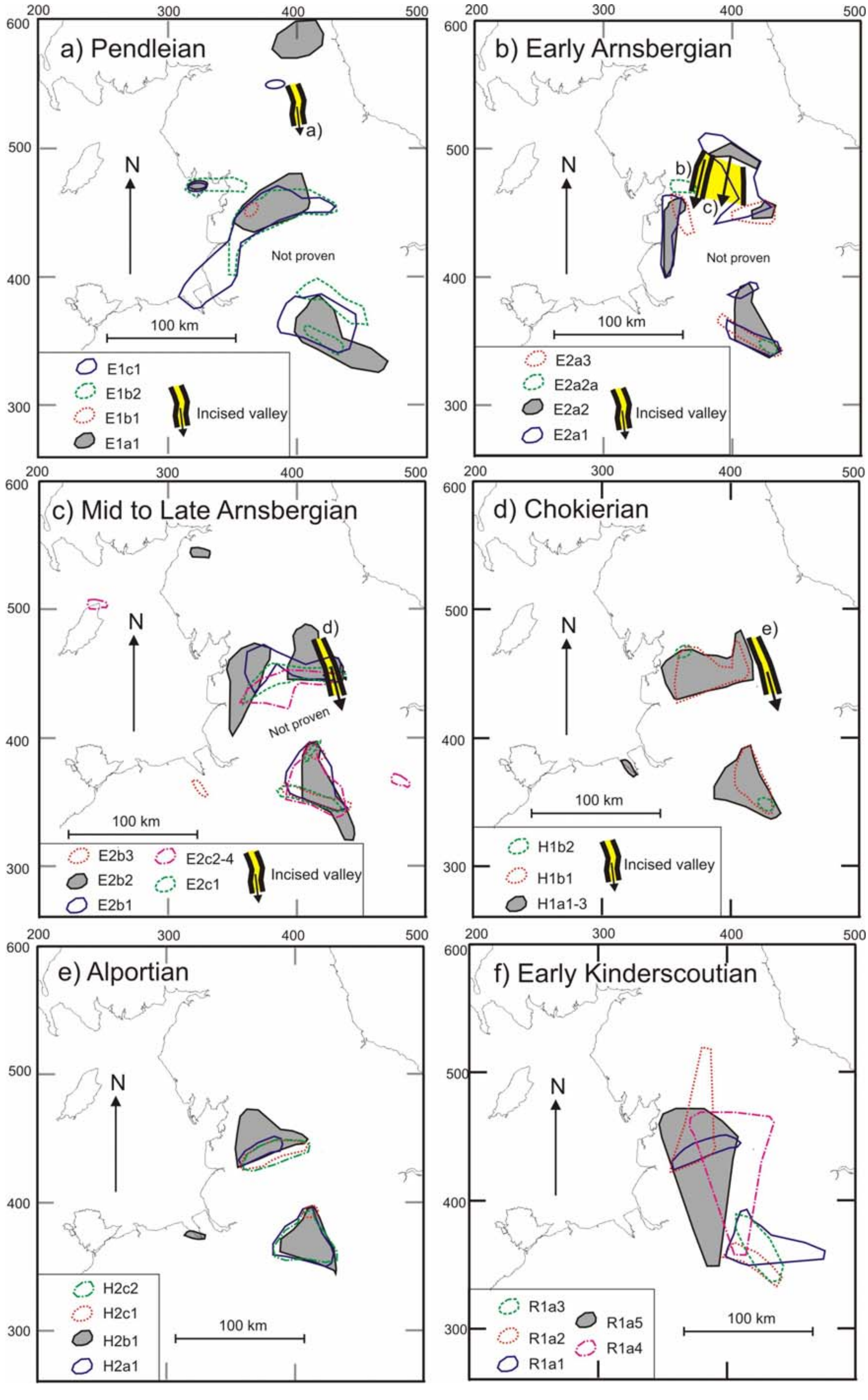


Fig. 3. Distribution of ammonoid acme facies in early Namurian marine bands: a) Pendleian; b) early Arnsbergian; c) mid to late Arnsbergian; d) Chokierian; e) Alportian; f) early Kinderscoutian. Grey tone denotes marine band with maximum areal extent for each interval. Key for Incised Valleys, as for Figure 5.

