A revised description of the lithostratigraphy of the Kimmeridgian-Tithonian and Kimmeridgian-Volgian boundary beds at Kimmeridge, Dorset, UK: Reply to Wimbledon 2012

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I would like to thank Dr Wimbledon for his interesting comments, not least because they highlight some of the differences between stratigraphy as an academic exercise and its practical use in economically important applications such as engineering (Gallois, 1978) and hydrocarbons exploration (Gallois, 1979; Taylor and Sellwood, 2002). First, it might be helpful to clarify some misunderstandings. We all agree that we are standing on the shoulders of giants and that due deference should be paid in the references to those who have contributed to the subject under discussion. The complaint that the works of Arkell and Blake are not acknowledged is incorrect: both are included in the references. I hope that we also all agree that including references that are irrelevant to the subject is bad practice, which is why no reference was made to Cope's (1967) account of the ammonite succession of Upper Kimmeridge Clay which falls outwith the succession described in the paper. Neither Arkell (1933, 1947) nor Cope (1967) divided the succession into numbered beds: they used Blake's (1875) bed numbers.

Dr Wimbledon objects to the use of the well-defined and well-established name Volgian Stage for the succession above the Kimmeridgian Stage in Dorset, and complains that the paper does not use the poorly-defined Bolonian[1] Stage. To dismiss the type Volgian sections as thin and land-locked is to ignore the thousands of peer-reviewed publications on Volgian stratigraphy which, taken together, provide a more detailed account of the ammonite succession than that available for the Tithonian. Thick successions are not necessarily stratigraphically advantageous or thin successions disadvantageous. The 3,000 m-thick Permo Triassic succession that is wholly exposed on the Devon coast has yet to yield an age-diagnostic fossil. In contrast, the 0.5 m-thick Beer Head Limestone in the same area contains the most complete succession of well-preserved Cenomanian ammonites recorded in Britain (Mortimore *et al*., 2001). And the Russian sections were by no means land-locked as evidenced by the presence in the Volgian of characteristic Tethyan ammonites including *Gravesia, Haploceras* and *Sutneria* (Mesezhnikov, 1988). The Bolonian Stage was proposed by Blake (1881) for the predominantly arenaceous succession of the Pas de Calais coast which broadly correlates with the upper part of the Kimmeridge Clay of Dorset. Cope's (1993) definition of the base of a revised Bolonian Stage was not taken at a faunal, geochemical or magnetostratigraphical event that would serve as a proxy for a time plane. It was taken at the base of Blake's (1875) Bed 42, an 0.3 m-thick laterally impersistent, secondarily cemented mudstone that is known from only one outcrop, at Hen Cliff [SY 9082 7858] adjacent to Kimmeridge Bay. This bed has no lithostratigraphical, biostratigraphical or chronostratigraphical value for correlation purposes. The same definition was used by Cope (1967) to define the base of the *Pectinatites (Virgatospinctoides) elegans* Zone, a biozone defined by an arbitrary lithological level 20 m below the lowest undoubted *Pectinatites* (Cope, 1967, Plate 8). Crushed, incomplete specimens of virgatosphinctids down to and below Blake's Bed 42 that do not preserve the distinctive horn on microconch forms could equally well belong to other genera including *Lithococeras, Subdichotomoceras* and *Subplanites*. Stratigraphy does not need another poorly defined stage for the beds represented by the upper part of the Kimmeridge Clay. It needs more detailed studies of the succession based on up-to-date measurements, which is why the paper under discussion was written. The reason for only describing the beds adjacent to the Kimmeridgian-Tithonian and Kimmeridgian-Volgian boundaries at this first part of a more comprehensive revision was because this is a stratigraphically critical level for correlation between the Boreal and Tethyan (strictly speaking the Sub-Boreal and Sub-Tethyan) provinces at a locality that is more complete than any other yet described in NW Europe or Russia (Figure 1).