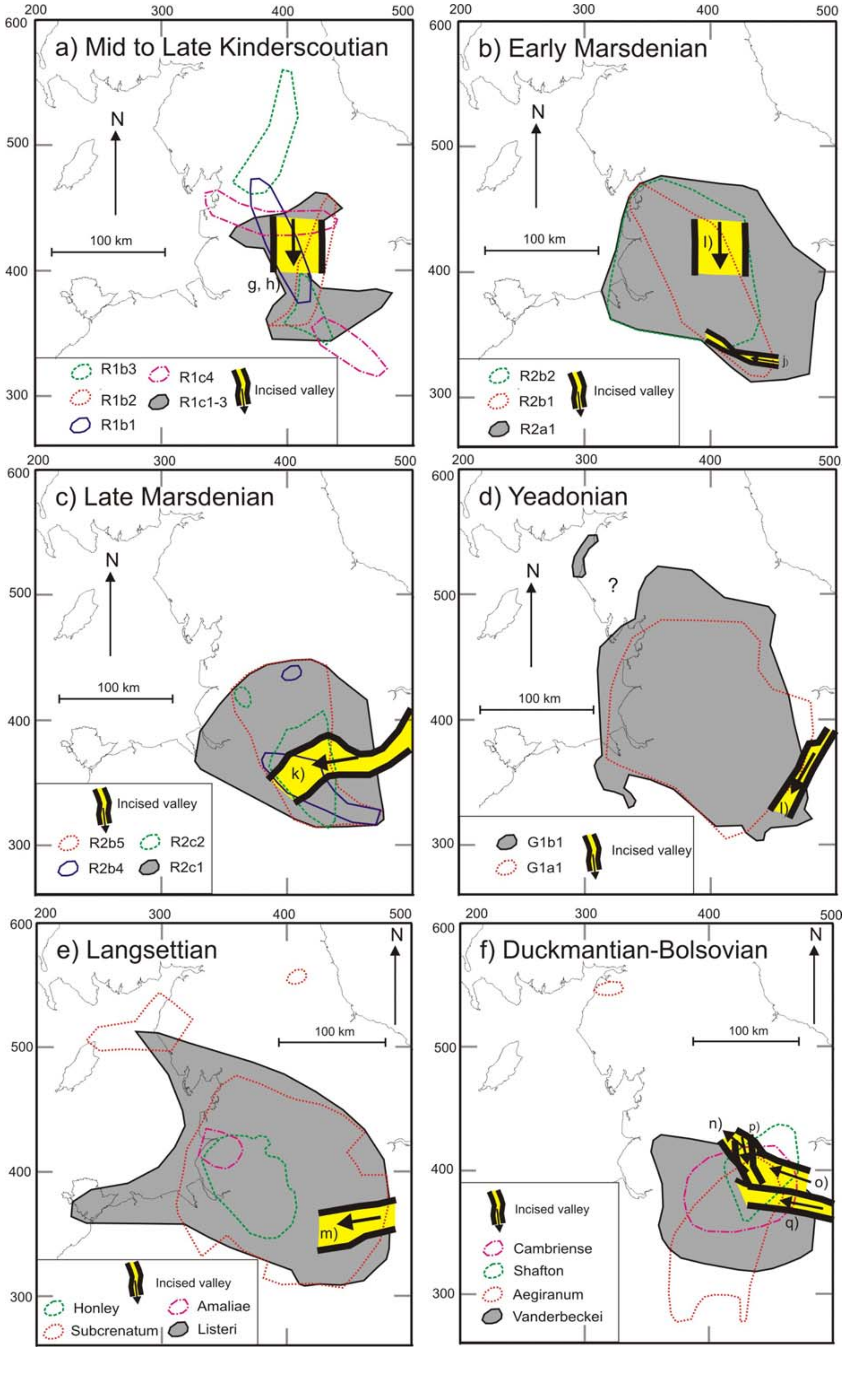
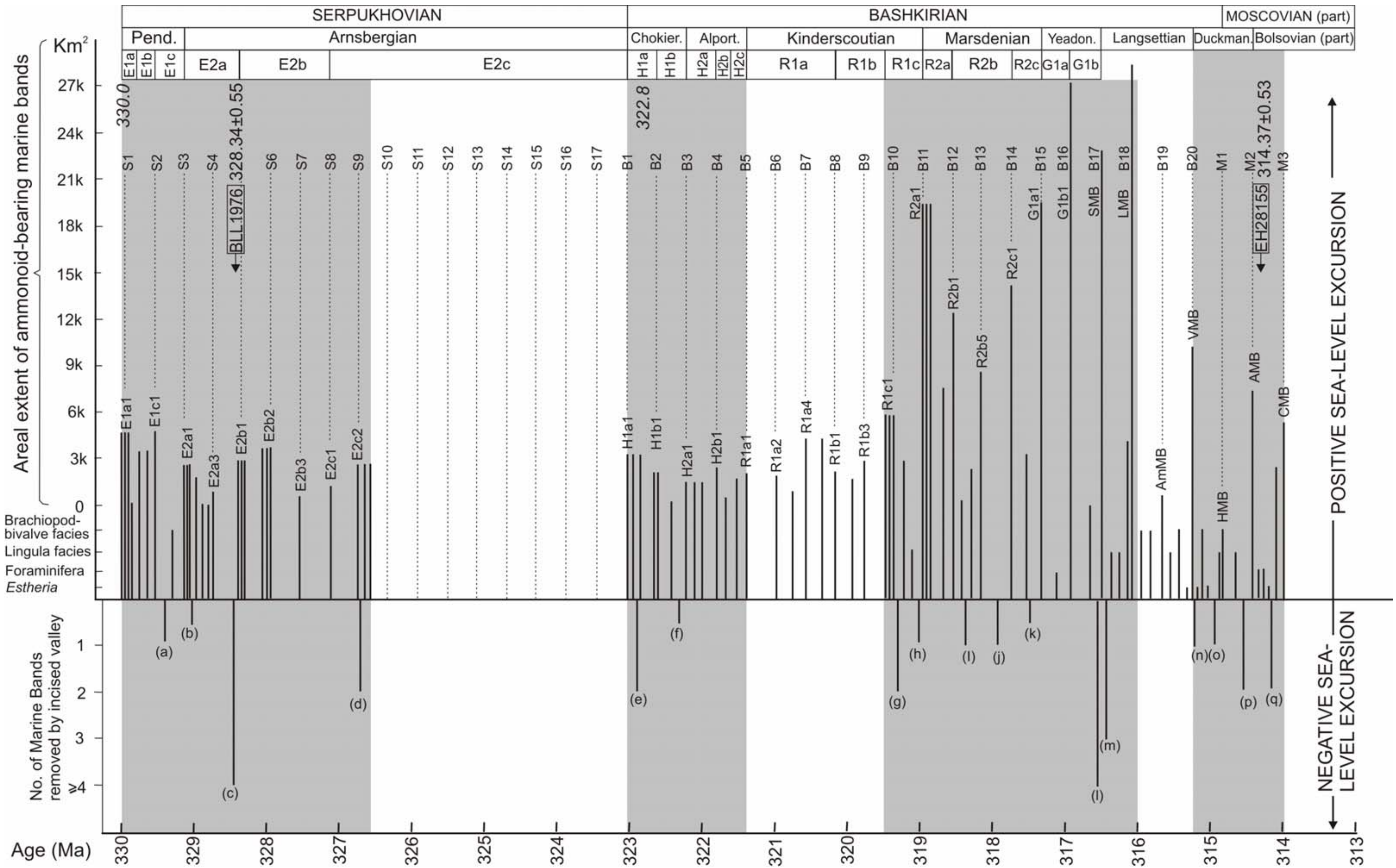