When using familiar chronostratigraphical terms such as Jurassic and Kimmeridgian is easy to forget that systems and stages are hypothetical constructs based on imaginary time planes, in contrast to rocks and fossils which are real objects. It was one thing for the International Commission on Stratigraphy to reach agreement in 1990 that the last stage of the Jurassic should be called the Tithonian on the basis that Oppel's (1865) Tithonian has priority over Nikitin's (1881) Volgien. It is more difficult to define the base of the Tithonian Stage and to decide on a type section that contains a faunal assemblage or other rock character that can be recognised with chronostratigraphical accuracy outside the Tethyan Faunal Province. I was therefore interested to learn that the "*international stratigraphic community thus knows very precisely what the Tithonian is, where it begins and where it ends*". 'Very precisely' in this context currently means a probable GSSP in southern France, Germany or Italy with the boundary being taken at the incoming of one or more named ammonites, or at a magnetostratigraphical event at a similar level. The Tithonian is overlain by the Berriasian, the lowest stage of the Cretaceous System in the Tethyan Province. As for precisely where the Tithonian ends, it may come as a surprise to those not familiar with Mesozoic stratigraphy that the base of the Cretaceous, a name which has been in use since 1822 (d'Halloy), has still not been defined and has no Global Boundary Stratotype Section and Point (GSSP). This is the only system boundary that has yet to be agreed.

At the time of writing the principal candidates for the GSSP for the Tithonian Stage are in limestone successions at Mount Crussol (Ardèche) and Canjuers (Var) in southern France. The suggested definition of the Kimmerdigian-Tithonian boundary at these localities is "*near base of Hybonoticeras hybonotum ammonite zone and lowest occurrence of Gravesia genus*" (Gradstein *et al*., 2012). Even if 'near base' was defined, *H. hybonotum* (Oppel) has not been recorded in NW Europe north of the Western European Shelf (Aquitaine, Paris and

[1] Variously spelt Boulognian, Bolonian, Bolonin, Boulonien and Bononin by different authors using different definitions. See Arkell (1933, p. 618) for details.