a) Mid to Late Kinderscoutian
R1b3
R1b2
R1b1
R1c4
R1c1-3
Incised valley
g, h)
100 km
N
b) Early Marsdenian
R2b2
R2b1
R2a1
Incised valley
i)
j)
100 km
N
c) Late Marsdenian
Incised valley
R2b5
R2b4
R2c2
R2c1
k)
100 km
N
d) Yeadonian
G1b1
G1a1
Incised valley
l)
?
100 km
N
e) Langsettian
Incised valley
Honley
Subcrenatum
Amaliae
Listeri
m)
100 km
N
f) Duckmantian-Bolsovian
Incised valley
Cambriense
Shafton
Aegiranum
Vanderbeckei
n)
o)
p)
q)
100 km
N
200
300
400
500
600

Fig. 4. Distribution of ammonoid acme facies in late Namurian–Westphalian marine bands: a) mid to late Kinderscoutian; b) early Marsdenian; c) late Marsdenian; d) Yeadonian- $G_{1b}1$ modified from Wignall (1987); e) Langsettian and f) Duckmantian–Bolsovian, in part based upon Calver (1968, 1969). Grey tone denotes marine band with maximum areal extent for each interval. Key for Incised Valleys, as for Figure 5.



SERPUKHOVIAN
BASHKIRIAN
MOSCOVIAN (part)
Pend.
Arnsbergian
Chokier.
Alport.
Kinderscoutian
Marsdenian
Yeadon.
Langsettian
Duckman.
Bolsovian (part)
Km²
Areal extent of ammonoid-bearing marine bands
Brachiopod-bivalve facies
Lingula facies
Foraminifera
Estheria
No. of Marine Bands removed by incised valley
330.0
328.34±0.55
BLL1976
322.8
314.37±0.53
EH28155
POSITIVE SEA-LEVEL EXCURSION
NEGATIVE SEA-LEVEL EXCURSION
Age (Ma)

Fig. 5. Magnitude and duration of sea-level oscillations. Sea-level maxima are estimated through the determination of maximum areal extent of acme ammonoid facies. Abbreviations for Westphalian marine bands: SMB Subcrenatum Marine Band; LMB Listeri Marine Band; AmMB Amaliae Marine Band; VMB Vanderbeckei Marine Band; HMB Haughton Marine Band; AMB Aegiranum Marine Band; CMB Cambriense Marine Band. For marine bands lacking ammonoid fauna the magnitude of sea-level is determined through the acme marine fauna, ranging from *Estheria* to brachiopod-bivalve facies. Sea-level minima are determined through the presence of incised valleys, with the magnitude recorded by the number of underlying marine bands removed beneath the sequence boundary. Sources for incised valleys are as follows: a) Rogerley Channel (Dunham 1990); b) Upper Howgate Edge channel (Martinsen *et al*. 1995); c) Red Scar Grit (Brandon *et al*. 1995); d) Lower Follifoot Grit (Martinsen 1993); e) Intra-H_{1a} unconformity (Owens *et al*. 1990); f) Upper Follifoot Grit (Martinsen 1993); g) Todmorden Grit/Kinderscout Grit (Hampson 1997); h) Upper Kinderscout Grit (Hampson 1997); i) Midgley Grit (Brettle 2001); j) Ashover Grit/Roaches Grit (Jones & Chisholm 1997; Church & Gawthorpe 1994); k) Chatsworth Grit (Waters *et al*. 2008); l) Rough Rock (Church & Gawthorpe 1994); m) Crawshaw Sandstone (Hampson *et al.* 1997); n) Thornhill Rock (Lake 1999); o) Woolley Edge Rock (Aitken *et al*. 1999); p) Oaks Rock (Lake 1999); q) Mexborough Rock (Aitken *et al*. 1999). Radiometric dates are from this study and estimated ages of stage boundaries are from Davydov *et al*. (2010), with an imposed 400 ka long-duration eccentricity oscillation numbered sequentially for each international stage: S Serpukhovian; B Bashkirian; M Moscovian. The proposed four main glaciations are highlighted as grey bands.

Table 1. Comparison of Carboniferous chronological ages from selected published literature. Picks are at base of Regional Stage or Substage unless stated otherwise. Hess & Lippolt (1986) [1] and Berger *et al*. (1997) [2] provide $^{40}Ar/^{39}Ar$ plateau ages (Ma ± 1σ), with the exception of the early Arnsbergian age which is Ma ± 2σ: recalibrated ages appear in italics, as quoted in Davydov *et al*. (2004); Kryza *et al*. (2010) [3], Riley *et al*. (1995) [4] and Claoué-Long *et al*. (1995) [5] provide SHRIMP (Ma ± 2σ) ages; Trapp & Kaufmann (2002) [6], Gastaldo *et al*. (2009) [7] and Davydov *et al*. (2010) [8] provide U-Pb TIMS (Ma ± 2σ) ages. Stippled lines denote correlation of regional substage boundaries.

$^{40}Ar/^{39}Ar$ plateau ages	U-Pb SHRIMP	Davydov *et al.* (2004)	Ogg *et al.* (2008)	U–Pb TIMS	This study	International Stage	Regional Substage	Regional Stage
302.7 ± 0.5 (late) [1]		306.5 ± 1.0	307.2 ± 1.0	307.26 ± 0.11 (early) [8]		Kasimovian	Cantabrian	Early Stephanian
308.0 ± 1.8 (mid) [2] *(310.26 ± 1.8)*						Moscovian	Asturian	Westphalian
309.0 ± 3.7 (late) [1] 309.7 ± 2.0 (mid) [2] *(312.0 ± 2.0)* 310.0 ± 1.0 [2] *(313.0 ± 1.0)*	311.0 ± 3.4 [5]	311.7 ± 1.1	311.7 ± 1.1	310.55 ± 0.10 (late) [8] 314.40 ± 0.06 (early) [8]	**314.37 ± 0.53**		Bolsovian	
310.7 ± 1.3 (late) [1]						Bashkirian	Duckmantian	
							Langsettian	
							Yeadonian	Namurian
							Marsdenian	
							Kinderscoutian	
							Alportian	
		318.1 ± 1.3	318.1 ± 1.3				Chokierian	
319.9 ± 1.6 (mid) [1] *(322.3 ± 1.7)* 324.8 ± 1.2 (early) [1] *(327.0 ± 2.2)*	314.4 ± 4.6 (mid) [4] 314.5 ± 4.6 (early) [4]				**328.34 ± 0.55**	Serpukhovian	Arnsbergian	
		326.4 ± 1.6	328.3 ± 1.6	328.01 ± 0.36 (late) [7] 328.14 ± 0.11 (early-mid) [8] 328.84 ± 0.38 (early) [7]			Pendleian	
						Late Visean	Brigantian	Late Visean
	334 ± 4 [3]			326.8 ± 0.98 (late) [6]			Asbian	

Regional Substages	ZONES			WESTERN EUROPEAN MARINE BANDS			'Meso-thems'
	Index	Ammonoid	Index	Diagnostic ammonoid	Former name	Associated ammonoids	
BASHKIRIAN STAGE (NAMURIAN REGIONAL STAGE)							
YEADONIAN	G1b			*Anthracoceras*		None, typically *Lingula* facies	N11
		Cancelloceras cumbriense	G1b1	*Ca. cumbriense a & b*	*Gastrioceras cumbriense*	*B. superbilinguis, Cancelloceras* sp., *Ca. crenulatum , Gastrioceras carbonarium, G. listeri, Homoceratoides* sp., *Hm..divaricatus,*	
	G1a					Owd Betts Marine Band- anoxic event lacking marine fauna	
		Cancelloceras cancellatum	G1a1	*Ca. cancellatum a, b & c*	*Gastrioceras cancellatum*	*Agastrioceras carinatum, B. superbilinguis, Cancelloceras* sp., *Ca. branneroides,Ca. crencellatum, Ca. crenulatum , Ca. cumbriense Ca. Rurae, Homoceratoides* sp., *Hm..divaricatus*	
MARSDENIAN	R2c	*Bilinguites superbilinguis*	R2c2	*Verneulites sigma*	*Donetzooceras (Gastrioceras) sigma*	*B. superbilinguis, Ca. cumbriense, Gastrioceras* sp., *Ca. crenulatum, Homoceratoides* sp., ,	N10
			R2c1	*B. superbilinguis*	*R. superbilingue, R. reticulatum mut. γ,*	*Gastrioceras* sp., *G. lineatum, Homoceratoides sp. Hm..divaricatus, Hm. fortelirifer, Verneulites sigma*	
	R2b	*Bilinguites bilinguis*	R2b5	*B. metabilinguis*	*R. bilingue late mut. β*	*Bilinguites* sp., *B. bilinguis, B. eometabilinguis, Verneulites sigma*	N9
			R2b4	*B. eometabilinguis*	*R. bilingue late mut. β*	*B. bilinguis*	
			R2b3	*B. bilinguis*	*R. bilingue mut. β*	*Bilinguites* sp., *R. circumplicatile*	
			R2b2	*B. bilinguis*	*R. bilingue mut. β*		
			R2b1	*B. bilinguis*	*R. bilingue early mut. β*		
	R2a	*Bilinguites gracilis*	R2a1	*B. gracilis a, b & c*	*R. gracile, R. reticulatum mut. α*	*Bilinguites* sp., *R. reticulatum, R. gracilingue, R. graciloides*	
KINDERSCOUTIAN	R1c	*Reticuloceras reticulatum*	R1c5			Butterly MB- *Lingula*	N8
			R1c4	*R. coreticulatum*		*Anthracoceratites* sp., *Homoceratoides divaricatus, Hudsonoceras ornatum, R. reticulatum* (late form) , *V. striolatus*	
			R1c3	*R. reticulatum*		*Homoceratoides prereticulatus, R. davisi, R. regularum, Vallites sp., V. striolatus*	
			R1c2	*R. reticulatum*			
			R1c1	*R. reticulatum*			
	R1b	*Reticuloceras eoreticulatum*	R1b3	*R. stubblefieldi*	*Eumorphoceras stubblefieldi*	*Vallites striolatus, Hudsonoceras ornatum, R. Moorei, R. regularum*	N7
			R1b2	*R. nodosum*		*Homoceras spiraloides, Vallites striolatus*	
			R1b1	*R. eoreticulatum*		*Reticuloceras* sp.	
	R1a	*Hodsonites magistrorum*	R1a5	*R. dubium*		*Reticuloceras* sp., *R. adpressum*	N6
			R1a4	*R. todmordenense*		*Homoceras* sp., *Reticuloceras* sp., *R. paucicrenulatum, R. adpressum*	
			R1a3	*R. subreticulatum*		*Homoceratoides* sp., *Reticulatum pulchellum*	
			R1a2	*R. circumplicatile*		*Homoceratoides* sp. *Vallites (Homoceras) henkei,*	
			R1a1	*Ho. magistrorum*		*R. compressum*	
ALPORTIAN	H2c	*Vallites eostriolatus*	H2c2	*Homoceratoides prereticulatus*	*Hm. prereticulatum*	*Homoceras* sp.	
			H2c1	*V. eostriolatus*	*Homoceras eostriolatum*	*Ho. undulatum*	
	H2b	*Homoceras undulatum*	H2b1	*Ho. undulatum*		*Ho. beyrichianum, Ho. smithii*	N5
	H2a	*Hudsonoceras proteum*	H2a1	*Hd. proteum a, b & c*	*Hd. proteus*	*Homoceras smithii*	
CHOKIERIAN	H1b	*Homoceras beyrichianum*	H1b2	*Isohomoceras.* sp. nov.		*Homoceras* sp.	N4
			H1b1 a & b	*H. beyrichianum*		*Ho. diadema, Ho. subglobosum, Isohomoceras* sp.	
	H1a	*Isohomoceras subglobosum*	H1a3	*I. subglobosum*	*Homoceras subglobosum*		
			H1a2	*I. subglobosum*			
			H1a1	*I. subglobosum*			