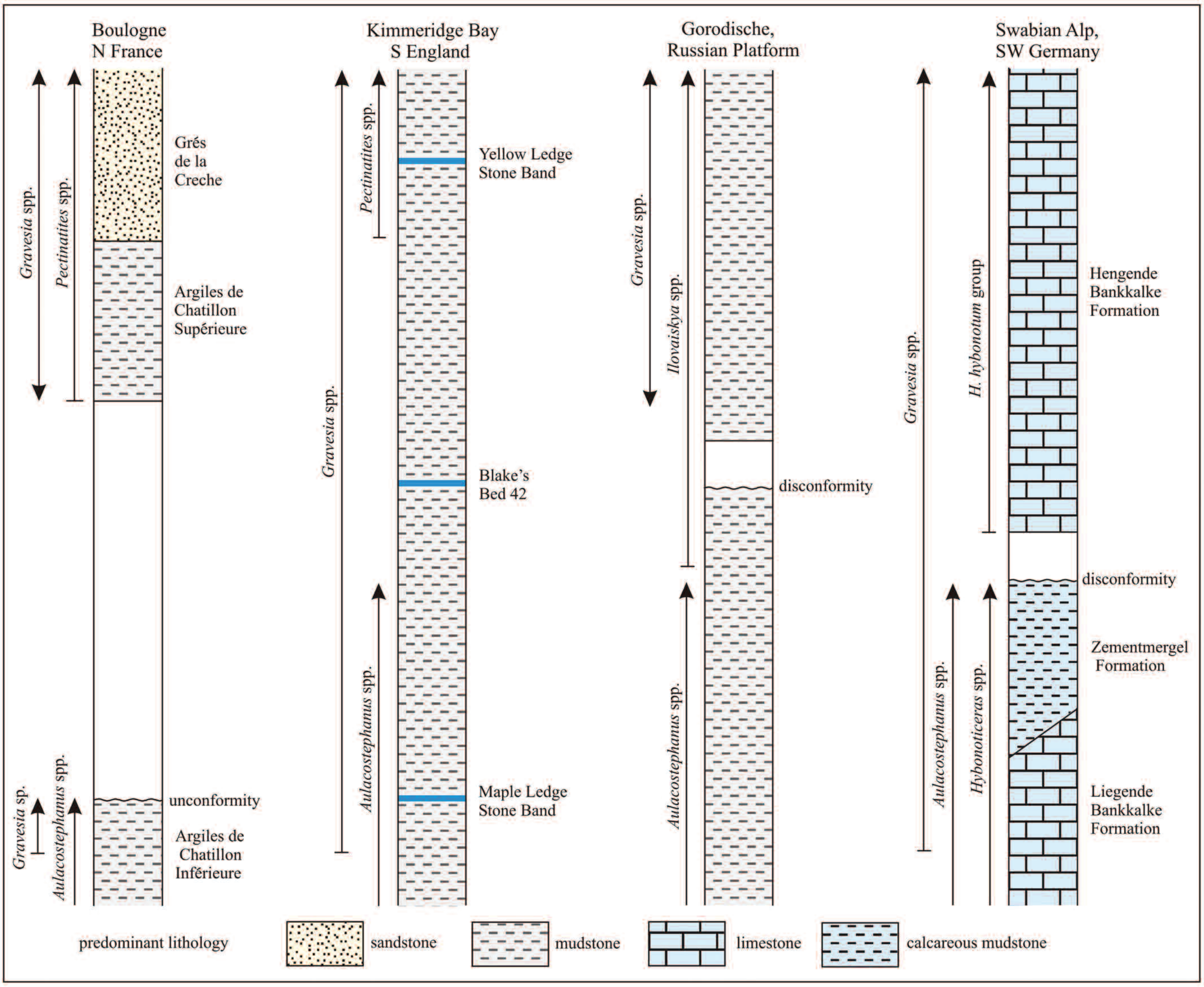

Figure 1. *Comparison of key ammonite ranges in selected sections in the Sub-Boreal and Sub-Tethyan faunal provinces to illustrate the importance of the last occurrence of Aulcostephanus spp. for regional correlation. Boulogne ammonite ranges after Geyssant et al.(1993), Gorodische after Rogov (2002) and Swabian Alp after Schweigert (2000). Not to scale.*

Swabian Basins) of Hantzpergue (1995), and is not therefore useful for correlation between the Tethyan Province and large parts of the Boreal Faunal Province. The internationally agreed base of the Volgian Stage, the First Accession Datum (FAD) of the ammonite *Ilovaiskya klimovi* (Ilovaisky) is, as far as can be determined in our present state of knowledge, synchronous with the FAD of *H. hybonotum* (Rogov, 2010). *I. klimovi* has not been recorded in the Kimmeridge Clay, but both zonal boundaries are close above the Last Accession Datum (LAD) of *Aulacostephanus* spp. in the Tethyan and Boreal Provinces, a geographically widespread palaeontological event in the Kimmeridge Clay. The sudden disappearance of large numbers of *Aulacostephanus* over an upward thickness of <50 mm in boreholes and exposures throughout the Kimmeridge Clay onshore outcrop and subcrop has proved to be one of the most useful and chronostratigraphically reliable marker beds in the U.K. Mesozoic (e.g. Gallois, 1979). It is the best proxy for the bases of the Tithonian and Volgian Stages recorded to date in the U.K.

The FAD of *Gravesia*, an ammonite that inhabited parts of both the Tethyan and Boreal Provinces, might be applicable in Britain where rare specimens of the genus have been recorded throughout the onshore Kimmeridge Clay (Cox and Gallois, 1981). However, until the taxonomy of *Gravesia* and the 'related' genera *Crussoliceras* and *Tolvericeras*, and the morphological variants of the microconch, macroconch, immature and mature forms have been described, the FAD of *Gravesia* may be impossible to identify with certainty at many localities. In addition, all the type specimens are preserved in limestone preservation that has retained taxonomically important characters such 3-D shape and sutures that are not present in the crushed forms in the Kimmeridge Clay (Gallois and Etches, 2010).

Given the faunal provincialism in the late Jurassic provinces and sub provinces, whichever palaeontological definition is chosen for the base of the Tithonian different regions will require different proxies. Even if a non-palaeontological definition is chosen, such as the base of Normal-Polarity Zone M22 (Lowrie and Ogg, 1986), it will need to be correlated with local biostratigraphical successions to be identifiable in outcrops and boreholes.

The cliff and foreshore outcrops at Kimmeridge Bay in Dorset expose the most complete succession described to date in NW Europe through the beds adjacent to the Kimmeridgian-Tithonian and Kimmeridgian-Volgian stage boundaries. The practical problem of accurately correlating the positions of well-preserved fossils collected from the intertidal ledges with the weathered exposures in the cliffs has been resolved by making use of the rhythmic nature of the succession (Gallois, 2011). This has enabled the biostratigraphical succession, in particular the ranges of the ammonites, to be described with greater accuracy than was previously possible.

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