Regional	ZONES	WESTERN EUROPEAN MARINE BANDS	

Substages	Index	Ammonoid	Index	Diagnostic ammonoid	Former name	Associated ammonoids	'Meso-thems'
SERPUKHOVIAN STAGE (NAMURIAN REGIONAL STAGE)							N3
ARNSBERGIAN	E2c	*Nuculoceras stellarum*	E2c4	*N. nuculum*		*C. darwenense, Ct. fragile, E. bisulcatum, Kazakhoceras hawkinsi*	
			E2c3	*N. nuculum*			
			E2c2	*N. nuculum*			
			E2c1	*N. stellarum*	*Cravenoceratoides stellarum*	*Fayettevillea holmesi,*	N 2
	E2b	*Cravenocera-toides edalensis*	E2b3	*Ct. nititoides*		*Cravenoceras* sp., *Eumorphoceras rostratum*	
			E2b2 a-c	*Ct. nitidus*	*Ct. nitidum*	*Cravenoceras* sp., *C. subplicatum, Cravenoceratoides* sp., *Eumorphoceras* sp., *E. bisulcatum, E. leitrimense, Fayettevillea holmesi, Glaphyrites* sp., *Gl. Kettlesingense,*	
			E2b1 a-c	*Ct. edalensis*		*Cravenoceras* sp., *C. subplicatum, Fayettevillea* cf. *holmesi*	
	E2a	*Cravenoceras cowlingense*	E2a3	*Eumorphoceras yatesae*		*Cravenoceras* sp., *C. gairense, Eumorphoceras* sp.	N 1
			E2a2β	*Anthracoceras*		Saleswheel Marine Band	
			E2a2α	*C. gressinghamense*		*C.* cf. *gairense, Eumorphoceras* sp.,	
			E2a2	*Eumorphoceras ferrimontanum*	*Eumorphoceras bisulcatum*	*Cravenoceras* sp., *C. gairense, E. erinense, Kazakhoceras scaliger*	
			E2a1 a-c	*C. cowlingense*	*Eumorphoceras bisulcatum*	*Cravenoceras* sp., *E. grassingtonense*	
PENDLEIAN	E1c	*Cravenoceras malhamense*	E1c2			Blacko Marine Band- *Sanguinolites*	
			E1c1	*C. malhamense*		*Cravenoceras* sp., *Eumorphoceras* sp.	
	E1b	*Cravenoceras brandoni*	E1b2 a & b	*Tumulites pseudobilinguis*	*Eumorphoceras pseudobilingue*	*Edmooroceras angustum, Ed. hudsoni, Ed. stubblefieldi, Eumorphoceras* sp., *Tumulites* sp,	
			E1b1	*C. brandoni*		*Edmooroceras stubblefieldi*	
	E1a	*Emstites leion*	E1al a-c	*E. leion*	*Cravenoceras leion*	*Cravenoceras* sp., *Cousteauceras rota*, *Eumorphoceras* sp., *E. involutum, Edmooroceras bisati, Ed. medusa, Ed. pseudocoronula, Ed. tornquisti*	

Table 2. Ammonoid zones and subzones of the Namurian regional stage with diagnostic ammonoids and indices mainly from Riley *et al*. (1995). 'Mesothem' nomenclature is that of Ramsbottom (1977). Former names and a compilation of ammonoid assemblages for each marine band were used when studying sample collections and literature reviews to determine the extent of ammonoid facies within specific marine bands. a) Serpukhovian international stage; b) Bashkirian international stage (part).

Table 3. Marine bands of the Westphalian regional stage with diagnostic ammonoids or acme facies, mainly from Waters *et al*. (2011). 'Mesothem' nomenclature is that of Ramsbottom (1979). Former names and a compilation of ammonoid assemblages for each marine band were used when studying sample collections and literature reviews to determine the extent of ammonoid facies within specific marine bands.

STAGE	REGIONAL SUB-STAGES	WESTERN EUROPEAN MARINE BANDS				'MESO-THEM'
		MARINE BAND NAME	**Diagnostic ammonoid** or acme facies	Former name	Associated ammonoids	
MOSCOVIAN (PART)	BOLSOVIAN	Cambriense	***Donetzoceras cambriense***	Top		W10
		Shafton	***Anthracoceras hindi***			
		Main Estheria	***Estheria***			
		Edmondia	foraminifera			W9
		Carway Fawr	foraminifera		Proved in S. Wales only	W8
		Aegiranum	***Donetzoceras aegiranum***	Mansfield	*Anthracoceras hindi, Gastrioceras* sp., *G. depressum, Homoceratoides politus*	
	DUCK-MANTIAN	Sutton	*Lingula*			
		Haughton	*Levipustula*			W7
		Clown	*Lingula*			
		Manton Estheria	***Estheria***			
BASHKIRIAN (PART)		Maltby	*Myalina*	Two Foot		W6
		Lowton Estheria	***Estheria***			
		Vanderbeckei	***Anthracoceras vanderbeckei***	Clay Cross		
	LANGSETTIAN	Low Estheria	***Estheria***			W5
		Burton Joyce	*Caneyella, Posidonia*			W4
		Langley	*Lingula*	Upper Band		
		Amaliae	***Gastrioceras amaliae***	Norton (Tonge's)		W3
		Meadow Farm	*Dunbarella, Posidonia*	Forty Yard		
		Parkhouse	*Lingula, Caneyella*			
		Listeri	***Gastrioceras listeri***	Alton	*G. circumnodosum, G. coronatum, G. retrorsum, Homoceratoides divaricatus*	W2
		Honley	***Gastrioceras*** sp.	First Smalley		
		Springwood	*Lingula*	Second Smalley		
		Holbrook	*Lingula*	Lower Bassey		
		Subcrenatum	***Gastrioceras subcrenatum***	Pot Clay	*Gastrioceras* sp., *G. carbonarium, G. listeri, G. retrorsum, Homoceratoides* sp., *H. divaricatus, Reticuloceras superbilingue*	W1/ N11